REPUBLIC OF SOUTH AFRICA

REPORT OF THE BOARD OF INQUIRY INTO THE HELDERBERG AIR DISASTER

ISBN 0-621-13030-3

Printed by the Government Printer.

REPORT OF THE BOARD OF INQUIRY INTO THE LOSS OF SOUTH AFRICAN AIRWAYS BOEING 747 - 244B COMBI AIRCRAFT "HELDERBERG" IN THE INDIAN OCEAN ON NOVEMBER 28TH 1987

C H A I R M A N

THE HON. MR JUSTICE C S MARGO	[South Africa]

B O A R D   M E M B E R S

MR G N TOMPKINS, Jr	[United States of America]
MR G C WILKINSON	[United Kingdom]
THE HON. MR JUSTICE H GOBURDHUN	[Mauritius]
DR Y FUNATSU	[Japan]
MR L LUNG	[Republic of China]
DR J GILLILAND	[South Africa]
MR J J S GERMISHUYS	[South Africa]

TABLE OF CONTENTS

VOLUME 1

TABLE OF CONTENTS

(Continued)

TABLE OF CONTENTS

(Continued)

The Hon The Minister of Transport and of Public Works
and Land Affairs
PRETORIA

May 14, 1990

Sir

We have the honour to submit herewith the final Report of the Board of Inquiry into the loss of South African Airways Boeing 747 - 244B Combi aircraft "Helderberg" in the Indian Ocean on November 28th 1987.

Our Report is unanimous.

C S MARGO (CHAIRMAN)

Y FUNATSU

H GOBURDHUN

J J S GERMISHUYS

GEORGE N TOMPKINS JNR

JAMES GILLILAND

G C WILKINSON

LIANG LUNG

PARAGRAPH 6.11 OF ANNEX 13 OF THE CONVENTION ON CIVIL AVIATION

Pursuant to paragraph 6.11 of Annex 13 to the Chicago Convention, the United States of America, as the State of manufacture, was invited to submit comments on the draft Final Report of the Board. Dr Barry Strauch, the U.S. Accredited Representative, submitted comments to the Board on behalf of the National Transportation Safety Board (NTSB) of the United States. Dr Strauch also forwarded to the Board separate and independent comments of the Federal Aviation Administration, the airworthiness authority of the United States, and The Boeing Company, the manufacturer of the aircraft. These comments have been given full consideration by the Board in the preparation of this Final Report.

The comments of the NTSB as contained in its letter of March 9, 1990 are annexed hereto as Appendix J. See Volume 2 pp 85-86.

FOREWORD

The Board of Inquiry extends its profound sympathy to the families and friends of the passengers and crew who lost their lives in the Helderberg accident.

The Board believes that all concerned would wish to join it in this expression of gratitude to the Mauritian, French, United States and Australian authorities (named in paragraph 1.15 page below) for their humanitarian response and participation in the search and rescue operations.

The Board places on record its appreciation of the outstanding services of Mr R W van Zyl, the Director of Aviation Safety in the Chief Directorate of Civil Aviation, Department of Transport, and of his technical investigation team, consisting of himself, Mr P de Klerk, Capt R Downes and Mr B Jordaan. In particular, Mr van Zyl's direction of the underwater search is to be highly commended. That search, known as Operation Resolve, was carried out at depths of the order of 4,5 km, and represents a remarkable and pioneering technological achievement.

The Board also wishes to record its appreciation of the valuable guidance and information given by the United States Federal Aviation Administration (FAA) representatives who assisted the technical investigation team and who attended the public hearings. They were Messrs Harold Donner, Richard Hill, and Wes Slifer.

Of great importance to the investigation at all stages was the the assistance and ready co-operation of South African Airways, which, through Mr Albert Boshoff, assisted by Mr J Prozesky, Mr T Kruger, Mr T Perfect and other technical personnel, played a vital role in organizing and conducting Operation Resolve, and in carrying out numerous other important investigations and tests.

The Board is likewise indebted to The Boeing Company for its unhesitating response to the innumerable requests for assistance and for the mass of technical information furnished from time to time.

Also deserving of the Board's appreciation are the S A Bureau of Standards, Capt A D van Heerden, who represented the International Federation of Airline Pilots Associations, and the counsel and attorneys who appeared at the hearings to represent interested parties. They were Mr B R Southwood, SC, with him Mr R W Nugent, instructed by Mr J N J van Rensburg, of Rooth & Wessels, Pretoria, who acted for the Board in presenting the evidence (Mr van Rensburg also acted as the Board's attorney); Mr S A Cilliers, SC, with him Mr L Bowman, instructed by Mr D E Jooste, of Bowman, Gilfillan, Hayman, Godfrey Inc., Johannesburg, and Mr Rex Browning of Attorneys Perkins, Coie, of Seattle, USA, for The Boeing Company; Mr C E Puckrin, SC, with him Mr C M Eloff, instructed by Mr P D de Wet, of Bowens, Johannesburg, and Solicitors Barlow, Lyde & Gilbert, London, for South African Airways; and Mr D M Antrobus, instructed by Mr P Naude, of Deneys Reitz, Johannesburg, and by Mr P Kemp, of Kemp Evenhuis, Johannesburg, for the widows of two of the passengers.

Recognition must also be given to the contribution by of way of technical expertise made by Mr Toru Tatebe, of All Nippon Airways, and Dr Bang-Lee Ho, of the Aviation Medical Centre, Civil Aeronautics Administration, Republic of China.

The Board conducted its proceedings in public at Johannesburg on 15th, 16th, 17th, 18th, 22nd, 23rd, 24th and 25th August 1989. This was after notice had been given and advertisements placed of the date and place of the hearings and of the right of all interested parties to appear before the Board in person or via authorized representatives, to cross-examine witnesses, to call their own evidence and to make submissions to the Board. The United States National Transportation Safety Board (the NTSB), as representing the State of Manufacture, was specially invited to send representatives to the hearings, but notified the Board that it was unable to do so because of its numerous other commitments and shortage of available personnel. It pointed out, however, that there would be representatives of the FAA present, to whom the Board could turn for advice and information.

In addition to the public hearings, the Board, during March 1988, conducted inspections of a Boeing 747-244B Combi aircraft at Jan Smuts Airport, and viewed demonstrations of fire fighting equipment and procedures. The Board also inspected, during August 1989, the wreckage assembled in the "Debris Hanger" at Jan Smuts Airport, and it viewed the more important of the more than 3 000 photographs of the wreckage on the sea-bed taken in Operation Resolve, and certain of the more than 800 hours of video tapes of some aspects of the underwater operations. The Board also received and considered numerous reports of fires in aircraft, and a great deal of documentation from ICAO, IATA, various airlines, pilots' associations and the statements of numerous experts which had been obtained by the technical investigation team in the course of assembling the data placed before the Board at the public hearings. Also investigated and considered were numerous communications from members of the public, particularly on their experiences of spontaneous fires in various types of goods.

Some explanation is warranted of the time taken since the accident to reach the stage of public hearings. As Mr van Zyl stated in his testimony, "We have spent thousands and thousands of hours on the Helderberg investigation". The fruitless search for pinger signals and thereafter the prolonged search for the wreckage of the aircraft were followed by extensive efforts to find a suitable contractor for the endeavours to reach the wreckage and to lift selected portions thereof. In the then state of the art this was a difficult and lengthy operation which necessitated obtaining the required information and advice, working from scratch, negotiating a suitable contract and making the required provision for personnel, organization, auxiliary and support services and finance. Considerable time was also involved in the contractor's preparations, which included the manufacture of 22 000 feet of specially designed cable. Eventually, after much time, Operation Resolve got under way, only to be delayed repeatedly by cable failures, necessitating more often than not a return to port in Mauritius, and by unfavourable weather. Meanwhile, as evidence was gradually being accumulated, more and yet more scientific and technical research and testing were called for. In particular, after the recovery of the cockpit voice recorder (CVR) and selected items of wreckage, the work of identifying and assembling as much of the wreckage as possible, and of analyzing and evaluating the metallurgical, chemical and other signs, had to be pursued painstakingly and thoroughly.

In the event the time taken up was more than justified.

AIRCRAFT ACCIDENT REPORT

OPERATOR AND OWNER : SOUTH AFRICAN AIRWAYS

AIRCRAFT : BOEING 747-244B "COMBI" - SERIAL NO.22171

NATIONALITY : SOUTH AFRICAN

REGISTRATION : ZS-SAS

PLACE OF ACCIDENT : In the Indian Ocean 134 nautical miles North-East of Plaisance Airport, Mauritius.

DATE AND TIME OF ACCIDENT : November 28th 1987, at approximately 00:07:00

Note: Save where otherwise expressly indicated all times stated in this report are in Co-ordinated Universal Time (UTC).

SYNOPSIS

On November 27th 1987 at 14:23, flight SA 295, a Boeing 747-244B Combi of South African Airways, departed from Taipei's Chiang Kai Shek Airport for Mauritius' Plaisance Airport with 159 persons on board. In the main deck cargo hold 6 pallets of cargo had been loaded. Some 9 hours out and some 46 minutes before the estimated time of arrival at Plaisance the flight deck informed the approach control at Plaisance that there was a smoke problem in the aeroplane and that an emergency descent to flight level (FL) 140 had been initiated. The last radio communication was at 00:04 on November 28th 1987. At about 00:07 the aeroplane crashed into the sea. The wreckage, consisting of thousands of fragments, sank to the ocean bottom at depths of the order of 15 000 feet (about 4,5 kilometers), although many of the lighter materials floated away on the currents. Some of the latter items were recovered from the sea, or from the sea-shores where they had been washed up far from the scene of the crash. Months later one such item was found on a beach in Natal, over 2 000 nautical miles away. There are clear indications that a fire developed in the right hand front pallet in the main deck cargo hold, that the fire got out of control and that it eventually led to the crash.

There were no survivors.

The State of Registry, the Republic of South Africa (RSA), was notified of the accident by Plaisance Air Traffic Control (Mauritius) at 01:15 on November 28th 1987.

As the accident had occurred outside the territory of any State, the investigation of the accident was conducted by the State of Registry in terms of paragraph 5.3 of Annex 13 to the Convention on International Civil Aviation. This was agreed to by the Government of Mauritius.

The State of Manufacture of the aircraft, the United States of America (USA), was notified of the accident on November 30th 1987 at 08:10 and was requested to participate in the investigation, in response to which request an accredited representative was appointed from the NTSB. The accredited representative was accompanied by representatives of the FAA and The Boeing Company respectively. All the representatives had full access to all the phases of the investigation and all the available information. They were most helpful and co-operated fully with the investigator-in-charge.

The Operator provided advisers and all possible assistance and logistic support needed in all the phases of the investigation. It also had full access to all available information. Full co-operation was given to the investigator-in-charge.

The representatives of the Operator, The Boeing Company and the NTSB, undertook to provide the investigator-in-charge with all the available information that might be required for the investigation of the accident. The investigator-in-charge provided the factual report to the representatives of the participating parties for information and comments.

The State conducting the investigation (RSA) appointed an Accident Inquiry Board in terms of section 12(1) of the Aviation Act 74 of 1962. The Board comprised one member from each of the States of Japan, the Republic of China, Mauritius, the UK and the USA, and three members, including the Chairman, from the RSA. The members from Japan, the Republic of China and Mauritius, were appointed by their respective governments. The members of the Board, by name, were Mr Justice C S Margo, DSO, DFC, FRAeS, of the RSA, (Chairman), Mr Justice H Goburdhun, of Mauritius, Mr George N Tompkins Junior, of the USA, Mr G C Wilkinson, CBE, FRAeS, of the UK, Dr Y Funatsu, of ANA, Japan, Mr J J S Germishuys, of the RSA, Dr J Gilliland, of the RSA, and Colonel Liang Lung, of the Republic of China.

1. FACTUAL INFORMATION

1.1 History of the Flight

On November 27th 1987 flight SA 295 was scheduled to depart from Taipei's Chiang Kai Shek Airport at 13:00 for Mauritius' Plaisance Airport on a scheduled international air transport service. Due to adverse weather and the late arrival of a connecting flight the departure time was delayed and the aeroplane took off at 14:23 with 149 000 kg of fuel, 43 225 kg of baggage and cargo, 140 passengers and a crew comprising 5 flight crew members (including an extra co-pilot and an extra flight engineer) and 14 cabin crew members. The calculated flight time was 10 hours 14 minutes. According to the tape recording of the radio communication with Taipei Approach Control the take-off was normal in all respects. At

14:56:04 the crew communicated with Hong Kong radar and thereafter routine position reports were given to the flight information centres (FICs) at Hong Kong, Bangkok, Kuala Lumpur, Colombo, Cocos Islands and Mauritius. At 15:55:18 a routine report was made to the Operator's base at Jan Smuts (ZUR). The information given was that the aeroplane had taken off from Taipei at 14:23, was flying at FL 310 and that the arrival time at Mauritius was estimated as 00:35. The ZUR radio operator informed flight SA 295 that the selective calling system (SELCAL) was unserviceable and requested that the next call be at 18:00. SELCAL is a coded system whereby a radio station can call an individual aircraft. The flight crew's attention is drawn to a call by audio and visual means. In fact there was no further contact between ZUR and the aircraft, although the latter continued to have routine communications with the FICs en route. For further details of the omission to call ZUR, see paragraphs 1.9 p 30 and 2.16 p 137 below.

At about 22:30:00 the pilot called Mauritius FIC, using HF radio on frequency 3476 KHz, and advised that the aircraft had been at position 070° East at 22:29:00 at FL 350 and that the time at position 065° East was estimated as 23:12:00. At 23:13:27 the position report of 065° East at FL 350 was given to Mauritius FIC. The estimated time of arrival (ETA) over position 060° East was given as 23:58:00. As it can be accepted that the aircraft was on track, the position given as 065° East would have been at latitude 15°40'12" South and position 060° East at latitude 18°57'54" South.

There is no suggestion whatsoever of any distress in the routine HF radio transmissions which ended at 23:14:00.

On the tape of the 30 minute cycle CVR (see paragraph 1.11 p 37 below), which had no time injection, much of the first 28 minutes period was unintelligible. Sufficient data was, however, recovered to indicate that the conversation was on purely personal topics and did not relate to the flight in any way. The Board acceded to a request by the representative of IFALPA not to publish details of this purely personal conversation. That ruling was in accord with the Board's understanding of the general practice in accident inquiries. The character of the flight deck conversation changed abruptly 28 minutes 30 seconds after commencement of the recording cycle, when the master fire warning alarm sounded. Somebody, probably the pilot, inquired where the warning had come from and received the reply that it had come from the main deck cargo. The pilot then asked that the check list be read. Some 30 seconds later somebody on the flight deck uttered an oath. This was followed by the CVR 800 Hz test tone on all four channels which ended in a warble at 29 minutes 52 seconds after commencement of the recording. These sounds indicate that the audio input and test signal wiring were being affected by the fire. It is assumed that the recorded cockpit conversation had commenced very shortly after the HF communication with Mauritius FIC at 23:14:00 and ended shortly before the VHF communication with Mauritius Approach Control at 23:48:51, reporting trouble.

According to the Plaisance tower tape recording (a full rendering of which is given in paragraph 1.9 p 32 below) the pilot called Mauritius Approach Control at 23:48:51 on 119.1 MHz. At 23:49:07 he said that they had a smoke problem and were doing an emergency descent to FL 140. The approach controller gave clearance for the descent and the pilot asked that the fire services be alerted. The controller asked if full emergency services were required to which the pilot replied in the affirmative. At 23:51:02 the approach controller asked the pilot for his actual position. The pilot replied: "Now we have lost a lot of electrics, we haven't got anything on the ... aircraft now". At 23:52:33 the approach controller asked for an ETA at Plaisance and was given the time of 00:30. At 23:52:50 the pilot made an inadvertent transmission when he said to the senior flight engineer: "Hey Joe, shut down the oxygen left". From this time until 00:01:34 there was a period of silence lasting 8 minutes and 44 seconds. From 00:01:34 until 00:02:14 the pilot inadvertently transmitted instructions, apparently to the senior flight engineer, in an excited tone of voice. Most of the phrases are unintelligible. At 00:02:43 the pilot gave a distance report as 65 nautical miles. This was understood by the approach controller to be the distance to the Airport. In fact it was the distance to the next way-point, Xagal. The distance to the Airport at that point was approximately 145 nautical miles. At 00:02:50 the approach controller recleared the flight to FL 50 and at 00;03:00 gave information on the actual weather conditions at Plaisance Airport, which the pilot acknowledged. When the approach controller asked the pilot at 00:03:43 which runway he intended to use he replied one three but was corrected when the controller asked him to confirm one four. This is no reflection on the pilot for what was one three had recently been changed to one four in conformity with a change of magnetic variation. At 00:03:56 the controller cleared the flight for a direct approach to the Flic-en-Flac (FF) non-directional beacon and requested the pilot to report on approaching FL 50. At 00:04:02 the pilot said: "Kay". From 00:08:00 to 00:30:00 the approach controller called the aircraft repeatedly but there was no reply.

The aeroplane crashed into the Indian Ocean at a position determined to be about 19°10' S and 59°38' E. The accident occurred at night, in darkness, at about

00:07. The local time was 04:07. This time was determined from 2 damaged wrist watches recovered from hand baggage.

Two persons who were on the South-Eastern shore of Flat Island, situated approximately 6 nautical miles North of Mauritius, stated that at about the time of the accident (04:07 local time) they had seen a red and yellow coloured object coming down rapidly from an estimated height of 6 to 7 feet above the horizon and disappearing behind Round Island. This evidence emerged only after some days, and, when tested, did not tally with the facts. The direction was different, and the wreckage of the aircraft and the undersea photographs established that there was no "torching", i.e. no flames ouside the aircraft. It would appear that they had probably seen a meteorite.

1.2 Injuries to Persons

INJURIES	CREW	PASSENGERS	OTHERS
FATAL	19	140	nil
SERIOUS	nil	nil	nil
MINOR/ NONE	nil	nil	

1.3 Damage to Aircraft

The aeroplane was totally destroyed. Thousands of wreckage pieces were found scattered on the ocean floor.

1.4 Other Damage

There was no damage to property outside the aircraft.

1.5 Personnel Information

1.5.1 The pilot-in-command (pilot) was Mr Dawid Jacobus Uys, age 49 years. He held valid and appropriately rated airline transport pilot licence No TA 03896 issued on April 18th 1967. The licence was valid until February 4th 1988. He was also rated to fly Boeing 707, Boeing 727 and Airbus A300 series aeroplanes. His total flying experience amounted to 13 843 hours of which 3 884 hours were on Boeing 747 series aeroplanes. Flying time during the 90 days preceding the accident was 92 hours, all of which were on Boeing 747 series aeroplanes.

The pilot had had a rest period of 79 hours before he commenced his duties on the last flight.

According to information supplied by the Institute of Aviation Medicine a skin affliction was reported on January 25th 1979 and was diagnosed as Sézary Cell Syndrome, of which the most obvious and important symptom experienced by the pilot was intense itching. On February 16th 1979 he was declared temporarily unfit to fly. On June 8th 1979 a medical panel found him physically fit to fly as an airline transport pilot, after which time he regularly passed the subsequent medical examinations until July 7th 1987, when a medical panel again declared him temporarily unfit while further examinations were being conducted and cortisone treatment was given for a period. On August 18th 1987 a medical panel decided that he was fit to fly as an airline transport pilot with effect from August 18th 1987 to February 5th 1988, with the following restrictions:

(1) To fly with or as a co-pilot.

(2) Reports by specialist physician and dermatologist, and of haematological tests, to be submitted every 6 months.

It was considered that the possibility of sudden incapacitation due to the skin condition was extremely improbable. All the reports on medical examinations from January 25th 1984 to January 12th 1987 included the restriction that suitable corrective lenses be worn and this restriction was also entered in the pilot's licence.

The pilot's training record was inspected as far back as December 1st 1983. Remarks of "good", "proficient", "satisfactory" and "passed rating" were generally made. On June 2nd 1986 and on July 4th 1986 remarks of "Procedures good, passed rating but have organised extra period to polish manual flying" and "Satisfactory test - have pointed out the urgency to keep up to date on handling" were respectively made. Remarks on two route check forms dated May 27th 1986 and March 13th to March 21st 1987 were generally favourable. A remark on the last route check form reads thus: "Capt Uys copes well generally with his flying in spite of his sometimes obvious discomfort due to his skin affliction. This is indeed a credit to him!".

1.5.2 The co-pilot was Mr David Hamilton Attwell, age 36 years. He held valid and appropriately rated airline transport pilot licence No TA 01182 issued on September 22nd 1976. The licence was valid until January 30th 1988. He was also rated on Boeing 737-244 and 707 series aeroplanes. His total flying experience amounted to 7 362 hours of which 4 096 hours were on Boeing 747 series aeroplanes. Flying time during the 90 days preceding the accident was 219 hours all of which were on Boeing 747 series aeroplanes. His last medical examination was on July 20th 1987 when he was declared fit for 6 months with effect from July 31st 1987 without restrictions. Rest period before duties on the last flight was 79 hours.

1.5.3 The third pilot was Mr Geoffrey Birchall, age 37 years. He held valid and appropriately rated airline transport pilot licence No TA 02779 issued on August 18th 1976. The licence was valid until April 3rd 1988. He was also rated on Boeing 727 series aeroplanes. His total flying experience amounted to 8 749 hours of which 4 254 hours were on Boeing 747 series aeroplanes. Flying time during the 90 days before the accident was 170 hours all of which were on Boeing 747 series aeroplanes. His last medical examination was on September 25th 1987. He was declared fit for six months without restrictions. Rest period before duties on the last flight was 79 hours.

1.5.4 The senior flight engineer was Mr Guiseppe Michele Bellagarda, age 45 years. He held valid and appropriately rated flight engineer's licence No 209 issued on June 27th 1974. The licence was valid until March 22nd 1988. He was also rated on Airbus A300 series aeroplanes. His flying experience as at October 30th 1987 was as follows :

Total: 7 804 hours

Total on Boeing 747 series aeroplanes : 4 555 hours

During 90 days preceding the last flight : 158 hours, all of which were on Boeing 747 series aeroplanes.

His last medical examination was on March 31st 1987 when he was declared fit for 12 months. Rest period before duties on the last flight was 79 hours.

1.5.5 The second flight engineer was Mr Alan George Daniel, age 34 years. He held valid and appropriately rated flight engineer's licence No 389 issued on May 8th 1985. The licence was valid until February 21st 1988. His flying experience as at October 30th 1987 was as follows :

Total : 1 595 hours all of which were on Boeing 747 series aeroplanes.
During the 90 days preceding the last flight : 227 hours, all of which were on Boeing 747 series aeroplanes.

His last medical examination was on January 28th 1987 when he was declared fit for 12 months. Rest period before duties on the last flight was 79 hours.

1.5.6 The 14 cabin crew members (8 male and 6 female) were trained by the Operator. They all received refresher training during the course of 1987. Six received practical training in water and in fire emergencies during the period October to November 1987.

1.5.7 Prior to the accident the Commissioner for Civil Aviation (CCA) in conjunction with various operators had devised supplementary airworthiness requirements in respect of the training of cabin crew members engaged in public transport operations on aircraft registered in the RSA. These requirements were introduced as from July 1st 1986. As with the introduction of any new system, the requirements were not immediately achievable in their totality. The Operator therefore obtained waivers from the CCA in the form of extensions for certain aspects.

Notwithstanding the fact that at the time of the accident, the Operator was still not in a position to comply fully with the requirements, all fourteen members of the cabin crew had received recurrent emergency procedure training during 1987. This included practical training in fire fighting, in accordance with the new supplementary requirements.

The new supplementary requirements were not retroactive and therefore were not applicable to the initial training of the cabin crew of flight SA 295.

1.5.8 A report of an inspection of the Operator's training facilities during August 1988, i.e.

after the accident, suggested that not all the requirements of Document LS 101, issued in terms of regulation 14.3(1) of the Air Navigation Regulations, had been complied with during the initial training of cabin crew members.

These apparent shortcomings were examined in evidence before the Board, from which it appeared that most of the complaints were based on the hyper-critical views of an inspector whose own training was of a very limited nature.

1.6 Aircraft Information

The type certification of the aeroplane had been approved on December 23rd 1970 under the airworthiness requirements current at the time. The aeroplane was imported into the RSA in November 1980 as a new aircraft. The certificate of airworthiness (C of A) in categories (a), (c), (d), (e) and (f) was issued on December 5th 1980 and was based on the submission of an USA export C of A in accordance with the bilateral agreement between the USA and the RSA. No recertification was required. Nor were any certification data requested or provided. FAA standards were accepted in good faith. The RSA C of A was continuously valid provided that the conditions prescribed therein were observed.

The aeroplane had flown 26 743,48 hours and completed 4 877 operating cycles since new. It had flown 360 hours since the last Phase A inspection, which was required by the approved maintenance schedule to be carried out at 430 flying hours intervals, and 81 hours since the last terminal inspection which was required at 120 flying hour intervals.

An inspection of the aircraft's maintenance records revealed that it had been maintained in accordance with the requirements of the approved maintenance schedule and the applicable Air Navigation Regulations. There were no known defects when the aircraft departed on the last flight. A certificate of safety for flight was issued on October 16th 1987 and was valid for another 70 flying hours, that is until 26 814,09 flying hours had been reached.

Because of the in-flight fire which occurred in the main deck cargo compartment, special attention has been paid by the technical investigation team to the maintenance history of the smoke detection system in that compartment.

During the periods August 11th to October 21st 1987 and November 10th to November 14th 1987 several defects relating to the main deck cargo compartment smoke detection system were recorded in the on-board technical defect log. Rectification actions included the replacement of no 2B and no 3A smoke detectors and a differential pressure switch. The recovered cockpit voice recording provided conclusive proof that the smoke detection systems of the main deck cargo compartment functioned.

The approved maintenance schedule prescribes that the orifices in the smoke detection sampling manifolds be inspected for obstructions at every tenth Phase A inspection, i.e. at 4 300 hour intervals. Such an inspection was carried out on February 2nd 1987 at 24 394 total hours i.e. 2 349 flying hours before the accident.

The aircraft's empty mass and balance were last determined on January 23rd 1984 at which time the basic empty mass was 166 129 kg and the centre of gravity (CG) position 34,1226 m (1343,41 inches) aft of the datum. This equals 26.1% of the mean aerodynamic chord (MAC) . The structural maximum certificated mass was 377 842 kg for take-off and 285 762 kg for landing.

The aircraft's mass at the time of the accident was calculated as 242 855 kg and the CG position estimated as 28,78% MAC. The CG limits at this mass are 13% and 33% MAC. The aircraft was thus correctly loaded.

The underwater inspection of the stabiliser trim actuator jackscrew revealed that 9 screw threads were exposed above the ball nut and 4 threads below the nut. No noticeable bending of the jack-screw had occurred. This suggests that the break in this area may have occurred flush with the ball nut on impact and that the jackscrew may have moved during the break-up following the impact. The actuator setting as found, equates to a CG position of 27% MAC. If the break had occurred flush with the ball nut and if the aeroplane was trimmed for level flight, the CG position would have been 21,47%. Both CG positions are within the safe cruising trim range. With all 159 occupants concentrated in the most forward passenger compartment the CG position would have been 21,5% MAC.

The quantity of aviation turbine fuel in the aircraft at the time of the impact was calculated as approximately 24 370 kg.

Of the 43 225 kg of cargo and baggage carried in the aircraft, 14 588 kg of cargo was loaded on 6 pallets in the main deck cargo compartment. This cargo consisted mainly of electrical components and parts, electronic components and parts, hardware, paper articles, textiles, medicines and sports equipment. Some articles from the main deck cargo which were recovered showed evidence of fire damage. None of the observed cargo from the lower holds had any signs of fire or heat.

Extensive investigations have been made into rumours that the cargo included a quantity of fireworks. The results have been negative. The South African Bureau of Standards (SABS) conducted numerous tests to determine whether signs of nitrates and/or ferrites were present, but the evidence is inconclusive. Pallet PR, in which the fire started, could not have carried a large quantity of fireworks because almost all the contents of that pallet were accounted for. But even a very small quantity could have provided a source of ignition because of the instability of the chemicals used and their responsiveness to heat.

1.7 Meteorological Information

Very little information on the actual weather conditions at the accident site is available. From the actual condition at Mauritius and Rodrigues together with the 03:00 satellite picture, the following weather conditions were estimated :

Upper wind FL 140 : 160/5-8 kt

Visiblity : 10 km or more

Cloud : Scattered cumulus and stratocumulus at 5 000 ft

No medium level cloud at FL 140.

The night was dark. The moon had set at 20:16 on November 27th 1987.

1.8 Aids to Navigation

The aeroplane was equipped with the following navigational aids and associated displays :

3 inertial navigation systems (INS)
2 weather and mapping radars with 300 nm range.
2 radio magnetic indicators (RMI)
1 standby compass
2 automatic direction finders (ADF)
3 very high frequency omni range (VOR) units
3 distance measuring units (DME)
3 instrument landing systems (ILS)

Plaisance Airport was equipped with the following terminal navigational aids :

2 VOR stations
2 DME stations
2 NDB stations

Runway 14 was equipped with an ILS system.
The ground stations were serviceable.

1.9 Communications

The aeroplane was equipped with 2 high frequency (HF) and 3 very high frequency (VHF) transmitter-receiver radio sets. Interphone (sometimes referred to as intercom) and passenger address systems were also provided.

The take-off and departure communications with Taipei departure control were normal in all respects.

Some 34 minutes after departure from Taipei, SA 295 called Hong Kong Radar at 14:56:04 and obtained direct clearance from ELATO to ISBAN. Normal position reporting was made over ELATO at 15:03:25; SUNEK at 15:53:52; ADMARK at 16:09:54 and SUKAR at 16:34:47. At 15:55:18 a routine report was made to the Operator's base station at Jan Smuts (ZUR). The crew was asked to report again at 18:00 as the selective calling system (SELCAL) was unserviceable. The communication with ZUR ended at 15:56:55. The ZUR tape recording ran until about 16:34. As the follow-on tape was apparently later mislaid or inadvertently re-used, there is no further communication between SA 295 and ZUR on record. The ZUR operator confirmed that there was no other communication. The ZUR log shows that at 04:48 on November 28th flight MK 057 had asked the ZUR radio officer when he last had contact with flight SA 295 and was informed "1600 UTC on

27". The ZUR episode is analysed in paragraph 2.16 p 137 below, and the Board's findings are to be found in paragraph 4.17 p 174 below. From 16:49:41 to 21:43:00 position reports were made to Bangkok, Colombo and the Cocos. The first HF call to Mauritius on 3476 KHz was made at about 21:46:00 when the crew reported the time at the Mauritius FIR boundary as 21:43:00. At about 22:30 a report of crossing longitude 070° East was made. At 23:13:27 a position report of 065° East at FL 350 was made to Mauritius. From 15:41:06 until 23:14:00 all position reporting was by means of high frequency transmissions. At 23:48:51 the pilot called Mauritius approach control on VHF. The communication which followed has been transcribed from the Plaisance control tower tape recording and is set out below. Free translations of Afrikaans phrases are in brackets. While most of the words were clearly recorded and could be easily transcribed, some of them and some of the unintentional transmissions from SA 295 cannot be made out clearly. In the transcription below the best available interpretation has been given to these passages, based on the conclusions of an expert on eletronic recordings, Dr Jansen, and of an experienced airline captain, Capt R Downes, who listened to the recording repeatedly and became acquainted with the voices of some of the crew.

KEY

295 : PILOT IN COMMAND OF FLIGHT SA 295

MRU : MAURITIUS APPROACH CONTROL

TIME	SPEAKER	RECORDED INFORMATION
23:48:51	295	Eh, Mauritius, Mauritius, Springbok Two Niner Five
23:49:00	MRU	Springbok Two Niner Fife, eh, Mauritius, eh, good morning, eh, go ahead
23:49:07	295	Eh, good morning, we have, eh, a smoke, eh, eh, problem and we're doing emergency descent to level one five, eh, one four zero
23:49:18	MRU	Confirm you wish to descend to flight level one four zero
23:49:20	295	Ya, we have already commenced, eh, due to a smoke problem in the aeroplane
23:49:25	MRU	Eh, roger, you are clear to descend immediately to flight level one four zero
23:49:30	295	Roger, we will appreciate if you can alert, eh, fire, eh, eh, eh, eh
23:49:40	MRU	Do you wish to, eh, do you request a full emergency?
23:49:48	295	Okay Joe, kan jy ... vir ons (Okay Joe can you ... for us)
23:49:51	MRU	Springbok Two Nine Five, Plaisance
23:49:54	295	Sorry, go ahead
23:49:56	MRU	Do you, eh, request a full emergency please a full emergency?
23:50:00	295	Affirmative, that's Charlie Charlie
23:50:02	MRU	Roger, I declare a full emergency, roger
23:50:04	295	Thank you

TIME	SPEAKER	RECORDED INFORMATION
23:50:40	MRU	Springbok Two Nine Five, Plaisance
23:50:44	295	Eh, go ahead
23:50:46	MRU	Request your actual position please and your DME distance
23:50:51	295	Eh, we haven't got the DME yet
23:50:55	MRU	Eh, roger and your actual position please
23:51:00	295	Eh, say again
23:51:02	MRU	Your actual position
23:51:08	295	Now we've lost a lot of electrics, we haven't got anything on the on the aircraft now
23:51:12	MRU	Eh, roger, I declare a full emergency immediately
23:51:15	295	Affirmative
23:51:18	MRU	Roger
23:52:19	MRU	Eh, Springbok Two Nine Five, do you have an Echo Tango Alfa Plaisance please
23:52:30	MRU	Springbok Two Nine Five, Plaisance
23:52:32	295	Ya, Plaisance
23:52:33	MRU	Do you have an Echo Tango Alfa Plaisance please?
23:52:36	295	Ya, eh, zero zero, eh eh eh three zero
23:52:40	MRU	Roger, zero zero three zero, thank you
23:52:50	295	Hey Joe, shut down the oxygen left
23:52:52	MRU	Sorry say again please
00:01:34	295	Eh Plaisance, Springbok Two Nine Five, we've opened the door(s) to see if we (can?) ... we should be okay
00:01:36	295	Look there (?)
		(Exclamation by somebody else, and is said over the last part of the previous sentence)

TIME	SPEAKER	RECORDED INFORMATION
00:01:45	295	Donner se deur t... (Close the bloody door) (?)
00:01:57	295	Joe, switch up quickly, then close the hole on your side
00:02:10	295	Pressure (?) twelve thousand
00:02:14	295	... ... Genoeg is ... Anderster kan ons vlug verongeluk (is enough ... Otherwise our flight could come to grief)
00:02:25	295	Carrier wave only
00:02:38	295	Eh Plaisance, Springbok Two Nine Five, do (did) you copy
00:02:41	MRU	Eh negative, Two Nine Five, say again please, say again
00:02:43	295	We're now sixty five miles
00:02:45	MRU	Confirm sixty five miles
00:02:47	295	Ya, affirmative Charlie Charlie
00:02:50	MRU	Eh, Roger, Springbok eh Two Nine Five, eh re you're recleared flight level five zero. Recleared flight level five zero
00:02:58	295	Roger, five zero
00:03:00	MRU	And, Springbok Two Nine Five copy actual weather Plaisance Copy actual weather Plaisance. The wind one one zero degrees zero five knots. The visibility above one zero kilometres. And we have a precipitation in sight to the north. Clouds, five octas one six zero zero, one octa five thousand feet. Temperature is twenty two, two two. And the QNH one zero one eight hectopascals, one zero one eight over
00:03:28	295	Roger, one zero one eight
00:03:31	MRU	Affirmative, eh and both runways available if you wish
00:03:43	MRU	And two nine five, I request pilots intention
00:03:46	295	Eh we'd like to track in eh, on eh one three

TIME	SPEAKER	RECORDED INFORMATION
00:03:51	MRU	Confirm runway one four
00:03:54	295	Charlie Charlie
00:03:56	MRU	Affirmative and you're cleared, eh direct to Foxtrot Foxtrot. You report approaching five zero
00:04:02	295	Kay
00:08:00	MRU	Two Nine Five, Plaisance
00:08:11	MRU	Springbok Two Nine Five, Plaisance
00:08:35	MRU	Springbok Two Nine Five, Plaisance

(NO ANSWER)

A NTSB human performance expert commented as follows on the pilot's last VHF communication with the approach controller :

"The air traffic recording is generally of very good audio quality. After screening it, I had a definite impression that there were changes in the stress level of the speaker (who was identified to me as the captain) over the course of the tape. From 23:48:51 to 23:49:30 the speaker sounds relatively calm, speaking slowly and courteously (although the seriousness of his communication is clear from its content). At 23:49:30 he fails to complete the sentence, and there is a definite impression that someone or something in the cockpit is distracting him due to the growing emergency. From this point until the end he definitely sounds more agitated, is definitely more distracted, and appears to be talking more quickly. Several of the transmissions, for example from 00:01:34 to 00:02:14, appear to have the high levels of fundamental frequency, speaking rate, and amplitude which are generally characteristic of great psychological stress (the statement at 00:01:45 seems so high it is close to screaming). It should be noted, however, that these statements appear to be inadvertent transmissions meant for the on-board crew and that the speaker may be yelling partly to be heard through his oxygen mask and above the background noise in the cockpit. In the final section, from 00:02:38 to the end, the speaker appears to be more composed and responsive than he was in the preceding section. It seems possible that he has calmed down somewhat and feels that the emergency is more under control at this point than it was at earlier points. These comments are based on simply reviewing the tape and do not reflect scientific measurement for psychological stress."

