AAIB Bulletin No: 8/93 **Ref: EW/C93/1/2** **Category: 4**

INCIDENT

Aircraft Type and Registration:	Boeing 757-236, G-BIKN
No & Type of Engines:	2 Rolls-Royce RB211-535C-37 turbofan engines
Year of Manufacture:	1984
Date & Time (UTC):	23 January 1993 at about 1130 hrs
Location:	Near London Heathrow Airport
Type of Flight:	Public Transport
Persons on Board:	Crew - 12 Passengers - 86
Injuries:	Crew - None Passengers - None
Nature of Damage:	None
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	45 years
Commander's Flying Experience:	9,500 hours (of which 2,726 hours were on type) Last 90 days - 77 hours Last 28 days - 26 hours
Information Source:	AAIB Field Investigation

History of the flight

The aircraft was departing on a scheduled public transport flight from London Heathrow to Helsinki. All pre-flight checks were normal and, with the first officer handling the controls, the aircraft took off from Heathrow at 1108 hrs and climbed on course following a standard instrument departure (SID) via Brookmans Park. The climb was carried out in instrument meteorological conditions (IMC) where moderate icing was encountered, and the wing and engine ice protection systems were selected to 'ON'. The flight crew also reported seeing a considerable build-up of ice on the windshield wipers.

The flight data recorder showed that, as the aircraft passed 5,700 feet in the climb, the reverse (REV) amber caption for the right engine illuminated on the engine indication and crew alerting system (EICAS) screen (a description of the system operation and its associated warnings is included later). However, the warning was not noticed by the flight crew until the aircraft passed FL140, when the

first officer also observed that he needed five divisions of left rudder trim to maintain heading. The crew consulted the Quick Reference Handbook (QRH) which states that following the illumination of a REV amber caption in flight, the engine may be operated normally provided that the indication is not accompanied by buffeting, vibration, abnormal handling characteristics, abnormal engine parameters or yaw. In view of the amount of rudder trim needed to maintain aircraft heading, which although unusual was not excessive, the commander decided to seek advice from the company's engineering base. After discussing the problem with the engineers on the company's discrete radio frequency, the commander was advised and agreed to shut the engine down and return the aircraft to Heathrow. As he closed the right engine thrust lever, prior to shutting down the engine by operating the fire handle, the REV amber caption extinguished. The thrust lever was then partially re-opened to check that the caption did not re-appear, after which the engine drill was completed. The aircraft returned to Heathrow where an uneventful single engine approach and landing was made.

Flight recorders

The aircraft was fitted with a quick access recorder (QAR) and the mandatory flight data recorder (FDR). The QAR records additional parameters in addition to the mandatory parameters, which are identical to those recorded on the FDR. The information was extracted from the QAR by the operator and supplied to the AAIB; the FDR was removed but was not replayed. Rudder trim is not directly recorded by the QAR, which only records rudder position. The trim positions quoted therefore have been calculated from data supplied by the manufacturer; the range of rudder trim is ±14 divisions.

Figure 1 shows a plot of some of the recorded parameters from the QAR for the relevant period. The aircraft was climbing through an altitude of 5,700 feet, with the No 2 autopilot engaged, when the Thrust Reverse Unlock indication on No 2 engine activated, there was no apparent crew intervention at this time. The recorded engine power settings remained unchanged; there was no indication of thrust asymmetry, and no movement of recorded rudder position. The calculated rudder trim was 2.7 div. left, from the recorded rudder position of -0.4° at an airspeed of 280 kt CAS.

As the aircraft climbed through an altitude of 12,000 feet there was a movement of rudder position from -0.4° to -1.1° over a period of about 12 seconds, which corresponded to a left rudder trim of 5.7 div. at an airspeed of 300 kt CAS. There was also a corresponding movement of aileron to balance the rudder input and maintain aircraft heading. There was no change in the engine power setting. This control movement is shown in more detail in Figure 2, and was not directly associated with the Thrust Reverse Unlock indication.

At an altitude of 20,900 feet, No 2 engine was throttled back initially to the flight idle position, and the Thrust Reverse Unlock indication ceased. The power was increased slightly on No 2 engine to an engine pressure ratio of 1.27 without the warning recurring. The power was decreased again after 12 seconds and the engine was then shut down. Examination of the data until after the landing and shutdown revealed no further Thrust Reverse Unlock indication.

The data from five previous sectors was analysed and this showed that the rudder position varied between -0.3° and -0.6°, and so the use of -1.1° on the incident flight was unusual. The manufacturer's analysis showed that the 5 div. of left rudder trim was more than was necessary to maintain heading and was being compensated by the use of right aileron. During the climb as the composite rudder control surface distorts due to temperature effects, and possible airframe icing, a change in rudder trim can occur. There is a Service Bulletin, No 757-27-67 (CAA-AD 007-04-88), which details the installation of a rudder thermal compensator. This was fitted to this aircraft.

