

3. CONCLUSIONS

(a) Findings

The aircraft

- 1 The aircraft had a valid certificate of airworthiness in the transport category (passenger) and had been maintained in accordance with an approved schedule.

The flight deck crew

2. The flight deck crew were properly licensed and rested to undertake the flight.
3. The flight deck crew experienced moderate to severe engine induced vibration and shuddering, accompanied by smoke and/or smell of fire, as the aircraft climbed through FL283. This combination of symptoms was outside their training or experience and they responded urgently by disengaging the autothrottles and throttling-back the No 2 engine, which was running satisfactorily.
4. After the autothrottle was disengaged, and whilst the No 2 engine was running down, the No 1 engine recovered from the compressor stalls and began to settle at a slightly lower fan speed. This reduced the shuddering apparent on the flight deck, convincing the commander that they had correctly identified the No 2 engine as the source of the problem.
5. The first officer reported the emergency to ATC, indicating that they had an engine fire and intended to shut an engine down, although there had been no fire warning from the engine fire detection system.
6. Whilst the commander's decision to divert to East Midlands Airport to land with the minimum of delay was correct, he thereby incurred a high cockpit workload which precluded any effective review of the emergency or the actions he had taken.
7. The flight crew did not assimilate the readings on the engine instruments before they decided to throttle-back the No 2 engine. After throttling back the No 2 engine, they did not assimilate the maximum vibration indication apparent on the No 1 engine before they shut down the No 2 engine 2 minutes 7 seconds after the onset of vibration, and 5 nm south of EMA. The aircraft checklist gave separate drills for high vibration and for smoke, but contained no drill for a combination of both.
8. The commander remained unaware of the blue sparks and flames which had issued from the No 1 engine during the period of heavy vibration and which had been observed by many passengers and the three aft cabin crew.

9. During the descent, the No 1 engine continued to run apparently normally, although with higher than normal levels of vibration.
10. Flight crew workload during the descent remained high as they informed their company at EMA of their problem and intentions, responded to ATC height and heading instructions, obtained weather information for EMA and the first officer attempted to re-programme the flight management system to display the landing pattern for EMA. Some 7½ minutes after the initial problem, the commander attempted to review the initial engine symptoms, but this was cut short by further ATC heading and descent information and instructions to change to the EMA ATC radio frequency.
11. Fifteen minutes after the engine problem occurred and some 4 minutes 40 seconds before ground impact, the commander increased power on the No 1 engine as the aircraft descended towards 3000 feet amsl and closed with the centreline of the instrument landing system. At this point, the indicated vibration on the No 1 engine again rose to its maximum value of 5 units but did not attract the attention of either pilot.
12. Fifty three seconds before ground impact, when the aircraft was 900 feet agl and 2.4 nm from the runway with landing gear down and 15° flaps selected, there was an abrupt decrease in power from the No 1 engine.
13. The commander immediately called for the first officer to relight the No 2 engine. The attempted restart was not successful, probably because there was insufficient bleed air pressure from the No 1 engine, pressure air from the APU was not connected and the bleed air crossfeed valve was closed. Even if pressure air had been available it is unlikely that power could have been obtained from the No 2 engine before the aircraft hit the ground.
14. The training of the pilots met CAA requirements. However, no flight simulator training had been given, or had been required, on the recognition of engine failure on the electronic engine instrument system or on decision-making techniques in the event of failures not covered by standard procedures.
15. The change from hybrid electro-mechanical instruments to LED displays for engine indications has reduced conspicuity, particularly in respect of the engine vibration indicators. No additional vibration alerting system was fitted that could have highlighted to the pilots which of the two engines was vibrating excessively.

The Cabin Crew

16. All members of the cabin crew were properly trained to undertake the flight.

17. Although the cabin crew immediately became aware of heavy vibration at the onset of the emergency and three aft cabin crew saw flames emanating from the No 1 engine, this information was not communicated to the pilots.
18. During the descent, the cabin crew carried out their emergency drills, checking that all passengers had their lap belts fastened and stowing all loose carry-on luggage in the overhead bins.