1.10 Aerodrome Information

The emergency services at Plaisance Airport conformed to category 8 standards as laid down in ICAO's Annex 14. All navigational, landing and communication aids were functioning normally. At 00:25 everything was ready to receive the aircraft in distress and everybody was on alert. The aerodrome was not equipped with surveillance radar and only runway 14 was equipped with an ILS.

1.11 Flight Recorders

The following recorders were fitted :

(1) Penny and Giles quick access recorder (QAR) type D50761 for logging flight data. The QAR was mounted in the main equipment bay just forward of the lower cargo hold at station 460. This recorder was not recovered.

(2) Lockheed model 209F digital flight data recorder (DFDR) Part no. 10077 A500 - 803 fitted with a Dukane N15F210B underwater locator beacon. The DFDR was mounted on top of a stowage facility in the left hand rear side of the main deck cargo compartment at station 2320. This recorder was not recovered.

(3) Collins type 642 C-1 cockpit voice recorder (CVR) Part no. 522 - 4057 -002 fitted with a Dukane N15F210B underwater locator beacon. The CVR was mounted next to the DFDR and was the only recorder found and recovered from the sea bed.

After the CVR was found it was handled with great care and all possible precautions were taken to ensure that the recorded information would be retained. To prevent the formation of air bubbles on the tape and hence a deposit of sea water chemicals, the transfer from the lifting tackle to the transport container was performed under the water. Once on board the ship the sea water was replaced with de-ionised water whilst ensuring non-entry of air into the recorder unit. Ice made from de-ionised water was progressively added to maintain the temperature within the range of 4 to 12°C. The CVR, in the transport container, was then flown to the Operator's suitably equipped laboratory for removal of the tape. All metal tools used for this process were de-magnetised. The tape was removed with the unit submerged in de-ionised water and cleaned in such water by winding it from one reel to another after which it was dried in a vacuum chamber with periodic nitrogen purging. After drying the tape was hand carried to a NTSB laboratory in Washington DC for copying and analysis.

Examination of the recorder revealed impact damage to the outer casing. It had been exposed to heat as evidenced by blistering of the paint. The insulation of electrical wiring found attached to the mounting rack plug was scorched. The solder of some electrical wire joints had melted which was a further indication that the unit had been exposed to heat. The melting point of the solder is 183°C. The interior of the unit was covered with an oily soot, ingress of which was probably through an aperture in the front cover. The plastic blanking plug of this aperture had melted. The signal and control wiring was routed along the top left hand side of the main deck cargo compartment in raceway G and was next to the DFDR wiring. The power supply cable was routed along the top right hand side in raceway H.

The CVR locator beacon was examined by the manufacturer who concluded that the unit had been subjected to external heat in excess of 190°C. This temperature caused the solder surrounding the water switch spring to reflow and hold the switch in the compressed position. This high temperature also damaged the potting compound around the transducer and the transducer itself, and the reflowed solder in the module caused it to short-circuit. The electronics module was also found to be internally short-circuited across the battery connection.

The CVR was powered directly from the essential 115v AC bus and was wired to record from the audio selector panels of the pilot, co-pilot, flight engineer and from the cockpit area microphone. The CVR was not wired for "hot mic" recording but all verbal communications from the abovementioned crew members via oxygen masks, hand held and boom microphones would have been recorded.

"HOT MIC" recording means that the microphones are connected to a recorder in a manner that ensures the recording of all cockpit sounds within the range of the microphones regardless of audio control panel selections.

Although the tape was not damaged , much of the information which was recorded on the area microphone channel only, was unintelligible. Only the last 1 minute and 14 seconds of the 30 minute recording cycle were reasonably clear. However, sufficient data was recovered to determine that the cockpit conversation prior to the sounding of the fire bell had been on personal and general topics only. "Joe" referred to in the following transcription was the senior flight engineer. Free translations of Afrikaans phrases are in brackets. Here again the best available interpretation has been put on words which are not clear.

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
28:31	Fire alarm bell (was stopped very quickly by the crew)	
28:35	Intercom chime	
28:36	Joe	What's going on now?
28:37	?	Huh?
28:40	Joe	Cargo?
28:42	Joe	It came on now afterwards
28:45		Strong click sound
28:45	?	And where is that?

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
28:46		Click sound
28:48	Joe(?)	Just to the right
28:49	?	Say again(?)
28:52	Joe	Main deck cargo
28:57	Joe	Then the other one came on as well, I've got two
29:01	Joe	Shall I (get/push) the (bottle/button) over there
29:02	?	Ja (Yes)
29:05	Capt	Lees vir ons die check list daar hoor (Read the check list there for us please)
		(Double click sound)
29:08	?	The breaker (presumably referring to the circuit breaker) fell out as well
29:09	?	Huh
		(Two click sounds)
29:11	?	We'll check the breaker panel as well
29:12	Capt	Ja (Yes)
		(Sounds of movement can be heard with clicks and clunks)
29:33	Capt	Fok dis die feit dat altwee aangekom het - dit steur mens (Fuck it is the fact that both came on - it disturbs one)
29:36	Intercom chime (while captain is speaking)	
29:38	?	Aag shit
29:40	!!!	(800 Hz TEST TONE signal commences)

TIME IN MINS. AND SECS. FROM BEGINNING OF TAPE	ORIGIN	CONVERSATION/REMARKS
29:41	Capt	Wat die donner gaan nou aan? (What the hell is going on now?) This is said in a surprised tone of voice.
29:44		Sudden loud sound
29:46		Large and rapid changes in amplitude of test tone start
29:51		End of test signal, very irregular near end
29:52		End of recording. There is about 1 second of old recording on this side of the tape.

The 800 Hz test tone is introduced on all four CVR channels. After about 6 seconds rapid changes in amplitude (warbling) commence. After another 5 seconds the signal ends. As noted above (in paragraph 1.1 p 14), these concluding sounds indicate that the audio input and test signal wiring were being affected by the fire.

The tape ran for exactly 29 minutes and 52 seconds. It was noted that neither the last HF communication with MRU at 23:14:00 nor the first VHF communication with MRU approach control at 23:48:51 was recorded on the CVR.

1.12 Wreckage and Impact Information

1.12.1 The search for the bodies and wreckage was commenced on November 30th 1987 after a decision was made to abandon the search for survivors. Numerous ships, aircraft and helicopters took part in the search. From December 2nd 1987 the search was concentrated on an accumulation of debris which was drifting in a westerly direction. Spotting was by aircraft crews who directed the ships to the floating wreckage. Helicopters were used to search the coral reefs for trapped wreckage. The search for floating wreckage continued in earnest until December 10th 1987.

The floating wreckage consisted mainly of articles of light cargo, cabin panelling, cabin furnishing and escape slides or rafts. It was soon noticed that many of the retrieved articles had been subjected to heat or smoke. Several cargo articles carried in the main deck cargo compartment were burned and some panels in the passenger compartment adjoining the main deck cargo compartment were covered with soot. The cabin to main deck cargo compartment door showed signs of heat damage. None of the retrieved articles positively identified as coming from the lower cargo holds had any signs of exposure to heat or smoke.

On 11 December 1987, 3 ships commenced the search for the underwater locating beacons (pingers) which were fitted to the CVR and to the DFDR. To accomplish this it was essential to set up a grid of navigational beacons. An oceanographic research vessel, which happened to be available at Mauritius, was contracted to do a sonar sea bed survey and to map the sea bed. This survey was conducted from December 12th to 21st 1987 during which time some light pieces of debris were seen on the sea bed by means of TV cameras and photographed.

The pinger search continued until January 2nd 1988 without success. Another vessel with special manoeuvring features was hired and then fitted with side scan sonar equipment to search for the wreckage field. Because of unfavourable weather conditions the search could only commence on January 25th. On January 28th the main wreckage field was identified at co-ordinates 19°10'5" S and 59°36'57" E at a depth of 4 400 m. The debris field position was then marked by the use of two underwater transponder beacons.

The wreckage pieces on the sea bed were found dispersed in two oblong areas with light wreckage some 2,4 kilometres to the North-west of the two areas which were displaced in the direction of the normal flight path. A plan of these areas is annexed as Appendix A Volume 2 pp 1-5.

The longitudinal axes of the two oblong areas were in a general direction of approximately 320° magnetic, which is the estimated direction of the ocean current in that region. This does not imply that the aircraft was not on a more or less correct flight path at the time of the initial impact. The flight path, if not disturbed, would have been in the direction of 250° magnetic.

The two oblong wreckage areas can be referred to as the North-eastern and South-western areas. The North-eastern area is approximately 900 m long and 450 m wide. The centres of the areas are approximately 600 m apart and their perimeters are separated by a zone of some 200 m. Some cargo items, mainly computers, and fragments of wreckage were observed in this area.

The North-eastern area contained debris from aft of No 4 doors and included the following: Horizontal and vertical stabilizers.

Some 70% of the aft fuselage structure.

The main deck cargo door.

Two sections of the main deck cargo floor.

No 4B galley.

Rear pressure bulkhead.

The auxiliary power unit with its compartment and the tail cone.

Numerous items of main deck cargo.

The South-western area contained the highest concentration of debris from forward of No 4 doors, which was extensively fragmented. Major items in this area included three engines, four landing gear assemblies and numerous items of fuselage and wing structures.

The debris in both areas had drifted while sinking. The dispersion of items was influenced by their individual sinking characteristics and the effect of the ocean current. High density items were found in the South-eastern area with a progressive spread of items with low sink rates in a downstream (North-westerly) direction.

After location of the wreckage a contractor was selected to provide the technology and equipment necessary to photograph pieces of significance and to retrieve selected pieces. The then state of the art made this a difficult and lengthy investigation, with a large experimental factor. Recovery of the recorders was considered first priority. Photography and recovery of the wreckage were conducted from a specially equipped ship, the STENA WORKHORSE, by means of a remotely operated vehicle (ROV). This took place under the control and supervision of the investigator-in-charge, and with the technical assistance and support of SAA on all aspects of the search, and of Boeing in the identification of items of wreckage.

The photographic and video equipment installed on the ROV also enabled visual inspection of the wreckage. It was therefore possible to identify and inspect many of the wreckage pieces on the sea bed and to decide on recovery priority. Some 3 940 colour photographs were taken and 806 hours of video tape recordings were made. Wreckage pieces of importance were given designated target references and numbered in sequence. Attempts were made to retrieve all items of cargo and all wreckage pieces showing evidence of heat, but unforeseen circumstances prevented these optimistic intentions. It was, however, possible to retrieve 25 targets, some of which proved very valuable for investigation purposes. Amongst these were the cockpit voice recorder, rearmost galley support structure, sections of main cargo deck fuselage and crown skin and a section of the rear pressure bulkhead.

1.12.2 Examination of the wreckage was described to the Board under four headings, namely :

Recovered floating wreckage.
Wreckage recovered from the sea bed.
Wreckage observed on the sea bed.
Recovered wreckage of which the actual position in the aeroplane could not be determined.

(Photographs of the various items and lists of all wreckage items are too numerous to be annexed to this Report. All important items have been studied by the Board. After this Report has been released all photographs, videos and lists of wreckage items will be filed in the library of the Directorate of Civil Aviation in Pretoria.)

Some of the wreckage pieces from the passenger cabin and from the main deck cargo compartment as well as articles of cargo carried in this compartment were stained blue. A consignment of blue organic dye powder was carried in the left hand front pallet, PL.

1.12.2.1 Recovered floating wreckage.

Examination of the wreckage revealed the following :

(1) Parts of wing secondary structures, such as pieces of access panels, wing leading edges, flaps and ailerons, showed no evidence of smoke or exposure to heat.

(2) None of the items from the lower

cargo hold, the forward upper deck and from Zones A, B and C of the passenger compartment showed any signs of smoke deposit or exposure to heat except that the portable fire extinguisher from door No 2 right showed soot deposits and a splatter of molten plastic material. (Appendix B, Volume 2 p 6 shows the different zones.)

Two rearward facing attendants' folding seats from doors 1 and 2 left were also recovered. The seat at No 1 left hand door was extensively damaged by impact while the seat pan was in the occupied (horizontal) position. The buckle on the right side safety harness was latched and the belts had broken close to the buckle. The harness was found detached from the seat frame. The seat at No 2 left hand door was also extensively damaged, but impact occurred while the seat pan was in the stowed (vertical) position. The safety harness was found unlatched and remained attached to pieces of the seat frame.

(3) The only items from Zone D (see Appendix B, Volume 2 p 6), which showed evidence of exposure to heat and smoke, were two pieces of the right hand life raft stowage bin at body station 1700. Other items such as galley stowage doors at body station 1680, the lower bustle of cabin door No 4 right and the escape slide packboard of cabin door No 4 left showed signs of smoke deposits only.

(4) A number of items from the main deck cargo compartment (Zone E - see Appendix B Volume 2 p 6), showed evidence of exposure to heat and smoke. The partition door between the main deck cargo compartment and the passenger compartment showed heat discolouration on the upper section of the rear lining. This section of lining was delaminated from the honeycomb core structure. There was also evidence of blue dye staining and splatter on the inner

surface of the aft lining and on the exposed honeycomb structure. The door knob assembly had been ripped out of the door receptacle. The rear door handle adjacent to the knob was adrift at the upper attachment. The retaining collar was missing and the exposed threads showed no signs of smoke deposits. There was some evidence of splatter of molten plastic material on the forward decorative lining but no sign of heat or smoke exposure. Part of the upper lining was missing. The door hinge which remained attached to the door support frame showed evidence of smoke streaking and distortion while in the closed position.

The upper bustles of No 5 left and right doors, a shelf from the aft coat closet and a section of left upper side wall lining showed signs of heat damage and smoke deposits. The top section of the left side wall lining showed signs of heat damage and smoke deposits.

(5) Three slide/rafts and one off-wing slide were recovered. The only observation of possible significance is that damage to the girt bar assembly of the slide/raft identified as from door No 2 left, indicated that this door was probably in the automatic mode. Damage to the girt bar assembly of a slide/raft of which the door number could not be determined, also indicated a probable automatic mode of the door. The position of the third slide/raft was determined as No 4 door left.

1.12.2.2 <u>Wreckage recovered from the sea bed.</u>

Examination of the debris revealed the following :

(1) Section of overhead bin support structure. (Target 213 : see App C Volume 2 p 7.)

Evidence of heat and smoke deposits was noticed on the structure extending forward to body station 1320 above the passenger cabin ceiling in Zone D.

(2) Transverse beam structure above galley 4B in Zone E. (Target 214 : see App C Volume 2 p 7.)

Deposits of molten aluminium, nylon 6.6 with a ball bearing entrapped and a partially melted aluminium bracket with a screw and anchor nut attached, were found on the centre section upper surface of the beam. Insulation of wiring at the rear centre section of the beam was destroyed by heat and showed evidence of arcing. Two of these wires were identified as the 115v AC power leads for the main deck cargo compartment crown lights.

(3) Section of the forward right main deck cargo floor. (Target 219 : see App C Volume 2 p 7.)

The floor structure fractured laterally at body stations 1760 and 1960 and longitudinally along the centre line. A piece of fuselage side structure remained attached to the right side which showed evidence of water impact. Molten material and burn marks were evident on the upper surface of the floor between body station 1760 and 1780. No evidence of heat damage or smoke deposits was noted on the lower surface.

(4) Piece of the forward left main deck cargo floor. (Part of Target 13E : see App C Volume 2 pp 7, 16 and 17.)

The floor section failed at body station 1720 and subsequently at body station 1740 during attempted recovery of target 13E. Deposits of molten aluminium, nylon 6.6 and polyester were evident on the upper surface. No evidence of heat or smoke was observed on the lower surface.

(5) Section of R/H aft fuselage structure (Target 197 : see App C Volume p 7.)

The structure failed at body

stations 1720 and 1860 and at stringers 12R and 25R. Heat damage to frames and skin was evident between body stations 1780 and 1840 and stringers 12R and 17R. Heat discolouration of paint occurred on the outer skin surface between body stations 1800 and 1840 and above stringer 16R. Heat damage was apparent on the two lower horizontal straps of the 9G barrier net forward of pallet position PR. The remainder of the horizontal straps above the cabin window level were burned off either at a position forward of pallet PR or at the fuselage attachment points.

(6) Section of 9G barrier net with floor mount.

All vertical straps at body station 1750 and forward of pallet position PR were burned off at approximately 1,3 meters above the main deck floor level.

(7) Upper section of galley 4B at body

station 1700. (Target 204 : see App C Volume 2 p 7.)

There was evidence of heat exposure and smoke deposits on the left and right rear top panels and upper surfaces of the galley unit, particularly in the centre and on the right hand side. The unit was relatively intact with some lateral distortion evident on the left. The right side oven doors showed evidence of severe water impact damage.

(8) Large section of the lower aft fuselage structure (Target 244 : see drawing App C bis Volume p 18).

No signs of heat exposure or smoke deposits were evident on the inner or outer surfaces. The structure showed evidence of water impact damage on the lower right side of the fuselage which is consistent with the impact damage observed on target 219. The lower section of the lower aft cargo door was still secured to the fuselage structure by its latches.

(9) Section of R/H aft fuselage structure. (Target 256 : see App C Volume 2 pp 7-8.)

The structure fractured at body stations 1640 and 1960 and at stringers 4R and 17R. Extensive heat damage occurred to frames and stringers between body stations 1760 and 1880 and between stringers 4R and 11R. Smoke deposits and heat discolouration of the paint were evident on the skin surfaces behind some frames and stringers which had become detached from the skin. Eight 9G barrier net straps burned off at their fuselage attachment fittings. Blistering and discolouration of the paint occurred on the outer skin surface between body stations 1800 and 1840 and stringers 4R and 11R. Deformation and buckling of the skin were also evident in this area. This structure matches with targets 197 and 263 :

see App C Volume 2 pp 7-8.)

(10) Section of right hand aft fuselage structure (Target 263 : see App C Volume 2 pp 7-8.)

The structure fractured at body stations 1940 and 2140 and at stringers 13R and 24R with a small section extending below cabin floor level. Although exposed to the main deck cargo compartment, the insulation blankets in this area provided adequate protection to prevent the formation of smoke deposits.

(11) Piece of R/H aft fuselage structure. (Target 221 : see App C Volume 2 p 7.)

This piece of fuselage structure fractured at body stations 2120 and 2220 and at stringers 5R and 15R. The structure mates with target 263 at body station 2120 and stringer 15R. Limited heat damage and smoke deposits were evident along the upper section above stringer 7R.

(12) Section of aft fuselage crown structure. (Targets 255 and 267 : see App C Volume 2 p 7 and p 9.)

The structure fractured at body stations 1960 and 2200 and at stringers 5R and 8L. It showed evidence of heavy smoke deposits on the inner surface and heat discolouration of the paint on both the inner and outer surfaces. Deformation of the structure through impact showed a twist due to a high torsional load in a clockwise direction. This deformation is consistent with the mode in which Target 256 fractured at body station 1740.

(13) Dorsal fin with piece of empennage structure. (Target 38 : see App C Volume 2 p 10.)

The structure separated at body stations 2200 and 2300 and at stringers 5R and 4L. Paint discolouration, smoke deposits and paint peeling were evident on the inner surfaces at the forward and aft sections of the structure. Blistering of paint was evident on the outer surface. Structural deformation through impact indicated that the dorsal fin had peeled off from the empennage structure in a forward and left direction.

(14) Life raft support beam at number 5 door position. (Target 130 : see App C Volume 2 p 7.)

This item showed evidence of slight heat discolouration and heavy smoke deposits on both top and bottom surfaces. Although subjected to heat, the attached electrical wiring insulation remained intact. Only slight structural deformation was evident.

(15) Passenger entry door, number 5 left. (Target 282 : see App C Volume 2 p 7.)

The inner surface of the door structure showed evidence of light smoke deposits. The door upper trim bustle (item No 072) showed blistering of the paint due to heat. The door separated from the hinges on impact with only slight damage to the door and its operating mechanism.

(16) Two sections of the upper half of the aft pressure bulkhead with elevator cables attached. (Targets 39 and 232 : see App C Volume 2 p 7 and p 11.)

Heavy smoke deposits and heat discolouration were evident at the top centre sector location and all control cable aperture seals were damaged. There was evidence of light smoke deposits on the aft surface of the bulkhead.

1.12.2.3 <u>Wreckage observed on the sea bed.</u>

Examination of the wreckage revealed the following :

(1) Landing gear.

Components associated with the left wing and body gears, the right wing gear and the nose gear, were examined and it was established that the landing gear was retracted at the time of impact.

(2) Power plants.

The power plants were extensively damaged by impact forces and only three of the four were found. The nature of damage sustained by the power plants indicated low power, or rotation at the time of impact. (See the report of the power plant manufacturer, App C Volume 2 pp 12-15.)

(3) Large section of left aft fuselage structure incorporating the main deck cargo door. (Target 13E : see App C Volume 2 p 7 and pp 16-17.)

The structure fractured at body stations 1720 and 2000 and extends from below cabin floor level to stringer 1R. Severe heat damage was evident on the fuselage crown structure with signs of smoke deposits extending down to the upper main deck cargo door frame. A large section of the main deck cargo floor is attached to the fuselage structure and deposits of molten material were noted between the 9G barrier net and pallet position PL. Several straps of the 9G barrier net, which were visible, showed some heat damage and signs of blue stains.

(4) Horizontal stabilizer assembly. (Target 41 : see App C Volume 2 p 10.)

The horizontal stabilizer was found to be complete with elevators attached. There was no evidence of heat or smoke deposits on the skin surfaces. The left stabilizer leading edge was detached from the front spar. The tip and adjacent structure were extensively damaged i.e. split and bent upwards. The outboard elevator tip was detached. It was observed that the stabilizer actuator jackscrew had sheared below the gimbal ball nut with four grooves protruding below the ball nut and nine grooves above. No distortion of the jackscrew was evident. The inboard rib at the root end of the right hand stabilizer leading edge was deformed, indicating an anti-clockwise rotation of the aft fuselage structure.

(5) Vertical stabilizer. (Target 36 : see App C Volume 2 p 10.)

The stabilizer was complete with both upper and lower rudders intact and a section of empennage structure remained attached to the base. There was no evidence of heat or smoke deposits on the outer surfaces and no significant impact damage was apparent.

(6) Pallet stack tie down net.

Only one net was recovered. The centre portion which covered the the pallet stack top had burned away.

1.12.2.4 <u>Recovered wreckage of which the actual positions in the aeroplane could not be determined.</u>

Some of these wreckage pieces showed signs of exposure to heat and smoke. Examples are pieces of cabin ceiling panels and pieces of air ducts.

1.13 Medical and Pathological Information

Fifteen lots of human remains were found and presented for post-mortem examinations. One lot contained the fragmented remains of two different bodies. The lower respiratory passages of one of these two bodies contained soot. The contents of six lots were only described and not further reported on.

The reports on the medico-legal post-mortem examinations on 8 bodies indicated extensive injuries to the upper parts namely to heads, chests and ribs. The cause of death of six accident victims was given as multiple injuries and of two as multiple injuries plus carbon monoxide intoxication. The blood specimens of these two bodies were in an advanced state of decomposition. Analyses for carboxyhaemoglobin were done by gas chromatography. The carboxyhaemoglobin saturation was 60,5% and 67,2%. (see paragraphs 1.14.2 p 68 and 2.12 pp 130 - 138 below). No cyanide was found in the blood from the victim that had 67,2% saturation. No mention was made of a cyanide test of the other blood specimen or of any other blood tests. The allocated seat numbers of the two victims with high carboxyhaemoglobin saturations were 30E and 40D. Seat 30E was located in the Business Class, at body station 1160, which was fairly far forward in the passenger cabin. The respiratory passages of all eight bodies examined, contained soot. Five of the victims could be identified. They had been allocated seats 30E, 37A, 37D, 40D and 42A.

Radiological examinations were conducted on 5 bodies. No signs of radio opaque foreign objects were found.

1.14 Fire

1.14.1 The first known indication of fire was an alarm signal on the flight deck (recorded on the CVR) that was identified by the flight crew as coming from the main deck cargo compartment smoke warning detectors. This occurred 28 minutes 31 seconds from the beginning of the CVR recording. Approximately twenty six seconds later the flight engineer stated that the "Other one came on as well, I've got two". At 29 minutes 5 seconds into the recording the main deck cargo fire check list was called for, and at 29 minutes 52 seconds the recording ended. This was 1 minute 21 seconds after the fire alarm bell was recorded.

At about 23:49 the pilot contacted Mauritius approach control and stated that the flight was in an emergency descent to FL 140 due to a smoke problem in the aeroplane. Two minutes later, in response to Mauritius' request for a position report, the pilot stated "Now we've lost a lot of electrics, we haven't got anything on the on the (sic) aircraft now". About nine minutes later, at 00:02:25 the pilot reported and confirmed "We are now sixty five miles". The flight was recleared to FL 50, which was acknowledged by the pilot. In the last series of communciations with Mauritius, the pilot requested runway 14 and in the last contact with Mauritius acknowledged an instruction to report approaching FL 50. There was no mention of smoke or fire by the crew during these last series of transmissions.

1.14.2 Examination of the aeroplane wreckage disclosed heat and smoke damage that was most prominent in the main deck cargo compartment, consistent with the alarm recorded on the CVR. Some heat and smoke damage was, however, found in the aft galley area, which is forward of the partition that separates the passenger cabin from the main deck cargo compartment. Additionally, lethal levels of carboxyhaemoglobin were found in the blood of two passengers from which specimens were obtained. See paragraph 1.13 p 66 above. These findings were challenged by counsel for Boeing before the Board, but as appears from the Analysis in this Report (paragraph 2.12 pp 130-138 below), the Board is satisfied that they are correct. Soot deposits were present in the respiratory tracts of the eight bodies that could be examined. It was noted that the area of greatest concentration of structural damage due to heat was in the upper area of the fuselage in the right front portion of the main deck cargo compartment.

1.14.3 The main deck cargo compartment in the 747-244B Combi (Zone E) is a Class B compartment as defined by FAR 25.857(b). The compartment is divided into two smoke detection zones, each of which is equipped with a dual smoke detection system providing a warning to the flight crew. There is no evidence that the flight crew were aware of any indications of fire prior to the sounding in the cockpit of the main deck cargo warning alarm bell. None of the warning systems was recovered from the ocean.

The Boeing Flight Manual approved for the aeroplane does not prescribe emergency procedures for a main deck cargo fire but these procedures are contained in the Operations Manual and are included in the Operator's emergency check list carried in the cockpit. (See Appendix D Volume 2 pp 19-20.) The check list specifies that the flight crew should don their oxygen masks (and smoke goggles, if needed) and that a flight attendant must don an oxygen mask and portable oxygen cylinder and at the captain's direction enter the cargo compartment. The flight attendant must then close the partition door, unclip the fire extinguisher from its stowage, unclip the cargo net gate, remove the 3 m long applicator from its stowage and attach it to the extinguisher nozzle, find the source of the fire and apply the extinguishant. The areoplane must be landed at the nearest suitable aerodrome.

The flight crew is referred to the Upper and Main Deck Smoke Evacuation check list from the main deck cargo fire/smoke procedure "if a smoke condition exists in the passenger area". This procedure instructs the non-flying pilot to determine the status of the smoke in the cabin, and outlines a descent to 14 000 feet or the Minimum en-route Altitude (MEA) "if an immediate landing cannot be made and smoke condition is extremely severe". The procedure also calls for the crew to be on 100% oxygen, with smoke goggles on if necessary. The pilot not flying is to identify the cabin doors to be opened for smoke evacuation. The aeroplane is de-pressurized, is slowed to below 200 knots, and the doors to be opened placed in manual mode. The door/s is/are partially opened at the captain's direction. The captain stated to Mauritius approach control that the aeroplane was in a descent to FL 140 due to a smoke problem in the aeroplane, but he did not say whether the smoke had reached the flight deck. Cockpit smoke evacuation procedures are not used unless the smoke source is inside the cockpit.

1.14.4 None of the cockpit oxygen masks were recovered for examination, nor was any part of the oxygen system. Similarly, none of the fire fighting equipment for the main deck cargo compartment was found. It was noted that two of the cargo barrier net clips were unclipped at the release fittings. Evidence to indicate that fire fighting procedures had been commenced is provided by the splatter of barrier net material (i.e. from the cargo hold) on the Halon fire extinguisher from door 2R (i.e. from the passenger cabin).

There were in total eight 2.5 lb Halon 1211 fire extinguishers installed in the passenger and flight deck areas of the aeroplane. Three 3.63 lb water extinguishers completed the portable fire extinguisher complement that was available in the passenger cabin and cockpit. Of these, one Halon extinguisher that was installed at door 2R was recovered with the floating debris. The bottle was full, but this was the extinguisher on which there was some melted nylon present on the outside surface. All these fire extinguishers were checked and recertified during 1987.

1.14.5 Supplemental oxygen is provided by separate fixed systems for the flight crew and passengers, and portable oxygen bottles are positioned throughout the cabin and cockpit for use if needed. Individual oxygen masks are automatically released from the passenger service units when the cabin altitude is at or above 14 000 feet. The B-747 Operations Manual warns that passenger oxygen use should be discontinued "below 14 000 feet when smoke or an abnormal heat source is present. The use of passenger oxygen will not prevent passengers from inhaling smoke at any altitude".

1.14.6 Numerous articles of cargo carried in the main deck cargo compartment and also compartment structure, fittings, and components were damaged by fire. Many of the cargo articles and all the packing materials used were flammable. The cargo was largely comprised of electrical components and parts (mainly computers), hardware, paper articles, textiles and sports equipment. Inquiries revealed that several computers and some computer circuit boards were fitted with either nickel cadmium or lithium batteries. Visits to the places of business of 66 consignors revealed that packing materials were mainly polystyrene, polyurethane, polyethelene sheeting and paper. Light articles such as computers and parts were packed in cardboard cartons while heavy units such as machines were either in wood crates or wood boxes. The crates, boxes and cartons were stacked approximately 2 m high, on 6 pallets designated PL, RL and SL from front to rear on the left hand side of the main deck cargo compartment and PR, RR and SR on the right hand side. The base dimensions of the pallets were 3,175m x 2,235m for PL and SL and 3,175m x 2,438m for RL, PR, RR and SR. The longitudinal aisle width between two 2,235m wide pallets is 48,75cm (19,5 inches) and 9,062cm (3 5/8 inches) between two 2,438m wide ones. The left front (PL) and left rear (SL) stacks had been covered with polyethelene sheeting. The stacks had been secured to the pallet bases with nylon nets.

The pallets on which particular cargo consignments were placed could only be determined from the master air waybills as only these waybills had been recorded when the pallets were made up, but many of the master waybills were consolidations of house waybills from consignors. This means that a consignment on one master waybill was spread out on two or more pallets. For example, master air waybill No 4852 was a consolidation of 36 house waybills mentioning the articles despatched. The packages containing these articles were placed on pallets PR, SR and RL.

From the retrieved cargo items and from photographs taken of items on the sea bed it was determined that most of the cargo showing evidence of heat was on pallets PR (right front), RL (left centre) and SR (right rear). No heat exposed cargo items on pallets PL (left front), SL (left rear) and RR (right centre) were found.

The two pallets containing cargo consigned from Japan were PL and SL. Neither of these appears to have been involved in any way in the fire.

1.14.7 The Operator was not aware of any dangerous cargo in the aircraft and had ensured that cargo handling would be in accordance with procedures laid down by the International Air

Transport Association (IATA). The Operator's manager in Taipei stated that he would have been informed of any dangerous cargo and that he had not received any such information. He further stated that security measures at Chiang Kai Shek Airport were above average. Security of cargo at Chiang Kai Shek Airport was investigated and found satisfactory. Taiwan's Commissioner for Customs had conducted random sampling of the cargo consignments from Taiwan before they were loaded on the aeroplane. A computer selected 10 house waybills and one master waybill out of 111 bills. It was found that the items in the consignments agreed with the respective documents. The Chief of the South African Defence Force confirmed that no weapons or explosive devices were carried in the aeroplane for the SA Defence Force . The Executive General Manager of Armscor confirmed that there was no consignment of cargo to or from Armscor on the aeroplane.

Lithium batteries and activated carbon are listed as dangerous goods in the Technical Instructions for Safe Transportation of Dangerous Goods by Air (Doc 9284 - AN/905) published by the International Civil Aviation Organisation (ICAO). Six consignments of electronic equipment contained small lithium battery cells fitted to circuit boards. These cells were considered non-dangerous as Special Provisions A45 of Doc 9284 - AN/905 had apparently been met. A small quantity, 300 g, granulated activated carbon was carried in the lower cargo hold. According to Special Provision A51 of Doc 9284 - AN/905 granular activated carbon is considered non-dangerous if cooled for more that 8 days since manufacture. The manufacturer stated that the activated carbon in the consignment had been cooled for longer than 180 days after production.

1.15 Survival Aspects and Search and Rescue

On November 27th 1987 at 23:50 the approach controller at Plaisance Airport, who throughout acted with commendable efficiency, declared an emergency and an ALERFA was issued, followed by a DETRESFA at 00:40 on the 28th. At about this time two search and rescue co-ordinators activated the Search and Rescue Centre (SARC).

At 01:15 on November 28th 1987 an ALERFA - DETRESFA was sent to the civil aviation authorities and the Search and

Rescue Centre (SARC) of the State of Registry. Plaisance ATC was asked if assistance was required and was informed that a Lockheed 382 aeroplane would be ready to depart from Jan Smuts Airport at 08:00 on November 28th 1987.

At 02:29 an Air Mauritius helicopter and a Mauritius Police helicopter departed for a search North of Mauritius. They were followed at 02:40 by a DHC-6 (Twin Otter) of Air Mauritius and a Transall of the French Air Force at 02:40. The search areas were extended to areas West, North-east and South-west of the island but nothing was found. At 12:47 the crew of a Beech 18 aeroplane, who took part in the search on their own initiative, saw wreckage pieces 136 nm North-east of Plaisance. At 15:20 the SARC issued a situation report giving the following information : "Position of accident site at 1904S and 5936E. One empty dinghy and some debris located including one escape chute, something resembling a kerosene tank and some luggage. Two ships proceeding to the accident site, estimated time of arrival 21:00. A search craft has dropped an emergency locator beacon to mark the accident site. The search will continue at first light (01:12) on November 29th. French C160, United States of America (USA) P3 Orion and Air Mauritius Aircraft will continue search for survivors as from dawn on 29th. Sea search is being carried out by a Mauritian navy vessel and other fishing vessels operating in the region".

On November 29th at 02:56 the wreckage pieces were relocated by the crew of a Transall aeroplane and the ships started with retrieval of bodies and floating wreckage. This was a slow process as floating objects were spread over a large area.

On November 30th at 07:30 it was decided, after anxious deliberation, to terminate the search for survivors and to concentrate on recovery of wreckage pieces. By this time mutilated human remains were retrieved but only 8 bodies were substantial enough for medico-legal post-mortem examinations. The nature of the injuries indicated that the impact forces were far too high for survival.

The following organisations immediately reacted positively to the search and rescue operations :

Mauritius Marine Authority
National Coastguard of Mauritius
Helicopter Section of Mauritius Police
Air Mauritius
French Air Force and Naval Base at Reunion
United States Navy at Diego Garcia
Perth Rescue Co-ordination Centre Australia
SARSAT Toulouse

The gratitude of all concerned for the unhesitating response of these authorities has been noted in the Foreword to this Report.

1.16 Tests and Research

1.16.1 In an endeavour to determine the probable source of energy that ignited the cargo, special attention was paid to lithium battery cells installed in some computers and electronic equipment carried as cargo, as reports were received that certain types of lithium batteries had exploded in emergency locator beacons e.g. those in which sulphur dioxide was used as electrolyte. Six small cells of the kind installed in the electronic equipment were examined by an expert. He reported inter alia that two battery cells were lithium-thionyl chloride types, two of lithium-carbon monofluoride and the other two nickel-cadmium. He concluded with the following summary :

"Characteristics and safety aspects of nickel-cadmium, lithium-carbon monofluoride and lithium-thionyl chloride batteries that were on board the SA Helderberg have been reported. All batteries sent to the CSIR (Council for Scientific and Industrial Research) for investigation were of small size either coin or cylindrical design and low capacity (less than 1900 mA/hr). The nickel-cadmium batteries (some of which were believed to be in a discharged state) and Li/CFx coin cells are generally recognised as being very safe to transport. Low-rate lithium-thionyl chloride cells have been widely accepted for use in consumer applications and during storage are generally regarded to be safe. However, if these cells are abused, for example by sudden short-circuiting or excess heating, the possibility of these cells exploding cannot be entirely discounted."

1.16.2 The FAA appointed a special review team in January 1988 to evaluate the adequacy of existing criteria for the certification of main deck class B cargo compartments. This team concluded its report as follows :

(1) The existing rules, policies and procedures being applied to the certification of class B cargo or baggage compartments in terms of smoke and fire protection are inadequate.

(2) The use of pallets to carry cargo in class B compartments is no longer

acceptable.

(3) While entry into the cargo compartment is available, not all cargo is accessible.

(4) It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

(5) The reliance on crew members to fight a cargo fire must be discontinued.

(6) The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

(7) The level of visibility in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

(8) Most existing transport aeroplane smoke or fire detection systems were certified prior to FAR 25 Amendment 25 - 54 and are incapable of giving timely warning.

(9) There were differences in the smoke testing procedures and criteria used from manufacturer to manufacturer, prior to issuance of FAA Advisory Circular (AC) 25 - 9.

The team recommended that no new main deck class B compartment designs be approved to the existing class B criteria and that main deck cargo compartments provide a level of safety equal to class C compartments or that cargo be carried in fire resistant containers meeting class C requirements including smoke detection and fire suppression capability. Changes to the rules were being considered.

