Boeing 747-136, G-AWNJ

AAIB Bulletin No: 9/99 Ref: EW/C97/12/2/025 Category: 1.1

Aircraft Type and Registration:	Boeing 747-136, G-AWNJ
No & Type of Engines:	4 Pratt & Whitney JT9D-7 turbofan engines
Year of Manufacture:	1972
Date & Time (UTC):	6 December 1997 at 1447 hrs
Location:	London (Heathrow) Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 18 - Passengers - 323
Injuries:	Crew - Nil - Passengers - Nil
Nature of Damage:	No 2 engine damaged beyond economic repair, nacelle components fell from aircraft
Commander's Licence:	Air Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	10,585 hours (of which 3,573 were on type)
	Last 90 days - 221 hours
	Last 28 days - 43 hours
Information Source:	AAIB Field Investigation

History of the flight

The aircraft and crew were to operate a scheduled passenger service from London (Heathrow) to New York (J F Kennedy) Airport and the crew reported for duty at 1235 hrs The aircraft was serviceable for the flight and the forecast meteorological conditions for the take off were good. The relevant Airport Terminal Information System information included a surface wind of 220û/11 kt with a temperature of +11ûC, the visibility was greater than 10 km with no significant weather or cloud and the QNH was 1018 mb. Runway 27R was the departure runway and the surface was dry. The engine start procedure was normal for all four engines and the crew requested taxi clearance at 1416 hrs. The first officer (FO) was to be the handling pilot for the take off which was initiated at an all up weight of 314,000 kg with the flaps set to 10.

The aircraft was cleared to take off at 1446 hrs and the initial part of the take off run was normal. At a speed between V_1 and V_R the commander saw a large bird ahead of the aircraft flying from right to left. He called "Rotate" at the correct speed, at which point the bird was on the left side of the aircraft but it then appeared to veer back and upwards towards the aircraft. All three crew members felt a pronounced 'thump' at about 100 feet agl, at which time the speed was estimated to be 165 KIAS. Almost immediately the Exhaust Gas Temperature for the No 2 engine rose rapidly, exceeding the maximum limit, and the crew noted that the other engine parameters for the No 2 engine also indicated damage to that engine. None of the other engines showed any unusual indications and the FO encountered no significant handling problems in controlling the aircraft. The crew of another aircraft which had been cleared for take off at 1447:10 hrs saw debris fall from the inboard left engine of the incident aircraft and informed ATC whilst electing to remain at the holding point.

The gear was selected up and the aircraft was climbed straight ahead as the crew confirmed the engine failure. Once above 400 feet agl the drill for 'Engine fire, severe damage or separation' was initiated for the No 2 engine and the FO transmitted a Pan call at 1447:40 hrs informing ATC of the engine failure; this call was acknowledged by the controller. The FO engaged the autopilot, the commander took control of the radio and upon reaching 4,000 feet they were given radar vectors towards the south coast. They were offered a discrete frequency, but declined because the frequency they were then operating was very quiet. The flight engineer confirmed that the Checklist items for an 'Engine fire, severe failure or separation' had been completed and then carried out the associated drills followed by the after take off checks. Once the No 2 engine had been shutdown the thrust lever became locked in position and the related 'Rev Unlock' amber light illuminated. The cabin services director had already reported to the flight deck that the cabin crew had witnessed significant damage to the No 2 engine.

The aircraft was levelled at FL 120 over the sea to the south of the Seaford VOR and 50,000 kg of fuel was jettisoned to reduce the aircraft weight to the maximum for landing. When the jettison drill had been completed the flight engineer went back into the passenger cabin to conduct a visual inspection of the No 2 engine and noted that the intake nose cowl and the fan cowls were missing; he did not observe any related damage to the airframe. Although there were no apparent hydraulic or flap/slat problems, the crew decided that they would reduce the speed early at every stage of the subsequent approach in order to detect any handling problems as soon as possible. Whilst in the holding pattern, which was flown at 260 KIAS in the clean configuration, there was noticeable airframe vibration. The vibration level increased as speed was reduced and flap progressively extended and was most marked at 205 KIAS with flaps 5. However, the level of vibration did not affect the operation of the aircraft and the crew did not experience any difficulty in reading the flight deck instruments.

