Airbus A320-231, G-OOAC

AAIB Bulletin No: 11/97 Ref: EW/C97/5/7Category: 1.1

Aircraft Type and Registration:	Airbus A320-231, G-OOAC
No & Type of Engines:	2 International Aero Engine V2500-A1 turbofan engines
Year of Manufacture:	1992
Date & Time (UTC):	26 May 1997 at 0555 hrs
Location:	Bristol Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 7 - Passengers - 175
Injuries:	Crew - Nil - Passengers - Nil
Nature of Damage:	Damage to the No 3 brake pack
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	39 years
Commander's Flying Experience:	7,680 hours (of which 3,720 hours were on type)
	Last 90 days - 212 hours
	Last 28 days - 77 hours
Information Source:	AAIB Field Investigation

History of the flight

After the aircraft arrived at Bristol, it was prepared for thenext flight to Mahon. The oncoming commander confirmed from theTechnical Log that there had been no unserviceabilities on theprevious flight and that there were no 'Carried Forward Defects';he also completed an external check which revealed no apparentdefects.

The pre-start checks were normal as was the start and pushbackfrom the stand. No abnormalities were noted and the aircraftwas taxied to the active runway. The first officer had been designatedas the handling pilot for the outbound sector and, after a shorthold, he carried out a normal take-off. When safely airborne,the commander retracted the landing gear and the aircraft wasestablished in the climb. The flight continued uneventfully untilapproximately 35 minutes later when, with the aircraft under BrestATC control, the crew were advised by ATC that parts of a brakeunit and some hydraulic fluid had been found at Bristol. Thecommander then contacted Bristol ATC to clarify the message andit was confirmed that brake unit parts and hydraulic fluid hadbeen found on the taxyway, at the runway hold area and on therunway; he was also advised that the debris was suspected to havecome from his aircraft. The commander then made a comprehensivecheck of the aircraft displays and instrumentation, but therewere no fault indications. Following radio contact with his companyoperations department, who confirmed that the debris had probablycome from G-OOAC, the commander decided to divert to London Gatwick. He chose this destination as the most suitable considering hislocation, the company engineering support at Gatwick, the runwaylength and his experience of the airport.

The diversion was uneventful and the commander took over the handlingduties for the approach to Runway 26 at Gatwick. He did not declarean emergency, but advised ATC of the situation and requested thatthe Airport Fire Service (AFS) meet the aircraft after landing. The cabin staff and passengers had been briefed before the approach. The commander made a gentle landing and then used full reversethrust to retard the aircraft; autobrake had intentionally notbeen selected and gentle wheel braking was applied as the groundspeed slowed to 60 kt. Once the aircraft had cleared the runway,the commander brought it to a halt and shut both engines down. The AFS were already positioned and confirmed that there wasno excessive heat evident from the aircraft wheels; on the flightdeck, the crew noted that the brake temperatures remained below100°C. The aircraft was then towed to the parking standwhere the crew and passengers disembarked normally. An initialexamination revealed that the No 3 brake unit had failed.

Brake unit description and history

The brake units fitted to this aircraft were of the 'carbon' type,with the rotors, stators and end discs (the heat pack) all madefrom a carbon/carbon matrix. Each disc is manufactured from stackedlayers of Rayon fabric, and processed under a combination of heatand pressure such that a rigid, almost pure, carbon material isformed which has good structural strength resulting from the directionalityof the original Rayon fibres. The type of brake unit fitted tothis aircraft is shown in Figure 1 and comprised four rotor discs,three stator discs, and two pressure plates. All discs have wearingsurfaces on both sides except the two pressure plates, which abutonly against the first and last rotors. The rotors and statorsare 'keyed', respectively, to the wheel hub and torque tube byintegral metal capped lugs at their outer or inner edges. Togenerate braking torque, pressure is applied across the stackby a multiple piston hydraulic assembly, each piston acting throughmetal insulators and a thrust plate. Half of the pistons areassociated with the parking brake system, the other half withthe normal braking system. The aircraft hydraulic supplies tothe brake units have hydraulic fuses installed to limit fluidloss in the event of a serious leak. The claimed advantages of'carbon' disc brakes are that they are significantly lighter thansteel based brakes and have a higher thermal capacity. They possessgood friction characteristics and generally should exhibit longlives, particularly if used in a manner such that they become'hot', as advocated by the manufacturer. At low temperaturesthey are prone to 'snatch', or operate roughly, and wear morequickly. In common with most brakes, high braking torque is oftengenerated at low rotational speed. Other similar brake failuresexamined during this investigation had occurred at low speedsor on pushback from the stand. The failed unit from GOOAChad been overhauled by the manufacturer and released to the operatoron 19 December 1995. It entered service on 7 April 1996 at positionNo 3 where it remained until the failure. During that time ithad accumulated 4,924 flight hours and 1,661 landings.