1.16.3 Many of the floating wreckage pieces that were recovered shortly after the accident, were analysed for explosives by forensic scientists. No signs of explosives were found.

1.16.4 The tape recording of the cockpit area microphone was examined in Canada in search of a fuselage vibration signature which could indicate an explosive cause of the cargo fire. No recognisable signature was found.

1.16.5 Numerous specimens of aeroplane parts and articles from the passenger cabin and main deck cargo compartment were examined by an independent scientific institution in order to identify certain objects and materials, to determine temperature ranges at certain positions, to determine melting points of heat damaged components and to search for evidence which could be used to establish a probable cause of the fire which started in the main deck cargo compartment. The most significant findings can be summarised as follows :

(1) The metal buckle of a carry-on bag had melted at one end. The melting point of the metal was found to be 327°C. The assumed owner of the bag had been allocated seat No 42B in the rear-most row.

(2) The temperature in the main deck cargo compartment had ranged from 240°C at the rear end to 600°C at the partition between the cargo and passenger compartments. Tests on portions of the aircraft structure which were recovered indicated that

those particular portions had been exposed to a maximum temperature of the order of 300°C.

(3) A globule of molten nylon 6.6 found on the rearmost galley ceiling support structure contained a 3,1 mm diameter metal ball. Control cable pulleys in the area are made of nylon 6.6 and fitted with ball bearings having 3,1 mm diameter balls.

(4) A pantihose in a toilet bag was found partially melted to a heat damaged pallet load tie-down net. The toilet bag was not one of those provided by the Operator. Particles of copper, iron and melted plastic material were found inside the pantihose. Holes caused by hot particles were noticed in the hose and the toilet bag. Molten metal and molten plastic droplets were found on the netting.

(5) Sections of the 9G cargo barrier net had been heated to its melting point and the molten polyester net material then smeared over contamin-

ants during impact.

(6) Small pieces of glass were found driven into fragments of crating wood. The glass was similar to that of computer monitors carried as main deck cargo.

(7) Spherical iron particles were found in the insulation of an unidentified piece of electric conductor. The particles showed air flow patterns which indicated that they were travelling at high velocities while in molten states.

(8) The solder points inside the CVR started to melt at 183°C but components such as transistors seemed intact.

(9) Examination of two 1/8" diameter elevator control cables installed in the crown of the main deck cargo compartment revealed that they had been heated to a temperature in the region of 700°C at their fracture points. From tensile tests it was apparent that a cable heated to

700°C will break if a tensile load of between 56 and 100 lbs is applied to it. The minimum breaking strength of a sound cable is 2000 lbs.

(10) Microscopic examination of a black bag revealed the presence of tiny rust spots and a round black particle which was similar to those found in the electrical conductor mentioned above.

1.16.6 The aeroplane manufacturer advised that a slack elevator control cable would not allow overcontrol inputs. A completely slack cable would result in a neutral elevator which would be mechanically driven to neutral by a spring loaded roller and cam arrangement. The cable tension regulator can take up 5,05 inches of cable slack.

1.16.7 The manufacturer of the aeroplane analysed the structural capability of the cargo compartment crown section where the most heat damage was observed i.e. between body stations 1640 and 1960. The material allowables used are the properties at room temperature. The results can be summarised as follows :

(1) During level flight (1g) and manoeuvres within the operational spectrum (1g plus/minus 0,3g) the fuselage monocoque structure (skin and stringers) above the main deck floor is subjected to tensile loads.

(2) Damage to the crown structure is more critical than below stringer 4.

(3) The maximum operating manoeuvre loads are 1g plus/minus 0,3g. This represents an operational flight spectrum between 1,3g and 0,7g.

(4) A 1,3g manoeuvre is the maximum operating flight condition at cruise altitude combined with the normal cabin pressure of 8,9 pounds per square inch (psi).

(5) At the maximum operating manoeuvre load of 1,3g without cabin pressurisation the structure will tolerate damage to the skin between stringers 13L and 13R even if the 26 upper-

most stringers are all damaged. With the cabin pressurised to 8,9 psi the structure will tolerate skin damage between stringers 5L and 5R even if the 10 uppermost stringers have fractured.

(6) The fuselage skin panels can sustain operating loads of 1,3g plus 8,9 psi cabin pressure if the 38 uppermost stringers have fractured.

The Board considers that it was reasonably possible that in the unusual circumstances the loading on the aircraft substantially exceeded 2g.

1.16.8 Tests with a Boeing 747 Combi simulator showed that the emergency descent time from FL 350 to FL 140 was 3 minutes 30 seconds. The pitch angles were 15° nose down at entry of the descent and 10° nose down when the aeroplane was stabilised in the descent.

1.17 Additional Information

1.17.1 The electrical wiring in the main deck cargo compartment was routed in the fuselage crown area on the left and right sides and identified as raceways G and H respectively. Each raceway comprised several channels and each channel in turn comprised several groups of wire bundles relating to the various systems. Examples of these systems are the CVR, DFDR, automatic pilots, yaw damper, stabiliser electric trim, empennage control surface position indicators, lights and interphone system.

Circuit-breakers installed at various locations, many of which are in the cockpit, provide protection for all wiring by opening in the event of short-circuits, thereby isolating the affected system. In the event of an intense fire in the main deck cargo compartment it is possible that all or many of the wire bundles in raceways G and H would be damaged causing short-circuits. This would result in the opening of related circuit-breakers, a possible total of 80, of which 58 are located on various cockpit panels. Opening of the circuit-breakers would be accompanied by cockpit warnings and indications such as illumination of amber lights, flashing red lights and gauge indications.

The horizontal stabiliser trim is normally electrically controlled and hydraulically operated, but it can be controlled manually in the event of an electrical system failure. The elevators and rudders are cable controlled and hydraulically operated. All of these control cables are routed along the centre of the fuselage crown area and so are the pitot pressure and static tubes to the rudder ratio control modules, the pitot tubes to the elevator Q feel unit and stabiliser rate control sensing unit. If the control cables and/or the fuselage structure were not severely damaged by heat there should not have been any loss of pitch or yaw control.

As the electrical wiring, pitot pressure and pitot static pipe lines to the pitch and yaw control units had probably been damaged by the fire, the manufacturer of the aeroplane was requested to advise what the effects of such damage could have been on the flight characteristics of the aeroplane. The following answers were given to the following questions :

(1) Q. Loss of pitot static pressure to the elevator feel system?

A. The elevator feel system is a purely passive system, which means that the elevator feel system cannot cause elevator movement by itself. Even in the event of complete loss of pitot static senses a positive stick force always remains, e.g. 9 lbs at 2,5° of up elevator instead of 49 lbs under normal conditions.

(2) Q. Loss of associated electrical wiring to the elevator feel computer?

A. Loss of all wiring (short-circuited to ground) to the elevator feel computer would result in an elevator feel light on the master caution panel (assuming that panel still has 28v DC power) and the autotrim threshold could go to minimum (if autopilot is still operative and engaged); there would be no effect on control. The feel force for this occurrence would be normal as no electric power is used in the feel computation function.

(3) Q. Loss of all elevator channels, i.e. manual control?

A. Loss of pitch autopilot presents no hazard. The elevators remain centered by the feel unit springs.

(4) Q. Loss of a combination of the above?

A. Reversion to light feel forces under manual elevator control is easily handled by the pilot. This was demonstrated as part of the certification process. It should be noted that since the amount of required column movement for most flight operations is small, the difference in stick force with and without the feel system is also small and the amount of column movement that a pilot would make, even before noticing the lower force, is likewise small.

(5) Q. Loss of pitot static pressure to stabilizer trim system?

A. As with the feel computer the static

source is at outside atmospheric pressure. At 19 000 ft and above the stabilizer trim rate is at minimum; it would then vary with altitude down to 16 000 ft where the trim rate would be maximum. Stabilizer trim rates range from 0,2 to 0,5 degrees/second in manual control and from 0,1 to 0,25 degrees/second under autopilot control. These changes in trim rate do not affect controllability.

(6) Q. Loss of associated electrical wiring, i.e. main electrical control inputs and autopilot inputs?

A. Loss of electrical connections to the stabilizer trim would result in the loss of stabilizer trim from wheel trim switches and/or autotrim if autopilot were still engaged. The stabilizer trim brake release lights may illuminate if wiring to switch(es) is shorted and if 28v DC is still available at the master caution panel. If the stabilizer starts trimming from other than the autopilot, the autopilot would disconnect.

(7) Q. Loss of any combination of the above?

A. No combination of the above can create a control problem.

(8) Q. Loss of the Yaw Damper System?

A. The yaw damper suppresses the basic aeroplane dutch roll mode and provides modal suppression to reduce fatigue loads on the structure in turbulence. At worst the aeroplane could sustain a low amplitude dutch roll after a gust and slowly damp out without pilot correction. Handling characteristics without yaw damper, light feel forces, and higher than normal trim rate are not seriously degraded as only the light feel forces would even be noticed.

(9) Q. Loads on aeroplane structure due to the loss of any single or a combina-

tion of all of the above-mentioned systems?

A. The mentioned systems : Stabilizer rate, elevator control forces and yaw damper are tailored for best possible handling qualities and passenger comfort rather than structural protection by limiting pilot manoeuvre capability in manual flight.

1.17.2 The control relays for the pressurisation system outflow valves were mounted on the P85 panel beneath the flight recorder. The operating temperature range of these relays is from -65°C to +85°C.

The aeroplane manufacturer advised that failure times of the relays are dependant on test temperature and whether or not a relay is being repeatedly energised or de-energised (switched). Normal automatic operation would not result in the relay being switched. Testing of the relays indicates that at 300°C the switching capability may be lost in approximately 6 minutes when the relay is repeatedly switched during the test period but may be operable up to one hour without prior switching. At 500°C the times are approximately 3 minutes and 6 minutes respectively. The lost switching capability is due to softening and flowing of the arc barrier material around the contacts.

Heat damage to the control relays could have caused the outflow valves to remain in the normal cruise position in which event the crew could have experienced difficulity in depressurising the aeroplane in order to evacuate smoke from the cabin.

1.17.3 If essential AC and DC power were in fact lost when the pilot said, "Now we have lost a lot of electrics, we haven't got anything ... on the aircraft now", the VHF communications indicate that the standby 28v DC bus was still powered.

The No 1 VHF transreceiver, the No 1 ILS and the marker beacon were all powered from the standby 28v DC bus which was in turn powered from the battery bus via the 28v DC "hot bus". The static inverter that supplied the 115v AC power to the standby horizon unit was also powered from the battery bus.

In addition, the No 1 Glide Slope receiver was powered by the 28v DC Standby Bus; the the main interphone system and passenger address system were powered by the Battery Bus; and the No 1 HSI, No 1 ADI and the No 1 INS were powered by the 115v AC Standby Bus, through the static inverter. Even if all essential AC and DC power were lost, sufficient instrumentation and equipment were provided under emergency battery power to navigate and operate the aeroplane safely.

1.17.4 The main deck cargo compartment of the Boeing 747 Combi aeroplane is classified as a class B cargo compartment. Fire protective measures for certification of the aeroplane were based on the following Federal Aviation Regulations (FAR's) which were current at the time.

FAR 25.857(b) defines a class B cargo compartment as one in which :

(1) There is sufficient access in flight to enable a crew member effectively to reach any part of the compart-

ment with the contents of a hand fire extinguisher.

(2) When the access provisions are being used, no hazardous quantities of smoke, flames or extinguishing agents will enter any compartment occupied by the crew or passengers.

(3) There is a separate approved smoke or fire detector system to give warning at the pilot or flight engineer station.

(4) There is a fire resistant lining.

FAR 25.851(a)(4) prescribes that an approved fire extinguisher must be readily available for use in a class B cargo compartment. It must have a type and quantity of extinguishant appropriate to the kinds of fires likely to occur.

FAR 25.853(b) specifies fire protection criteria with which materials used in cargo compartments must comply.

FAR 25.855 requires cargo compartments to be free of wiring, equipment or accessories whose failure would affect safe operation unless such items cannot be damaged by cargo, or their failure will not create a fire hazard. Cargo must not interfere with the functioning of fire protective features and heat sources must not ignite cargo. In addition flight tests must be conducted to show compliance with 25.857 above concerning:

(1) Compartment accessibility;

(2) The entry of hazardous quantities of smoke or extinguishing agent into compartments occupied by the crew or passengers.

FAR 25.1301 requires that installed equipment must be of a kind and design appropriate to its intended function and function properly.

FAR 25.1309 requires systems to be designed and installed in such a manner as to ensure that they perform their intended functions under any foreseeable operating condition. Systems must also be designed to prevent hazards to the aeroplane if they were to malfunction or fail.

1.17.5 The fire detection, suppression and extinguishment certification requirements and the relevant design features of the aeroplane can be summarized as follows :

(1) The 9 600 cubic feet main deck cargo compartment is separated from the passenger compartment by a partition fitted just forward of the side cargo door at body station 1723. The 25 mm thick partition panels are constructed of Nomex honeycomb core and fibre glass face sheets. The partition is not an air tight seal between the two compartments. It is intended to provide a restriction that aids in air flow directional control within the aeroplane. Air is introduced into the compartments just below the ceiling levels, passes through the compartments and exits through sidewall grilles at floor level to move downward towards the rear to the two outflow valves located aft of the lower cargo hold. At the same time some air flows into the overhead space above the main deck passenger compartment and moves aft. During normal conditions the

recirculation fans pick up air from this area and transfer it to the passenger cabin. It is a requirement, however, to shut down the recirculation fans if fire or smoke conditions are encountered. When the aeroplane is used in the Combi configuration a flow reducing valve in the cargo compartment distribution duct is set to reduce air flow into the compartment. Under normal conditions the air pressure in the cargo compartment should thus be slightly less than in the passenger compartment. This pressure differential has not been measured but during certification test flights it was observed that smoke did not penetrate into the passenger compartment even when the access door was ajar. This is without taking into account thermal expansion caused by a fire. Tests to show non-ingress of flames into the passenger compartment have not been conducted. A computation by the FAA showed that the effect of thermal expansion could have caused smoke and flames to enter the passenger compartment since a fire producing a constant 10 000 BTU's per minute would eliminate a differential pressure of 0,1" of water within a few minutes under normal ventilation conditions. The smoke generation used in the certification tests produced a thermal release of about 6 000 BTU's per minute. Polystyrene and polyurethane produce 18 100 and 10 300 BTU/lb respectively. The soot deposits in the passenger cabin and in the respiratory passages of accident victims and the fire damage to the rear galley support structure seem to verify the FAA computation.

As the crew executed an emergency descent it is probable that they had gone from the main deck cargo fire/smoke check list to the smoke evacuation check list. The latter requires that the recirculating fans be switched on.

The Nos 2 and 3 recirculating fans are located at body stations 880 and 1110 respectively above the cabin ceiling. The fans have a capacity of 670 cubic feet per minute.

There is evidence of soot deposits above the ceiling as far forward as body station 1320. It is probable that the fans continued to operate, assuming there was not a loss of AC power, and to force the products of combustion into the cabin.

There were no ceiling panels in the cargo compartment. Instead insulation blankets, retained in position by means of nylon fasteners, were fitted. As many of the fasteners were found melted and sooting of the exposed skin had occurred, it can be assumed that some of the blankets had become detached. The side panels are similar to those in the passenger cabin.

The empennage flight control cables run along the compartment roof.

The electrical wiring in the main deck cargo compartment did not include any main bus wiring.

(2) Access to the cargo compartment from the passenger compartment was first through a door in the partition at the end of the left side passenger aisle and then through a "gate" in the cargo barrier net which was spanned across the front end of the compartment. The "gate" is opened by unclipping the left hand lower portion of the net. The partition door was normally kept locked in flight but the key was stowed next to the door. A 16 lbs (7,25 kg) Halon 1211 fire extinguisher was stowed next to the access door inside the cargo compartment. A 2,5 m applicator or wand with a curved end was stowed on the cargo barrier net, adjacent to the entry gate. This wand could be attached to the fire extinguisher hose nozzle to

apply extinguishant high up and on top of the cargo stacks. The amount of fire extinguishant is considered sufficient for 1 250 square feet of floor area where moderate size fires and ordinary hazards could be expected in a warehouse. The floor area of a 7 pallet Combi is 880 square feet. The continuous discharge time of the fire extinguisher was 12 seconds.

(3) The lower cargo hold was fitted with photo-electric smoke detectors in each of the three compartments. Smoke in any of the compartments would have activated the annunciator lights on the pilot's overhead panel and the flight engineer's panel. The two freon gas fire extinguishers (105 lbs and 60 lbs) could be discharged electrically into the forward or aft lower cargo compartments by appropriate switch selection on the flight engineer's panel.

The auxiliary power unit (APU) compartment was fitted with continuous loop heat sensors in the upper and lower areas and would have warned the flight crew of dangerous temperatures by means of annunciator lights on the pilot's overhead panel and the flight engineer's panel. The 18 lbs freon gas fire extinguisher is electrically discharged into the APU compartment.

1.17.6 A NTSB expert on fires gave the following interesting view on the aeroplane's fire protection :

(1) In the case of pallet stacks covered with polyethelene sheets the smoke from a smouldering fire low down in the centre of a stack would be trapped under the cover and eventually escape at the bottom to flow out through the grilles at floor level. Only when the temperature of the air in the stack reaches about 250°C to melt the polyethelene, will the smoke rise to enter the sensing manifolds. When

this happens the materials in the stack will be sufficiently pre-heated to provide a very rapid fire growth. By the time a crew member enters the compartment it will in all probability be too large a fire to extinguish with a portable fire extinguisher. Even if a fire were detected early and fire fighting took place quickly it may be difficult to suppress a fire which originated in the middle of a large pallet, with a hooked wand (applicator).

It must be remembered that these are general observations, and that the evidence shows that the pallet where the fire occurred was not covered by polyethylene sheets. Furthermore, limited testing which was conducted in the B-747-400 Combi using theatrical smoke generators and released at the base of a covered pallet at the outboard side and again at the inboard side resulted in smoke detection within one minute. It was observed during these tests that a significant portion of the cold smoke rose towards the ceiling. Nevertheless the rate at which smoke would rise would depend on the conditions in the cargo compartment at the time.

(2) Access to various pallets is made between the pallets and the fuselage which is very restrictive. Under the most ideal conditions fire fighting with the equipment provided would be difficult. During the search for the fire the fire fighter has both hands occupied, one hand carrying the 16 lb extinguisher and the other holding the 10ft wand. It must be remembered that the whole philosophy of fire protection in the Combi relies on early detection, rapid location of the fire and extinguishing with Halon. Furthermore, early detection and suppression are dependent on the fire being on the outside edge of a pallet, not towards the centre of a given pallet.

1.17.7 On the Combi aircraft communication between the pilots and the flight engineer, while wearing oxygen masks, could be accomplished by either selecting the interphone channels on the audio controllers and pressing the transmit buttons on these units, or by means of rocker switches on the control columns.

In order to standardise the procedures on the Operator's Boeing 747 fleet, the crews were trained to use the former method.

1.17.8 The operation of the cockpit crew oxygen regulators is described in Appendix 1 Volume 2 p 84.

1.18 Investigation Techniques

1.18.1 On Site Investigation

The remoteness and depth of the site at which the wreckage of the aircraft was believed to be lying necessitated the utilization of specialized techniques to locate and recover both floating and sunken wreckage. After completion of the search for survivors, the emphasis changed to the recovery of bodies and floating wreckage which by then had dispersed over a large area. Search aircraft were used to direct ships to specific areas. Much time had to be devoted to this operation. Not all floating wreckage could be retrieved. Although some floating wreckage ended up on the beaches of Mauritius and even South Africa, wreckage washed up on beaches on Malagasy could not be retrieved because of the political differences between that country and the Republic of South Africa.

First indications from the ATC tape were that there had been a fire related problem in the aircraft which was confirmed by floating wreckage recovered from the aft section.

It was considered essential to recover the CVR, DFDR, and even the quick access recorder to obtain as much information on the cause of the fire and the subsequent flight path of the aircraft. The assistance of the United States Navy was requested. Nearly one week elapsed before the necessary agreement could be reached between the Governments of the USA and the RSA. It took yet another week to transport the necessary equipment from Miami (USA) to Mauritius by heavy lift aircraft. Thus more than 14 days of the guaranteed 30 day battery lives of the pingers, as fitted to the CVR and DFDR, were lost. During this time an RSA effort utilizing subcontractors was initiated and two RSA based tugs were despatched to act as search platforms. They took 10 days to reach Mauritius. In the meantime Dukane broomstick locators were used to search for the wreckage, but without success. A further search ship fitted with hull under water detectors was chartered.

As the area in which the wreckage was believed to be was relatively uncharted a German research ship was contracted to chart the sea bottom. The sea bed charted varied from 5 000 m below sea level to as little as 300 m.

A navigation system had to be deployed and supported on the islands of Mauritius, Roderigues and Cargados to ensure that adequate grid pattern searches were carried out.

The pinger search, as it was known, was a multinational effort and ended 33 days after the crash. More than 1 000 square nautical miles were searched without success. This large area was covered of necessity as it was not known whether the aircraft had broken up at altitude.

Three areas of probability were identified and covered by sidescan sonar search.

Because of the depth of the sea bed where the wreckage was located, contractors qualified and able to search for, locate, and recover the recorders and selected wreckage were not readily available. Various contractors worldwide were visited prior to a specification being drawn up and tenders called for. This included a "no cure no pay" clause which required the contractor to prove his capability to carry out the task before any payment was made. The company Eastport International of the USA was contracted by the Department of Transport, and Operation Resolve, as it became known, was initiated. This called for the manufacture of a 22 000 ft umbilical fibre optic cable to control the remotely operated vehicle (ROV), known as the Gemini.

Problems were experienced with the ship to ROV navigation system, as well as with ROV and deployed sea bed transponders. No real time navigation was possible because of acoustic interference. ROV thrusters had to be switched off each time a fix had to be obtained. Use of INS in future ROV's could overcome this. Ship navigation was by means of GPS which had a limited window in this portion of the Indian Ocean (about 4 hours in 24 hours).

Photomapping and recovery of the CVR were successful. However, with recovery of selected wreckage (it was impossible to recover all wreckage), two significant items were lost at 4 000 ft and 400 ft below the surface respectively. These were the horizontal stabilizers and a section of the main deck cargo floor. Smaller items were placed in a basket which could be closed prior to recovery to prevent loss through drifting. Bigger items were recovered by means of a lift line on a drum on the sea bed.

Ballistic tests carried out in water tanks indicated that the drift-down characteristics of the CVR and the DFDR were different with the DFDR being less stable and less predictable on location. The CVR was in fact located within the predicted area.

Although the minimum contract period for Operation Resolve was 20 days, it soon became apparent that a minimum of 40 days was more realistic. In fact Operation Resolve lasted 101 days. Notwithstanding the high cost, Operation Resolve was undoubtedly a highly successful undertaking.

1.18.2 Cockpit Voice Recorder and ATC tape analysis

After recovery, the cockpit voice recorder (CVR) was transferred under water, to a transport container. The sea water in the container was then replaced with deionised water and ice to maintain the temperature below 12°C, during transportation to the Operator's laboratory.

In the laboratory the temperature was allowed to stabilize at room temperature, approximately 21°C. The CVR was opened. There was minimal internal damage, and the tape was transferred, without difficulty, to a reel. Cleaning was then accomplished by reeling it from reel to reel in deionised water, with frequent salinity checks. The tape was then dried in a vacuum chamber, with dry nitrogen purging at 10 minute intervals. This process was continued for 24 hours.

The tape was then carried by hand, circumventing all magnetic security checks to the National Transportation Safety Board flight recorder laboratory in Washington D.C. There the tape was copied. The first generation master copy was made from reel to reel.

The CVR tape voice analysis was carried out in the Republic of South Africa. The only recorded data was on the cockpit area microphone channel (CAM) and as most of the conversation, before the master fire warning bell sounded, was between the 2 flight engineers, the quality of the recording was exceptionally poor.

The system of data recovery employed was unique in that the data was digitized and then computer analyzed. Approximately 60% of the data were retrieved using this method. This figure was remarkable considering that less than 5% was recovered by conventional methods.

A first generation copy of the CVR tape was analyzed by the National Research Council (NRC) in Ottawa, Canada, in an endeavour, using techniques developed by the NRC, to identify an explosion signature. The results of this highly complex and time consuming technique were conclusively negative.

The Air Traffic control (ATC) tape recording was also computer analysed in an attempt to retrieve the data from the very garbled inadvertent transmissions made from the aircraft. This was less successful than the CVR tape analysis.

The manner in which the 3 940 still photographs, taken on the sea bed, were utilized is worthy of note. The photographs were mounted on stands in the dive sequences. From the photographs, the operator's experienced maintenance personnel, together with representatives of the manufacturers, were able to identify most of the components, in spite of the degree of fragmentation that had occurred. The video tapes, after being suitably catalogued, were analyzed in a like manner.

In preparation for the possible recovery of both the flight recorders, a team of investigators visited no less than 5 establishments in the USA and 2 in the United Kingdom, to obtain first hand knowledge of problems likely to be encountered with the recording medium after so long an immersion in sea water at such a great depth. The successful recovery and tape handling methods were devised from the information received.

2. ANALYSIS

2.1 When the aircraft disappeared there was scant evidence of what had occurred and of where it was. Step by step, by painstaking and at times very costly efforts, important evidence has been recovered. That evidence has come from, inter alia, the findings at the post mortem examinations performed on the few bodies which, by an extraordinary chance, were recovered from the sea; the location by sonar side-scan devices, after prolonged, expensive and fruitless searching, for the wreckage in the Indian Ocean 134 nautical miles North-east of Plaisance Tower, lying at depths of the order of 15 000 feet (about 4,5 kilometers); the identification, in Operation Resolve, of two distinct fields of wreckage; the expert analyses and interpretation of the ATC tape, portions of which were unintelligible; the remarkable technological achievement of locating and recovering the CVR from the ocean floor and the expert analyses and interpretation of garbled but significant items of speech and noise recorded thereon; the location and recovery of important elements of wreckage from the ocean floor; the production and analysis of some 3 900 photographs and over 800 hours of video studies of selected items of wreckage at these great depths; the identification and sources of the cargo packed in the respective pallets on board the Helderberg at the time of the accident; a mass of expert findings on numerous other aspects of the crash, following metallurgical, chemical, electronic and other tests of pieces of wreckage and items of cargo; the flight characteristics of the Boeing 747 with heat damaged portions of the structure and controls; the significance of the wreckage pattern; the evidence of experts on aircraft fires and explosions; and volumes of documentary data on Combi aircraft, spontaneous fires and other matters relevant to this Inquiry.

2.2 From evidence pieced together it is clear that a fire commenced in the front pallet on the right hand side (pallet N° PR) in the main upper deck cargo hold. The fire developed rapidly and could not be controlled. It generated smoke, carbon monoxide and carbon dioxide, some of which penetrated to the passenger cabin and possibly to the flight deck.

Mr Hill, the FAA expert explained that there were too many unknown variables to determine whether smoke could in fact have reached the cockpit.

He said : "... it depends on the airflow and whether the airflow systems are working or not, as to what is going to happen, whether the smoke is going to propogate into the cockpit or not, or how long it would take, and I couldn't tell you whether it would or it wouldn't, without knowing all the conditions that were going on inside that aircraft at that particular time".

Another FAA expert, Mr Slifer, agreed with this view on the complexities of analyzing the air movements in an aeroplane, particularly when that analysis must take into consideration a thermal driver, such as a fire. If, as is believed, the crew were following the smoke evacuation check list, the requirement for the recirculating fans to be on could have significantly increased the flow of the products of combustion into the passenger cabin. The fire also caused heat damage in varying degree to the aircraft's skin and the supporting (longitudinal) stringers, mainly between stringers R4 and R16; to (circumferential) frames, mainly between body stations 1640 and 1960; to the empennage flying control cable pulley clusters above the No 4 galley and as far back as body station 2080 (the controls involved here were the elevators, the rudder, the rudder trim and the manual operation of the horizontal stabilizer); to part of the elevator cables; to the crown of the cargo hold; and to the electric wiring running in the raceways on either side thereof, including the wires supplying current to the CVR and DFDR at the rear end of the aircraft. Further, the fire caused a number of plastic supports for the insulation blankets to melt, and damaged some of the blankets themselves.

The effects of the fire eventually led to the aircraft crashing into the sea, with severe impact damage and disintegration of the aircraft itself, and of items of cargo and baggage.

2.3 The two main aspects upon which the evidence does not justify precise findings are the ignition source of the fire and the causal chain between it and the aircraft's crashing into the sea. Nevertheless, the evidence has provided positive guidelines on both these aspects.

2.4 On the question of the ignition source, the possibility of an explosion is considered to be remote, for the following reasons :

(a) The CVR tape was tested in Canada by the National Research Council for the presence of an explosion "signature" indicative of a disturbance which would be registered by an explosion of as little as 300 gm of explosive. The findings were negative. Forensic tests on many pieces of floating wreckage were also negative (see para 1.16.3 p 83 above).

(b) An explosion of any consequence would have resulted in depressurization, but there was no mention of any such occurrence on the ATC tape of the communications between the flight deck and Plaisance Tower.

(c) The CVR tape also contains no mention of any explosion or depressurization.

(d) According to the CVR, the emergency which developed in the aircraft was not the occurrence of an explosion, but the activation of the fire alarm's signal on the flight deck by smoke sensors in the cargo hold.

(e) For what that may be worth, there was no claim by any organisation of a terrorist attack on the Helderberg.

(f) Mr Southeard, an expert on fires and explosions, examined the wreckage and photographs for indications of "an explosion in terms of high explosives", i.e. one that creates a shock wave greater than the speed of sound. He found no evidence of any such explosion.

(g) Radiological investigation of the bodies recovered from the sea revealed no radio-opaque objects.

2.5 Sabotage by means of an incendiary device also appears to be improbable. Here again, no claim by any organisation was made. Obviously there was no pressure-activated device, for the aircraft had been at its final cruising altitude for some six hours when the fire developed. The indications are also against a timing device. The aircraft was one and a half hours late in take-off through an unexpected delay that developed after it had been loaded. If a timing device had been used it would have been calculated to explode approximately an hour after the aircraft had already landed in Mauritius.

2.6 There was nothing in the cargo contents in pallet PR, as declared, that could be described as dangerous goods. Some of the computers consigned in pallet PR and other pallets were fitted with nickel-cadmium or lithium batteries, but in the circumstances those items were not likely to have caused any ignition or explosion. See paragraph 1.16.1 pp 80-81 above. Moreover a security check at Taipei of a representative percentage of the cargo on board the Helderberg showed that the cargo manifests tallied with the cargo itself. Subsequent investigation of the consignors of the cargo in pallet PR revealed nothing suspicious. Nevertheless, the possibility of a misdeclaration or a false declaration in the consignment notes or cargo manifests cannot be ruled out entirely.

2.7 Practical experience of and research into cargo hold fires, as communicated to the Board, demonstrate that such fires can originate from any of a wide variety of causes. Ignition is certainly not limited to items such as matches ignited by friction, fireworks, cigarette lighter fluid, nitric acid, peroxides, or any of the many other chemicals which when mixed together can burst into flame or generate temperatures high enough to cause fire in other materials in the vicinity. As Mr Hill, the FAA expert on fires, put it when consulted by the Board: "... (A) fire initiated from just about any source spreading through packing material and cardboard boxes can lead to catastrophic occurrences. ... (T)here are numerous ways of igniting various materials". Mr Hill expressed the opinion that the damage to the aircraft was entirely consistent with a fire in typical cargo packing materials, and that cardboard and plastic packing materials could have generated enough heat to produce the results that occurred in this particular instance. He explained that a fire in such packing materials can build up rapidly and within three to five minutes from the time of ignition develop into a "flash fire", i.e. a fire in which the material has given off combustible gas which ignites at the ceiling level, with flames progressing rapidly at the ceiling from one end of the compartment to the other, and consuming much of the oxygen in that compartment. With such a fire the temperatures at the ceilings generally range upwards to 2000°F (about 1093°C) and last for a period of anything from thirty seconds to a few minutes, depending on how quickly and violently this occurs, and on the amount of material in the compartment. Sometimes the fire dies down from lack of oxygen and reaches an equilibrium point depending on how much air is being induced back into the compartment. The fire can stay in a steady state of smouldering for as long as two hours, or if enough oxygen is induced back into the compartment as part of the air, the fire can go back into a flaming mode. Exactly how a fire would burn in a compartment therefore depends on a number of variables. The generation of smoke in a "flash fire" or even a "flash over" where a number of other materials are ignited is rapid and dense. There have been instances in actual fires in aircraft where visibility was severely limited by smoke. In a test of these conditions run by the FAA, the obscuration, i.e. the amount of light visible over a distance exceeding one foot, went to zero almost immediately upon the flash fire in the compartment and stayed there for a total of two hours of the test. The only thing that burnt were the packing materials. That was what was making the smoke. Also the amount of material consumed at the end of the two hours was relatively little and most of it was in the area in which the fire started.

2.8 Mr Southeard, the fire and explosions expert, who was called to testify by The Boeing Company, discounted discarded smoking materials as a possible cause of the fire, and also electrical arcing from the raceways in the crown. In his opinion the fire started as a result of something within the cargo in pallet PR.

Having regard, inter alia, to the signs of fire damage in the cargo hold, to the restricted oxygen supply within the pallet, and to the amount of oxygen that would have been necessary to achieve the energy output for that fire, Mr Southeard considered that the source was not a diffusive fire (i.e. one in which combustion feeds on an outside supply of oxygen), but a promoted fire (i.e. one in which there is an intrinsic supply of oxygen within the material involved in the combustion).

In the opinions and experience of the FAA and of Mr Southeard, the fire could have developed very rapidly into a "flash fire" even before the smoke sensors activated the fire alarm system on the flight deck, or at least within a minute of that alarm sounding.

2.9 In the Board's view there is insufficient evidence to determine the precise source of ignition. Nevertheless certain inferences on the fire and its effects can safely be drawn, viz :

(a) Whatever the source of ignition, the cardboard and plastic packing materials in pallet PR were undoubtedly involved in the fire, which caused the damage described in the evidence.

(b) The burning of those materials produced the smoke problem mentioned on the ATC tape, and also carbon monoxide and carbon dioxide, which, as noted earlier, penetrated to the passenger cabin and possibly to the flight deck.

NOTE: On the presence of carbon monoxide see paragraphs 1.13 p 66 and 1.14.2 p 68 above and paragraph 2.12 pp 130-138 below.

(c) The fire could have developed rapidly, so rapidly indeed that by the time a crew member or members arrived in the cargo hold, visibility could have been severely restricted by the smoke, and by then the lights in the cargo hold could have gone out through damage to the wires in the crown, or were of little value because of the smoke.

(d) There was no torching, i.e. the fire did not burn outside the fuselage.

(e) The heat given off by the fire while flashing, and reflashing, and the residual heat, would have prevented the crew from getting close enough to it to operate a fire extinguisher effectively.

2.10 The next aspect to be examined is the causal chain between the fire and the aircraft's crashing into the sea.

Certain inferences can be stated with certainty, viz :

(a) The cause of the crash was the fire.

(b) The fire got out of control and either remained so or was only extinguished after an irretrievable position had developed.

(c) The smoke problem led the crew to decide on an emergency descent to FL 140.

(d) "Something catastrophic" (as it was put in the testimony of the Director of Flight Operations of SA Airways) occurred between the last communication from the flight deck at 00:04:02, when the aircraft acknowledged "Kay" in respect of the Tower's instruction to report approaching FL 50, and 00:07:00 when the crash occurred as indicated on the two watches found in the wreckage.

2.11 On all the evidence, the total range of possibilities, which were examined at great length before the Board, is as follows :

1. The crew were overtaken by toxic levels of carbon monoxide and carbon dioxide, and ceased to control the aircraft effectively or at all, or they became disorientated or unable to see the instruments because of smoke.

2. Crew distraction.

3. The aircraft broke up through weakening of the structure by fire damage.

4. The aircraft became uncontrollable through expansion beyond the limits of tolerance, or a fracture of the elevator control cables, and/or through damage to the empennage flying control cable pulley clusters.

5. The aircraft became uncontrollable through deformation of the fuselage by heat from the fire.

2.12 On the first point, it was suggested by Boeing's counsel before the Board that the medical evidence, of fatal levels of carbon monoxide in the blood samples taken from two of the bodies, was unreliable. The evidence of carbon monoxide in the blood of these two persons, however, becomes overwhelmingly probable when account is taken of the further facts that the fire penetrated via the crown of the cargo hold to the passenger cabin, that the crew reported a smoke problem, and that soot was found in the respiratory tracts of the passengers upon whose bodies post-mortem examinations were performed.

The scientific evidence presented on the laboratory investigations in regard to carboxyhaemoglobin levels thus becomes particularly cogent.

Besides, the analyses for carboxyhaemoglobin were carried out by the use of gas chromatography, which largely obviates false readings due to decomposition haemoglobin pigments. Medical evidence was led that the blood samples were obtained from closed thoracic cavities and had not been exposed to outside air or water.

The high levels of carboxyhaemoglobin found (60,5% and 67,2%), together with the post-mortem observations, indicate that there were fairly high levels of smoke, soot and carbon monoxide in the passenger cabin.

The allocated seat numbers of the passengers with high carboxyhaemoglobin saturations were 30E (business class, fairly far forward in the passenger cabin), and 40D (economy class). Other identified passengers in allocated seat numbers 37A, 37D and 42A (all in economy class) had soot in their respiratory systems, and, presupposing that they were in those seats when the fire occurred, the indications are that they too were exposed to carbon monoxide gas. On the probabilities, most if not all of the passengers would have moved as far forward as possible after the smoke had penetrated the passenger cabin.

