AAIB Bulletin No: 7/93 **Ref: EW/A93/1/1** **Category: 4**

INCIDENT

Aircraft Type and Registration:	Boeing 747-236B, G-BDXG
No & Type of Engines:	4 Rolls-Royce RB211-524D4 turbofan engines
Year of Manufacture:	1977
Date & Time (UTC):	24 January 1993 at 1512 hours
Location:	Over Amboise, France
Type of Flight:	Scheduled Passenger
Persons on Board:	Crew - 18 Passengers - 278
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:	12,800 hours (of which 3,000 were on type) Last 28 days - 39 hours
Information Source:	AAIB Field investigation

History of the flight

The aircraft departed from London Gatwick Airport at 1442 hours on a scheduled passenger service to Lagos, Nigeria. The engine anti-ice system was selected 'ON' for take off, as the ambient temperature was below +10° C and there was rain shower activity in the area. However, the aircraft remained clear of cloud, and the anti-ice was selected 'OFF' during the climb. The aircraft was cleared direct to the Amboise VOR in France, and during the climb as the aircraft was crossing the French coast a layer of cloud was encountered between FL150 and FL200. The engine anti-ice system was selected 'ON' prior to entry, and remained 'ON' until the aircraft was above the cloud layer. There was no apparent ice accretion on the aircraft as a result of this encounter. The climb continued normally, and the aircraft levelled off at its assigned level, FL290, at approximately 1510 hours.

Some 1½ minutes later, at Mach number 0.845, the flight engineer alerted the commander to the fact that the number 4 engine vibration monitor (AVM) reading was increasing. It then increased above the warning indication light level of 2.5 units. The first officer detected an audible rumble, and both vibration monitor loops were checked in accordance with the memory recall drills prescribed in the Flying Manual for the aircraft. Both channels were indicating above the warning level, and the engine was therefore shut down in accordance with the standard drill. All other engine operating parameters were apparently normal.

The aircraft was in the vicinity of the Amboise VOR at this time, some 112 nm south west of Paris. The commander made the decision to return to London Gatwick, and this intention was communicated to ATC, along with a request for descent. This was approved by ATC with a descent to FL180 and a left turn towards the Mantes VOR. The aircraft commenced descent, with the remaining three engines operating at flight idle.

At approximately 1520 hours, on levelling off at FL180, power on the remaining engines was increased to attain a three engine cruise condition. However, on application of power, the number 1 engine AVM system indication increased above the warning level, with the associated warning light illuminated. On this occasion, all three flight deck crew perceived an audible rumble. All other engine indications were normal. The crew carried out the recall actions, as previously, and shut down the number 1 engine after a brief check to confirm that the vibration level was adversely affected by increased power demand above flight idle.

The decision was then made to divert to the nearest suitable airport, Paris (Charles de Gaulle). A full emergency was declared, and subsequent ATC co-operation was good. The aircraft jettisoned some 60 tonnes of fuel, in order to achieve a landing weight below the maximum permissible limit, before making an uneventful two engine approach and landing on Runway 28 at Charles de Gaulle, at 1602 hours. The aircraft was then taxied under its own power to the parking stand.

Flight recorders

The aircraft was fitted with a quick access recorder (QAR) in addition to the mandatory flight data recorder (FDR). The QAR records extra parameters, including engine vibration, in addition to the mandatory parameters which are recorded on the FDR. The information was extracted from the QAR by the operator and supplied to AAIB. There were a number of unserviceable parameters on the QAR. The FDR was removed, but not replayed.

Figure 1 shows a plot of some of the recorded parameters from the QAR for the relevant period, beginning as the aircraft climbed to FL 290. The engine vibration is sampled once every four seconds on each engine; only the values for No 1 and No 4 engines are plotted. The warning light illuminates above a value of 2.5 units of vibration. The engine pressure ratio (EPR) values are plotted for all four engines.