Initial examination

Debris removed from the runway at Bristol and the damaged brakeunit from the aircraft were transported to the AAIB where an initialexamination was carried out in conjunction with a representativeof the manufacturer. It was determined that the carbon pressureplate nearest to the pistons housing, the adjacent rotor and firststator disc were all missing from the heat pack, but it was apparentthat the debris from the runway was composed of elements fromthese missing parts, with all but one of the stator clips havingbeen recovered (Figure 2). The distribution of this debris onthe runway indicated that disc failure had occurred at, or about,the point of brake release prior to the take-off roll, with thefragmentation and general disc damage having probably occurredduring the take-off run. The severely damaged metal thrust plateand nine of the fourteen insulators, two of which had broken diametricallyacross the rivet hole, were also recovered. Distortion and damagealso occurred to several of the hydraulic pistons as these hadextended to full travel during the brake failure, releasing aquantity of hydraulic fluid. It was apparent that the failurehad been initiated by detachment of one or more lugs, probablyon the first stator, and that the resultant entrapped debris hadcaused major disruption of the affected discs as the wheel rotatedduring taxi and the take-off roll.

Initial visual inspection of the carbon discs in this brake unitshowed all to exhibit evidence of oxidation, the severity of whichincreased towards the piston housing end of the brake. Generally,the inner regions of the discs had suffered to a greater extentthan the outer. In these circumstances, oxidation is manifestby loss of the material (with the consequent reduction in load-carryingability of the discs, particularly around the inner and outerlugs), with carbon combining with oxygen to form CO and CO_2(carbon monoxide and carbon dioxide gases). This effect becomesevident above 426°C and is dependent both on time and temperature. The rate of material loss, however, increases rapidly with increasingtemperature. Figure 3 shows a comparison between lightly andseverely oxidised surfaces.

In order to counter oxidation, the exposed 'non-wearing' surfacesof each carbon disc are treated with an inhibitor or anti-oxidant(AO), in this case the manufacturer's proprietary material basedon phosphoric acid (H_3PO_4). This is painted on by hand in the form of a transparent liquidand then baked at high temperature. Under magnification, it normallyappears as a crystalline salt deposit which should completelycover the surface. Soon after the introduction of these brakesthe AO compound used was modified, due to its poor performance,to a standard known as M-1 and this was the standard releasedfor production in December 1992 and applied to the discs in thesubject brake.

Detailed examination

Discussions with the brake manufacturer and several UK based operatorsof the A320, who used the same brake units, revealed that therehad been a series of similar failures affecting, particularly,the three main charter airlines operating A320 aircraft in theUK. One operator in particular had experienced 11 incidents ofdisc failure between August 1996 and May 1997 over a fleet of7 aircraft, with landings achieved at failure varying between857 and 1,318. In an attempt to further understand this problem,detailed examination was carried out on samples taken from discsin the failed brake and from two newly manufactured/unused discs(one treated and one untreated) which were supplied by the manufacturer. This examination was performed using a scanning electron microscope(SEM) and energy dispersive X-ray (EDX) analyses with the aimof obtaining data on the degree of protection afforded by theM-1 inhibitor on both used and new discs. This was to be assessedin terms of surface coverage, penetration into the matrix of thecarbon material, the level of any contamination on the faileddiscs and the possible effects of elevated temperature. The manufacturerhad indicated that certain contaminants such as sodium, potassium,calcium, chromium, iron and seawater, can act in a catalytic mannerto oxidise carbon and pointed out that potassium acetate is amajor constituent of many commercially available runway de-icers. Phosphoric acid has an affinity with iron.