The commander positioned the aircraft for an ILS approach to Runway 27L with flap 25 selected; the approach and landing were normal with full reverse selected on the outboard engines after touchdown; the aircraft landed at 1554 hrs. Once clear of the runway, a visual inspection was conducted by the Airport Fire Service crews who then followed the aircraft as it taxied to the allocated stand.

Flight recorders

The Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) were removed from the aircraft and replayed by the AAIB at Farnborough. The optical disk from the Quick Access Recorder (QAR), which recorded a larger selection of engine parameters than the FDR, was also removed and the data recovered by the operator. The CVR, being of 30 minutes duration, had recorded over the period of the incident take off but covered the subsequent landing and taxi to the stand. The recorded data added detail to the accurate description of events provided by the operating crew.

At 1446 hrs the aircraft had made a flap 10 take off from Runway 27R with rotation occurring at 164 kt. An airspeed of 177 kt and an aircraft nose-up pitch of 12° had been established when, at a radio altitude of between 70 feet and 80 feet, the Engine Pressure Ratio for No 2 engine reduced from 1.4 to 1.0 over two seconds. Simultaneously the No 2 engine fan speed (N1) and fuel flow reduced to zero over the same period. The recorded values of core speed (N2) also started to decay, but more slowly. No abnormalities were observed in the readings from the other engines. The aircraft yawed to the left by 9° before being corrected with the application of opposite rudder and control wheel inputs. The readings of turbine gas temperature rose rapidly to a valid maximum of 1014°C before they exceeded the recording range of the monitoring system. The landing gear was raised and the aircraft climbed straight ahead on a heading of 270°M.

At 400 feet agl the thrust lever for No 2 engine was retarded. At 1150 feet agl flap retraction was initiated and the aircraft accelerated to 220 kt. During the subsequent climb, holding pattern, descent and approach no unusual control inputs were observed to be required to handle the aircraft although there were slight increases in the perturbations of the lateral accelerometer readings.

Examination of the aircraft and engine

Initial examination by the AAIB, after the aircraft had returned to a stand, showed that the left inner (No 2) engine had suffered severe damage to the fan; two adjacent fan blades had lost substantial portions of their outer length and all the blades had some hard object damage. It was also observed that the complete intake assembly, fan cowls, jet pipe and exhaust cone had separated from the powerplant assembly; these components, together with fragments of fan blade and some feathered bird remains were retrieved from the western end of Runway 27R (see Airport diagram). The feathers were sent to the Birdstrike Avoidance Unit of the Central Science Laboratory, where they were identified as having come from a Grey Heron.

More detailed examinations of the engine were conducted at Heathrow and at the engine overhaul facility used by the operator. These revealed that the outer half of the first of the two fan blades and the outer two thirds of the second had separated. Blades either side of these had suffered leading edge tearing and the relatively large radius bending typical of birdstrike damage. The blade stubs remaining in the fan disc were removed and their remaining moment weights established. This showed that the moment weight imbalance resulting from the initial outer blade separations had been 5% greater than the loss of one entire blade, including its root end fitting.

All the fan blades had suffered hard object damage, mostly confined to the outer third and tip zones, and the abradable liner of the fan tip path had completely eroded away. Examination of the fan stream straightener vanes showed that the birdstrike had occurred just below the horizontal diameter on the inboard (right) side of the engine. There was evidence in both the intake and fan stream ducts that separated fragments of fan blade had spiralled round their outer peripheries. In the fan stream duct the fragments had torn and distorted the acoustic lining before damaging the straightener vanes. In the intake duct, abrasion paths spiralled forward from the fan plane and there was evidence that two of the larger fragments had penetrated the structure and emerged through the intake outer skin.

In addition to the fan damage, hard object damage was found on blades of all compressor stages and the outer lining of the gas path was eroded throughout the core engine. Both the high and low pressure turbines had suffered tip rubbing. Six of the eight bolts attaching the main gearbox to the diffuser case had sheared, only the two aft bolts on the right side remaining intact. The overall damage to the engine was sufficient to render it beyond economic repair.