The recorded QAR data indicated that the aircraft levelled at FL290 and the engines were throttled back from around 1.63 EPR. The EPR on No. 4 Engine was slightly lower at 1.59, to around 1.55 EPR at about 55 seconds as given by the time scale in Figure 1. At this power setting the vibration level was 1.1 units on No 1 engine and 1.4 units on No 4 engine; Nos 2 and 3 engines had low vibration levels of 0.7. The vibration on No 4 began to increase, as the EPR again reduced slightly to 1.45 EPR at 150 seconds, to a maximum of 2.9 units over a period of 8 seconds. (Figure 2 shows this in more detail). The EPR on No 4 was then reduced at 176 seconds, and the vibration reduced correspondingly to a value of around 0.4 units, before the engine was shutdown.

The EPR values on the remaining three engines were then increased to 1.6 to maintain altitude at 240 seconds, before decreasing as the aircraft was cleared to descend at 290 seconds. As the EPR on No 1 engine reduced, there was an increase in vibration for around 10 seconds to a maximum value of 1.9 units, before the vibration reduced to 1.1, and then again to 0.7, with the reducing EPR. During the descent, the vibrations on Nos 2 and 3 engines reduced from 0.5 to between 0.2 and 0.3 units. Figure 3 shows a more detailed plot of the engine parameters during the descent.

The aircraft then levelled at FL180 at 630 seconds as shown in Figure 1, and as the EPR on the three engines rose the vibration on No 1 engine increased from 0.6 to a maximum of 2.9 units over about 60 seconds. The EPR then reduced on No 1 engine, and the vibration reduced correspondingly. The EPRs on No 2 and No 3 engines were increased to around 1.6, and the aircraft descended. The No 1 EPR was increased 20 seconds later, for about 10 seconds, which again produced a vibration increase to a maximum of 2.2 units. The EPR was reduced and the vibration reduced correspondingly. The engine was then shutdown and the vibration reduced to zero.

Inspections and ground runs

The engines were subsequently inspected visually, and by means of a boroscope, for turbine and compressor damage, but none was found. The oil levels, filters and chip detectors were all examined and were satisfactory. After some consultation with the operator's maintenance organisation, the aircraft was prepared for ground running of engine Nos 1 and 4. However, by this time strong winds were affecting the airport. The first ground run was carried out at low power and during this run all the flight deck indications were normal, including the vibration levels, however a loud rumble was heard emanating from the No 1 engine. Following this, the signal conditioning unit and the tracking filter of the vibration monitoring system were changed and a further ground run carried out. During this ground run it was the intention to carry out an airflow check by plotting N2 against IEPR, however the high crosswind existing at the time prevented this being completed at all power settings. Sufficient data points were plotted, however, to ascertain that the variable inlet guide vane (VIGV) controller was not significantly off-schedule. During this second run all the flight deck indications, including vibration levels, were normal and the rumble was not apparent. Following this ground run it was decided to change both the VIGV controller and the fuel flow regulator (FFR) on the No 1 engine. The water drains on the aircraft were checked and fuel samples from tanks 2 and 4 were checked for suspended water content and all were found satisfactory. Tank 2 was sampled, rather than tank 1, because the fuel dumping carried out during the flight had depleted tank 2, which had been replenished from tank 1. The fuel supplier at Gatwick was required to retain samples pending analysis. These samples were also checked and found satisfactory. During refuelling, a water content check had been carried out by the supply company while the hose was still connected to the aircraft. In addition the French investigating authority, the Bureau Enquette-Accidents, conducted laboratory tests on the fuel samples taken from the aircraft. These showed that the fuel was of a satisfactory specification, uncontaminated and fit for use.

Following this work, a further ground run was conducted and a further airflow check made. All parameters were within limits and no abnormalities of any kind were observed, and so the aircraft was cleared for a non-revenue ferry flight back to London Heathrow.

