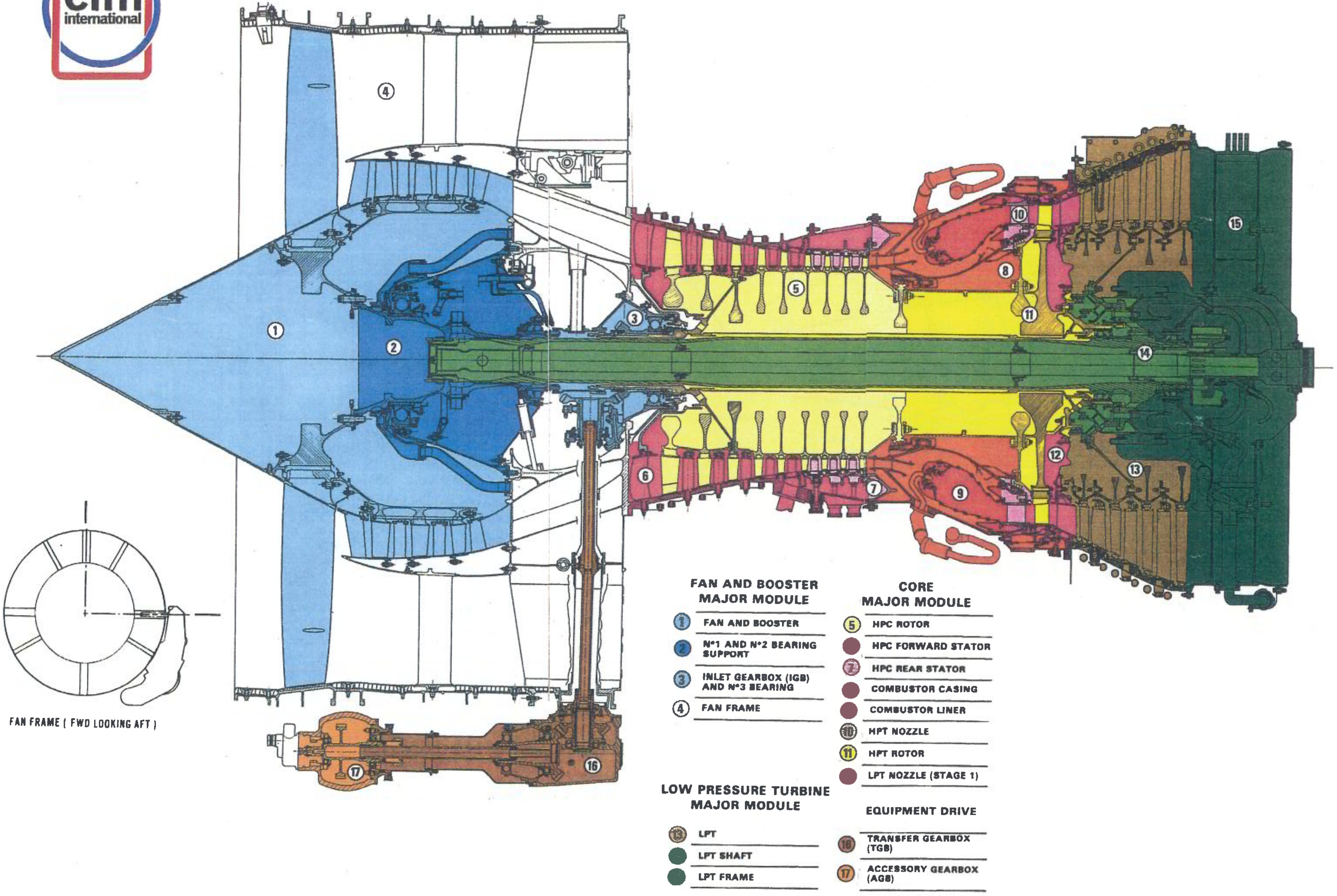
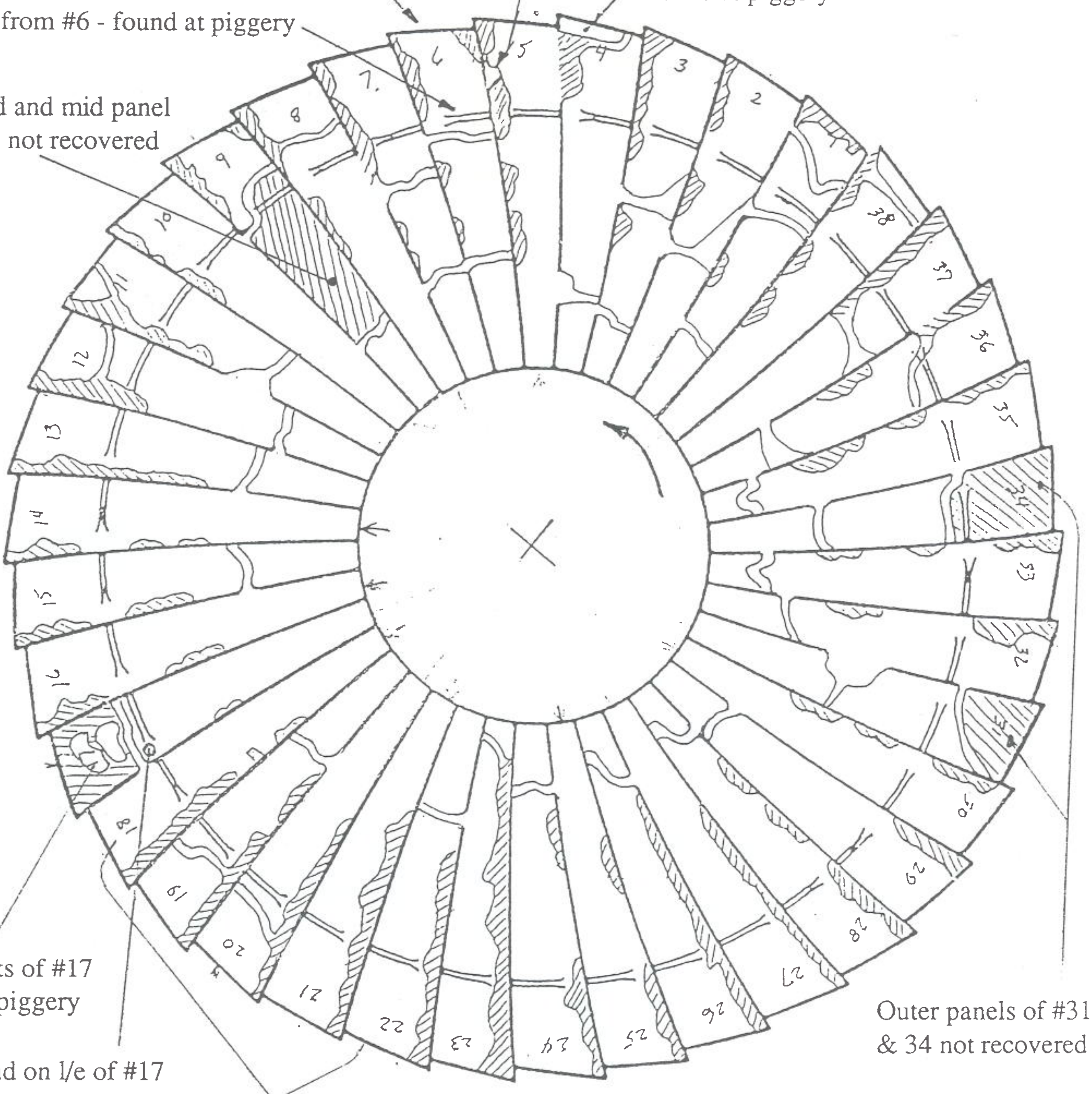
APPENDIX 1 FIG 1

CFM56-3



Appendix 1
Figure 2

Fragmentation and other damage features of the fan of No.1 engine from G-OBME



Outer panel & shroud of #6 metal/metal rubbed and discoloured

Piece of #5 l/e found at piggery

Piece of #4 found at piggery

Concave face shroud ear from #6 - found at piggery

Shroud and mid panel of #9 - not recovered

Fragments of #17 found at piggery

Bend on l/e of #17

Group of blades #18 to#22 with curled and bulged l/es

Outer panels of #31 & 34 not recovered

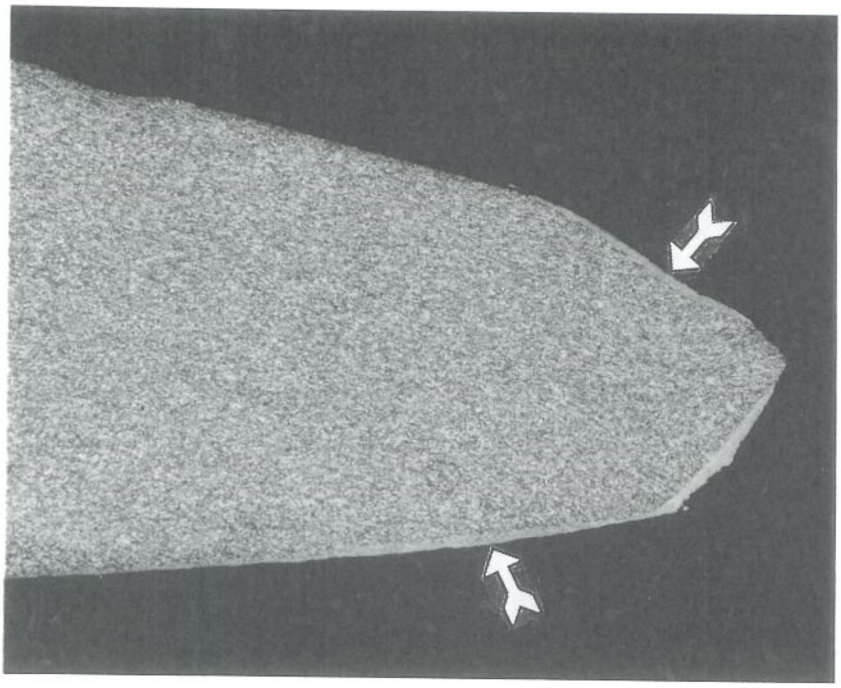


Figure 3

Microsection through the leading edge of blade 17 immediately below the plane of the fatigue crack.

This shows the even microstructure of the blade material as a whole and where the microstructure has been modified by high energy impacts.

The arrows point to the pressure (lower) and suction face impact facets where a shallow modified layer can be seen. The leading edge itself shows a much deeper bright modified layer.

Appendix 1
Extract 1

Extract from Joint Airworthiness Requirements **JAR E ENGINES**

JAR E SUB-SECTION C3-TURBINE ENGINES FOR AEROPLANES [CHAPTER C3-4 TYPE SUBSTANTIATION]

3 **VIBRATION SURVEYS** Vibration surveys shall be made on the major rotating parts, compressor and turbine blading, and the Engine carcass.

3.1 General

3.1.1 Each survey shall cover all Engine conditions from Ground Idling to at least Maximum Engine Overspeed. Should there be any indication of a stress peak arising at high speed conditions, the survey shall be extended sufficiently to reveal the maximum stress values present, except that the survey need not extend beyond 105% of the maximum speed to be approved (other than Maximum Engine Overspeed) or 2% above Maximum Engine Overspeed, whichever is the higher.

3.1.2 Each survey shall enable an evaluation to be made of the effects, if appropriate to the particular part of the Engine being surveyed, of running with the most adverse compressor intake airflow distortion pattern declared by the constructor and the most adverse exhaust conditions, including the use of a thrust reverser.

3.1.3 The effects of likely fault conditions (such as out-of-balance, turbine entry blockage, fuel nozzle blockage, etc.) shall also be evaluated, if appropriate to the particular part of the Engine being surveyed.

3.1.4 For turbo-propeller Engines a representative flight propeller shall be fitted in cases where the results could be influenced by the presence of the Propeller.

3.2 **Compressor and Turbine Rotors.** It shall be shown by tests on an Engine or by other acceptable means that no dangerous vibratory stresses are likely to occur in compressor and turbine rotors (ie discs or drums) within the range of rpm covered by the survey.

NOTE: The evaluation of shafts is detailed in **C3-4** App..12

3.3 Compressor and Turbine Blades

3.3.1 It shall be shown by strain gauging or other acceptable means that no unacceptable vibratory stresses are likely to occur in the compressor and turbine blading.

NOTES: (1) If, to avoid unacceptable blade vibratory stresses, the constructor declares prohibited speed ranges, these should be agreed by the Authority.
(2) The blade vibration survey and the variation of the incremental running referred to in 6.6.1 may be waived wholly or in part if the Authority is satisfied that the total hours run on the test bed or in flight, under representative conditions, prior to certification, is such as to demonstrate that the vibration stress levels are satisfactory. This may apply particularly in the case of small Engines if the dimensions of the blades make it difficult to complete a satisfactory vibration survey.

3.3.2 The blade rows to be investigated and the number of blades in each row shall be agreed with the Authority. The blade rows will normally include:-

(a) the first compressor rotor blade row, all rows adjacent to variable incidence stator blades, and these stator blades if cantilevered, ie unshrouded,

(b) the last turbine blade row and the adjacent stator turbine blades if cantilevered,

(c) as many other rows of compressor and turbine rotor blades and the adjacent stator blades if they are cantilevered, as may be shown from the test results of (a) and (b) to be necessary.

NOTE: Should the investigation indicate resonances of large amplification factor in the above rows of blading, or should the investigation, development experience, calculation, etc., suggest that such resonances may be expected to occur in other rows of blading, the Authority reserves the right to require the vibration survey to be extended as necessary. In estimating from limited measurements the highest stresses likely to be experienced in the worst blade of any row, allowance should be made for the inevitable scatter in peak amplitudes which will occur when blades have the usual production tolerances on frequency.

3.4 **Engine Carcass.** Acceptable levels of Engine carcass vibrations shall be established from experience of development and type testing, and shall be declared for selected datum positions.

NOTE: These will be used in assessing the vibration characteristics of the Engine when installed in an aeroplane.

Extract from Joint Airworthiness Requirements JAR 25 LARGE AEROPLANES

JAR 25.939 Turbine engine operating characteristics

(a) Turbine engine operating characteristics must be investigated in flight to determine that no adverse characteristics (such as stall, surge, or flame-out) are present, to a hazardous degree, during normal and emergency operation within the range of operation limitations of the aeroplane and of the engine. (See ACJ 25.939(a).)

(b) Reserved.

(c) The turbine engine air inlet system may not, as a result of air flow distortion during normal operation, cause vibration harmful to the engine. (See ACJ 25.939 (c).)

(d) It must be established over the range of operating conditions for which certification is required that the powerplant installation does not induce engine carcase vibration in excess of the acceptable levels established during engine type certication under JAR-E, C3-4, paragraph 3.4. (See ACJ 25.939 (d).)

ACJ 25.939(a)
Turbine Engine Operating Characteristics (Interpretative Material)
See JAR 25.939(a)

1 The wording 'in flight' should be interpreted to cover all operating conditions from engine start until shut-down.

2 If the airflow conditions at the engine air intake can be affected by the operating conditions of an adjacent engine, the investigation should include an exploration of the effects of running the adjacent engine at the same and at different conditions over the whole range of engine operating conditions, including reverse thrust. An investigation of the effect of malfunctioning of an adjacent engine should also be included.

ACJ 25.939(c)
Turbine Engine Operating Characteristics (Acceptable Means of Compliance and Interpretative Material)
See JAR 25.939(c)

1 The investigation should cover the complete range, for which certification is required, of aeroplane speeds attitudes, altitudes and engine operating conditions including reverse thrust, and of steady and transient conditions on the ground and in flight, including crosswinds, rotation, yaw and stall. Non-critical conditions of operation which need not be considered should be agreed with the Authority.

2 If the airflow conditions at the engine air intake can be affected by the operating conditions of an adjacent engine, the investigation should include an exploration of the effects of running the adjacent engine at the same and at different conditions over the whole range of engine operating conditions, including reverse thrust. An investigation of the effect of malfunctioning of an adjacent engine should also be included.

3 Compliance with the requirement may include any suitable one or combination of the following methods; as agreed with the Authority.

a. Demonstration that the variations in engine inlet airflow distortion over the range defined in 1 are within the limits established for the particular engine type.

b. An investigation of blade vibration characteristics by the method and of the scope indicated in JAR-E, C3-4 para 3.3 (except that Maximum Take-off rpm need not be exceeded) carried out on:-

i a representative installation on the ground using test equipment where the actual conditions of operation in the aeroplane are reproduced, or

ii a representative aeroplane on the ground and in flight as appropriate to the conditions being investigated.

c. The completion of sufficient flying with representative installations prior to certification such as to demonstrate that the vibration levels are satisfactory.

d. Any other method acceptable to the Authority.

ACJ 25.939(d)
Turbine Engine Operating Characteristics (Acceptable Means of Compliance)
See JAR 25.939(d)

Compliance with JAR 25.939(d) may consist of flight tests using vibration measuring equipment on which engine test bed vibration levels were established, or the equipment intended to be supplied on production engines provided the Authority considers the equipment sensitive enough for the purpose of showing compliance with the requirements.

Appendix 1
Extract 1

Extract from Federal Airworthiness Regulations **FAR 25 ENGINES**

GENERAL

§25.901 Installation

(a) For the purpose of this part, the airplane powerplant installation includes each component that -

(1) Is necessary for propulsion;
(2) Affects the control of the major propulsive units; or
(3) Affects the safety of the major propulsive units between normal inspections or overhauls.

(b) For each powerplant -

(1) The engine installation must meet the applicable provisions of this subpart;
(2) The components of the installation must be constructed, arranged, and installed so as to ensure their continued safe operation between normal inspections and overhauls;

§25.903 Engines

(a) *Engine type certification.* Each engine must be type certificated under Part 33.

§25.939 Turbine engine operating characteristics

(c) The turbine engine air inlet system may not, as a result of air flow distortion during normal operation, cause vibration harmful to the engine.

Extract from Federal Airworthiness Regulations **FAR 33 ENGINES**

§33.11 Applicability

This subpart prescribes the general design and construction requirements for reciprocating and turbine aircraft engines.

§33.19 Durability

Engine design and construction must minimize the development of an unsafe condition of the engine between overhaul periods. The design of the compressor and turbine rotor cases must provide for the containment of damage from rotor blade failure.

Appendix 1
Extract 1

§33.61 Applicability

This subpart prescribes additional design and construction requirements for turbine aircraft engines.

§33.62 Stress analysis

A stress analysis must be performed on each turbine engine showing the design safety margin of each turbine engine rotor, spacer, and rotor shaft.

§33.63 Vibration

Each engine must be designed and constructed to function throughout its normal operating range to rotational speeds and engine power without inducing excessive stress in any engine part because of vibration and without imparting excessive vibration forces to the aircraft structure.

§33.82 General

Before each endurance test required by this subpart, the adjustment setting and functioning characteristic of each component having an adjustment setting and a functioning characteristic that can be established independent of installation on the engine must be established and recorded.

§33.83 Vibration test

(a) Each engine must undergo a vibration survey to establish the vibration characteristics of the rotors, rotor shafts, and rotor and stator blades at the maximum inlet air distortion limit, over the range of rotor shaft speeds and engine power or thrust, under steady state and transient conditions, from idling speed to 103 percent of the maximum desired takeoff speed rating. The survey must be conducted using, for turbopropeller engines, the same configuration of the propeller type which is used for the endurance test, and using, for other engines, the same configuration of the loading device type which is used for the endurance test.

(b) The vibration stresses of the rotors, rotor shafts, and rotor and stator blades may not exceed the endurance limit stress of the materials from which these parts are made. If the maximum stress in the shaft cannot be shown to be below the endurance limit by measurement, the vibration frequency and amplitude must be measured. The peak amplitude must be shown to produce a stress below the endurance limit; if not, the engine must be run at the condition producing the peak amplitude until, for steel parts, 10 million stress reversals have been sustained without fatigue failure and, for other parts, until it is shown that fatigue failure will not occur within the endurance limit stress of the material.

(c) Each accessory drive and mounting attachment must be loaded, with the load imposed by each accessory used only for an aircraft service being the limit load specified by the applicant for the engine drive or attachment point.

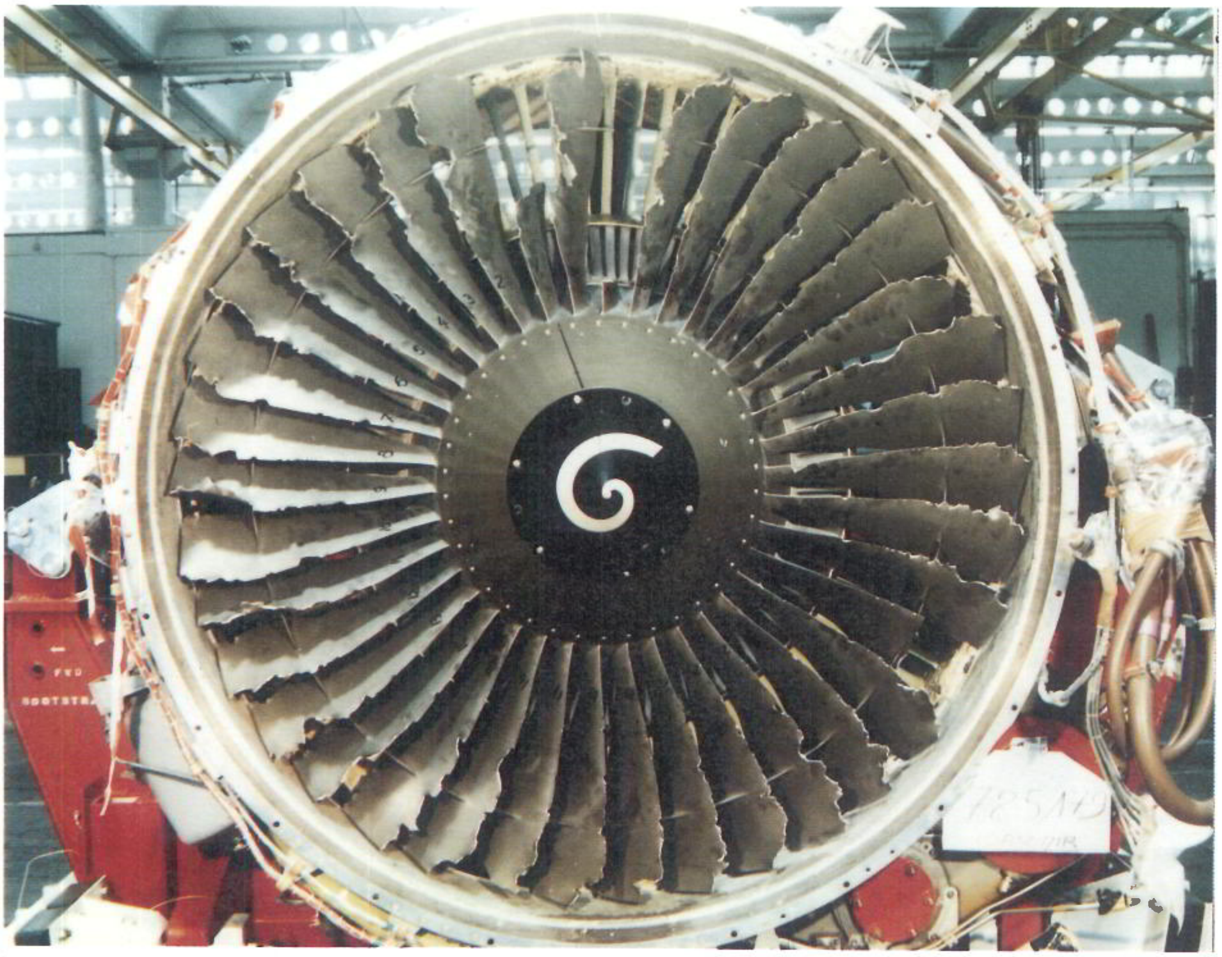


Figure 4(a)

View on front of fan of G-BNNL after in-flight fan blade outer panel separation showing the very severe leading edge damage to all the remaining blades.

The blade which suffered outer panel separation is at the 4 o'clock position.

Note also, at the 12 o'clock position where a full blade and a half blade have been broken away.