System description

The thrust reverser system on each engine includes two half cowls that translate aft, uncovering cascade segments and pulling blocker doors into the fan duct and forcing the fan flow radially outwards through the cascade segments. Each reverser is powered by a separate aircraft hydraulic system that is designed to be actuated only when the aircraft is on the ground with the forward thrust lever at idle and the fire switch at normal. Normal full extension takes approximately 2.5 seconds. Each half cowl is moved by three hydraulic actuators, only one of which (the lowermost) contains an integral locking mechanism. The three actuators are mechanically synchronised to each other by a rotating flexible shaft running within the hydraulic supply tubing, and to the three synchronised actuators on the opposite side of the engine by another flexible shaft which runs over the top of the engine. Thus all six actuators are synchronised together, with the complete system held closed by the two mechanical locks in the two lowermost actuators, left and right, as shown in the diagram at Figure 3. Either locking actuator, however, is capable of holding the cowls closed.

Each locking mechanism is connected to an external lever which operates a visual indicator mechanism mounted on the cowling, in addition to the target for a lock/unlocked proximity sensor. As the actuator is unlocked by hydraulic pressure the target moves away from the sensor and the REV amber caption appears in the top right corner of the upper EICAS screen on the flight deck. The visual indicator also moves out from the surface of the cowl and, as both cowls reach full travel, the REV caption changes colour from amber to green.

The amber coloured caption is approximately 0.25 inches high and is displayed in capital letters. Of the three levels of alert messages (ie, WARNINGS -aural siren plus master warning light; CAUTIONS - aural beeper plus master caution light; ADVISORY - no aural warning or master light) the REV amber caption is in the third level and is designed to activate only when either of the two actuators are unlocked. The crew cannot determine directly from such an advisory whether one, or both, locks are disengaged and/or if the cowls are in transit, or if it is a spurious warning. The lock sensor performs no function other than to signal the REV amber advisory on the EICAS. The lever, sensor and target are all mounted on the actuator body, which itself is mounted on the 'C' duct structure, whereas the visual indicator is mounted on the inner surface of the fixed engine cowl, as illustrated in Figure 4. Under flight loads, the manufacturer advises that a degree of relative motion between the two is known to occur, but that this should not activate a caption if the sensor/target is correctly adjusted.

Selecting a reverse thrust lever to the reverse position actuates a switch that signals the hydraulic isolation valve to open. At the same time a mechanical link from the same lever operates on a directional control valve (DCV) which allows hydraulic pressure to be ported to both sides of the piston head in all six differential area actuators. This first unlocks the two lower actuators, following which all six are free to translate the cowls aft. An automatic re-stow system, which senses uncommanded movement of the system during forward engine thrust operation through a separate proximity sensor on each cowl half, forces the cowls to the closed position by opening the isolation valve (ISLN VAL). With the thrust levers in the forward position, the DCV will always port the hydraulic pressure from the isolation valve to the stow (small area) side of the piston heads of the differential area actuators. In doing so, a REV ISLN light and an EICAS caption illuminate in the cockpit and the system maintains stow pressure for 5 seconds after the cowls have closed. In addition, the thrust reverser system contains an interlink such that if the cowls translate aft with the thrust lever forward, then that lever is mechanically pulled to idle as the cowls move.

Engineering examination

As soon as the aircraft had parked at LHR upon its return a ground engineer reported to the crew that the visual indicator for the thrust reverser left actuator lock was deployed on the right engine, apparently confirming the REV amber message as genuine. Also, a BITE check carried out on the system indicated code 170 (RH engine, LH 'C' duct, lock actuator proximity sensor 'far' condition). However, approximately 10 minutes later two other engineers reported that the same indicator was in the actuator locked, ie flush with cowling, position. At no time after the REV amber caption extinguished, as the engine was initially throttled back in flight, did the crew report, or the DFDR and QAR record, the presence of that caption again up to engine shutdown.

After the aircraft had been towed into a maintenance hangar, an investigation was begun by the airline's maintenance personnel. Apart from a leak at the hydraulic connection to the deploy side of the subject locking actuator, no other defects were apparent and the system was satisfactorily functioned several times, the REV amber caption illuminating and extinguishing correctly. The leak was traced to slightly damaged faces on the mating surfaces of the connection. The major elements of the left cowl reverser system, i.e. the lock actuator complete with proximity sensor and target, the DCV, the isolation valve and crossover synchronisation shaft, were subsequently removed for detailed examination, these items being replaced by units from the airline's spares inventory. At this time the AAIB, having been made aware of the incident, became involved with the airline's investigation and witnessed the satisfactory functional testing of the complete system on the aircraft. G-BIKN was returned to service and this system was subsequently reported to have operated satisfactorily. All components, with the exception of the lock actuator, were bench tested by the airline and found to be serviceable. Close examination of the crossover shaft did not reveal any evidence of distress, such as might have occurred if one lock had unlocked, thereby inducing high torsional loads in the shaft.