Engines start and taxi for the ferry flight were normal. As the aircraft was light, max IEPR reduction was used for the take off, during which the vibration indications were monitored closely. The only unusual event was that the No 1 bleed air valve closed light was on, but this extinguished as soon as one of the pneumatic packs was selected. Max climb power and graduated climb power were both used and the aircraft was climbed to FL290. At that altitude a representative cruise was set up and the vibration levels on both loops recorded for all engines were as follows:

LOOP A

	Normal	N1	N2	N3
Engine 1	1.0	0.8	0.6	0.9
Engine 2	0.4	0.4	0.3	0.2
Engine 3	0.5	0.4	0.3	0.4
Engine 4	0.5	0.1	0.1	0.4

LOOP B all readings within 0.2 of A loop.

With No 4 engine at max continuous power there was no significant shift in the vibration readings. This engine was also checked at 1.6 EPR, since in the recent past a bearing problem had been identified on this engine type which showed up at that power setting and was associated with similar

N1 and N2 shaft speeds. This also was satisfactory. At 85% N2 the thrust levers for engines Nos 1 and 4 were cycled relatively rapidly, without adverse effect. The flight was held for 25 minutes at Ockham and then landed normally.

Detailed powerplant investigation

After the ferry flight the aircraft was placed on a major check, for which it was already scheduled. The line replaceable units removed from the aircraft were investigated separately, with the following results:

The fuel flow regulator was rig checked at the overhaul facility in accordance with the manufacturer's instructions. Throughout the schedule the FFR was within specified limits except that a drain in the air control unit was leaking a small amount of fuel at a rate outside the acceptable limits. This had no effect on the operation of the FFR. However the unit was subsequently stripped and investigated. It had completed 34,797 hours since new and 5,739 hours since the last check. The strip inspection showed that the leak had been caused by a deteriorated seal within the air control unit.

The VIGV controller was also rig checked at the overhaul facility. The manufacturer's test schedule was completed satisfactorily and the unit was passed as serviceable. It had completed 31,247 hours since new and 5,963 hours since its last check.

The transducers from the No 1 and No 4 engines, the signal conditioning unit, the tracking filter, the indicator lights and vibration level indicator display unit were examined in the avionics workshop. The tracking filter showed a number of anomalies associated with the phase lock indicators, however only the channel for engine No 3 was outside limits, and this gave a lower than required reading. The signal conditioning unit was passed as serviceable, however both units were returned to the manufacturer for further investigation, which revealed no other defects. Examination of the wiring diagram showed that a signal corresponding to high vibration must have been output from the signal conditioning unit for both the flight deck indicator and the quick access recorder to have indicated high vibration levels.

While the aircraft was on its scheduled check, the fan attrition linings on all four engines were re-examined. Some minor damage had occurred to the No 4 engine's fan seal but this was considered not unusual and may, or may not, have occurred at the time of the incident. No damage or witness marks were evident on any of the other engines. The fan blades from the No 1 and No 4 engines were removed for examination. It was observed that the blades on engine Nos 2 and 3, which were not removed, showed minimal traces of lubricant at the clapper faces. Also, the No 1 engine fan module tubular bolt was found to be under-torqued. Some reduction in the torque setting of these tubular bolts has been observed to occur in service and can lead to vibration if fan movement occurs; this can also be this can also be associated with rub in the IP and LP turbine module. In this case, however, there was no evidence of any fan movement.

The fan blades and disk assembly from the No 4 engine were found to be out-of-balance. Although accurate measurements were taken, it was only possible to say that these were significantly outside delivery limits. It was not possible to decide whether the out-of-balance recorded would have caused a vibration problem, or even if it was any worse that other fans after a period in service. It was observed, however, that the clappers were very dry with little evidence of lubricant paste on the surfaces and bright polishing of the clapper faces . There was also some edge erosion or 'chipping' of the hard coating. This could be indicative of disassembly, transportation damage or in-service deterioration, as well as clapper lock-up due to insufficient lubrication.