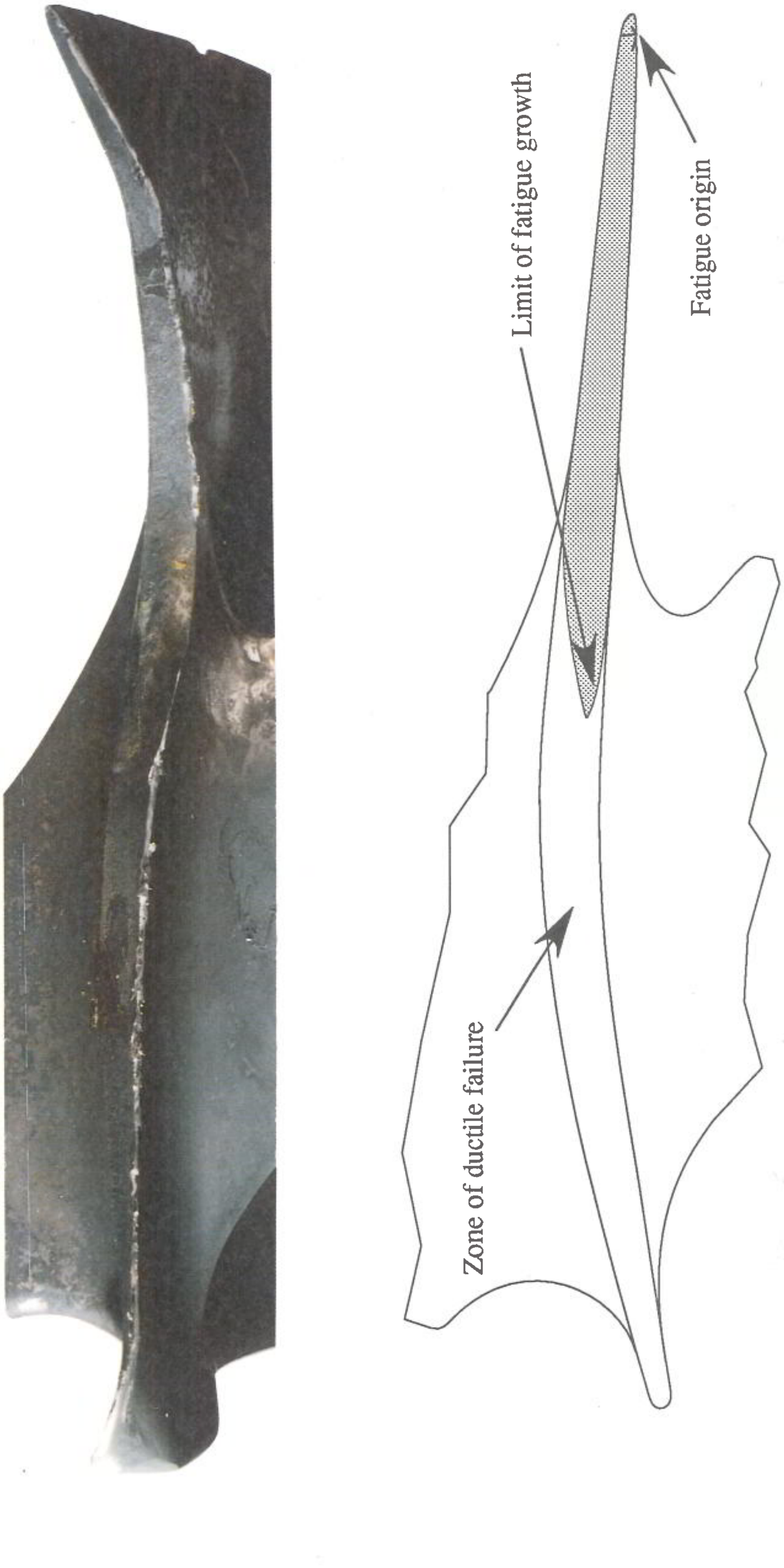
Appendix 1

Figure 4(b)

View on front of fan of G-OBMG after in-flight fan blade outer panel separation showing the nearly total absence of leading edge damage on all the remaining blades.

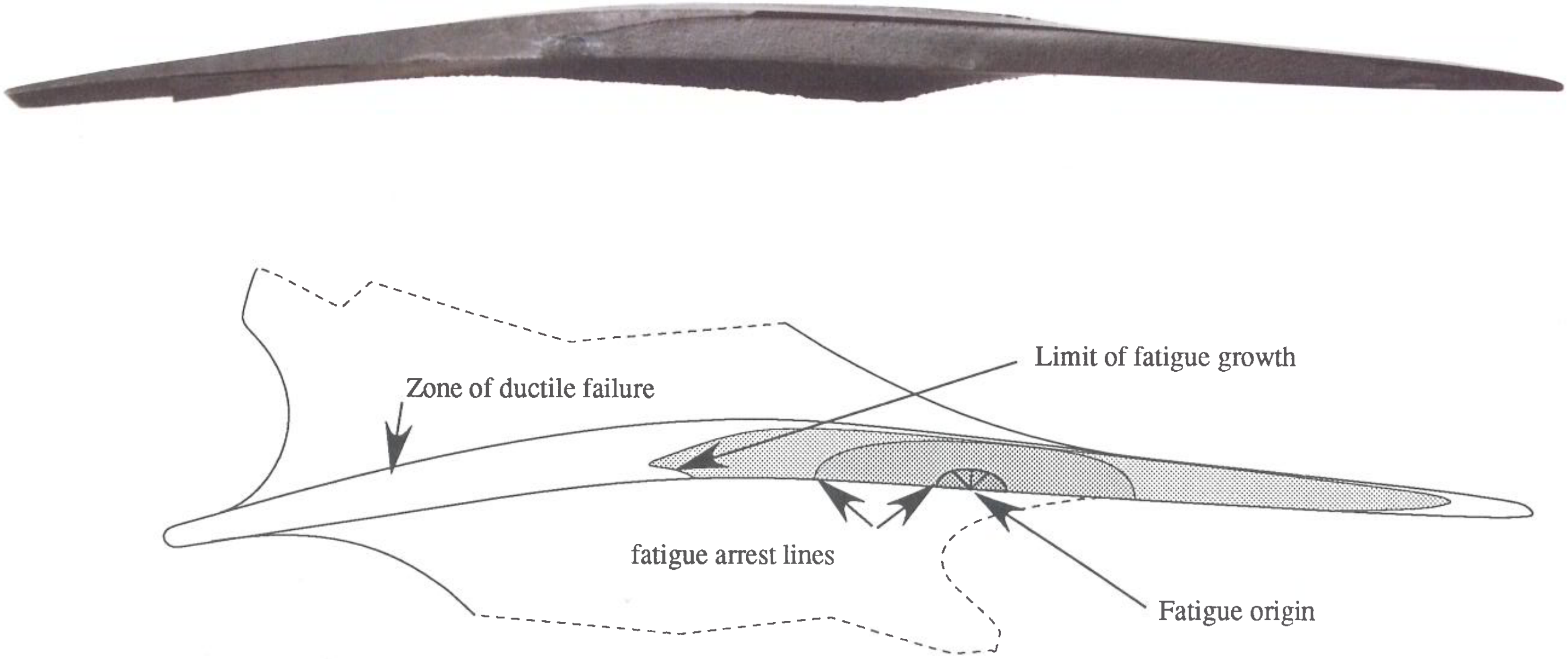
The blade which suffered outer panel separation has been removed from the 12 o'clock position.

Appendix 1 Fig 5



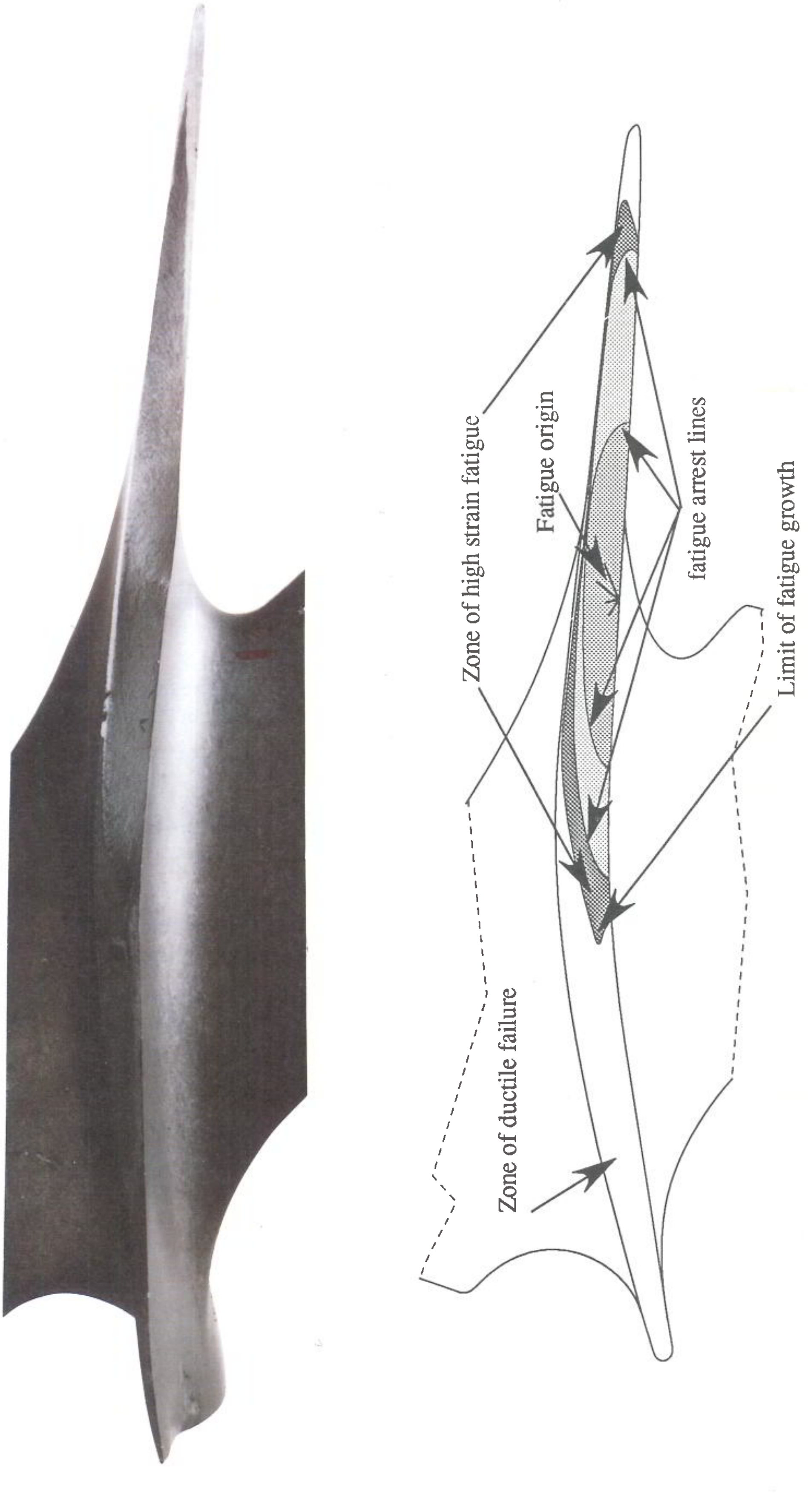
Features of fan blade fracture from G-OBME

Appendix 1 Fig 6



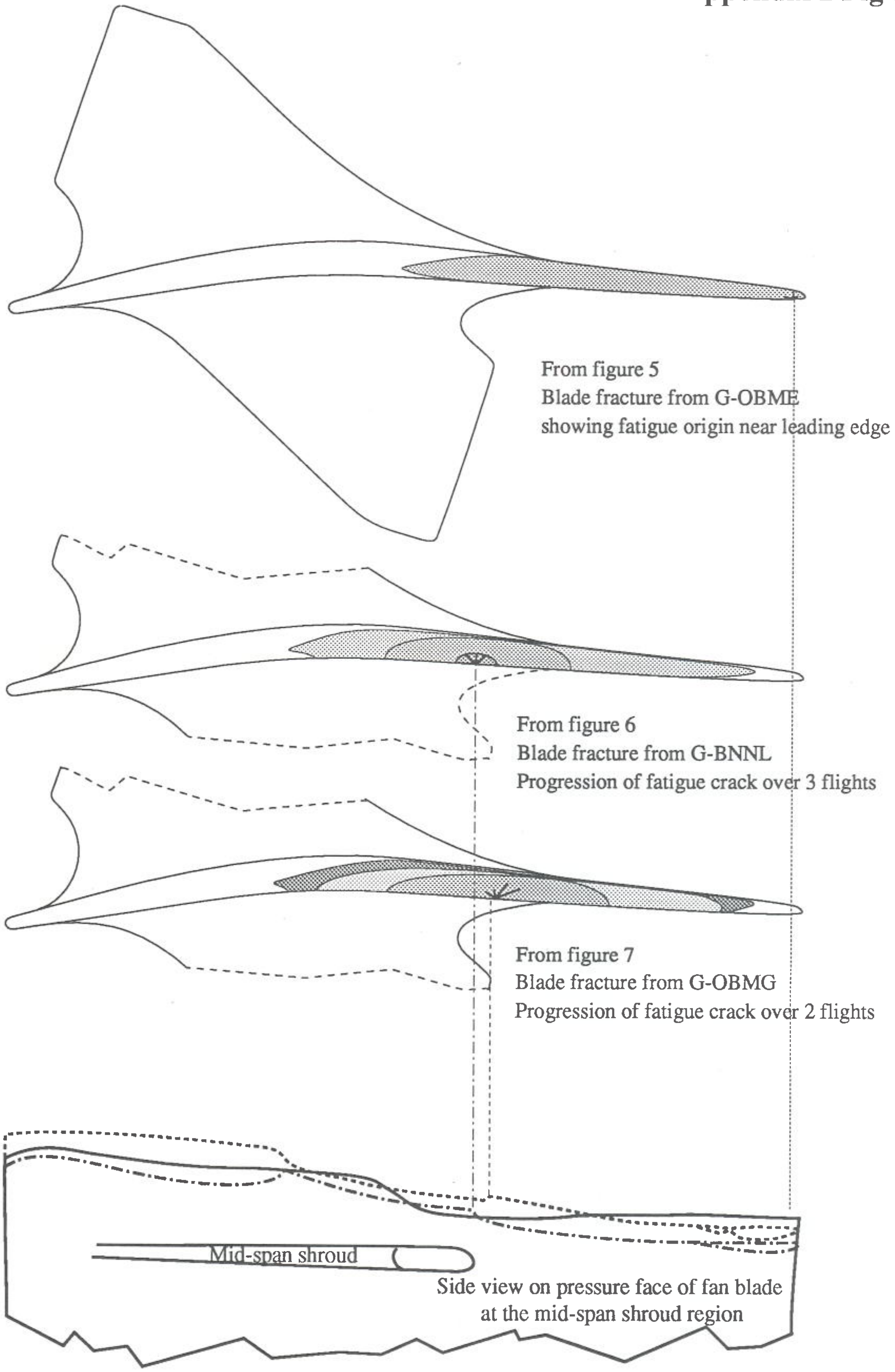
Features of fan blade fracture from G-BNNL

Appendix 1 Fig 7



Features of fan blade fracture from G-OBMG

Appendix 1 Fig 8



From figure 5
Blade fracture from G-OBME
showing fatigue origin near leading edge

From figure 6
Blade fracture from G-BNNL
Progression of fatigue crack over 3 flights

From figure 7
Blade fracture from G-OBMG
Progression of fatigue crack over 2 flights

Side view on pressure face of fan blade
at the mid-span shroud region

Comparison of fracture lines on 3 fan blades

FIG 1: SHOWING HYBRID ELECTROMECHANICAL POINTER/LED COUNTER INSTRUMENTS USED FOR DISPLAY OF ENGINE PARAMETERS WITH VIBRATION INDICATORS ARROWED

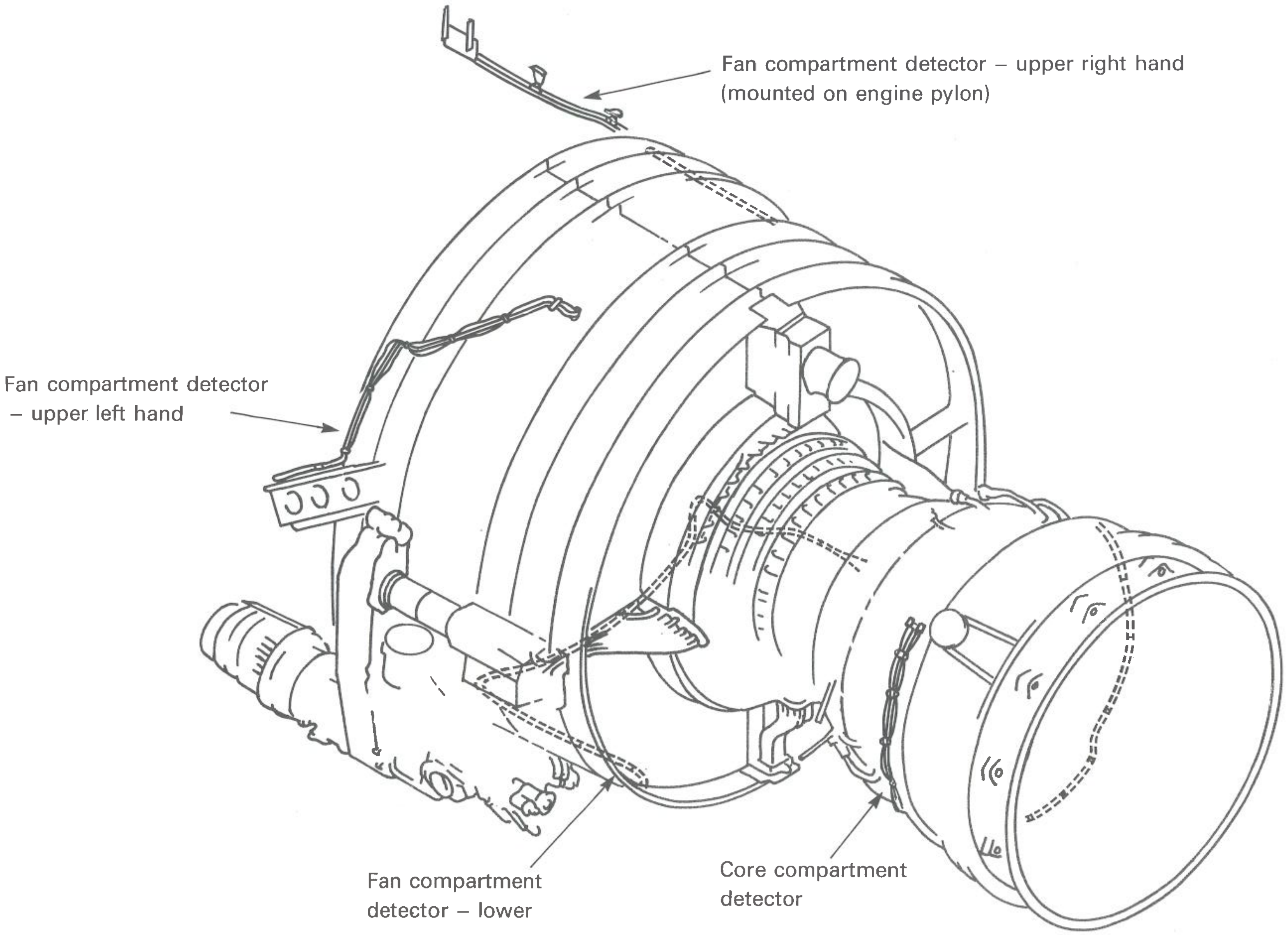
APPENDIX 2

FIG. 2: SHOWING SOLID-STATE ELECTRONIC ENGINE INSTRUMENT SYSTEM (EIS), AS FITTED TO G-OBME, WITH VIBRATION INDICATORS ARROWED

PRIMARY ENGINE DISPLAY

SECONDARY ENGINE/
HYDRAULIC DISPLAY

ACTUAL SIZE



LOCATION OF FIRE/OVERHEAT DETECTION ELEMENTS

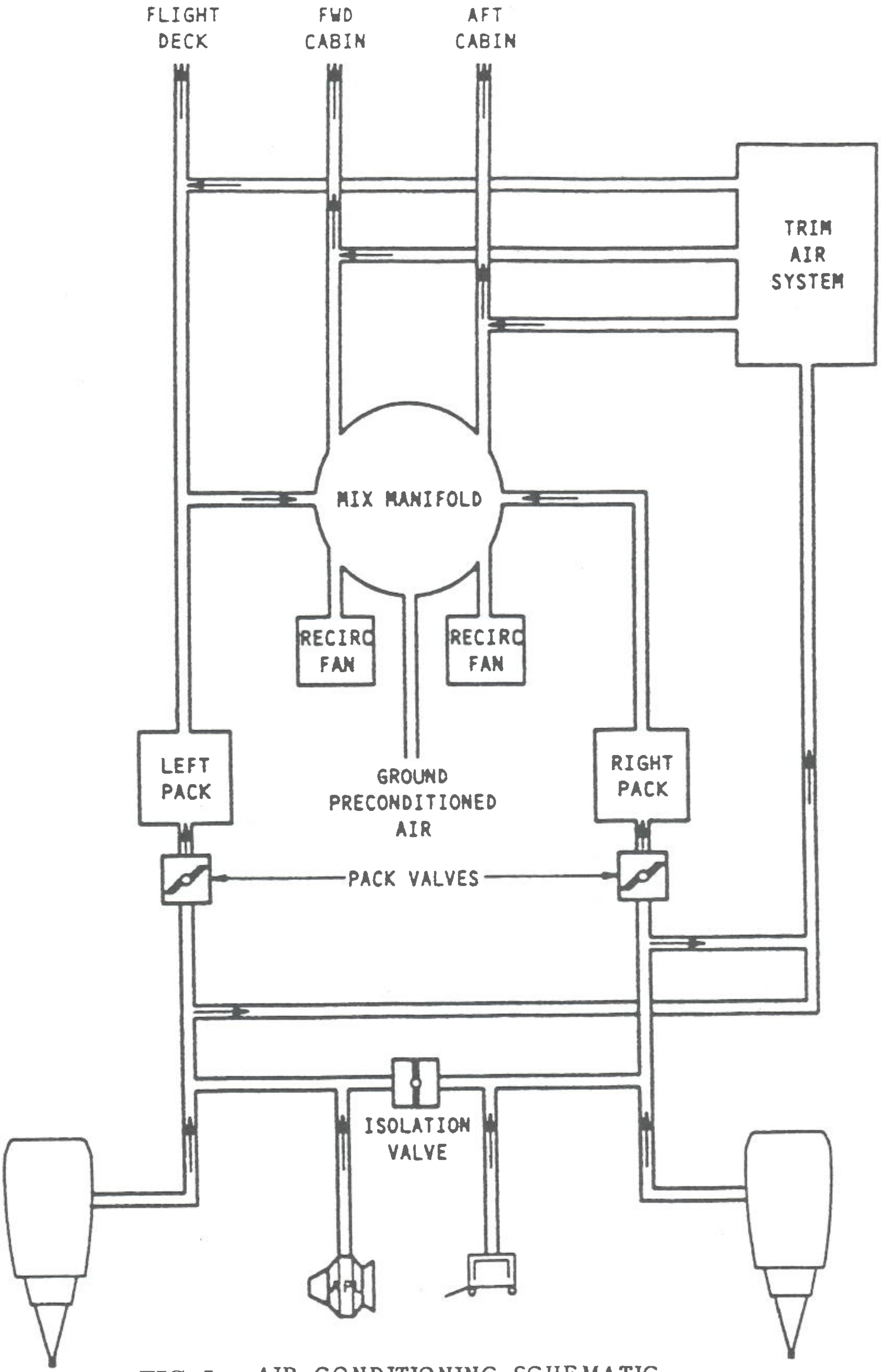


FIG 5 AIR CONDITIONING SCHEMATIC

APPENDIX 2.6

Accident Flight

↓

FLIGHT ID	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
FLIGHT NUMBER	00	01	02	03	04	05	06	07	08	09
LEFT ENGINE	E1	E1	E1	E1	E1	E1	E1	E1	E1	E1
COMPRESSOR N1 VIBRATION	5.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
COMPRESSOR N2 VIBRATION	1.1	1.3	1.9	0.4	1.8	0.4	0.2	1.7	0.5	0.3
TURBINE N1 VIBRATION	5.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
TURBINE N2 VIBRATION	1.0	0.0	0.0	1.7	0.0	1.9	0.1	0.1	2.2	1.7
N1 SPEED	93	27	26	20	25	19	81	23	19	19
N2 SPEED	93	60	61	46	60	47	86	61	44	44
ELAPSED TIME	05	10	01	00	09	00	04	08	00	00
RIGHT ENGINE	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2
COMPRESSOR N1 VIBRATION	0.0	0.0	0.0	1.2	0.6	0.6	0.4	0.4	0.0	0.0
COMPRESSOR N2 VIBRATION	1.1	1.4	1.2	0.0	0.4	0.3	0.1	0.3	1.2	1.8
TURBINE N1 VIBRATION	0.1	0.0	0.0	0.7	1.1	1.0	1.9	1.1	0.1	0.2
TURBINE N2 VIBRATION	0.2	0.1	0.0	0.0	0.4	0.4	0.2	0.3	0.2	0.2
N1 SPEED	22	22	21	55	96	96	99	96	25	22
N2 SPEED	60	59	59	79	98	97	94	97	60	60
ELAPSED TIME	00	00	12	05	02	01	03	01	00	00

FLIGHT ID	FF	FF	FF	FF	FF	FF	FF	FF	FF	FF
FLIGHT NUMBER	10	11	12	13	14	15	16	17	18	19
LEFT ENGINE	E1	E1	E1	E1	E1	E1	E1	E1	E1	E1
COMPRESSOR N1 VIBRATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COMPRESSOR N2 VIBRATION	0.4	0.4	0.3	1.3	0.3	0.3	0.3	0.4	0.4	0.4
TURBINE N1 VIBRATION	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TURBINE N2 VIBRATION	2.2	2.1	2.0	0.0	1.5	1.7	1.9	1.8	2.1	2.2
N1 SPEED	20	19	19	21	19	20	19	20	21	19
N2 SPEED	46	46	43	59	47	44	45	47	45	45
ELAPSED TIME	00	00	00	00	00	00	00	00	00	00
RIGHT ENGINE	E2	E2	E2	E2	E2	E2	E2	E2	E2	E2
COMPRESSOR N1 VIBRATION	0.0	0.0	0.0	0.0	0.4	0.0	0.5	0.4	0.5	0.0
COMPRESSOR N2 VIBRATION	1.2	1.4	1.4	1.7	0.0	1.4	0.4	0.0	0.1	1.3
TURBINE N1 VIBRATION	0.1	0.0	0.2	0.0	1.9	0.1	1.1	1.8	2.1	0.2
TURBINE N2 VIBRATION	0.2	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.0	0.2
N1 SPEED	25	23	22	23	40	23	96	99	40	24
N2 SPEED	60	59	60	59	94	60	97	95	93	60
ELAPSED TIME	00	09	00	09	03	00	04	03	06	00

Read-out of the last 20 flights recorded on G-OBME Airborne Vibration Monitor Solid State Memory. Values represent the peak experienced on each flight.

