DATA SUMMARY

LOCATION

Date and time	**Saturday, 9 June 2012; 12:15 local time**
Site	**Igualada Aerodrome (Barcelona, Spain)**

AIRCRAFT

Registration	**EC-GGF**
Type and model	**PIPER PA-23-250 Aztec E**
Operator	**Private**

Engines

Type and model	**LYCOMING IO-540-C4B5**
Number	**2**

CREW

Pilot in command

Age	**45 years old**
Licence	**Private pilot license (aircraft)**
Total flight hours	**202 h**
Flight hours on the type	**35 h**

INJURIES

	Fatal	Serious	Minor/None
Crew			**1**
Passengers			**5**
Third persons			

DAMAGE

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

FLIGHT DATA

Operation	**General Aviation – Private**
Phase of flight	**Landing**

REPORT

Date of approval	**24 July 2013**

1. FACTUAL INFORMATION

1.1. History of the flight

On Saturday, 9 June 2012 at 12:15[1], a Piper PA-23-250 aircraft, registration EC-GGF, suffered a runway excursion and broke its left landing gear during the landing run at runway 17 of the Igualada Aerodrome (Barcelona).

The aircraft had taken off from the Sabadell Airport on a private flight with one pilot and five passengers onboard. The flight had been uneventful until the landing when, after the initial contact, the pilot noticed that the left main gear was giving way. The aircraft stopped after traveling some 330 m and going off the runway to the left (Figure 1). After stopping, it was supported by the nose gear, right main gear and the left wing. All six people onboard were uninjured and left the aircraft under their own power. Weather conditions were not a factor.

Figure 1. Final position and contact area

1.2. Personnel information

The pilot, a 34-year old Belgian national, had obtained his private airplane pilot license in July 2011. In September 2011 he started flying twin-engine airplanes as part of his training for obtaining the ATPL[2] license. He had had a multi-engine rating since January

[1] Time reference in local time.
[2] ATPL- Airline Transport Pilot License.

2012. At the time of the incident he had a total of 202 flight hours, of which 35 had been on the type, most of them on aircraft EC-GGF.

In the last month he had flown 8 hours on single- and multi-engine aircraft. His last flight before the incident had been 8 days before.

He had valid medical and linguistic competency certificates at the time of the incident.

1.3. Aircraft information

The PA-23-250 aircraft, registration EC-GGF and S/N 27-4810, property of the Aeroclub de Sabadell, was manufactured in 1972. It had first belonged to Spain's air force under registration E.19-4. In 1996, with 4,263 flight hours, it was bought by Asturiana de Aviación, S.L., which registered it in Spain. In December 1997, with 4,308 h, it was bought by Aeroclub de Sabadell for training activities. It had valid and in force assurance and airworthiness certificates. At the time of the incident the aircraft had a total of 7,312 flight hours. The number of landings and takeoffs (gear cycles) is unknown, since this information had not been recorded by the Spain's air force and Asturiana de Aviación. Aeroclub de Sabadell had recorded, in each flight sheet, the number of landings. Despite of the fact that this information had not been recorded in the Log Book, according to the Aeroclub de Sabadell, the number of cycles between 2003-2012 was 4815.

1.3.1. *Maintenance*

The maintenance and airworthiness management center for aircraft EC-GGF was the Aeroclub de Sabadell, authorized as ES.MF.003 and ES.MG.118, respectively. The aircraft had been maintained in accordance with its maintenance program.

On 13 April 2012, with 7,293 flight hours, the aircraft passed the 100-hour check. On 28 October 2011 it passed the 50-hour check with 7,241 flight hours. Between the last 100-hr check and the incident, the main left gear had undergone maintenance due to a hydraulic leak. This action consisted of replacing the O-rings, refilling the hydraulic fluid and adjusting the actuator pressures.

The air force's maintenance sheets and the aircraft log books did not list any special maintenance involving the gear, with the exception of the periodic checks specified by the manufacturer. The landing gear was the factory original.

