DC-10-30F, N601GC

AAIB Bulletin No: 9/2001 **Ref: EW/C2000/10/1** **Category: 1.1**

Aircraft Type and Registration:	DC-10-30F, N601GC
No & Type of Engines:	3 General Electric CF6-50C2 turbofan engines
Year of Manufacture:	1973
Date & Time (UTC):	1 October 2000, at 1858 hrs
Location:	Shannon Airport, Ireland
Type of Flight:	Public Transport (Cargo)
Persons on Board:	Crew - 5 - Passengers - Nil
Injuries:	Crew - Nil - Passengers - Nil
Nature of Damage:	No 1 engine damaged beyond economic repair. Impact damage from engine nacelle components to port inboard aileron and flap. Pylon web cracked.
Commander's Licence:	US Airline Transport Pilots Licence
Commander's Flying Experience:	Approximately 8,500 hrs total of which 800 were on type
Information Source:	AAIB Field Investigation

Synopsis

The aircraft suffered a bird strike shortly after take off from Shannon, Ireland, which caused severe damage to the No. 1 (left) engine and caused some large nacelle components to separate from the engine. These parts struck and damaged the left inboard aileron and flap before falling to the ground. The aircraft diverted to London Heathrow for inspection and repair. Whilst ATC written procedures specify that aircraft in emergency should preferably not be routed over densely populated areas, the commander of the aircraft was not advised of this procedure and the approach to London Heathrow Airport from the east took his aircraft over densely populated urban areas.

Three Safety Recommendations were made as a result of this investigation, pertaining to the method of attachment of the aft centre body on the CF6-50 engine and air traffic control procedures for aircraft in emergency situations.

History of the flight

The aircraft and crew were scheduled to fly from Stockholm, Sweden to San Juan, Puerto Rico with a refuelling stop in Shannon. The flight from Stockholm to Shannon was uneventful. The weather for departure from Shannon was wind 270°/27 gusting 40 kt, visibility 8 km in light showers, broken cumulonimbus clouds at 1,800 feet with conditions temporarily deteriorating to wind 290°/30 gusting 45 kts, visibility 5 km. Severe turbulence was forecast for the Shannon area and a windshear warning was in force for Shannon airport.

Runway 24 was in use and, because of the poor weather conditions, the commander, who was the handling pilot, was obliged by his company standard operating procedures to carry out a maximum thrust take-off. The take-off proceeded uneventfully until 300 feet agl, when there was a loud bang and bright flash from the left side of the aircraft. Significant airframe vibration and a rumbling sound followed the bang. Almost at the same time the No. 1 (left) engine 'REVERSER UNLOCK' light illuminated on the pilot's centre instrument panel and the No. 1 engine exhaust gas temperature (EGT) gauge over-temperature warning light illuminated. The commander retarded the No. 1 engine throttle and the flight engineer (F/E) started to locate the REVERSER UNLOCK emergency checklist, but before it could be found the No. 1 engine fire warning activated and the commander called for the ENGINE FIRE checklist.

The F/E and first officer (F/O) started the ENGINE FIRE checklist with the F/E moving the necessary controls. The checklist was carried out normally but the F/E experienced some difficulty in moving the FUEL selector lever to the OFF position. By the time the crew reached the point where the No. 1 engine fire handle was to be pulled the fire indication in the handle had gone out. They nevertheless completed the checklist and fired one of the two fire extinguishers.

The flight crew declared an emergency with Shannon Approach Control and, since the commander considered the weather at Shannon to be unsuitable for a one-engine inoperative approach and landing, they stated their intention of diverting to 'LONDON OR POSSIBLY BRUSSELS'. Later, when in contact with Shannon Control, the crew requested a diversion to an 'AIRFIELD IN ENGLAND WITH A TEN THOUSAND FOOT RUNWAY AND DECENT WEATHER'. The aircraft then climbed to cruising level and was vectored by radar to the east.

Some minutes after the initial fire indication, the light in the No. 1 engine FUEL selector lever illuminated again, but none of the other normal fire indications were present. The crew were concerned about the validity of the warning and discussed whether to discharge the second fire extinguisher into the engine but before any action could be taken the light went out.