Engine certification requirements

The current engine certification requirements (FAR 33.77 and JAR-E 800 combined with the associated Advisory Circular, ACJ E 800) specify the tolerance to the ingestion of small (85 gm), medium (680 gm) and large (1.8 kg) birds which the engine must demonstrate. Typical Grey Herons fall into the weight range of 1.3 to 1.6 kg. and as such are regarded as large birds. The Pratt and Witney JT9D engine was granted Type Approval by the FAA to earlier requirements in which the criteria for tolerance to the ingestion of large birds was specified in Advisory Circular 33-1A and was certificated by a test using two, 2 lb (907 gm) birds. However, its performance in this incident indicated that the basic engine would probably have met current requirements for this category of engine.

There are also airworthiness requirements which specify that the loads generated by the damage resulting from a large bird strike will not cause failure of the engine mountings and separation of the

engine from the aircraft; these were also met. There do not, however, appear to be any requirements that nacelle parts should remain attached to the engine during a violent event such as this incident.

Birdstrike hazard at Heathrow Airport

A bird control patrol, consisting of two trained operations personnel with a Land Rover, is on permanent patrol at Heathrow Airport to monitor bird activity visually; this can supported by another operations vehicle on immediate demand. When significant concentrations of birds are observed on the airport, dispersion and scaring techniques, appropriate to the specific type of bird, are employed. However, at the time of this bird strike incident, the bird control patrol considered that there was no significant bird activity. The Grey Heron is regarded as a solitary bird and, although sensitive to scaring techniques, is more difficult to locate and intercept.

Statistics for the previous month, November, provided by this bird control unit, indicated a decrease in overall bird activity in comparison to the same month in the previous year; sightings of the Grey Heron in particular reduced from 17 in November 1996 to 11 in November 1997. This decrease in recorded bird activity was reflected in the incidence of bird strikes; one having occurred in November 1997 compared to five in November 1996.

However, from data obtained during a series of observations at Heathrow conducted by the Birdstrike Avoidance Team of the Central Science Laboratory, there is a particular and increasing problem of large water bird species being likely to be encountered in the areas near the runway ends. This is the result of the presence, at the western end, of Perry Oaks sewage farm, reservoirs and the river Colne valley and, at the eastern end, of the river Crane. In addition to Herons, Swans (which weigh typically between 5.5 and 15 kg) and Canada Geese (typically between 1.5 and 7.5

kg) transit these areas at relatively low altitudes. Canada Geese, in particular, are likely to pose an increasing hazard, being relatively recently introduced into the area but with a rapidly increasing population and a tendency to fly in sizeable formations, thereby increasing the possibility of multiple catastrophic engine strikes. Multiple birdstrikes affecting more than one engine on an aircraft shortly after take off clearly have the potential to cause a major accident.

Much of the bird activity is transit flying across the Heathrow Airport which originates from roosting and feeding sites, widely dispersed over the local area and, as such, is not within the direct ambit of the airport's bird control patrol. The only bird hazard warning system normally available is the visual detection of flocks or single birds in transit by the unit patrolling within the Airport boundary. Although bird activity does not usually appear on the radars in service at Heathrow, it is understood that it is possible to tune weather radars to detect large flocks of birds and there are indications that single large birds may be detected using specifically tuned short waveband radars which are more commonly used in marine applications.

From observations made by Birdstrike Avoidance Team personnel and Airfield bird observers, it has been established that most local flight activity by birds takes place below 1,000 feet agl and becomes more concentrated closer to the surface; activity is most dense in the region up to 200 feet, but is significant up to 500 feet. Of all birdstrikes occurring at Heathrow in the period from 1991/95, 24% involved aircraft still on the ground, 47% (including those 24% which occurred on the ground) occurred below 100 feet, 60% below 200 feet, 76% below 500 feet and 89% below 1000 feet. Of these, seven involved birds of more than 1 kg; 2 ducks, 4 herons (which were all reported in a way that suggested that they were below 100 feet) and 1 Canada Goose at 150 feet.

