Aircraft Type and Registration:	McDonnell Douglas DC-10-30, S2-ADB
No & Type of Engines:	Three CF6-50 C2 turbofan engines
Year of Manufacture:	Not known
Date & Time (UTC):	28 September at 1209 hrs
Location:	London Heathrow Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 21 Passengers - 210
Injuries:	Crew - None Passengers - None
Nature of Damage:	Loss of left half of No 1 engine thrust reverser cowl
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	47 years
Commander's Flying Experience:	17,000 hours (of which 4,500 were on type) Last 90 days - 175 hours Last 28 days - 50 hours
Information Source:	AAIB Field Investigation

Following an uneventful flight from Rome, the aircraft landed at Heathrow on Runway 27L. Reverse thrust was applied for the landing and, when the reverser levers were returned to the 'stow' position, the No 1 engine 'REVERSER UNLOCK' and 'VALVE OPEN' lights remained on. The crew had not received any prior warnings concerning the reverser malfunction, and did not try any reselections before shutting down the engine. ATC then informed them that something had fallen off their left engine and that it was being recovered. The aircraft was taxied to Terminal 3 where the passengers disembarked normally.

It was subsequently found that the entire left half of the No 1 engine thrust reverser translating cowl had departed from the thrust reverser assembly. Parts of the attachment fittings were not recovered, and this hampered the subsequent investigation.

Thrust reverser description

The thrust reverser translating cowl consists of two separate, semi-circular halves, which slide in 'T' shaped tracks located at the top and bottom of the reverser assembly. Each half is attached to three ballscrew actuators, the operation of which causes the cowl to move along the 'T' tracks. Motive power is provided by a pneumatic drive motor (PDM) mounted on top of the reverser, and which runs off compressor bleed air. A shut-off valve controls the supply of air to the PDM. Flexible drive shafts run from the PDM to the centre actuator on each cowl half; secondary drive shafts run from the centre actuator to the upper and lower actuators. Blocker doors are mounted on the inner surface of each cowl half and these are connected, via struts, to the centre body of the fan duct. Aft movement of the cowls causes the blocker doors to deploy into the airflow from the fan, which is thus deflected out of cascade assemblies, thereby providing reverse thrust. The diagram at FIG 1 shows some of the pertinent features.

The deploy and stow actions of the reverser are signalled via switches on the throttle quadrant, and by cable drums operating directly on the relevant parts of the pneumatic system. Feedback signalling functions are performed by a feedback rod on either side of the reverser. A feedback yoke is mounted on the inner surface of each translating cowl half. When the cowl approaches its limit of travel, either in the deploying or stowing direction, the yoke engages with one of two lugs on the feedback rod, causing it to move against spring pressure and in so doing operate a linear cam system. This in turn operates the 'stow' or 'deploy' switches, as appropriate, which shut off the air supply to the PDM, in addition to controlling the flight deck indicators. The left side feedback rod also operates stow and deploy pneumatic limit switches which are activated at approximately 90% of cowl travel. These are actually valves which bleed off PDM supply air, causing the PDM to run at reduced speed. Thus the cowls slow down over the final 10% or so of travel, which minimises the shock loads on the cowl structure as it reaches its limit of travel. These limits are largely determined by internal stops within the ballscrew actuators.

The flexible drive shafts operate gearboxes attached to the actuators. The outer cylinder of each actuator is threaded onto the rotating inner shaft, and terminates in a rod end which is located, by means of a pin, in a clevis riveted to the cowl structure. An anti-rotation lug on each actuator outer cylinder locates into a slot in the clevis, so preventing rotation as a result of friction between the inner shaft and outer cylinder.

Examination of reverser assembly

Photographs of the engine minus its translating cowl, and of the detached cowl are presented at FIGs 2 and 3.

All three ballscrew actuators were found in the stowed position, which initially gave the impression that the attachments had failed after the cowl had reached the end of the stow operation. This was reinforced by the fact that the feedback yoke had failed along a weld such that the yoke no longer made proper contact with the forward lug on the feedback rod. This could have resulted in the loss of the cancellation signal, with a consequent high speed impact into the stow position. However, a metallurgical examination of the yoke showed that the weld was of good quality and had failed as a result of a single overload application. It was then found, by experimenting with the actuators, that although the outer cylinders were no longer constrained from rotating following their detachment from the cowl, they could still be wound towards the stow position if the drive shafts were rotated. This was probably achieved as a result of the outer cylinders intermittently contacting the structure of the reverser as they rotated, thus slowing them down relative to the inner shafts. Marks on the cascades confirmed this, and locally severe damage had been inflicted by the anti-rotation lugs where they had flailed against the cascade vanes after the actuators had reached the stow stops.