During the flight to London Heathrow fuel was jettisoned and, on handover to the London Area and Terminal Control Centre, the crew were offered the possibility of landing at RAF Brize Norton, which was 50 miles closer than London Heathrow. However, the commander decided to continue to Heathrow where the aircraft landed without further incident.

The diversion to London Heathrow

At the time of the engine failure the weather forecasts for Shannon and Dublin airports both included warnings of windshear, and a Sigmet warning of severe turbulence was in force for the Shannon FIR. At maximum landing weight the aircraft's Landing Distance Required was considerably less than 10,000 feet but, in requesting a diversion airport in the UK with 10,000 feet of runway, the commander sought to keep matters simple both for his crew and ATC. However, in requesting such criteria he reduced considerably the number of possible airports available.

AAIB Recommendation 93-40 issued in May 1993 recommended that the CAA take action to advise the appropriate agencies that when selecting the route for an aircraft in an emergency the avoidance of densely populated areas should be a primary consideration; when appropriate, and subject to the agreement of the aircraft commander a diversion to an alternate runway or airfield should be considered.

In response to this recommendation Section 5 of the Manual of Air Traffic Services (MATS), Part 1 was amended and contains the following instructions and advice for the handling of aircraft emergencies:.

> **'Handling Aircraft Emergencies**
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> When a pilot has declared an emergency and stated the aerodrome to which he wishes to proceed, controllers shall acknowledge this message. If the controller is instructed to inform the aircraft that it is required or requested to divert to another aerodrome then the reason for this change should be established. The message, together with the reason, shall then be passed to the captain and his intentions requested.
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> It is desirable that aircraft in emergency should not be routed over densely populated areas. If this is inconsistent with providing the most appropriate service to the aircraft, for example when any extended routing could jeopardise the safety of the aircraft, the most expeditious route is the one that should be given. Where possible, suggestions of alternative runways or aerodromes, which would avoid densely populated areas and be consistent with safety, should be passed to the pilot and his intentions requested.
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> The decision to comply with advice or instructions to land at an airport, other than his selected diversion, lies with the captain of the aircraft who has ultimate responsibility for the safety of his aircraft.
>
> It is recognised that controllers providing en-route services at ACCs may not be aware of the boundaries of major cities, towns or villages. However, controllers providing aerodrome, approach or approach radar control services should be familiar with the centres of population within their areas of jurisdiction.'

In this incident ATC advised the crew that RAF Brize Norton was a potential alternative diversion to Heathrow, but the information was provided more in the context of another airfield capable of providing 10,000 feet of runway and suitable weather conditions rather than as an alternate to prevent overflying built-up areas. ATC gave no reason for suggesting Brize Norton as an alternative diversion and the aircraft, which had suffered considerable damage, was routed over the centre of London on approach to Runway 27R. MATS Part 1 emphasises the commander's ultimate responsibility for the safety of his aircraft and an ATC service will ultimately be subordinate to a commander's decisions during an emergency. Nevertheless, in this incident neither the commander nor his crew were familiar with London Heathrow or the surrounding area. If ATC had advised the crew that the approach to Runway 27 would be over densely populated areas the commander would at least have been aware of the potential hazard and might have reconsidered his choice of diversion airport.

The final decision on where to divert in an emergency must rest with the aircraft commander, and ATC controllers must be careful when trying to influence the commander's decision. In this case a simple statement to the effect that the approach to Runway 27 is over extensively built up areas may have sufficed. It is therefore recommended that the CAA should include in the provisions relating to 'Handling Aircraft Emergencies' in MATS Part 1 instructions for controllers to inform the pilot of an aircraft in emergency if it is known that an intended route takes the aircraft over densely populated areas. [Recommendation 2001-35].

Aircraft and engine maintenance history

The aircraft Technical Log was reviewed and it did not contain any carry forward defects relating to the No. 1 engine. A full power take-off had been performed on the day before the incident, with no reported problems.

