Accidents Investigation Branch

Department of Trade

Report on the accident to Agusta Bell 206 B Jetranger G-BEKH at Dundee, Scotland on 11 December 1980

LONDON
HER MAJESTY'S STATIONERY OFFICE

List of Aircraft Accident Reports issued by AIB in 1982

No	Short Title	Date of Publication
11/81	Piper PA 38–112 Tomahawk G–BGGH Wood Farm, Kiddington, Oxfordshire May 1980	February 1982
1/82	Pilatus PC–6/B2–H2 Turbo Porter G–BHCR Peterborough (Sibson) Aerodrome February 1981	April 1982
2/82	McDonnell Douglas DC10–30 N 83 NA London Heathrow Airport September 1980	September 1982
3/82	Maule M–5–235C G–LOVE Cranfield Aerodrome Beds September 1981	September 1982
4/82	Cessna Citation 500 G–BPCP St Peters Jersey Channel Islands October 1980	November 1982
5/82	Piper PA28 (Cherokee) G–AVBJ and G–AXZC Hamble Aerodrome Hants April 1981	October 1982
6/82	Lockheed Jetstar 1329–N267L Luton International Airport March 1981	January 1983
7/82	Britten–Norman Islander BN2A G–BBRP Netheravon Aerodrome, Wiltshire February 1982	February 1983
8/82	Agusta Bell 206 B Jetranger G-BEKH Dundee Scotland December 1980	
9/82	British Airways Trident G-AWZT Inex Adria DC9 YU-AJR Zagreb Yugoslavia September 1976	
10/82	Bell 212 G–BIJF in the North Sea SE of the Dunlin Alpha platform August 1981	
1/83	Wasp Falcon IV Powered Hang Glider Wittenham Clumps, nr Didcot May 1978	

ISBN 0 11 513513 8

Department of Trade
Accidents Investigation Branch
Bramshot
Fleet
Aldershot
Hants GU13 8RX

21 January 1983

The Rt Honourable Lord Cockfield
Secretary of State for Trade

Sir,

I have the honour to submit the report by Mr K P R Smart, an Inspector of Accidents, on the circumstances of the accident to Agusta Bell 206 B Jetranger G–BEKH which occurred at Dundee, Scotland on 11 December 1980.

I have the honour to be
Sir
Your obedient Servant

G C Wilkinson
Chief Inspector of Accidents

Accidents Investigation Branch

Aircraft Accident Report No 8/82
(EW/C 725)

Operator:		Barratt Developments Ltd
Aircraft:	*Type:*	Agusta Bell 206 B Jetranger
	Nationality:	United Kingdom
	Registration:	G–BEKH
Place of accident:		Dundee, Scotland Latitude 56 29′N Longitude 003 00′W
Date and time:		11 December 1980 at about 1135 hrs.
		All times in this report are GMT.

Synopsis

The accident was notified to the Accidents Investigation Branch on the day of the accident and an investigation commenced the following morning.

The accident occurred during a private executive flight immediately after lift-off from a small helipad in the central area of Dundee. There was an explosion in the engine and, with loss of power, the helicopter settled onto the helipad. A limited fire was extinguished by the pilot and neither he nor his passengers sustained any injuries.

The report concludes that the first stage turbine wheel became disengaged, oversped and burst due to the failure, in fatigue, of a tie-bolt clamping it to the second stage turbine and compressor drive. The reason for the development of fatigue was not conclusively established but evidence is presented which suggests that the manufacturers should re-assess the loads sustained by the tie-bolt. Recommendations are also made concerning the vulnerability of the Agusta Bell 206 and other helicopters to secondary damage and fire following an uncontained engine failure.

1. Factual Information

1.1 History of the flight

On 11 December 1980 G–BEKH, which had been owned by Barratt Developments Limited since new, was operating in the Dundee area on business executive flights. It had completed five flights totalling 50 minutes when, at 1030 hrs, it landed on a small concrete helicopter platform at the Barratt Developments Ltd building site at Law Hill, Dundee. These flights appeared normal to the pilot but a witness to the final landing noticed puffs of black smoke from the exhaust at touchdown.

At about 1130 hrs the pilot re-boarded the helicopter together with three passengers. One of the passengers sat in the left front seat and the other two in the rear row of seats. The pilot stated that the Pre-flight Inspection and Engine Pre-start Check revealed no sign of any unserviceability. The engine started normally on the aircraft's battery, and the Engine Run-up Check and the Before Take-Off Check were both completed without any abnormality being noticed.

Before lifting-off the pilot checked that all the engine and transmission gauges were giving normal indications, and that none of the warning and caution lights were on. He then lifted off and settled into a hover with a skid clearance of about 5 feet, where he noticed that the torque gauge was indicating 75%, that the turbine outlet temperature gauge was indicating about 630° C, that all other gauges were reading in the normal range, and that again no warning or caution lights were on.