Fan blade or clapper "lockup" is a term used to describe a condition in which the fan blade clappers fail to move very slightly relative to each other. During normal operation the blades move with changes in altitude, temperature and power. This movement is in part axial, up to about 0.012 inch. If for any reason the clappers on two or more blades do not move as intended the disc becomes slightly asymmetric. This asymmetry can generate levels of vibration sufficient to require an engine to be shut down. In extreme cases, such as a birdstrike, the blade clappers can ride up over each other, causing considerable damage. Although this had not occurred in this case, the edge erosion and minor chipping of the hard coating indicated that the blades could have been in an unusual positon relative to each other at some time, possibly prior to the incident flight.

The fan blades from the No 1 engine had unfortunately been lubricated before removal from the aircraft, and they had also been cleaned upon arrival for checking. However, there remained evidence of polishing of the clapper faces although this was not as marked as on the No 4 engine fan blades. There was rather more evidence of chipping of the hard coating than on the No 4 engine.

At manufacture the clapper faces are treated with the hard coating which is then dry-film lubricated. A thin film of a lubricant paste is then applied and it is this lubricant paste which is renewed at 625 hour intervals. This had last been carried out 406 hours before the incident. An acceptable alternative is the use of a specified aerosol lubricant, which is easier to apply. Whichever lubricant is used it is necessary to apply it to the clapper faces and this can only be done while the clappers are separated. This naturally occurs only at the top of the fan assembly. Therefore it is necessary to rotate the fan assembly one blade at a time while lubricating the top clapper faces. It was apparent from the traces of lubricant that the aerosol lubricant had been used and that probably it had been done without rotating the fan. Since the incident, the operator has reduced the lubrication period to 155 hours by amendment of the Maintenance Schedule, and this has been highlighted in a Technical News Letter, and by other means, to ensure correct lubrication of the clapper faces using lubricant paste rather than aerosol.

Additionally the operator, airframe and engine manufacturers are reviewing the procedure for in-flight shutdowns solely as a result of high vibration indications, to include interrogation of individual spool vibration levels.