No 1 (Left) Engine

19. The No 1 engine suffered fatigue of one of its fan blades which caused detachment of the blade outer panel. This led to a series of compressor stalls, over a period of 22 seconds, until the engine autothrottle was disengaged.
20. The severe mechanical imbalance which arose because of the outer panel separation led to blade tip rubbing, particularly on the fan and booster sections abradable seals, which caused smoke and the smell of burning to be passed into the air conditioning system.
21. About 3 seconds after the autothrottle was disengaged, and whilst the No 2 engine was running down, the No 1 engine began to stabilise. However, its indicated vibration remained at maximum for at least 3 minutes until this engine was throttled back for the descent.
22. The evidence indicated that the timing of the sudden recovery of the No 1 engine from the compressor stalling was related to the autothrottle disengagement at a point when it had demanded a lower throttle lever angle than that required for rated climb, thereby allowing this engine to achieve stabilised running at a slightly lower speed.
23. During the descent, the No 1 engine responded apparently normally at the idle/low throttle settings used, although its indicated vibration remained higher than normal.
24. Fifty three seconds before ground impact, the No 1 engine abruptly lost thrust as a result of extensive secondary fan damage. This was accompanied by compressor stalling, heavy buffeting and the emission of pulsating flames. This damage was probably initiated by fan ingestion of the blade section released by the initial failure, which was considered to have partially penetrated, and temporarily lodged within, the acoustic lining panels of the intake casing before having been shaken-free during the period of high vibration following the increase in power on the final approach to land. Sections of fan blades were found below this point of the final approach, including two small fragments which were determined to be remnants of the blade section which detached initially.
25. The No 1 engine fire warning, which occurred on the flight deck 36 seconds before ground impact, was initiated by a secondary fire which occurred on the outboard exterior of the engine fan casing. It was concluded that the prolonged period of running under

conditions of excessive vibration had loosened fuel/oil system unions and seals on the exterior of the fan casing and that the inlet duct had probably been damaged sufficiently, by fan blade debris, to allow ignition of atomised fuel/oil sprays by titanium 'sparks' and/or intake flame.

26. This short duration in-flight fire on the No 1 engine was followed by a localised ground fire associated with this engine, which was successfully extinguished by the East Midland Airport Fire Service.
27. The fan blade fatigue fracture initiated as a result of exposure of the blade to a vibratory stress level greater than that for which it was designed, due to the existence of a fan system vibratory mode, induced under conditions of high corrected fan speed at altitude, which was not detected by engine certification testing.

No 2 (right) engine

28. The No 2 engine was running normally when it was throttled back to flight idle, and then shut down.
29. This engine showed no evidence of power at impact, consistent with the evidence from the flight data recorder.
30. Detailed strip inspection of this engine showed it to have been fully serviceable before ground impact.

Systems

31. The No 2 (right) engine vibration reports which appeared in the aircraft Technical Log during December 1988 but had been correctly addressed by ground technicians.
32. There were no malfunctions of the major airframe systems which contributed to this accident.
33. No evidence was found of any cross-connection or similar obvious wiring errors associated with either the engine instrument system (EIS) or the fire detection system.
34. The EIS fitted to the aircraft was serviceable at impact and tests indicated that it should have displayed those primary engine parameters recorded on the FDR, with close fidelity.
35. The airborne vibration monitoring system (AVM) was serviceable at impact. Tests showed that the system was capable of tracking vibration caused by the massive fan imbalance and of outputting its maximum value approximately 2 seconds after the start of the vibration.