The pilot then heard a loud report from behind the cabin and the aircraft lurched and yawed to the left. He applied full right yaw pedal, moved the cyclic stick to the right, raised the collective pitch lever slightly to cushion the touch-down, and closed the throttle to the ground idle position. The helicopter came to rest with no engine noise apparent, and the pilot heard workmen nearby shout that the helicopter was on fire. He instructed his passengers to evacuate the aircraft, which they did promptly. The pilot then switched off the battery, but he did not fully close the throttle or put the fuel valve switch off. He got out carrying the aircraft's portable fire extinguisher with which he was quickly able to extinguish a fire he found in the engine compartment. The pilot then returned to the cockpit and stopped the rotor with the rotor brake.

1.2 Injuries to persons

Injuries	Crew	Passengers	Others
Fatal	–	–	–
Serious	–	–	–
Minor/None	1	3	–

1.3 **Damage to aircraft**

The engine casing had been explosively ruptured around almost 360 degrees of its circumference in the plane of the first stage turbine wheel. The engine cowling had been holed and penetrations made through the fuselage below the engine. High velocity debris had penetrated the baggage compartment and had exited through the compartment walls and floor and the aircraft's outer skin. All this damage was radial in the plane of the turbine wheel.

The tail rotor drive shaft and the main Low Pressure (L.P.) fuel line to the external fuel filter had been severed.

The engine compartment had been further damaged by a fuel-fed fire. The fire had begun to melt and consume the aluminium engine cowling but, though causing damage to non-metallic components and general sooting, it had not seriously affected the structure of the aircraft and had not extended beyond the engine compartment.

One main rotor blade had been struck by debris on the underside of its "D" spar.

1.4 **Other Damage**

There was no other damage.

1.5 **Personnel Information**

Pilot:	Male, age 35
Licence:	Commercial Pilot's Licence valid until 5 February 1986, endorsed for the Bell 206 as pilot in command.
Instrument ratings:	None
Medical Certificate:	Last medical on 29 November 1980, Class I, no restrictions.
Competency check:	Last check in Bell 206 on 9 October 1980.
Total pilot hours:	3586
Total hours on Bell 206:	Approx. 509
Total hours in last 28 days:	43.50

1.6 Aircraft Information

1.6.1 General Information

Type:	Agusta Bell 206 B Jetranger
Manufacturer:	Costruzioni Aeronautiche Giovanni Agusta, Italy
Operator:	Barratt Developments Limited
Airframe Serial No:	8531
Date of Manufacture:	1976
Certificate of Airworthiness :	Transport Category (Passenger) valid until 22 February 1982
Certificate of Registration:	G–BEKH in name of Barratt Developments Ltd.
Certificate of Maintenance:	Validated on 14 November 1980 at 2129.30 aircraft hours
Next Check Due:	50 hr check at 2179.30 hrs or 15 January 1981
Total Airframe Hours:	2173.20
Engine Manufacturer:	Detroit Diesel Allison, USA
Engine Type:	Allison Model 250 C20
Engine Serial No:	CAE 822735
Turbine Module No:	CAT 32789P
Total Engine Hours:	2140.55
Total Engine Cycles:	3630
Turbine Module Hours since Overhaul:	305.30
Turbine Module Cycles since Overhaul:	480

A time between overhauls of 3500 hrs is specified for the engine with a turbine module re-work at half life (1750 hrs). The records show that when the engine was removed from G–BEKH for turbine module overhaul it had, at 1835.25 aircraft hours, overrun the specified time between overhauls (T.B.O.) for the turbine. After re-work the engine was reinstalled and had completed a further 305.30 hours (480 cycles) at the time of the accident.

1.6.2 *Aircraft Weight and Centre of Gravity*

The helicopter's weight at take-off was calculated to be 1354 kg. and its centre of gravity (C of G) as being 108.82 inches aft of the datum. The maximum approved gross weight was 1449 kg. and the C of G limits were 106.0 inches to 114.2 inches aft of the datum.

1.6.3 *Technical Log*

In the year before the accident there appeared in the technical log, records of defects which could be associated with problems in starting. These defects, six in number, involved the ignition system, the generator, the starter and the battery. Deficient starting performance can result in slow or hot starts and thus turbine damage and failure. No hot starts or slow starts were specifically recorded in the technical log.

The records contain no indication at any time of engine vibration level being abnormal.

1.6.4 *Turbine Module Overhaul Records*

The turbine module overhaul records of the United Kingdom agents for this engine, document all the inspections and procedures as having been carried out.

The two gas generator turbine wheels and the second stage nozzle ring were replaced. The number two wheel splined adaptor was renewed to conform to Commercial Engine Bulletin (CEB) 1136.

The gas generator turbine tie-bolt was recorded as being "satisfactory" on inspection. Its free length was noted as 6.849 inches which was found to be precisely the figure recorded by the manufacturer on initial build. The dynamic balance of the gas generator rotor was recorded as 0.002 ounce inches which is the maximum allowable.

A valid certificate of compliance had been entered in the aircraft log book for this work.