Appendix 2.7

Engine instrumentation

Layout

The design of engine instrumentation on multi-engined aircraft is inevitably a matter of compromise. The conventional and ergonomically accepted layout is for all instruments associated with a particular engine to be organised in a column, and for all instruments of the same type to be organised in a row. It is, moreover, clearly preferable for each column of instruments to be associated spatially with the throttle of the appropriate engine. This is the basic layout illustrated in Figure 1 and the desirability of using such a layout for the primary engine instruments is clear. Secondary engine information is not required on the front panel of the flight deck in those aircraft with three man crews, and the ideal layout of front panel engine instrumentation described above may thus be adopted.

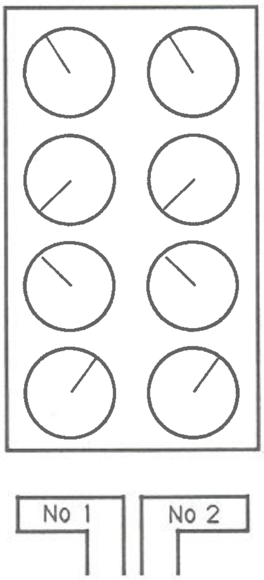


Figure 1

If the aircraft is provided with only two crew members, however, then the secondary engine instruments must be accommodated on the front panel as well. They cannot be accommodated by extending the height of the columns since panel height precludes such an option if the instruments are to be large enough to remain legible.

If the instruments are all to be located on the front panel, two possibilities are apparent. The first is to mount the secondary instruments to one side of the primary instruments as in Figure 2.

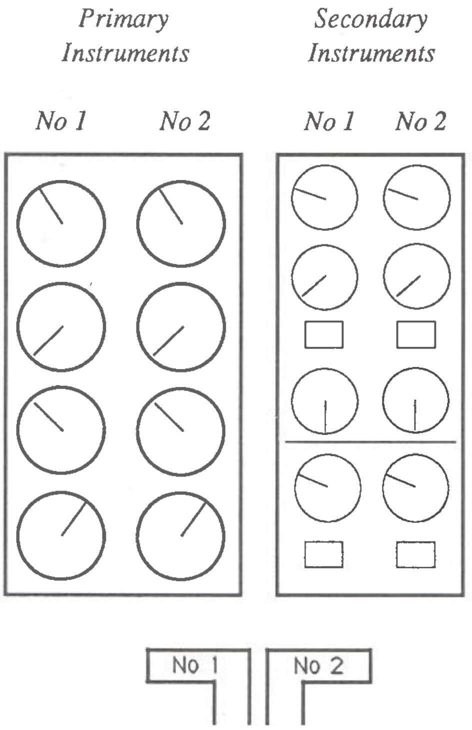


Figure 2

The second is to split the secondary instruments and mount them outboard of their respective primary instruments, as in Figure 3.

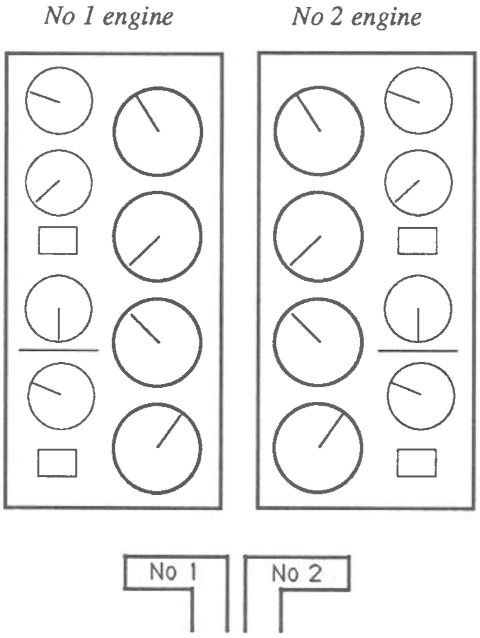


Figure 3

The advantage of the layout in Figure 3 is that the instruments for a given engine are all mounted together and are, if not spatially, at least cognitively, aligned with their associated power levers. This is achieved at the price of splitting the secondary instruments apart, with the associated possibility of disparate secondary readings going undetected.

Figure 2 achieves the goal of keeping the instruments paired together, and thus maximises the chances of disparate readings being detected, but does so at the price of splitting up the instruments associated with a given engine, and of losing the advantage of having all instruments cognitively aligned with their corresponding throttle levers.

Thus, Figure 3 could fairly be judged to maximise the probability that a given failure will be correctly identified by the crew as belonging to a given engine, at the possible cost of less efficient error detection on the secondary instruments, whereas Figure 2 may be judged as maximising the probability that disparate readings will be detected at the cost of degrading the probability that this detected failure will be associated by the crew with the correct engine.

The design of the EIS

The layout of the EIS in the Boeing 737 Series 300/400 conforms to Figure 2, which has been widely used without apparent difficulty in many two-engined, two-pilot aircraft. The illumination of the display, however, might aggravate the problem of perceived misalignment of the instruments with their respective throttles. On the hybrid instruments (LED counters with electro-mechanical pointers) fitted to other aircraft of this type, the faces of the instruments needed to be lit from in front to show the pointers, dials and scale marks. Such lighting does not, of course, illuminate only the legends and pointers on the instruments but also the general structure and limits of the display, so that the instruments could be argued to be viewed within a structured visual frame. In the EIS display, all symbology is edge-lit and set against a heavily constrasting background which, in an aircraft at night will be, to all intents and purposes, black. This may have the effect of enhancing the extent to which the instruments are seen as a single display rather than as two separate displays, and may degrade the extent to which deviant readings in, say columns 1 and 3 of the matrix could readily be associated with the No 1 engine.

The next most obvious and important change made between the hybrid system and the EIS is that the full-radius mechanical pointers have been changed to short LED pointers moving round the outsides of their scales. The mechanical pointers were relatively large, white and clearly linear devices, and their orientation on the display was immediately apparent. Not only was the absolute orientation of each pointer apparent but (and perhaps more importantly) it was readily apparent whether the pointers of each pair of instruments were parallel with one another. The pointers on the LED display are much shorter than the mechanical pointers, they are the same colour as the LED counters and they move in steps. They are much less conspicuous than the mechanical pointers, acting more as scale markers, and providing less immediate directional information. They are thus less well able to give the comparative information provided by the strong cue of parallelism of the mechanical pointers. This comparative information can be obtained with certainty only by interrogating each instrument to see if the LED pointers of each pair are at the same points on the scale or by comparing the readings of the pairs of counters.

Evaluation and testing

The entire function of any display on a flight deck is to transfer information from the aircraft to the pilot, and to do so in the way that will cause the pilot least workload and will be least likely to be interpreted wrongly. Although some principles, such as those discussed above, guide the design of displays, the only way of evaluating the adequacy of a display is by experiment and trial. It is therefore important that before any display is put into service, it is subjected not just to some form of acceptability judgement by company pilots, but to a structured assessment using average line pilots. Indeed, it could be argued that such assessments should be conducted using the least able pilots who are ever likely to use the display.

A display similar to the EIS was developed by Smith's Industries for use on the McDonnell Douglas MD88. It was held to differ from an earlier display which employed mechanical pointers, in that the colour coding of some dials was changed. The new display was evaluated by pilots employed by McDonnell Douglas and the Federal Aviation Administration (FAA). The evaluation was held to show that the new display provided clearly readable and interpretable information to the flight crew, showed whether the current state of powerplant operation was normal or abnormal, indicated the engine maximum/minimum safe operating range and showed whether the system(s) operation was being accomplished in a safe manner. These results were used by McDonnell Douglas to demonstrate to the FAA the acceptability of the new display as an equivalent means of compliance with current airworthiness regulations.

The EIS for the Boeing 737 was designed to represent a minimum change from the previous hybrid display and, accordingly, it was type certified by both the FAA and the CAA as fit for its purpose. The counters remained identical in size and colour but the dials of all instruments were reduced in size. The pointers were reduced in length by approximately two-thirds and placed on the outsides of the dials but the circumference swept by the needle tips (ie the instrument 'size') remained the same. The EIS display was deemed to have sufficient commonality with the hybrid display to circumvent the need for pilots to be separately rated for EIS-equipped models. It was tested for proper operation, compatibility and freedom from electrical interference but it was not evaluated for its efficiency in imparting information to pilots.

Although the desire for commonality is understandable, because a number of other factors were changed between the hybrid and the EIS displays, the apparent benefit of keeping size constant may have been offset or even negated by varying others such as illumination, contrast and pointer size. The desire to maintain consistency of display format while introducing new technology was responsible for the reduction in pointer size and conspicuity, and exemplifies a general problem. LED and CRT displays possess potential advantages over old technology instrumentation that may be exploited only if the display is designed afresh to exploit them. If a new technology display is designed simply to mimic the appearance of its precursors it may well fall into what is sometimes referred to as the 'electric horse' trap; the strengths of the old system are discarded because they cannot be duplicated, and the potential strengths of the new system are not exploited. Full length pointers cannot be represented on the LED system because the packing density of central LEDs cannot be achieved, and because symbology cannot be overlaid, and a potentially less satisfactory pointer is substituted.

It is reiterated that the general effectiveness of any new display may be judged only by trial and experiment, but even then some criterion of acceptability must be adopted. An obvious criterion in the case of engine instrumentation is that the new display should not prove less satisfactory to those pilots who use it than the display it replaces. When the EIS was introduced for use on the Boeing 737 no such tests were carried out.

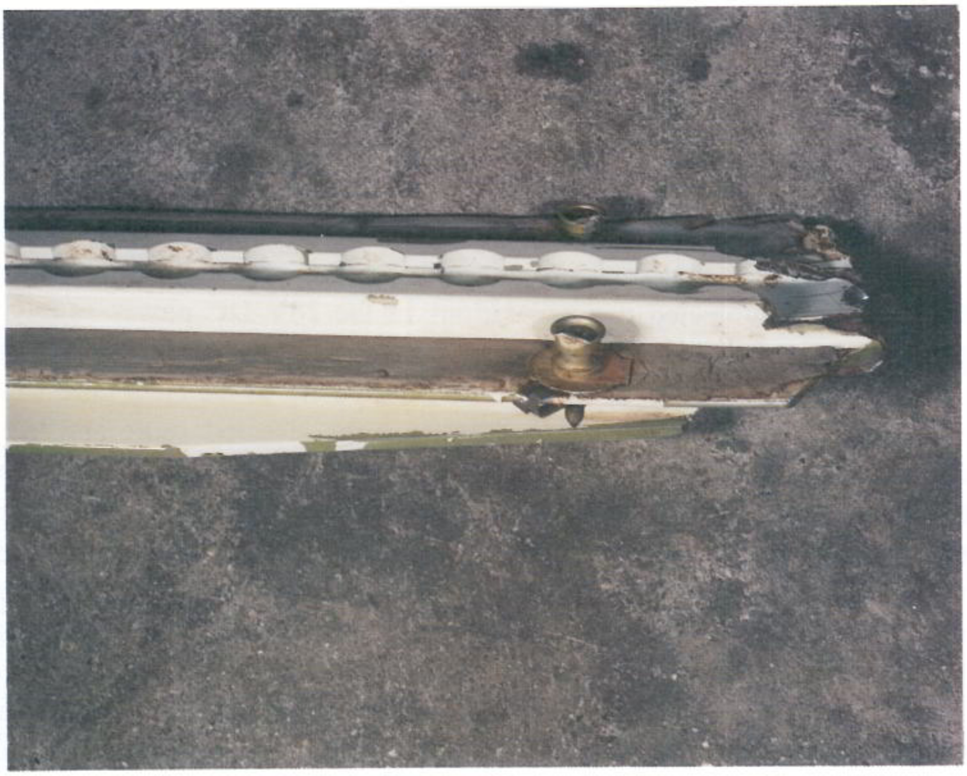
Conclusions

Although there seems to be no question that the EIS display on the Boeing 737 provides accurate and reliable information to the crew, the overall layout of the displays, and the detailed implications of small LED pointers rather than the larger mechanical ones, and of edge-lit rather than reflective symbology do appear to require further consideration. These factors should not be ignored and the suitability of such new displays for use by airline pilots should be evaluated before they are brought into use.

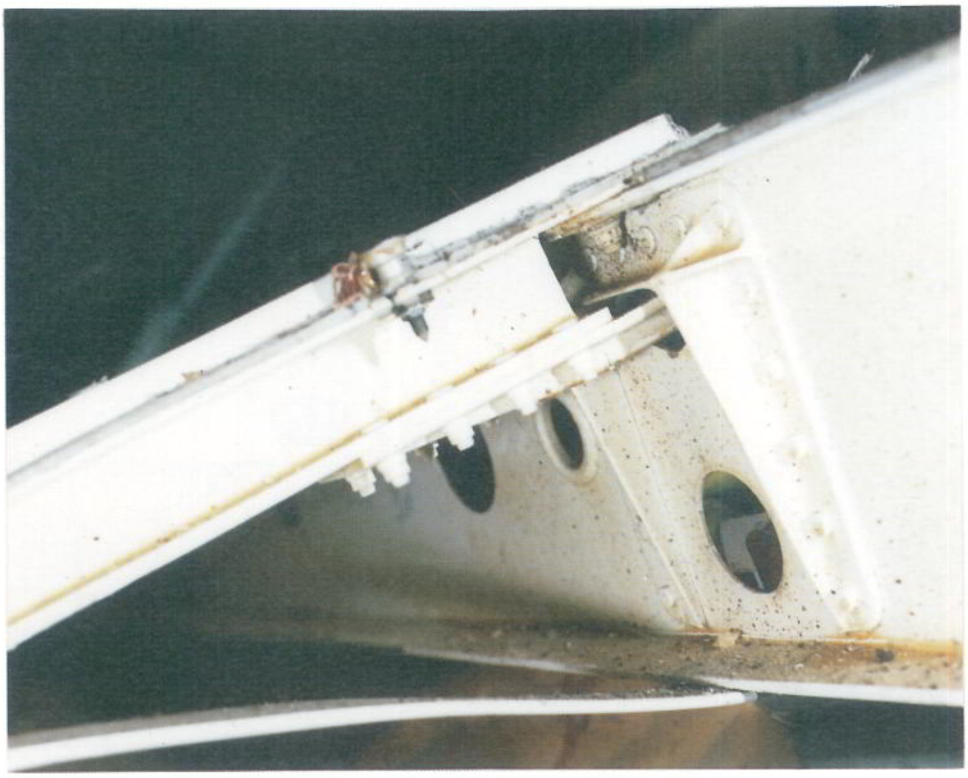
Appendix 2.8

LATCH-UP CONDITION

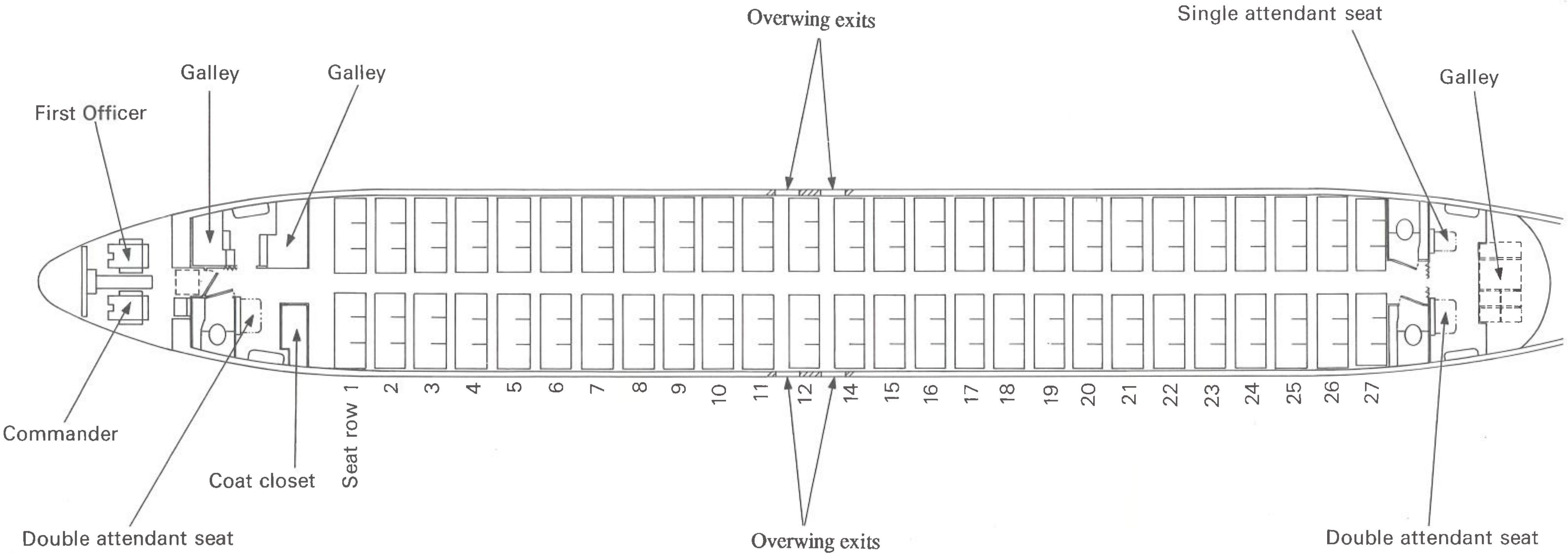
At about the time of the accident to G-OBME, reports were starting to be received by the manufacturer that certain control modules were exhibiting unusual behaviour when subjected to interruptions in the 28V DC power supply. It appeared that the module became 'dormant' for various lengths of time following the interruption but with no fault indications apparent to the crew unless they performed the cockpit self-test, in which case the affected audio and visual warnings of overheat and fire failed to illuminate. Detailed investigation showed that the problem lay in a microcircuit from a particular vendor and units liable to latch-up could be thus identified . While the module manufacturer devised a modification to their equipment, Boeing issued an Operations Manual Bulletin No.89-2 dated 6 March 1989 to all operators. This essentially called for flight crews to perform a test of the Fire/Overheat detection system after initial power-up or after a power loss or transfer to No.2 generator bus. The time interval between power loss, or transfer, and the test was later revised to one minute in recognition of the fact that some units might not latch-up immediately. Should the system fail the test in flight, crews were advised to land at the nearest suitable airport. It has been noted that the behaviour of individual modules exhibiting latch-up tended to vary both with respect to the time taken for the condition to occur and its duration.



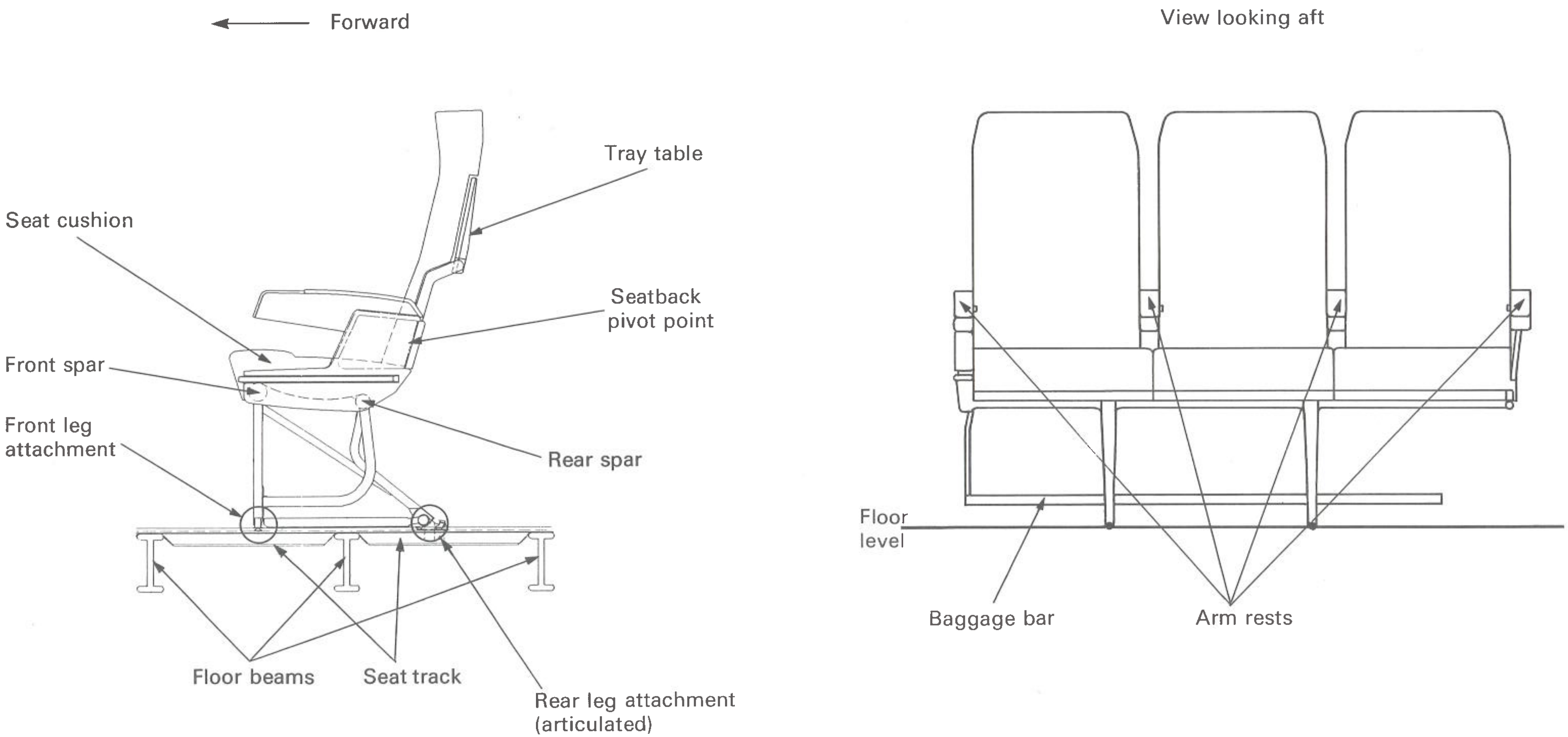
Appendix 3, figure 1 - Seat track, forward fuselage



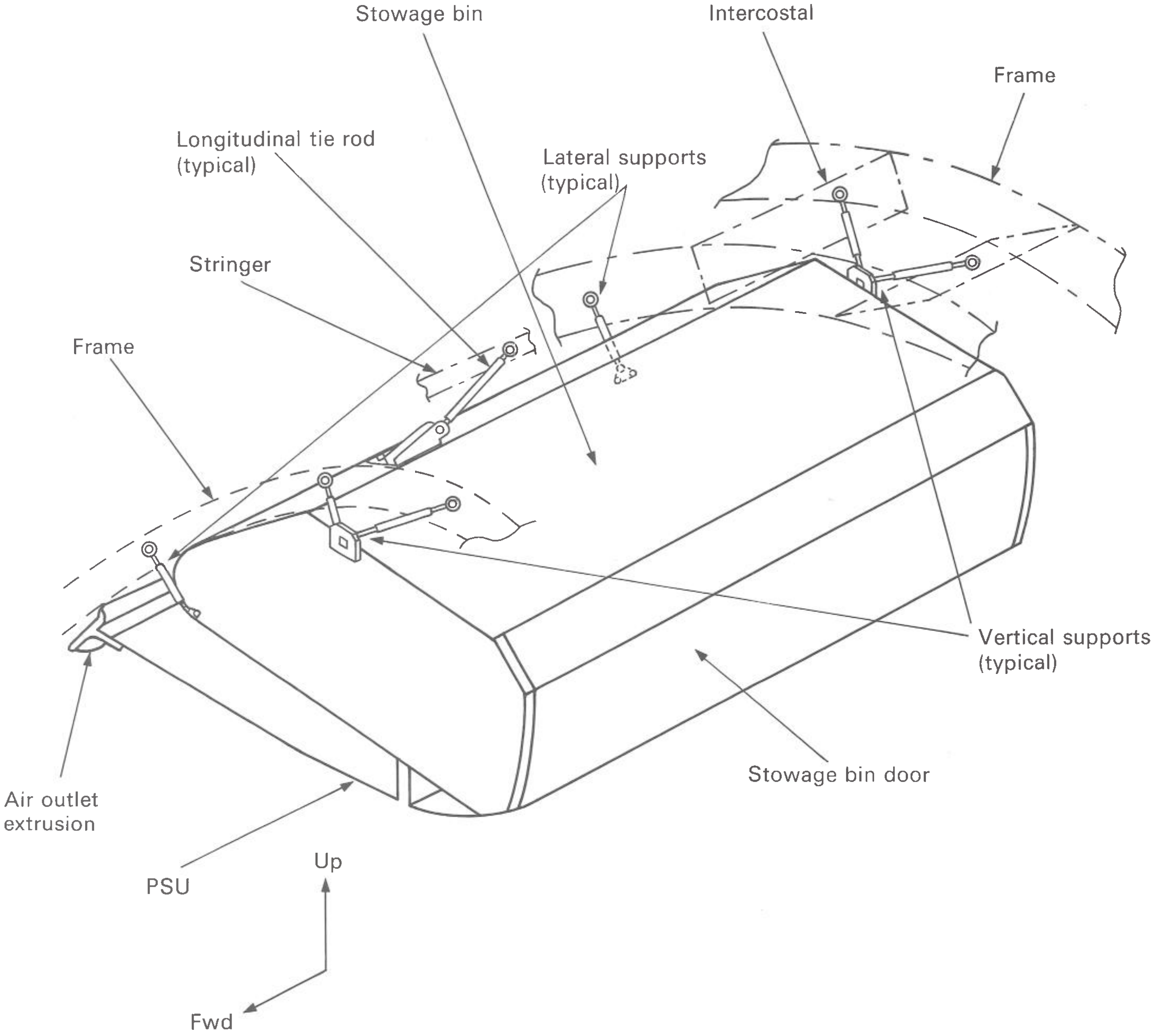
Appendix 3, figure 2 - Seat track, aft fuselage



