INCIDENT

Aircraft Type and Registration:	British Aerospace 146-200, D-AMGL	
No & Type of Engines:	4 Avco Lycoming ALF502R-5 turbofan engines	
Year of Manufacture:	1986 (Serial no: 2055)	
Date & Time (UTC):	16 August 2015 at 1736 hrs	
Location:	London City Airport	
Type of Flight:	Passenger Transport	
Persons on Board:	Crew - 4	Passengers - 77
Injuries:	Crew - None	Passengers - None
Nature of Damage:	Damage to right main gear shock-absorber and hole in right main gear door	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	N/A	
Commander's Flying Experience:	4,900 hours (of which 4,500 were on type)	
Information Source:	AAIB Field Investigation	

Synopsis

Fluid was seen on the ground around the right main gear after the aircraft parked. The head of a bolt on the shock-absorber on the right main gear leg was missing and there was a small puncture in the right main gear door. During the subsequent investigation it was concluded that the bolt had fractured due to fatigue, and the bolt had exceeded its 18,100 landing fatigue-life limit. The design of the shock-absorber is such that the small loss of oil does not cause a significant degradation in aircraft performance. At the time of the occurrence the operator was not monitoring the life of these bolts, but has since changed its procedures.

History of the flight

The aircraft was operating a scheduled service from Frankfurt to London City Airport (LCY). The approximate landing weight at LCY was 33,430 kg and the crew reported that the flight, including the steep approach to Runway 09 at LCY, was normal. The commander considered that the touchdown was "strongly positive with a slight bounce" before the aircraft settled onto the runway. The landing roll and taxi to the parking stand were both normal, and the crew later reported that there were no warnings or indications of any issue with the aircraft. However, after the aircraft was parked on the apron the ground crew informed the commander that there was fluid loss from the area of the right main landing gear. The crew then noticed that the aircraft was developing a slight tilt. The commander inspected the landing gear and withdrew the aircraft from service pending maintenance and investigation.

CCTV recordings from London City Airport showed the aircraft touching down in the appropriate place and that there was a 'bounce', as reported by the commander.

Inspection of the aircraft at London City Airport

The images in Figures 1 and 2 were taken by the commander shortly after the aircraft had taxied to the stand and the passengers had disembarked. An oil stain was readily visible on the ground around the right main gear leg and there was a piece of broken locking wire (Figure 1) attached to the top of the shock-absorber. Bubbles of oil were coming from a hole where a bolt head was missing and oil was seeping from the base of the bubbles. Over the next 24 hours the rate of bubbles originating from the hole slowed significantly. The shock-absorber was removed and taken to the manufacturer for examination.

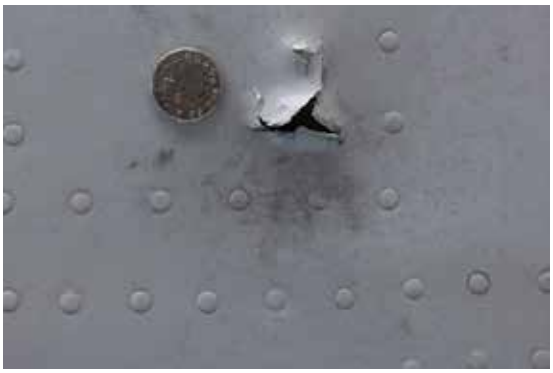
Figure 1

Image taken just after landing - shock-absorber on the right main gear leg

Figure 2

Image taken just after landing - right main gear

The landing gear door had been punctured from the inside – see Figures 3 and 4. The location and the size of the hole was consistent with the missing bolt head being forced against the inside of the door without the bolt head passing through the door structure.



Figures 3 and 4

Images of the hole in the right main landing gear door.
Note: the coin and bolt head have approximately the same diameter

Recorded information

The aircraft was fitted with a Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR), both of which used magnetic tape. These were removed from the aircraft and successfully replayed.

The CVR did not contain any pertinent information related to this investigation and supported the account of the operating crew.