1.6.5 *Service Information*

There were no airworthiness directives (FAA or CAA), applicable to the subject turbine module. One manufacturer's service bulletin, Commercial Engine Bulletin 1136, was applicable to the components relevant to the investigation and had been implemented at turbine module overhaul.

1.7 **Meterological Information**

The pilot stated that the weather at the Law Hill building site, Dundee at take-off was as follows:

Surface wind:	260 at 15 knots
Visibility:	Over 10 kms
Present weather:	Nil
Cloud:	1 okta at 5,000 feet
Temperature:	+9° C
QNH/QFE:	Not known.

1.8 **Aids to Navigation**

Not relevant.

1.9 **Communications**

Not relevant.

1.10 **Aerodrome and Ground Facilities**

The accident happened on lift-off from a small concrete helipad, approximately 10 feet square, situated in a building site within a built-up area of Dundee. The site was on the upper slopes of a prominent hill in the centre of Dundee and its altitude was approximately 400 feet. The helipad was marked with an "H" orientated north to south.

No fire extinguishing equipment was available specifically for the helipad and, as it was an unlicensed site, none was required to be available.

1.11 **Flight Recorders**

The aircraft was not equipped with a flight data recorder or a cockpit voice recorder, nor were these required to be fitted.

1.12 Wreckage and Impact Information

1.12.1 Examination of Site

The aircraft was removed from the site to a maintenance facility where it was initially examined.

Only a proportion of turbine and other debris was initially recovered from the site by the operator and assistance was obtained from the Dundee Police and from No 104 Field Squadron, Royal Engineers (V), who provided men and equipment for a ground search with metal detectors.

The search area included the building site, the adjacent street, open ground and the gardens of local houses. Two fragments, only, were found; a piece of engine casing and a small portion of number one turbine wheel.

The Dundee Police further assisted in having 150 leaflets printed for distribution to local households and in arranging for suitable statements to be broadcast on local radio and television. There was no response to this action.

No damage to local property was reported.

1.12.2 Examination of Aircraft

The rigging of the engine controls, which were undamaged, was checked before the engine was removed from the helicopter.

It was found that the maximum fuel flow adjuster on the gas generator fuel control unit was set and wire locked at 270 lbs/hr. This is the position normally set on the unit as new or at despatch after overhaul but, for the Augusta Bell (and Bell) Model 206 helicopter, it is required (Maintenance and Overhaul Instructions, Section VII, part 2 page 7–63) that the alternative position, of 235 lbs/hr, be set on installation in the aircraft. The maximum flow limit is not encountered in normal engine and aircraft operation.

No other anomalies were found in the adjustment of the engine controls but full confirmation of the power turbine governor controls requires a ground run and this was not possible.

An examination of engine instrumentation and its associated wiring revealed a 5° C discrepancy in turbine outlet temperature (TOT) relative to the prescribed calibration limits in mid-range. This was not considered significant and no other anomaly was found.

Both engine chip detectors were tested in another aircraft and found to give no indication of contamination.

As the engine was being removed from the aircraft it was noted that the nuts securing the engine mounts, though correctly wire-locked, required very little torque to undo them. Examination of the side mount studs showed that there had been long-term movement between the engine flange and the stud which had resulted in a groove being worn in the stud shank.

1.12.3 *Description of Allison Model 250 – C20 Engine (Reference Figure 1)*

The Allison Model 250–C20 engine is a two shaft free power turbine engine for helicopter applications. The engine is modular in construction with a centrally placed gear-box. The compressor module, mounted on the front of the gear-box, has a low pressure axial section and a high pressure centrifugal section which feed the combustion chamber at the rear of the engine through two external air ducts. From the combustion chamber the air flows in a reverse direction through two stages of turbine (gas generator turbine) which drive the compressor through an inner shaft and a further two stages (free power turbine) which drive the gear-box through a co-axial outer shaft. The exhaust manifold is mounted directly on to the rear face of the gear-box. The two stages of the gas generator turbine are connected by a "curvic" coupling, a device comprising circumferential dogs, held in engagement by a single central tie-bolt. The curvic coupling aligns and transmits torque between the two stages of turbine.

1.12.4 *Engine Strip Examination*

The engine was removed from the aircraft and taken to the overhaul facility of the UK agents and distributors for strip and investigation.

The turbine and combustion modules were fully stripped and the axial compressor casing split. The centrifugal compressor was examined, as far as was possible without dismantling, by inspection through the inlet and outlet apertures. The fuel system was rig checked.

There were no significant deficiencies in the fuel system or compressor and no evidence of foreign objects or debris passing through the engine up-stream of the stage one turbine.

