Engine failure, BAe 146-200, G-JEAR

Micro-summary: **A Bang! on rotation turns out to be a #3 engine failure.**

Event Date: **1998-11-06 at 0614 UTC**

Investigative Body: **Aircraft Accident Investigation Board (AAIB), United Kingdom**

Investigative Body's Web Site: **http://www.aaib.dft.gov/uk/**

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BAe 146-200, G-JEAR

AAIB Bulletin No: 10/2000 Ref: EW/A98/11/01 Category: 1.1

Aircraft Type and Registration:	BAe 146-200, G-JEAR
No & Type of Engines:	4 ALF 502-R5 turbofan engines
Year of Manufacture:	1983
Date & Time (UTC):	6 November 1998 at 0614 hrs
Location:	Lyon, France
Type of Flight:	Public Transport
Persons on Board:	Crew - 5 - Passengers - 13
Injuries:	Crew - None - Passengers - None
Nature of Damage:	No 3 engine turbine failure; minor cowling perforations
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	N/A
Commander's Flying Experience:	N/A
Information Source:	AAIB Field Investigation

History of the flight

The aircraft, which was on a scheduled service from Lyon to London Heathrow, had begun its take off run with all engine indications normal. However, as the pilot started to rotate the aircraft to lift off a loud noise was heard and the engine indications showed that the No 3 engine had failed. The appropriate flight deck actions were taken and the aircraft returned to land at Lyon without further incident.

Initial inspection of No 3 engine

Initial inspection of the No 3 engine showed that all of the stage 4 turbine blades had separated at or near their root ends. In addition, the jet pipe and fan-stream duct had been penetrated by fragments and there had been slight damage to the pylon rear underside cover. With the permission of the French Bureau Enquetes et Accidents (BEA), the fan of the No 3 engine was locked and the aircraft ferried to the UK operator's maintenance base for investigation.

Initial inspection at the operator's base confirmed the above damage and also revealed that the jet pipe and its attachment flange shield had been severely distorted. The engine was removed from the aircraft for further examination initially at the operator's maintenance facility and subsequently at the manufacturer's overhaul facilities in the UK and USA.

Detailed examination of the No 3 engine

Engine examination at the operator's base confirmed that all of the stage 4 turbine blades had failed near their roots. In addition, all of the stage 4 nozzle guide vanes (NGVs) had been badly damaged by debris impact, with the outer areas of the vanes the more damaged. Inspection of the stage 3 turbine blades, by viewing through the stage 4 NGVs, showed that these were also badly damaged, particularly on their outer trailing edges. It was also noted that a group of four consecutive stage 3 turbine blades had failed close to their root ends and that the retained blade length of the first of these (in order of rotation past a fixed point) was slightly longer than the other three. Inspection of the stage 1 and 2 turbines, using a borescope, showed that the blades of both turbine rotor stages and the stage 2 NGVs had been damaged by metallic debris impacts, but the stage 1 NGVs appeared to be undamaged. It was decided that the preliminary strip inspection should be performed at the manufacturer's UK overhaul facility, to fully determine the origin and extent of the turbine failure sequence.

Engine strip examination

When the engine was dismantled at the UK overhaul facility, in addition to the damage already noted it was found that all of the bolts that had attached the stage 4 nozzle to the stage 3 nozzle support frame had sheared, and the combustion liner had become twisted as a result of rotation of the stage 4 nozzle case. Following removal of the stage 4 turbine and nozzle assembly, the Low Pressure (LP) shaft and stage 3 turbine assembly was removed. The LP shaft exhibited rubbing abrasion marks on its outer diameter, just forward of the integral stage 3 turbine disc, over an arc of about 30° and an axial length of about 6 inches, with circumferential scoring over a greater length. The LP shaft and stage 3 turbine assembly was then sent for metallurgical examination.

When the LP shaft and turbines had been removed, it was found that the High Pressure (HP) turbines could be rotated without the HP compressor turning, indicating that the HP shaft had been severed. On removing the HP turbines, it was confirmed that the HP shaft had failed and at an axial position coincident with the area of abrasion found on the LP shaft. In the area where it had failed, the internal diameter surface of the HP shaft showed evidence of having been severely overheated by rotational contact with outer diameter surface of the LP shaft.

No other significant damage was found during the remainder of the engine strip examination.

Metallurgical examination

Metallurgical examination of the failed stage 3 turbine blades revealed that the longest of the four blade root ends exhibited a fatigue fracture which had initiated just behind the leading edge on the concave face of the blade aerofoil. This fatigue crack had propagated until the remaining cross section of the blade aerofoil had become insufficient to prevent its failure in overload with the engine running at high power. Examination of the tip platforms (or 'shrouds') of the other stage 3 turbine blades which had not failed found that they exhibited some evidence of wear on the platform contact faces and that they had not had the associated hard face coating applied, as recommended in the engine manufacturer's Service Bulletin (SB) ALF502R 72-279 (see later).