It is possible that smoke, soot, carbon monoxide and carbon dioxide penetrated to the flight deck. Dr Jansen, the expert on electronic tape recordings, expressed the opinion that the captain's voice on the ATC tape during the emergency indicated that he was not wearing an oxygen mask. It was, however, not a dogmatic opinion, and the Board is satisfied that the almost certain reaction of the crew, based on the evidence of the check list, their training and their responses to the critical situation confronting them, was to don their oxygen masks and keep them on at least until FL 140 was reached, if not until the end. There was an adequate supply of oxygen available to the flight deck crew, the duration of which for 3 crew members on "Emergency" selection was 42 minutes. It is believed that the inadvertent transmissions made on the approach frequency resulted from the captain repeatedly having to select between VHF1 and interphone, during a period of extreme tension in the cockpit. These inadvertent transmissions, the last of which was made some 4 minutes before the aircraft crashed, strongly suggest that the oxygen masks were worn by the crew right up to the end. If the flight deck crew were using oxygen masks immediately after the fire alarm sounded, as required by the check list, they would have been breathing one hundred per cent oxygen, and would have been largely protected from carbon monoxide intoxication and smoke inhalation. This assumes that the oxygen masks were fitted properly to the faces of the crew members concerned. The possibility cannot be ignored that, because of his skin ailment, the captain might from time to time have found the pressure of the mask on his face uncomfortable and have moved it to scratch the skin under it. In that event, he would from time to time have been exposed to the risk of inhaling carbon monoxide and carbon dioxide.

Carbon monoxide and carbon dioxide are toxic gases which can cause incapacitation. Carbon dioxide is evolved in large amounts in nearly all fires. Inhalation of air containing thirty per cent by volume of carbon dioxide induces anaesthesia in a few minutes.

Owing to the stability of carboxyhaemoglobin which continues to accumulate as the blood absorbs the gas from the lung alveoli, even very small proportions of the gas (not immediately dangerous), may eventually prove fatal. Thus one per cent by volume in the air can cause unconsciousness in fifteen to twenty minutes. It has been established that carboxyhaemoglobin levels as low as five per cent, particularly at high altitudes, can cause severe intellectual impairment. From the aforegoing it can be deduced that :

(a) There is a real possibility that some, if not all, of the passengers and cabin crew were unconscious or dead from carbon monoxide and carbon dioxide intoxication before the impact.

(b) If (as is unlikely), the flight deck crew were not using oxygen masks, it is possible that they too became incapacitated by carbon monoxide and carbon dioxide gases and smoke.

(c) If the flight deck crew reverted to normal oxygen on reaching FL 140, when the cabin oxygen was switched off, they would then have been inhaling a mixture of 40% oxygen and 60% cabin air, and could have been subjected to the effects of carbon monoxide and carbon dioxide, with a consequent possibility of ensuing impairment of intellectual and physical capacity.

2.13 On the question of the possible break-up of the aircraft in the air, there are arguments on both sides, but nothing conclusive.

The main arguments against a break-up in the air are that :

(a) calculations indicate that even if the damaged area of skin and underlying stringers and frames were to have broken away, there would not have been any structural failure of the airframe within the normal operating parameters of 1,3 to 0,7 g;

(b) there have been cases where, relative to this accident, proportionately larger areas of skin, stringers and frames have been lost from areas that are more critical to the aircraft's structural survival, and where no catastrophe ensued;

(c) the pattern of the wreckage is not consistent with structural failure unless such occurred at a very low altitude;

(d) the manufacturer of the engines is of the view that they were attached to the airframe at impact (see Appendix C Volume 2 p 12), although the fact that the engines were not "shed" in the air is not necessarily inconsistent with a prior break-up of the rear portion of the aircraft.

Some of the arguments in favour of break-up in the air are that :

(a) there is clear evidence of two separate fields of wreckage about 200 metres apart;

(b) there is evidence that the engine fans were not windmilling and had ceased or almost ceased to rotate before impact with the sea, which would indicate that the aircraft was not flying but falling or tumbling or engaged in some other unusual manoeuvre;

(c) there can be no assurance that the aircraft remained within the parameters of 1,3 to 0,7 g.

There was a wrinkling of the skin in the aft fuselage and empennage, suggestive of structural failure, which could be indicative either of in-flight break-up or impact damage.

In the Board's view it would not be helpful to pursue these and other arguments pro and con in any detail, because no sure findings can be made thereon, not even on the probabilities.

2.14 This view also applies to the question of whether there was interference with the empennage flying control cable pulley clusters or elevator control cables or the aerodynamic integrity of the aircraft. There is cogent evidence from the manufacturers of the Pratt & Whitney engines, with which the aircraft was fitted, based on the appearances of the engine fans as shown in the underwater photographs, that the aircraft must have hit the water with the wings perpendicular to the surface of the sea. That could mean either that the aircraft was out of control (but there is still no indication of precisely how that could have been caused), or that the aircraft "bounced" after its initial impact with the water and then proceeded to tumble.

2.15 It is necessary to analyse the actions of the crew, both those on the flight deck and those in the cabin, subsequent to the sounding of the fire alarm on the flight deck.

2.16 Before proceeding with that analysis, however, it is convenient at this stage to deal with an aspect of the flight prior to the sounding of the fire alarm. The history of the flight until the fire warning sounded appears, on all the evidence, to have been entirely normal, save for the omission to comply with standing instructions of the Operator relative to regular communication between the aircraft and ZUR, the high frequency radio transmitting station based at the Operator's headquarters at Johannesburg (see paragraph 1.9 p 30 above). The purpose of the standing instructions was that contact should be maintained between the Operator's home base and its aircraft flying in various parts of the world. The evidence reveals that those responsible for establishing such contact with the aircraft from time to time failed to carry out their instructions. Moreover, the tape recordings of the activities of the ZUR station over the relevant period were either mislaid or inadvertently wiped out. The circumstances were investigated in full by the Board, which is satisfied that there was no connection between the failure to comply with the instructions and the accident to the Helderberg. The kind of communication that normally takes place between ZUR and an aircraft flying on any of the Operator's routes would have had no bearing on the circumstances which befell the Helderberg. On the other hand, because of the fire on board the aircraft, the crew of the Helderberg would have been preoccupied with communications to and from Plaisance Tower. That was the source from which assistance would be expected, whereas ZUR could have done nothing in the circumstances. Insistence on communications with ZUR at that time would have been an interference with the handling of the aircraft and the reports of its progress to Plaisance Tower.

2.17 We return now to the actions of the crew subsequent to the sounding of the fire alarm on the flight deck.

According to the ATC tape, the first transmission from the aircraft to Mauritius Approach Control on VHF RTF was at 23:48:51. It is apparent that the fire warning bell and light signal preceded this transmission, as also the eighty seconds of cockpit voice recorder (CVR) recordings which contained such of the information regarding the fire situation as was available at that time. Because of the interruption of the electrical power supply to the CVR no further data was retrievable from this source.

It is not possible to establish positively how long after the fire warning bell had sounded the first call was made to Mauritius Approach Control. This period could have been anything between three and five minutes. If the fire was already burning as a "flash fire" when the alarm sounded, the development of the smoke and its penetration into the passenger cabin could have occurred very rapidly.

2.18 The most acceptable explanation of the intercom chime which is heard on the CVR four seconds after the master fire warning bell had sounded is that a cabin crew member became aware of the problem in the main deck cargo area behind the forward non-structural cargo bulkhead. In its transmission to Mauritius the aircraft stated that it was already established in an emergency descent to flight level (FL) 140. Some thirty four seconds after the bell had sounded, the captain requested the flight engineer to read the appropriate check list. Although he did not specify which check list should be used, it is overwhelmingly probable that it was the Main Deck Cargo Fire/Smoke : Mixed Passenger and Cargo check list.

2.19 The first action on this check list requires all cockpit crew to don oxygen masks and select one hundred percent oxygen on the regulators. The cockpit crew should have remained on oxygen until the fire was extinguished and any smoke had been evacuated. If there was smoke present on the flight deck, the crew should have donned smoke goggles. If there was no smoke apparent on the flight deck it is possible that the cockpit crew, consisting of the captain, co-pilot and flight engineer, removed their oxygen masks after reaching FL 140 (which would have been contrary to their training), or selected the "Normal" position on their oxygen regulators.

Under normal circumstances it would be probable that the extra flight crew members, i.e. the third pilot and the second flight engineer, would have been resting in the special crew rest area. However, the evidence of Captain Downes, who became familiar with the voices of some of the crew, indicates that the senior flight engineer (Joe) was in the jump seat behind the captain, and that the other flight engineer was in the flight engineer's seat on the starboard side of the cockpit. When the alarm sounded, it is probable that the extra pilot would have been sent back together with the second flight engineer, with Joe and the co-pilot remaining on the flight deck with the captain. It would have been more likely that the captain elected to send a flight engineer and/or pilot aft rather than leaving the situation to the evaluation of a member of the cabin crew.

2.20 Only sixty five seconds after the fire bell had sounded, the cabin intercom chime sounded again. It is considered that this was a further attempt by a cabin attendant to contact the flight deck. On the probabilities it would not have been the third pilot or the second flight engineer sounding the intercom chime, because they would not have had time to go initially to the cockpit to receive instructions from the captain, then proceed to the aft bulkhead adjacent to the main cargo area, then enter the cargo hold in order to evaluate the situation, and then only report to the captain on the intercom.

2.21 The CVR record does not contain any further reference to the check list. From the fragmentary evidence available it is clear that electrical supply problems were occupying the attention of the flight deck crew. It has been estimated by the Operator that a possible total of eighty circuit breakers, of which fifty eight were located in the cockpit, could have been "tripped" as a result of the fire damage to electrical circuits in the main deck cargo area. This is borne out by the VHF RTF conversations with Mauritius Air Traffic Control, during the course of which the comment was made from the flight deck "We have lost a lot of electrics, we haven't got anything on the ... aircraft now". This transmission at 23:51:08 followed the aircraft's affirmative response at 23:50:00 to the question by the Air Traffic Controller on whether or not they wanted a full emergency declared.

While the captain did not send a "Mayday" call, there is no doubt that he considered the situation to be extremely grave. There is a natural reluctance on the part of professional pilots to declare a "Mayday" except as a last resort.

2.22 At 23:52:40 an estimated time of arrival (ETA) at Mauritius was given as 00:30, i.e. some thirty eight minutes ahead. This was a fairly accurate prediction. Some ten minutes later, however, at 00:02:43 the aircraft gave a distance out from Mauritius of sixty five nautical miles. This figure could not have been accurate or derived from a DME as the aircraft at that time would have been one hundred and sixty nautical miles from Mauritius and possibly below the DME radio horizon. The most likely explanation would be that the sixty five mile figure was the distance to run indicated by the inertial navigation system (INS), which could have been operating off its own internal battery power, in the absence of the main bus electrical power, had this been lost. In the opinion of both the Manufacturer and the Operator, the circumstances were not such as to have caused the loss of the essential AC and DC power on the aircraft.

Sixty five nautical miles was actually the distance to the next way-point, Xagal.

The fact that the aircraft as yet had no DME reading, but was in VHF contact with Mauritius, could be explained either by loss of power to the DME or by the difference in altitude of the antenna for the two different facilities. The VHF RTF antennae were located some two thousand feet above sea level, while the DME aerial was sited virtually at sea level.

2.23 At 00:02:50 Mauritius cleared the aircraft to FL 50; this instruction was acknowledged. The Board believes that the aircraft would have started a descent immediately from FL 140, had it been at that altitude. This was estimated to be some three minutes before impact with the water. A descent under control to FL 50 in three minutes would by itself have required a rate of descent of some three thousand feet per minute, a fairly high rate under normal circumstances. The actual descent from FL 140 to the water in three minutes would have been much more rapid.

2.24 After the Mauritius weather was copied at 00:03:00, some four minutes before impact with the water, there was according to the ATC tape a noticeable reduction in the tension on the flight deck. The impression is that the crew felt that the situation was now under control and that a safe landing at Mauritius was possible. This impression might appear to be supported by the last few contacts with the aircraft which were almost normal, concerning the runway to be used and reclearance down to FL 50. The last transmission from the captain was a relatively relaxed "Kay" in response to the ATC indication to report approaching FL 50. Some three minutes later the aircraft crashed into the sea one hundred and thirty four nautical miles North-east of Mauritius. Notwithstanding these inferences of a greatly relieved crew, the basic anxiety generated by the situation must still have been felt. A possible sequence of events in such a context would be an over-rapid descent developing while the crew were concentrating on their problem, with the downward inertia forces overcoming any attempts to pull out and the aircraft crashing into the sea in a tail-down attitude, "bouncing" and tumbling and even breaking up into two main portions. Such a scenario could account for the finding of the manufacturers of the engines that the wings sliced into the water at an angle of 90°. That would have been in a secondary or even subsequent impact with the sea.

Because of the presence of cloudy conditions at FL 50, the captain rightly decided to use runway 14 at Plaisance Airport, which would have involved alignment with the ILS localizer approximately on the reciprocal of his approach to the Airport, rather than trying to save time by coming straight in on runway 32. The indications are that at that time the captain considered the aircraft to be under control. Even if at that stage the captain was under some degree of euphoria through carbon monoxide intoxication, his responses were logical and consistent. That supports the inference that he believed that the aircraft could be landed at Plaisance. It would follow from this that the situation in the aircraft must have deteriorated rapidly after the captain's last acknowledgement at 00:04:02. This is the conclusion of the two senior and experienced 747 pilots who testified before the Board, and it is to some extent confirmed by the absence of any further message from the aircraft. If the aircraft had broken up, there would have been little or no opportunity of transmitting an explanation of what was happening. The same applies if the crew had, without realising what was happening to them, been overcome by carbon monoxide and carbon dioxide intoxication. However, if the aircraft had been difficult to control, it is possible that a message would have been transmitted by the pilot who was not handling the aircraft. As earlier indicated, the reasons for the rapid loss of control can only be speculated upon.

In the aforegoing analysis of the actions of the crew, there is no indication of any culpable failure of judgment, or competence or appropriate response.

2.25 The inability of the Board, for want of adequate evidence, to arrive at a precise finding on what must have occurred after the fire broke out, does not mean that this Inquiry has been sterile. On the contrary, sufficient evidence has been recovered to enable the Board to determine that the fire broke out in the forward pallet on the right side, the circumstances being such that a similar fire could occur again in another aircraft; that the fire got out of control, and generated consequences, either by way of damage to the aircraft, or by way of loss of control of the aircraft, or by way of incapacity (which term includes distraction) of the crew, which caused the aircraft to crash into the sea. On these firm bases, the Board is able to make recommendations of a practical nature which are aimed at ensuring that such a situation will not happen again.

3. The USA Federal Aviation Administration's Response to the Helderberg Accident and the Board's Approach

3.1 The Background

3.1.1 The Board's attention has been directed to documentation emanating from IFALPA's Dangerous Goods Committee in June 1987, and to certain other memoranda from pilots' organizations in which it was contended that the use of Class B cargo compartments could be hazardous. Those contentions were not generally accepted, but it is no part of this Board's functions to comment on those issues in the light of knowledge and experience at that time.

In over 20 years of operations by Combi aircraft the Helderberg accident is the first in-flight fire which resulted in the loss of the aircraft. As a direct result of the accident, the FAA undertook an in-depth review of the adequacy of existing regulations, policies and procedures pertaining to the certification of main deck Class B cargo compartments with volumes exceeding 200 cu ft. Class B cargo compartments have been in use in transport aircraft for approximately 40 years. Over the years, however, the size of the compartments and the size of the cargo packages have increased substantially. The Helderberg accident has focussed attention on the fact that, although the size of the compartments and of the cargo packages have been increased, the criteria for certification of Class B cargo compartments have remained virtually the same and are inadequate. The Helderberg accident has established further that even compliance with existing certification criteria will not always prevent the development of an uncontrolled cargo fire which could result in system and/or structural damage and/or crew incapacitation, which in turn could lead to loss of the aircraft.

3.1.2. The certification criteria for Class B cargo compartments are based upon the assumptions of timely fire detection, fire location identification and manual fire suppression and extinguishment by a single crew member. For type certification, the FAA criteria consider only the required minimum flight crew, i.e. two pilots and a flight engineer. Therefore, the flight engineer was the crew member expected to extinguish the fire (although in practice use could be made of a cabin crew member). Those criteria clearly are no longer adequate since the assumptions have been proved by the Helderberg accident to be invalid. In Class C cargo compartments, by contrast, cargo is not accessible by a crew member. A Class C cargo compartment is self-contained and is equipped with cargo liners for containment of any fire, control of ventilation and drafts and fire detection and suppression systems to control and extinguish the fire. It is significant that there is no known loss of aircraft due to fire in a Class C cargo compartment.

3.1.3. While the Helderberg accident is the only loss of a Combi aircraft due to a fire in a main deck

Class B cargo compartment, it is beyond question that there can be others unless effective steps are taken by the appropriate licensing authorities to remedy the position, e.g. by prohibiting the transportation of cargo in a Class B cargo compartment.

3.2 The Inadequacies of Class B Cargo Compartments in Combi Aircraft

3.2.1 The existing certification standards with respect to Class B cargo compartments specify that a fire must be detected rapidly and that, following detection, a crew member must be able, within five minutes, to leave his or her station, don protective equipment, enter the cargo compartment, locate the fire extinguisher, attach an extension nozzle (applicator or wand) to it, locate the origin of the fire and extinguish it.

The type certification standard in effect for the B-747-244 Combi aircraft required that smoke detection be obtained within five minutes of fire initiation. During one of the certification tests, detection was received within 27 seconds. The flight engineer was able to configure the aircraft in accordance with the emergency procedure, then walk to the cargo compartment access door, don his protective breathing equipment, enter the compartment, open the cargo net access, pick up the portable fire extinguisher, connect the extension nozzle, and walk to the middle of the compartment in three minutes, thirty seconds after the initiation of the fire simulation in the compartment. In practice, however, conditions in the cargo hold could be more difficult because of factors, such as poor visibility in smoke, bulky and high pallets, delay in finding the source of the fire, and the aircraft being in a steep nose-down attitude.

Prior to the Helderberg accident, inadequate data was available to support the effectiveness of the sequence of fire detection, suppression and exinguishment techniques within the prescribed time in the face of an actual in-flight fire in a main deck Class B cargo compartment. The effectiveness of these fire suppression techniques relies essentially on rapid detection and extinguishment of the fire by a crew member. The inadequacy of the detection, suppression and extinguishment systems relied on when this accident occurred is demonstrated in the evidence, and in what the Board observed during its inspection of a simulated fire-fighting attempt.

3.2.2 Both the detection and suppression techniques relied upon can no longer be accepted as adequate. The smoke detectors in a Class B cargo compartment are located in the crown of the compartment, i.e., on the ceiling, and are ineffective to detect smoke which exits a pallet of cargo at the floor level until sufficient heat has been generated to force the smoke to the crown of the compartment where the smoke detectors will then activate the warning bell in the cockpit. It is true that in the limited testing which was conducted in the B-747 Combi, and which is referred to in section 1.17.6 (supra at page 107), a significant portion of the cold smoke rose towards the ceiling. That result must, however, depend on the conditions in the cargo compartment at the time. Thus, only after sufficient smoke has exited a pallet and the thermal energy of that smoke has exceeded the force of the downward air current within the compartment would the smoke rise to the smoke detectors. By this time, that is before the alarm bell has been activated by smoke detectors, the material in the pallet could be pre-heated to a point where a fire has developed and grown rapidly. The members of the Board have witnessed a demonstration of the fire suppression and extinguishment techniques in a Class B cargo compartment, from which it is readily apparent that, even under ideal circumstances, the ability of a crew member to locate and fight a fire in the compartment successfully is severely limited. At worst, the task could be impossible. After entering the compartment, donning the protective equipment and preparing the extinguisher and wand, a crew member is required first to find the source of the fire. The ability to do so is rendered extremely difficult if sufficient smoke already has been generated to reduce the visibility within the compartment, and/or if there is no or reduced illumination, and/or extreme heat, and/or difficulty in passing between pallets or in passing pallets on the outboard side, and/or if the fire origin is located in the internal portion of a cargo pallet. These difficulties would be increased if the aircraft were to be making an emergency descent at an angle of the order of 10° (as occurred in the case of the Helderberg). The crew member entering the cargo hold would then have to move "uphill". Additionally, the fire extinguishing agent available to fight the fire lasts for only twelve seconds and if the extinguisher is used to its limit without extinguishing the fire, the crew member is left with no other specific means to suppress the fire and ensure the safety of the flight. In this connection a fire extinguisher normally stowed adjacent to the No 2 right hand door in the passenger cabin was recovered from the sea. It had not been discharged and there were molten drops of nylon adhering to it which could only have come from material in the cargo hold. The probable inference is that it had been taken to the cargo compartment (which would have been standard procedure) but had not been used because the crew member concerned had been overcome, or because catastrophe had occurred before it could be used.

It is significant that, in tests conducted by SA Airways on March 1st, 1988, at the request of the Board, with a Combi aircraft stationary on the ground, and no passengers or obstacles, a fully trained cabin attendant took 5 minutes 15 seconds to follow the prescribed routine and to be ready to locate the fire and commence fire-fighting. Even though the pallets were located within the prescribed envelope, on several occasions the cabin attendant's portable oxygen cylinder snagged in cargo netting used to restrain the cargo on the pallets.

3.3 The National Transportation Safety Board Safety Recommendation

3.3.1 As a result of the information available from the preliminary investigation of the Helderberg accident, the National Transportation Safety Board (NTSB), on May 16th 1988, issued Safety Recommendation A-88-61 through 63 recommending that the FAA :

1. Require that all cargo carried in Class B cargo compartments of United States registered aircraft be carried in fire resistant containers until fire detection and suppression methods for Class B cargo compartment fires are further evaluated and revised as necessary.

2. Conduct research to establish the fire detection and suppression methods necessary to protect transport aircraft from catastrophic fires in Class B cargo compartments.

3. Establish fire resistant requirements for the ceiling and sidewall liners in Class B cargo compartments that equal or exceed the requirements for Class C and Class D cargo

compartments as set forth in the applicable FARs.

The NTSB Safety Recommendation of May 16, 1988 is appended to this Report as Appendix E Volume 2 pp 21-24.

3.4 The Evaluation of Certification Criteria and Findings of the FAA Review Team

3.4.1 The results of the FAA's review of existing regulations, policies and procedures for certification of main deck Class B cargo compartments are contained in a report entitled "Evaluation of Transport Airplane Main Deck Cargo Compartment Fire Protection Certification Procedures". A copy of this report, dated June 1 1988, is appended hereto as Appendix F Volume 2 pp 25 et seq. The FAA Review Team met with representatives of The Boeing Company, McDonnell Douglas Corporation, Alaska Airlines, Federal Express and the Los Angeles Fire Department.

The report concluded that aircraft equipped with main deck Class B cargo compartments complying with existing regulations "do not provide an acceptable level of safety in terms of smoke and fire protection".

3.4.2 The significant findings and conclusions of the FAA Review Team have already been summarized above in paragraph 1.16.2 pp 81-83. For convenience they are set out here, viz :-

" 3.4.2.1 Existing rules, policies and procedures being applied to the certification of Class B cargo or baggage compartments in terms of smoke and fire protection are inadequate.

3.4.2.2 The use of pallets to carry cargo in Class B compartments is no longer acceptable.

3.4.2.3 While entry into the cargo compartment is available, not all cargo is accessible.

3.4.2.4 It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

a) The reliance on crew members to fight a cargo fire must be discontinued.

b) The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

c) The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

3.4.2.5. Most existing transport airplane smoke or fire detection systems ... are incapable of giving timely warning."

These findings and conclusions were extensively criticised, mainly by members of the air transportation industry. The Board of Inquiry has given full consideration to these criticisms, but, upon the basis of the results of the investigation of the Helderberg accident and the evidence received during the Public Inquiry, the Board unanimously agrees with the foregoing findings and conclusions of the FAA Review Team.

3.5 The FAA Notice of Proposed Rule Making

3.5.1 Following the issuance of the report of the FAA Review Team on June 1, 1988, concluding that, notwithstanding compliance with existing regulations, aircraft with main deck Class B cargo compartments - Combi aircraft - "do not provide an acceptable level of safety in terms of smoke and fire protection", the FAA issued a Notice of Proposed Rule Making (NPRM) on July 8, 1988, which proposed a new Airworthiness Directive (AD) to require design changes in existing aircraft either to modify Class B cargo compartments to the Class C configuration or to require the use of flame penetration-resistant cargo containers in Class B cargo compartments. A copy of the NPRM is appended to this Report as Appendix G, Volume 2 p 52.

3.5.2 The NPRM and proposed AD were the direct outgrowth of the Helderberg accident and subsequent review by the FAA of existing certification standards for Class B cargo compartments. The AD, as initially proposed, would have required affected operators :

" To minimize the hazard associated with a main deck Class B cargo compartment fire, ... (by accomplishing) the following :

A Within 180 days after the effective date of this AD, or prior to carrying cargo in a main deck Class B cargo compartment, whichever occurs later, accomplish either of the following :

1. Modify all main deck Class B cargo compartments of volume exceeding 200 cu. ft. to comply with the design standards specified in the FAR 25.857(c) for a Class C compartment. In addition, the ceiling and sidewall liner panels must meet ..." the current FAR requirements.

" 2. Modify all main deck Class B cargo compartments to require that ..." a placard be installed in conspicuous locations that cargo carried in the compartment must be loaded in an approved flame penetration-resistant container meeting the requirements of currently effective FARs.

The FAA recognized in the NPRM that alternative means of compliance, or adjustment of the 180-day period, which provided an acceptable level of safety, might be used when approved by the FAA. The NPRM invited comments from interested parties by not later than November 7th 1988.

3.5.3 Extensive comments were received by the FAA from various industry interests in response to the NPRM.

Concerns expressed by operators generally were based on the contention that Class B cargo holds had not yet been shown to be unsafe. There were also representations relating to the very high capital cost of retrofitting of Class C cargo compartments in place of Class B, the increased operating costs and consequent jeopardy to certain highly economic and useful cargo operations with Combi aircraft, and the very short time allowed for the introduction of the proposed remedial measures. The operators also expressed the view, generally, that existing fire detection, suppression and extinguishment procedures, with some improvements, would be adequate to prevent a recurrence of a Helderberg type accident. Pilot associations, generally, urged a complete ban on Class B cargo compartments in Combi aircraft.

3.6 <u>The Final Airworthiness Directive issued by the FAA</u>

3.6.1 The FAA issued a final AD on August 10, 1989, to be effective September 25, 1989. The FAA recently revised the effective date of the AD to May 3, 1990. The AD requires certain operational and equipment changes and design modifications to maximize fire detection and control. The preamble to the AD recites that it is prompted by the loss of the Helderberg which apparently developed a major fire in the main deck cargo compartment. The FAA determined that this condition, "if not corrected, could result in an uncontrolled cargo fire that could cause system and structural damage leading to the loss of the airplane".

3.6.2 In issuing the AD, the FAA again emphasized that under existing regulations aircraft equipped with main deck Class B cargo compartments "do not provide an acceptable level of safety in terms of smoke and fire protection" for the reasons that :

" 1. The existing rules, policies, and procedures being applied to the certification of Class B Cargo or baggage compartments in terms of smoke and fire protection, are inadequate.

2. While entry into the cargo compartment is available, not all cargo is accessible.

3. It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

4. The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

5. The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

6. Most existing transport airline smoke and fire detections systems ... are incapable of giving timely warning.

7. Current designs do not provide adequate means to monitor conditions in the cargo compartment after fire warning and fire-fighting procedures have been implemented.

8. Cargo compartment lining does not provide adequate fire containment.

9. Current designs do not provide a means to shut off ventilation air into the cargo compartment to limit oxygen to the fire."

3.6.3 After further consideration of the AD proposed in the NPRM, in the light of the extensive comments received from industry interests, the FAA has determined that the following design changes and procedures are appropriate to achieve major fire safety improvements for Class B cargo compartments:

" 1. Provide a smoke or fire detection system that meets FAR 25.858 (Amdt. 25-54), FAR 25.1309, and also provide an aural and visual warning to the station assigned to individuals trained to fight cargo fires.

2. Require a compartment fire extinguishing system that provides an extinguishant concentration to knock down a fire and suppress it, allowing time for a trained individual to find and extinguish a fire, or to verify that the fire is extinguished; and provide a means of shut off ventilation system air inflow to the compartment from the flight deck.

3. Require individuals trained to fight cargo fires.

4. Provide a cargo compartment liner that meets FAR 25.855 (Amdt. 25-60).

5. Provide two-way communication means between the flight deck, the station assigned to the trained individual, and the interior of the cargo compartment.

6. Provide improved illumination within the cargo compartment.

7. Require cargo loading envelopes and limitations to provide access to all the cargo for fighting a fire.

8. Provide a cargo compartment temperature indication system to the flight deck and designated station."

3.6.4 In addition to the foregoing design changes and procedures, the FAA has determined that the following features are necessary to ensure that an acceptable level of safety is attained :

" 1. Additional portable fire extinguishers appropriately located for use in the compartment and a means to effectively discharge portable fire extinguishers into each container or into each pallet that is covered. This will provide sufficient extinguishing agent and will ensure a means to properly use that agent in containers or covered pallets.

2. Protective garments and protective breathing equipment for individuals fighting a cargo fire. This will provide protection for the

individual assigned to control a cargo compartment fire.

3. Fire thermal protective covers for cockpit voice and flight data recorders, windows, safety devices, wiring, flight controls (unless it can be shown that a fire could not result in jamming or loss of affected control systems), and other equipment necessary for safe flight and landing that is located within the compartment. This is necessary to ensure that items which are not critical for continued safe flight, but are essential for the overall safe operation of the airplane, are not damaged in the event of a cargo compartment fire."

3.6.5 The final AD adopted by the FAA was revised from the NPRM proposed AD to include the accomplishment of the design changes and procedures set forth above as an alternative means of compliance. The FAA has determined that if the foregoing design changes and procedures are incorporated, "they will adequately address the unsafe condition."

3.6.6 The position of the FAA on the revised approach to this acknowledged "unsafe condition" is stated as follows :

> " It is not the FAA's intent to deny the use of pallets in 'Combi' aircraft. The issue is the fire control and containment capability with cargo loaded on pallets. With the present practice, in which the cargo is loaded on pallets, a deep-seated fire could develop and result in the compartment being filled with dense smoke. By revising the final rule, as described above, the FAA has addressed these concerns by requiring a means to discharge portable extinguishers into covered pallets, improved access, lighting, and protective equipment for the individual fighting the fire."

3.6.7 The final AD, effective May 3, 1990, a copy of which is appended to this Report as Appendix H Volume 2 pp 79 et seq, provides for alternative means of compliance "to minimize the hazard associated with a main deck Class B cargo compartment fire". The alternative means of compliance, in summary, are :

3.6.7.1 PARAGRAPH A. Within one year after the effective date of the AD (May 3, 1990) or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, incorporate the manual revisions, procedures, systems and equipment set forth in paragraph A of the AD. See Appendix H Volume 2 pp 79-83.

3.6.7.2 PARAGRAPH B. Alternatively, within three years after the effective date of the AD (May 3, 1990), or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, either modify the Class B cargo compartment to comply with the requirements for a Class C cargo compartment (paragraph B.1) or modify all main deck Class B cargo compartments to require that a placard be installed in the compartment, that cargo carried in the cargo compartment "must be loaded in an approved flame penetration-resistant container ... with ceiling and sidewall liners and floor panels" meeting the requirements of applicable FARs (paragraph B.2) or in addition to the requirements of paragraph A, modify Class B cargo compartments and associated systems to include the systems, means and equipment as set forth in paragraph B.3 of the AD. See Appendix H Volume 2 pp 79-83.

3.6.7.3 The AD provides that if the requirements of either paragraph B.1 <u>or</u> B.2 are accomplished within 1 year after the effective date of the AD (May 3, 1990), compliance with paragraph A of the AD is unnecessary. The AD thus gives the industry the option of converting existing main deck Class B cargo compartments to Class C standards <u>or</u> restricting the carriage of cargo in main deck Class B cargo compartments to approved flame penetration-resistant containers with ceiling and sidewall liners and floor panels meeting the requirements of applicable FARs. Alternatively, if Class B cargo compartments are not upgraded to Class C standards or restricted to cargo carried in approved containers, substantial improvements in fire detection, suppression, design and procedures for extinguishment and protection must be adopted.

3.6.8 It is obvious that the FAA has given serious and in-depth consideration to the acknowledged unsafe condition posed by a fire in a main deck Class B cargo compartment. There can be no qualification of the FAA determination that an unsafe condition presently exists with regard to Class B cargo compartments. The original NPRM was designed to address this unsafe condition by eliminating main deck Class B cargo compartments or restricting their use to flame penetration-resistant containers, with appropriate ceiling and sidewall liners and floor panels. The final AD modifies the original proposed AD by giving the aircraft operator the option of retaining main deck Class B cargo compartments by improving existing fire detection, suppression, extinguishment and protection facilities and procedures.

3.6.9 It is the unanimous view of this Board, however, upon the basis of the evidence presented during the course of the Public Inquiry as to the circumstances surrounding the loss of the Helderberg, that there is no acceptable compromise for the acknowledged unsafe condition of main deck Class B cargo compartments.

Passenger and cargo should not be mixed on the same deck level of the aircraft in an adjacent compartment and in the same atmosphere under any circumstances. The licensing authorities throughout the world are urged to re-examine and re-assess whether there is any acceptable compromise to the outright prohibition of main deck Class B cargo compartments in passenger aircraft. The Board is of the view that in the light of present experience and knowledge the prohibition should remain if the acknowledged "unsafe condition" of Combi aircraft is to be eliminated.

3.6.10 The Helderberg accident has demonstrated that the procedures and regulations that heretofore were considered adequate can no longer be accepted. The circumstances of the Helderberg accident also have demonstrated that there is no acceptable compromise to the outright prohibition by the appropriate licensing authorities of the carriage of cargo and passengers on the same cabin floor level of Combi aircraft.

4. FINDINGS AND CONCLUSIONS

4.1 At the time of take-off from Chiang Kai Shek Airport, Taipei, the aircraft was serviceable, with no reported carried forward defects. It was correctly loaded and carried sufficient fuel.

4.2 The aircraft had current Certificates of Airworthiness and Fitness for Flight.

4.3 The cockpit and cabin crews were all properly licensed, experienced on the route and qualified to carry out the flight and had had an adequate rest period.

4.4 The aircraft was configured as a seven-pallet Combi with six pallets in place.

4.5 The flight proceeded normally until some nine hours after the aircraft had left Chiang Kai Shek Airport in Taipei, when an intense fire developed in the right-hand forward pallet (PR).

4.6 The substances involved in the combustion included plastic and cardboard packing materials, but the actual source of ignition cannot be determined.

4.7 It is virtually certain that there was no sabotage. There was no explosion in the aircraft, and the presence of a pressure or time activated incendiary device was extremely unlikely.

4.8 The fire generated considerable smoke, carbon monoxide and carbon dioxide, which penetrated to the passenger cabin and possibly to the cockpit.

4.9 The fire caused extensive heat damage to the fuselage structure, the insulation blankets and electric wiring in the main cargo deck area, including the wires serving the power supply to the cockpit voice recorder.

4.10 At the time of the accident, the aircraft, a Boeing 747-244B Combi, complied with the certification requirements of a Class B main deck cargo compartment, save that adequate flight tests do not appear to have been conducted in terms of FAR 25.855(e)(2) to show compliance with the requirements of FAR 25.857(b)(2) for Class B cargo compartments concerning the entry of hazardous quantities of smoke into compartments occupied by passengers. In the light of further experience since these requirements were formulated they can no longer be regarded as adequate from a safety point of view. The FAA has pointed out that "the configuration was shown during flight tests to exclude hazardous quantities of smoke from the occupied compartments using criteria for testing which had been developed from years of transport experience". In the Board's view, however, the effects of thermal expansion were not adequately demonstrated in the tests.

4.11 The fire/smoke detection systems in the Boeing 747-244B Combi main deck cargo compartment were inadequate. Although the evidence indicates that the fire/smoke detection systems functioned, the extent to which the fire developed and the fact that smoke penetrated the passenger cabin suggest that the fire was not discovered early enough to prevent these consequences.

4.12 The fire fighting facilities provided for the main deck cargo compartment were inadequate.

4.13 The aircraft crashed into the sea some three minutes after the last transmission from the captain, acknowledging clearance for a further descent to flight level 50.

4.14 The aircraft was not under control when it crashed into the sea.

4.15 The only possible causes for the loss of control were one or more of the following :

(a) pilot incapacity from carbon monoxide and carbon dioxide poisoning, and/or smoke inhalation, or disorientation consequent on reduced cockpit visibility in smoke, or pilot distraction;

(b) damage to the structure and/or to the control systems of the aircraft directly or indirectly caused by the fire.

4.16 Irrespective of which of these causes might have been operative in the crash itself, there is a strong possibility that the quantity of carbon monoxide and carbon dioxide released by the fire caused loss of consciousness in or the death of some, if not all, of the occupants before the aircraft crashed into the sea.

4.17 There was no connection between the accident and the omission of Station ZUR to communicate with the Helderberg at the pre-arranged time. Nor is there any significance in the fact that the ZUR tape covering that time was mislaid or wiped out by later use.

4.18 The Board agrees with and supports the findings and conclusions of the FAA Review Team in its Report of June 1st 1988 (Appendix F Volume 2 pp 25-51).