The hub section of the stage one turbine wheel was found loose, inside the engine. The wheel had evidently burst, losing all its periphery. The gas generator turbine tie-bolt, also recovered from within the engine, was found to have failed at its threaded end. There was heavy rotational damage and radial bursting damage to the components adjacent to the number one wheel. The remaining hub portion which was asymmetric and would have produced high out of balance loads had fouled the stage two nozzle diaphragm while rotating at high speed and had been brought to a halt. The stage one diaphragm, which supports the number eight bearing, was buckled, apparently due to either the out of balance or the fouling loads transmitted from the hub to the bearing. The wheel hub extension to the bearing was broken. The stage two wheel had suffered some scuffing to its rear face and leading edges of its blades but it had no gross damage and had evidently not run out of true to any extent. Examination of the curvic coupling revealed that the normally loaded side faces and the outside faces showed evidence of the dogs having disengaged and taken interference damage in the process. This being in the direction consistent with number one wheel accelerating relative to number two.

The tie-bolt was recovered in two parts. The bolt had fractured in the plane of the first loaded thread at engagement in the nut. The threaded portion of the bolt was still engaged in the nut which was found lying loose inside the number eight bearing sump cover. The nut, having become displaced from its normal position, had been trapped between the rotating turbine and the number eight bearing sump cover. The sump cover and turbine stub shaft both had resulting rotational damage.

The major portion of the bolt was found to be slightly bent, a continuous, not local, deformation over about half of its length. It had received some surface damage on the fracture face, on the shank adjacent to the threaded end and adjacent to the central mute. When this damage was considered, it was found that it was consistent with the broken bolt adopting a position as shown in Figure 2. It was later shown by electron spectroscopy that the damage to the fractured end face of the bolt had been caused by contact between the face and the front rim of the number one wheel bore.

Both bolt fracture faces were stained and contaminated and the fracture face on the main portion had relatively severe secondary damage (reference Figure 3). The fracture was evidently complex in its features and it was decided to take the bolt and other relevant engine components to the manufacturers, Detroit Diesel Allison, (DDA), Indianapolis, USA for detailed investigation.

A preliminary examination by the materials department of the RAE, Farnborough identified no pre-existing failures in the broken components other than the bolt. The tie-bolt itself was kept in the "as found" condition until DDA were able to examine it and surface damage and contamination prevented any full examination by the RAE at that time.

The general examination of the turbine module by the agents showed that though there was heavy contamination of the oil system by oil breakdown products this had not developed to the stage where the oil passages were blocked or the engine directly endangered.

DDA confirmed that there was no evidence of any pre-existing defect in any of the components other than the tie-bolt and found no evidence of an oil fuelled fire. Components which, if not manufactured within the drawing limits, could impose off-design loads on the tie-bolt, had suffered damage which severely limited the amount and the significance of the dimensional checking which could be carried out. The components examined comprised the tie-bolt and nut, the two turbine wheels and the splined adaptor which remained mounted as an interference fit on the number two wheel.

The number one wheel hub was an irregular fragment with the wheel bore intact and part of the labyrinth seal still attached. The bore's internal diameter and the outside diameter of the related central mute on the bolt were within drawing limits. It was estimated that the axis of the bore was perpendicular to the wheel face to within 0.0005 inches in terms of run-out at the face.

The nut was placed on a new bolt and circumferential eccentricity measured at 0.0015 inches which is within the limit set for the concentricity of the pitch diameter of the thread. The nut had taken damage in being jammed between the rotating number one wheel and the number 8 bearing sump cover and no further dimensional checking appeared justified.

The alignment of the splined adaptor is defined relative to the turbine wheels in assembly. Eccentricity was measured relative to no. 2 wheel alone and was found to be at the specified limit of 0.002 inches. Run-out at the splined adaptor end face, which is not specified, was measured as 0.0003 to 0.0006 inches.

1.12.5 *Detailed Examination of Tie-bolt Failure*

The gas generator turbine tie-bolt (Part No. 6876991) was manufactured from Inconel 718, a nickel based alloy, the thread being formed by a rolling process. The examination by the manufacturer revealed no discrepancy in its hardness, chemical composition or grain structure, in particular, in the thread root area where the fatigue originated. A single origin was identified and the fracture development was symmetrical about this origin. No mechanical defect was seen at the origin, either on the surface or sub-surface and progression of the fracture had been in fatigue from the point of initiation. The fatigue area occupied 50% of the fracture area, the remainder being a single tensile failure. There was no feature in the fatigue process which could be related to the double off-loading and reloading which would have occurred at overhaul (see 1.16).

The thread root containing the fracture was immediately outboard of the first engaged thread and thus at a position of stress concentration, a disproportionate part of the bolt tensile loading being normally transferred to the nut at the first thread. Because of the two-phase nature of the bolt material the appearance of the fatigue was "facetted" with conventional fatigue striations appearing in discrete, isolated pockets. The discontinuous nature of the fatigue precluded any fruitful analysis of its history and progression. In some areas bands of striations could be identified and an estimate was obtained for the number of bands from initiation to failure as being of the order of 2500. The finer structure of striations within the bands was not amenable to such an estimate.

As first seen both fracture faces were stained over approximately 50% of their areas, that on the aft (threaded segment) of the bolt coinciding with the fatigued zone. It was found, however, that the two areas did not match and, in fact, were caused by different phenomena; the aft segment being coated with heat affected oil and the other being heat affected (blued) presumably by friction experienced when it rubbed the number one wheel forward face (see Figure 2).