The No. 1 engine had completed 1,401 hours and 453 cycles since the previous workshop visit. The engine was boroscoped on 7 September 2000 and at the same time a visual inspection of the fan blades was carried out. No defects were found during these inspections.

Flight recorders

The CVR, being of 30 minutes duration, had recorded over the period of the incident and so was unable to provide any pertinent information.

The following information was derived from the FDR. [Note: Since engine parameters were recorded on the FDR at four second intervals, the timing and duration of certain events are approximate.]

The take-off was commenced at 1859 hrs when the throttles were gradually advanced to give a fan speed (N1) of 112% on all three engines. This corresponded to a throttle angle of 58° (by comparison the throttle angle at idle was 5.5°). Flap 15° was selected for the take-off. The take-off roll was normal, with rotation occurring at approximately 168 kt. As the aircraft approached 100 feet agl, the No. 1 engine N1 decreased to 91% over a period of approximately four to six seconds. The throttles were not moved during this period. The decrease in N1 was accompanied by an increase in the EGT from 890°C to 1,032°C and a reduction in fuel flow rate from 9,900 to 4,381 lb/hr.

After the initial drop in N1, the No. 1 engine partially recovered back to 105% N1, with the fuel flow increasing to 7,900 lb/hr and the EGT reducing to 950 °C. The parameters for the No. 2 and No. 3 engines continued to read normally. Twenty seconds after the event, at 1,000 feet agl, the No. 1 engine throttle angle was reduced from 58° to 24° (with N1 decreasing to 41%), where it remained for approximately 35 seconds.

Approximately 55 seconds after the event, at 1,500 feet agl, the No. 1 engine throttle angle was further reduced to 14°. The N1 stabilized at 31% for 30 seconds, before gradually decreasing to 17%. At the same time the fuel flow rate decreased from 1,150 lb/hr to approximately 500 lb/hr. The decrease in N1 and fuel flow rate are believed to be as a result of the crew moving the fuel selector lever to the 'OFF' position when carrying out the engine fire procedure.

After the fuel selector lever was moved to the 'OFF' position, the engine continued to run in a sub-idle condition at 17% N1 with a fuel flow rate of approximately 500 lb/hr for approximately 280 seconds, after which the fuel flow finally decreased to zero and the engine then ceased running. (Typical ground idle fuel flow rate for the CF6-50 is around 1,300 lbs/hr at 25% N1,). It would appear that, although the fuel selector lever had been selected to the 'OFF' position, a sufficient quantity of fuel was still being supplied to the engine to allow it to continue running at a very reduced speed. Coincidentally the No. 1 engine throttle was reduced to idle just prior to the fuel flow rate reducing to zero. According to the operator's engine fire procedure, the throttle should have been reduced to idle (5.5° throttle angle) prior to the fuel selector lever being selected to 'OFF', however, the data shows that this was not the case and the throttle was left at a setting slightly above idle (14° throttle angle) for several minutes after the fire drill was actioned, although the crew may have believed that they had fully closed the throttle.

The flaps were retracted at 1,600 feet agl and an airspeed of 230 kt and the aircraft continued to accelerate and climb satisfactorily on the remaining two engines.

Engine fire/shut down procedure

The operator's Flight Manual 'Engine Fire or Severe Damage' emergency procedure calls for the appropriate throttle to be reduced to idle and the fuel selector lever to be moved to the 'OFF' position. The engine fire handle is then pulled and the extinguishant is discharged. Apart from extinguishing the fire, these actions should result in both the High Pressure (HP) fuel valve on the engine and the low pressure (LP) fuel shut-off valve in the engine pylon moving to the closed position. Closure of the HP fuel valve will cause the engine to shut down almost immediately. Closure of the LP fuel shut-off valve isolates the engine from the fuel tank. In this incident, it would appear that the HP fuel valve remained partially open allowing the engine to continue to draw fuel from the fuel pipes between the engine and the pylon, which enabled it to continue running until the fuel in the pipes down stream of the pylon LP fuel shut-off valve was exhausted. Approximately 40 lb of fuel are contained in the pipes between the LP fuel shut-off valve and the engine, which is sufficient for the engine to run for nearly five minutes at a fuel flow rate of around 500 lb/hr. It is possible that the damage to the engine and the accessory gearbox mount may have affected the operation of the HP fuel valve, causing the fuel selector lever to become stiff thus preventing the valve from fully closing.