In this incident, the birdstrike occurred at an altitude of about 75 feet and the large nacelle components which subsequently detached all fell within the airfield boundary. At the time of the strike, the aircraft was climbing at about 25 feet per second (1,500 feet/min.) and traversing the ground at approximately 100 metres per second. The distribution of birdstrikes relative to altitude indicates that the height band below 500 feet agl is of significant concern. It can be seen that an aircraft following a similar take-off profile would have been below 200 feet, the height band of particular importance, for a further 5 seconds beyond the point at which this birdstrike occurred. During that time it would have traversed to a position half a kilometre further westwards and, if a birdstrike were to have occurred at that point, the detached nacelle parts might fall as far west as the A3044, Staines to Longford road. A further 10 to 12 seconds would have been required to reach 500 feet, with an associated traverse of 1 kilometre; parts liberated from an aircraft following a strike at 500 feet could, therefore, fall across the M25 and into Poyle (see Map). The areas at hazard from take-offs on other runways can be similarly assessed.

Attachment of powerplant components

Examination of the nacelle components which had separated showed that all of the bolts attaching the intake assembly to the fan case front flange had failed due to overload, as had those attaching the jet pipe and exhaust cone. All assemblies had sustained damage as a result of striking the ground but there was additional damage on both the jet pipe and exhaust cone which indicated that contact of the cone on the jet pipe may have caused the separation of the latter from the engine.

In another birdstrike incident, at Nairobi on 24 February 1998, involving a non-UK registered Boeing 747 fitted with JT9D-7 engines, collision with a 16 lb vulture resulted in broadly similar damage to that experienced by 'NJ', including separation of the intake assembly. In that case the birdstrike was reported to have occurred at between 800 and 1,000 feet agl and the separated nacelle components were later recovered from approximately 1 mile beyond the end of the runway. In that incident there was also reported to have been evidence of contact between the jet pipe and the exhaust cone.

Shortly after the introduction into service of the Boeing 747-100, the aircraft manufacturer developed a modified, fixed geometry, intake. To facilitate the interchange to this new standard intake from the original design and to 'minimise the excessive manpower and downtime required' to replace an intake, the manufacturer issued Service Bulletin 747-71-2065, which reduced the number of fasteners attaching the intake assembly to the engine from 74 to 37. Whilst service experience has shown that this reduced number of attachment bolts clearly has been sufficient for normal operating conditions it is, demonstrably, not reliably capable of retaining the intake assembly against the forces resulting from the damage resultant from a collision with a large bird. As a result of this incident the operator has, in agreement with the manufacturer, increased the number of intake attachment bolts and fitted increased strength bolts to attach the exhaust cone to the engine, in order to reduce the incidence of cone, and subsequent jet pipe, separation.

During the time that the Boeing 747 has been in service there have been several instances of major nacelle components separating after birdstrikes. Of these, most have been tail cones although at least the two mentioned in this report involved the separation of intake ducts as well. Since both these intake separations were the result of the imbalance caused by the loss of most of two adjacent, or nearly adjacent, fan blades, it would appear that this should be the criterion to which the attachment of nacelle components to the engine should be designed. See Figs 2 and 3

Discussion

Whilst, in this incident involving ingestion of a single bird, only one engine was damaged and the aircraft made a successful recovery to Heathrow, the investigation has highlighted not only the potential secondary damage which could arise from large nacelle parts falling from damaged engines onto busy areas adjacent to Heathrow, but also the increasing hazard of multiple birdstrikes on aircraft taking off or landing at the Airport.

The increase in this hazard, specifically from feral Canada Geese, was quantified in a report entitled 'Feral Canada Geese as a Hazard to Aircraft in Europe: Options for Management and Control' (BSC E22 WP3) which was compiled by the Birdstrike Avoidance Team and presented at a meeting of the Bird Strike Committee Europe in Vienna in August/September 1994. This report, based on periodic summer census figures from 1953 onwards, showed that as a result of deliberate relocation of hundreds of geese to southern UK around that time, the small and previously stable UK population of about 3,000 geese in 1953 began to increase at an average rate of about 8% per year. This resulted in a UK population of over 60,000 geese in 1991 and, if the rate of increase has been sustained, about 110,000 geese currently.