The central mute exhibited some damage to its surface; two distinct areas of pock-marked appearance which were discoloured and typical of the damage caused by long-term fretting and an area of bright damage marks which appeared to be related to the bolts contact with the number one wheel bore during the accident. As can be seen in Figure 4 the largest area of fretting (area 1) was symmetrically in the plane of the origin of the fatigue with the smaller zone (area 2) at 90° to that plane. The area of bright damage (area 3) was diametrically opposite area 1. Fretting damage to the mutes is commonly a feature of engines in service and the overhaul manual specifies limits and allows repair by chromium plating. The records show the central mute to have been satisfactory on strip examination and not to have been subject to any re-work.

Diametrically opposite the main fretting damage could be seen the previously mentioned bright damage attributed to contact with the number one wheel during break-up. Under the bright damage there was an area of more long-term surface polishing and staining which had not suffered the surface break-up seen in the other 2 fretted zones. The number one wheel hub was sectioned and examined. In the regions surrounding the normal position of the mute there was surface marking or contamination over 360 degrees but one particular area of discolouration matched the shape of area 3. Over this area of the bore the surface was depressed such that there was a part circumferential lip at its forward end. Diametrically opposite there had been some surface damage similar to area 1 on the mute but these two areas could not be positively related to one another.

The shape similarities of area 3 on the mute and the depressed surface in the bore enabled the original orientation of the bolt in the turbine assembly to be established. This also showed that there had been heavy radial contact between the bolt mute and number one wheel bore in the period since the turbine module overhaul when both wheels had been renewed and that this contact and the resulting bending loads had been in the plane of the fatigue origin.

The other surface evidence in the number one wheel bore shows that there had been other contacts between mute and bore during the running period between turbine overhaul and the accident. It appears that, as fretting on the mute is commonly seen after service, there are loadings and movements that occur between both components, possibly due to thermal and air-load cycling of the assembly, distortion of the wheels by gyroscopic forces during manoeuvres, or resonance of the bolt itself.

1.13 Medical and Pathological Information

Not applicable

1.14 Fire

A fire developed, following rupture of the engine casing, fed by aircraft fuel spilling from the low pressure fuel feed line to the external filter. The pilot, as an immediate action, switched the Master Switch to OFF and this would have stopped the aircraft boost pump and the flow of fuel into the engine compartment. The fire was then quickly extinguished by the pilot with the aircraft's hand-held fire extinguisher. Apart from sooting, the fire's effects did not extend beyond the engine compartment.

1.15 Survival Aspects

The helicopter settled on the ground in an upright manner on its skids. No unusual loading was exerted on the seats or seat belts and the pilot and passengers exited normally.

1.16 Tests and Research

The recommended procedure for overhaul is contained in the DDA model 250–C20 overhaul manual. The procedure concerning the gas generator turbine tie-bolt is summarised below.

At overhaul (TBO of 1750 hours for the turbine module) the tie-bolt can be re-used subject to being shown to be crack free and subject to an extension check during assembly.

The two HP turbine wheels are assembled with the stage 2 nozzle ring to make a sub-assembly of the turbine module. The loose assembly is placed vertically in a jig with a built-in socket for the bolt head and the nut is run loosely on to the bolt. The free length of the bolt is measured and the nut tightened to obtain a bolt extension of 0.014 – 0.015 inches within a torque limit of 350 lbs/ins. The nut is then undone and the bolt free length measured; permanent elongation beyond the original free length must not exceed 0.002 inches. The nut is finally tightened to give an extension of

0.014 – 0.015 inches from the final free length and a dimensional check is carried out across the assembly to confirm correct engagement of the curvic coupling. With the rotor supported on the bearing journals, run-out is checked at the splined adaptor which can be relocated to correct out of limit run-out. The rotors are then balanced in the assembly by removing material from a circumferential flange designed for that purpose on each wheel.

The overhaul manual does not specifically call for the tie-bolt to be checked for straightness during inspection. However, reference is made to a figure (6–27) for repair standards for worn or fretted mutes and the drawing includes requirements for straightness with run-out limits specified for the bolt head inner face and the thread pitch diameter with the axis of rotation fixed by the central and end mutes.

An exercise was carried out to determine whether it were possible to damage the tie-bolt during assembly under the assumption that the bolt could suffer bending loads during assembly if the curvic coupling were not properly engaged or if there were an obstruction within the coupling or under the flange of the nut.

It did not prove possible to induce a misengagement of the coupling such as to offset or angle one wheel relative to the other. During assembly the seal land assists in centralising the two wheels.

The gas generator turbine used in these tests was assembled a number of times with obstructions, represented by steel piano wire or feeler gauges, present in the curvic couplings or under the flange of the tie-bolt nut and run-out was measured on the bolt as received and after each assembly.