4.19 Despite intensive investigation the Board was unable to find or conclude that fireworks or any other illegal cargo were carried in the aircraft.

5. CAUSAL FACTORS AND RESPONSIBILITY

5.1 The accident followed an uncontrolled fire in the forward right pallet on the main deck cargo compartment. The aircraft crashed into the sea at high speed following a loss of control consequent on the fire.

5.2 In terms of Section 12(1) of the Aviation Act, No 74 of 1962, as amended, the Board is required to determine not only the cause of, but also responsibility for, the accident (compare paragraph 3.1 of Annex 13). There is, however, no basis in the evidence from which the Board would be justified in assigning responsibility for the accident to any person or body, and, therefore, the Board is unable to do so.

6. RECOMMENDATIONS

6.1 The Combi type of configuration, with passengers and cargo on the same deck and provision for fire fighting on the cargo deck based on, inter alia, crew access to the seat of the fire and hand fire extinguishers to fight the fire, should be prohibited as creating an unacceptable risk to life and property, at least until such time as adequate provision is made to overcome the present shortcomings in fire detection, fire fighting equipment and fire fighting procedures.

6.2 For as long as Combi operations are permitted, effective fire detection and fire fighting systems, as laid down in the FAA AD No 89-18-12 R1 of August 10th 1989 (Appendix H Volume 2 pp 79-83), should be strictly enforced. The recommendations in paragraph 6.1 and in this paragraph are designed to eliminate any risk to life and property emanating from a main deck cargo fire, whatever the source, whereas the purpose of the FAA AD, though a step in the same direction, is, as stated therein, "To minimize the hazard associated with a main deck Class B cargo compartment fire...".

6.3 Since it has by no means been established that the aircraft was carrying dangerous goods, it is not for the Board to comment on the various ICAO and IATA documents on the subject. See for example Annex 18, ICAO Technical Instructions for the Safe Transport of Dangerous Goods by Air - Doc. 9284 - AN/905; ICAO Dangerous Goods Training Programmes - Doc. 9375 - AN/913 Books 1 - 6; and IATA Dangerous Goods Regulations; and see also RSA Regulations for the Carriage in Aircraft of Dangerous Goods, 1986. Nevertheless, in the Board's view continuing vigilance and research are required to eliminate all possible sources of packaging and cargo ignition, whether from dangerous goods or otherwise. Moreover, if Combi operations are to be permitted to continue, consideration should be given to revising the categories of dangerous goods to distinguish between those made up into pallets and those loaded in approved flame penetration-resistant containers.

6.4 Cockpit Voice Recorders

(a) should retain flight deck communications and sounds for the last hour, and not be limited to 30 minutes only;

(b) should be fitted with a "hot mic" system, i.e. a system in which the microphones are connected to a recorder in a manner that ensures the recording of all cockpit sounds within the range of the microphones regardless of audio control panel selections;

(c) should be equipped with additional area microphones at the flight engineer's and supernumerary crew's station.

6.5 At least one pilot and the flight engineer should at all times use head-sets and boom microphones.

6.6 Both CVRs and DFDRs

(a) should be fire-protected in the aircraft, as should the wiring to the units;

(b) should where practicable have a back-up system of battery power in the event of failure of the primary power source;

(c) should be fitted with a pinger system in which a first pinger operates for 30 days and a second 30-day pinger only commences operating after the first pinger ceases to function;

NOTE: The suggestion that, on long transocean flights, the CVR and DFDR should be floatable, overlooks the fact that in a short time the recorders may drift away over long distances from the site of the aircraft wreckage.

6.7 The Boeing 747 emergency check lists for "Upper and Main Deck Smoke Evacuation - Mixed Passengers and Cargo" and for "Main Deck Cargo Fire/Smoke - Mixed Passengers and Cargo" respectively require to be integrated. No provision appears to be made for the situation in which there is an uncontrolled fire in the main deck cargo hold and a smoke problem in the passenger cabin and/or cockpit. The matter to be cleared up is whether the crew should follow the smoke evacuation check list if the fire is still burning.

6.8 Means should be established by ICAO by which assistance in respect of underwater location searches for DFDRs and CVRs can be accelerated. The existence of standard procedures and agreements in respect of necessary actions and the funding thereof could be of great benefit and should be encouraged.

VOLUME 2

HELDERBERG AIR DISASTER

APPENDICES

(A - J)

TABLE OF CONTENTS

VOLUME 2 — PAGE

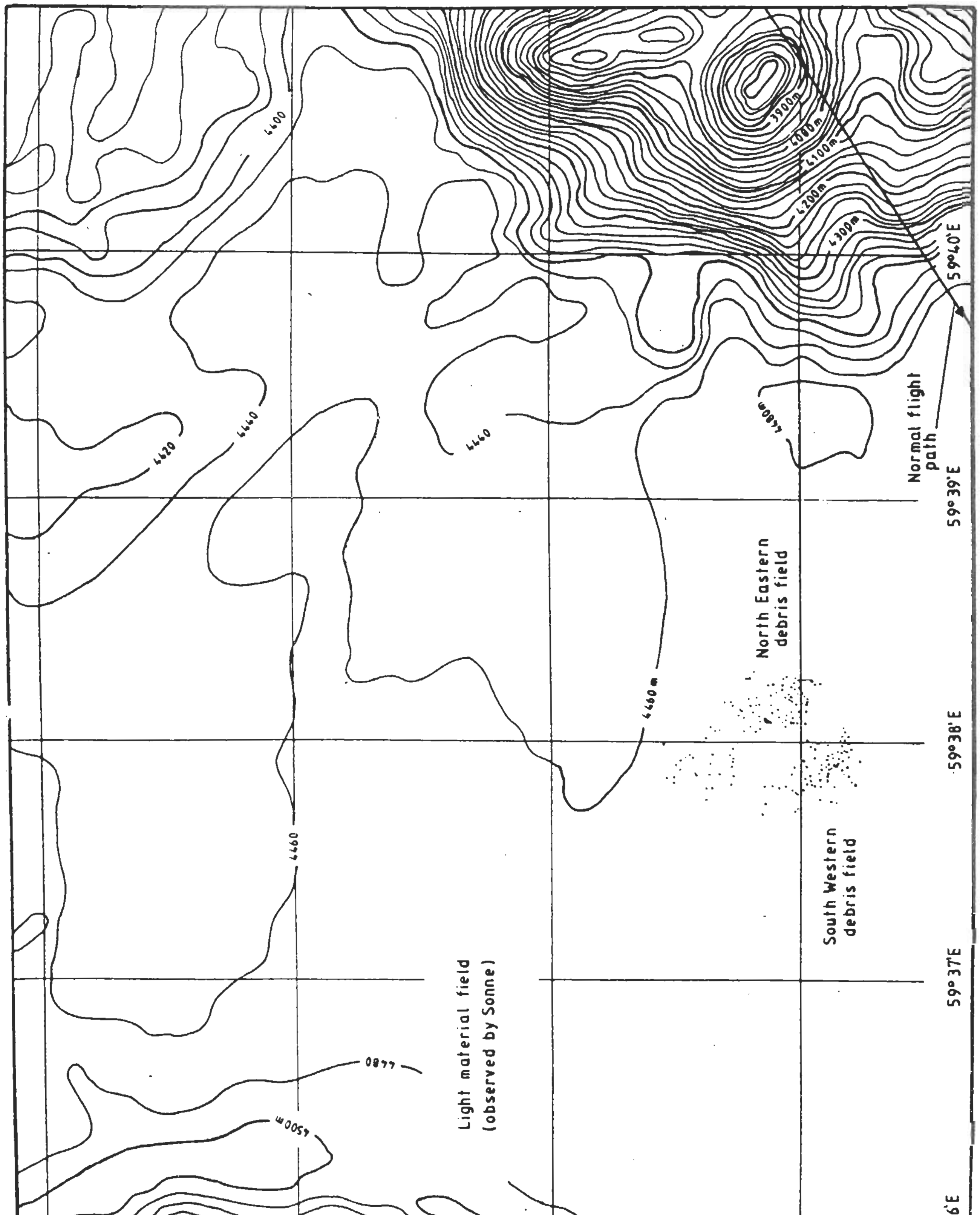

19°07'S
19°08'S
19°09'S
19°10'S
59°36'E
59°37'E
59°38'E
59°39'E
59°40'E
3900m
4000m
4100m
4200m
4300m
4400
4420
4440
4460
4460m
4480
4480m
4500m
4300
Light material field
(observed by Sonne)
North Eastern
debris field
South Western
debris field
Normal flight
path

Figure 1

2

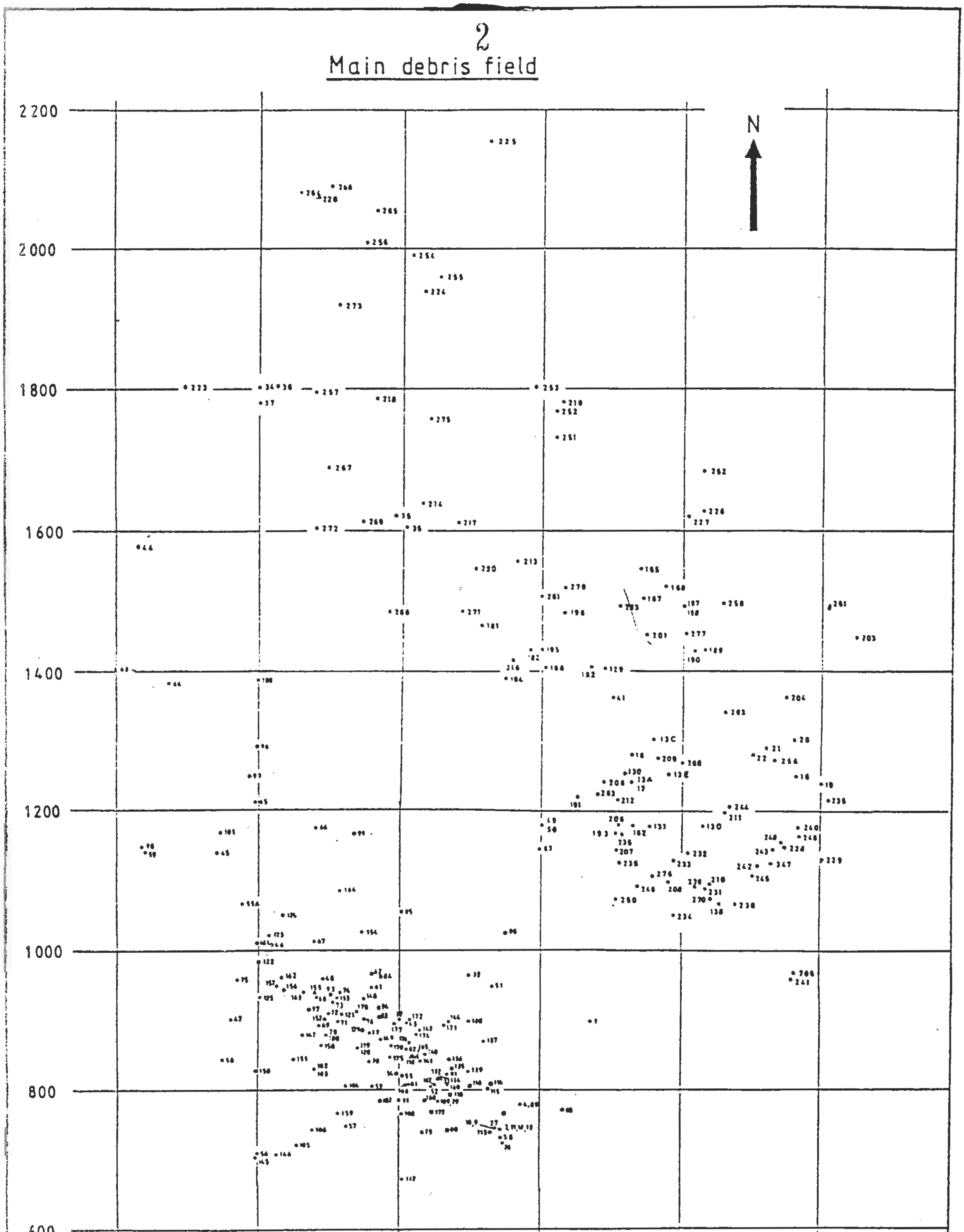
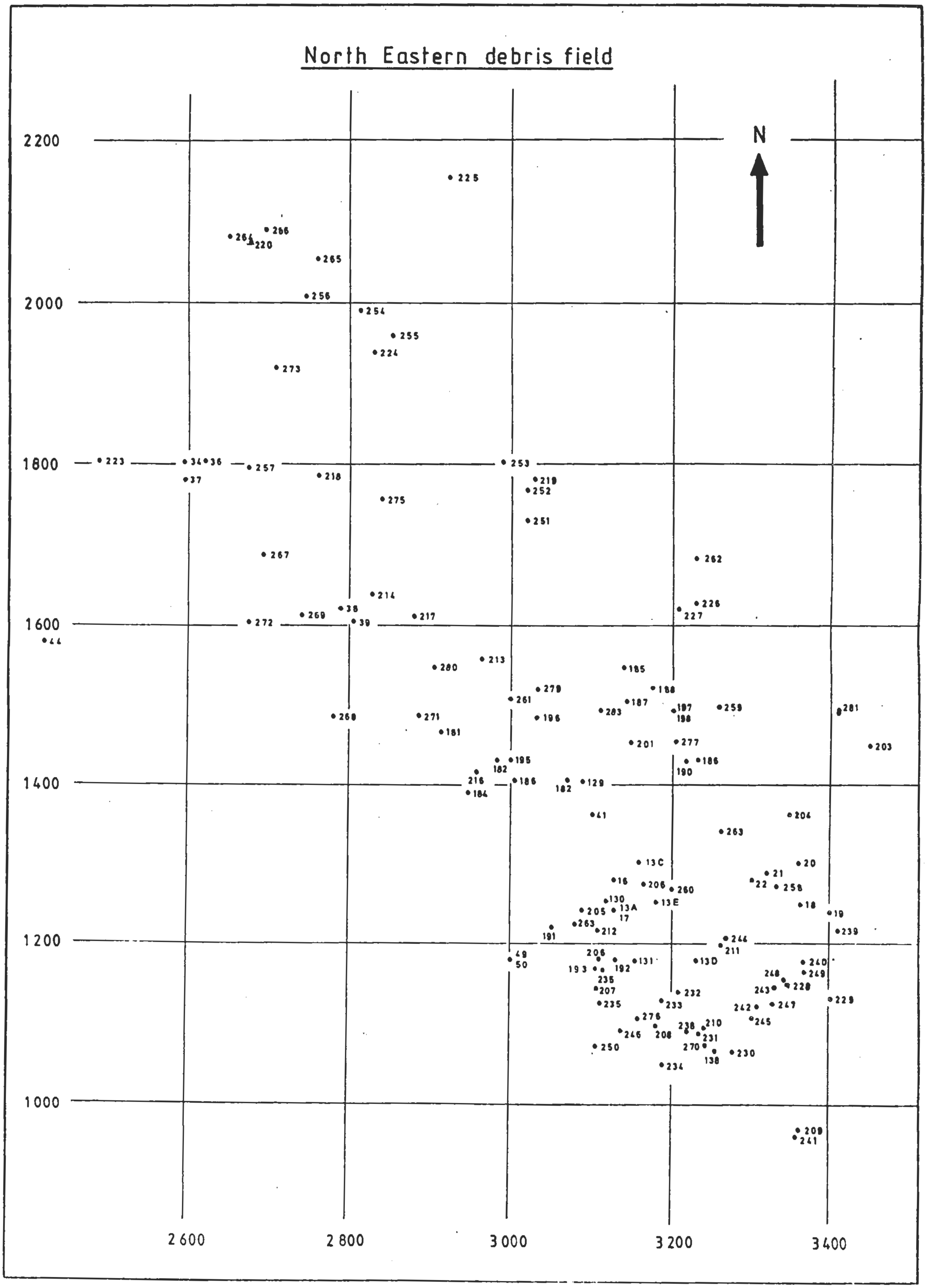
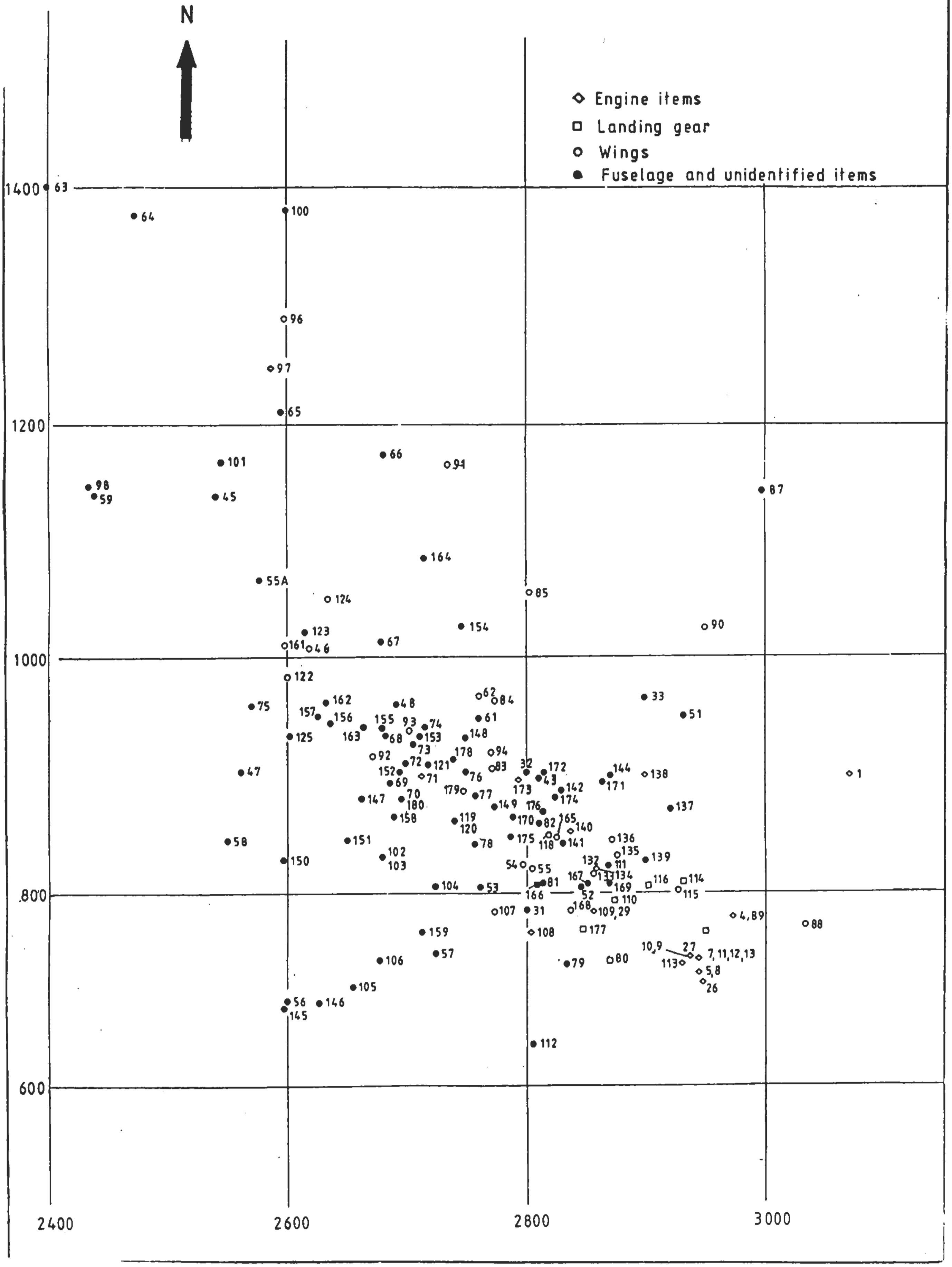

Main debris field
N
2200
2000
1800
1600
1400
1200
1000
800
600
2400
2600
2800
3000
3200
3400

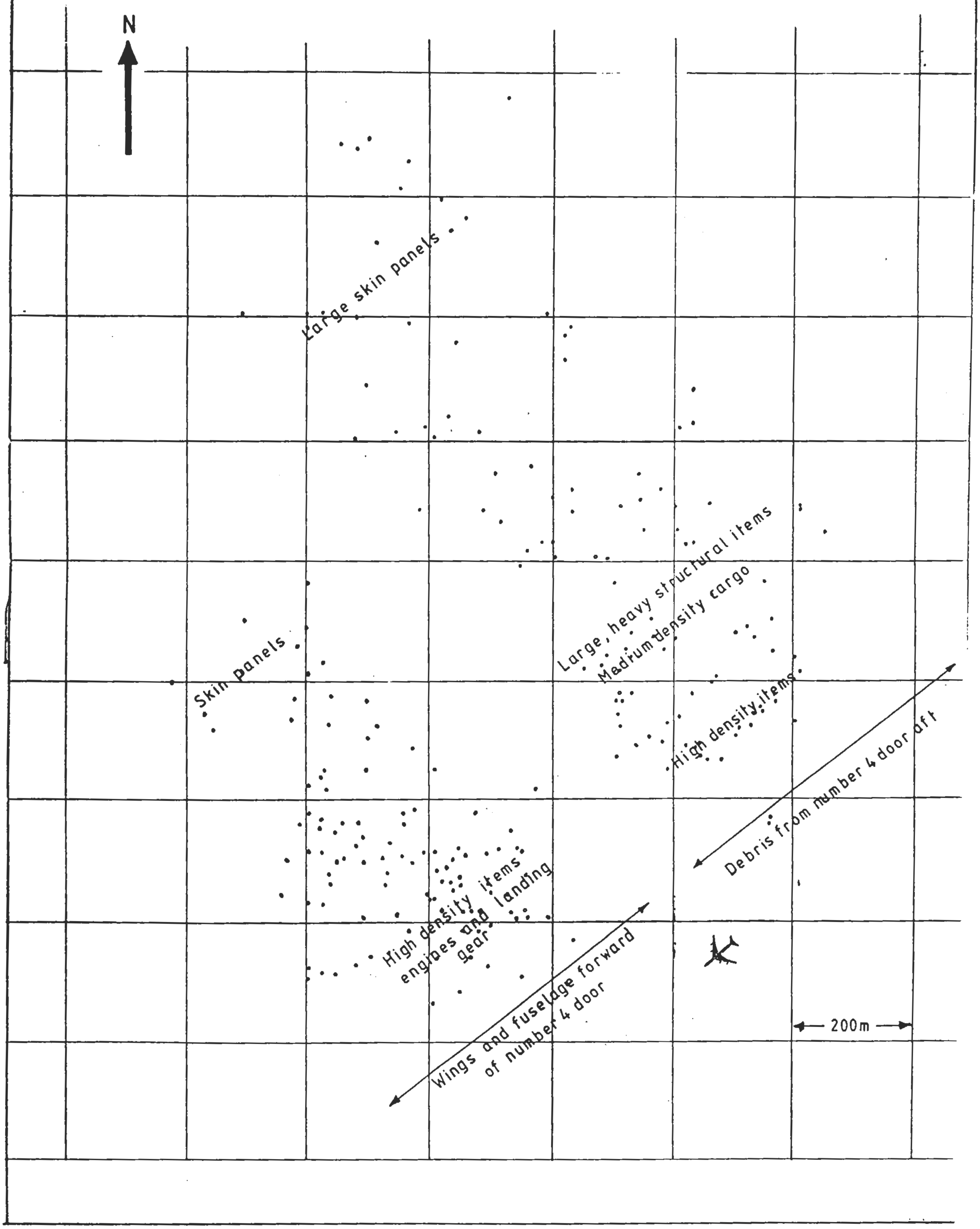
Figure 2


North Eastern debris field
N
2200
2000
1800
1600
1400
1200
1000
2600
2800
3000
3200
3400
225
264
266
220
265
256
254
255
224
273
223
34
36
257
37
218
253
219
252
275
251
267
262
214
226
38
227
269
272
39
217
44
213
280
185
188
279
261
187
197
259
281
268
271
283
198
196
181
201
277
203
195
186
182
190
216
186
182
129
184
41
204
263
13C
20
16
21
206
260
22
258
130
13E
18
19
205
13A
17
263
212
239
191
244
211
206
49
131
13D
240
50
193
192
248
249
236
243
228
207
233
232
229
235
242
247
276
245
238
210
246
208
231
270
250
230
138
234
209
241

South Western debris field



Debris distribution

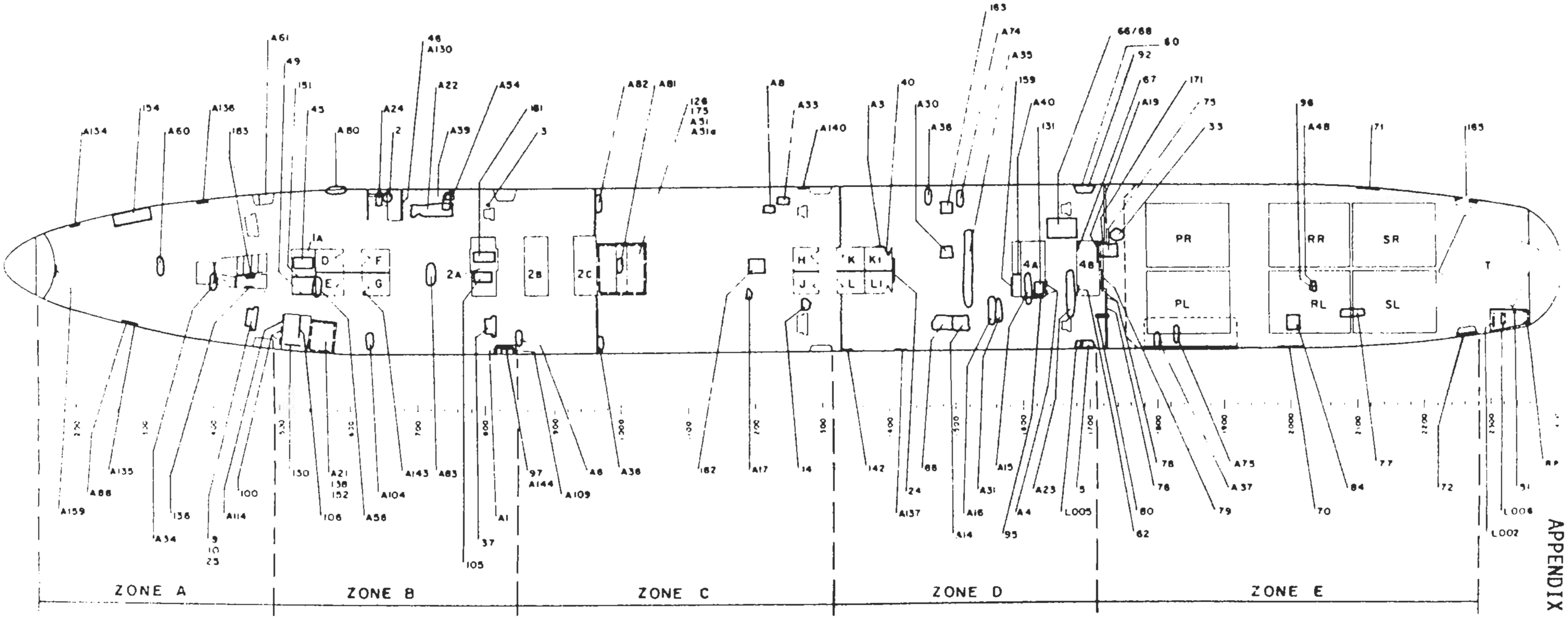


APPENDIX "B"

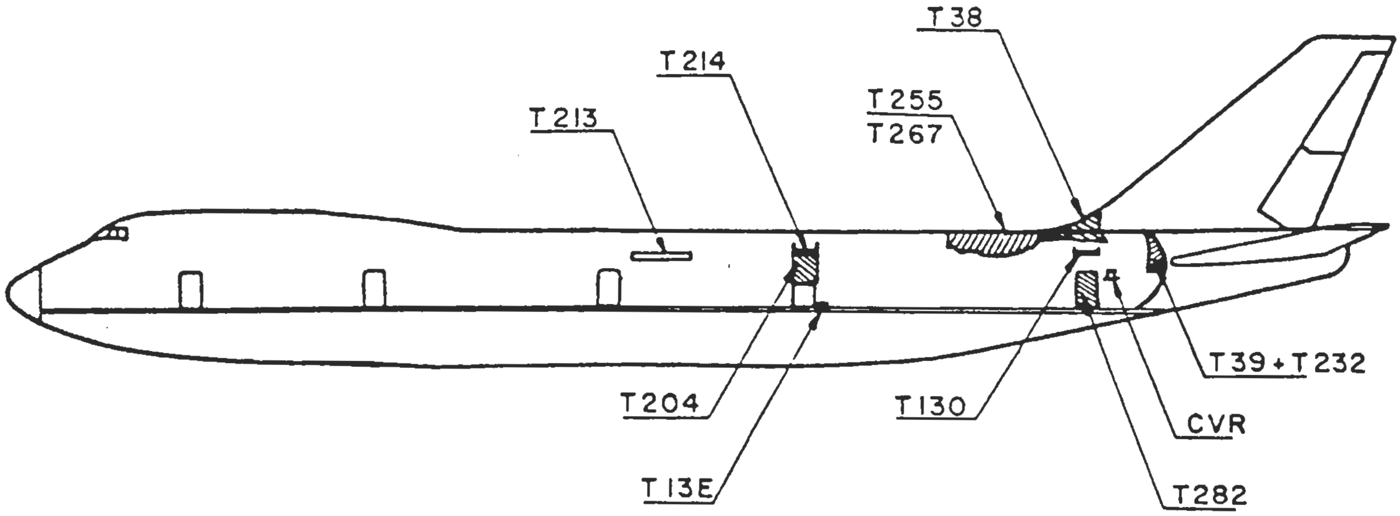
6

ACCIDENT - SAA B747 "HELDERBERG" REG: ZS-SAS FLT. SA 295 28 NOVEMBER 1987

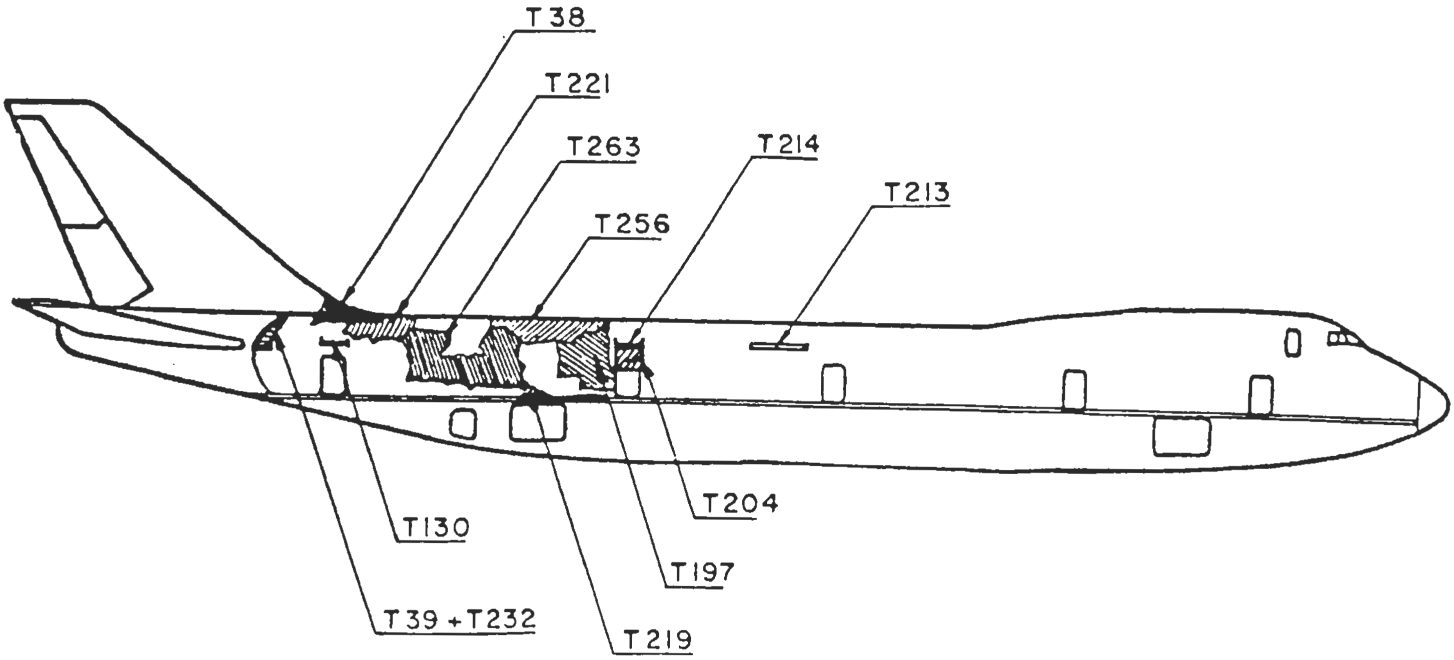
POSITION IDENTIFIED - FUSELAGE INTERIOR - DEBRIS CONDITION AND DISTRIBUTION DIAGRAM

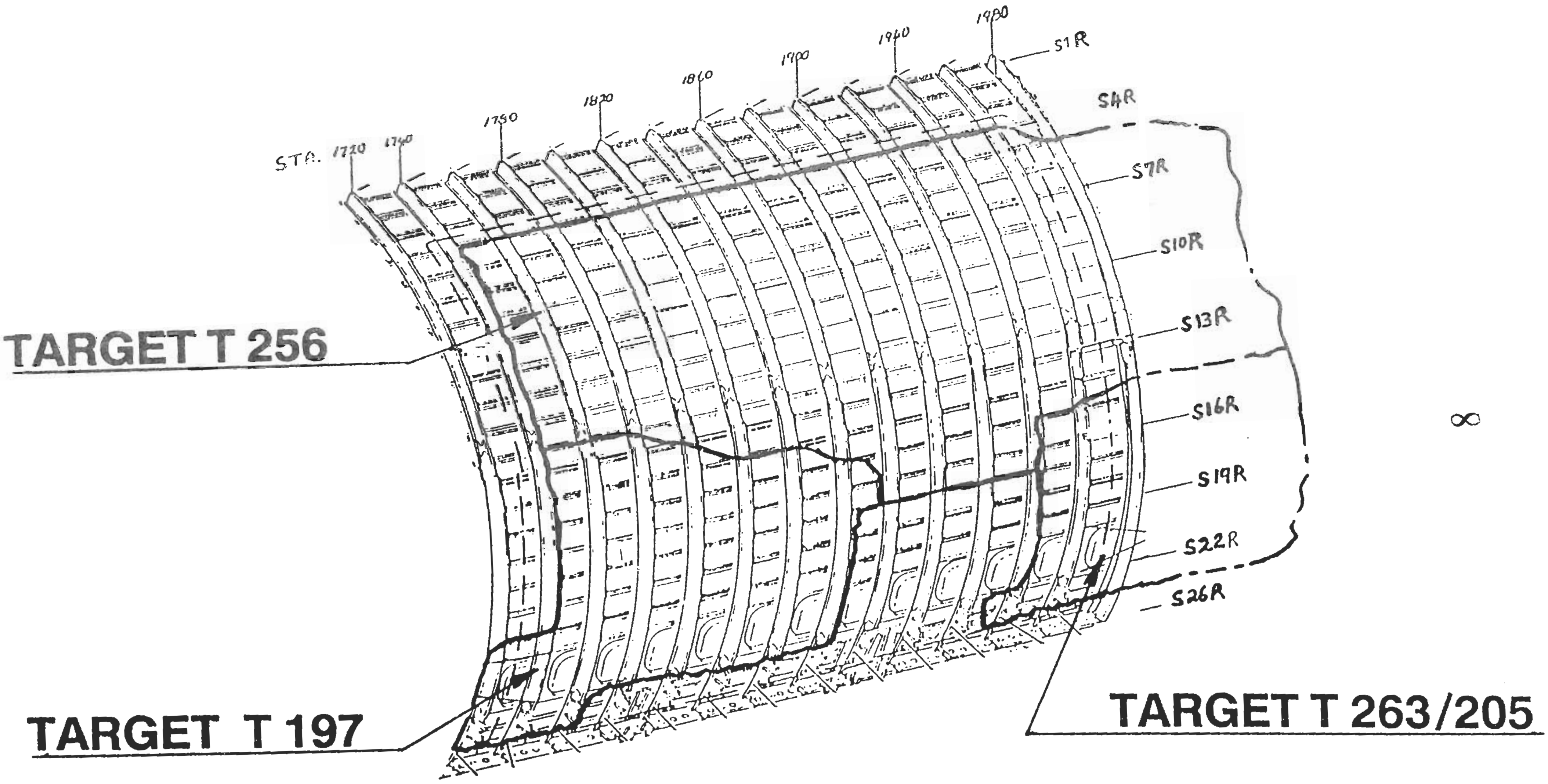


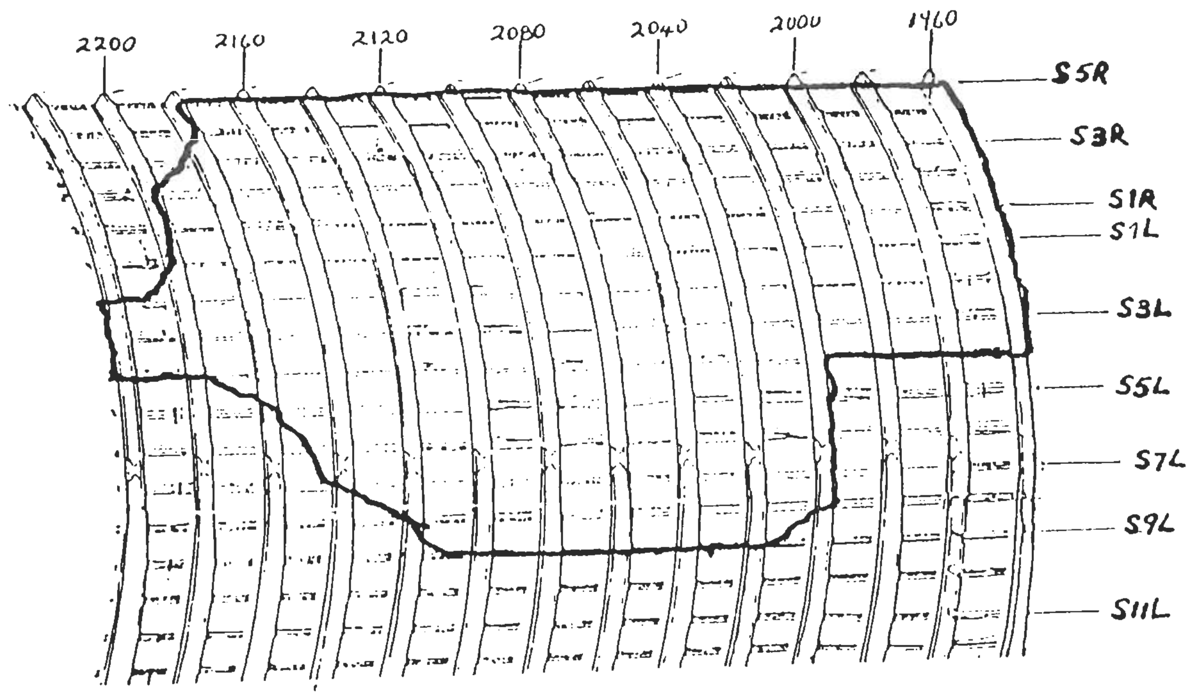
L/H VIEW OF RECONSTRUCTED REAR FUSELAGE COMPONENTS (RETRIEVED



R/H VIEW OF RECONSTRUCTED REAR FUSELAGE COMPONENTS (RETRIEVED)