In the figures referred to below, most SEM micrographs weretaken using the Backscattered Electron Detector (BSD) , whichimages regions of varying atomic weights as differences in greylevel - 'heavier' elements appear brighter than 'lighter' ones. Such images have the notation 'Detector = QBSD' in the data zone. Other SEM micrographs were taken using the Secondary Electron(SE) detector, which gives a higher resolution image and showsgood topography. These images have the notation 'Detector = SE1'in the data zone.

Samples for examination were cut from two locations, ie the outermostand innermost surfaces from the following discs (see Figure 1),including at least one surface which had been protected by a statormetal clip:- ie disc 7, disc 5, the uninhibited unusedstator (used as a reference) and the unused M-1 inhibited stator. All the samples, the external surfaces of which were to be examined,were mounted on SEM stubs such that the AO treated surfaces wereuppermost. As they were electrically conductive, it was possibleto examine them directly in the SEM. Samples to be sectionedwere first 'potted' in a resin block, ground and polished, andthen lightly 'sputter-coated' with platinum so that the entiresample became sufficiently electrically conductive to enable itto be imaged within the electron beam of the SEM.

Figure 4 and Figure 5 illustrate surface and sectional detail of theunused M-1 treated disc . It was apparent from these micrographs,which are representative of all the surfaces and sections examined,that the AO deposits (bright areas) did not completely cover thecarbon material, indicated here as fibre bundles of differentorientation, and that there was significantly more AO presenton the inner surface than the outer. It was also evident fromthe sectional views that the carbon matrix was not homogeneousbut contained voids, at least in the material close to the surface,and that there was significant, but not total, penetration ofthe AO into these voids with the better protection occurring atthe inner surface.

Figure 6 shows similar SEM views from disc 7 (failed brakeunit) and this was typical of the other discs examined from thisbrake. Incomplete coverage of the surfaces by the AO is apparentin addition to the effects of oxidation, ie rougher surfaces thanseen on the unused disc. Figure 7 illustrates an area of AO thathad become globular in form and this characteristic was seen inareas throughout the disc samples examined from the failed brakeunit. An EDX scan of the elemental composition of these globulesis shown in Figure 9 where, in addition to the main constituentsof the AO, there are traces of iron, sodium, aluminium, silicon,and potassium. This disc did not appear to have been contaminatedwith hydraulic oil (Skydrol LD4), as had occurred to the brokendiscs close to the piston housing. Two spectrochemical analysesof the oil taken from the affected system (green) several months(21 February 1997) before and shortly after this incident (5 July1997) are shown in Figure 10. Minor traces of the elements zinc,chromium, silicon and calcium were found to be present in theoil in the earlier sample and chromium and calcium in the latersample, but neither contained sodium or potassium as identifiedby the EDX scan of the globules. This also suggested that thesample shown in Figure 7 had not been contaminated with oil andthat the elements detected represented a low level of 'in-service'contamination.

Four of the samples taken from the unused M-1 inhibited disc,after initial examination, were each then heated to a differenttemperature ranging from 300°C to 600°C in a pre-heatedoven for 15 minutes. After cooling, each sample was re-examinedand no significant change in the appearance of the surface orthe character of the AO material was apparent. However, the sampleheated to

300°C was then re-heated to 1000°C and re-examined,whereupon it was seen that in some areas the AO had taken up aglobular form as shown in Figure 8. This sample also showed adifferent ratio of elements when compared with other samples. The levels of phosphorus (P) had decreased while the those ofaluminium (Al) and oxygen (O) had increased.