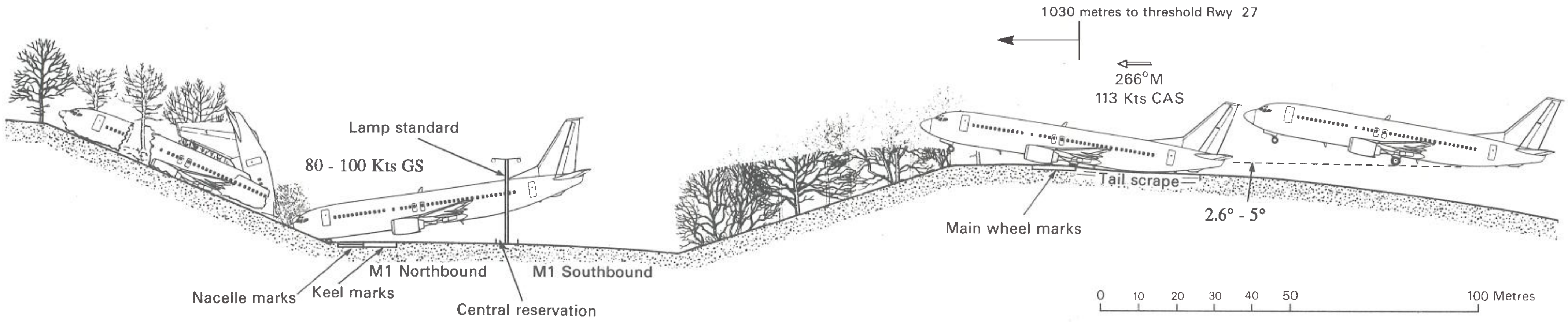
Appendix 3 Figure 3 G–OBME seating configuration



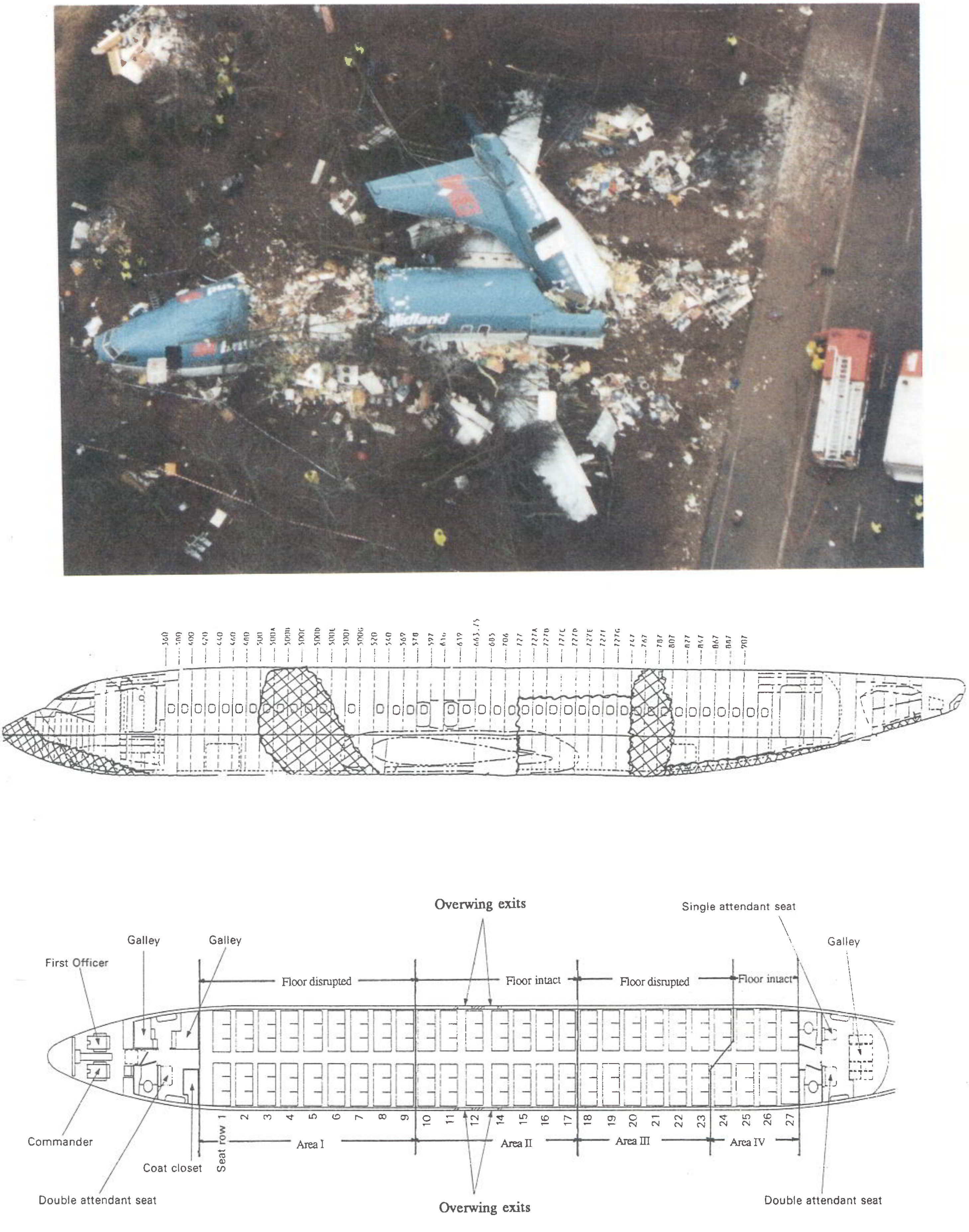
Appendix 3 **Figure 4 Passenger triple seat**



Appendix 3 Figure 5 Stowage bin attachments



Appendix 3 figure 6 - Impact sequence



Appendix 3, figure 7 - Structural disruption

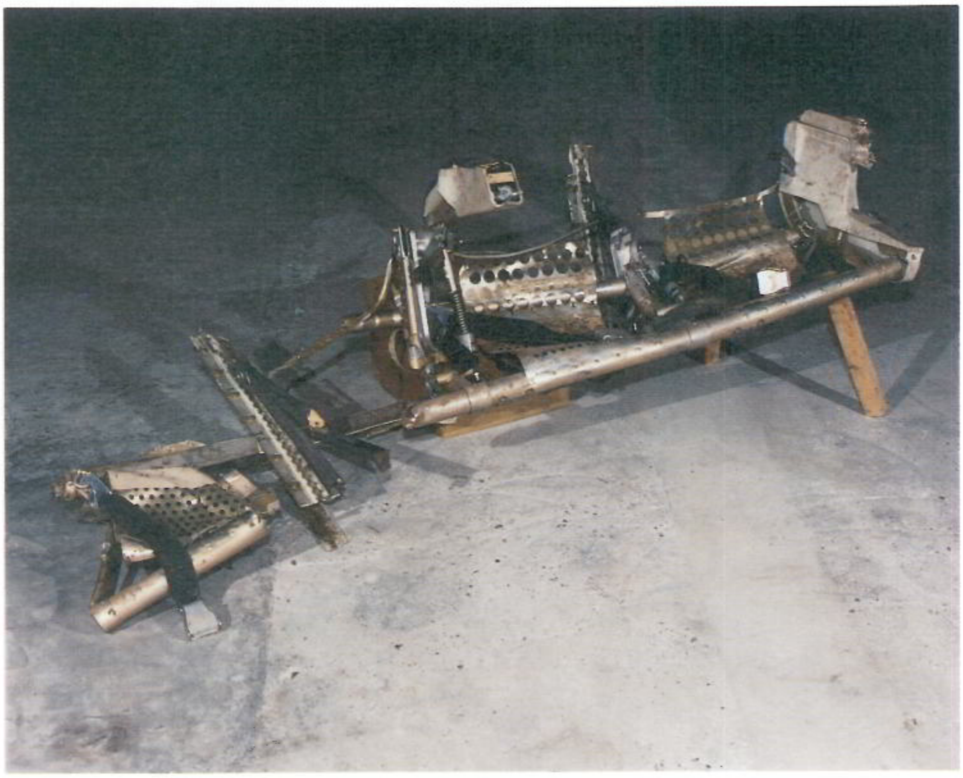
Area of cabin (fig. 7)	Triple Seats		Rear legs			Front legs								Seat backs	
			Attachment to track			Attachment to front seat spar				'U' - strap deformation				Attachment to seat	
	Row Nos.	Triples in area	Identified	Attached	Detached	Identified	Fully attached	Partially attached	Detached	Identified	Pristine	Deformed	Collapsed	Attached	Detached
I	1-9	18	33	27(82%)	6(18%)	35	17(49%)	12(34%)	6(17%)	35	4(11%)	18(51%)	13(37%)	46(85%)	8(15%)
II	10-17	14	28	28(100%)	0(0%)	28	23(82%)	5(18%)	0(0%)	27	5(19%)	2(7%)	20(74%)	56	0
III	18-23L /24R	13	25	18(72%)	7(28%)	24	7(29%)	13(54%)	4(16%)	24	5(21%)	14(58%)	5(21%)	(Fuselage buckle) 1 (Other) 17	20 1
IV	24L /25R -27	7	14	14(100%)	0(0%)	14	14(100%)	0(0%)	0(0%)	14	13(93%)	1(7%)	0 (0%)	14	0

Appendix 3 figure 8 - Summary of passenger seat damage

Appendix 3, figure 9 - Seat 3L (area I)

Appendix 3, figure 10 - Seat 15L (area II)

Appendix 3, figure 11 - Seat 18L (area III)

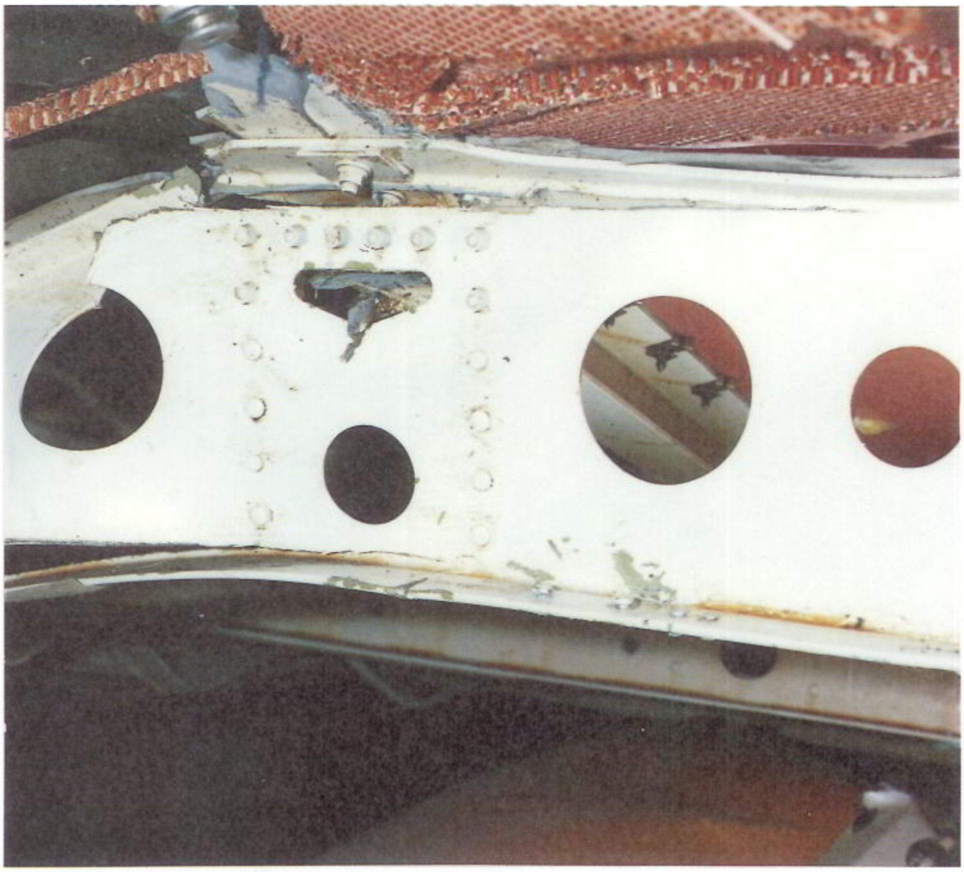


Appendix 3, figure 12 - Seat 22R (area III)

Appendix 3, figure 13 - Seat 25L (Area IV)

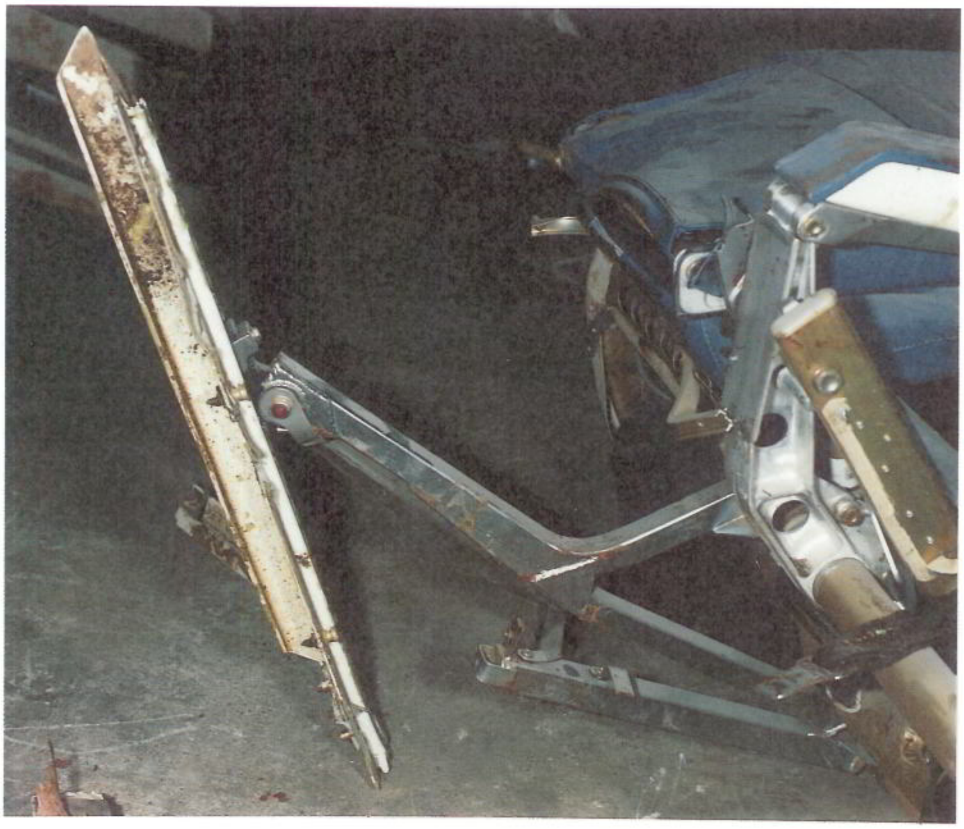
Appendix 3, figure 14 - Floor structure at station 867 (Area IV)

Appendix 3, figure 15 - Floor panel fasteners (area IV)

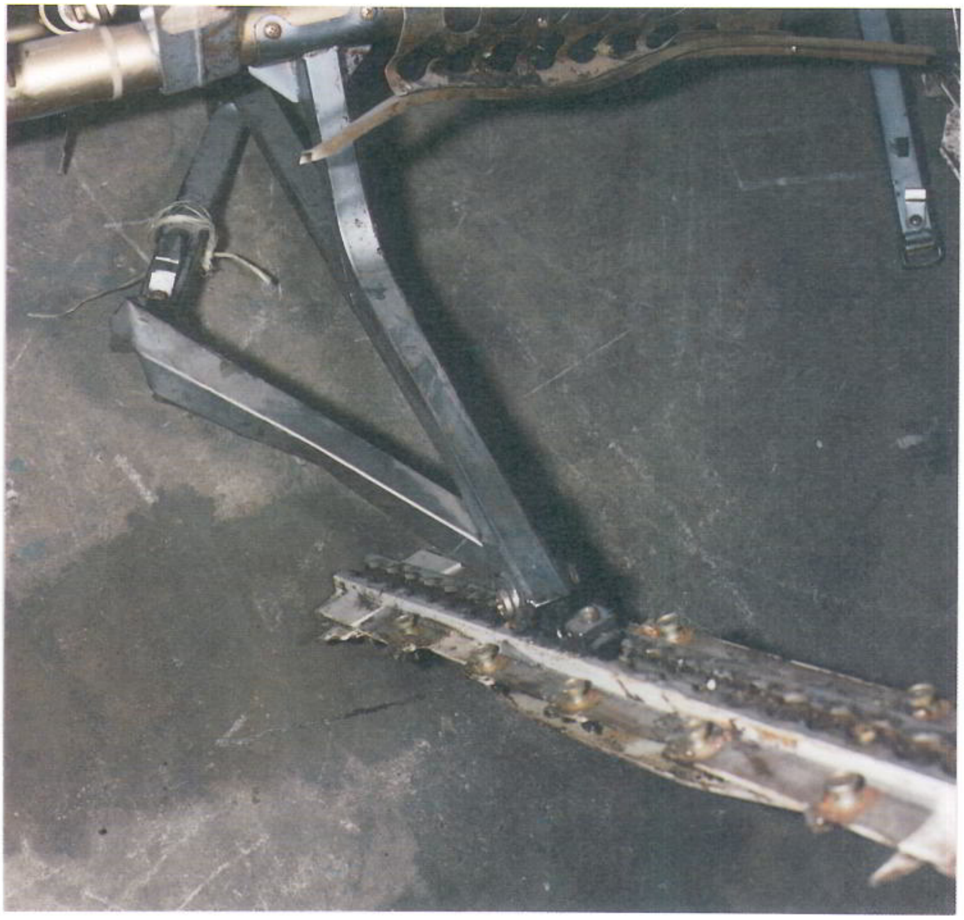


Appendix 3, figure 16 - Floor beam at station 807 (area IV)

Appendix 3, figure 17 - Seat track at station 727D (area III)

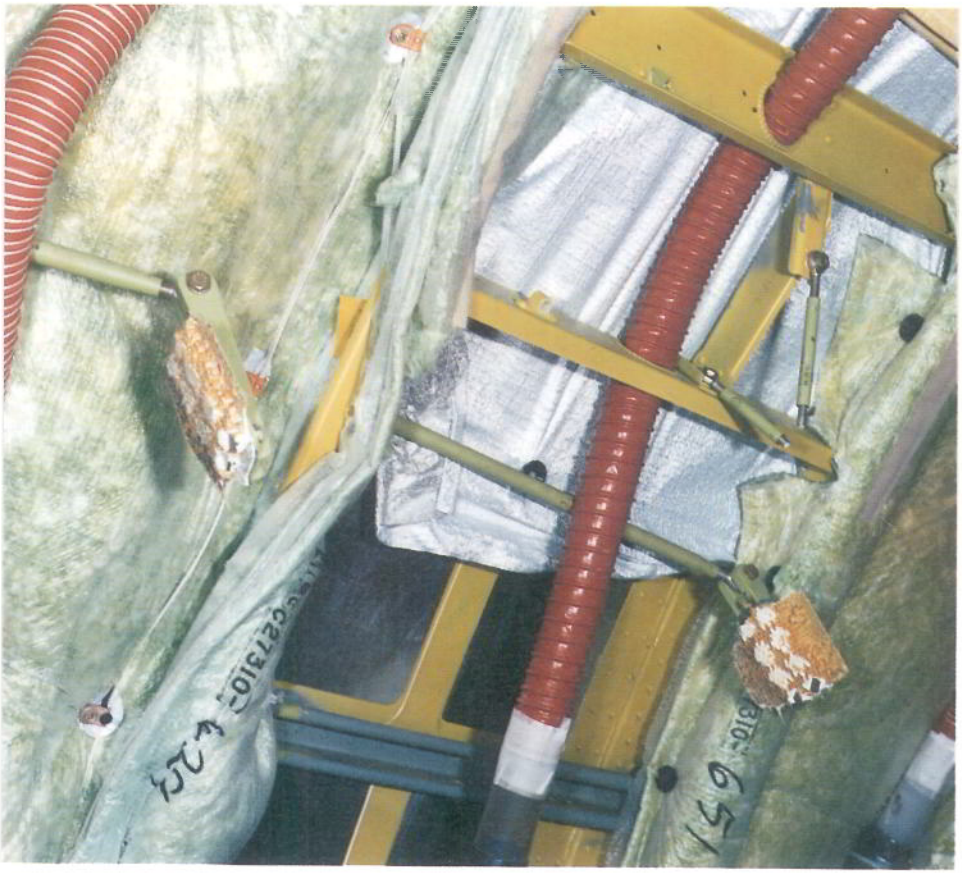


Appendix 3, figure 18 - Seat track and seat 5R (area I)

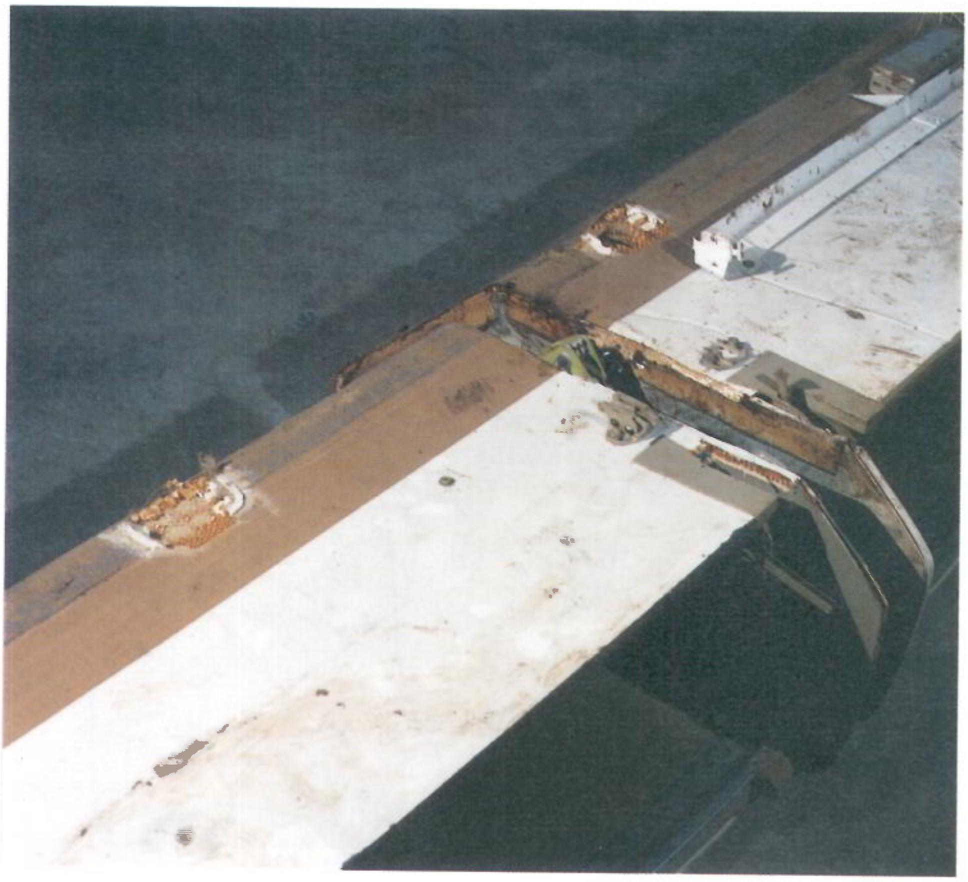


Appendix 3, figure 19 - Seat track and seat 3L (area I)