The inspection program specified by Piper includes 50- and 100-hr inspections, special inspections based on flight hours[3], calendar periods[4] and specific operation or

[3] Every 400, 500, 1,000, 1,200, 1,500, 2,000 and 2,400 h. The 400-hr inspection includes an item involving the gear torque link.

[4] Every 7, 30 and 90 days, 4, 6 and 12 months and 2, 3, 4, 5, 6, 7, 8, 10, 12 and 20 years.

environment[5], as well as non-scheduled inspections due to operational events[6]. Of all these inspections, the maintenance tasks involving the landing gear components damaged in this incident are as follows:

- Every 50 and 100 h, check for proper extension and evidence of fluid leakage[7].
- Every 100 h, check the condition and security of the gear struts[8].

There are no checks or inspections based on the number of gear cycles. There are also no overhauls specified for the gear, nor are there fatigue limitations for any aircraft component[9]. According to the maintenance center, only if a crack had been detected during an inspection would additional actions have been taken, such as a liquid-dye penetrant inspection, for example. According to the maintenance center, none of the inspections prior to the accident had revealed any cracks[10] or any fault indicative of a fracture.

1.3.2. *Load and balance*

The pilot, as a club member, had rented the aircraft on the day of the incident at the Aeroclub de Sabadell to go on a private flight. After being fully refueled the day before, the aircraft had not made any other flights. The load and balance calculation for the aircraft, taking into account the last figure for the aircraft's weight[11], a full load of fuel, 6 people onboard each weighing 75 kg and with no baggage, places the position of the center of gravity within limits.

1.3.3. *Description of the landing gear*

The landing gear is retractable. The gear structure consists, in general, of three elements (Figure 2):

- The leg itself, consisting of a strut assembly housing the piston tube, which absorbs the weight of the aircraft on landing, the piston and the fork assembly where the

[5] Operations in high dust or industrial pollution environment, operations in high salt or high humidity environment, operations in extreme cold and operations from soft or unusual terrain.
[6] Over-speed, turbulence, overweight or hard landing, mild impacts, extension of flaps above limit speed or immersion in water.
[7] Service Manual. Inspection. G. Landing gear group. 1: Check oleo struts for proper extension and evidence of fluid leakage.
[8] Service Manual. Inspection. G. Landing Gear group. 14: Inspect gear struts, attachments, torque links, retraction links, and bolts for condition and security.
[9] Piper Aztec Service Manual. I-Airworthiness limitations.
[10] According to the laboratory, this type of crak is not visible to the naked eye and is often mistaken for a scratch.
[11] Weighed on 30 November 2009: aircraft dry weight of 3,442 lb and 92.08 in.

wheel is mounted. The strut assembly and the fork assembly are joined by a torque link that allows relative movement to dampen any vibrations. The piston travels inside the cylinder. During landings, before contacting the ground, the piston is fully extended. The main gear is retracted in the forward direction. The strut assembly has three projections machined into it for attaching:

– the main gear drag link,
– the torque link that joins the strut and the fork, and
– the drag link fitting support.

- The main gear drag link is used to retract, extend and lock the gear. The link is moved by an actuator. When the gear is down, the drag link is at approximately a 45° angle from the vertical.
- The drag link fitting support attached the gear to the aircraft. The main gear drag link is also attached to it. The fitting support is parallel to the ground when the gear is extended.