History of this engine

This engine had been fitted to the No 3 position on this aircraft on 29 September 1997, immediately following a hot section inspection performed at the manufacturer's UK overhaul facility. During this inspection, the stage 3 turbine tip platform clearances would have been required to be measured, however no record of the clearances measured at the time of this inspection could be found. The overhaul records showed that the turbine assembly had been refitted at this time, but there was no record of embodiment of SB ALF502R 72-279. When the engine had been fitted to this aircraft after this overhaul, it had completed 13,949 hours/20,191 cycles since new. At the time of this incident this engine had completed a further 3,108 hours and 2,138 cycles, the permitted period between hot section inspections being 5,000 cycles.

Service Bulletin ALF502R 72-279

In service experience of this engine type had revealed that if wear of the stage 3 turbine tip platforms became excessive on their contact faces, the blades would then have the freedom to vibrate and develop fatigue cracking at an unpredictable rate. Consequential blade failure invariably caused severe secondary damage to the turbine.

As a result of this, the manufacturer had developed a hard surface coating which was applied to the contact faces of the stage 3 turbine blade tip platforms. This coating was introduced by SB ALF502R 72-279 in October 1991 and compliance was recommended when the blades or turbine assemblies were returned to Service Centres for repair. It was not permissible to replace only those stage 3 turbine blades which exhibited worn platform faces with the modified hard faced platform blades; if it was elected to fit modified blades it had to embodied as a complete stage 3 turbine set. It was, however, permissible to continue to use unmodified turbine blade sets if inspection, at engine overhaul, showed the tip platform wear to be within the prescribed limits. A similar Service Bulletin (72-1011) was issued in March 1996 relating to LF 507-1H and -1F engines, and hard face coated platform blades were incorporated into new production LF 507 engines from April 1997.

Although the installation of such modified stage 3 turbine blades was recommended by these Bulletins, the reason stated for the introduction of the hard faced blades was 'To provide greater wear resistance and longer service life for the third turbine rotor blade shrouds'. No mention was made in the text of the Service Bulletins of the potential for such wear to give rise to conditions in which fatigue cracking could develop and result in blade failure, with serious secondary turbine damage as occurred in this incident.

Summary

The fatigue induced failure of one stage 3 LP turbine blade had caused secondary failure of three adjacent stage 3 turbine blades, which had then caused secondary failure of all stage 4 LP turbine blades. The resultant LP turbine imbalance had caused the LP shaft to run sufficiently 'bowed' to bring its outer surface into contact with the bore of the HP shaft, which was rotating at higher speed. The HP shaft had been severely overheated, locally, by contact with the LP and had separated at this point as a result.

The most probable reason that fatigue initiated in the stage 3 turbine blade was the development of larger than permitted clearances between the tip platforms of adjacent stage 3 turbine blades, a condition which was known to allow the stage 3 turbine blades to suffer excessive vibration. Once initiated, such fatigue was likely to have progressed to blade failure relatively quickly, resulting in the release of the affected outer section of the blade and consequent secondary damage to the remainder of the turbine section of the engine. The wear of the stage 3 turbine blade tip platform contact faces to the point where the clearances between adjacent blades became excessive was a consequence of these blades having been returned to service in September 1997 after the last hot section overhaul, rather than electing to replace these blades with the modified blade type recommended by the manufacturer in Service Bulletin ALF502R 72-279. This Bulletin recommended that the modified type of blade should be fitted when such engines were next returned to a manufacturer's service centre, unless the blade platforms were not worn beyond specified limits. In this case, since SB ALF502R 72-279 was not embodied it would appear that the platform clearances had been assessed to be within the specified limits at overhaul, although no record of related measurements was found. However, the platforms of the refitted stage 3 turbine blades appear to have subsequently worn to the point where they became liable to excessive vibration in less than half the overhaul period since that inspection.

In Service Bulletin ALF502R 72-279, the wording of the reason for the introduction of the modified stage 3 turbine blades did not indicate the likelihood of the initiation of related fatigue cracking in these blades, if left unmodified. In addition, it did not give any indication of how serious the secondary engine damage was likely to be if a stage 3 turbine blade suffered a related fatigue failure and separation. The text of the first page of SB ALF502R 72-279 is reproduced at Appendix 1, with the wording of the reason for its introduction highlighted (AAIB change to original). It may be seen that although the wording of the stated 'Reason' is accurate, it does not reflect the degree of secondary turbine damage which is the likely outcome if an associated stage 3 turbine blade failure should occur through non-embodiment of this modification.

It is therefore concluded that an explanation of the root reasons behind the introduction of these Service Bulletins (ie platform wear induced vibration, leading to turbine blade fatigue failure and separation) and a description of the most serious likely outcome resulting from their non-embodiment (serious secondary damage to the turbine) would have given operators a better understanding of the related implications when deciding whether or not to comply with these 'recommended' Service Bulletins.