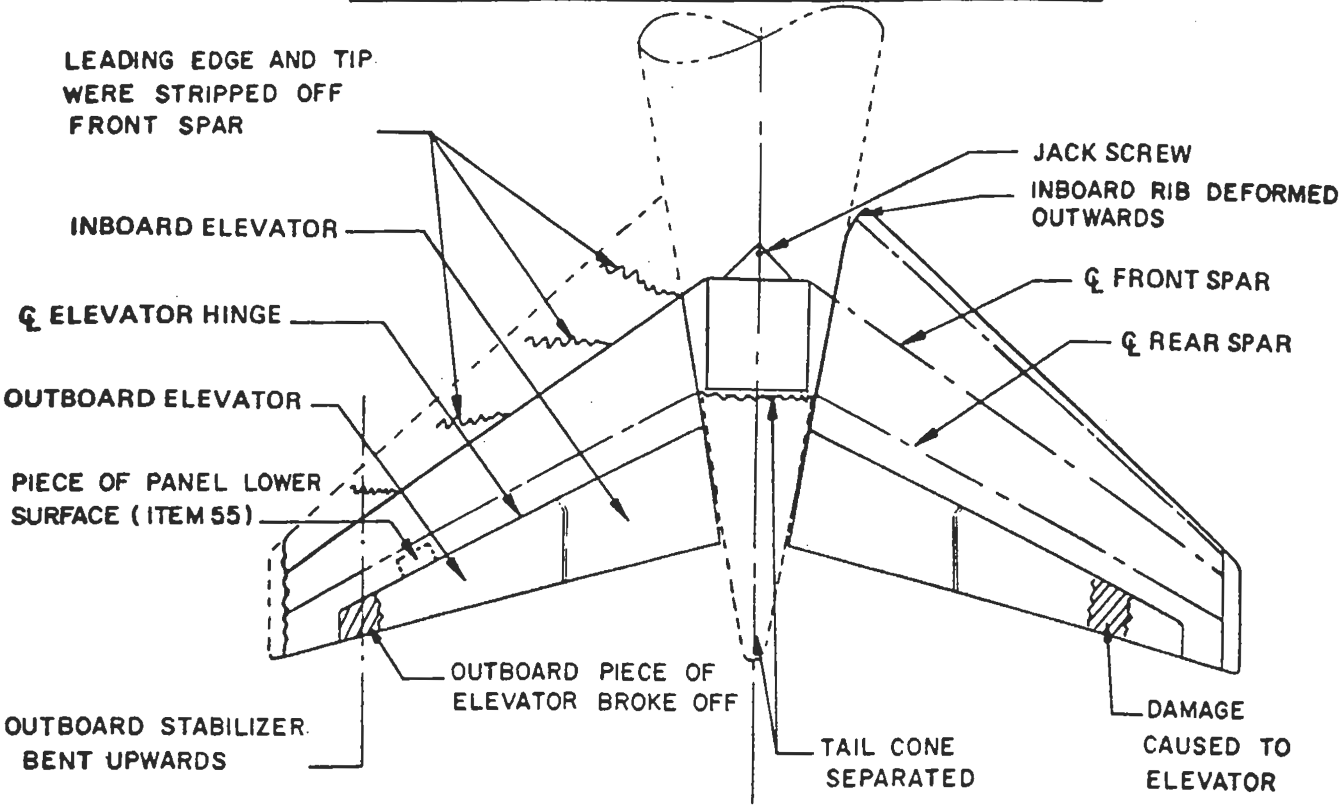



STA. 1720
1740
1780
1820
1860
1900
1940
1980
S1R
S4R
S7R
S10R
S13R
S16R
S19R
S22R
S26R
TARGET T 256
TARGET T 197
TARGET T 263/205

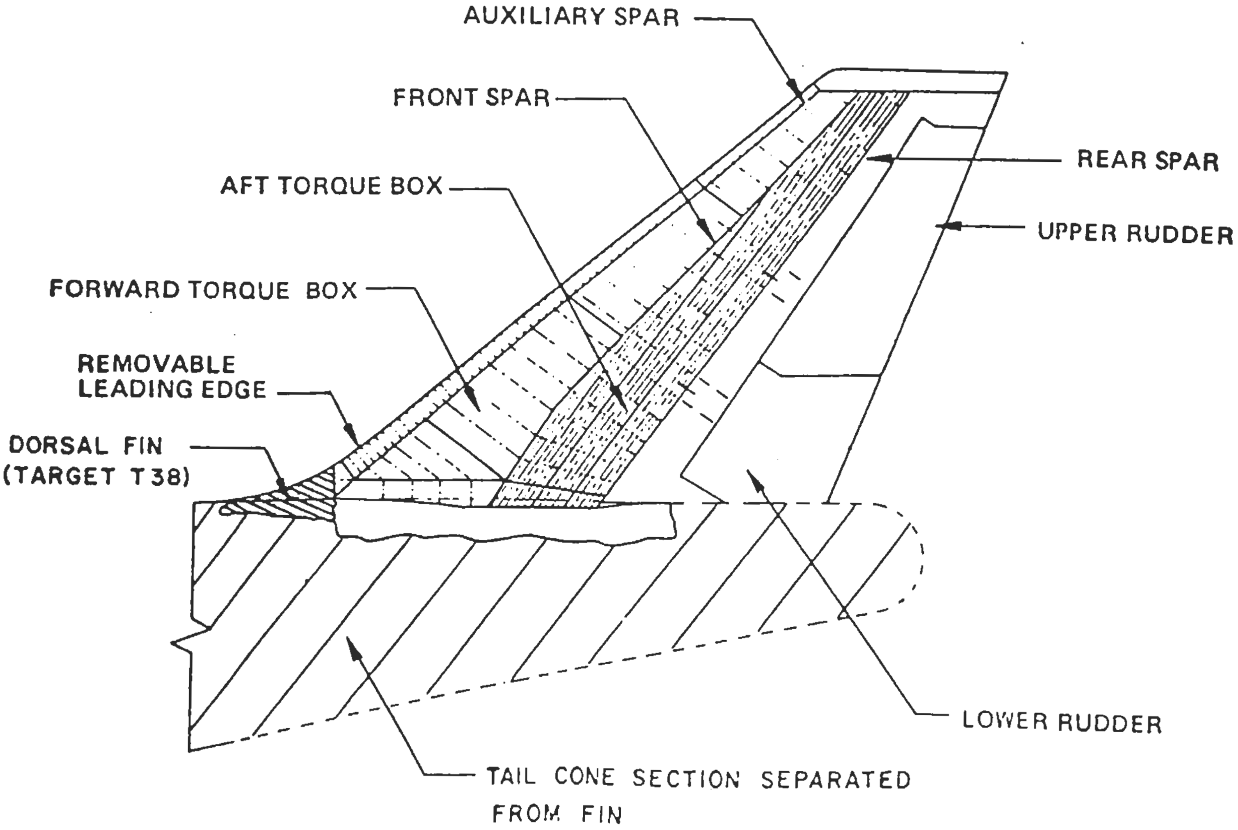

2200
2160
2120
2080
2040
2000
1960
S5R
S3R
S1R
S1L
S3L
S5L
S7L
S9L
S11L

TARGET T 267

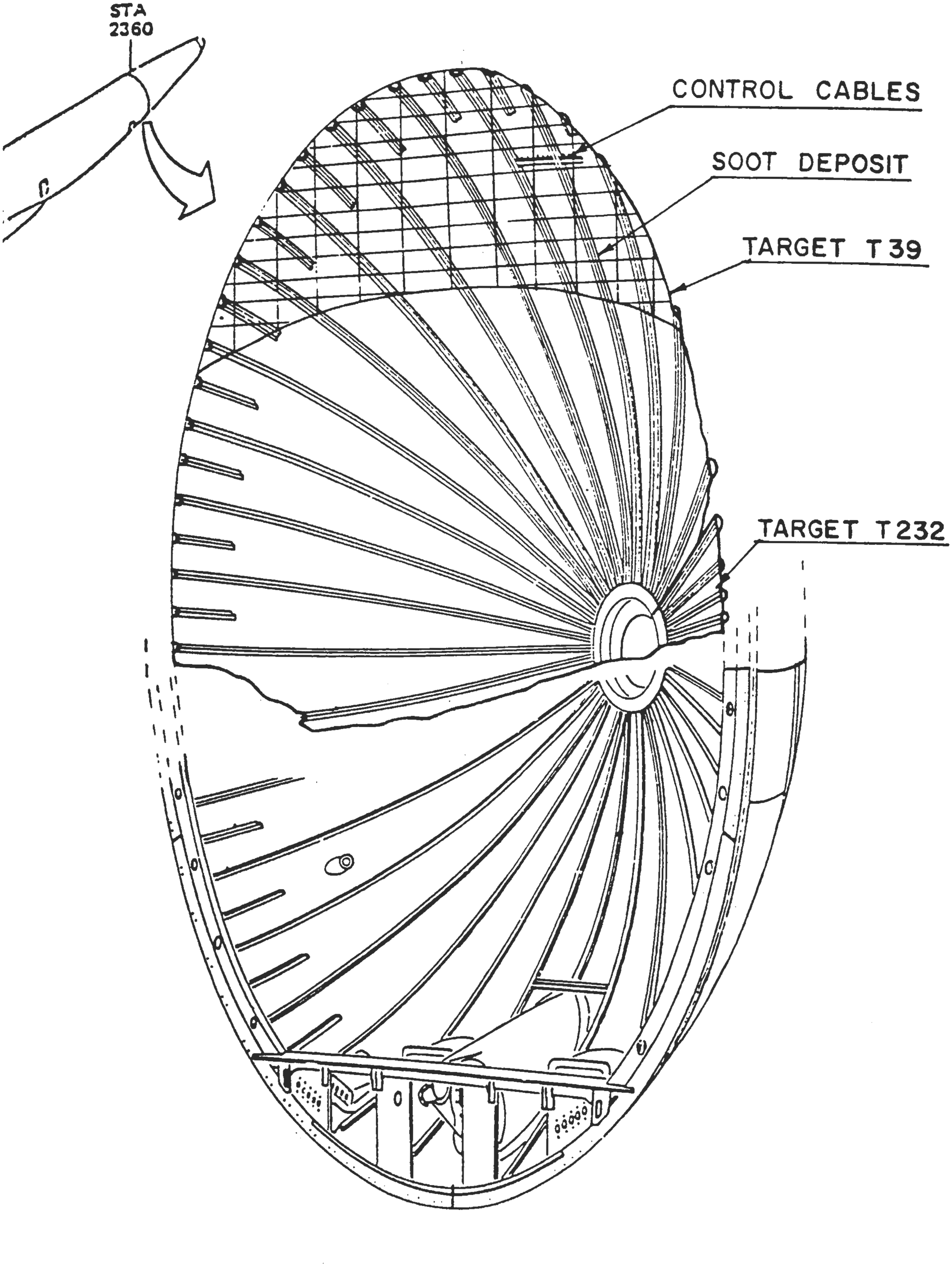
HORIZONTAL STABILIZER (TARGET T41)



VERTICAL STABILIZER (TARGET T36)



REAR PRESSURE BULKHEAD (RETRIEVED)



UNITED TECHNOLOGIES PRATT&WHITNEY

400 Main Street
East Hartford, Connecticut 06108

July 5, 1989

Mr. R. W. Van Zyl
Director, Aviation Safety
Department of Transport
Republic of South Africa
Forum Building
Struben Street
Pretoria, South Africa 0002

Re: South African Airways Boeing 747-244B "Combi" Registration ZS-SAS Accident in the Indian Ocean Northeast of Mauritius on 28 November 1987.

Dear Mr. Van Zyl:

Powerplant Section of the Accident Report

This powerplant report is based on the examination of photographs taken of the engines on the bottom of the ocean and is not based on actual observations of any engine hardware. This method of investigation limits the extent and depth of the analysis and also effects the accuracy of the determinations.

Conclusions:

Based on the analysis of the photographic evidence available of the engines and associated hardware, it is most probable that the engines were not under power and they were attached to the wings of the aircraft at the time of impact. The evidence also indicates that the wings of the aircraft were perpendicular to the surface of the water at the time of impact with the right wing down with no significant forward or aft velocity.

Summary of Findings:

- The engine mounts and support structure that could be identified in the photographs indicates that the engines were attached to the wings at the time of impact.

- The impact damage to the three engines and the one inlet cowl was consistently from the right side. The fourth engine was not located, therefore the damage to this engine could not be evaluated.

- The condition of the visible blades and vanes in the compressor sections of the three engines and visible sections of the separated low pressure turbine sections indicate that there was no significant engine rotation when impact occurred.

Details of examination:

All of the photographs were reviewed in Johannesburg, South Africa on April 27 and 28, 1989, and it was determined that three of the four engines, two engine tail plugs, and only one engine inlet cowl were located. The positions the engines occupied on the aircraft could not be determined and which engines the tail plugs and inlet cowl came from was also unknown. The photographs of the engine hardware were forwarded to Pratt & Whitney in East Hartford, Connecticut for analysis, and the following is the result of that effort.

The engine inlet cowl (photographs 10/J 163 T124, 10/J 170 T124) was in the shape of the letter "D" and it was determined that the impact to the cowl had occurred on the right side of the cowl. The center of the impact (the flat side of the cowl) was at about the 3:30 o'clock location (viewed from rear) and was in a radial direction with no evidence of any significant fore or aft component.

The determination that only three engines were located was based on the observation that only the front sections of three engines were photographed. In addition to these three major engine sections, there were also other engine components located. It could not be determined whether these components were from one of the three engines identified or could have been components of the fourth engine.

The damage to all of the engine hardware was consistent and indicated that there was no significant rotation of any of the engines at the time of impact. Where the location of the impact could be determined, it was established that all of the impacts occurred on the right side of the engines and was centered about the 3:00 o'clock location.

The first engine located (photographs 1/A 13 T4, 10/J 79 T4, and 9/I 16 T89) was lying on the ocean floor with the aft portion of the engine buried. The engine aft of the high pressure compressor cannot be seen, therefore, the condition or location of the turbine sections could not be determined. It was determined that the undamaged fan blades are on the left side of the engine and that the fractured and missing fan blades are on the right side of the engine. It was observed that the majority of the fan blades on the left side of the engine are straight and relatively undamaged. Based on previous accident investigations, these findings indicate that this engine impacted on the right side and there was no significant engine fan rotation at the time of impact. The separation of all of the engine cowling, all of the engine fan cases and duct hardware, and the fracture and liberation of the outer portion of the intermediate case indicates that the engine was traveling at high velocity when impact occurred, and the impact appears to have been in a radial direction with no significant fore or aft velocity. The determination of no fore or aft velocity is also supported by the observation of the straight fan blades. If there had been a significant fore or aft velocity component the fan blades would have been bent fore or aft. This lack of any significant fore or aft velocity component at the time of impact was also observed on the other two engines.

The second engine located (photographs 3/C 76 T26, and 3/C 80 T26) was lying flat on the ocean floor with about half of the engine buried. The exact location of the straight fan blades could not be determined but from the evidence that was available in the photographs those blades are on the left side of the engine, therefore the impact to this engine was also from the right side. The view of the aft section of the engine (photograph 3/C 80 T26) shows that everything aft of the high pressure turbine is missing. The first and second stage high pressure turbine blades have either fractured airfoils or the blades are missing from the disk and there are no 2nd stage turbine vanes visible. The lack of extensive damage to the trailing edges of the 1st stage turbine vanes, that would be expected if the 1st stage blades fractured at high rotor speed, indicates that there was no significant rotation of the turbine when the blade airfoils were fractured.

The third engine located (photographs 3/C 86 T27, and 11/K 217 T113 was lying aft end down and buried. Very little of the engine aft of the intermediate case can be seen therefore the analysis is based on the condition of the fan section. It was determined that the broken and missing fan blades were centered about the 3:00 o'clock location which indicates that this engine was also impacted on the right side. The fan containment case can be seen aft of the fan rotor which indicates a small forward velocity component of the engine during impact. The rest of the damage to the engine is mostly radial which further supports the determination that the forward velocity component was very small. The visible fan blades also indicate that there was no significant rotation during impact.

Although other engine components were photographed it could not be determined from which engine these components had been liberated. Two engine tail plugs were located and both showed damage from a radial impact. Due to the symmetry of the tail plug, the location of the radial impact could not be determined (photographs 8/H 102 T71 and 10/J 247 T).

The entire low pressure turbine case with blades and vanes installed was found lying aft end down (photograph 1/A 17 T5). The case was impacted on one side in the photograph but the clock location relative to the engine could not be determined. All of the third stage turbine blades were fractured at the point of impact but the remainder of the third stage blades are not fractured which again indicates no significant rotation at the time of impact.

The inner portion of an engine turbine exhaust case and the sixth stage disk and blades were located (photograph 11/K 219 T113). The damage to the turbine exhaust case struts and the sixth stage turbine blades is consistent with a radial impact load. The observation that in one area all of the blades are fractured and in the other area they are undamaged further supports that there was no significant engine rotation at the time impact occurred.

A section of fan case pieces was located (photograph 10/J 250 T138). The upper most case in the photograph indicates that the fan containment case was separated in a forward direction. This means that there was a small aft velocity component of the engine at impact. The rest of the damage to the fan cases indicate that the major impact force was in a radial direction.

One engine fan containment case was found separated from the engine (photograph 11/K 178 T). This case shows that the fan blades had rubbed the case lightly on the engine horizontal centerline which is the normal rub location which indicates that there was nothing abnormal while the engine was operating at power prior to impact.

Pratt & Whitney appreciated the opportunity to participate in the accident investigation. We are willing to provide further assistance in the clarification of our observations and analysis if necessary.

Sincerely,

UNITED TECHNOLOGIES CORPORATION
P&W Commercial Engine Business

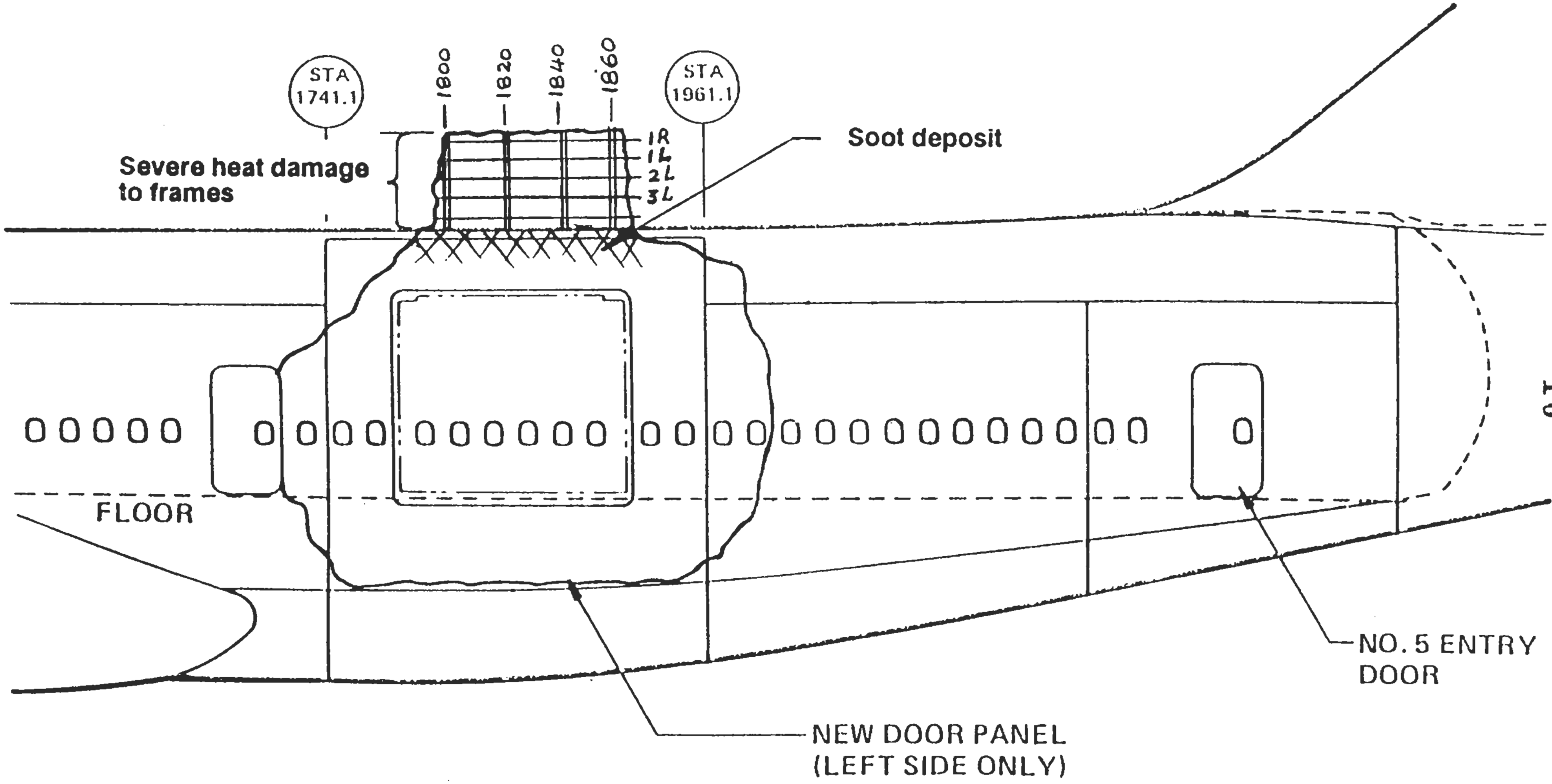
Robert E. North

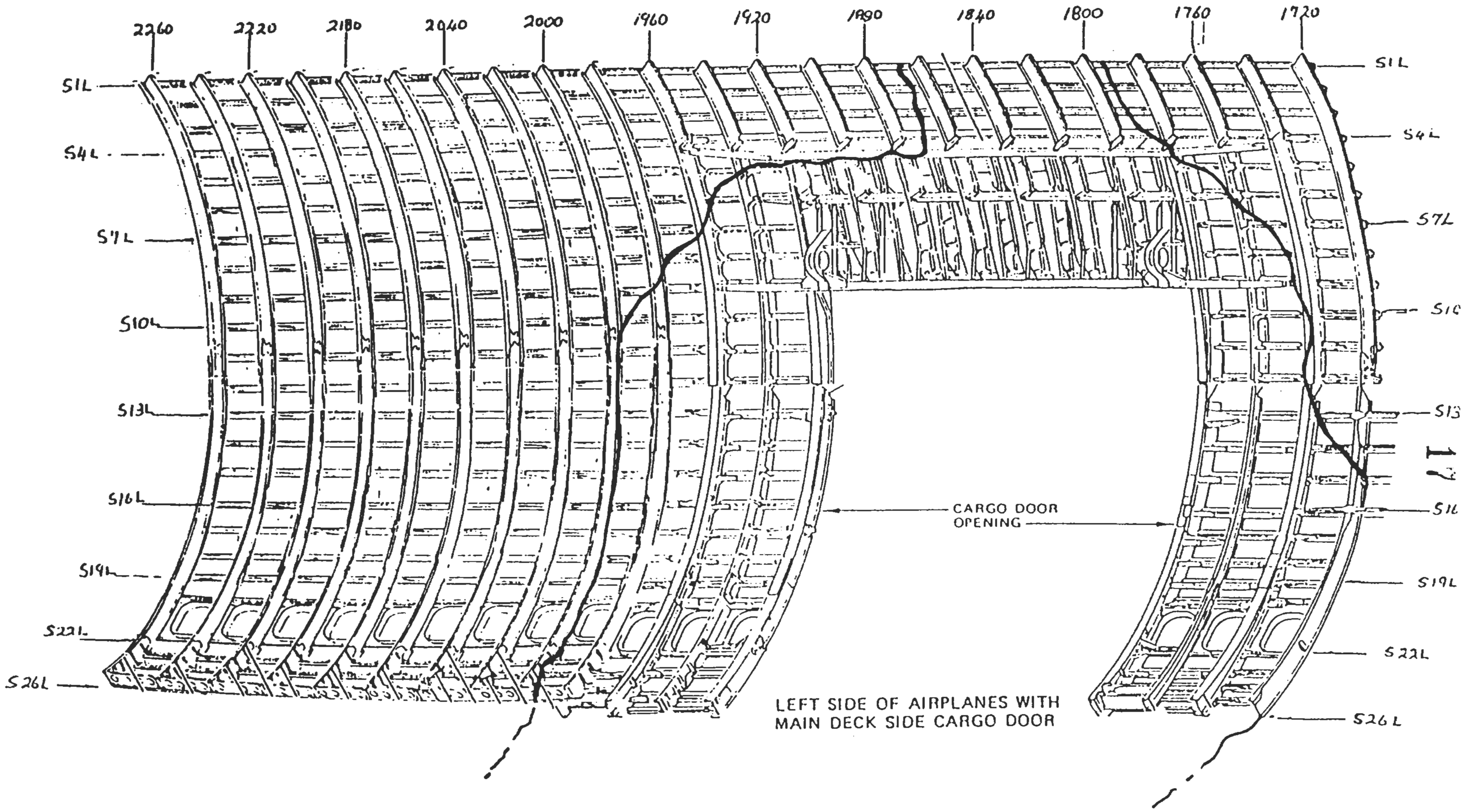
Robert E. North
Airworthiness
Product Integrity

REN/89001

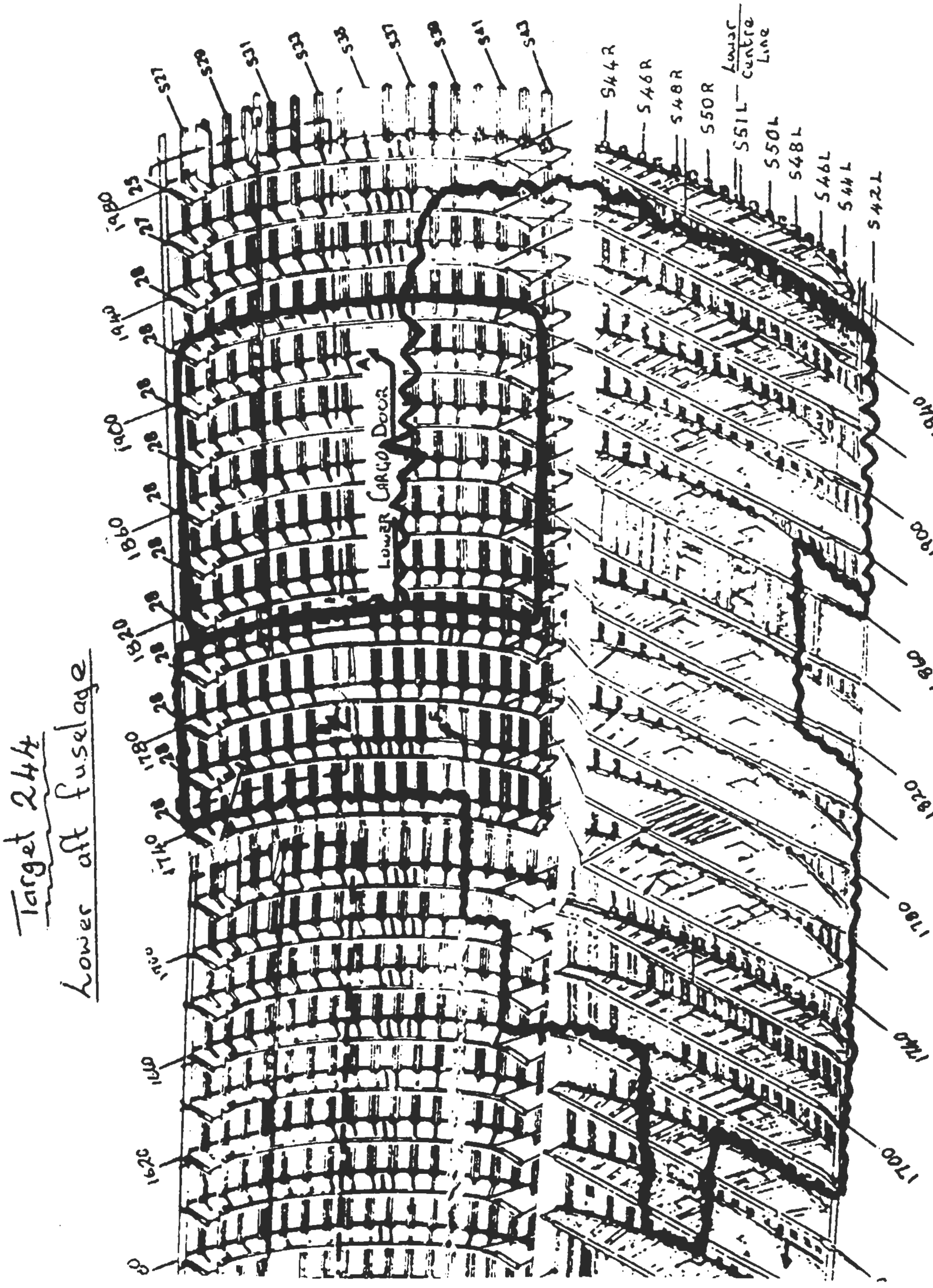
cc: Mr. Brian Richardson

MAIN CARGO DOOR (TARGET 13E)




2260
2220
2180
2040
2000
1960
1920
1880
1840
1800
1760
1720
S1L
S4L
S7L
S10L
S13L
S16L
S19L
S22L
S26L
CARGO DOOR OPENING
LEFT SIDE OF AIRPLANES WITH MAIN DECK SIDE CARGO DOOR

TARGET T 13 E


Target 244
Lower aft fuselage
Lower Cargo Door
Lower Centre Line
S44R
S46R
S48R
S50R
S51L
S50L
S48L
S46L
S44L
S42L
1980
1940
1900
1860
1820
1780
1740
1700

ANNEXURE "D"

747 EMERGENCY/ABNORMAL CHECKLIST

UPPER AND MAIN DECK SMOKE EVACUATION
Mixed Passenger and Cargo

Oxygen Masks and Regulators	ON 100%	ALL
Smoke Goggles (if required)	ON	ALL
Cockpit Door	CLOSED	F/E
Crew Communications	ESTABLISH	ALL

Cabin Signs	ON	PNF
Cabin Altitude Selector (Max. 10,000 ft.)	INCREASE	F/E
Pressurization Rate Selector	INCREASE	F/E
Bleed Air Valve Switches	OPEN	F/E
Duct Isolation Valve Switches	OPEN	F/E
Pack Valve Switches	ALL OPEN	F/E
Gasper Fan Switch	ON	F/E
Suppl. Vent Fans Switch (if installed)	OFF	F/E
Recirculating Fans Switches	ON	F/E
Smoke Condition	CHECK STATUS	PNF

- **If passenger cabin ventilation not adequate to dissipate smoke, land at nearest suitable airport.**

If immediate landing cannot be made and smoke condition is extremely severe:

Airplane Altitude	BELOW 14,000 FT. OR TO MEA	PF
PA Announcement	IF REQUIRED	PNF
Entry Doors to be Opened	IDENTIFY	PNF

NOTE: In 12-pallet configuration smoke barrier door must be secured open while evacuating smoke through entry doors.

Pressurization Mode Selector	MAN	F/E
Outflow Valve Manual Control Switches	OPEN	F/E
Airspeed	BELOW 200 KIAS	PF
Pack Valve Switches	CLOSE	F/E
Mode Selector Handles (Captain's Direction)	MAN	F/A
Selected Door Handles (Captain's (Direction)	ROTATE AND SECURE IN 12 O'CLOCK POSITION	F/A
Pack Valve Switches	OPEN	F/E

When smoke evacuated:

Forward Door	CLOSE	F/A
No. 4 Door (If opened)	CLOSE	F/A
Door Mode Selector Handles	AUTO	F/A

747 EMERGENCY/ABNORMAL CHECKLIST

MAIN DECK CARGO FIRE/SMOKE
Mixed Passenger and Cargo

Oxygen Masks and Regulators ....ON 100%	ALL
Smoke Goggles (if required) ....ON	ALL
Cockpit Door.....................CLOSED	F/E
Crew Communications ....ESTABLISH	ALL

Cabin Signs...........................ON	PNF
Bleed Air Valve Switches...............OPEN	F/E
Duct Isolation Valve Switches ....OPEN	F/E
Pack Valve Switches...............ALL OPEN	F/E
Recirculating Fan Switch ....OFF	F/E
Equipment Cooling Valve Switch .... NORM	F/E
Oxygen Mask and Portable Oxygen Bottle .....ON	F/A
Main Deck Cargo Compartment (Captains direction)................ENTER	F/A
Smoke Barrier Door ....CLOSE	F/A
Dry Chemical Fire Extinguisher ....OBTAIN	F/A
Dry Chemical Fire Extinguisher Extension ....ATTACH	F/A
Fire/Smoke Source .... EXTINGUISH	F/A

- If evidence of fire is detected within a fully enclosed cargo container, do not attempt to open the container. Monitor the container until landing can be made.
- Land at nearest suitable airport.

If smoke condition exists in passenger area, use UPPER AND MAIN DECK SMOKE EVACUATION Checklist.

National Transportation Safety Board

Washington, D. C. 20594

Safety Recommendation

Date: May 16, 1988

In reply refer to: A-88-61 Through -63

Honorable T. Allan McArtor
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On November 28, 1987, a South African Airways Boeing 747-244B, call sign Springbok 295, on a scheduled flight from Taipei, Taiwan, to Johannesburg, South Africa, with an en route stop in Mauritius, crashed into the sea about 140 miles northeast of Mauritius. All 141 passengers and 19 crewmembers on board were killed in the accident. Preliminary evidence, based on the estimated 1 percent of the wreckage that has been retrieved, and the communications between Springbok 295 and Mauritius air traffic control, suggests that an in-flight fire disabled the airplane, the flightcrew, or both.

The continuing investigation of the accident is being conducted by the Directorate of Civil Aviation of the Republic of South Africa, with the full participation of the National Transportation Safety Board representing the United States, the state of manufacture of the airplane, in accordance with the provisions of Annex 13 of the International Civil Aviation Organization. Considerable evidence remains to be obtained primarily by complex underwater recovery efforts. However, the accident has raised several issues which the Safety Board believes deserve immediate corrective action.

The Boeing 747-244B airplane was a "Combi" airplane, that is, an airplane in which a portion of the main, passenger compartment can be used to transport cargo. In the Boeing 747 Combi, the two aft cabins can be converted within hours to either passenger or cargo configurations. Federal Aviation Regulations (FAR) categorize aircraft cargo compartments into five classes, A through E, according to their volume, in-flight accessibility, air flow, and fire containment capabilities (see 14 Code of Federal Regulations (CFR) 25.857). Accordingly, the aft, main deck, cargo compartment of the Boeing 747 Combi is a class "B" compartment. Among other requirements of 14 CFR 25.857, this type of compartment must have: sufficient access to enable a crewmember to effectively reach any part of the compartment while in flight; separate smoke or fire detectors to alert flightcrew members at their stations to smoke or fire within the compartment; and the ability to prevent smoke from the compartment from entering the passenger compartment.

National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: May 16, 1988

In reply refer to: A-88-61 Through -63

Honorable T. Allan McArtor
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On November 28, 1987, a South African Airways Boeing 747-244B, call sign Springbok 295, on a scheduled flight from Taipei, Taiwan, to Johannesburg, South Africa, with an en route stop in Mauritius, crashed into the sea about 140 miles northeast of Mauritius. All 141 passengers and 19 crewmembers on board were killed in the accident. Preliminary evidence, based on the estimated 1 percent of the wreckage that has been retrieved, and the communications between Springbok 295 and Mauritius air traffic control, suggests that an in-flight fire disabled the airplane, the flightcrew, or both.