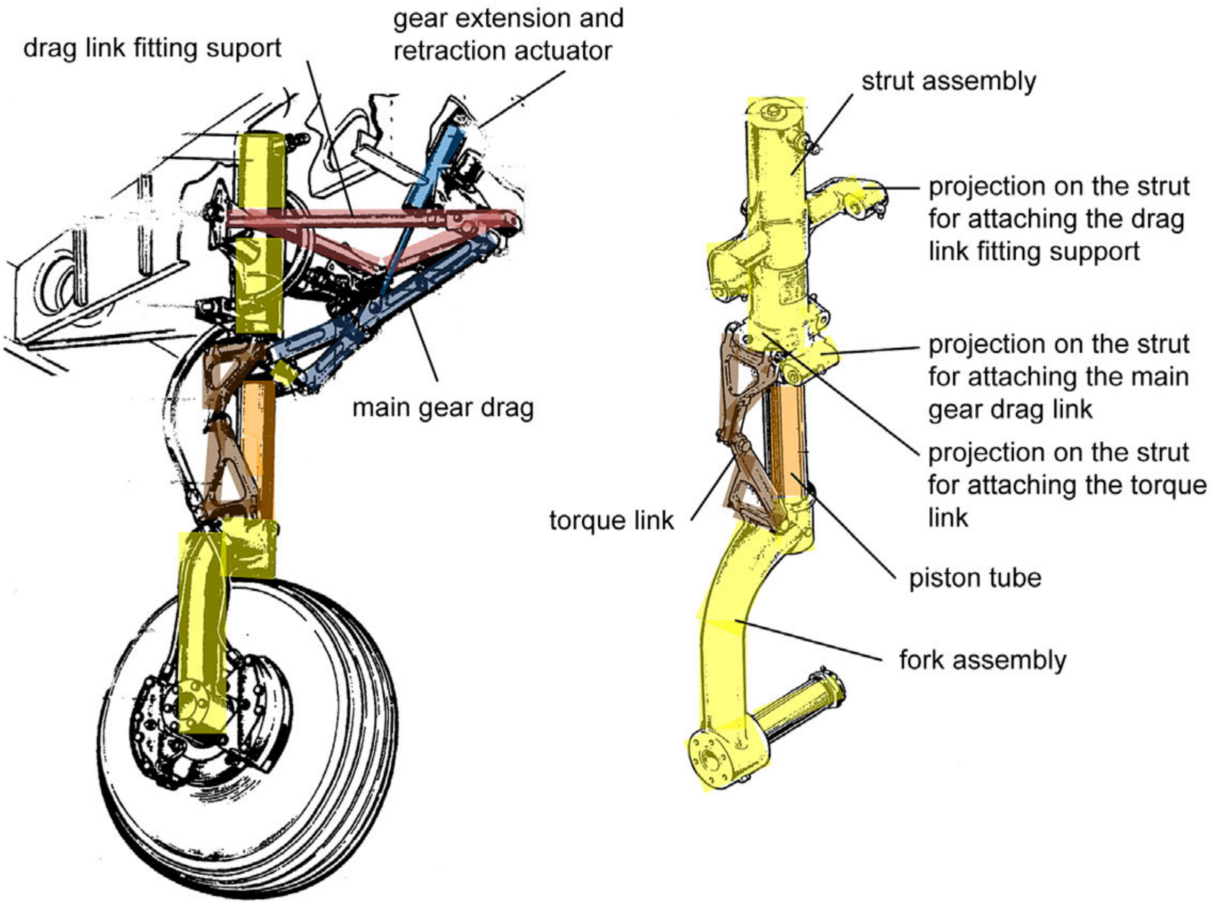

Figure 2. Parts of the main gear (view of left gear)

1.4. Wreckage and impact information

The aircraft made contact with the runway just before the threshold (Figure 1). The initial marks identified belonged to the left gear. The part of the landing run on the runway showed marks left by the left propeller, a continuous longitudinal line in the direction of motion and tracks from the left tire. The tracks from the right tire appeared further forward and showed signs of braking. The aircraft travelled about 70 m on the runway in practically a straight line at a 25° left angle with respect to the centerline. The rest of the trajectory was also straight but on the runway shoulder, which had a dirt surface. The marks on the ground showed that the aircraft pivoted left at the end of the landing run, coming to a stop on a heading of approximately 040° (Figure 1).