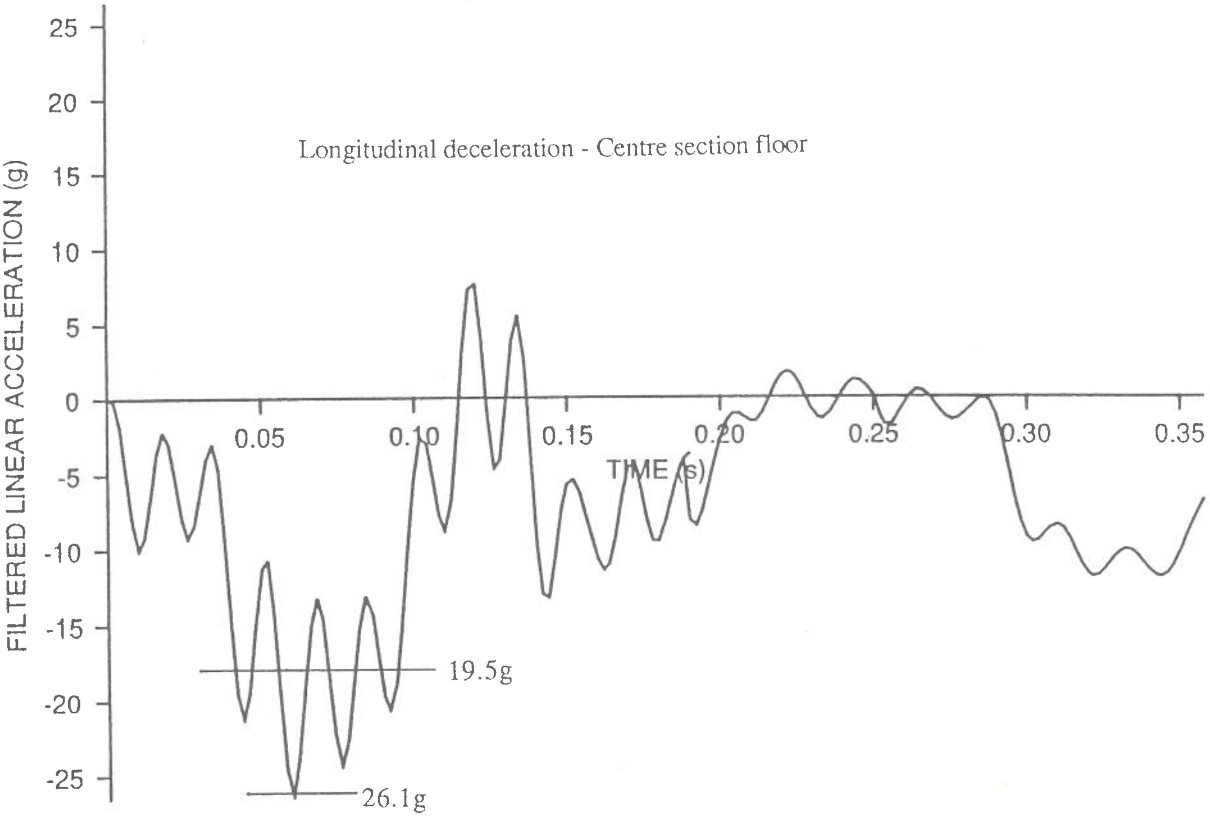
Appendix 3, figure 20 - Floor beam at station 460 (area I)



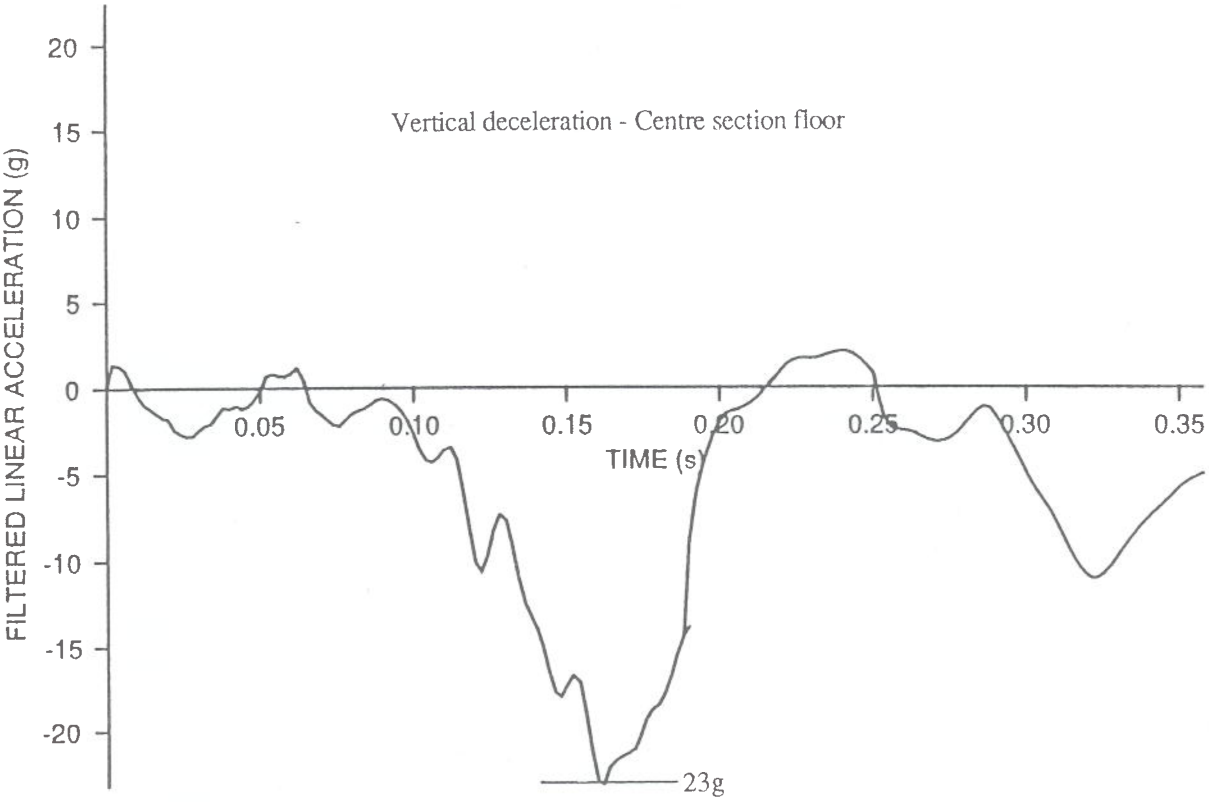
Appendix 3, figure 21 (a) - Stowage bin attachments



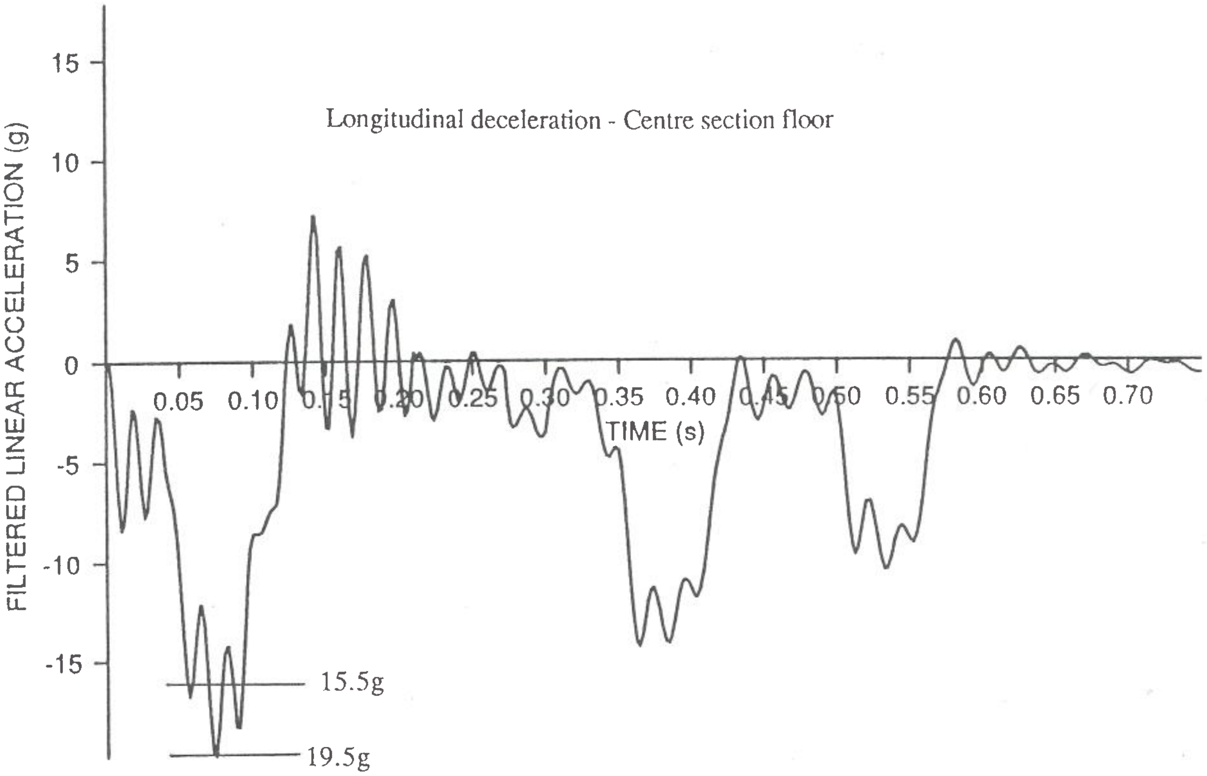
Appendix 3, figure 21 (b) - Stowage bins



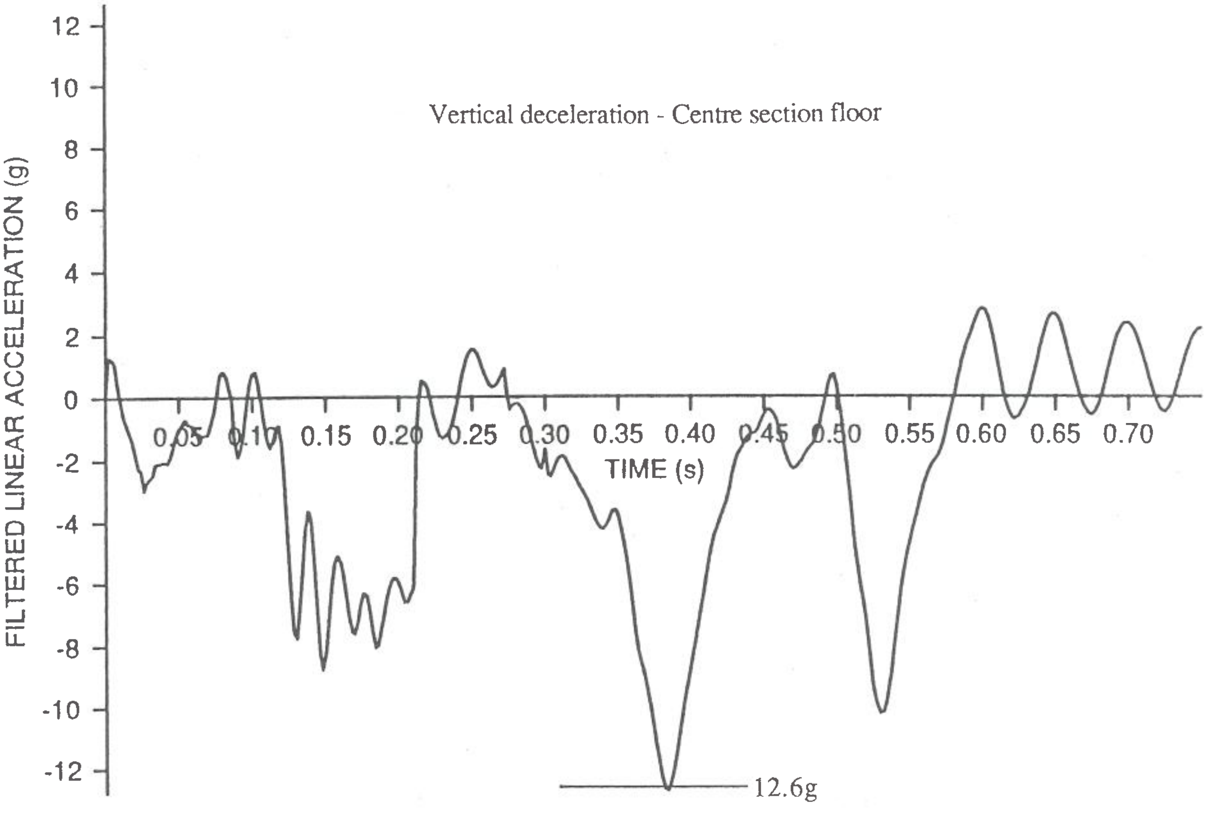
Appendix 3, figure 22 (a) - KRASH longitudinal deceleration - Run 2



Appendix 3, figure 22 (b) - KRASH vertical deceleration - Run 2



Appendix 3, figure 23 (a) - KRASH longitudinal deceleration - Run 3

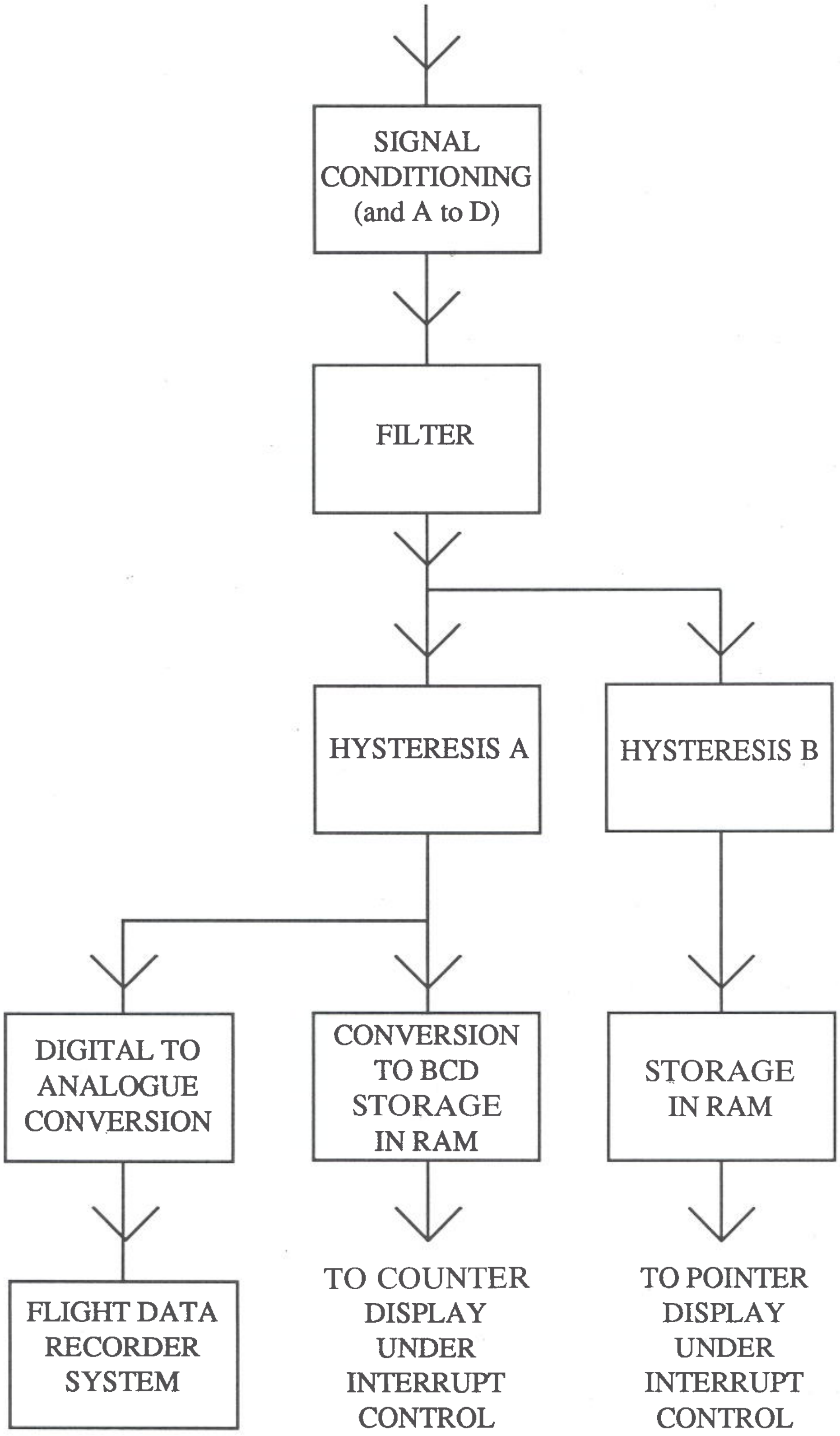


Appendix 3, figure 23 (b) - KRASH vertical deceleration - Run 3

No.	Date	Location	Type	Operator	Registration	Report	Comments
1)	11 Sept 1974	Charlotte, NC	DC9-31	Eastern	N8984E	AAR-75-9	82 SOB, 71 F
2)	27 Apr 1976	St. Thomas, VI	B727-95	American	N1963	AAR-77-1	89 SOB, 37 F
3)	16 Nov 1976	Denver, CO	DC9-41	Texas Int	N9104	AAR-77-10	86 SOB, 0 F
4)	14 Apr 1977	New Hope, GA	DC9-31	Southern	N1335U	AAR-78-3	85 SOB, 62 F
5)	25 Oct 1986	Charlotte, NC	B727-222	Piedmont	N752N	AAR-87-08	119 SOB, 0 F
6)	28 Dec 1978	Portland, OR	DC8-61	United	N8082U	AAR-79-7	189 SOB, 10 F (inc. 3 infants)
7)	31 Aug 1988	Dallas, TX	B727-232	Delta	N473DA	AAR-89-04	108 SOB, 14 F
8)	27 Dec 1973	Chattanooga, TN	DC9-32	Delta	N3323L	AAR-74-13	79 SOB, 0 F
9)	20 Dec 1972	Chicago, Il	CV880/DC9	Delta/N. Cent	N8807E/N954N	AAR-73-15	45 SOB, 10 F
10)	7 Aug 1975	Denver, CO	B727-224	Continental	N88777	AAR-76-14	134 SOB, 0 F
11)	24 Jun 1975	JFK, NY	B727-225	Eastern	N8845E	AAR-76-8	124 SOB, 112 F
12)	18 May 1972	Fort Lauderdale, FL	DC9-31	Eastern	N8961E	AAR-72-31	10 SOB, 0 F
13)	26 June 1978	Toronto, Ontario	DC9-32	Air Canada	CF-TLV	H80002	107 SOB, 2F

Appendix 3, figure 24 - Sample of North American jet transport accidents (paragraph 1.17.17)

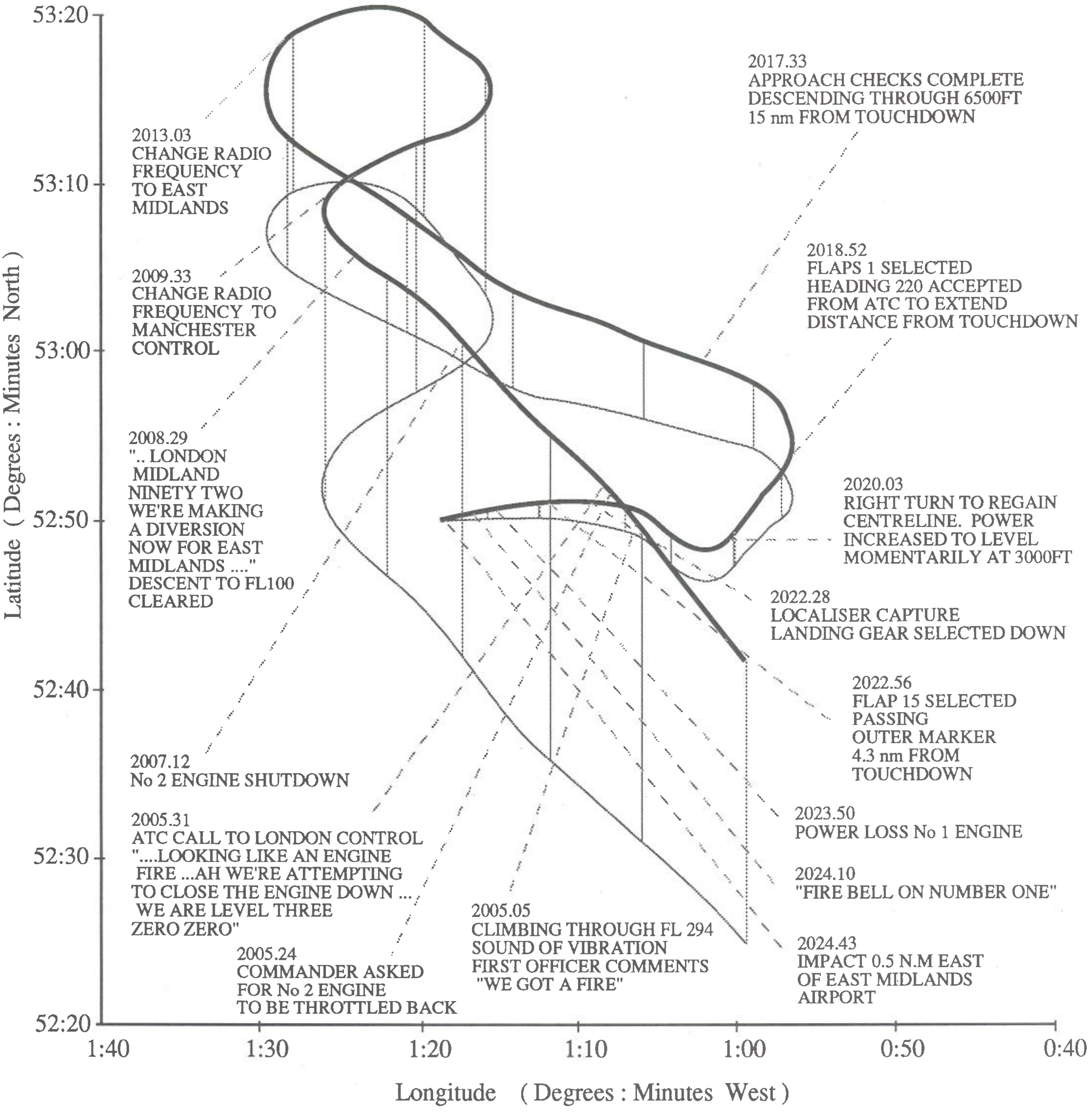
APPENDIX 4, FIGURE 1



SIMPLIFIED BLOCK DIAGRAM OF EIS SIGNAL PATH

APPENDIX 4, fig 2

G-OBME TRACK PLOT



2013.03
CHANGE RADIO
FREQUENCY
TO EAST
MIDLANDS

2009.33
CHANGE RADIO
FREQUENCY TO
MANCHESTER
CONTROL

2008.29
".. LONDON
MIDLAND
NINETY TWO
WE'RE MAKING
A DIVERSION
NOW FOR EAST
MIDLANDS ...."
DESCENT TO FL100
CLEARED

2007.12
No 2 ENGINE SHUTDOWN

2005.31
ATC CALL TO LONDON CONTROL
"....LOOKING LIKE AN ENGINE
FIRE ...AH WE'RE ATTEMPTING
TO CLOSE THE ENGINE DOWN ....
WE ARE LEVEL THREE
ZERO ZERO"