At the AAIB's request, arrangements were made to transport the lock actuator to the aircraft manufacturer's facility in Seattle where, following a meeting attended by representatives of the airline, engine and cowl manufacturers and the AAIB to discuss various aspects of the thrust reverser and warning system, it was examined in detail. After a partial strip examination, which revealed the unit to be in good mechanical condition, the unit was reassembled and sent to its manufacturer for a full 'production acceptance test'. This demonstrated that the unit was serviceable, in good condition and with all internal leakage rates within limits. The external leak rate from the ram seal was outside limits but had no effect on the operation of the actuator. It was, however, established that the gap between the proximity sensor and its target, with the internal lock fully engaged, was inconsistent (an observation made by maintenance personnel generally) and could be set anywhere between a zero gap and .028 inches, due to clearances within the actuator between the lock lever and non-rotating serrated lock disc, ref. Figure 4. A light torsion spring is installed to bias the lock lever with the intention of removing the effects of backlash, the allowable limits of which are given as 0.050 inches. The gap rigging limits specified in the maintenance manual are $0.010 \pm .003$ inches.

The system is designed such that it should sense a target 'far' condition at a gap of around 0.065 to 0.070 inches, and measurements made on several aircraft would seem to bear this out. The sensor was tested satisfactorily using a 'centre weighted' proximity sensor electronics unit (PSEU) but, as the manufacturer advises that the greatest variability in the point of sensor operation is derived from within the PSEU, the operating point of the sensor may have been different on the aircraft to that measured on test. This unit, which processes signals from all proximity sensors on the aircraft (landing gear, doors etc.), remained on G-BIKN and has continued to function satisfactorily in service.

REV amber caption history

Information was sought from operators of Boeing 757 aircraft in the UK concerning their experiences of in-flight REV amber captions over the last few years. This revealed a relatively high rate of associated occurrence on the RB211-535C series engines (for example, 102 REV amber captions in 1992 across one fleet of 39 aircraft), the majority of which could not be traced to any specific technical fault. Additionally, the majority of these warnings (67) had occurred during the take off/climb/cruise phases of flight. By contrast there was a much lower incidence of such warnings on Boeing 757 aircraft which have RB 211-535E4 engines and, generally, of isolation valve false captions. Examination of the events which generated these figures showed no reliable evidence of genuine unlock conditions having occurred in-flight, rectification being largely associated with re-rigging of the proximity sensor and/or lubrication of the visual indicator mechanism. No occurrences of uncommanded in-flight thrust reverser cowl translation had been associated with these captions.

Following the catastrophic accident in Thailand to a Pratt and Whitney 4060 powered Boeing 767 on 26 May 1991, in which a thrust reverser is believed to have deployed at high engine power whilst in the climb, additional locking devices have been produced which are available for both the Boeing 757 and 767 aircraft. With the Rolls Royce powered Boeing 757 this takes the form of a single additional solenoid operated lock fitted to the flexible synchroniser shaft and signalled through a separate logic circuit. This modification was also accompanied by a change in the philosophy of associated warnings. Firstly, the REV ISLN light is deleted. Secondly, on the ground, a L or R REV ISLN VAL advisory message appears on the EICAS when the reverser isolation valve is open with the reverse thrust lever in the stow position. However, if this fault is detected above 80 kt during take off, or in flight, the message is inhibited until after landing. Previously in this circumstance the REV ISLN light and an EICAS caption illuminated in flight. The REV amber caption remains unchanged. At the time of the incident to G-BIKN the modification was not available, although the airline concerned intends to have it fitted to all aircraft in the fleet by the end of 1993.

Conclusions

In the absence of, a) any specific technical defect being identified which could have caused a REV amber caption to appear, b) any evidence of an actual reverser deployment and c) the probability that airframe icing could have induced an out-of-trim condition at about the time the crew noticed the caption, it was concluded that this incident was yet another false warning of a reverser unlocked condition. The available evidence suggested that this had been brought about by incorrect rigging of the sensor/target gap and was possibly influenced by PSEU characteristics and cowl flexure under flight loads inducing movement of the target through the visual indicator mechanism. It was noticed

that any stiffness in the indicator mechanism could also influence the sensor/target gap and that wear in the same system could allow the indicator to protrude 'leading edge first' into the slipstream and potentially generate additional movement of the target lever. Such protrusion might also be subject to icing, which could only exacerbate the problem. Modifications are in hand to reduce the effects of wear and stiffness, although these were not considered factors in this incident since the 'C' ducts (complete with reverse thrust mechanism) had been replaced in October 1992 and were known to be in good condition. (It is reported that aircraft which have had this mechanism modified are experiencing a reduced incidence of warnings). However, since that time false REV amber indications have occurred on both engines of G-BIKN, although not on the right engine between 2 December 1992 and the time of the incident. The right engine left lock sensor was replaced in mid November 1992.