The aircraft's left wing exhibited scratches along its underside near the tip, specifically, on the outboard hinge support for the left aileron. This part did not have any soil fragments in it, meaning the contact had been with the runway. The tips of the left propeller blades had been damaged by contact with the ground. The left flap had been bent by the action of the gear folding backwards.

Figure 3. Gear seen from the tip (left) and trailing edge on the left wing (right)

The gear was configured and damaged as follows (Figure 3):

- The main gear drag link was in the down and locked position.
- The drag link fitting support was in its normal position and attached to the structure.
- The fitting support reinforcement was bent. This was because the main gear strut had rotated approximately 90° back with respect to its down and locked position and was contacting and bending this reinforcement.
- The rear gear door was bent due to the backward movement of the main gear strut.
- The main gear strut was cracked and missing components. Specifically, the projection where the main gear drag link is attached had completely separated from the strut and was joined to the main gear drag link (see Section 1.5.3).

- The fork assembly was twisted 90° left (as seen from the back) with respect to the piston tube and was touching the ground (Figure 3 shows the left wheel perpendicular with respect to the right). A part of the bottom of the fork assembly had been abraded due to friction.
- The lower torque link had detached from the upper torque link (the lower link can be seen in Figure 3).
- The strut had lost all of its hydraulic fluid.

1.5. Tests and research

1.5.1. *Pilot's statement*

The pilot stated that the approach and landing were normal, and that a few seconds after touching down on the runway he felt the gear giving way. There was some wind but not much and the weather conditions were good. He recalls that the right gear touched down first, followed by the left and then the nose. After sensing the gear collapse, he decided to go left to avoid generating sparks, thinking that the grass was better than the asphalt.

1.5.2. *Eyewitness statements*

The landing was seen by three eyewitnesses: a tow pilot, an instructor and a ULM pilot who was waiting to take off. All three agreed that the landing was very hard and that the gear collapsed at the point of contact.

1.5.3. *Analysis of the fractures*

The main gear strut and the strut fragment that had detached and remained joined to the main gear drag link were sent to a laboratory for analysis. The following fractures were identified (Figure 4):

- Two fractures (A and B) on the strut that had managed to completely separate the projection where it attaches to the main gear drag link.
- Fractures A and B joined at a point, after which fracture C continued to the other end of the strut.
- The torque link exhibited two fractures where the lower torque link hinges (fractures D and E).

The analyses ruled out microstructural defects or heterogeneities at the fault initiation area that could have caused the material to break.