The FDR was used to plot the key parameters that were available for the landing and these are shown in Figure 5. However, it should be noted that around the point of touchdown the recording was corrupt for a number of parameters. Tape-based recorders are more sensitive to impact shock and such corruption does not affect solid-state devices.

It was not possible to make a precise assessment of the descent rate at touchdown; however, over the preceding few seconds of data, descent rates of around 10 ft/sec were recorded. The applicable Aircraft Maintenance Manual quotes, in the section related to '*Inspection after overweight, hard or high drag/side load landing*':

> *'The aircraft has been designed for a vertical descent velocity at touchdown of:-*
>
> - *6 ft/sec at Maximum take-off weight.*
> - *10 ft/sec at Maximum landing weight.*
>
> *In association with the recommended approach speeds.'*

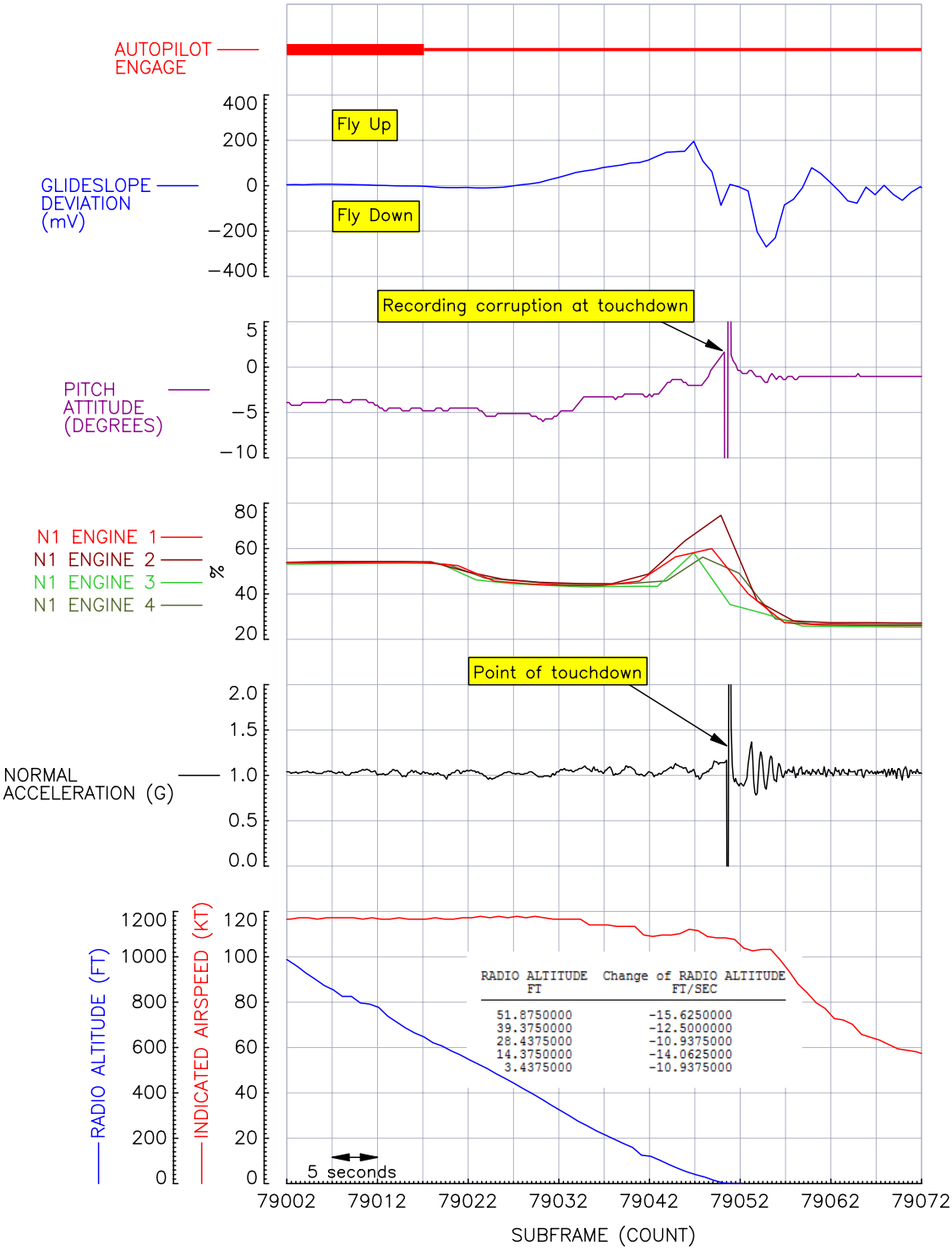


Figure 5

Flight Data Recorder parameters for the landing sequence including tabular information on the change of Radio Altitude over the last 5 seconds of flight