A programme of further investigation has been agreed by the various manufacturers in order to resolve the apparent inability of airlines to prevent false warnings, which includes a review of the maintenance procedures regarding actuator and proximity sensor rigging, required and actual, and detailed examination of the next aircraft identified to have a poor history of false REV amber captions. (As a result of 3 false warnings experienced by G-BIKD in the last two weeks of April 1993, this aircraft was chosen for further close examination. On this aircraft it was established that sensor gaps of between 0.062 inches and 0.080 inches were required to illuminate the REV amber caption. The range of possible gaps measured with the actuators closed and locked were between 0.008 inches and 0.015 inches for the left engine and 0.012 and 0.033 inches for the right.). The manufacturer has also agreed to review the information made available to crew in the Operations Manual with respect to the operating details of the thrust reverser system.

Safety Recommendations

The large number of false REV amber captions advisories that have been recorded can only have a negative effect on flight crews' perception of the associated alerting system. However, there is formidable protection against the possible deployment of thrust reversers in flight. Specifically, this includes the fact that one locked actuator is able to restrain the complete system, an auto restow system is fitted, throttle pullback occurs on cowl translation in forward thrust, and a secondary solenoid lock modification is available (although not mandatory). In view of the findings from this investigation, two Safety Recommendations have been made to the CAA:

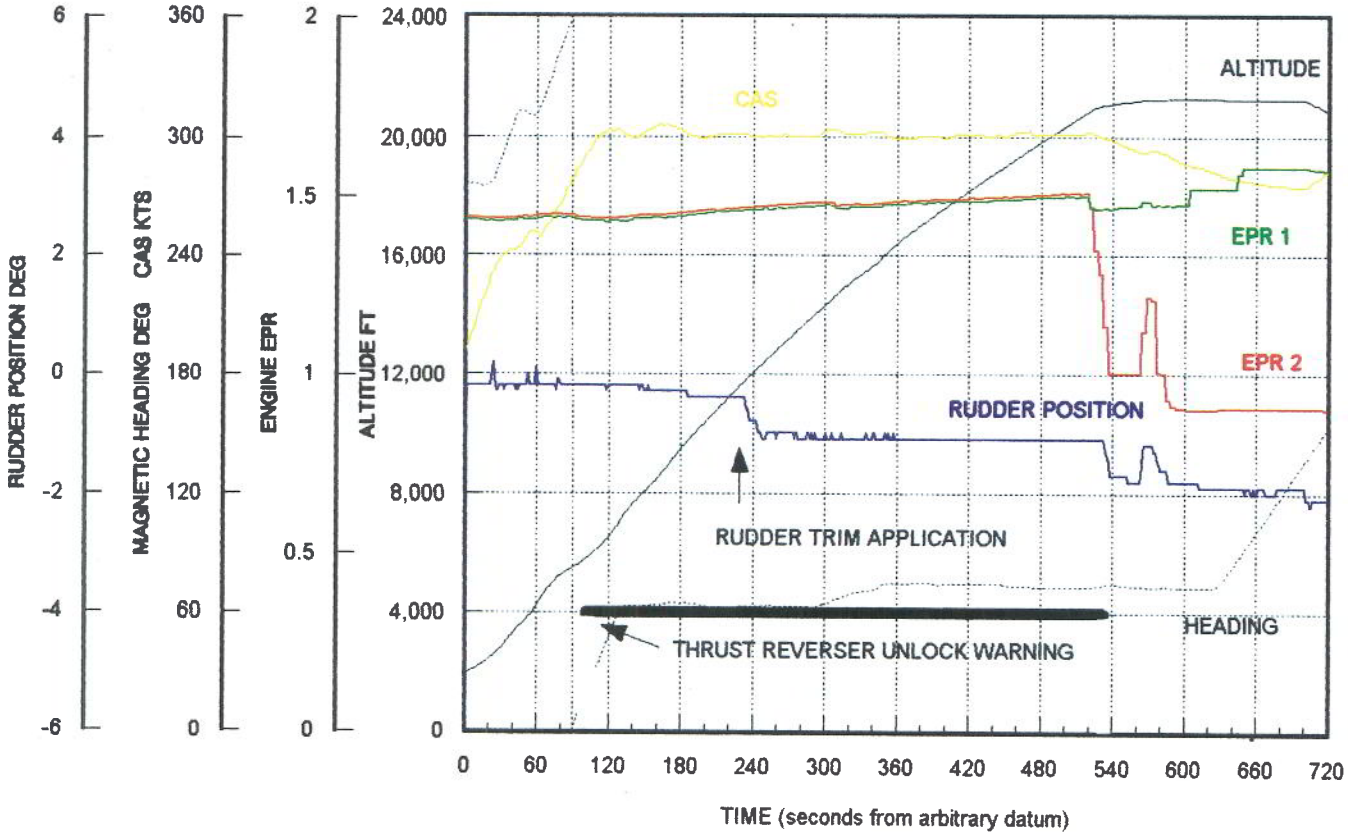
93-41 The CAA, in conjunction with the FAA and associated manufacturers, should review the need to display an EICAS REV amber message to the crew of Boeing 757 aircraft, in flight, when this is activated by only one of the two lock actuator sensors fitted to each engine, and actively consider

upgrading the status of the message to a CAUTION or WARNING should two sensors on any one engine indicate both lock actuators unlocked in flight. (Issued 21 July 1993).