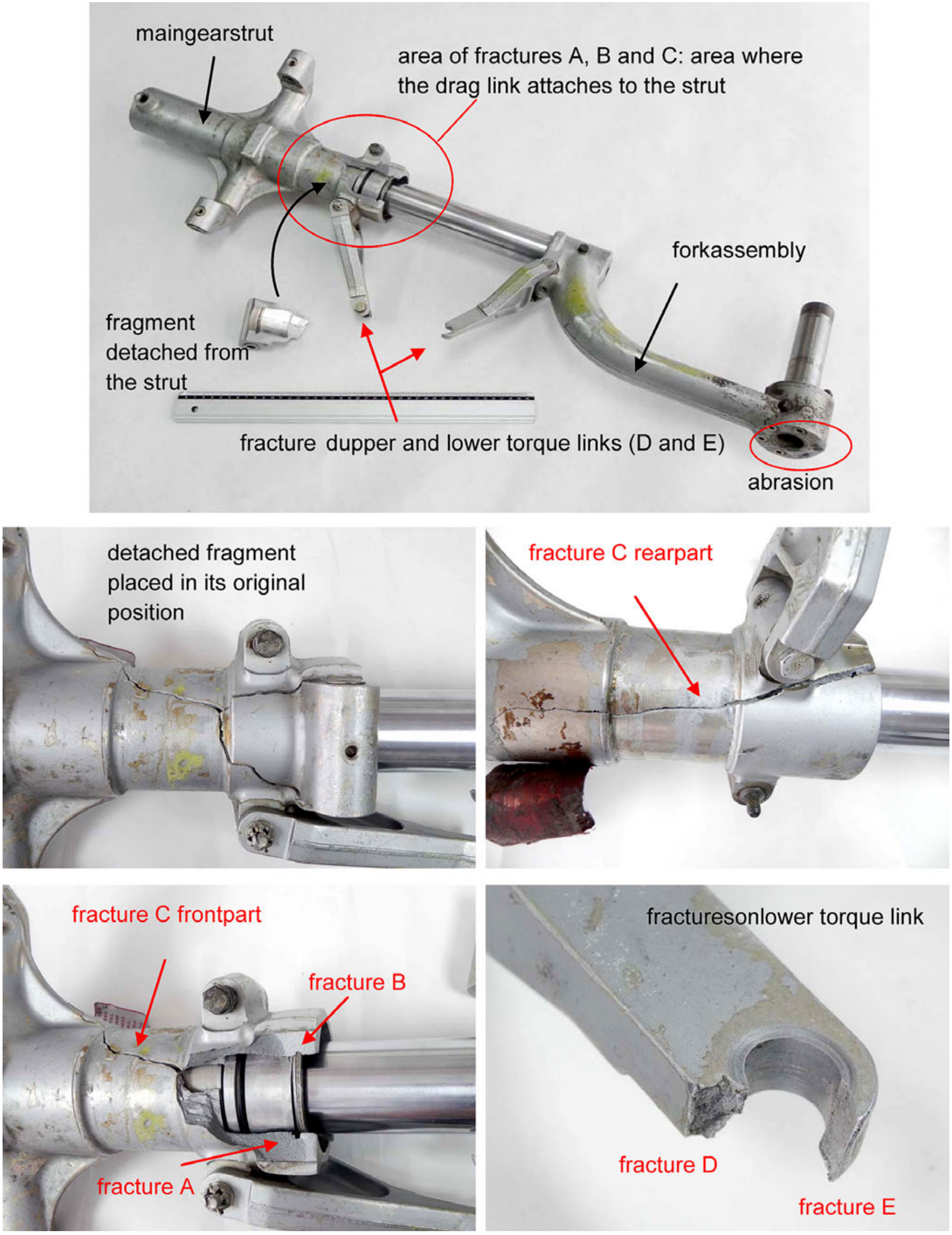

Figure 4. Fractures on the left main gear on aircraft EC-GGF

The fracture analyses concluded that fractures A and B started jointly and were the main fractures. The other three (C, D and E) originated as a result of the first two.

Fractures A and B (Figure 5) started on the piece's outer surface and resulted from a fatigue incubation process in the transition area between the cylindrical body of the