Both flexible drive shafts from the PDM were found to have failed close to the body of the motor. On the right-hand side, the failure had the appearance of a torsional overload, which probably occurred when the right cowl actuators hit the stow stops at high speed due to the absence of the 'slow down' and 'stow' feedback signals following the loss of the left side cowl. The left side drive shaft failure was different in that its outer casing had been ruptured. The broken strands of the shaft that were visible through the rupture were discoloured as a result of intense heat, and it was clear there was an absence of graphite grease in comparison to that found on the right side. This led to the conclusion that the failure of this shaft had occurred as a result of seizure due to continuous rotation within its outer casing. The lack of feedback signals noted above would have caused the PDM to continue to run at high speed, and also would have accounted for the 'VALVE OPEN' indication on the flight deck.

Attention then turned to the 'T'-shaped rails at the top and bottom of the cowl that were located in the T tracks on the reverser. Considerable distortion had occurred in these areas in a manner which suggested that the cowl had become skewed, ie the top and bottom had moved different distances along the tracks. Silicon rubbing strips were bonded to the surface of the 'T'-shaped rails, and it was noted that a section of strip on the lower rail had been peeled off in a rearwards direction. It was apparent that the peeling action had been caused by a corner at the aft end of the 'T' track on the reverser, as the cowl was being pulled towards the stowed position. For this to have occurred, the cowl must have been in a skewed attitude, with the upper rail most probably out of its track. This in turn suggested that the upper actuator attachment was the first to fail, possibly at the end of the preceding deploy cycle, or even the stow operation before that.

The lower actuator was attached via a cast bracket; it was clear this had failed in overload. The centre and upper attachments are identical in design in that the clevis mentioned earlier is attached (via rivets and two screws) between the inside of the cowl outer skin and a clevis flange plate which is in turn riveted to a circumferential stiffening hoop inside the cowl. A representation of the actuator attachments is shown at FIG 4. The centre actuator clevis had pulled out cleanly, leaving the flange plate behind. The upper clevis (which was not recovered) had been pulled out complete with its plate. Access to both attachment areas was restricted due to the narrow gap between the inner and outer cowl panels, and examination was conducted with the aid of a boroscope. This showed that the centre clevis had departed due to overload, in shear, of the rivets. The upper clevis attachment rivet holes, in contrast, showed evidence of 'working', with of some of them being elongated. It was clear that the cowl outer skin in this area had been the subject of a repair, with a small repair patch visible on the exterior. The patch covered the outer surface close to a butt joint; this was removed for examination (see FIG 5). The cowl outer skin in fact consisted of a double thickness, and a section of the outermost skin, measuring approximately 100 mm by 20 mm, which had presumably contained the damage that necessitated the repair, had been cut away and replaced with a similarly shaped piece of skin. This merely served as a packing piece between the innermost skin layer and the patch, and contributed nothing to the load bearing capability of the repair. The presence of sealant showed that the three layers had not been pressed tightly together, which may have resulted in a somewhat flexible riveted joint. This view was reinforced during a laboratory examination of the component parts, when evidence of fretting was found on some of the remaining rivets.

The engine manufacturer had published a repair scheme for the centre and upper clevis attachments (Ref Repair No 10 in General Electric CF6-50 Shop Manual, Section 78-32-01). Much of the associated detail is concerned with replacing the clevis flange, mounted on the stiffening hoop. This area had not been touched during the repair, which involved only the outer skin. Nevertheless, an outer skin patch plate is called up in the repair scheme, and it was noted that it was approximately 30 mm wider than that found on the subject cowl. Furthermore, no mention is made of removing one of the outer skin layers and inserting a packing piece in its place. Although a larger patch plate would distribute the actuator loads over a larger area of the cowl, it was clear that no problem had resulted, in this case, from the use of a smaller patch, as it had remained securely attached. It was thus concluded that the failure had occurred due to weakness brought about by the removal of the section of skin underneath the patch plate.

The airline leased the aircraft from the manufacturer, and had the maintenance carried out by Alitalia in Rome. Despite requests, Alitalia did not supply any maintenance history information on the reverser. It was therefore not possible to establish where, or when, the repair was accomplished.

Summary

It was established that the upper actuator attachment had been the subject of an unauthorised repair, which had probably resulted in a weakened joint between the clevis and cowl. It is considered likely that the joint progressively lost strength in service to the point where it failed completely on either the stow or deploy cycles prior to the detachment of the reverser cowl. When reverse thrust was selected on landing at Heathrow, the top of the cowl would have overtravelled, probably coming out of the 'T' track on the reverser. Although the exact sequence of events was difficult to determine, it is possible that the associated distortion on the cowl caused the feedback yoke to jump over the aft lug on the feedback rod. During the subsequent stow attempt, the yoke would have been pushed against the aft face of the lug, causing the weld failure in the web of the yoke. The fact that the cowl became skewed as a result of the top end overtravelling caused it to jam, with consequent overload failures of the centre and lower actuator attachments. The absence of feedback signals from the left side allowed the PDM to continue to run, with the actuators flailing against the cascades, and gradually winding themselves to their stowed positions.