93-42 The CAA should review, in conjunction with the FAA and associated manufacturers, the design of the lock/unlock indication system on Boeing 757 aircraft in relation to the present Maintenance Manual proximity sensor rigging instructions in view of their evident inability to prevent associated false warnings. (Issued 21 July 1993).

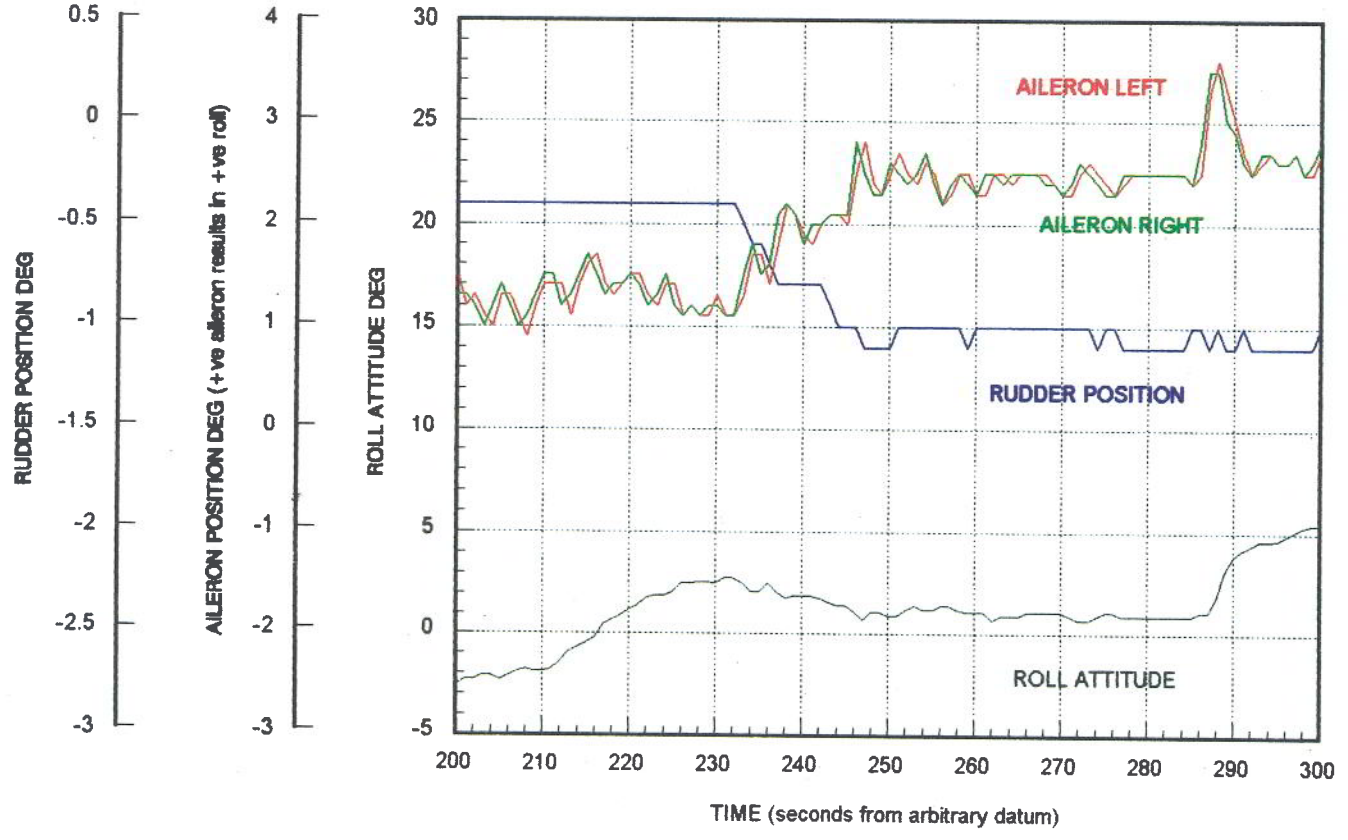
G-BIKN SELECTED PARAMETERS FROM FLIGHT RECORDER DATA DURING INCIDENT

FIGURE 1

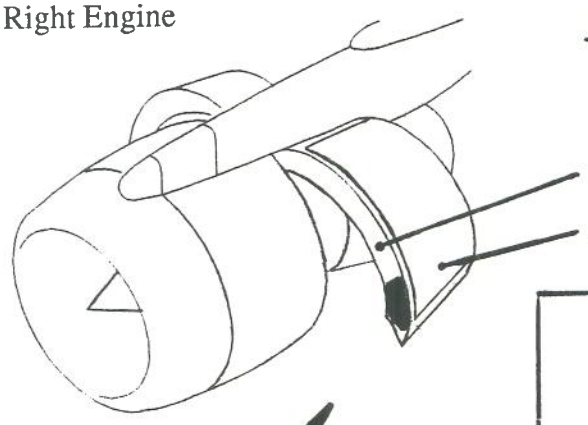


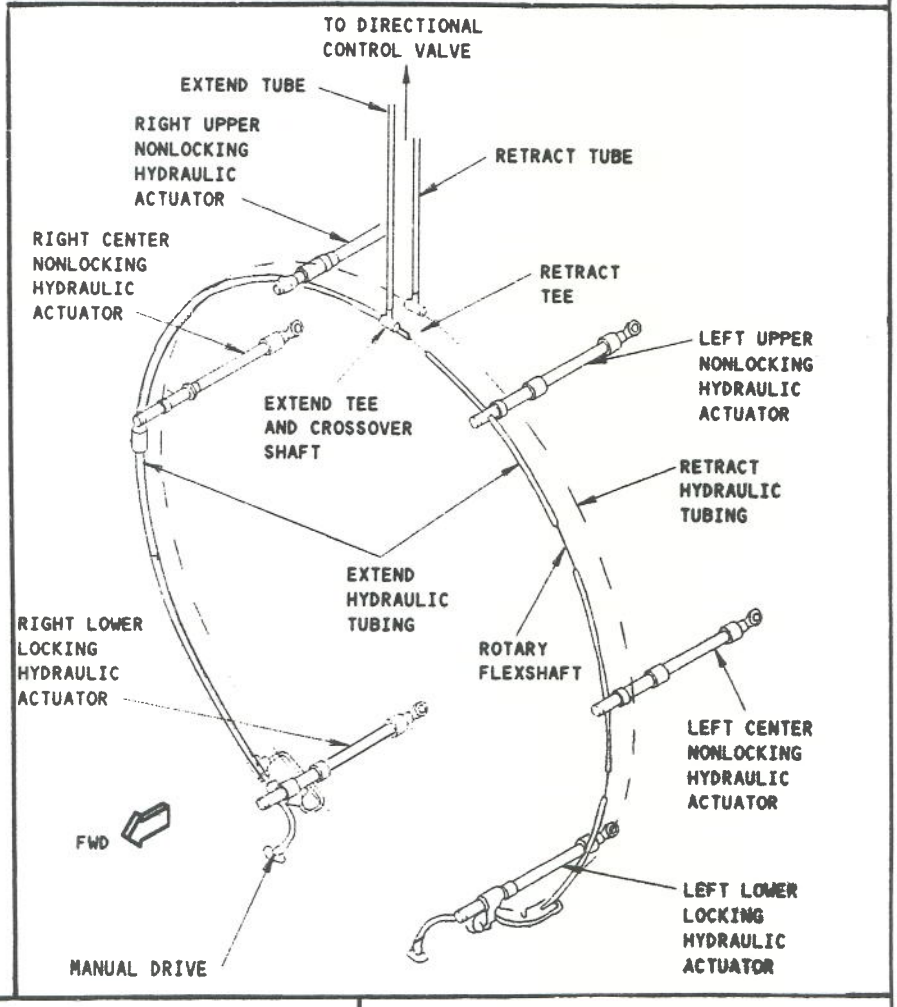
G-BIKN EXPANDED FDR PLOT SHOWING APPLICATION OF RUDDER TRIM