With the apparatus used it proved difficult to obtain repeatable results but no permanent deformation was detected. This test appeared to indicate, therefore, that the bolt was insensitive to such mishandling in terms of measurable distortion, but did not demonstrate its effect directly on fatigue life.

1.17 Additional Information

1.17.1 Tie-bolt Design Standards

Two standards of tie-bolt are listed in the parts catalogue as applicable to the C20 engine; Part No. 6843388 (minimum shank diameter 0.25 inches, material Inconel 901) and Part No. 6876991 (minimum shank diameter 0.265 inches, material Inconel 718). Part No. 6876991 is to be used, according to the parts catalogue when supplies of Part No. 6843388 are exhausted. Part No. 6876991 was introduced in 1974 to combat permanent stretching of the bolt in service.

During assembly both bolts are torque loaded to the same specified extension which, because of its lower Young's Modulus, gives a 3% lower tensile stress in the shank of the modified tie-bolt (Part No. 6876991) while producing, because of its larger diameter, a 9% greater preload. However, the larger shank diameter, with the thread diameter being constant in both cases may produce a higher stress concentration factor in the area of transition from shank to thread and of load transference from bolt to nut.

One of the loading cycles which must be assessed in considering the tie-bolts vulnerability to fatigue is the thermal cycle with differential expansions between turbine wheels and tie-bolt. From consideration of the coefficients of thermal expansion of the materials involved, calculations show that for both tie-bolts the preload is relieved slightly at high temperature. The load relief is slightly less in the case of the Inconel 718 modified bolt.

From these limited considerations it would seem that the modified bolt is subjected to a less severe fatigue regime with a lower basic stress level and a smaller cyclic stress, but for a full assessment the stress concentration factor, notch sensitivity and material fatigue properties over the relevant temperature range would have to be considered in the context of all possible modes of loading. The manufacturers have initiated such a test and analysis program to re-examine the design of the bolt.

1.17.2 *Cases of Tie-bolt Failure*

Information has been obtained on three other cases of tie-bolt failure which may be relevant to failure in G–BEKH.

(a) Hughes 369–500 registered G–BEJY

Turbine module CAT 37095

Engine No. 832858

Date July 1981

(i) A loud rattling noise was heard from the engine during start-up. The engine was shut-down and subsequent strip examination showed that the gas generator tie-bolt (Part No. 6876991) had failed. Number one turbine wheel had not ruptured. The tie-bolt was returned to the manufacturers and AIB have not had the opportunity to examine it, but photographs showed the failure to be similar in its fracture face and identical in its position to that from G–BEKH.

The engine had completed 103 hours (103 cycles) since new. There had been no indications of any mechanical problem with the engine prior to the failure.

(ii) Following the tie-bolt failure at 103 hours in July 1981 the engine was rebuilt by the manufacturer's UK agents. The engine had completed a further 302 hours, when, at 405 total engine hours a second tie-bolt failure occurred. This second failure was at the same location as the failure at 103 hours.

Subsequent examination of the engine by the UK agents in conjunction with the manufacturer revealed a possible misalignment of the compressor module and undue loading on the compressor drive shaft due to an oversize gearwheel in the gearbox module.

(b) Turbine Module CAT 30059P
Date February 1981

This module was fitted to an engine returned to the UK agents from service in Saudi Arabia for rectification of "low power" thought to be due to sand erosion. Post strip inspection revealed a crack in the gas generator tie-bolt (Part No. 6843388). The crack was 0.812 inches from the threaded end of the bolt and thus in the shank, clear of the thread. Tie-bolt life details are not known but the turbine module had operated for 3374 hours since new and 1395 hours since the last overhaul.

1.17.3 *Re-examination of Engine Number CAE 822735*

In view of the double tie-bolt failure suffered by engine number CAE 832858 (see 1.17.2) components from CAE 822735 were re-examined. It was confirmed that the gearwheel fault was not present and the recorded values of compressor alignment shims were found to be correct for proper alignment though the actual values used could not be determined.

1.17.4 *Protection of Aircraft Systems*

No protection from the high velocity debris resulting from an uncontained engine failure is given in the Model 206 to the tail rotor drive shaft, which was severed in the case of G–BEKH, or the tail rotor pitch controls below the engine compartment floor.

The British Civil Airworthiness Requirements do not include a requirement for such protection.

The Civil Aviation Authority made a submission to the United States Federal Aviation Administration during the 1980 Regulatory Review Programme that FAR 29.903 be supplemented to the effect that, "design precautions must be taken to minimise the hazards to the rotocraft in the event of an engine rotor failure or of a fire originating in the engine which burns through the rotor case".

1.17.5 *Fuel Line Routing*

The external fuel filter on this aircraft was positioned in the engine compartment alongside the combustion section of the engine, ie the aft end. As the fuel supply line entered the compartment at the forward end and as the engine fuel system was mounted on the centrally positioned gear-box module both inlet and outlet lines attached to the filter were routed through the planes of the turbine wheels and were thus vulnerable in the event of an uncontained turbine failure.