2005.24
COMMANDER ASKED
FOR No 2 ENGINE
TO BE THROTTLED BACK

2005.05
CLIMBING THROUGH FL 294
SOUND OF VIBRATION
FIRST OFFICER COMMENTS
"WE GOT A FIRE"

2017.33
APPROACH CHECKS COMPLETE
DESCENDING THROUGH 6500FT
15 nm FROM TOUCHDOWN

2018.52
FLAPS 1 SELECTED
HEADING 220 ACCEPTED
FROM ATC TO EXTEND
DISTANCE FROM TOUCHDOWN

2020.03
RIGHT TURN TO REGAIN
CENTRELINE. POWER
INCREASED TO LEVEL
MOMENTARILY AT 3000FT

2022.28
LOCALISER CAPTURE
LANDING GEAR SELECTED DOWN

2022.56
FLAP 15 SELECTED
PASSING
OUTER MARKER
4.3 nm FROM
TOUCHDOWN

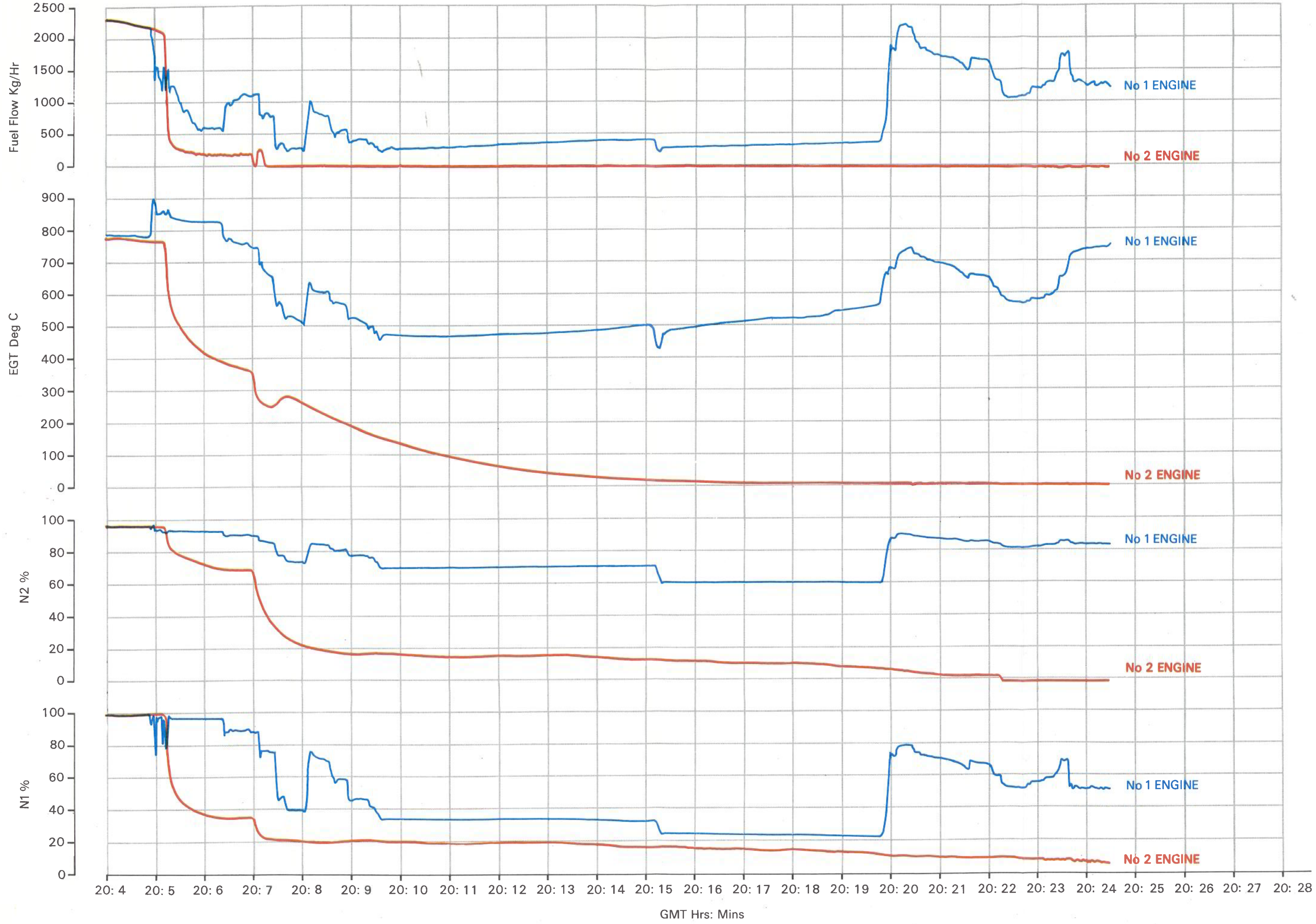
2023.50
POWER LOSS No 1 ENGINE

2024.10
"FIRE BELL ON NUMBER ONE"

2024.43
IMPACT 0.5 N.M EAST
OF EAST MIDLANDS
AIRPORT

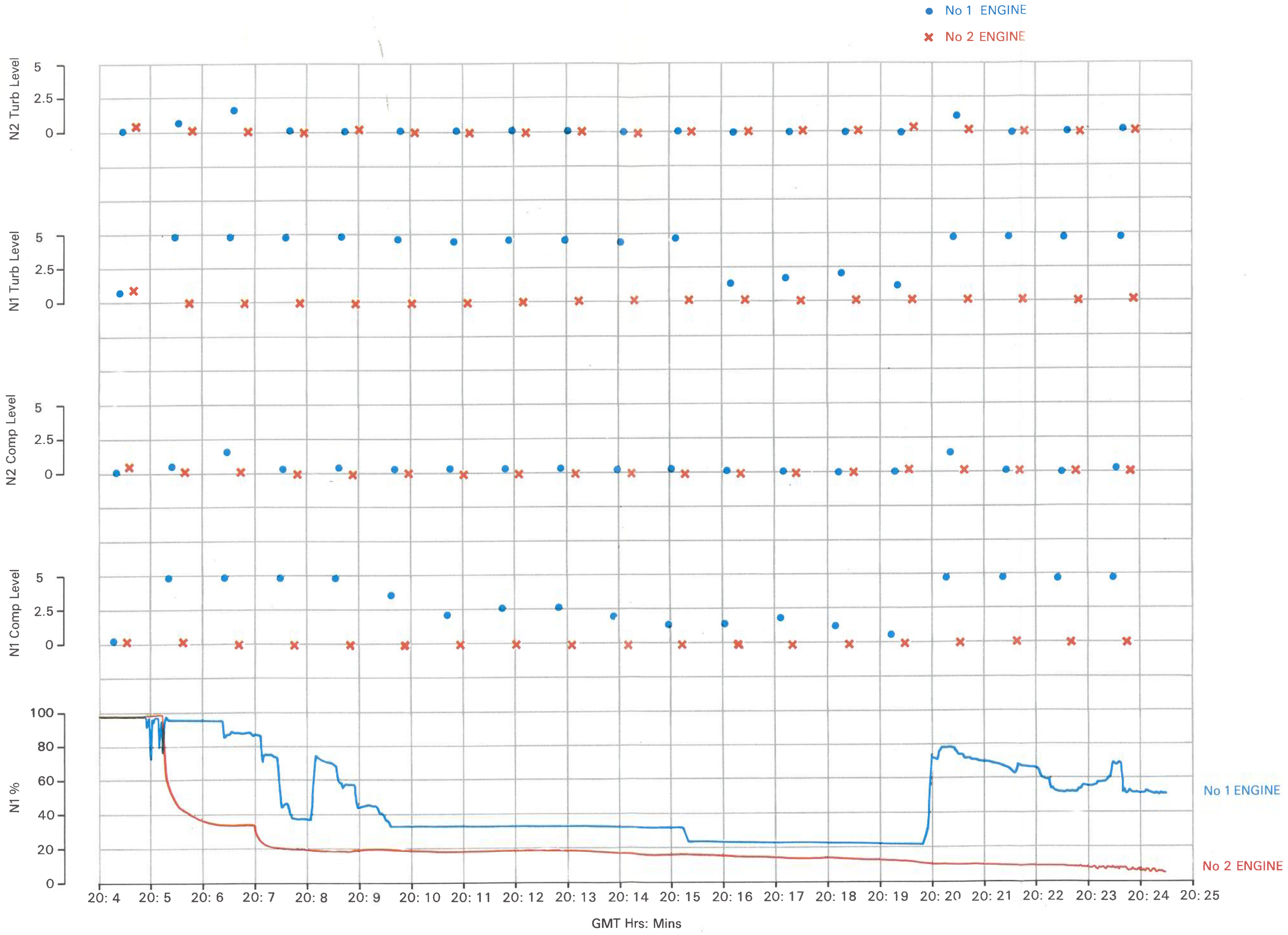
APPENDIX 4 FIGURE 3

G–OBME ENGINE PARAMETERS FROM FLIGHT DATA RECORDER

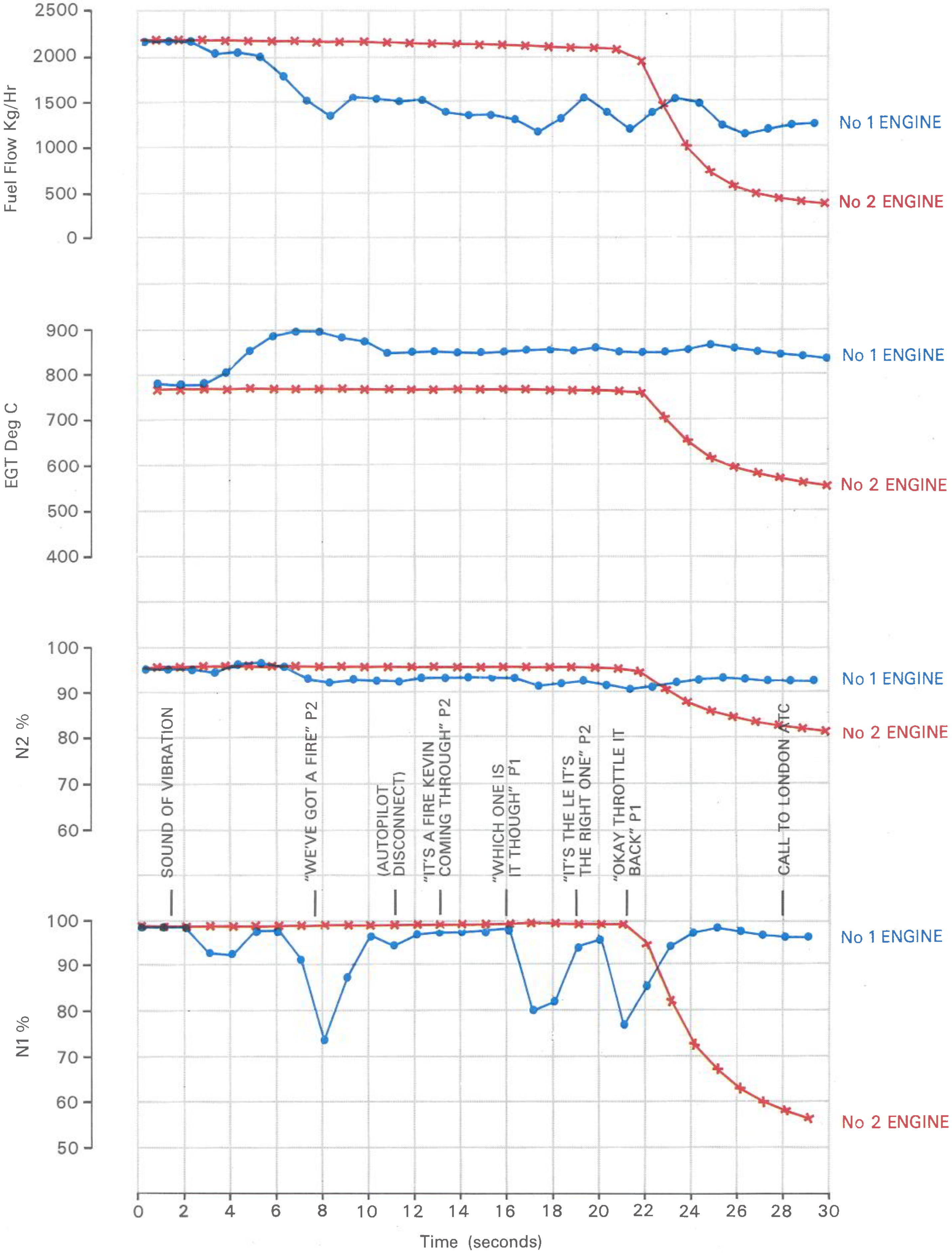


APPENDIX 4 FIGURE 4

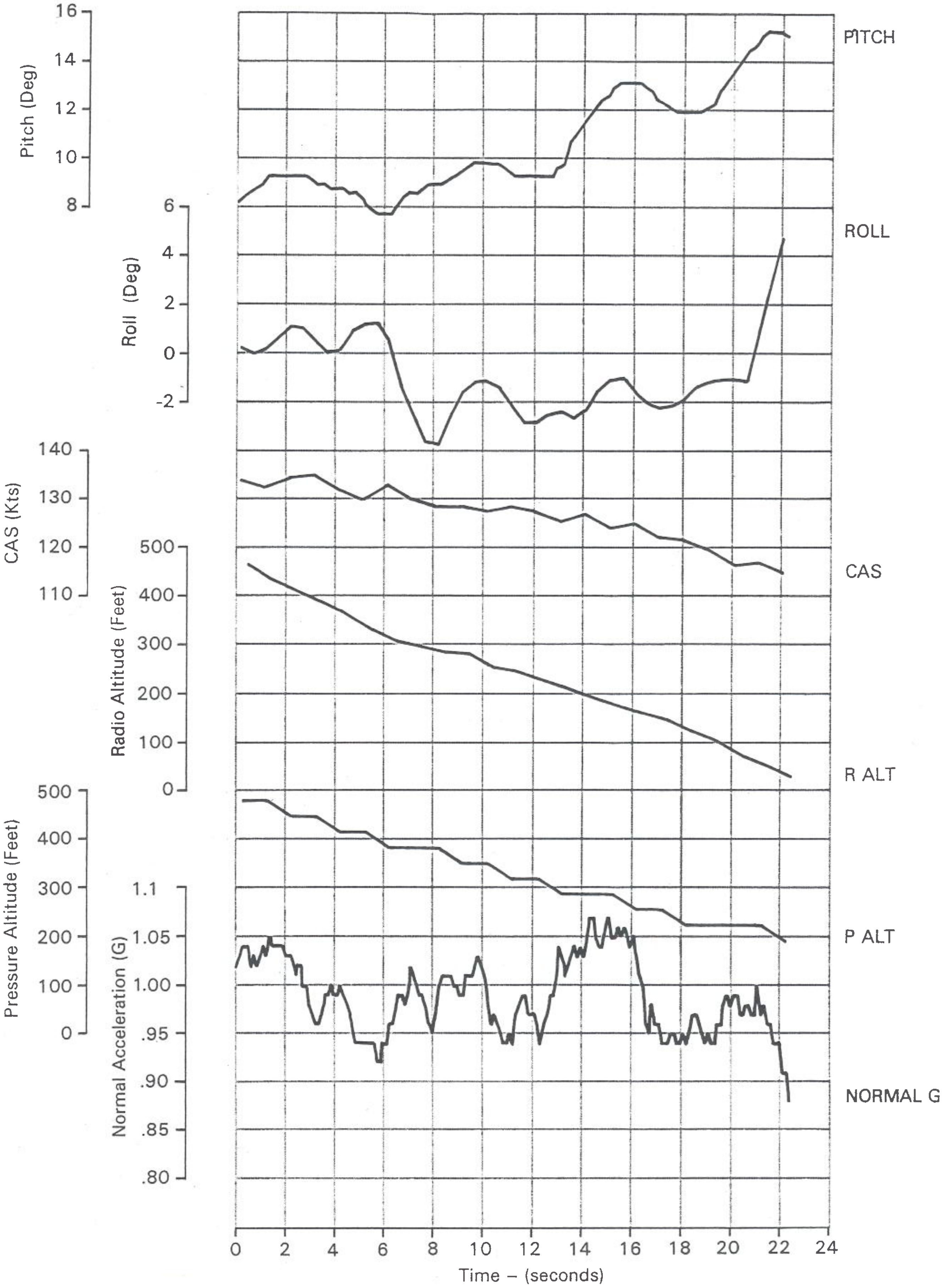
G–OBME VIBRATION LEVELS



G–OBME PRIMARY ENGINE PARAMETERS AT EVENT 1

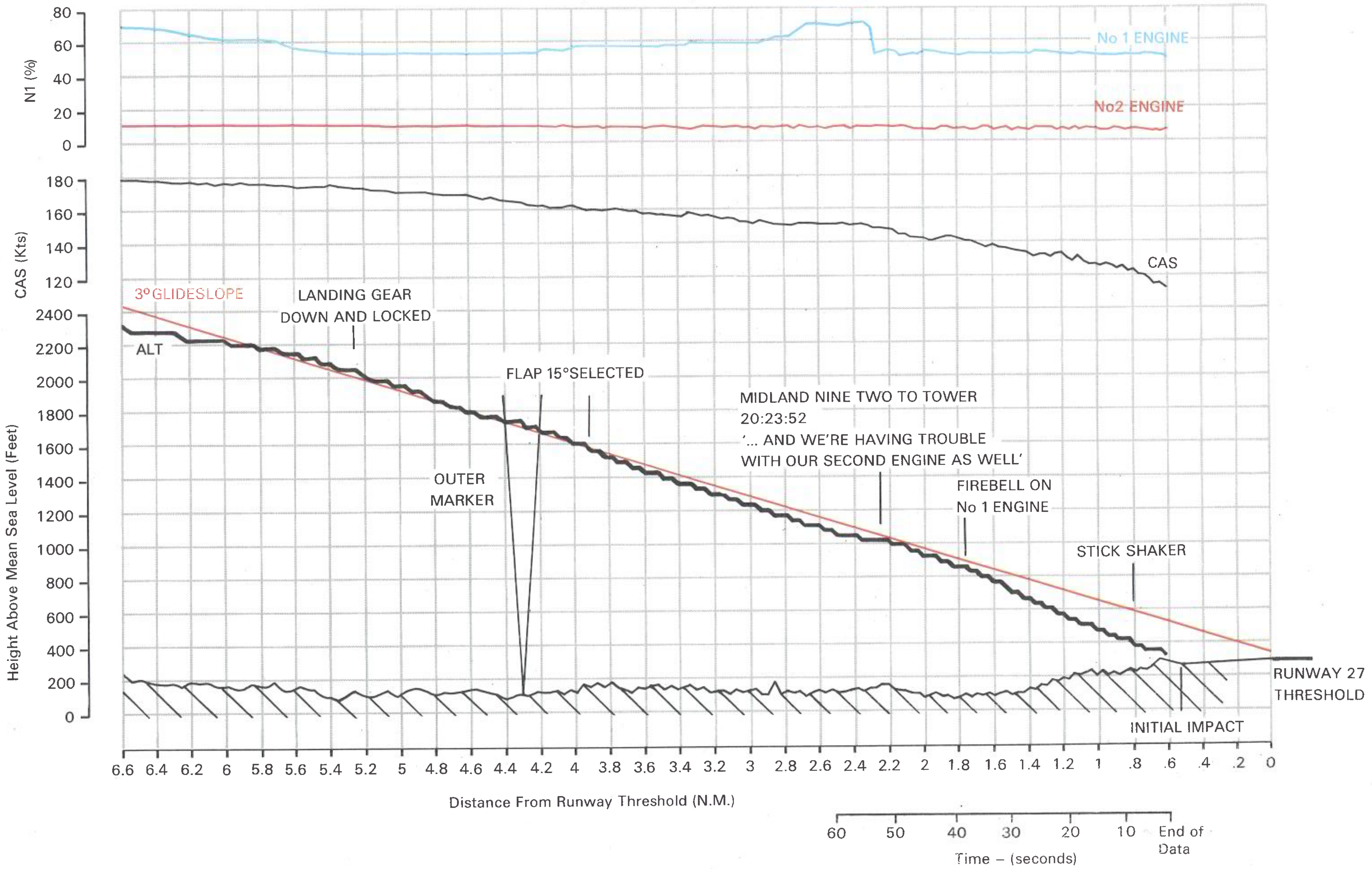


G–OBME FINAL DATA FROM FLIGHT RECORDER



APPENDIX 4 FIGURE 7

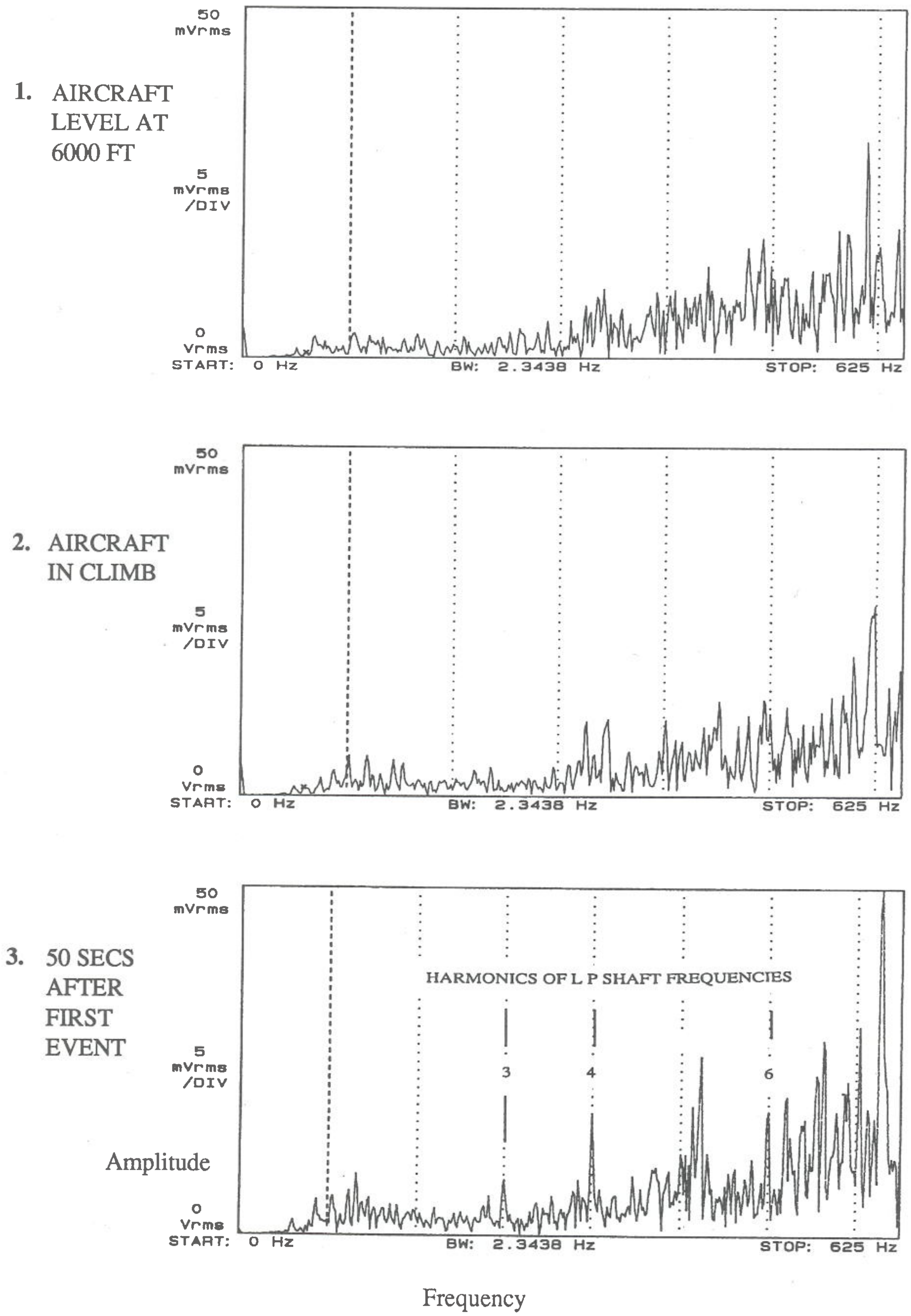
G–OBME FINAL FLIGHT PATH



APPENDIX 4, Fig 8

COMPARISON OF SIGNATURES BEFORE AND AFTER FIRST EVENT

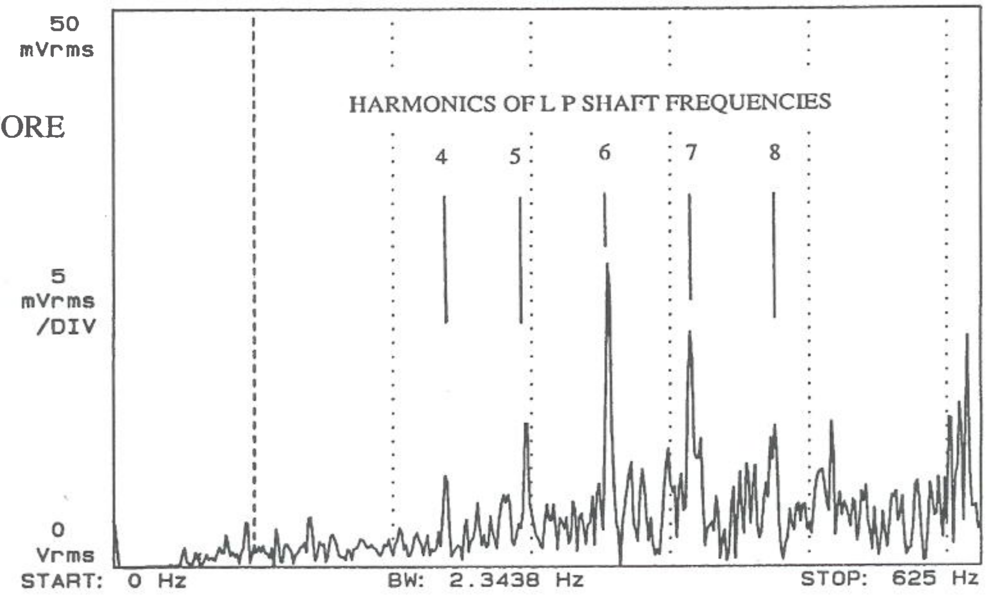
(FROM CVR AREA MIC)