Initial examination of the aircraft and No. 1 engine

On examination it was confirmed that, as reported by the crew, the No. 1 engine fuel selector lever, which is located on the centre pedestal and operates the HP fuel valve on the engine, was much stiffer to operate than those of the No. 2 and No. 3 engines. An unusually large amount of force was required to move it past the gate into the 'OFF' detent and once placed in the 'OFF' detent, the lever would spring up against the gate at the top of the 'OFF' detent with some pressure. In order to operate the integral button to place the lever back into the 'ON' position, it was first necessary to push the lever downwards to release the pressure against the gate. It was evident that the fire handle for the No. 1 engine had been pulled.

From examination of the exterior of the aircraft it was evident that the No. 1 engine had suffered severe damage. The aft centre body and aft section of the core exhaust nozzle were missing from the rear of the engine. The outer portion of the Number 17 fan blade had broken off just below the part-span shroud. All of the remaining fan blades exhibited hard body impact damage to the outer two thirds of their span due to impact with the liberated fan blade fragments. The fan case was permanently bulged outwards and the fan case inner surface badly gouged at the 10 o'clock position as viewed from the front of the engine looking aft. Many of the fan blade tip 'knife edges' were severely abraded, and in some cases completely worn away from contact with the fan case or liberated fan debris. The fan abradable lining was entirely missing and the fan inlet cowl acoustic lining and inner skin were badly torn and punctured by fragments of fan blade which had travelled forwards and outwards. Fragments of fan blade had penetrated the outer skin of the fan inlet cowl in two locations, but had exited travelling in a direction away from the aircraft. On opening the fan cowls, large pieces of the outer portion of the Number 17 fan blade and pieces of low pressure compressor stator vane fell out of the engine.

Sooty deposits on the aft faces of the section of the fan blades exposed to the low pressure compressor inlet face indicated that the engine had surged, which is consistent with the crew's reports of seeing a bright flash and a loud 'bang' from the left side of the aircraft. The high pressure bleed air duct had burst immediately upstream of the high stage bleed valve due to the overpressure caused by the engine surge. This allowed hot, high pressure (HP) compressor air to leak into the engine nacelle. The temperature of this air was sufficiently high that the engine fire detection system was triggered, producing the No. 1 engine fire warning observed by the crew.

The Shannon Airport Fire Service recovered the missing aft centre body and a two foot section of the core exhaust nozzle from beyond the end of Runway 24. One or more of these parts had struck the port inboard aileron and wing flap, cutting a 2.5 foot gouge in the lower skin of the aileron and damaging the inboard end rib of the flap. Numerous fragments of fan blade, low pressure compressor stator vane and engine inlet cowl were also recovered approximately 300 metres from the end of Runway 24 at Shannon.

The loads on the engine had caused one of the thrust reverser position sensors to shear off, causing the reverser unlocked warning observed by the crew. The No. 1 engine accessory gearbox outboard mounting lug had failed in tension loading, allowing the outboard side of the accessory gearbox to drop by about 1.5 inches. This may have placed abnormal loads on the cable mechanism between the fuel selector lever and the HP fuel valve which is located on the accessory gearbox, perhaps causing the stiffness in operation of the fuel selector lever.

On performing post-engine surge inspections in accordance with the Maintenance Manual, a crack was found in one of the webs in the No. 1 engine pylon, which required repair prior to flight. On closer examination of the No. 1 engine, a single, small, grey feather was recovered from the No. 18 fan blade shroud and a small quantity of fresh bird remains was found embedded in the cooling fins of the integrated drive generator (IDG) oil cooler, which is located in the fan bypass duct and exposed to the fan airstream.

Detailed examination of engine

The Nos. 16, 17 and 18 fan blades and recovered fragments of the No. 17 blade were examined under ultraviolet light, revealing further evidence of the presence of organic material. Metallurgical analysis of the fracture faces on the No. 17 fan blade indicated that the blade had failed in overload. No evidence was found of any pre-existing defect or fatigue failure in the blade.