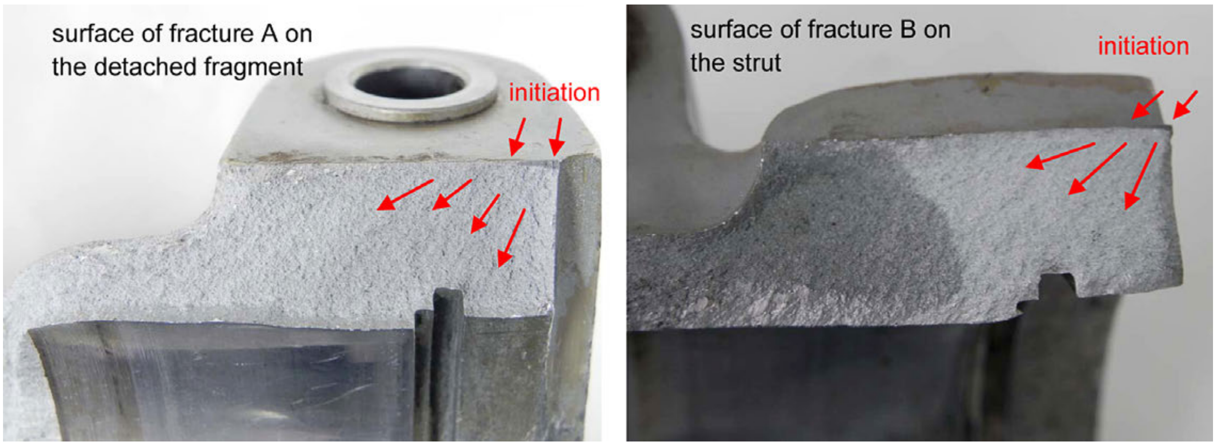

Figure 5. Close-up of fractures A and B

strut and the projection for attaching the main gear drag link. The initial fracture surfaces were rusted, meaning the aircraft operated for a long time with these cracks on the gear. The rust prevented the identification of any fractographic features involved with the start of the failure that could have indicated any other potential mechanism besides fatigue that might have contributed to the initiation of the cracks by fatigue. In any case, the presence of several microcracks near the fracture, exhibiting features typical of fatigue, and the absence of flaws in the material, indicate that the main crack also started as the result of a fatigue mechanism.

Both the microcracks and the fractures had initiated in places where the geometry of the piece and its changing cross section promoted the accumulation of stress.

The laboratory was unable to determine if the weakening caused by the cracks was enough to cause the break during a landing under normal conditions, but the crack would eventually have advanced to the point where the gear would have undergone a complete failure under normal loading. The crack was invisible to the naked eye. This type of crack is often mistaken for a scratch. The only way to detect them is through non-destructive testing using liquid penetrants. Once the laboratory findings were received, the right gear on aircraft EC-GGF was subjected to a liquid penetrant test and found to be free from cracks.

1.5.4. *Similar events*

The manufacturer had no records of fatigue failures similar to that involving aircraft EC-GGF. The FAA's SDR (Service Difficulty Reports) database, which has information on operator-reported incidents going back to 1995, only contained one reported case of the lower main gear drag link breaking from the upper link due to a hard landing. There were no signs of fatigue in that case.

2. ANALYSIS

2.1. Analysis of the landing

The analysis of the marks on the runway, of the path taken during the landing run, of the damage to the aircraft, combined with the statements from expert eyewitnesses and the pilot yielded the following conclusions:

- The gear was down and locked.
- The airplane was at a left angle when it landed.
- Based on the damage, it was not possible to determine whether the landing was hard.
- The gear collapsed after landing.

The right main gear and the nose gear were in the down and locked position, as confirmed by the fact that the aircraft remained supported by these legs once it came to a stop. The left main gear was also in the down and locked position before the landing, as verified by the position of the main gear drag link. The left gear being in an intermediate position and this contributing to the failure can thus be ruled out.

The landing must have taken place with a left bank angle, since the abrasion present on the outboard hinge support for the left aileron could only have occurred if that wing had been tilting left. Probably this impact took place shortly after contact was made with the ground. The friction marks on the support were clean and shiny, meaning they must have resulted from contact with the asphalt runway.

Although the pilot stated that the landing was normal, all three eyewitnesses agreed that it was very hard. This aspect could not be confirmed through the analysis of the damage or of the marks left on the runway. The force needed to cause a landing gear in perfect conditions to fail structurally would be high and would most likely have caused injuries to the people onboard. Even though none of the passengers complained of any aches, the hard landing cannot be ruled out, since the force necessary to collapse a gear with developing fatigue cracks would be much lower than those needed if the gear were in perfect condition.

The marks left on the runway by the left propeller, the tire and the unbroken line left by the fork assembly indicate that the left gear collapsed upon touching the ground. The propeller can only make contact with the ground if the distance between the wing and the ground is reduced, which only occurs if the gear is unable to maintain its normal position. Moreover, the abrasion on the underside of the wheel support and the evident friction marks on the asphalt indicate that the contact was with the runway. In order for this area to be in contact with the asphalt, the fork assembly must have rotated left and the strut shifted backward. In other words, the damage confirms that the gear collapsed shortly after landing.