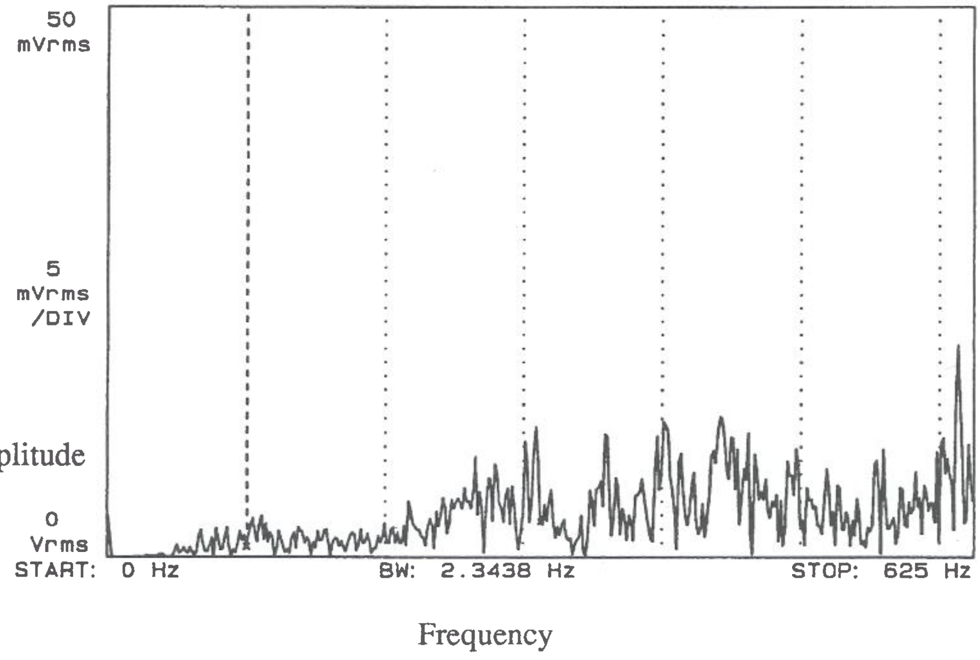
APPENDIX 4, Fig 9

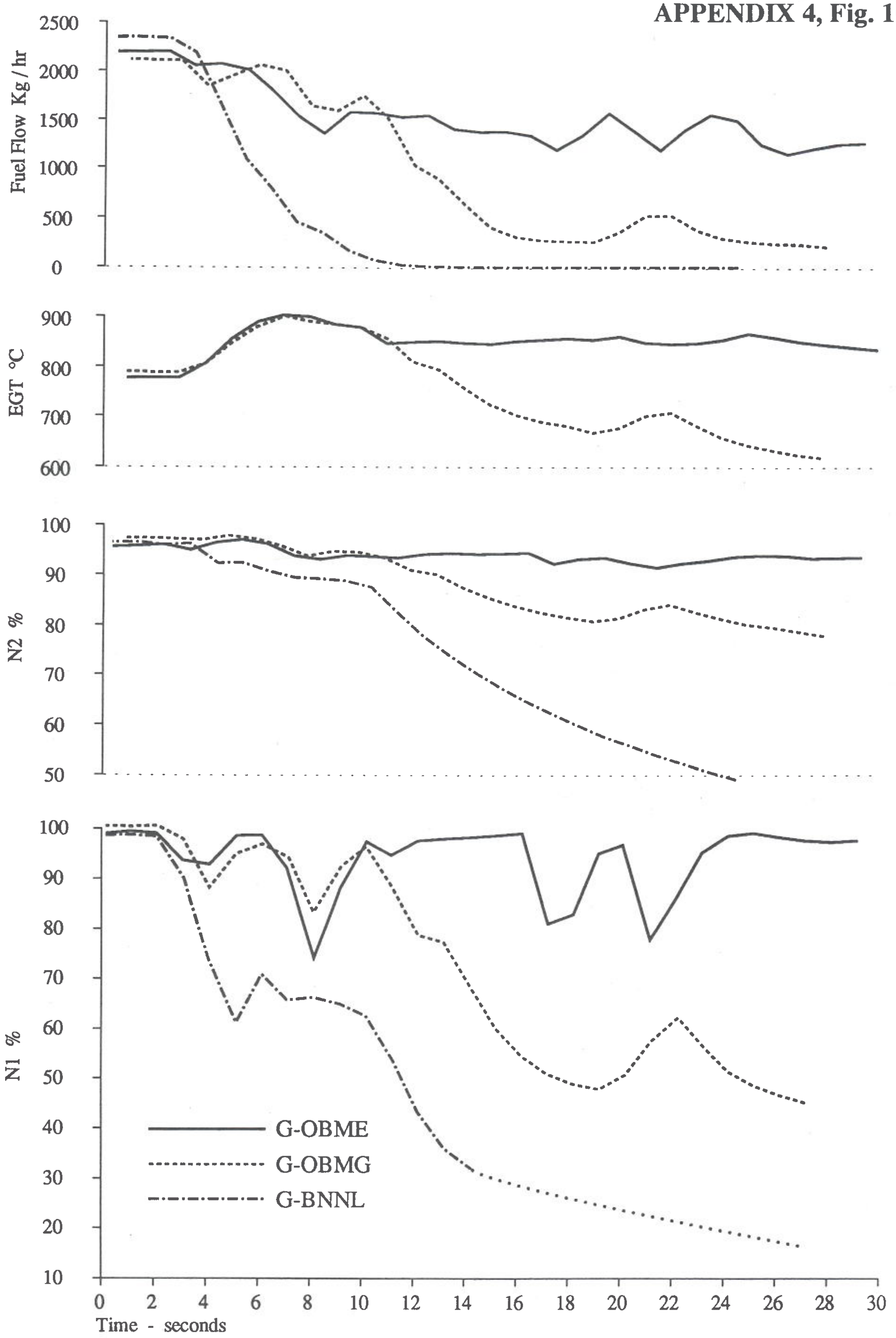
COMPARISON OF SIGNATURES BEFORE AND AFTER SECOND EVENT
(FROM CVR AREA MIC)

4. JUST BEFORE SECOND EVENT

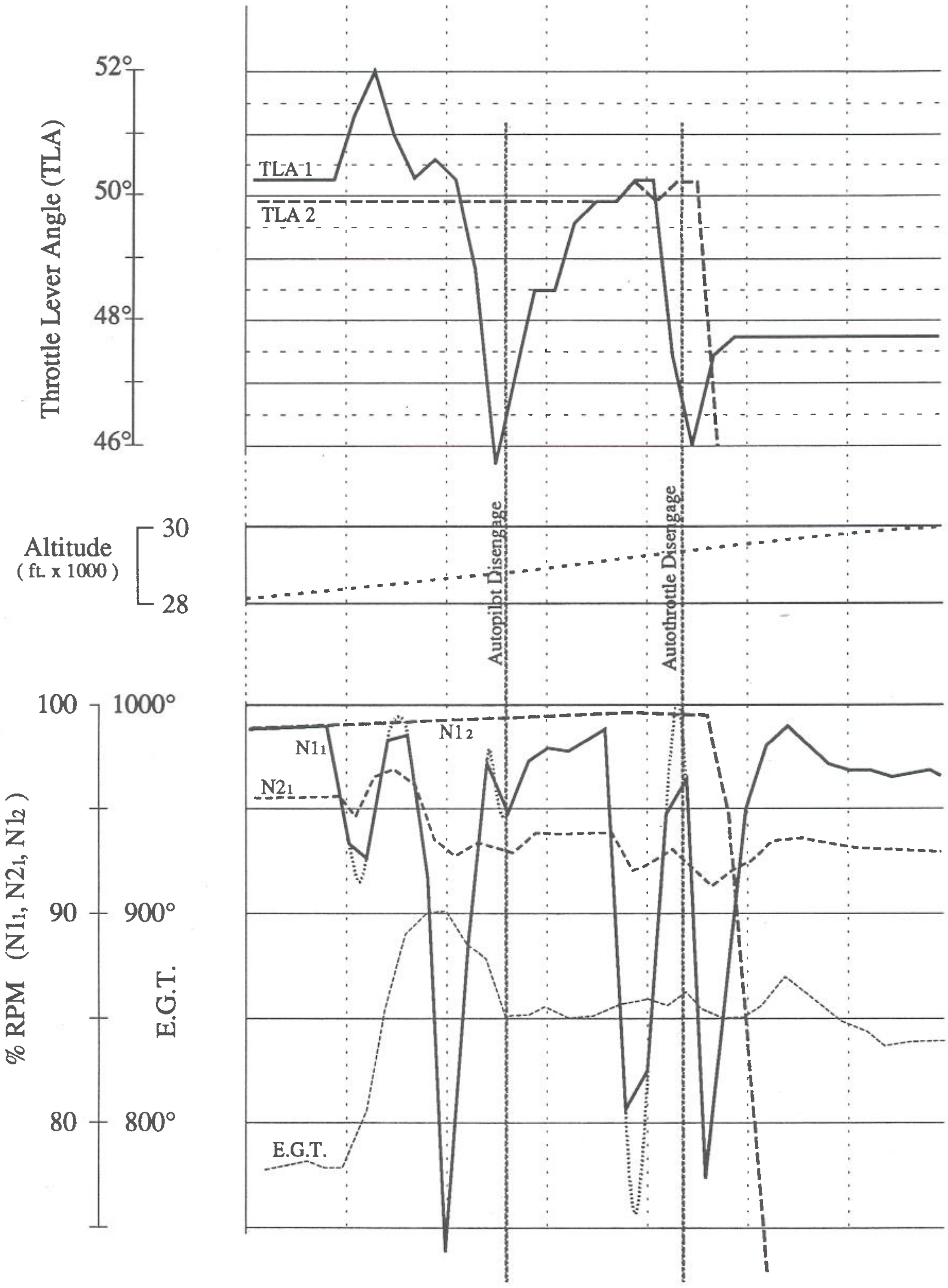


5. SECOND EVENT

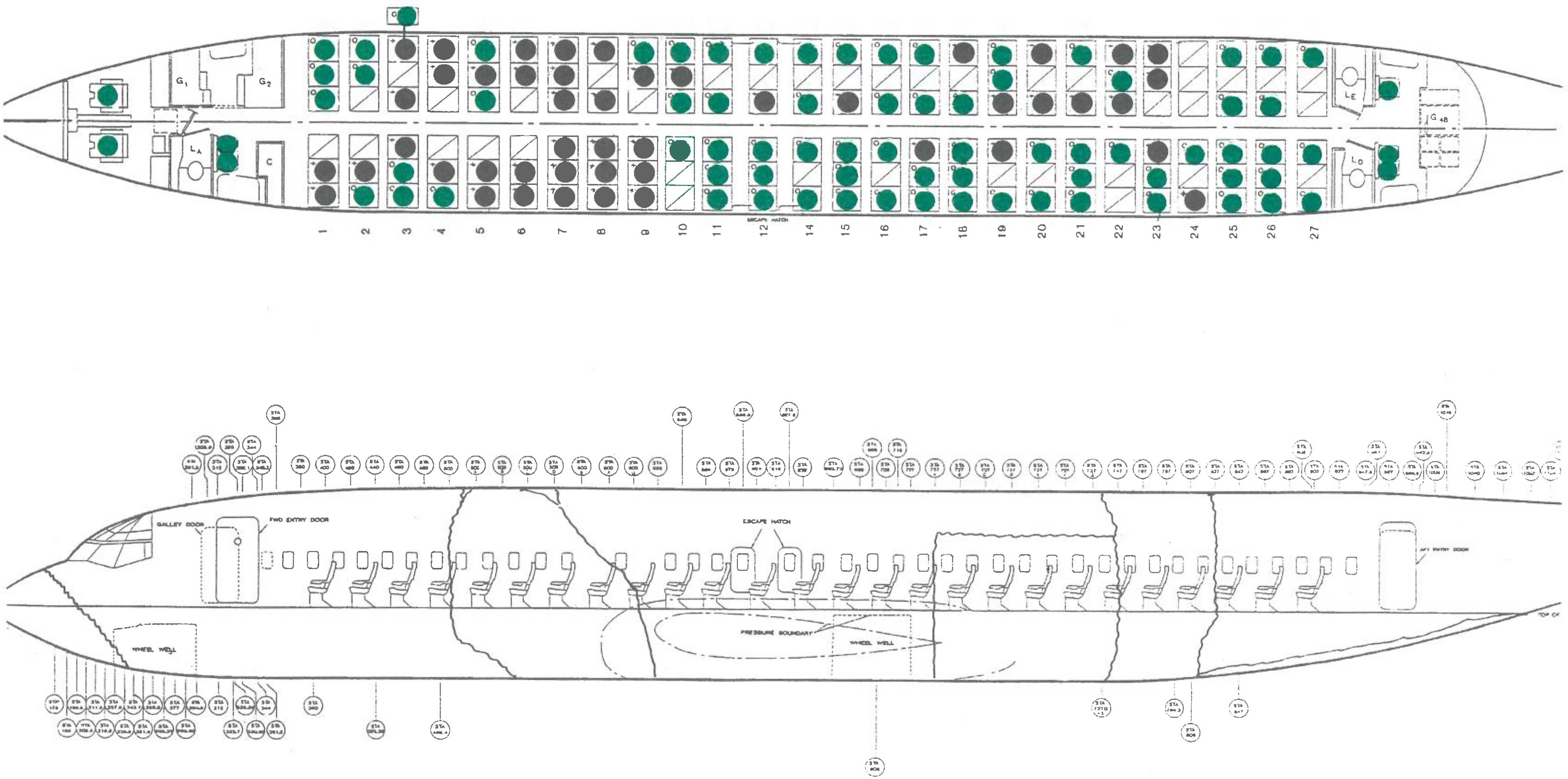




Comparison of engine parameter response following fan blade outer panel separation on three aircraft (G-OBME, G-OBMG, G-BNNL)



Variation of Throttle Lever Angle
related to engine parameters and altitude during Event 1



KEY:

- ● FATALITY
- ● SURVIVOR
- ▨ UNOCCUPIED SEAT

FIG 1: SHOWING SEAT POSITIONS OF FATALITIES AND SURVIVORS

BMA BOEING 737 – 400 G – OBME

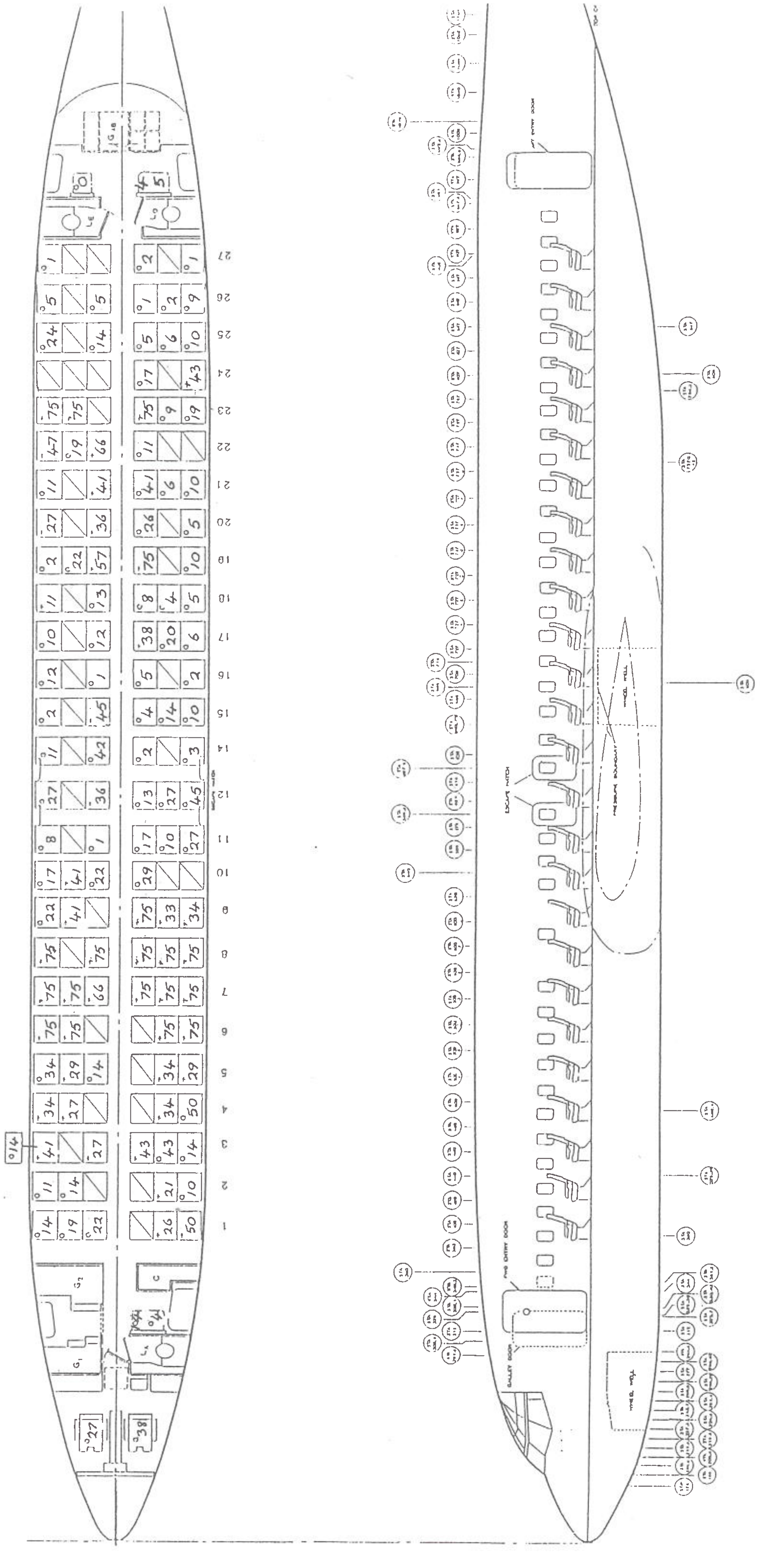
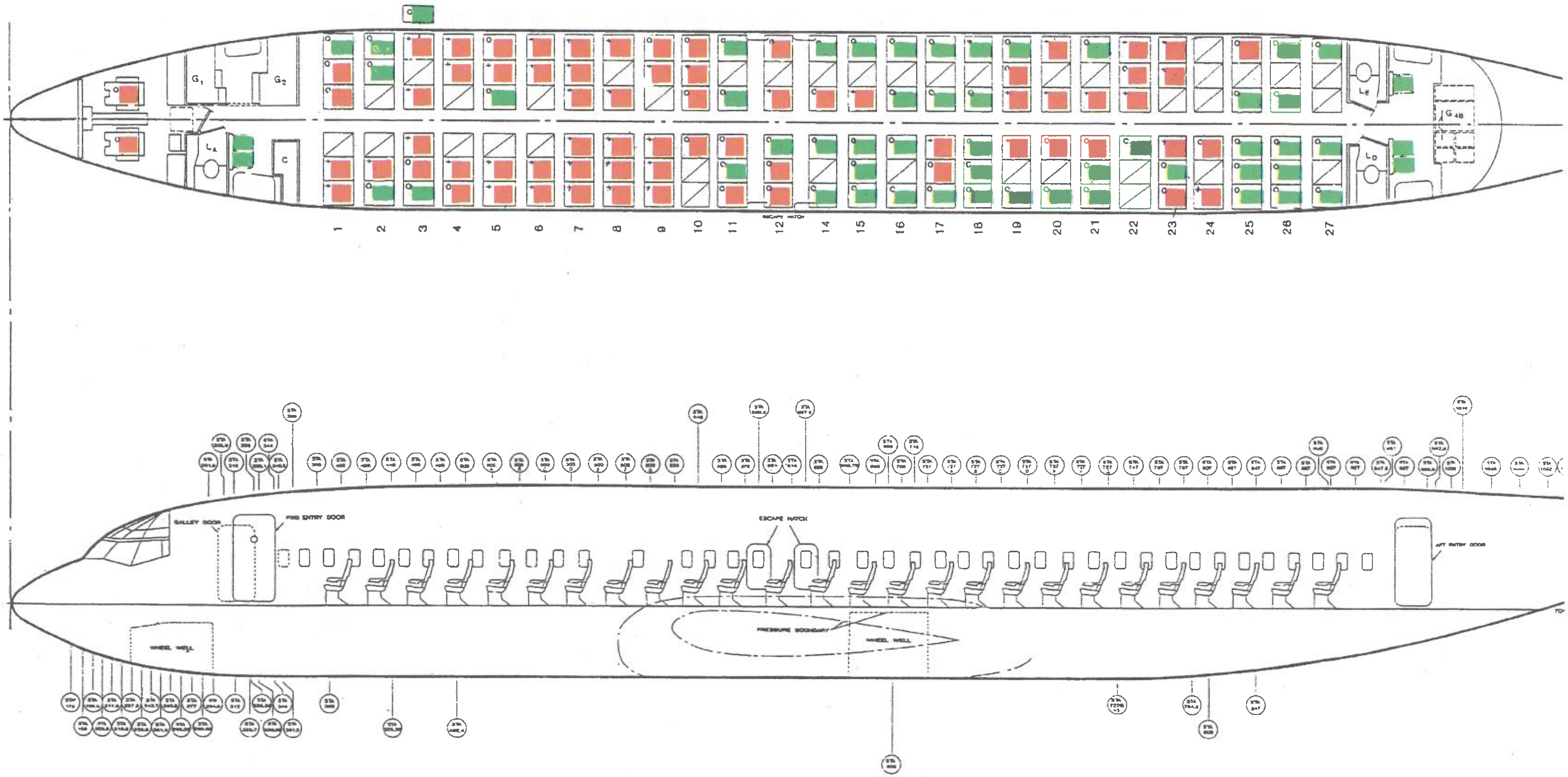


FIG 2: SHOWING INJURY SEVERITY SCORES FOR OCCUPANTS

BMA BOEING 737 - 400 G - OBME



KEY:

🟥 L.S.S.>16

🟩 L.S.S.<16

▨ UNOCCUPIED SEAT

FIG 3: SHOWING DISTRIBUTION OF INJURY SEVERITY

BMA BOEING 737 - 400 G - OBME

APPENDIX 5

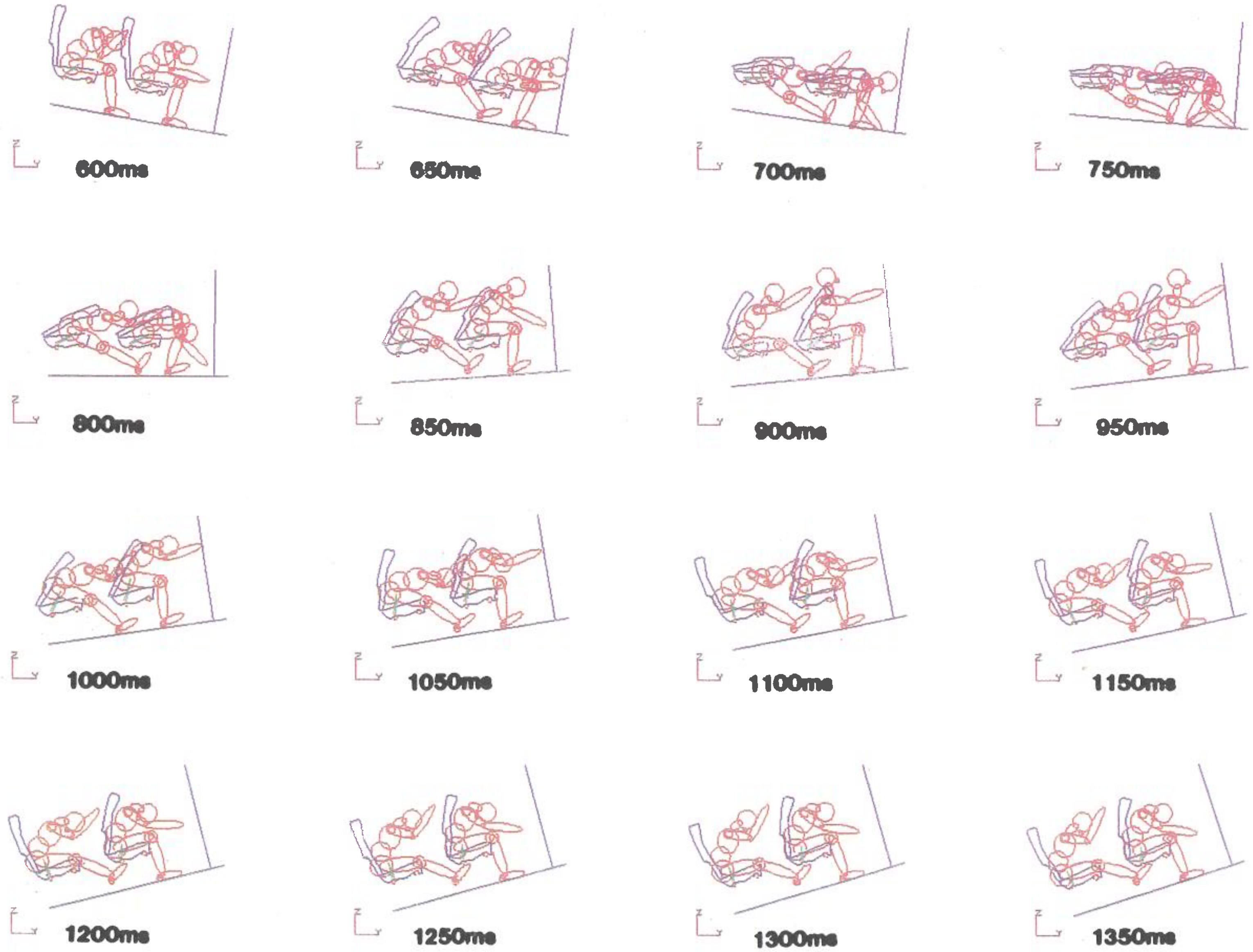


FIG 4: SHOWING COMPUTER SIMULATION OF IMPACT INDUCED OCCUPANT DISPLACEMENT, WITH LAP BELT RESTRAINT

APPENDIX 5

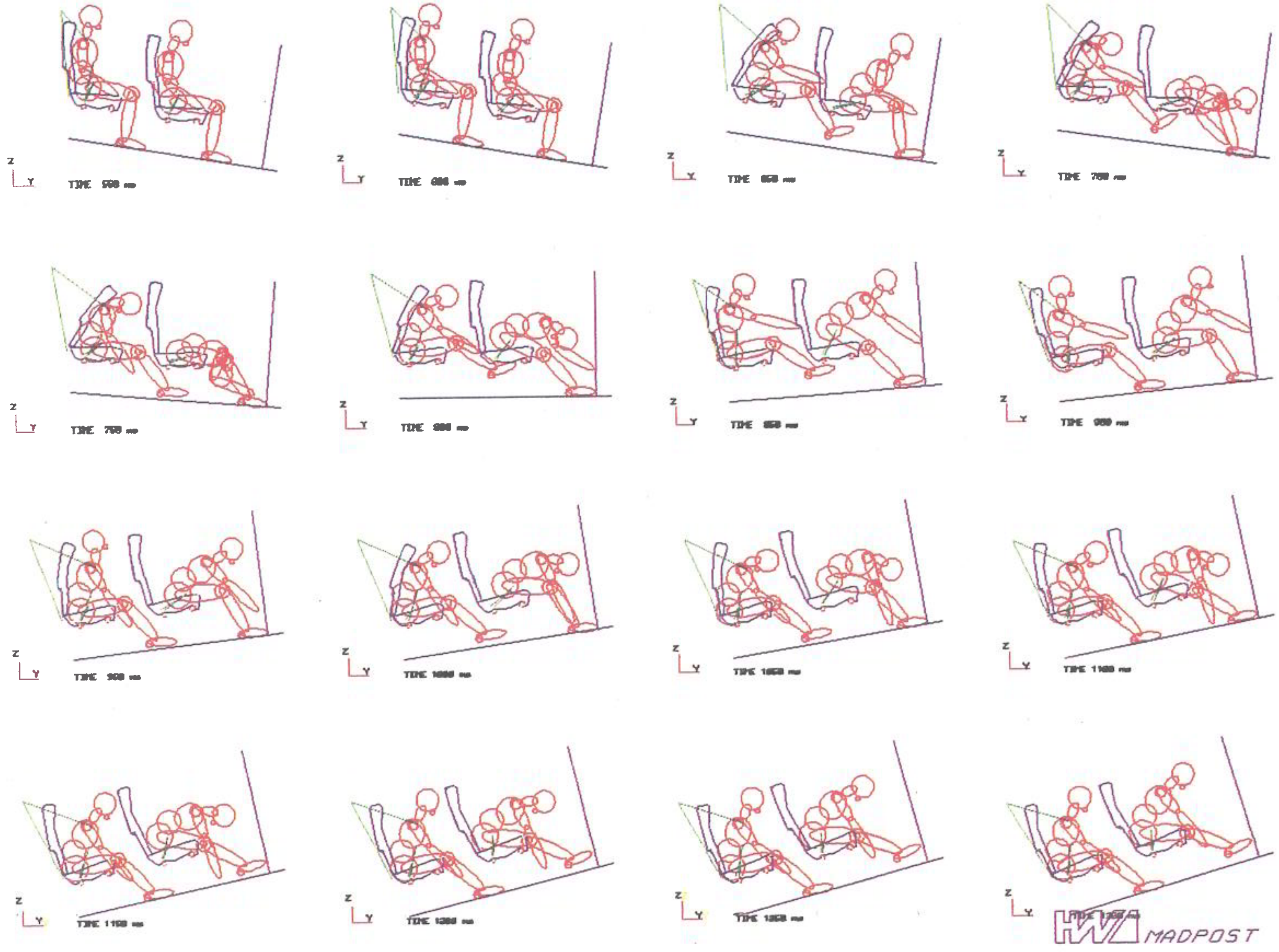


FIG 5: SHOWING COMPUTER SIMULATION OF IMPACT INDUCED OCCUPANT DISPLACEMENT, WITH LAP BELT AND UPPER TORSO RESTRAINT OF REAR OCCUPANT