In addition to the FDR and CVR, the aircraft was also fitted with a Quick Access Recorder (QAR) which in this case was designed to record to a removable solid state CompactFlash (CF) card. The card was downloaded but found to be blank. On further investigation, the QAR was found to have damage to two pins that are part of the electrical interface from the unit to the CF card. Figure 6 shows the visible damage to one of these pins, highlighted in yellow.

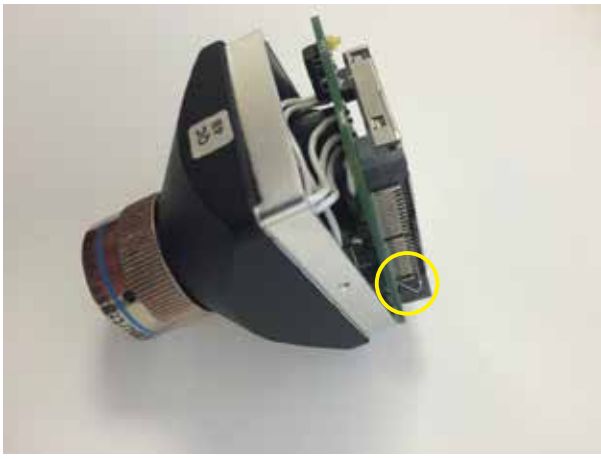


Figure 6

Damage to one of the pins forming the QAR unit's CF card electrical interface

The manufacturer of the QAR confirmed that the affected pins were the electrical ground signals for the CF card. The risk of potential damage to the QAR unit, by incorrect insertion of a CF card, had been highlighted by the manufacturer in a Service Information Letter, QAR001, dated 1 July 2005.

After the aircraft operator was informed of the damage to the QAR unit, a check of other units in their fleet highlighted two examples where damage had occurred. The operator subsequently published its own internal bulletin advising of the issue and has placed decals on the QAR units, showing the correct CF card orientation.

The QAR units were being used by the operator to provide data for their Flight Data Monitoring programme, with downloads planned for their fleet on a 28-day cycle. However, during the course of this investigation it was established that for the incident aircraft two download cycles had resulted in no data being recovered from the unit. Detection of this anomaly would have allowed the faulty QAR unit to be repaired or replaced at an earlier date.

On the QAR unit there is a FAULT light and a MEMORY FULL light on the front face of the unit. When the damaged QAR was tested with 115VAC power provided on the unit's main connector, as would be the case when the unit was installed on one of the operator's aircraft, the FAULT light did not immediately illuminate despite the presence of bent pins. However, the FAULT light did illuminate when the CF card was removed from the unit and the manufacturer has been asked to verify that the observed behaviour is as expected.

Aircraft information

The BAe 146 is a four-engined, high-wing passenger transport aircraft. The aircraft has two main landing gear legs mounted on the fuselage inside two fairings. Mounted on each main gear leg is a shock-absorber, which features a two-stage floating piston with four chambers. Nitrogen is contained in the lower outer and the upper inner chambers, and oil is contained in the upper outer and the lower inner chambers (Figure 7). The overhaul period for the shock-absorber is 15,000 landings (for European operations) or 12 years.