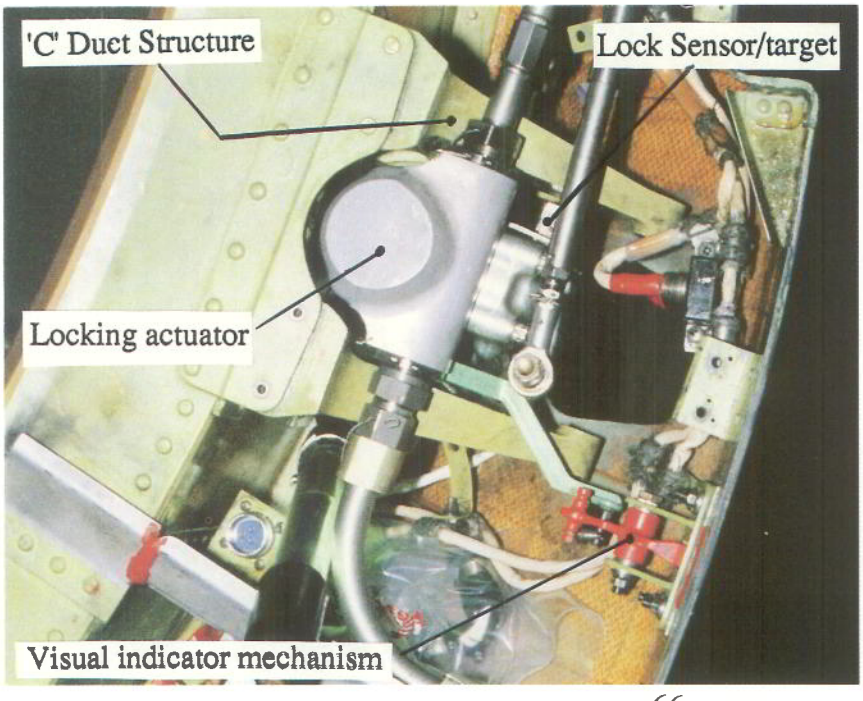
FIGURE 2



B757 Thrust Reverser Details - RB211-535C engine







Visual Lock Indicator showing T/R closed and locked

Visual Lock Indicator 'drooped' due to wear in mechanism T/R closed and locked

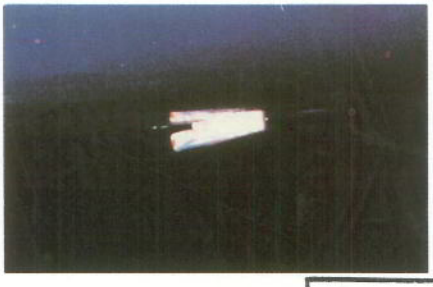
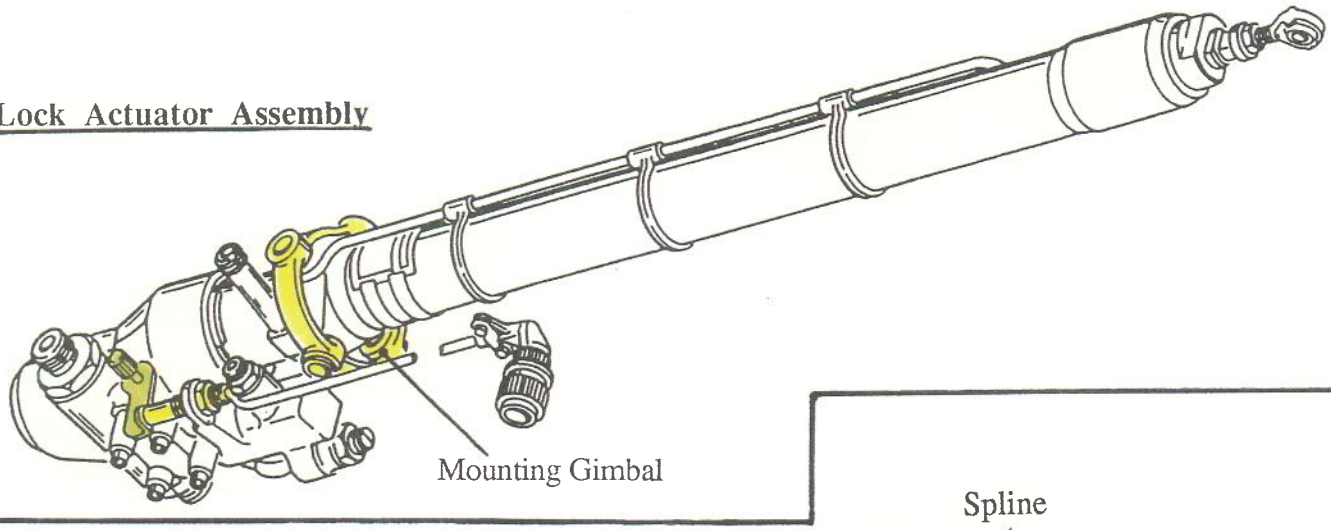