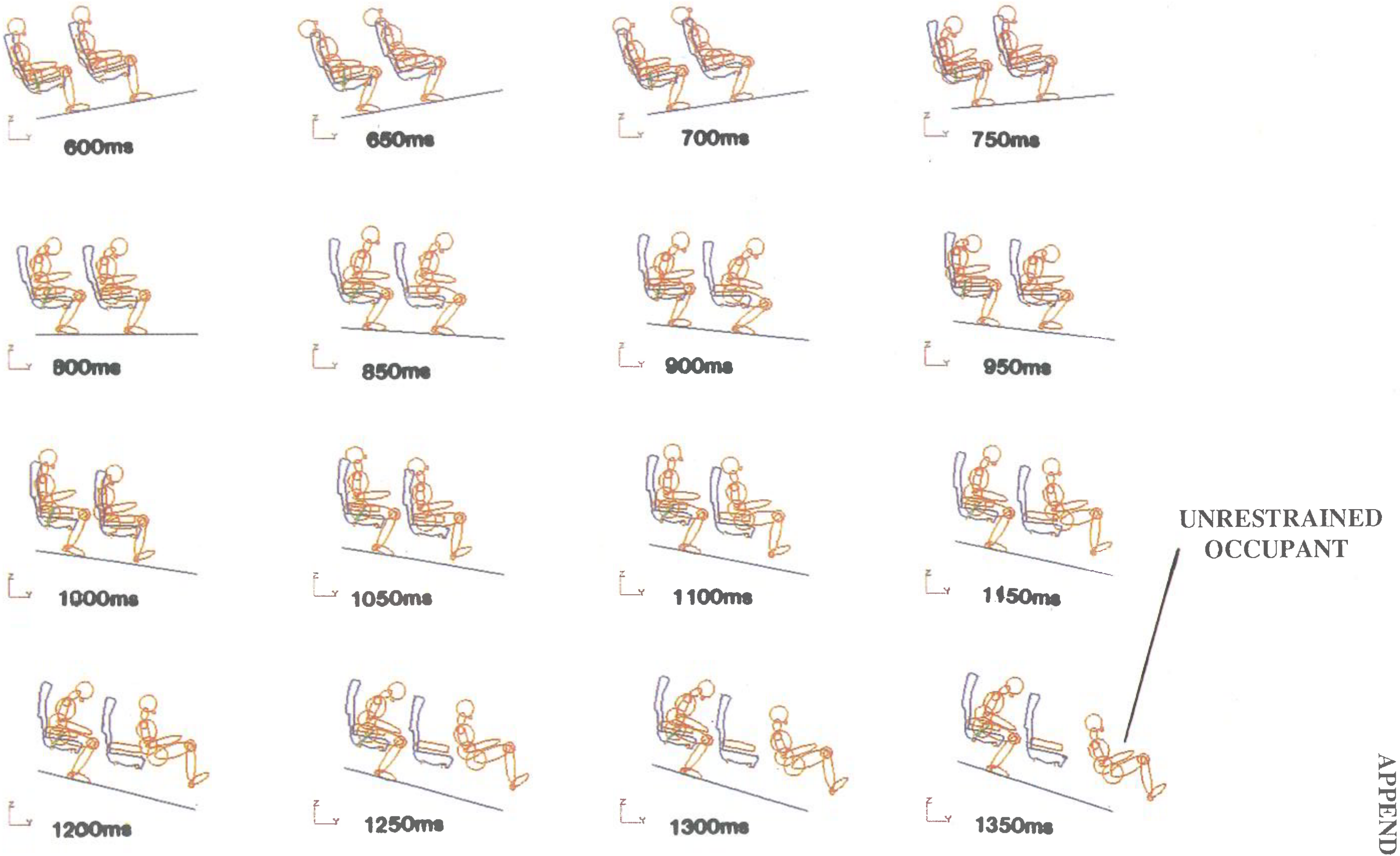


FIG 6: SHOWING COMPUTER SIMULATION OF IMPACT INDUCED OCCUPANT DISPLACEMENT, WITH AFT-FACING SEAT (STANDARD SEAT)

Appendix 5.7

REFERENCES

1) Trent Regional Health Authority. "Aircraft Accident BD092, M1 Motorway/East Midlands Airport. Sunday 8th January 1989". Emergency Planning Ref JAC/C17/24.

2) Kirsh, G., Rowles, J.M. & Macey, A.C. Personal communication. NLDB Study Group. University Hospital Nottingham.

3) American Association for Automotive Medicine: The Abbreviated Injury Severity Score. 1985 revision. AAAM, 1985.

4) Baker, S.P., O'Neill, B., Haddon, W., Long, W.B. "The Injury Severity Score: A Method for Describing Patients with Multiple Injuries and Evaluating Emergency Care." J Trauma 1974, 14,3: 187.

5) White, D.B., Mumford, C., Rowles, J.M. & Firth, J.L., "Head Injuries in Survivors of the M1 Aircrash." Personal Communication. NLDB Study Group, University of Nottingham.

6) H.W. Structures Ltd. 1989. H.W. Structures Ltd, Leamington Spa, Warwickshire.

Air Accidents Investigation Branch
Department of Transport
Royal Aerospace Establishment
Farnborough
Hants GU14 6TD
Tel: 0252-510300

Air Accidents
Investigation
Branch

APPENDIX 6

THE DEPARTMENT
OF TRANSPORT

AAIB Bulletin
SPECIAL

S2/89

ACCIDENT TO BOEING 737-400 G-OBME AT KEGWORTH, LEICESTERSHIRE ON 8 JANUARY 1989

This bulletin contains a statement of the facts which have been determined up to the time of issue. It is published under Regulation 6 of the Civil Aviation (Investigation of Accidents) Regulations 1983 to inform the aviation industry and the public of the general circumstances of the accident. It must necessarily be regarded as tentative, and subject to alteration or correction if additional evidence becomes available. The bulletin is not an accident report - either final or interim.

On the 8 January the Chief Inspector of Accidents appointed Mr E J Trimble, a Principal Inspector of Accidents, to carry out an "Inspector's Investigation" in accordance with the regulations. Much work remains to be done before his report can be compiled. Following this he, as the Inspector, must invite and consider representations on the draft report from the parties involved (in accordance with Regulation 11) before it is completed for submission to the Secretary of State for Transport. Unless one of these parties asks for a Review Board (under Regulation 12) the report will then be published.

Thus nothing in this bulletin is to be taken as a final statement of the facts and circumstances of the accident, nor would it be right to draw any conclusions from it as to the cause(s) of the accident.

This bulletin can be reproduced without specific permission providing that the source is acknowledged.

ISSN 0309-4278

Aircraft Type and Registration:	Boeing 737-400, G-OBME	
No & Type of Engines:	2 CFM 56-3C high by-pass turbo-fan engines	
Year of Manufacture:	1988	
Date and Time (UTC):	8 January 1989 at 2025 hrs	
Location:	Kegworth, near East Midlands Airport, Leicestershire	
Type of Flight:	Scheduled passenger	
Persons on Board:	Crew - 8	Passengers - 117 + 1 infant
Injuries:	Crew - 7 (serious) 1 (minor)	Passengers - 47 (fatal). 66 + 1 infant (serious) 4 (minor)
Nature of Damage:	Aircraft destroyed	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	43 years	
Commander's Total Flying Experience:	13180 hours (of which 765 were on Boeing 737-300/400 types)	
Information Source:	AAIB Inspector's Investigation under the Civil Aviation (Investigation of Accidents) Regulations 1983	

History of the Flight

The aircraft was engaged on a double shuttle between London Heathrow and Belfast. It landed at Heathrow at 1845 hrs after completing the first shuttle flight and took off again for Belfast at 1952 hrs with the first officer handling the aircraft. After take-off, the aircraft climbed initially to flight level (FL) 60, where it levelled off above a layer of stratocumulus cloud for two minutes, before receiving clearance to climb to FL 120. Soon afterwards, at 1958 hrs, clearance was passed for the aircraft to continue its climb to its cruising FL of 350 on a direct track to the Trent VOR (Very high frequency Omni-Range beacon).

At 2005.05 hrs, as the aircraft was approaching FL 290, the flight crew experienced moderate to severe vibration, a burning smell and smoke. The commander immediately took control of the aircraft, disengaging both the auto-pilot and the automatic throttle. The two pilots then diagnosed the symptoms of vibration and smoke as indicating a problem in the right engine and 20 seconds after the onset of the vibration, the commander instructed the first officer to throttle back the right engine. The commander later stated that the action of closing the right throttle reduced the smell and signs of smoke and that he remembered no continuation of the vibration after the right throttle was closed.

Immediately after throttling back the right engine, the first officer advised London Air Traffic Control (ATC) that the aircraft was at FL 300 and that they had an emergency situation which looked like an engine fire. When this message had been passed, the commander ordered the first officer to shut-down the engine; the flight crew were then engaged in ATC radio transmissions, stating their intention to divert to Castle Donington (East Midlands Airport). During this period a female cabin attendant used the cabin address system to advise the passengers to fasten their seat belts. The right engine was shut down 2 minutes and 7 seconds after the vibration began. By that time power had been reduced on the left engine, which continued to operate at comparatively low power. After the accident, the commander stated that during the remainder of the descent the indications from the engine instruments were such as to confirm that the emergency had been successfully concluded and that the left engine was operating normally. The recorded engine parameters associated with this stage of the flight are included in the section on "FDR and CVR evidence".

In the cabin, the passengers and the cabin attendants had heard an unusual noise accompanied by moderate to severe vibration. Some passengers had also been aware of what they described as smoke, but none were able to describe its colour or density. They described the smell of burning as "rubber", "oil" and "hot metal". Many had seen signs of fire from the left engine, which they described variously as "fire", "torching" or "sparks". Several of the cabin attendants described the noise as a low, repetitive "thudding", and one described how the vibration had been severe enough to shake the walls of the forward galley. Soon after the right engine had been shut-down, and in response to a cabin "chime" from the commander, the flight service manager (FSM) came to the flight deck. The commander asked him if they had had smoke in the cabin. He replied that they had. Later, after another statement from the FSM that the passengers were becoming concerned, the commander broadcast on the cabin address system that there was trouble with the right engine which had produced some smoke in the cabin, that the engine was now shut-down and that they could expect to land at East Midlands Airport in about 10 minutes. Passengers stated that the smell of smoke had dissipated by the time the commander made this announcement.

The right engine had been shut-down approximately 5 nm north-west of East Midlands Airport. Having cleared the aircraft to turn right and descend to FL 100, London ATC passed control to Manchester ATC, who passed headings for the aircraft to descend to the north west of East Midlands Airport, before vectoring it to the east of the airport to begin its approach to runway 27. ATC control of the aircraft was then transferred to Castle Donington Approach.

The approach then continued until the aircraft was on the localiser of the instrument landing system (ILS) for runway 27, with flaps lowered to 5°. At 2,000 ft the landing gear was lowered and, as the outer marker was passed at 4.3 nm from touchdown, 15° of flap was selected. One minute later, at 2023.50 hrs, when the aircraft was 2.4 nm from touchdown and at a height of 900 ft above ground level (agl), the left engine lost power with compressor speed reducing rapidly and high vibration levels. The commander told the first officer to relight (*ie* restart) the right engine. 17 seconds after the power loss, the fire warning system operated on the left engine. No power became available from the right engine before the aircraft struck the ground at 2024.43 hrs, 36 seconds after the fire warning.

The initial ground impact was in a nose-high attitude on level ground just to the east of the M1 motorway. The aircraft then passed through trees and suffered its second, and major, impact on the western (*ie* northbound) carriageway of the M1 and the lower part of the western embankment: this second impact occurred some 70 metres after the initial impact and 10 metres lower. The fuselage was extensively disrupted and the aircraft came to rest entirely on the wooded western embankment, approximately 900 metres from the threshold of runway 27 and displaced 50 metres to the right of the centreline of the approach lights.

Ground witnesses who saw the final approach of the aircraft saw clear evidence of fire associated with the left engine. The intake area of the engine was filled with yellow/orange fire and flames were observed streaming aft of the nacelle, pulsating in unison with "thumping noises" which emanated from this engine. Metallic "rattling" noises were also heard and flaming debris was observed falling from the region of the burning engine.

Wreckage examination

Examination of the fuselage showed that two major structural failures had occurred in the impact, one slightly forward of the wing leading-edge and one aft of the wing trailing-edge. These had respectively resulted in the fuselage nose section becoming detached from the centre section and the tail section buckling over, and to the right of, the centre section. The forward fuselage had therefore sustained a high degree of disruption in the passenger cabin, with floor structure, seats and furnishings becoming detached; similar damage had occurred around the aft fuselage failure. The floor structure and seating were much less disrupted in the centre (*ie* over-wing) section of the cabin and in the inverted tail section.

The Flight Data Recorder (FDR) and Cockpit Voice Recorder (CVR) were removed during the early morning of Monday 9 January and taken to AAIB Farnborough for readout and analysis.

The No.1 (left) engine showed evidence of fire damage, including that arising from ground fire. The left wing appeared to have contained its fuel, whereas the right wing had suffered sufficient impact damage to cause leakage of its fuel contents, which had run back down the embankment slope, on to the motorway.

The No.2 (right) engine showed no evidence of fire.

Fragments of engine fan blades from No.1 engine were found under the approach path, up to 3½ km east of the crash site.

The airframe wreckage was progressively removed from the site and transported to AAIB Farnborough during the period from the 10-14 January and the engines were transported directly to the manufacturer, CFMI at Villaroche in France on 13/14 January where they were the subject of detailed strip down examination, under AAIB supervision.

FDR and CVR evidence

The aircraft was equipped with a Sundstrand Universal Flight Data Recorder and a Fairchild A100 Cockpit Voice Recorder. Both were replayed satisfactorily at AAIB. The FDR read-out established that, as the aircraft was approaching FL 290, an event occurred which led to the No.1 (left) engine recording its maximum indicated vibration level ("5 units"), recordings of rapidly fluctuating fan speeds and fluctuating HP core speeds, with an associated rise in exhaust gas temperature (EGT) and fluctuation in fuel flow. Approximately 20 seconds after this occurrence, the No.2 (right) engine was throttled back, at which point the No.1 engine fan and core speeds settled down, although at slightly different values, with the indicated vibration level remaining at maximum and EGT markedly higher than before - *ie* 840°C, compared to 780°C previously. Prior to being throttled back, the No. 2 engine had been operating with steady engine indications, with a fan speed (N1) of 99%, HP compressor speed (N2) of 96%, EGT of 770°C and low vibration level ("0.5 units"). 1 minute and 47 seconds later, the No.2 engine was shut-down. It was apparent that the flight crew were aware of smoke on the flight deck and thought that they had a possible engine fire. There was no fire warning at this time.

The flight proceded under the control of London, Manchester, and finally Castle Donington ATC. The No.1 engine appeared to respond reasonably to applied throttle demands, although the engine was at "flight idle" for a considerable time (10 minutes).

At about 900 ft above ground level on the final approach, the No.1 engine fan speed dropped rapidly and EGT increased significantly with other engine parameters unchanged, and a maximum indicated vibration level. The No.1 engine lost considerable power and some 17 seconds later the fire warning bell sounded. About 36 seconds later the aircraft impacted with the ground.

Engine strip examination

Inspection of the fan assembly of the No.1 (left) engine showed extensive damage had occurred to the titanium alloy blades, with many associated damage-induced overstressing failures. One fan blade was found to have fractured outboard of the "mid-span shrouds", due to a progressive fatigue failure originating near the leading edge of this blade, adjacent the pressure face. This failure had released the outer "panel" (approximately 4 inches) of this blade. The cause of this fatigue failure, which was the only instance of fatigue fracture found amongst the fan blades, is being pursued.

The abradable seal material which surrounds the fan assembly would have been progressively removed by the damaged fan assembly, as would the rubberized seals surrounding the low pressure compressor "booster" section, due to out-of-balance running, and would have led to associated smoke products entering the air conditioning system.

Inspection of the No.1 engine revealed evidence consistent with the anticipated effects of this engine having run under severe out- of -balance conditions due to fan damage, with some damage to the high pressure compressor arising from fan debris ingestion. No failures were found within the core-module rotating assemblies.

Investigation of the source(s) and development of the airborne fire on the No.1 engine is still in progress. Evidence found to date is provisionally indicative of two areas of fire, one of which was located around the upper/outboard region of the exterior of the fan casing and the other which appears to have trailed from the thrust reverser duct on the left side. It is considered that the sources of both areas of fire were secondary to, and were induced by, the primary engine failure and subsequent continued operation with attendant high vibration.

Detailed investigation of the No.1 engine and its operating history will continue in an attempt to identify the cause of the fan blade fatigue and to explain fully the initiation and progression of the fire.

The No.2 (right) engine has been fully stripped and shows no evidence of pre-crash fire or failure.

Systems examination

Checks have been made of the wiring leading to the Engine Indicating System (EIS). These have confirmed that the indications of both primary and secondary engine parameters were displayed in the correct sense. The primary EIS display unit passed a full function and calibration check. The secondary EIS unit exhibited an obvious fault condition affecting the display of oil pressure, hydraulic pressure and oil quantity, but not the engine vibration indicators. The secondary EIS unit had suffered significant impact damage and the fault appears consistent with such damage. Since the Flight Data Recorder receives engine data (except vibration) from the EIS output to its display, it is implicit that such data was displayed by the EIS.

The Airborne Vibration Monitor unit (AVM), which feeds vibration signals from the engines to the EIS and FDR, was subjected to a full test schedule and, despite some minor external case damage, fully met the acceptance requirements. Both engine vibration indicators operated satisfactorily. The engine vibration indicators and FDR cannot register vibration levels higher than "5 units", since the AVM limits its output.

The Engine and APU fire detection module was severely damaged by impact, such that a functional test was not possible, and will require detailed inspection. Checks of the actual detector loops on the engines concluded that those not damaged beyond meaningful test by impact were capable of providing both overheat and fire detection warnings. The Engine and APU fire suppression bottles were found fully charged. There were no indications that an attempt had been made to discharge any extinguisher.

Further investigation of the systems aspects will include an appraisal of the EIS/Flight crew interface to evaluate the effectiveness of the presentation of engine indications to pilots. This evaluation will be assisted by the RAF Institute of Aviation Medicine Flight Skills Section.

Survival factors

A full evaluation of passenger and crew testimony and injury, combined with an analysis of the pathology, is being progressed. This information will be related to the crash-induced damage to the cabin structure and seating in order that the causes of injury are identified, with a view towards consideration of what improvements may be indicated to reduce injuries and maximise survivability in future accidents.

AAIB Safety Recommendations

Shortly after the accident, on the 11 January 1989, AAIB made 2 Safety Recommendations to the CAA. These were made at a stage in the investigation when it was known that the left engine had failed in-flight, but the reason for the in-flight shut-down of the right engine had not yet been established. In addition, it was considered prudent to address the possibility of a defective engine vibration or fire/overheat warning system although no evidence of such defect(s) had been found. The following precautionary Safety Recommendations were made to the CAA:

1. That the CAA consider increasing the frequency of existing engine inspections and engine health monitoring on Boeing 737-300 and Boeing 737-400 aircraft until the causes of the engine failure(s) are established.

2. That the CAA call for an examination of the Boeing 737-300 and Boeing 737-400 engine Fire/Overheat and Vibration monitoring circuitry for left/right engine sense.

As a result, the CAA issued letters to owners/operators Nos. 905 and 906 on 11 January 1989 which required (respectively) testing of the engine overheat/fire warning and vibration monitoring systems for "correct-sense" operation; and increased frequency of certain engine "health monitoring" checks on Boeing 737-300, 737-400 and Airbus 320 aircraft.

On 10 February 1989, the AAIB advised the CAA that the left engine had suffered a fatigue-failure of a fan blade and that there was no continuing justification for the increased inspections of the "oil-wetted" components of the CFM 65-3 and -5 engines. However, in view of the fan blade failure (the cause of which has not thus far been established) and AAIB caution concerning any possible means by which the fatigue strength of such fan blades may be inadvertently compromised, the following 2 Safety Recommendations were made to the CAA:

3. The Civil Aviation Authority, in conjunction with the engine manufacturer, consider instituting inspection procedures for the examination of the fan stage of CFM 56 engines to ensure the early detection of damage that could lead to the failure of a blade.

4. The Civil Aviation Authority review the advice given in the Boeing 737-400 Maintenance Manual concerning the excessive generation of heat during blending operations with power grinding and blending tools.

CFMI and Boeing issued letters to operators, emphasising the daily visual check on the engine inlet and fan blades and the detailed fan blade inspection at the aircraft "B check" (approximately every 750 hours). In addition, operators were recommended to review their policies and instructions for the maintenance and repair of CFM 56 fan blades, with particular emphasis on adhering strictly to the limits and procedures detailed in the aircraft maintenance manual for fan blade repair.

On 23 February 1989, the AAIB made a further 3 Safety Recommendations to the CAA:

5. The CAA take action to advise pilots of Boeing 737-300/400 aircraft, and of other types with engines which have similar characteristics, that when instances of engine-induced high vibration occur, they may be accompanied by associated smoke and/or smells of burning entering the flight deck and/or cabin through the air-conditioning system, due merely to blade tip contact between fan/compressor rotating assemblies and the associated abradable seals.

6. The CAA request the Boeing Airplane Company to produce amendments to the existing aircraft flight manuals and checklists to indicate what actions should be taken when engine-induced high vibration occurs, accompanied by smoke and/or the smell of burning entering the flight deck and/or cabin.

7. The CAA review the current attitude of pilots to the engine vibration indicators on Boeing 737-300/400 aircraft and other applicable types with turbo-fan engines, with a view towards providing flight crews with an indication of the pertinence of such vibration instruments when certain engine malfunctions or failures occur.

Produced from camera ready copy supplied by the department.
Printed in the United Kingdom for HMSO
Dd 293160 9/90 C00 488/2 12521