The engine was removed from the aircraft and sent to the aircraft operator's engine overhaul agency for strip and examination. In additional to the damage already described, heavy internal engine damage was observed on the compressor and turbine rotors and stators consistent with parts of fan blade, abradable lining and low pressure compressor stator vanes having been ingested into the engine core. The overall damage sustained by the engine was sufficient for it to be rendered beyond economic repair.

Apart from a small sample of feathery remains on the No. 13 fan blade part-span shroud, no other bird remains were found during the engine strip.

The aft centre body, core exhaust nozzle and parts recovered from the runway were sent to the engine manufacturer for examination. It was established that the aft centre body had been installed with the wrong type of bolt. This had resulted in a weakened joint between the forward and aft centre bodies. The centre body attachment bolts had failed when exposed to the high vibration loads following the bird strike. Evidence suggested that as the aft centre body separated, it rotated and struck the core nozzle lip, causing the aft section of the core exhaust nozzle to break away.

CF6-50 aft centre body and core nozzle attachment

There are two configurations of forward-to-aft centre body joint; an 8-bolt configuration and a 16-bolt configuration. Service Bulletin (SB) 78-216, issued in 1987, increased the number of bolts from 8 to 16 and changed the bolt type from a fully-threaded tension bolt to a shear-type bolt. The pre- and post-modification centre bodies may be mixed, but this is subject to constraints on fastener types as specified within the SB. Mixing of the pre and post-modification standards of bolts is not permitted as this results in insufficient clamping forces at the forward-to-aft centre body joint. However, it is physically possible for an operator to mix pre- and post-modification standards and it would appear that some operators have inadvertently used the wrong type of bolt and been unaware of the constraints on and implications of mixing the bolts types.

Improvements to the method of attachment of the core exhaust nozzle were introduced in SB 78-240. This SB introduced a strengthened 'C'ring, to which the core exhaust nozzle is attached, to address a problem of cracking of the 'C'ring. Incorporation of this SB terminates the requirement to routinely inspect the 'C'ring for cracks.

The engine manufacturer is of the opinion that if the forward-to-aft centre body bolted joint had been in compliance with existing SBs, the forward-to-aft centre body joint would not have failed under the loads encountered and the parts would not have been liberated.

Examination of the bird remains

The IDG oil cooler containing the bird remains and the feather recovered from the Number 18 fan blade were sent to the Birdstrike Avoidance Unit of the Central Science Laboratory (CSL) at Sand Hutton, near York, for DNA analysis. In both cases the results indicated that the samples were from a Grey Heron, an indigenous species of bird with an average weight of 3.5 lb. The feathery remains recovered from the No. 13 fan blade part-span shroud during the engine strip were sent independently by the engine manufacturer to the CSL for DNA testing. These remains were also established as belonging to a Grey Heron.

Based on this information and the lack of any evidence of a pre-existing defect on the engine, it was concluded that the engine failure was as a result of bird ingestion. The lack of the usual obvious visible evidence of bird remains was attributed to the fact that the aircraft had been airborne for a considerable time after the bird ingestion and had flown through rain showers which would have washed most of the bird remains from the engine. The engine manufacturer stated that the engine could not be expected to be capable of continued operation after ingesting a bird as large as a Grey Heron at maximum take off power at the outer panel location on the fan blade where this bird struck.

Previous related incidents

This incident was similar to a previous incident on 27 August 1999 involving ingestion of a Western Gull (average weight 2 lb) into the No. 3 engine of a CF6-50 powered Boeing 747-300 aircraft on take off from Los Angeles International Airport (LAX). The engine in this and the LAX incidents appeared to have sustained almost identical damage. In the LAX incident, the aft centre body and a large section of the core exhaust nozzle also detached from the engine, landing on a beach approximately one mile west of the airport. Fortunately no persons on the ground were injured. [The incident is referred to in US National Transportation Safety Board file number LAX00SA316]. It was determined that the separation of aft centre body and core cowl in this event were also attributable to the use of the wrong type of bolt for attaching the aft centre body.