Additional information

Due to concern arising from these brake failures, several measureshave been introduced/proposed by the airlines concerned and thebrake manufacturer, such as wheel removal on a regular basis forexamination of the exposed areas of the outer surfaces of discsfor units with in excess of 1,100 landings. As part of an on-goingreliability assessment, one of the affected airlines had requiredcrews to log post-landing peak brake temperatures as indicatedon the Engine Indicating and Crew Alerting System (EICAS), some5 minutes after the aircraft was parked, over a period of some5 weeks. The results from this showed that, generally, indicatedtemperatures ranged between 200°C and 400°C but that,following approximately 5% of the documented landings, temperaturesexceeded 400°C. The maximum temperature recorded duringthis period was 680°C following a landing with a tailwindwhere medium autobrake was used. These were sensed temperaturesfrom a probe fitted to the pistons' housing; actual disc temperaturesmay have been higher.

In order to obtain a comprehensive assessment of brake operatingconditions of that airline, the brake manufacturer has developeda 'data logger' known as the Brake Performance Monitoring System(BPMS), which is designed to fit into the standard electronicequipment rack without requiring modification. All informationrelevant to the brakes on the various data busses would be monitoredand logged over a period of several weeks of revenue service. Approval to install this unit by the manufacturer and airlineis currently being sought from the CAA.

Conclusions

Whilst the examination of the samples from this failed brake unitwas not exhaustive, and other failed brake unit discs were notexamined in such detail, this investigation revealed apparentsimilarities between the new M-1 treated disc supplied by themanufacturer and discs samples from lightly oxidised areas ofthe failed brake unit. The distribution of the AO was extremelypatchy, and the amounts on the inner and outer surfaces differed,leaving areas of 'non-wearing' carbon exposed to the atmosphere. Where the carbon had been heavily oxidised it was not possibleto be certain of the extent of the original AO coverage but, ifthe new disc was typical of in-service discs, then oxidation wouldhave occurred whenever the disc temperature rose above 426°C. The AO penetration into the material below the surface of thisunused disc was 8.5mm. There were, however, many voids withinthe carbon of all disc sections examined, with only a proportionexhibiting evidence of AO penetration from the surface to provideany protection. It therefore seemed probable that when high braketemperatures were experienced oxidation could also have occurredbelow the protected surfaces if air were able to access thesevoids.

The heating tests on the samples showed that the general appearanceand elemental content of the AO did not appear to change appreciablyup to 600°C. The one sample initially heated to 300°Cand subsequently to 1000°C, however, showed the AO to havepartially adopted a globular form at the higher temperature, similarto that seen in areas on the surfaces of the discs from the failedbrake. This suggested that the brake unit had been operated totemperatures significantly higher than for the onset of oxidationto occur, the extent of oxidation indicating that this had mostlikely been occurring on a regular basis. This view was supportedby the peak temperatures logged by flight crews over a periodof normal revenue operation.

Some contamination of the AO was found on discs from the failedbrake. A large amount of this contamination appeared to be iron,but sodium and potassium were also present in many areas, particularlyon disc 7 (least damaged and apparently unaffected by hydraulicoil contamination), where there was more AO on the surfaces.Much of the globular formation of the AO was particularly richin iron, one of the elements recognised to act in a catalyticmanner in the oxidation of carbon. Thus the severe oxidationseen on these failed discs seems to have resulted from incompleteAO coverage on the exposed surfaces and penetration of the sub-surfacevoids, compounded by operation at disc temperatures in excessof 426°C. Contamination by 'catalytic' elements was foundand these may have been a contributory factor in the failure modeof the discs. Since August 1996 the manufacturer has again modifiedthe composition of the AO to further enhance its performance,this latest version being known as M-2, and data is currentlybeing gathered from their various overhaul facilities with a viewto identifying an expected improvement in disc condition and life. The operator which had experienced 10 brake failures advisedthat, of some 40 installed brake units on two aircraft fleetsfor which it had responsibility, there were currently only 3 unitswhich were known to contain M-1 treated discs. Since the installationof M-2 treated heat packs, they reported a marked reduction inthe presence of carbon oxidation and a gradual increase in thenumber of landings achieved to overhaul.