At the moment of landing, the speed, the presence of some lift and the braking action of the pilot on the right gear made it possible to offset the drag generated by the collapsed gear which, in addition to being relatively close to the airplane's longitudinal axis, must not have generated an excessively high yaw moment. The aircraft's path was relatively straight until the end. It was only when the aircraft had practically stopped that it rotated on the left gear, ending up in its final position.

The weather conditions are not regarded as having had an effect on the incident.

2.2. Analysis of the collapse of the left main gear

The following aspects were considered based on an analysis of the fractures, the geometry of the gear components and their configuration during the landing:

- The fatigue origin of the cracks on the strut, which rules out problems with the sizing of the gear or defects introduced during the manufacturing process.
- The sequence of the gear fractures and the contribution of the unconfirmed hard landing accelerating the existing fatigue problem, but not causing the collapse.
- The part of the strut where the fatigue occurred as it is an area of stress build-up due to the geometry of the fully extended piston with respect to the strut on landings, the tilt angle of the entire assembly from the vertical during a landing and the change in the part's cross-sectional area.

The gear failure started in the projection on the strut where the main gear drag link attaches; specifically, on the fragment that detached from the strut. The cyclic stresses that occur during landing operations must have resulted in the incubation of fatigue cracks in this area. As these cracks grew, the component gradually weakened, leading to further stress build up until the material's strength in this area was exceeded, causing the component to fail.

The fact that no defects were found on the material, along with the length of time in service (since being manufactured in 1972), rule out any design or manufacturing defects in the gear, something that would have undoubtedly been made evident much earlier. In other words, the gear is not undersized for the loads to which it is subjected. The presence of defects introduced during the manufacture of the gear can also be ruled out. A more likely possibility is that the fault occurred due to the high number of cycles and to the lack of a requirement to overhaul the gear.

The fact that there was rust around the area where the cracks started confirms that the fatigue process had been present for a long time, though exactly how long the aircraft had been in operation with that problem could not be determined. The cracks would not have been visually detectable during the prescribed maintenance inspections. The way to detect this type of defect is through non-destructive testing using liquid penetrants.

Once the initial fractures A and B (Section 1.5.3, Figures 4 and 5) grew to the point where they caused the projection to detach from the strut, crack C developed as a continuation of cracks A and B toward the opposite direction of the strut, causing the torque link to fracture. While fractures A and B had developed some time in the past, they grew until they joined and caused part of the strut to detach instantaneously upon landing, at which time fractures C, D and E also developed. The investigation could not determine whether the collapse of the part took place as a result of the cracks reaching a critical size (at which point the part breaks), meaning the part would have fractured even under the load of a normal landing. The three eyewitnesses to the incident, regarded as qualified in the matter, agreed that the landing was hard, in which case the forces of the landing would only have accelerated the growth process of an already existing crack. In other words, the gear would have failed eventually, and the hard landing, if it occurred, accelerated the failure but did not cause it.

As regards the geometry of the landing forces, it has to be considered on the one hand the relative position of the piston cylinder and the strut before the landing, and on the other the position of the assembly with respect to the vertical.

Landings take place with the strut piston in its fully extended position and at a certain tilt angle of the strut with respect to the vertical axis, as a consequence of the aircraft's position during the flare. In other words, the strut of the axis is not fully perpendicular to the ground when it makes contact with it. When the aircraft's weight is transferred to the gear, the piston slides inside the strut, resulting in relative motion between the two while the assembly is at an angle with respect to the vertical. The fatigue cracks started in the lower front section of the strut, which faces forward during landings and is at the pivot point of the piston with respect of the strut. When the piston is extended, the moment arm is higher, subjecting this area to greater stress.