Figure 3

Lock Actuator Assembly



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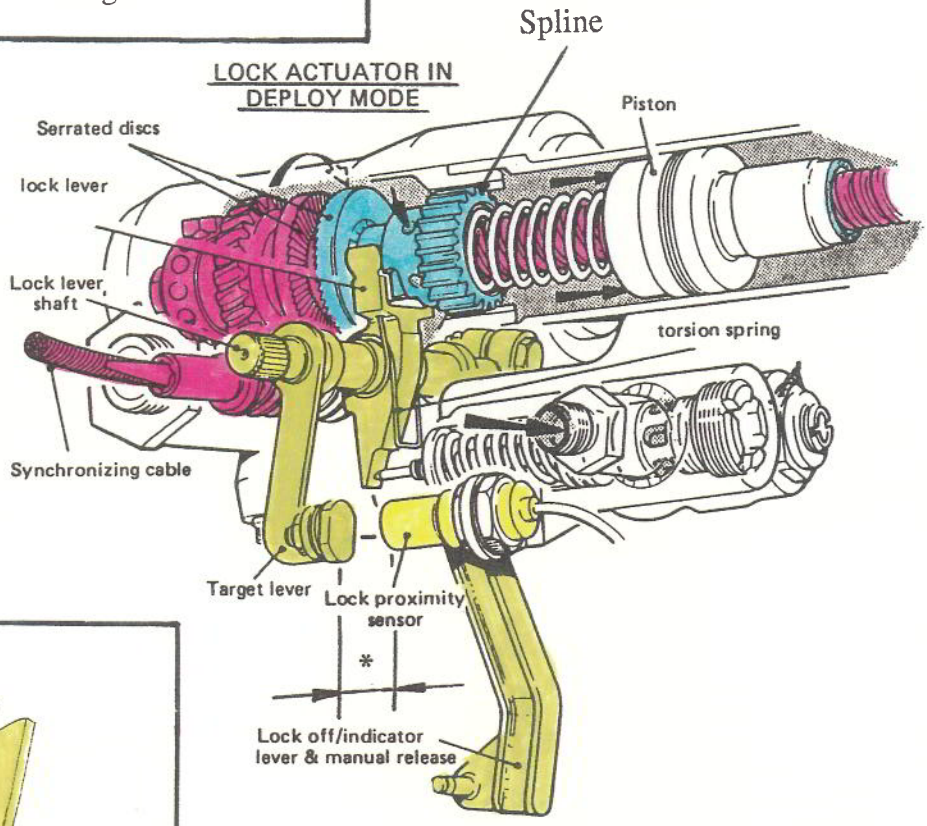
Required sensor/target gap when closed and locked:-

0.010" ± .003"

Gap measured on actuator:-

Max= 0.028" Min 0.000"



Sectional View of Actuator Head

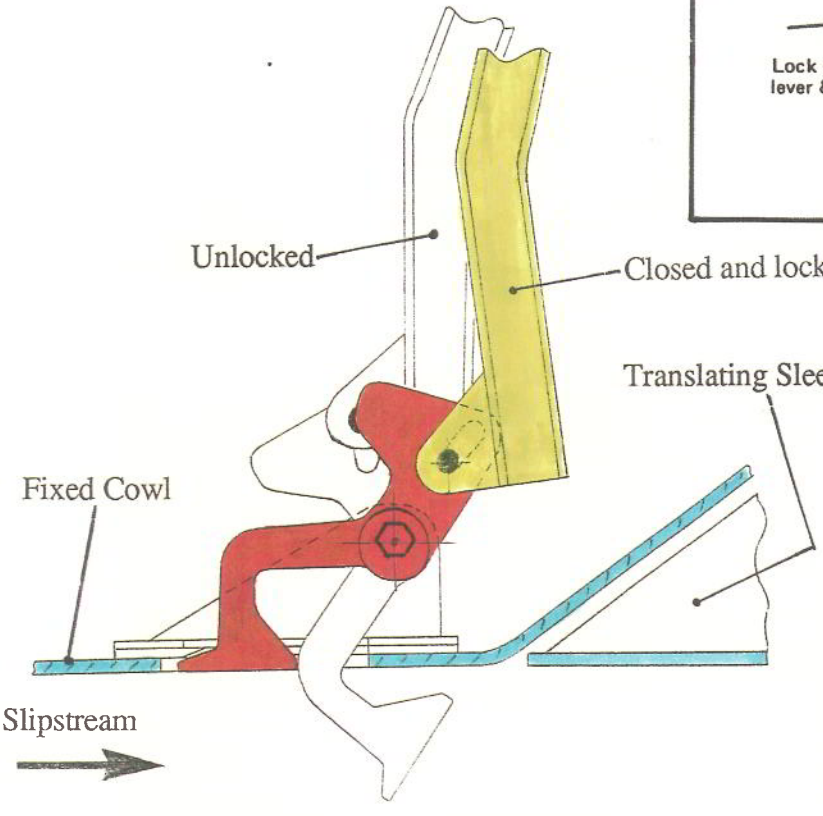


Diagram of Visual Lock Indicator Mechanism

Actual Indicator shown in unlocked position

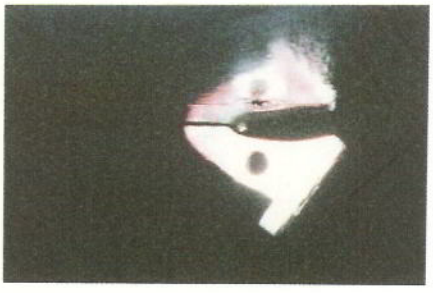


Figure 4