36. Flight crew reports concerning the response of the AVM system during the two other cases of fan blade fracture on CFM56-3C engines which occurred subsequent to this accident supported the behaviour described above. Two cases of bird impact which resulted in fan damage generated crew reports of late indication on vibration gauges, although vibration was clearly felt by the flight crew. This was the result of the non-linear sensitivity of this engine type to small imbalances with changes of fan speed in the take-off and climb thrust range.
37. The engine fire and overheat detection system contained a fault which could have rendered it incapable of providing warning of a fire in either engine. However, the CVR evidence indicated that it did, in fact, provide a warning of the fire in the No 1 engine 36 seconds before impact.

Impact with the ground

38. The aircraft suffered two distinct impacts with the ground, the first just before the eastern embankment of the M1 motorway and the second on the western edge of the northbound M1 carriageway, at the base of the western embankment.
39. The first impact was at an airspeed of 113 knots CAS, with a rate of descent of between 8.5 feet/sec and 16 feet/sec. The pitch attitude was 13° nose up.
40. The second and major impact occurred at a speed of between 80 and 100 knots, at an angle of approximately 16° below the horizontal and with the aircraft at a pitch attitude of between 9° and 14° nose down. The associated peak deceleration was of the order of 22 to 28g, predominantly longitudinal.
41. In the second impact the forward fuselage separated from the overwing section of fuselage and the tail section buckled over, and to the right of, that section of fuselage just aft of the wing.
42. The incidence of passenger fatality was highest where the floor had collapsed in the forward section of the passenger cabin and in the area just aft of the wing. The cabin floor and the passenger seating remained almost entirely intact within the overwing and tail sections.
43. There was no major post impact fire, largely because the main landing gear legs and the engines separated from the wing without rupturing the wing fuel tanks. The separation of the landing gear legs was in accordance with their design. In the case of the engines, however, the separations occurred within the engine pylons themselves, leaving the fuse-pin bolts intact

Survivability

44. Of the 8 crew and 118 passengers on board, all crew members survived but 39 passengers died from impact injuries at the scene and a further 8 passengers died later in hospital. A further 74 occupants were seriously injured.
45. The decelerations generated in the second impact were greater than those specified in the Airworthiness Requirements to which the airframe and furnishings were designed and certificated. They were, however, within the physiological tolerance of a typical passenger.
46. Passenger survivability was improved due to the passenger seats being of a design with impact tolerance in advance of the current regulatory requirements. This was most evident in the overwing and tail sections of the cabin, where the floor had remained intact.
47. There is considerable potential for improving the survivability of passengers in this type of impact by improving the structural integrity of the cabin floor so as to retain the seats in their relative positions and by detail design improvements to the seats themselves.
48. There is a need for a structured programme of research into alternative seating configurations, with particular emphasis on the provision of effective upper torso restraint or aft-facing seats.
49. The injuries to the mother and child in seat 3F highlighted the advantages of infants being placed in child seats rather than in a loop-type supplementary belt.
50. Although the overhead stowage bins met the appropriate Airworthiness Requirements for static loading, all but one of the 30 bins fell from their attachments, which did not withstand the dynamic loading conditions in this accident.
51. Some of the doors on the overhead stowage bins opened during the last seconds of flight, demonstrating the need for some form of improved latching of the doors.

(b) Cause

The cause of the accident was that the operating crew shut down the No 2 engine after a fan blade had fractured in the No 1 engine. This engine subsequently suffered a major thrust loss due to secondary fan damage after power had been increased during the final approach to land.

The following factors contributed to the incorrect response of the flight crew:

1. The combination of heavy engine vibration, noise, shuddering and an associated smell of fire were outside their training and experience.
2. They reacted to the initial engine problem prematurely and in a way that was contrary to their training.
3. They did not assimilate the indications on the engine instrument display before they throttled back the No 2 engine.
4. As the No 2 engine was throttled back, the noise and shuddering associated with the surging of the No 1 engine ceased, persuading them that they had correctly identified the defective engine.
5. They were not informed of the flames which had emanated from the No 1 engine and which had been observed by many on board, including 3 cabin attendants in the aft cabin.