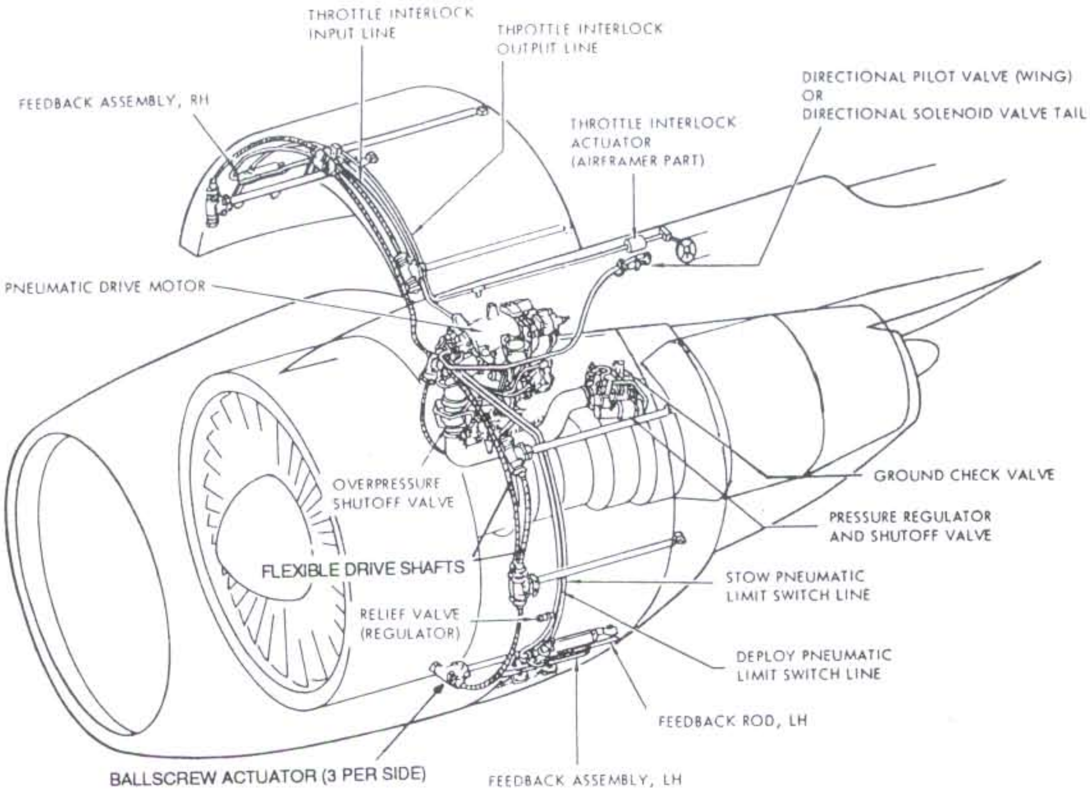
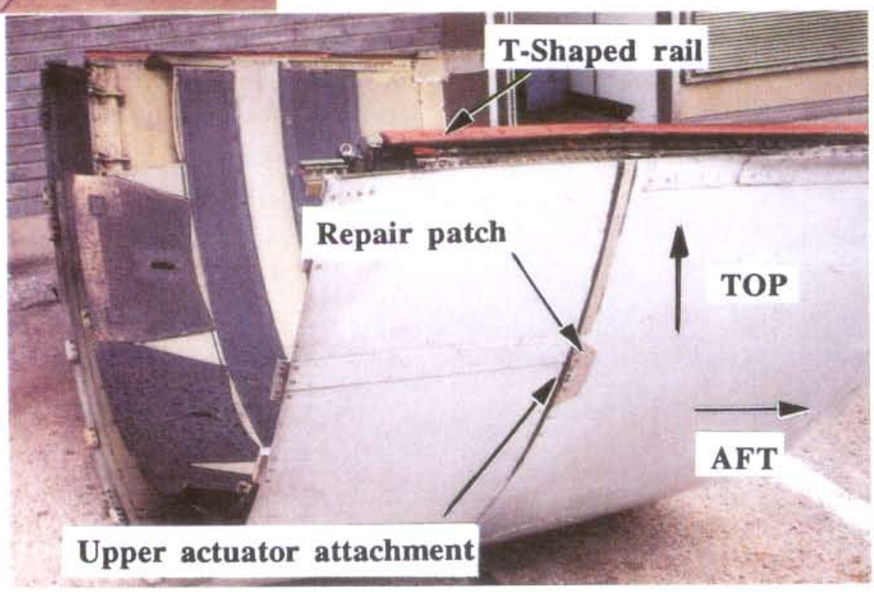