In the event of the inlet line being broken, as in G–BEKH, a fuel spillage into the engine compartment spill tray would be promoted by the operation of the aircraft fuel pump until the LP cock or the pump switch or the battery master switch was switched to OFF by the pilot.

A Bell Helicopter Textron Alert Service Bulletin number 206 L-80-13 was produced following accidents to a developed version of the Bell 206, the 206L-1 Longranger. This version of the Longranger (-1) is powered by a later version of the Allison engine designated C28. This engine had suffered a number of turbine failures which had resulted in aircraft fires following rupture of the fuel lines. The Service Bulletin required the repositioning of the fuel filter on to the front fire-wall, thus taking the fuel lines out of the planes of the turbine wheels. This Bulletin did not apply to the 206 B model.

Subsequent to the accident to G–BEKH, on 28 August 1981, helicopter manufacturer published a Technical Bulletin (T.B. 206-81-55) which enabled operators of Model 206 B helicopters to re-position the aircraft fuel filter on to the front fire-wall. Compliance with this Bulletin was at customer option.

1.17.6 *Flight Manual Procedures*

Study of the aircraft's Flight Manual, Part II – Emergency Procedures revealed that:

a) There was no procedure given for dealing with a fire in the air.

b) The only procedure given for a fire on the ground was for an engine fire during starting.

2. Analysis

The evidence obtained from examination of the engine is entirely consistent with the fracture of the tie-bolt Part No. 6876991 being the initial failure which led to the separation, overspeeding and uncontained failure of the number 1 turbine wheel. Examination of all the other fractures in the individual components of the gas generator turbine assembly identified no other pre-existing defects. Though all of the number one wheel periphery was not recovered, the parts that were gave no indication of having been subjected to overheating or to an oil fire.

The fracture evidence indicates that the fracture occurred due to a high cyclic stress with no unusual stress raising feature present and that bending in a single plane was a significant part of the total load on the bolt. The single origin was not associated with any mechanical or material defect, and development of the fatigue was symmetrical about the origin. The bending load need not itself have been cyclic; there could have been a constant in-built load from distortion of the bolt or mis-alignment of the assembly with other additive, cyclic running loads.

The "facetted" appearance of the fatigue fracture face, a normal feature of fatigue in this material, limited the extent of any analysis of the fracture's progression. Only an order of magnitude estimate of the number of bands was obtained (2500), there being a finer structure of individual striations within each band. There was no objective indication of the length of time taken from initiation to failure but it is considered below whether anything can be reasonably deduced from the estimate above and the other characteristics of the failure.

The fact that the features counted were bands of striations suggests that they did not correspond with a one per revolution loading cycle. Further, if there had been a preceding event, say a turbine blade or rim failure, which precipitated a fatigue failure in the bolt the estimated number of cycles (2500) would require a minimum time to failure, given the gas generator shaft speed of 50000 RPM, of the order of 3 seconds. Neither the pilot nor any other witness was aware of any marked event of that nature during the time immediately before the turbine burst and it would seem that this possibility can be discounted given this and the lack of physical evidence of any other pre-existing defect. Puffs of black smoke from the exhaust were seen during the preceding landing but such smoke is characteristic of an engine with the oil breakdown contamination seen in this case.

Another possible interpretation of the fatigue evidence is that the striation count represents engine start cycles, and, given that the features were described as bands of striation rather than individual striations, this is, in any case, more plausible. The order of magnitude figure obtained for the number of striation bands is, perhaps, consistent with the total engine cycles from new (3630 logged) but not with the number since overhaul (480 logged) bearing in mind that there must be additional unknown allowances for the number of cycles to initiation.

The surface damage in the bore of the number one wheel indicates loaded contacts between it and the tie-bolt over the period since the turbine module overhaul. Most of the surface evidence on the bolt central mute is typical of normal wear but the damage identified as area 3 is distinct and particularly marked and in the plane of the fatigue origin. It would thus appear, circumstantially, at least, to be related to the fatigue loading. It is not possible from this evidence however, to determine whether the fault which produced the interference between mute and bore lay in the bolt or the number one turbine wheel.

To suggest that overloading of the bolt occurred during the period since overhaul only, however, would seem to be at odds with the estimated number of cycles to failure assuming one per flight cycle. During the "hot end" overhaul the bolt had been subjected to checks for straightness, cracking and for extension and permanent set under load. If fatigue damage had been accumulating since the engine was new then, at that time, it would have sustained 85% of its ultimate fatigue damage. It is unlikely, though not, of course, impossible, that the bolt could have survived these inspections (carried out by three inspectors) with no fault being detected. Further, the fatigue progression shows no evidence of the unloading and reloading that would have occurred twice at overhaul.

The contradiction in the evidence can only be resolved if it is surmised that the striation bands (which are not continuous over the fracture) correlate with peak loadings during flight manoeuvres rather than with individual flights. This would then allow the conclusion that the fatigue damage occurred in the period after the hot-end overhaul to be the most probable interpretation of the evidence. Given the nature of the evidence such a conclusion can only be tentative, however.