The existing Heathrow Airport bird control patrol is primarily responsible for scaring birds away from within the airport boundary, but cannot provide a reliable means of early detection and warning of transiting large birds or formations. An automatic system to monitor such transit activity could provide timely warnings of such incursions so that the flight crews of aircraft about to take off could be alerted before related conflicts occurred, possibly by using related warning lights located near the ends of the runways. ATC could advise aircraft on approach of potential bird conflicts. In this context, it appears that radar technology already exists which may be suitable for adaption to detect large birds and associated formations. Other types of automated systems may be feasible and thus a review of such technical options would be required, in addition to assessment of potential effectiveness and of ATC integration problems within a busy operational environment. Thus whilst such a technical development could potentially improve the protection of departing or arriving aircraft against such multiple bird strikes, such an automated system would be unlikely to be made available in the short term. Consequently, in order to effect some reduction in this multi birdstrike risk in the near term it will be necessary to more effectively manage the large bird habitat and population adjacent Heathrow Airport, which Heathrow Airport Limited (HAL) currently has little direct influence to control, since such areas lie outwith the Airport boundaries. Effective management of such areas will therefore require enhanced cooperation between HAL, associated local authority bodies and related land owners in order to aleviate this transport/environment problem. Such cooperation between the operators of other major airports and associated local authorities etc should be also be undertaken to improve the management of any significant bird roosting and feeding sites within those external areas which could affect aircraft operations where they have the potential to cause a major accident to a public transport aircraft during departure or late stages of approach to land.

Safety recommendations

Whilst the primary cause of this incident was the ingestion by the right engine of a single 'large' bird which had approached the western area of Runway 27R undetected, it is apparent that there is a growing population of large birds adjacent to Heathrow Airport which poses an increasing hazard to aircraft. It is evident that the scale of this hazard needs to be quantified and improved measures devised to control the bird population in the short term and to further protect public transport aircraft using the Airport. An effective automated Airport system to detect large birds about to transit across the Airport could enable the pilots of departing or arriving aircraft to be alerted to potential multiple birdstrike conflicts. Such a future development could reduce the risk of a related large scale accident in the congested vicinity of the Airport as a result of associated multiple engine damage, and also reduce the commercial costs of damage arising from lesser birdstrike incidents. As a result of such concerns and considerations, the following Safety Recommendations are made:

Recommendation 98-58

In view of the apparent increased incidence of large bird formation (eg Canada Geese) transit flying over London Heathrow Airport, with the attendant increasing risk of multiple birdstrike occurrence involving departing or arriving public transport aircraft, it is recommended that Heathrow Airport Limited and the CAA should set up a working group, in conjunction with Airport Operators, to review available technology to determine if a radar based large bird flock detection system, or an alternative automated system, could more effectively alert pilots and ATC to potential multiple birdstrike encounters.

Recommendation 98-59

In order to reduce the risk of multiple large birdstrike encounters, involving bird formations over-flying London Heathrow Airport conflicting with departing or arriving public transport aircraft, Heathrow Airport Limited should seek maximum cooperation with the relevant local authority bodies and associated land owners to expedite effective management of the associated large bird habitat and population around Heathrow Airport. Similar co-operative initiatives should be actively promoted by the CAA around other affected major airports in the UK.

Recommendation 99-18

The CAA should expand the remit of its sponsored current study by the Central Science Laboratory Birdstrike Avoidance Team of the habitat, population and transit flight behaviour of flocking large bird species around Heathrow Airport to include the formulation of recommendations on the best means of managing and reducing the associated hazard of multiple birdstrike encounters involving departing or arriving public transport aircraft.

In addition, since the detachment of large heavy engine nacelle parts from aircraft in flight poses a serious hazard to populated areas being overflown, the following Safety Recommendations are made:

Recommendation 98-60

In order to reduce the likelihood of large intake assemblies suffering in-flight detachment from Pratt and Whitney JT9 powerplants on Boeing 747 aircraft as a result of bird ingestion damage-induced vibration effects, the aircraft manufacturer should be review the reduction in the number of associated intake attachment bolts (from 74 to 37) which was introduced by Service Bulletin 747-71-2065 to ease intake interchange.

Recommendation 98-61

The current engine certification requirements, FAR 33.77 and JAR-E 800, should be amended to require that large nacelle components remain attached to the engine up to the limit of forces on the engine and nacelle which result in the detachment of the entire nacelle from its pylon or wing attachments.