The continuing investigation of the accident is being conducted by the Directorate of Civil Aviation of the Republic of South Africa, with the full participation of the National Transportation Safety Board representing the United States, the state of manufacture of the airplane, in accordance with the provisions of Annex 13 of the International Civil Aviation Organization. Considerable evidence remains to be obtained primarily by complex underwater recovery efforts. However, the accident has raised several issues which the Safety Board believes deserve immediate corrective action.

The Boeing 747-244B airplane was a "Combi" airplane, that is, an airplane in which a portion of the main, passenger compartment can be used to transport cargo. In the Boeing 747 Combi, the two aft cabins can be converted within hours to either passenger or cargo configurations. Federal Aviation Regulations (FAR) categorize aircraft cargo compartments into five classes, A through E, according to their volume, in-flight accessibility, air flow, and fire containment capabilities (see 14 Code of Federal Regulations (CFR) 25.857). Accordingly, the aft, main deck, cargo compartment of the Boeing 747 Combi is a class "B" compartment. Among other requirements of 14 CFR 25.857, this type of compartment must have: sufficient access to enable a crewmember to effectively reach any part of the compartment while in flight; separate smoke or fire detectors to alert flightcrew members at their stations to smoke or fire within the compartment; and the ability to prevent smoke from the compartment from entering the passenger compartment.

These requirements have hitherto been assumed to provide adequate protection from the potentially catastrophic consequences of an in-flight fire because, the Safety Board believes, the incidence of such events on transport category aircraft has been quite low. As a result, little opportunity has been available to demonstrate the effectiveness of these requirements in actual in-flight occurrences. For example, the Safety Board is aware of only five major fatal in-flight fires on board transport category aircraft in the last two decades: on July 11, 1973, near Paris, France, a fire on a Varig Airlines Boeing 707 killed 124 people; on November 3, 1973, in Boston, Massachusetts, a fire on a Pan American Airways Boeing 707 freighter killed all three crewmembers; on November 26, 1979, near Jeddah, Saudi Arabia, a fire on a Pakistan International Airlines Boeing 707 killed all 156 people on-board; on August 19, 1980, in Riyadh, Saudi Arabia, a fire which was believed to have originated in a class D compartment of a Saudia Lockheed L-1011 killed all 301 persons on-board; and on June 2, 1983, a fire on an Air Canada McDonnell Douglas DC-9 in Cincinnati, Ohio, killed 23 people.

Following the accident involving the Saudia Lockheed L-1011, the Safety Board issued Safety Recommendation A-81-13 which urged the Federal Aviation Administration (FAA) to:

> Review the certification of all baggage/cargo compartments (over 500 cu. ft.) in the "D" classification to insure that the intent of 14 CFR 25.857(d) is met.

In response to the recommendation, the FAA carried out extensive research to determine the fire containment capabilities of class C or D cargo compartments. 1/ The results of the research changed several assumptions regarding the fire containment and/or suppression capabilities of inaccessible, i.e., class C and D, cargo compartments. For example, certain cargo liner material that had been considered to be fire resistant was shown to be unable to contain a sustained fire for even several minutes. As a result, the FAA upgraded the fire-resistance standards of class C and D cargo compartment liners and revised other regulations governing fire detection, containment, and suppression in class C and D cargo compartments.

According to the final rule requiring changes in cargo liner fire resistance, 2/ the proposed changes were to be applied ". . . to all classes of cargo or baggage compartments that depend on liners for fire control," i.e., class C and D cargo compartments and not class B and E cargo compartments, which rely on crewmember access to combat a fire. Thus, aircraft manufacturers can comply with current FARs by demonstrating that class C and D cargo compartments can contain a fire and, due to their ability to restrict internal air flow, smother it with extinguishing agent, starve it through oxygen depletion, or both. Further, fire containment in ceiling and sidewall liners of

1/ Blake, D.R., and Hill, R.G., Fire Containment Characteristics of Aircraft Class D Cargo Compartments, Atlantic City, New Jersey: FAA Technical Center, 1983 (FAA/DT/CT-82/156); and Blake, D., Suppression and Control of Class C Cargo and Compartment Fires, Atlantic City, New Jersey: FAA Technical Center, 1985 (DOT/FAA/CT-84/21).

2/ Department of Transportation, Federal Aviation Administration, 14 CFR Part 25, Airworthiness Standards; Fire Protection Requirements for Cargo or Baggage Compartments, Federal Register 51, May 16, 1986.

class C and D cargo compartments is required to be demonstrated by holding a flame to them for a minimum of 5 minutes, while certification requirements specify that flames be held to liners of class B compartments for only 12 seconds. The Safety Board believes that to provide the needed fire resistance for class B cargo compartments, the FAA should establish fire resistant requirements for the ceiling and sidewall liners in class B cargo compartments of transport category airplanes that equal or exceed the requirements for class C and D compartments as set forth in 14 CFR Part 25, Appendix F, Part III.

Class B cargo compartment certification standards specify that a fire be detected rapidly and, following detection, that a crewmember can then, within 5 minutes, leave his or her station, don protective equipment, enter the cargo compartment, locate the fire extinguisher, attach an extension nozzle to it, and point it at the fire. In the certification of the Boeing 747 Combi, the manufacturer demonstrated that all required actions could be accomplished well within the allowable interval.

Yet, while the certification requirements of the Boeing 747 Combi's class B cargo compartment were met, the Safety Board is unaware of any data which can support the effectiveness of the fire detection and suppression techniques against an actual fire in a class B cargo compartment. Moreover, while the effectiveness of fire suppression techniques relies on rapid detection, examination of the certification of the fire detection in the Combi's main deck cargo compartment brings into question the rapidity with which a fire can actually be detected due to several factors. All certification demonstrations used a smoke generator from which the smoke was directed vertically toward the compartment ceiling where the smoke collectors are located. No tests were carried out with smoke generated horizontally at the floor level. Further, all tests were conducted in an empty compartment, and, as a result, smoke detection was not measured in the environment in which an actual fire would be likely to occur, i.e., a compartment containing cargo, as Springbok 295 was. Moreover, the cargo pallets on board Springbok 295 were wrapped with polyethylene covers to protect them from weather during loading and unloading. Such covers could prevent smoke generated from within the pallets from rising up to the ceiling during early stages of a fire. The smoke would probably exit the pallets at the floor level. As a result, only after sufficient smoke had exited the pallet and the thermal energy of that smoke had exceeded the force of the downward air current within the compartment would smoke rise to the collectors and be detected. By this time, the material in the pallet could be preheated to a point where very rapid fire growth would result.

Moreover, based upon an examination of the wreckage that has been retrieved from Springbok 295, the air traffic control communications between it and Mauritius control, and a review of the in-flight firefighting procedures of several operators, the evidence suggests that once a fire propagates in a class B cargo compartment, the effectiveness of the crewmember assigned to combat the fire would, under the most ideal circumstances, be limited. First, the crewmember would be required to find the source of the fire, a difficult task if sufficient smoke had been generated to reduce the visibility within the compartment, or if the fire was deep-seated within a cargo pallet. Second, should the crewmember expend the fire extinguishing agent, which requires only 12 or 14 seconds for the commonly used 16-pound Halon unit, without suppressing the fire, it is highly unlikely that the agent would remain sufficiently concentrated within the compartment to suppress the fire. The air flow to the Boeing 747 Combi's main deck, aft cargo compartment cannot be shut off, and the constant air flow within the compartment would dilute the agent to the point where it would no longer be effective. Therefore, no other means would be available to contain or extinguish a fire and ensure the safety of flight. The only available option would be to land at the nearest airport.

Yet, as the accident involving Springbok 295 demonstrates, for many long, overwater flights flown by present generation transport category aircraft, the nearest airport may be several hours away. Perhaps even more significant, the next generation of transport aircraft, such as the Boeing 747-400 which also will be available in a Combi version, will have considerably more range than its predecessors and, as a result, will be capable of flying longer overwater routes than current aircraft.

The Safety Board concludes that the present regulations regarding certification of fire detection and suppression capabilities of class B cargo compartments are based on inadequate and limited data and assumptions that may be inappropriate, and, thereby may pose an immediate threat to the safety of the flying public. Therefore, until such time as research can be conducted to actually demonstrate the effectiveness of the fire detection and suppression techniques against class B cargo compartment fires, the Safety Board believes that, as an interim measure, all cargo in class B compartments of United States registered aircraft should be transported only in fire-resistant containers. FAA-sponsored research 3/ has demonstrated the effectiveness of such containers to smother cargo fires and to prevent their propagation outside the containers. The Safety Board further urges the FAA to conduct research to establish the effectiveness of the fire detection and suppression methods needed to protect transport category airplanes from catastrophic fires in class B cargo compartments.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Until fire detection and suppression methods for class B cargo compartment fires are evaluated and revised, as necessary, require that all cargo carried in class B cargo compartments of United States registered transport category airplanes be carried in fire resistant containers. (Class I, Urgent Action) (A-88-61)
>
> Conduct research to establish the fire detection and suppression methods needed to protect transport category airplanes from catastrophic fires in class B compartments. (Class II, Priority Action) (A-88-62)
>
> Establish fire resistant requirements for the ceiling and sidewall liners in class B cargo compartments of transport category airplanes that equal or exceed the requirements for class C and D compartments as set forth in 14 CFR Part 25, Appendix F, Part III. (Class II, Priority Action) (A-88-63)

BURNETT, Chairman, KOLSTAD, Vice Chairman, and LAUBER and NALL, Members, concurred in these recommendations.

By: Jim Burnett
Chairman

3/ Blake, D., Evaluation of Fire Containment of LD-3 Cargo Containers. (DOT/FAA/CT-TN83/38) Atlantic City, New Jersey: FAA Technical Center, 1983.

Yet, as the accident involving Springbok 295 demonstrates, for many long, overwater flights flown by present generation transport category aircraft, the nearest airport may be several hours away. Perhaps even more significant, the next generation of transport aircraft, such as the Boeing 747-400 which also will be available in a Combi version, will have considerably more range than its predecessors and, as a result, will be capable of flying longer overwater routes than current aircraft.

The Safety Board concludes that the present regulations regarding certification of fire detection and suppression capabilities of class B cargo compartments are based on inadequate and limited data and assumptions that may be inappropriate, and, thereby may pose an immediate threat to the safety of the flying public. Therefore, until such time as research can be conducted to actually demonstrate the effectiveness of the fire detection and suppression techniques against class B cargo compartment fires, the Safety Board believes that, as an interim measure, all cargo in class B compartments of United States registered aircraft should be transported only in fire-resistant containers. FAA-sponsored research 3/ has demonstrated the effectiveness of such containers to smother cargo fires and to prevent their propagation outside the containers. The Safety Board further urges the FAA to conduct research to establish the effectiveness of the fire detection and suppression methods needed to protect transport category airplanes from catastrophic fires in class B cargo compartments.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

> Until fire detection and suppression methods for class B cargo compartment fires are evaluated and revised, as necessary, require that all cargo carried in class B cargo compartments of United States registered transport category airplanes be carried in fire resistant containers. (Class I, Urgent Action) (A-88-61)
>
> Conduct research to establish the fire detection and suppression methods needed to protect transport category airplanes from catastrophic fires in class B compartments. (Class II, Priority Action) (A-88-62)
>
> Establish fire resistant requirements for the ceiling and sidewall liners in class B cargo compartments of transport category airplanes that equal or exceed the requirements for class C and D compartments as set forth in 14 CFR Part 25, Appendix F, Part III. (Class II, Priority Action) (A-88-63)

BURNETT, Chairman, KOLSTAD, Vice Chairman, and LAUBER and NALL, Members, concurred in these recommendations.

By: Jim Burnett
Chairman

3/ Blake, D., Evaluation of Fire Containment of LD-3 Cargo Containers. (DOT/FAA/CT-TN83/38) Atlantic City, New Jersey: FAA Technical Center, 1983.

EVALUATION OF TRANSPORT AIRPLANE MAIN DECK

CARGO COMPARTMENT FIRE PROTECTION CERTIFICATION PROCEDURES

1. EXECUTIVE SUMMARY

a. Purpose

A team was formed to review the existing regulations, policies and procedures in place for the testing, certification, operation and maintenance of main deck Class B cargo or baggage compartments smoke and fire protection for Federal Aviation Regulations (FAR) 25 airplanes. This investigation was initiated by the Manager, Aircraft Certification Division, ANM-100, to determine the level of safety established by existing criteria used in that certification. In addition, the team was to develop and present, as appropriate, recommendations for improved fire/smoke protection for new and existing airplanes.

b. Problem:

A South African Airways Boeing Model 747-244B was lost over the Indian Ocean November 28, 1987. While the cause of the accident hasn't been determined, there was evidence of a major fire on board the airplane, which developed from an undetermined origin and progressed within the main deck cargo compartment. 159 passengers and crew were lost as a result of the accident. There was evidence of significant heat present in the upper areas of the cargo compartment, severe charring on top of the cargo, and charring and soot in certain portions of the interior of the cargo compartment. Smoke and soot had apparently penetrated past the barrier separating the cargo compartment and passsenger compartment and progressed through the main deck of the airplane.

As a result, a review of the existing rules, policies and procedures, was made to establish whether there were any deficiencies which could have been contributing factors in this accident, and whether any similar event was likely to occur on other airplanes operated in the combination passenger and cargo mode.

c. Investigation:

A team comprised of members from the Seattle Aircraft Certification Office, Long Beach Aircraft Certification Office, and Flight Standards Aircraft Evaluation Group met with representatives from the Boeing Company, the McDonnell Douglas Company, Alaska Airlines, Federal Express, and the Los Angeles Fire Department to discuss the manufacture, testing, approval, maintenance, and training involved with this kind of operation.

d. Conclusions:

The Team concluded the following:

1. The existing rules, policies and procedures being applied to the certification of Class B cargo or baggage compartments in terms of smoke and fire protection are inadequate.

2. The use of pallets to carry cargo in Class B compartments is no longer acceptable.

3. While entry into the cargo compartment is available, not all cargo is accessible.

4. It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

4a. The reliance on crew members to fight a cargo fire must be discontinued.

4b. The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

4c. The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

5. Most existing transport airplane smoke or fire detection systems were certified prior to FAR 25 Amendment 25-54 and are incapable of giving timely warning.

6. There were differences in the smoke testing procedures and criteria used from manufacturer to manufacturer, prior to issuance of FAA Advisory Circular (AC) 25-9.

e. <u>Recommendations:</u>

Because of the unsafe design features described above, no new designs should be approved to existing Class B criteria. For previously approved designs, rulemaking should be initiated to correct this unsafe condition as follows :

1. The main deck cargo compartment must provide a level of safety equal to that of Class C cargo compartments or;

2. Existing main deck Class B cargo compartments shall carry only containers meeting the following criteria.

   All containers in Class B compartments used to carry cargo must meet cargo liner requirements listed in FAR 25.855(a)(1) amendment 25-60, must contain a fire/smoke detector and must have a fire extinguisher connected to it. The extinguisher may be either an integral part of the airplane or a portable system. It must be of a type and of sufficient size and quantity to suppress and control any fire within the container. Metal or fiberglass containers meeting the intent of Class C compartments with respect to smoke/fire detection and extinguishing are acceptable.

3. Smaller Class B compartments meeting the original intent of the rule, namely those that provide accessibility to all pieces of cargo so that a person can move each piece and reach any given item, may continue to be approved in the Class B configuration. Such an area would be similar in size to a Class A compartment, or a large closet, and should be no larger than 200ft^3, unless it can be shown that the geometry of the larger volume would allow easy access to the contents. Baggage areas in "VIP" airplanes, and cargo compartments in smaller transport category airplanes would be examples of such areas.

4. For either the Class B or Class C cargo compartments, the following apply:

   a. The response time of any required smoke/fire detection system should be 1 minute or less (ref: FAR 25.858, Amendment 25-54).

   b. The smoke barrier between the cargo area and the occupied area should be shown to exclude smoke under the conditions described in AC25-9.

   c. Hazardous material must be handled per the applicable provisions of Part 178 of Title 49, Transportation.

2. TABLE OF CONTENTS

3. INTRODUCTION

a. Purpose:

The team was established to determine the adequacy of existing criteria established for the certification, crew training, and continued airworthiness of smoke and fire detection systems used in transport airplane main deck Class B cargo compartments in Combi airplanes.

The team's intent was to develop recommendations as necessary for updating the criteria for certification of Class B cargo compartments.

b. Scope:

The team was to address existing and future Class B cargo compartments.

The following subjects were encompassed by the investigation.

a. Rules
b. Policies
c. Smoke/Fire Detection Systems
d. Certification Test Procedures
e. Airline Crew Procedures
f. Crew Training
g. Airplane Design
h. The Operating Environment

c. Background:

A Boeing Model 747-224B airplane was lost November 28, 1987, over the Indian Ocean. There was evidence a major fire in the Class B cargo compartment was a contributing factor to the crash.

Class B cargo compartments have been in use for approximately 40 years. Over that period of time, the size of the cargo compartments has been enlarged many times over; however, the criteria has changed relatively little for certification of the smoke/fire protection systems. The consequence is having rules established for what was essentially hand loaded cargo being applied to large pallets and containers that can be up to 10 feet wide, 10 feet high, and 20 feet long.

The accident of the model 747-224B has called for a re-examination of the actual operating environment that exists for the airplanes, and what action may be necessary for updating the smoke/fire protection criteria. A series of meetings were held to examine the issue, the synopsis of which follows.

4. SYNOPSIS OF MEETINGS

January 18, 1988 - A special review team was formed to study the existing certification criteria for main deck Class B cargo compartments on combi airplanes, and to make whatever recommendations for changes and improvements that may be necessary.

January 27, 1988 - A meeting conducted by the Division Manager of the Aircraft Certification Division, ANM-100, Mr. Leroy Keith, provided some specific guidelines and concerns to the team. Additional team member inputs were encouraged. The goal of April 30 was established for a completed report.

February 4, 1988 - A team meeting was held to discuss possible topics to be investigated. The following areas were included:

a. Maintenance aspects of compartments and smoke/fire activities.
b. Crew capabilities, responsibilities
c. 2-Crew airplane considerations
d. Testing for fire vs. smoke
e. Crew training of fire/smoke fighting - Part 121
f. Amounts of extinguishing agent
g. Operational procedures
h. Combi airplane configurations
i. Access to fire fighting equipment
j. Existing rules, policies - FAR 25
k. Airplane ceiling and sidewall liners
l. Test results available from the FAA Technical Center
m. Known domestic users of combi airplanes
n. Known population of combi airplanes world-wide
o. Capability and requirements for switching configurations for a combi airplane
p. Requirements for sealing pallets
q. Requirements for structural containers/nets/curtains
r. Carrying of hazardous material
s. Operator requirements for training
t. Ability to get to fire area with fully loaded airplane
u. Ongoing testing at Tech Center
v. Recurrent training requirements
w. Flight manual requirements
x. New fire detectors
y. Flammability of barriers

January 29, 1988 - Presentation by Boeing to FAA - Boeing presented a proposed customer option which would provide automatic fire knockdown capability by flooding the Class B cargo compartment with Halon. This would establish a concentration of approximately 6% Halon in less than 1 minute. This percentage of Halon is effective to keep a fire from rekindling until it is depleted to a concentration of approximately 3%.

The Boeing Company had not completed its investigation and was not prepared to provide information on the time duration the minimum 3% accepted concentrations of Halon could be maintained.

February 11 - 12, 1988 - Meeting with the Boeing Company and FAA on current configurations of Model 747 combis and what criteria were used in certifying the airplane.

Subjects addressed were :

- Airflow management
- Operational procedure upon smoke detection
- Smoke sensor equipment (vacuum/sampling tubes)
- Reduction of air conditioning draw-through capabilities
- Smoke evacuation procedures/1981 update
- Use of fire extinguisher hose extension and nozzle to reach a fire
- Operational procedure of opening doors to relieve smoke in airplane
- Use of Underwriters Laboratories listings for hand held extinguishers
- Percent of light transmissivity vs. the ability of crew member to cope with smoke and see source of fire
- Hazards of using Halon due to breakdown into more hazardous compound at high fire temperatures
- Cargo barrier design to 9g's and barrier maintenance
- The use of ionization smoke/fire detectors on Model 747-400 (a customer option)
- The various types of containers available and which would be the most fire resistant.
- Containers that would contain a fire
- Protective covers to limit the growth of the fire

A visit to the 747 cargo mock-up was made. Protective breathing equipment (full face mask and portable oxygen bottle) was donned. Wearing that, and carrying the hand held fire extinguisher (attached with an approximately 6 foot section of hose to the 8 foot wand) an attempt was made to proceed to the rear of the cargo compartment which contained 6 maximum volume pallet loads. It was evident the ability of a crew member to access and fight a fire in the rear of the cargo compartment was restricted. Accomplishing this task in a dimly lit, smoke filled environment was considered to be nearly impossible.

It was brought out that the fire extinguishing agent had to be deposited at the base of the fire to be effective, and the total amount of agent could be spent in approximately 12 seconds.

February 16, 1988 - Meeting with Alaska Airlines flight line personnel. Reviewed the combi airplane configuration used on Boeing Model 737 airplanes. This configuration had the cargo forward of the passengers, just aft of the forward crew entry, and on a regular basis the number of pallets/passenger seats was changed several times a day. The seats were on pallets which made them easily installed and removed. The cabin attendants for the most part, reportedly remained in the aft portion with the passengers. The fire extinguisher and wand were positioned against a cargo net forward of the cargo. Alaska Airlines had acquired a new device which, as part of the fire extinguisher equipment, could penetrate the side of a rigid container. They, however, did not have one to show us.

The condition of the cargo/passenger barrier was observed to have some wear, as expected for this much use. If there was smoke in the cabin, differential pressure was to keep the passenger area free of smoke.

February 29, 1988 - Meeting with Alaska Airlines crew training personnel. Discussions were held with the supervisor of flight attendant training, safety, and pilot emergency procedure training. They reviewed initial training and recurrent training for Boeing Models 727,737 and McDonnell Douglas Model MD-80.

During initial training, crewmembers actually put out an oil pan fire.

In initial training the crewmembers do not don all the equipment (face mask) nor use a large fire extinguisher.

For initial and recurrent training for smoke in the airplane, flight crews go through procedures in an actual cockpit, and flight attendants have a mock-up where reduced visibility by use of goggles is used in evacuation training.

For recurrent training, they discuss the procedures, don the mask, connect the wand, and put on asbestos gloves. They don't conduct a walk around with the equipment in place.

During this meeting, we were shown the new container penetration device referred to in the previous meeting. A demonstration of its use had not been observed. The device allows the curved portion of nozzle to be removed, exposing a hardened tip to puncture some types of containers and through which extinguishing agent could be discharged.

The training of the cabin crew together with the flight crew is very limited but steps were being taken to increase that.

In the event of a fire, the airline's emphasis is on landing the airplane at the nearest airport. They take their basic operating procedures from the Boeing and McDonnell Douglas operations manuals and add their own company procedures for the final version.

When the Boeing Company and McDonnell Douglas present revisions to the operations manuals, Alaska often adopts those changes for their own use.

On the Model 737 airplanes with a 2 man crew the copilot is the fire fighter.

March 15 - 16, 1988 - Meeting - FAA Seattle, Boeing, National Transportation Safety Board (NTSB), FAA, Washington D.C., South African Directorate of Civil Aviation (DCA).

The representatives from South African Airways and the South African DCA presented the scenario of the loss of the model 747 on November 28, 1987, as best they understood it. A range of subjects were then discussed, trying to establish the relevance of each in terms of potentially contributing to the accident.

The subjects of fire/smoke detection, fire fighting procedures, and the means for crew to fight a fire were explored. Also, the specifications for types of cargo compartments were discussed.

A portion of time was spent discussing the deep-seated fire (as opposed to the surface fire which can be more easily reached). It was noted the pallets on the aforementioned flight were covered with polyethylene which could trap the smoke, cause additional heat build-up and prevent early detection of a fire. It was surmised that given sufficient thermal expansion due to a raging fire in the airplane cargo compartment, none of the existing protective measures to prevent smoke penetration into the passenger cabin would be of value, including cabin differential pressure or other means.

The question of having a fire when beyond 180 minutes from a suitable landing site was also discussed.

The amount of fire extinguishing agent available was discussed, as well as training requirements for using the extinguisher. It was noted there was approximately 12 seconds of useful Halon agent in the 16 pound fire extinguisher bottle.

Test procedures - kinds of test smoke, and the use of actual fire testing were discussed. No testing using an actual fire is conducted on an airplane for certification purposes. It was also brought out that no fire fighting expert was present during testing or during proposed testing of the airplane/smoke detection or fire protection systems.

The maintenance requirements and procedures for fire/smoke detector systems were described.

A question was asked concerning visual inspection of material going on the pallet during normal operation, and the requirements for inspections prior to loading. There is no known requirement to date.

No specific cause for the loss of the airplane was proposed or provided at the meeting. The recovery of additional debris and data from the wreckage is still being carried out by the South African government and South African Airways.

The DCA did request the FAA to review the existing certification requirements to analyze whether adequate criteria are established for the certification of Class B combi cargo compartments.

The meeting closed with statements that the NTSB would support the DCA investigation with technical asssistance along with the FAA pursuing recommendations covering certification of Class B combi airplanes.

March 24, 1988 - Team visit to Federal Express, which operates a McDonnell Douglas DC-10 with a Class E cargo compartment. The main purpose of the visit was to familiarize the team with the general layout of the DC-10, the cabin airflow patterns, smoke/fire detector locations, and procedures for controlling smoke/fire on the airplane. The procedures for loading the pallets were discussed as well as the requirement for hazardous material being placed in special containers at the front of the compartment forward of the main cargo door. This placed those two or three containers at the forward positions, side by side, with fire extinguishers containing 9lb. of Halon 1211 connected directly to them by means of quick disconnect hoses. The upkeep of the airplane was noted to be excellent.

March 24, 1988 - Team visit to Los Angeles International Airport Fire Department - Discussions were held with two of their captains on procedures for the fire department training for fighting an airplane fire on the interior and exterior. It was emphasized they had conducted and participated in continual training and all members at the station had over twenty years experience.

The captains stated that they would not send a fire fighter into a smoke-filled environment without hands-on training, and without using a buddy system. They emphasized the requirements to be totally familiar with any equipment being used. They also stated that regardless of the individual's training, they never knew if that individual would approach and fight a fire until after that individual had actually been observed fighting the fire in a real situation.

It was expressed by the captains that using a crewmember to fight a fire on an airplane without specific initial training and continual ongoing practice would probably be unsuccessful and would provide only a false confidence that the task will be accomplished.

The fire department captains displayed a device to penetrate the skin of the airplane and inject fire extinguishing agent. That particular system was a two man system and was too large to carry on an airplane, but the concept was worth reviewing. The system is basically a pneumatic drill (nitrogen driven) which, after penetrating a side window, etc. can then discharge Halon through it's tip.

The captains indicated that they had offered a class to discuss with pilots and crewmembers, their role as fire fighters and how they could be of more assistance to aircrews in case of an emergency landing, or a ground evacuation. Only one person attended, an airline captain from a foreign operator.

March 25,1988 - McDonnell Douglas presentation to the team. The company presented the following:

- Fleet configurations for DC-8's, DC-9's, DC-10's and MD-11, including the MD-11 combi.

- Cargo loading, pallet positioning within the airplane.
- Crewmember access to the cargo area.
- Smoke barrier design and maintenance.
- Liner materials and installation.
- Smoke/fire detection and extinguishing equipment description. For testing, they had tried several different kinds of smoke generators before deciding a specific type met their requirements. It was noted that there is no specific measuring criteria for what is "adequate" smoke generation.
- Smoke penetration prevention philosophy.
- Airflow patterns within the passenger and cargo compartments were described (the outflow valve is approximately mid-body).
- Crew procedures; requirements for training crewmembers was basically left to the operators unless the operator had a specific training contract. In general, the company provides the equipment, but has no responsibility to provide training to the airline. There was not much information provided from the airline to McDonnell Douglas on the airlines training. It was not clear how all technical data was provided to the operators for training.
- McDonnell Douglas at this time has no known combi airplanes with Class B cargo compartments in service. Six MD-11 combi airplanes with the Class C cargo compartment have been ordered.

April 4, 1988 - Meeting with FAA Technical Center representative Richard Hill. He provided a copy of a video on various cargo compartment container testing. He also provided technical reports on the following: fire characteristics in cargo compartments; fire containment in Class D cargo compartments; fire extinguishing methods for new passenger/cargo compartment fires; and burn through resistance of aluminum ceiling panels in simulated Class D cargo compartment.

He also made his facility available for further testing should specific requests be made.

We did contact the FAA Technical Center to obtain any available information about the effects of a thermal (fire) source in the cargo compartment on the airflow and the slight positive pressure differential that normally is maintained in the passenger compartment. The technical center asked for some basic parameters to use in making a computation. We assumed the following for those purposes:

a. Cargo Compartment of 10,000 cubic feet
b. Passenger Compartment of 19,000 cubic feet
c. Passenger Compartment ventilation rate of 0.25 Cubic Feet per Minute (CFM) per cubic foot of volume
d. Cargo Compartment ventilation rate of 0.17CFM per cubic foot of volume
e. An initial positive pressure differential of 0.1 inches of water pressure present in passenger compartment.

Using those parameters in a gross analysis, the following was determined:

a. A fire producing a constant 10,000 British Thermal Units (BTU's) per minute would eliminate the 0.1 inch of water positive pressure differential by thermal expansion.

b. A fire producing a constant 50,000 BTU's per minute would provide sufficient thermal expansion to overpower the 0.1 inch of water positive pressure differential and drive air/smoke into the passenger compartment.

c. A fire producing a constant 100,000 BTU's per minute would consume all the oxygen in the compartment and that brought in by the ventilation.

It should be recognized that normally an uncontained fire will grow exponentially unless some means are present to limit or control it. Each of the above 3 cases would occur within a matter of a few minutes or more. For reference, burning one pound of aviation fuel produces approximately 21,000 BTU's.

4. FACTS, ANALYSIS, AND DISCUSSION

A. Federal Aviation Regulations (FAR) Applicable to Combi's

For Cargo Compartments

These specific requirements, as part of the type certification basis, are as follows :

1. FAR 25.851, formerly Civil Aviation Regulations (CAR) 4b.380(a) & (b) and CAR 4b.383(a), second sentence and 4b.383(b)(3), Fire extinguishers. An approved portable extinguisher must be readily available for use in a Class B cargo compartment. It must have a type and quantity of extinguishing agent appropriate to the kinds of fires likely to occur where used.

2. FAR 25.1439, formerly CAR 4b.380(c), Protective breathing equipment (PBE). PBE required for airplanes containing Class A, B, or C cargo compartments.

3. FAR 25.853, formerly CAR 4b.381, Compartment interiors. This specifies criteria that materials used to construct cargo compartments must meet.

4. FAR 25.855, formerly CAR 4b.382 and 4b.384, Cargo and baggage compartments. Requires the compartment to be free of controls, wiring, equipment, or accessories whose failures would effect safe operation unless those items can't be damaged by cargo, or their failure will not create a fire hazard. Cargo can't interfere with functioning of fire protective features, and heat sources can't ignite cargo. In addition flight testing is required to show compliance with FAR 25.857.

5. FAR 25.857(b), formerly CAR 4b.383 (less second sentence of (a) and (b)(3).

   Cargo compartment classification; The "Combi" airplane main deck cargo compartment has been certified as Class B. This regulation specifies that sufficient access exists in flight to effectively reach any part of the compartment with the contents of a hand fire extinguisher; that no hazardous quantity of smoke, flames, or extinguishing agent will enter an occupied compartment; and that a separate approved smoke or fire detector system be provided to give warning at the pilot or flight engineers station.

6. FAR 25.858, Cargo compartment fire detection systems. This regulation became effective September 11, 1980, with the adoption of Amendment 25-54. It requires a visual indication to the flight crew within one minute of start of fire, be capable of detecting a fire at a temperature significantly below that which decreases structural integrity, be functionally checked in flight, and be effective in all operating configurations and conditions.

7. **FAR 25.1301**, formerly CAR 4b.600 and 4b.601, Function & **installation.** Requires that installed equipment be of a kind **and design** appropriate to its intended function and function **properly.**

8. **FAR 25.1309**, formerly CAR 4b.606, Equipment systems and **installations.** As applies to the smoke detection system **requires the** system to be designed and installed in a manner **to ensure** it performs its intended function under any **forseeable** operating condition. The system also required **design to** prevent hazards to the airplane if it was to **malfunction** or fail.

The following is a brief tabular summary of cargo compartment classification requirements as applicable to the model 747:

CARGO COMPARTMENT CLASSIFICATION

FAR 25.857 REQUIREMENT	A	B	C	D	E
DETECTION MEANS	Crew-member at sta.	Separate smoke/ fire detec-tor	Separate smoke/ fire detec-tor	None	Separate smoke fire detector
Reg. Subpara-graph	(a)(1)	(b)(3)	(c)(1)		(e)(2)
EXTINGUISHMENT/ SUPPRESSION	Port-able Implied	Port-able exting-uisher	Built-in exting-uisher	Contain-ment	None
Reg. Subpara-graph	(a)(1)	(b)(1)	(c)(2)		
CONTROL OF VENTILATION AND DRAFT, TO OR WITHIN	NONE	NONE	YES	YES	YES
Reg. Subpara-graph			(c)(4)	(d)(3)	(e)(3)
MEANS TO EXCLU-DE HAZARDOUS QUANTITY OF SMOKE, ETC. FROM OCCUPIED COMPARTMENTS	NONE	YES	YES	YES	YES
Reg. Subpara-graph		(b)(2)	(c)(3)	(d)(2)	(e)(4)
ACCESSIBILITY	YES	YES*	NONE	NONE	NONE
Reg. Subpara-graph	(a)(2)	(b)(1)			
FIRE RESISTANT LINER	NONE	YES	YES	YES	YES
Reg. Subpara-graph		(b)(4)	(c)(5)	(d)(4)	(e)(1)

*CAR Amendment 4b-10, effective April 1959, deleted the requirement that while the aircraft is in flight, a member of the crew must be able to move by hand, all contents of the compartment.

b. Regulatory History

Cargo compartments on civil transport aircraft go back a considerable time. Civil Air Regulation (CAR), Amendment 04-1, dated November 1, 1946, included the Class A, Class B, and Class C cargo compartments in the regulation. These compartments had the shared concept of (a) detection by a crew member while at their duty station and (b) the suppression of the fire by the crewmember when detected.

On July 20, 1950, Amendment 04-6 to CAR 04 added a Class D cargo compartment classification to the transport category aircraft certification requirements. As the need for an all-cargo transport category airplane developed, the Class E cargo compartment classification certification requirements were adopted with the issuance of CAR amendment 4b-10, dated April 23, 1959.

It should be noted that with CAR Amdt 4b-10 the CAB specifically deleted the requirements applicable to use Class B cargo compartment "that while the aircraft is in flight a member of the crew must be able to move by hand all contents of the compartment". This deletion is considered to be consistent with the requirements for Class A and Class E compartments. The preamble also discussed large volume cabins relative to compliance with the conditions set forth for Class D compartments because so much oxygen exists that prompt suppression of the fire through oxygen depletion is not attainable, thereby indicating the need to control the fire at a very early stage.

Parallel to the development of type certification requirements for transport category aircraft cargo compartments was the development of regulations restricting the carriage of hazardous cargo on civil aircraft. This was very important as it was becoming impractical to design an effective containment capability for the many cargo possibilities that were developed, and exist today. This supports the basic assumption of transport category aircraft cargo compartment class certifications that the cargo must be packed, identified, and be of materials as defined in the applicable portions of Part 178, Code of Federal Regulations, Title 49, Transportation.

Based on the above premise, the concepts of early detection, protection of structure, a means of extinguishment or suppression, and a means to prevent the accumulation of hazardous quantities of smoke, fumes, noxious gases, and flames in a occupied compartment became the basis of the regulatory requirements.

The FAA established the following policy/criteria as acceptable means for showing compliance with the smoke detection and smoke penetration requirements of CAR 4b.380 through 4b.384, which became FAR 25.855 and 25.857:

1. Smoke detection must occur within 5 minutes of initiation of smoke generation using only a small quantity of smoke representative of an incipient fire condition or a small fire that may only produce a small quantity of smoke.

2. A very dense and large quantity of smoke must be generated in the cargo compartment at the most critical location for penetration, generally near the cargo/passenger barrier.

3. This very dense smoke must be maintained within the cargo compartment for a period of time sufficient to establish that a stabilized air flow condition exists and that the criteria of item 4 below is not exceeded.

4. A few small wisps of smoke (similar to that which comes from a cigarette in an ash tray) may penetrate into an adjacent occupied compartment, but there may not be any significant build-up in any part of the compartment prior to the appropriate emergency procedure being completed. After the emergency procedure has been completed, there cannot be any haze present in the occupied compartment.

5. When using the access door to enter or exit the cargo compartment, a small amount of smoke may enter, but must immediately dissipate.

It should be noted that the history of cargo fires, until more recently, were shown to be baggage fires. Based on that type of background, the early detection of a fire was believed to ensure that significant amounts of heat were not generated. This concept was considered to be consistent with the size of fire represented by the Bunsen or Tirrill burner used for showing compliance with FAR 25.853 and 25.855. This size burner has recently been replaced, see Amdt. 25-60, for testing of some cargo liners.

With the exception of the new regulatory requirement of FAR 25.858 which has not yet been applied to a new type design transport, the current transport aircraft have been shown to meet the above criteria.