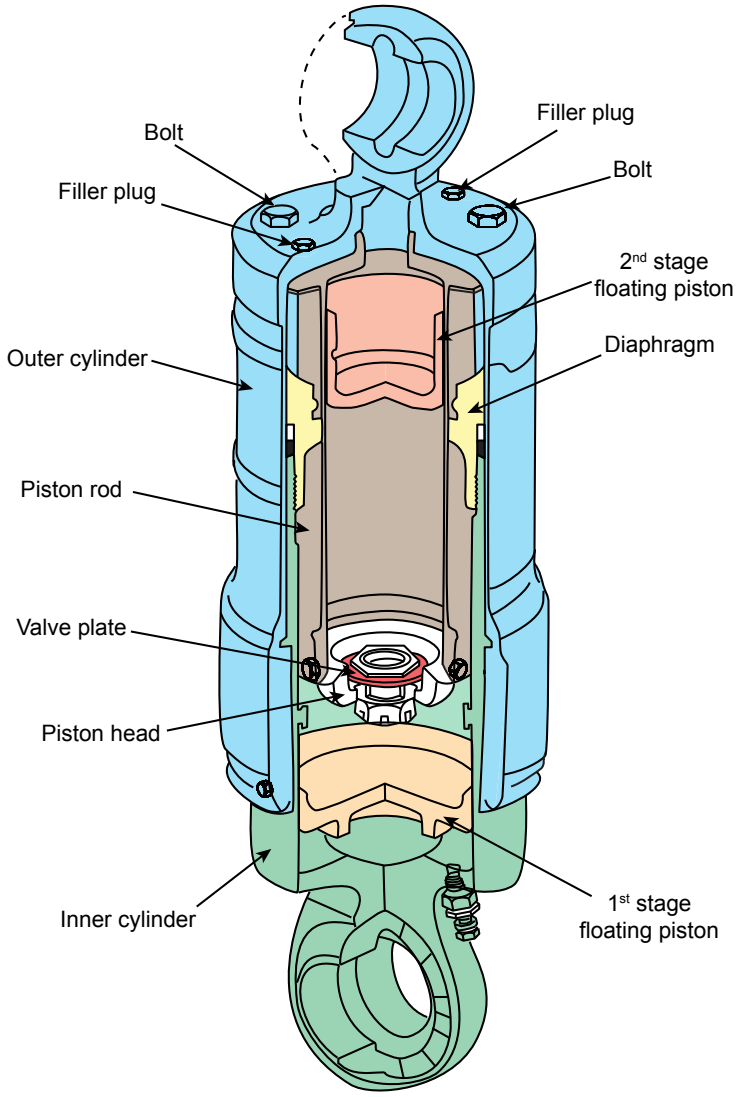


Figure 7

Cutaway drawing of the shock-absorber

At the top of the shock-absorber are six bolts. The two smaller bolts are oil filler plugs, the other four are bolts that attach the inner cylinder to the outer cylinder. These four bolts are lifed at 18,100 landings. Each bolt has a serial number written on its head. On assembly the bolts are lubricated, fitted with an 'O'-ring, tightened to a torque of 66 lbft, wire-locked and then sealed with mastic.

Shock-absorber examination

The shock-absorber was removed and sent to the manufacturer for a teardown examination.

The torques on the three remaining attachment bolts were checked by carefully marking a line on both the bolt and the surrounding surface, the bolts were loosened, and then the torque required to re-tighten the bolt to the point where the two marks aligned was measured. This gave an estimate of the torque applied when the bolt was installed during assembly.

The 're-tightening' torque for the three bolts was measured at between 84 and 92 lbft. A further re-tightening of the bolts to the correct torque (66 lbft) resulted in the lines on the three bolts being within approximately 1° to 2° short of the line on the surrounding surface. It was concluded that the bolts might have been slightly over-torqued during reassembly at the previous maintenance, but it was not possible to be conclusive from the evidence available.

The half of the fractured attachment bolt that had remained in the shock-absorber was removed and subjected to a metallurgical examination (Figure 8a). Three crescent-shaped fatigue cracks were observed on the outer edge of the fracture surface (Figure 8b). The conclusion of the metallurgical examination was that the bolt had fractured due to the initiation of multiple fatigue cracks from a number of locations. These locations were where the bolt interfaced with the outer cylinder, and no defects were observed at these initiation sites. No evidence of cracking was found in the other three bolts.