Electro-magnetic compatibility trials

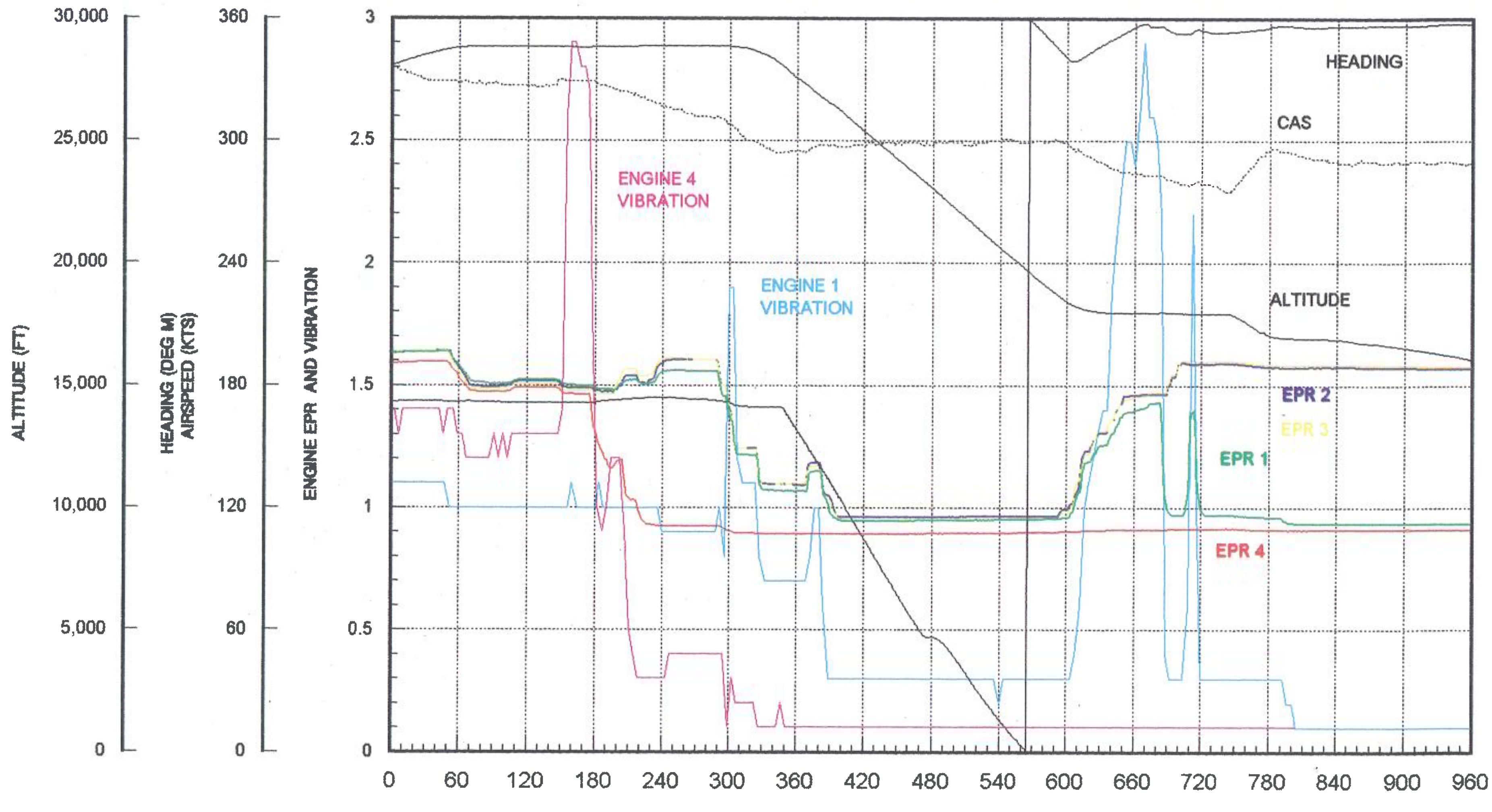
A trial was conducted to determine the effects, if any, of electrical interference on the AVM system. This was regarded as an initial trial which might lead to a requirement for further investigation. G-BDXG was positioned at Gatwick and prepared for ground running of engines Nos 1 and 4. With both engines running at ground idle and their respective generators on-line, the AVM system was monitored. During the test, both A and B loops and the 'Normal' and N1, N2 and N3 positions were all selected periodically. No spurious indications of any kind were observed. It was noted that the indicator movements were quite heavily damped, reducing sensitivity to transient conditions. The following systems were tested for possible interference: various galley equipment units; radar in ground map and weather modes; HF radios 1 and 2 at frequencies between 3 and 30 MHz, including amplitude modulated transmissions; the newly fitted video in-flight entertainment system; and the emergency lighting system. In addition, a mobile radio-telephone was operated within the aircraft, particularly in cabin areas adjacent to the wing leading edge and avionics bay where the AVM system cables are located. These tests produced no observed effect on the AVM system.

Engine manufacturer's investigation

The engine manufacturer was provided with data from the QAR and conducted an investigation based on this and on inspection of the engine components. That investigation determined that the most probable cause of the vibration on both engines was fan blade clapper lock-up. It was noted that although the No 4 engine only began to vibrate some 1½ minutes after power reduction, there was in fact a further small reduction in indicated EPR at the time the vibration began. This small power change was regarded by the engine manufacturer as being sufficient to cause clapper lock-up. The engine manufacturer further considered that the audible rumble reported during the low power ground run could have been caused by intake distortion effects due to the crosswind at the time.