FIG 1 CF6-50/-45 THRUST REVERSER SYSTEM

FIG 2

As found-translating cowl missing

FIG 3 View of cowl



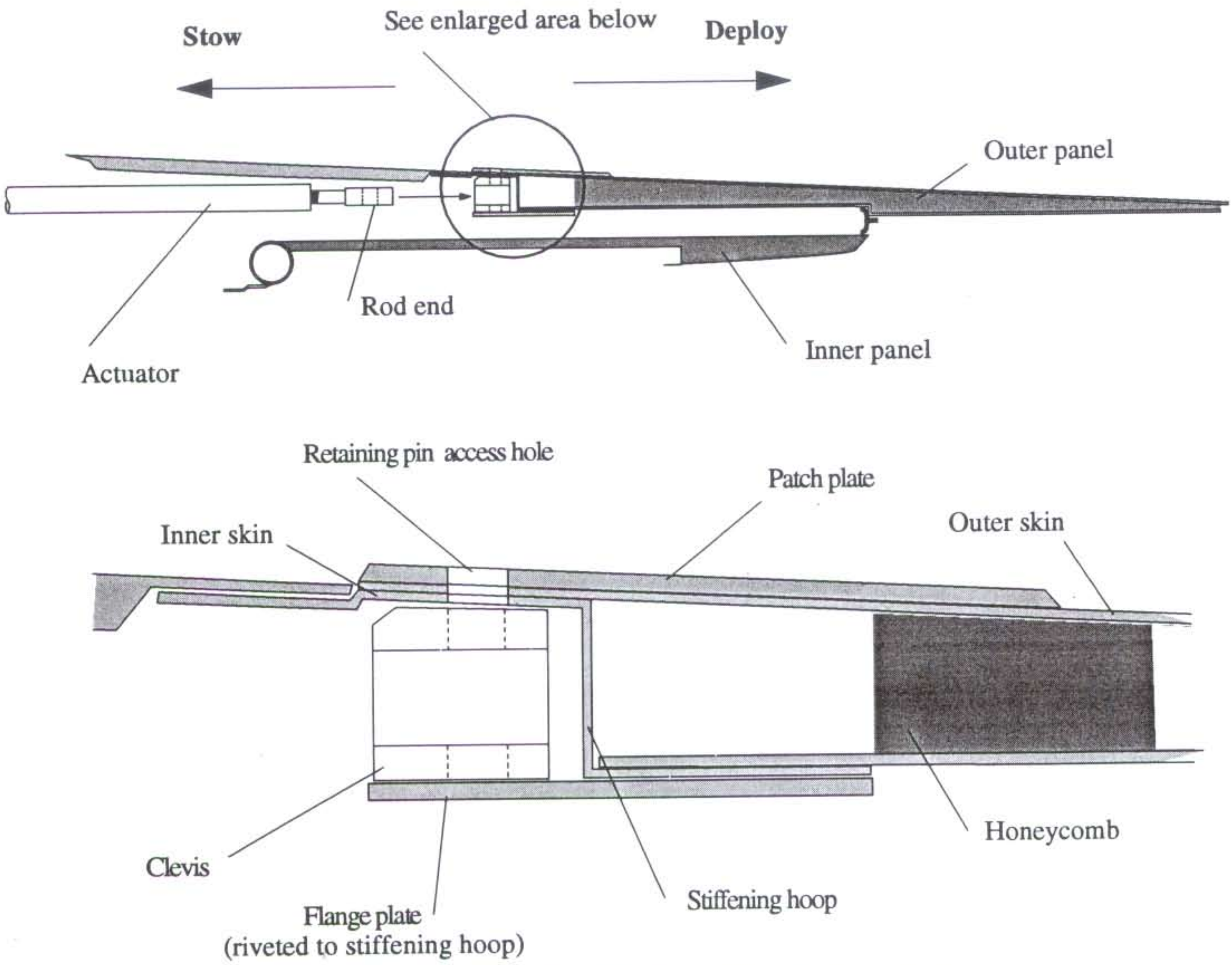


FIG 4 SECTION THROUGH TRANSLATING COWL, SHOWING CLEVIS ATTACHMENT TO STRUCTURE *(based on diagram in Repair Manual)*

FIG 5 View of repair, with patch plate and "packing piece" being removed from cowl