Figure 8a

Image of fractured bolt compared with the three remaining complete bolts

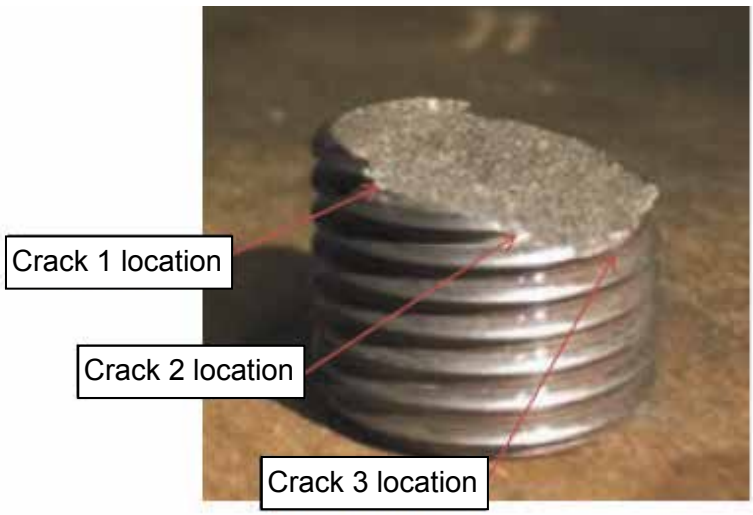


Figure 8b

Image of fractured bolt showing fatigue crack locations

The general condition of the shock-absorber was assessed as being good. A sample of oil was analysed and was found to be satisfactory. Prior to disassembly of the shock-absorber a test was carried out to measure the leakage rate in an un-pressurised condition. The leakage rate from the bolt hole with the bolt head missing was around 50 ml per hour.

Landing gear performance with a fractured shock-absorber bolt

With the two-stage floating piston design, the manufacturer calculated that the oil loss is only around 0.6 litres of the 12 litres capacity when the outer piston is on its stops. The pressure change due to this loss of oil is from around 86 psi to 74 psi. Thus the degradation in shock-absorber performance with a missing bolt was considered minimal in this condition.

Maintenance information

The shock-absorber was manufactured in 1985, and was overhauled by the manufacturer in 1998 when it had 2,013 landings. It was repaired by the manufacturer in 2002 at 4,327 landings; however there is no requirement to fit new bolts during a repair.

The serial number on the heads of the three remaining bolts confirmed that these three bolts were fitted during the overhaul in 1998. In April 2015 the shock-absorber had completed over 23,100 landings. Given that the bolts were replaced in 1998 after 2,013 landings, then at the time of the incident the bolts had completed at least 21,000 landings, which exceeds their 18,100 landing fatigue-life limit.

The operator did not record, and did not have a record for, the number of landings for these shock-absorber bolts. They noted that when the aircraft was bought from another operator they did not inherit any records for the bolts.

Safety action taken by the operator

As a result of this occurrence the operator has put in place a system to record the landings for the bolts on the shock-absorbers.

Discussion

This investigation showed that, if a shock-absorber bolt fractures in this design, there is a significant 'tell-tale' warning in the form of an oil spill around the gear leg. This will be evident during a pre-flight walk-around and thus the bolt fracture does not represent a significant safety issue.

A subjective comparison of the rate of oil loss between that observed at London City Airport and that measured during the investigation of the shock-absorber suggested that the bolt became detached within a few hours of landing at London City. The location and dimensions of the hole in the landing gear door were consistent with the bolt becoming detached and then being pressed against the inside of the landing gear door on retraction. It is therefore probable that the bolt became detached either during, or shortly before, the takeoff from Frankfurt.

From the serial numbers on the three non-fractured bolts, together with the maintenance records, it was determined that these three bolts had exceeded their landing fatigue-life

limit, and hence the bolt that fractured had also probably exceeded this limit. There was some evidence that the three remaining bolts were slightly over-torqued, which might have contributed to the bolt fracturing.

At the time of the incident the operator was unaware of the need to keep a record of the number of landing cycles that the bolts had experienced. However, since the incident the operator has changed its procedure to require monitoring of the usage of the bolts and hence there is no safety recommendation.