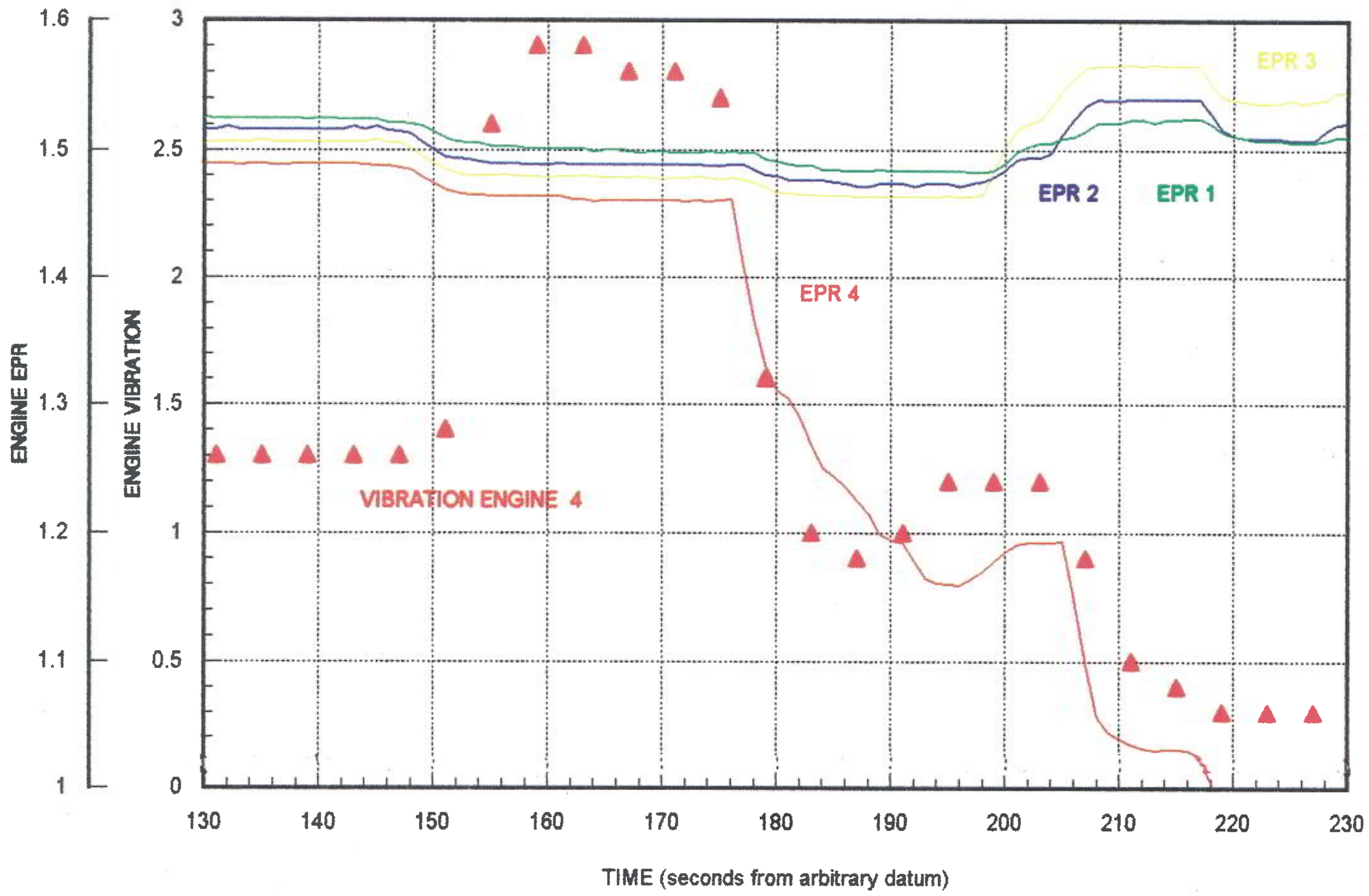
BA B747 G-BDXG DOUBLE ENGINE SHUTDOWN OVER AMBOISE, FRANCE ON 24 JANUARY 1993

FIGURE 1



START UTC 1507

G-BDXG NO 4 INITIAL ENGINE VIBRATION FIGURE 2



G-BDXG NO 1 ENGINE VIBRATION INCREASE DURING DESCENT FIGURE 3