In addition to the geometry of the stresses in the lower front section of the strut during landings, this part of the strut also has a changing cross-sectional area to allow housing the main gear drag link connection. This results in an area that is particularly critical in terms of the stresses that build up during landing.

2.3. Analysis of the maintenance performed on the gear

The gear had been in operation for 40 years, the same as the aircraft. Since its manufacture it had not been replaced or overhauled, not being required by the manufacturer as part of the maintenance program.

Maintenance inspections are based solely on flying hours, and do not take cycles into consideration. Despite of the fact that during the last 8 years the number of cycles had been recorded, it is unknown the total number of cycles since the previous owners had not recorded this information. The number of total flight hours and cycles cannot be assumed to be equal in the case of training aircraft, since the ratio of takeoffs and landings to flight hours is far in excess of 1:1. Training aircraft, due the nature of the activity, is subjected to more hard landings and to be conducted in various ways.

The gear that underwent fatigue failure, then, had been in operation for 40 years, the last 15 years devoted to training flights where a higher likelihood exists for hard landings and for non-standard operations. It was also never overhauled.

The last inspection performed on the aircraft, shortly before the incident, was a 100-hr inspection, during which the maintenance center detected no cracks in the structure. The pilot also saw no cracks in the gear during the pre-flight inspection, which includes a visual check of the gear. The maintenance inspections specified by the manufacturer do not contain any specific actions for detecting fatigue cracks. In addition, this type of crack is invisible to the naked eye.

This incident was reported to the manufacturer. Taking into account the number of aircraft built, the number of safety reports regarding landing gear, and this incident is the only one with fatigue issue, it is not warranted a safety recommendation to modify the maintenance program.

3. CONCLUSIONS

3.1. Findings

- The pilot and aircraft were in conditions to make the flight.
- Weather conditions were not significant and are regarded as having no effect on the incident.
- The pilot had very little experience: 202 total hours and 35 on the type.
- The load and balance calculations with the fuel tanks full, six people onboard and with no baggage, placed the center of gravity within limits.
- The aircraft landed before the threshold and most likely with a left bank angle.
- The gear was down and locked before the landing.
- Investigators could not confirm whether the landing was hard, but if it was, it only accelerated an already existing fatigue failure process in the gear.
- The gear collapsed after landing. The initial break involved the strut and the projection where the main gear drag link attaches.
- The strut broke due to a fatigue process present in the projection where the main gear drag link attaches.
- The fatigue process was invisible to the naked eye.
- The part of the strut where the fatigue occurred is an area of stress build-up due to the geometry of the fully extended piston with respect to the strut on landings, the tilt angle of the entire assembly from the vertical during a landing and the change in the part’s cross-sectional area.

- There were no microstructural defects or heterogeneities in the area where the crack started.
- Problems with the sizing of the gear or defects introduced during the manufacturing process can be ruled out.
- The gear had been in operation for 40 years: the last 15 years devoted to training flights.
- The aircraft had been maintained in accordance with its maintenance program.
- The manufacturer's maintenance program does not include an overhaul or inspection of the area where the fatigue took place, nor cycle-based maintenance. The last 100-hr inspection had taken place less than two months earlier and did not detect any cracks in the gear.

3.2. Causes

The incident involving aircraft EC-GGF occurred due to the breaking of the left main gear as a result of a fatigue process in the projection on the strut to which the main gear drag link is attached. The break took place in an area where the build-up of stresses is high due to the geometry and configuration of the strut-piston assembly during landings and due to the change in the part's cross-sectional area.

The following factors resulted in the presence of fatigue:

- The absence of inspections specifically intended to detect fatigue cracks in the area where the gear failed.
- The high number of cycles and the number of years in operation (40).
- High demands placed on the landing gear by the conditions of use at the school in the previous 15 years.
- The absence of maintenance based on the number of cycles and of overhauls for the gear.