The fact that the engine mount nuts were found to be loose after the accident could be evidence of a high vibration level during operations since the hot-end overhaul but its significance is arguable. Though there were no reports of such vibration being noticed, high frequency vibration in a helicopter can be difficult to detect. The looseness of the nuts could alternatively be due to incorrect torque loading at engine installation, there being no way of distinguishing between the two cases. Excessive vibration, while being indicative of an out of balance condition which could be associated with the failure of the tie-bolt, does not identify the source of the un-balance.

The checks specified for the tie-bolt in the overhaul manual appear comprehensive if the concentricity limits illustrated are taken as overhaul inspection requirements, though, of course, they are subject to the human fallability of the inspectors involved.

Though, in this case, a discrepancy in one of the components of the gas generator turbine assembly, or even elsewhere in the engine, could have produced static or vibratory bending loads in the tie-bolt, the investigation revealed no direct evidence of any such discrepancy. It may be that no individual component was out of limits but that the present specified tolerances or a particular combination of tolerances allow, in extreme cases, the bolt to be loaded excessively. In the case of CAT 30059P, though the bolt is of a different standard, its failure supports the view that fatigue loading on these bolts can be more severe than currently believed though, perhaps in this case because of the bolt's different geometry, the failure manifested itself in another location.

It would seem appropriate that the manufacturer reviews the design of the tie-bolt and their assessment of its operating environment and it is noted that the manufacturers are carrying out such a test and design analysis programme.

The loss of power following the turbine failure presented the pilot with the sudden necessity of carrying out an emergency landing but the hazard was further increased because of two secondary effects; loss of tail rotor drive and a fire in the engine compartment fed by fuel from a ruptured line.

It was fortunate that the failure occurred when the helicopter was in a low hover, and not during the climb out or at a later stage in flight when the pilot would have been faced with the particularly hazardous situation of having to execute a power-off landing without yaw control and with the helicopter on fire. The fire, in this case, was contained within the firewall boundaries of the engine compartment and did not affect the integrity of the aircraft. Its duration, however, was short. From a higher altitude the fire would have been free to burn until a landing was effected, there being no fire warning to the pilot and no drill which would have stopped the flow of fuel into the compartment. This would have increased the possibility of airframe damage. Also, given that, with such a turbine failure, there is a possibility that both tail rotor drive and yaw controls could be severed and, therefore, the landing made less controllable, the fire represents an additional severe hazard to the occupants in the event of a hard or unstable landing.

It is observed that a deflector plate of only limited dimensions would be required to protect the tail rotor drive and yaw controls, systems which, if ruptured, add handling problems to those already faced by the pilot following a power loss.

In view of the inherent risk of damage to components situated in the planes of the engine turbine wheels, again illustrated by this accident, it would seem prudent that the aircraft manufacturers Technical Bulletin 206 81-55 be made mandatory in the case of 206 B helicopters. Also, that the Airworthiness Authorities reconsider design requirements in line with the Civil Aviation Authority's submission to the United States Federal Aviation Administration 1980 Regulatory Review Programme (see 1.17.4).

3. Conclusions

(a) *Findings*

(i) The pilot was properly licenced and adequately experienced to conduct the flight.

(ii) The helicopter had been maintained in accordance with an approved maintenance schedule and the Certificates of Airworthiness, Maintenance and Registration were valid at the time of the accident.

(iii) An uncontained turbine failure resulted from the rupture, due to fatigue, of the gas generator turbine tie-bolt Part Number 6876991.

(iv) The fatigue failure of the tie-bolt developed as a result of a non-design bending load.

(v) The source of the non-design bending load could not be identified.

(vi) In the event of an uncontained engine failure the aircraft is vulnerable to a fuel fed fire because of the location of the external fuel filter.

(vii) In the event of an uncontained engine failure the tail rotor drive shaft and controls are vulnerable to rupture due to lack of protection.

(viii) This and the other cases of failure sited indicate the possibility that the tie-bolt's normal fatigue loading may be more severe than currently believed.

(b) *Cause*

The accident was caused by the failure, in fatigue of the engine gas generator turbine tie bolt.

4. Safety Recommendations

It is recommended that:

1 The Engine Manufacturers reconsider the design of the gas generator turbine tie-bolt and their assessment of its operating environment.

2 The Aircraft Manufacturers and the Airworthiness Authorities consider the mandatory application of Bell Helicopter Textron Technical Bulletin 206-81-55 to Bell and Agusta Bell 206 A and 206B helicopters.

3 The Aircraft Manufacturers and Airworthiness Authorities reconsider the requirements for protection of essential aircraft systems following an uncontained engine failure or fire.

4 The Jetranger Flight Manual include procedures for fire in the air.

K P R Smart
Inspector of Accidents

Accidents Investigation Branch
Department of Trade

February 1983

Produced in England by Her Majesty's Stationery Office, Reprographic Centre, Basildon

Bas 95457/718423 8c 2/83 TP