Conclusions and Safety Recommendations

Following ingestion of a large bird by the No 1 engine, which sustained considerable damage, the aircraft diverted to London and landed on Runway 27R at Heathrow. Given the adverse weather conditions at Shannon, the commander's decision not to return for a one-engine inoperative landing was reasonable. In the course of the approach to Runway 27R at London Heathrow the aircraft flew over the large built-up areas in and around London.

ATC HANDLING AIRCRAFT EMERGENCIES

MATS Part 1, Section 5, states that it is desirable that aircraft in emergency should not be routed over densely populated areas. In order to provide guidance to controllers on how best to advise flight crew of any problems associated with their intended routing it is recommended that:

Recommendation 2001-35

The CAA should include in the provisions relating to 'Handling Aircraft Emergencies' in MATS Part 1 instructions for controllers to inform the pilot of an aircraft in emergency if it is known that an intended route takes the aircraft over densely populated areas.

AFT CENTRE BODY AND CORE NOZZLE ATTACHMENT

Ingestion of a Grey Heron into the No. 1 engine resulted in the outer portion of the No. 17 fan blade separating and being ingested into the fan. This resulted in a cascade of further damage to the fan, fan inlet duct and engine core, such that the engine was no longer capable of producing a sustained, significant level of thrust without excessive levels of vibration. The warnings of thrust reverser unlocked and engine fire were as a consequence of the engine failure. Use of the incorrect type of bolts for attaching the aft centre body had resulted in a weakened joint, which failed under the vibration loads due to the engine damage caused by the bird strike. Failure of the attachment bolts in the joint allowed the exhaust centre body and a section of the core exhaust nozzle to detach from the rear of the engine and strike the port inboard aileron and flap before falling to the ground. A previous, similar event involving loss of the aft centre body and core exhaust nozzle from the No. 3 engine of a CF6-50 powered 747-300 following a bird strike was also attributed to the use of incorrect bolts to attach the aft centre body.

In order to reduce the likelihood of large engine exhaust nacelle parts detaching in-flight from General Electric CF6-50 engines as a result of bird ingestion or other foreign object damage-induced shock loading or vibration effects the following recommendation is made:

Recommendation 2001-36

To prevent further cases of aft centre body and core cowl separation from CF6-50 engines following a bird strike , the engine manufacturer should take appropriate actions to ensure that there is no possibility of confusion in future as to the correct type of bolt to be used when installing the aft centre body

ENGINE MANUFACTURER'S SAFETY ACTION

The engine manufacturer intends to implement the following actions to prevent a recurrence of this incident:

1. An article will be included in the 'Fleet Hilites' bulletin to airline operators and an 'All-Operators Wire', to reiterate the importance of full implementation of current SBs which improve the integrity of the bolted centre body and riveted core nozzle joints.

2. Issue a new SB which does not allow interchangeability of modified and unmodified forward and aft centre body sections to reduce the likelihood of mixing the types of bolts which would result in an unapproved combination, and reduced joint strength. This SB will also further improve the integrity of this joint by incorporating larger diameter bolts to provide a greater margin of robustness.

3. Review and improve the assembly section of the engine Shop Manual to ensure proper assembly of the core nozzle C-channel rivet joint.

It is considered that the current designs of centerbody and core nozzle will not result in the release of either part as a result of birds or other foreign objects when maintained to prescribed Manual limits. In order to reduce the potential of non-conforming hardware the engine manufacturer will prohibit the use of certain currently permissible hardware combinations. In the mean time the airworthiness authority should initiate a one off inspection of all affected engines so as to eliminate any non-conforming hardware . It is therefore recommended that:

Recommendation 2001-50

To ensure the integrity of the forward-to-aft centre body joints on the CF6-50 engine, the FAA should require that inspections be carried out of the aft centre body attachment bolts on all affected CF6-50 engines as soon as possible, to ensure that the correct type of bolts have been used, based on whether the joint is an 8-bolt or 16-bolt configuration.