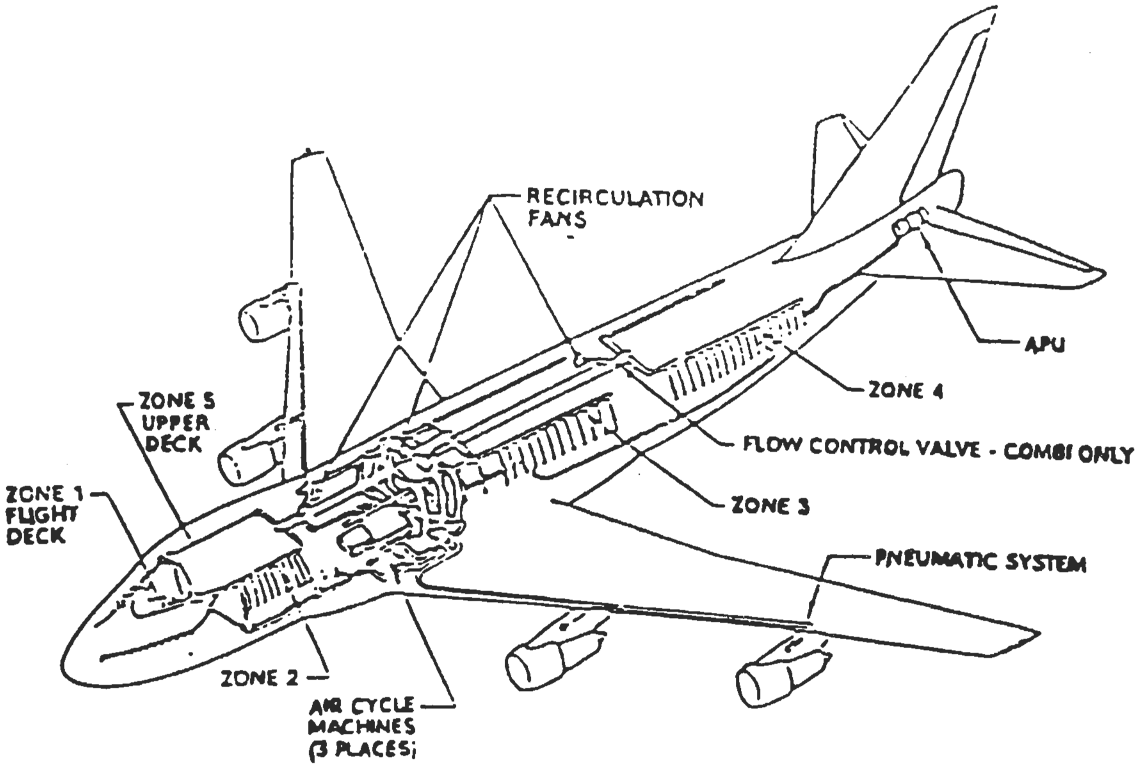
c. Combi Air Flow-Control

The air flow distribution design concept used for airplanes generally introduces air into the passenger compartments and main deck cargo area just below the compartment ceiling levels. For dedicated Class B cargo compartments, the air is often introduced from distribution ducts located near the center line of the ceiling or from duct drops along the sidewalls. For airplanes that can be converted, the air is distributed into the cargo compartment through the passenger system. The air passes through the compartment and exits through the floor level sidewall grilles. This air then moves downward and through the cove area outside the lower lobe cargo compartments, passing over the wing center section in the process, to the outflow valve(s) located in the fuselage pressure vessel. Outflow valves may be located in the aft fuselage, mid fuselage, forward fuselage, or in a combination of these locations. At the same time some cabin air is drawn in to the overhead volume above the passenger compartment ceiling and/or into the floor beam areas where part of the flow is collected by recirculation fans and returned to the cabin air distribution system.

Example of an Air-Conditioning Duct System

AIR-CONDITIONING DUCT SYSTEM

(PASSENGER, CONVERTIBLE & COMBI AIRPLANES)



d. Combi Compartment Sizes

Below is a table listing approximate cargo compartment volume, cargo compartment floor area, maximum and minimum ventilation rate per minute

Airplane	Class B Cargo Compartments: Approx. Vol. (ft^3)	Approx. Area Floor	Approx. Ventilation Rate CFM/ft MAX.	MIN.	Ratio*
707-320C Min	1206	315	877	----	2.107
Max	4083	848	2631	----	4.237
727-100C Min	730	272	678	----	2.757
Max	1460	391	1100	----	2.588
737 Min	1571	234	418	----	0.608
Max	3580	549	1344	----	0.957
747 Combi 6/7 Combi 12/13	9600	880	3 pack 0.17 $\left(\frac{CFM}{ft3}\right)$	2 pack 0.11 $\left(\frac{CFM}{ft3}\right)$	0.67
DC8- DC-61, -63, -71, -73	1605	N/A	N/A	N/A	N/A
DC9/MD80	257	----	285	----	N/A

$$*\text{Ratio} = \left(\frac{\text{Cargo Vent}}{\text{Cargo Vol.}}\right) \left(\frac{\text{Pass. Vent}}{\text{Pass. Vol.}}\right)$$

$$= \left(\frac{CFM}{ft^3}\right) / \left(\frac{CFM}{ft^3}\right)$$

Note the wide variance in Class B cargo compartment sizes and ratios as defined above. A ratio greater than one indicates a proportionately greater airflow per unit volume into the cargo compartment while a ratio less than one indicates a greater airflow per unit volume into the passenger compartment. The ratio would not be the only factor but a value less than one would imply a better ability to prevent penetration of smoke or fumes into an occupied compartment assuming the same configuration.

e. <u>Smoke Detection System</u>

Main deck cargo compartments of large transport airplanes will generally be divided into smoke detection zones, the number being dependent on the compartment size. A smoke detection zone is a given portion (volume) of the cargo compartment with a dedicated smoke detector system that monitors the air in that area for the presence of smoke. When smoke is detected in the zone, the flight crew is alerted and the zone identified on the Flight Engineer panel.

Smoke detector systems can be divided into two basic types. One employs an air sampling tube with orifices in it and a line connecting the sampling tube to the smoke detector and amplifier. This type of detector system is powered by a vacuum sources such as a bleed air operated ejector or a fan. The other type of smoke detector system is essentially a free standing unit, i.e., one which is appropriately mounted within the compartment so that as smoke reaches it, the smoke is drawn into the detection chamber convectively. For both systems, when light transmission in the detector is reduced by the presence of smoke to about 94 percent of that of clear air, a DC voltage signal is sent to the amplifier. The amplifier on receiving this signal actuates a relay providing a fire warning indication to the cockpit. This indication must be visual and in some cases, is also an aural alert.

The fire warning, both visual and aural, is given to the pilot/co-pilot by the master fire warning indicators and the fire warning module on the pilots' overhead panel. In addition, for airplanes with a flight engineer station, the fire warning is given by a warning light on the cargo smoke detection module. This allows the flight engineer to determine in which zone smoke detection has occurred. In all cases, the smoke detection module includes a test switch to permit testing of each smoke detector.

f. Cargo/Passenger Fire/Smoke Barriers

Because of structural growth under pressurization loads and other relative motions due to flight loads, it is difficult to design a maintainable airtight seal. In addition, for operational convenience, the cargo/passenger barrier is designed to be installed at several different body locations. The Combi cargo/passenger barrier is not designed to be a skin to floor air tight seal. The purpose of the barrier is to provide a restriction that provides air flow directional control within the airplane. This is to allow airflow only into the cargo compartment from the occupied compartment but not from the cargo into the passenger area. These features provide for a very small positive pressure differential in the occupied compartment relative to the cargo compartment.

In most transport airplanes, the cargo fire/smoke emergency procedure calls for maximum ventilation and to shut off all recirculation/supplemental fans. Therefore, the actual deterrent to smoke penetration into the passenger area is that upon detection of a cargo fire there is a means to assure that air from the cargo compartment flows overboard rather than entering the passenger and/or cockpit areas. This airflow control is accomplished by providing a proportionately greater mass air flow into the passenger areas than into the cargo area through restriction valves in the ventilation distribution system, by the passenger/cargo fire/smoke barrier, and by proper location of the outflow valves for the specific cargo passenger configuration. This is evidenced during certification flight testing of the smoke detection equipment by the lack of smoke penetration into the passenger compartment, even when the access door is opened for individuals moving into and out of the cargo area during the smoke penetration tests.

g. Fire Extinguishers for Combi Airplanes

The Boeing mixed passenger/cargo (Combi) airplanes, starting with the Model 707, were originally certified with a 20 lb. dry chemical hand-held fire extinguisher with an Underwriter Laboratories (UL) rating of 3A-20B:C. This fire extinguisher is used with an extension wand which allows the operator to reach over or between the cargo pallets. In 1980, a 16 lb. Halon 1211 extinguisher UL rated at 2A-20B:C was approved as a replacement for the dry chemical extinguisher when the manufacturer discontinued production of the units for aircraft use.

FAA Advisory Circular 20-42C, dated March 7, 1984, recommends at least 13 lbs. of Halon 1211 and a minimum UL rating of 2A-40B:C.

Boeing decided on a minimum UL rated fire extinguisher size of 2A-12B:C based on a National Fire Protection Association (NFPA) 10-1969 recommendation of a unit of "A" rating for 1250 square feet of floor area where fires of moderate size and ordinary hazard may be expected in warehouse, mercantile storage, etc. The floor area of a six pallet Combi in the Model 747 Combi is approximately 880 square feet.

The McDonnell Douglas DC-8 had a 17 lb. dry chemical and extension wand, however, Douglas stated there are none of their airplanes currently configured as Combi's in commercial service. The Air Force KC-10 could be operated as a Combi. We understand that airplane has a 34 lb. Halon 1211 fire extinguisher.

h. Fire Containment of Cargo Containers

The FAA Technical Center conducted a series of tests to assess the fire containment capability of LD-3 cargo containers. These containers have a volume of approximately 150 cu. ft. Some of the containers would not contain a fire but those constructed of aluminum with aluminum doors or rigid fiberglass with a fiberglass door contained the fire with no damage to the container. An aluminum container with two six by eighteen inch holes cut in the side also contained the test fire. A high density polyethylene container with an aluminum door showed minimal damage after the test.

Boeing has suggested covering the cargo pallets with a fire resistant material. Discussions with Dick Hill of the FAA Technical Center indicate that there are fire resistant materials available although expensive. The primary concern is maintenance of these coverings and to assure they are installed properly to provide an air tight cover.

i. Cargo Compartment Liners

The Boeing Model 747 Combi and freighter and the McDonnell Douglas DC-10 freighter use the insulation blankets as the cargo liner on the ceiling and upper sidewall. The lower sidewall of the Model 747 generally has passenger compartment sidewall panels installed over the blankets and the DC-10 freighter has fiberglass panels.

The narrow body models (707, 727, 737) Combi airplanes use the passenger interior panels as the liner. The overhead bins, Passenger Service Units (PSU's), etc. remain in the airplane when it is converted to carry cargo.

Prior to FAR 25 Amendment 25-60, effective June 16, 1986, all cargo compartment liner material was required to be tested in accordance with the 45° test procedures currently described in FAR 25 Appendix F, Part I. These requirements were originally listed in Para. 4b.383, later in Para. 25.857 and currently in Para 25.855. This test exposes the liner material to a bunsen burner flame for 30 seconds with the test specimen held at 45° angle. To pass the test, the flame must not penetrate the sample.

FAR 25 Amendment 25-60 upgraded the test requirements for cargo compartment liners in Class C and Class D cargo compartments. These liners must be tested using a two-gallon-per-hour kerosene burner. This burner produces a 1700°F flame and the sample panel is exposed for 5 minutes in either a horizontal of vertical orientation depending on how it is to actually be installed in the airplane. Again, the flame must not burn through the material. In addition, the temperature on the upper side of the test panel must not exceed 400 °F. This test procedure was developed by the FAA Technical Center based on full-scale testing.

It is unlikely that the existing insulation blankets or the passenger sidewall and ceiling panels would meet the new two-gallon-per-hour kerosene burner test.

j. Problems likely to prevent converting an existing Class B to Class C

Due to the large airflow through a typical passenger cabin, adding a full-flood fire extinguishing system to an existing Class B cargo compartment is not practical. The Halon will not remain in sufficient concentration for more than a short period of time. Boeing looked at the 12 pallet arrangement on the Model 747 and concluded that 350 lbs. of Halon 1301 would provide for an initial concentration of 6 1/2%, but would decay to 3% in 7 minutes and 1% in 15 minutes with a 2000 cu. ft. per minute airflow. A 3% Halon concentration is generally accepted as the minimum necessary to suppress a fire. Some reduction of airflow is possible but a redesign of the system would probably be necessary.

Converting to a Class C would also require relining the interior. An NPRM has been issued to require materials that meet either the new kerosene burner test or are constructed of fiberglass to be retrofitted in Class C and Class D Compartments.

k. <u>Crew Training</u>

Crewmember emergency training is required for those persons being used as crewmembers on air carrier aircraft. The specific type of emergency training is listed in Federal Aviation Regulation (FAR) 121.417, which must be provided to all crewmembers.

Air Carriers must submit a training program to the assigned Principal Operations Inspector (POI) for approval. Prior to final approval of the program, the POI will conduct an on-site review of the actual training classes and course content. Once satisfied that the training program meets the minimum requirements of the operating rule, the program will be approved. No changes may be made to the program by the air carrier without approval of the POI.

FAR 121.417(b)(2)(iii) states, in part, that emergency training must provide the following:

(b)(2) Individual instruction in the location, function, and operation of emergency equipment.

(b)(2)(iii) Individual instructions on portable fire extinguishers with emphasis on type of extinguishers to be used on different classes of fires.

The above type training is included in the air carrier's training program. In addition, FAR 121.417(3)(ii) states, in part, that "instruction in handling of emergency situations including fire in flight and smoke control procedures" must be provided.

The aircraft manufacturer develops procedures during the flight testing phase for eliminating smoke in the aircraft. Those procedures are included in the manufacturer's cockpit checklist. The air carrier makes up their own checklist based on the manufacturer's checklist, which must then be approved by the POI. Crewmember training is conducted based on information contained in the checklist.

Additional emergency drill requirements must be accomplished during initial training and once each 24 calendar months during recurrent training. Each crewmember must operate each type of hand fire extinguisher installed in the aircraft.

Although the above training does not include an actual fire fighting drill which requires extinguishing a fire, the operating rules have been amended to include this. Effective July 6, 1989, no crewmember may serve in operation unless that crewmember has performed a fire extinguishing drill which also includes using protective breathing equipment (PBE). When all crewmembers have been trained in accordance with the new operating rule (FAR 121.417(d)), they will be better prepared to cope with actual fires aboard the aircraft.

The training of crewmembers is considered adequate to handle small fires which are exposed and readily accessible within the aircraft cabin. History has shown that fires in galleys, seats, lavatories have been extinguished by trained crewmembers.

Large separated Class B compartments on wide body aircraft created a completely different environment regarding fire fighting.

The compartment could be filled with large containers, or pallets which would make accessibility very difficult in trying to locate the fire. If the compartment filled with smoke, the situation would be extremely difficult.

Appendix I

List of Participants

Federal Aviation Administration

F. Duvall	ANM-270S	Team Member
A. Habbestad	ANM-130S	Team Leader
K. Kuniyoshi	ANM-130L	Team Member
W. Slifer	ANM-130S	Team Member
R. Young	ANM-120S	Team Member
W. Ashworth	ANM-100S	Seattle Aircraft Certification Office Manager
B. Donner	Washington D.C.	
R. Hill	Tech Center	
F. Jenkins	ANM-130L	
L. Keith	ANM-100	Aircraft Certification Division Manager
G. Lium	ANM-112	
D. Klempel	ANM-103S	
K. Olson	ANM-120L	

National Transportation Safety Board

M. Birky
B. Richardson
B. Strauch

Los Angeles International Airport Fire Department

Captain Shook
Captain Wigfield

Republic of South Africa

B. Jordaan - Department of Civil Aviation
R. Van Zyl - Department of Civil Aviation
R. Davidson - South African Airways

Alaska Airlines

A. Peterson - Engineering
S. Vincent - Training
D. Wasserstrom - Training
S. Wiggens - Training

Federal Express

G. Layton
B. Malcki

The Boeing Company

J. Aydelotte
F. Bereswill
J. Boyle
E. Campbell
A. Abneter
J. Lee
C. McMillan
R. Metter
R. Miller
D. Moyle
B. Pigg
J. Simons
R. Wilder

The McDonnell Douglas Company

A. Aggarwal
L. Anderson
G. Bartz
D. Deschaines
J. Drobnich
A. Erickson
J. Grieco
S. Hariram
W. Heath
P. Kiefer
J. Leland
T. Peacock
T. Ottaviano
H. Servais
B. Shook
E. Smith
W. Steelhammer
G. Stuffel
J. Tischler
L. Thompson
D. Williams

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

(Docket No. 88-NM-80-AD)

AIRWORTHINESS DIRECTIVES: Boeing Models 707, 727, 737, 747, and 757 Series Airplanes; and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 series), and DC-10 Series Airplanes.

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Notice of Proposed Rulemaking (NPRM).

SUMMARY: This notice proposes a new airworthiness directive (AD), applicable to certain transport category airplanes certificated for operation with a main deck Class B cargo compartment, which would require design changes either to modify the cargo compartment to the Class C configuration or to require the use of flame penetration-resistant cargo containers. This action is prompted by the recent loss of a Boeing Model 747 "Combi" airplane that apparently developed a major fire in the main deck cargo compartment.

DATES: Comments must be received no later than November 7, 1988

ADDRESSES: Send comments on the proposal in duplicate to Federal Aviation Administration, Northwest Mountain Region, Office of the Regional Counsel (Attn: ANM-103), Attention: Airworthiness Rules Docket No. 88-NM-80-AD, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168.

FOR FURTHER INFORMATION CONTACT: Mr. Weston B. Slifer, Systems & Equipment Branch, ANM-130S, FAA, Northwest Mountain Region, Seattle Aircraft Certification Office, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168, telephone (206) 431-1945; or Mr. Kevin Kuniyoshi, Systems & Equipment Branch, ANM-130L, FAA, Northwest Mountain Region, Los Angeles Aircraft Certification Office, 4344 Donald Douglas Drive, Long Beach, California 90808, telephone (210) 514-6323.

SUPPLEMENTARY INFORMATION:

COMMENTS INVITED

Interested persons are invited to participate in the making of the proposed rule by submitting such written data, views, or arguments as they may desire. Communications should identify the regulatory docket number and be submitted in duplicate to the address specified above. All communications received on or before the closing date for comments specified above will be considered by the Administrator before taking action on the proposed rule. The proposals contained in this Notice may be changed in light of the comments received. All comments submitted will be available, both before and after the closing date for comments, in the Rules Docket for examination by interested persons. A report summarizing each FAA/public contact concerned witn the substance of this proposal will be filed in the Rules Docket.

AVAILABILITY OF NPRM

Any person may obtain a copy of this Notice of Proposed Rulemaking (NPRM) by submitting a request to the FAA, Northwest Mountain Region, Office of the Regional Counsel (Attn: ANM-103), Attention: Airworthiness Rules Docket No. 88-NM-80-AD, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168.

DISCUSSION: A Boeing Model 747 "Combi" airplane, operating with a main deck Class B cargo compartment, as defined by Federal Aviation Regulation (FAR) 25.857(b), was lost over the Indian Ocean on November 28, 1987. While the cause of the accident has not been determined, there was evidence of a major fire on board the airplane, which developed from an undetermined origin and progressed within the main deck cargo compartment.

This information prompted an FAA review of existing regulations, policies, and procedures pertaining to the certification of large main deck Class B cargo compartments with volumes exceeding 200 cu. ft. The results of this review are contained in a report titled "Evaluation of Transport Airplane Main Deck Cargo Compartment Fire Protection Certification Procedures," which has been made a part of the Rules Docket for examination by interested persons. The report concludes that, notwithstanding compliance with the existing regulations, airplanes equipped with main deck Class B cargo compartments do not provide an acceptable level of safety in terms of smoke and fire protection.

The FAA is considering the development of new type certification and operations regulations to address this issue; however, the existing unsafe condition requires immediate action, applicable to both new production and in-service airplanes. This Notice, therefore, proposes to require a design change for all airplanes listed above that are operated with main deck Class B cargo configurations with volumes exceeding 200 cu. ft. This design change would require either that the Class B cargo compartment be modified to a Class C configuration, meeting the requirements of FAR 25, Appendix F, Part III; or that flame penetration-resistant containers, meeting the requirements of FAR 25, Appendix F, Part III, and having smoke detection and fire extinguishing systems, be used to carry all cargo. The requirements for a Class C cargo compartment are contained in FAR 25.855 and FAR 25.857(c). Class C cargo compartments require a smoke detection system and a built-in fire extinguishing system controllable from the cockpit.

FAA recognizes that other alternative design changes may be developed which may provide a level of safety equivalent to the options stated above. Therefore, the proposal includes provisions for the use of alternate means of compliance, when approved by FAA.

It should be noted that the applicability of this proposal is not limited by airplane serial number. Accordingly, the provisions of the AD, upon becoming effective, would also apply to new designs of the affected models and approved designs that are in production. When such airplanes are inspected for the issuance of an airworthiness certificate, they would be required to comply with the provisions of the AD resulting from this proposal.

Since this condition is likely to exist or develop on other airplanes of these same type designs, an AD is proposed which would require the modification of all main deck Class B cargo compartments to the Class C configuration; or the use of flame penetration-resistant containers with smoke detection and fire extinguishing systems to carry all cargo; or an alternate means of compliance approved by the FAA.

It is estimated that a total of approximately 80 U.S.-registered Boeing Model 707, 727, 737, and 747 series airplanes, and 124 U.S.-registered McDonnell Douglas Model DC-8, DC-9, and DC-10 series airplanes, ~~of U.S. registry,~~ have been certificated to operate with a Class B main deck cargo compartment. Many of these airplanes have been permanently converted to the all-passenger configuration and are, therefore, not affected by this proposal. Approximately 40 of these model Boeing and McDonnel Douglas series airplanes are presently operating in the mixed cargo/passenger configuration. There are no known U.S.-registered McDonnell Douglas DC-8 or DC-9 series "combi" airplanes in service.

The design alternative selected by an operator will have a significant impact on the cost of complying with this proposed AD. The highest cost option is expected to be the conversion to a Class C compartment, as defined in paragraph A. of this proposal. A conservative cost estimate for such a modification, based upon costs of required materials, labor, and testing, between $750,000 and $1,000,000 per airplane. Based on these figures, the total cost of this AD on U.S. operators is estimated to be between $30,000,000 and $40,000,000.

The regulations set forth in this notice would be promulgated pursuant to tne authority in the Federal Aviation Act of 1958, as amended (49 U.S.C. 1301, et seq.), which statute is construed to preempt state law regulating the same subject. Thus, in accordance with Executive Order 12612, it is determined that such regulations do not have federalism implications warranting the preparation of. a Federalism Assessment.

For these reasons, the FAA has determined that this document (1) involves a proposed regulation which is not major under Executive Order 12291 and (2) is not a significant rule pursuant to the Department of Transportation Regulatory Policies and Procedures (44 FR 11034; February 26, 1979); and it is further certified under the criteria of the Regulatory Flexibility Act that this proposed rule, if promulgated, will not have a significant economic impact, positive or negative, on a substantial number of small entities because few, if any, large transport airplanes are operated by small entities. A copy of a draft regulatory evaluation prepared for this action is contained in the regulatory docket.

LIST OF SUBJECTS: 14 CFR Part 39 - Aviation Safety, Aircraft.

THE PROPOSED AMENDMENT

Accordingly, pursuant to the authority delegated to me by the Administrator, the Federal Aviation Administration proposes to amend Section 39.13 of Part 39 of the Federal Aviation Regulations (14 CFR 39.13) as follows:

1. The authority citation for Part 39 continues to read as follows:

   Authority: 49 U.S.C. 1354(a), 1421 and 1423; 49 U.S.C. 106(g) (Revised Pub. L. 97-449, January 12, 1983); and 14 CFR 11.89.

2. By adding the following new airworthiness directive:

BOEING and McDONNELL DOUGLAS: Applies to Boeing Models 707, 727, 737, 747, and 757 series airplanes; and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 series), and DC-10 series airplanes; equipped with a main deck Class B cargo compartment, as defined by FAR 25.857(b) or its predecessors, with a volume exceeding 200 cu. ft.; certificated in any category. Compliance is required as indicated, unless previously accomplished.

To minimize the hazard associated with a main deck Class B cargo compartment fire, accomplish the following:

A. Within 180 days after the effective date of this AD, or prior to carrying cargo in a main deck Class B cargo compartment, whichever occurs later, accomplish either of the following:

   1. Modify all main deck Class B cargo compartments of volume exceeding 200 cu. ft. to comply with the design standards specified in FAR 25.857(c) for a Class C compartment. In addition, the ceiling and sidewall liner panels must meet FAR 25, Appendix F, Part III, effective June 16, 1986. The modification must be approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (for Boeing airplanes), or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (for McDonnell Douglas airplanes).

2. Modify all main deck Class B cargo compartments to require the following placard installed in conspicuous locations approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (for Boeing airplanes), or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (for McDonnell Douglas airplanes), throughout the compartment:

   "Cargo carried in this compartment must be loaded in an approved flame penetration-resistant container meeting the requirements of FAR 25.857(c), with ceiling and sidewall liners and floor panels that meet the requirements of FAR 25, Appendix F, Part III, effective June 16, 1986."

B. An alternate means of compliance or adjustment of the compliance time, which provides an acceptable level of safety, may be used when approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (Boeing Models); or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (McDonnell Douglas Models).

   NOTE: The request should be forwarded through an FAA Principal Maintenance Inspector (PMI), who may add any comments and then send it to the Manager, Seattle Aircraft Certification Office, or the Manager, Los Angeles Aircraft Certification Office, as appropriate.

C. Special flight permits may be issued in accordance with FAR 21.197 and 21.199 to operate airplanes to a base in order to comply with the requirements of this AD.

Issued in Washington, D.C., on July 8, 1988

M. C. Beard
Director
Office of Airworthiness

[4910-13]

DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

(Docket No. 88-NM-80-AD; Amendment 39-6301

Airworthiness Directives; Boeing Models 707, 727, 737, 747, and 757 Series Airplanes; and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 Series), and DC-10 Series Airplanes.

AGENCY: Federal Aviation Administration (FAA), DOT.

ACTION: Final Rule, Request for Comments.

SUMMARY: This amendment adopts a new airworthiness directive (AD), applicable to certain transport category airplanes, certificated for operation with a main deck Class B cargo compartment. This AD requires that certain operational and equipment changes and design modifications be accomplished to maximize cargo fire detection and control. This amendment is prompted by the loss of a Boeing Model 747-200 "Combi" airplane that apparently developed a major fire in the main deck cargo compartment. This condition, if not corrected, could result in an uncontrolled cargo fire that could cause systems and structural damage, leading to the loss of the airplane.

DATES: Effective September 25, 1989

Comments must be received by September 25, 1989.

ADDRESSES: The applicable service information may be obtained from Boeing Commercial Airplanes, P. O. Box 3707, Seattle, Washington 98124; or McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846, Attention: Director, Publications and Training, C1-750 (54-60). This information may be examined at the FAA, Northwest Mountain Region, Transport Airplane Directorate, 17900 Pacific Highway South, Seattle, Washington;

the Seattle Aircraft Certification Office, 9010 East Marginal Way South, Seattle, Washington; or the Los Angeles Aircraft Certification Office, 3229 East Spring Street, Long Beach, California.

FOR FURTHER INFORMATION CONTACT: Mr. Weston B. Slifer, Systems & Equipment Branch, ANM-130S, FAA, Northwest Mountain Region, Seattle Aircraft Certification Office, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168, telephone (206) 431-1945; or Mr. Kevin Kuniyoshi, Systems & Equipment Branch, ANM-130L, FAA, Northwest Mountain Region, Los Angeles Aircraft Certification Office, 3229 East Spring Street, Long Beach, California 90806, telephone (213) 988-5337.

SUPPLEMENTARY INFORMATION: A proposal to amend Part 39 of the Federal Aviation Regulations to include an airworthiness directive, applicable to Boeing Models 707, 727, 737, 747, and 757 series airplanes, and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 series), and DC-10 series airplanes, which requires either (1) modification of all Class B cargo compartments to Class C cargo compartments, or (2) the use of flame penetration-resistant cargo containers equipped with smoke detection and fire extinguishing systems, was published in the Federal Register on July 15, 1988 (53 FR 26786).

Interested persons have been afforded an opportunity to participate in the making of this amendment. Due consideration has been given to the comments received.

There were a total of 38 commenters, representing manufacturers, airlines, crew unions, consumer advocates, and foreign airworthiness authorities.

Some commenters stated that not enough technical/research data is available either to substantiate that an unsafe condition exists or to determine a consummate design modification to address the unsafe condition, and suggested that the proposal be withdrawn. The FAA disagrees. As explained in the Notice, the FAA conducted an in-depth review of existing regulations, policies, and procedures pertaining to the certification of large main deck Class B cargo compartments with volumes exceeding 200 cu. ft. This review revealed that, notwithstanding compliance with the existing regulations, airplanes equipped with main deck Class B cargo compartments do not provide an acceptable level of safety in terms of smoke and fire protection, for the following reasons:

1. The existing rules, policies, and procedures being applied to the certification of Class B cargo or baggage compartments in terms of smoke and fire protection, are inadequate.

2. While entry into the cargo compartment is available, not all cargo is accessible.

3. It is unlikely that personnel would have the means available to extinguish a fire (particularly a deep-seated fire).

4. The quantity of fire extinguishing agent and the number of portable extinguishers are inadequate.

5. The level of visibility available in a smoke filled cargo compartment is not adequate for locating and fighting a fire with a portable fire extinguisher.

6. Most existing transport airplane smoke or fire detection systems were certified prior to FAR 25 Amendment 25-54 and are incapable of giving timely warning.

7. Current designs do not provide adequate means to monitor conditions in the cargo compartment after fire warning and firefighting procedures have been implemented.

8. Cargo compartment lining does not provide adequate fire containment.

9. Current designs do not provide a means to shut off ventilation air into the cargo compartment to limit oxygen to the fire.

In addition to that study, data available from full-scale fire tests at the FAA Technical Center reveals the rapid exponential growth of cargo fires and the quick loss of visibility in the compartment. Past testing in Class C, D, and E compartments indicates that, without a fire suppression system, "cargo fires can easily reach dangerous proportions in any size compartment." (Reference 1) It was also concluded that "fire in large loaded cargo compartments may be expected to result in a flash fire shortly after detection and the shutoff of ventilation air." (Reference 2) Testing utilizing smoke detection systems similar to those presently used in newer Class B compartments led to the conclusion that "the smoke detection system did not always give early warning of fire and subsequently gave false warnings of fire and subsequently gave false indications of the level of smoke in the compartment." (Reference 3) Although a shorter detection time could increase the time available for fire fighting, all the referenced FAA studies indicate that a flash fire could occur in as little as 2 to 3 minutes after ignition of standard type cargo packing material in cardboard boxes. It was concluded from testing in References 3 and 4 studies that a Halon 1301 suppression system could effectively suppress and control a cargo fire as long as the initial concentration was in excess of 5 percent and at least a 3 percent concentration was maintained.

REFERENCES

Reference 1 - Blake, D. R. and Hill, R. G., Fire Containment Characteristics of Aircraft Class D Cargo Compartments, FAA Technical Report No. DOT/FAA/82-156, March 1983.

Reference 2 - Gassmann, Julius J., Characteristics of Fire in Large Cargo Aircraft (Phase II). FAA RD-70-42, September 1970.

Reference 3 - Blake, David R., Suppression and Control of Class C Cargo Compartment Fires, DOT/FAA/CT-84/21, February 1985.

Reference 4 - Gassmann, Julius J. and Hill, Richard G., Fire Extinguishing Methods for New Passenger/Cargo Aircraft, FAA-RD-71-68, November 1971.)

In light of the considerable amount of data and information available, the FAA has determined that an unsafe condition exists with regard to Class B cargo compartments, and considers this AD action a positive step in addressing the unsafe condition posed by fire in Class B cargo compartments.

Some commenters contend that the proposed AD would be inflexible, ineffective, or inappropriate, and that the means of dealing with the described safety deficiency would be more appropriate as a change to FAR Part 25 or FAR Part 121. The FAA disagrees with these comments. FAR Part 39 provides for the issuance of airworthiness directives when an unsafe condition exists in a product and is likely to exist or develop in other products of the same type design. As discussed in the Notice, the FAA has determined that an unsafe condition exists with regard to fire hazards in the Class B cargo compartment. The proposal was prompted by information from a specific accident, a Boeing Model 747 "Combi" airplane operating with a main deck Class B cargo compartment, as defined by FAR 25.857(b), that was lost over the Indian Ocean on November 28, 1987. Although no formal findings have been issued by the foreign authority having jurisdiction over the accident investigation, there is firm evidence that an inflight fire occurred in a Class B cargo compartment, which contributed to the loss of the airplane.

Some commenters suggested that the Class C compartment was not as good as a Class B because a Class B compartment can be accessed by an individual to identify and evaluate the fire situation. Further, this method prevents adverse action being taken in the event there is a smoke alarm failure instead of a fire. The FAA acknowledges that for the false warning situation, where there is no fire, the Class B cargo compartment has an advantage over the Class C. Verification that there is a fire, or that the fire is extinguished is not an option with the Class C compartment. It is generally assumed for a Class C cargo compartment that a fire warning constitutes a fire, the compartment is flooded with Halon, and the airplane is landed at the nearest suitable airport. If there is no fire then it is only a case of inconvenience, lost time, and fuel, but safety is not adversely affected. When there is a fire in a cargo compartment, which is the critical situation as opposed to the false warning condition, optimum safety within technological limits has been provided by the Class C cargo compartment. That is not the case with the Class B cargo compartment. Simulated fire tests have shown that the smoke detection systems and the compartment liner materials may not be adequate to contain the fire until it can be reached by a fire fighter with extinguishing agent. Further, the fire fighter may not be able to locate the fire to extinguish it because of the presence of smoke and obstructing cargo.

Over the years, the size of Class B cargo compartments and the size of cargo packages has increased, making timely fire detection, fire location identification, and manual fire suppression much more complicated, difficult, and ineffective. In Class C cargo compartments, cargo is not accessible by a fire fighter; therefore, the compartment is equipped with cargo liners for containment, control of ventilation and drafts, and fire detection and suppression systems to control or extinguish the fire. There are no known cases of loss of aircraft due to fire in Class C cargo compartments.

Several commenters agreed with the intent of the rule, but opposed the proposed requirements. In general, these commenters pointed out significant technical difficulties with converting in-service airplanes with Class B cargo compartments to Class C cargo compartments. There are significant design considerations, since most Class B compartments are designed for easy and quick conversion for carriage of passengers or cargo on short notice. Therefore, to maintain the proper fire extinguishing agent concentration, major changes would be necessary not only to provide compartment ventilation and air exhaust, but also to provide protection against rapid decompression. The commenters stated that conversion to a Class C cargo compartment would probably prevent them from having the needed flexibility of rapid compartment size changes to support certain customer requirements. These commenters suggested that there were other alternate actions and/or modifications to the Class B compartment that were appropriate safety improvements and more easily accomplished. The following were suggested as areas of improvements:

1. Reducing the detection time to 1 minute.

2. Providing a means to "knock down" fire, plus a method to stop direct flow of ventilation system air into the compartment. (NOTE: "Knock down" is a term often used to refer to a process that occurs when a sufficient concentration level of extinguishing agent is present at the fire to reduce it to a non-threatening level.)

3. Improving the firefighting training.

4. Providing an improved smoke "barrier."

5. Providing public address (PA) speakers in the compartment.

6. Providing improved lighting in the compartment.

7. Reviewing the "access" to cargo within the compartment.

8. Installing viewing ports in access doors to the compartment for monitoring compartment conditions.

As stated in the preamble to the Notice, the FAA recognized that other alternative design changes may be developed which would provide a level of safety equivalent to the options proposed in the Notice. Therefore, as a result of these concerns raised by the commenters, the high cost of retrofit of Class C cargo compartments, and the jeopardy to certain highly desirable cargo operations, the FAA has evaluated the suggested alternative design features and concurs in part with the commenters. In regards to the suggestions listed above, the FAA has determined that the following design changes and procedures are appropriate to achieve major fire safety improvements for Class B cargo compartments:

1. Provide a smoke or fire detection system that meets FAR 25.858 (Amdt. 25-54), FAR 25.1309, and also provide an aural and visual warning to the station assigned to individuals trained to fight cargo fires.

2. Requiring a compartment fire extinguishing system that provides an extinguishant concentration to "knock down" a fire and suppress it, allowing time for a trained individual to find and extinguish a fire, or to verify that the fire is extinguished; and provide a means to shut off ventilation system air inflow to the compartment from the flight deck.

3. Requiring individuals trained to fight cargo fires.

4. Provide a cargo compartment liner that meets FAR 25.855 (Amdt 25-60).

5. Provide two-way communication means between the flight deck, the station assigned to the trained individual, and the interior of the cargo compartment.

6. Provide improved illumination within the cargo compartment.

7. Requiring cargo loading envelopes and limitations to provide access to all the cargo for fighting a fire.

8. Provide a cargo compartment temperature indication system to the flight deck and designated station.

In addition to the above items, the FAA has determined that the following features are necessary to ensure that an acceptable level of safety is attained:

1. Additional portable fire extinguishers appropriately located for use in the compartment and a means to effectively discharge portable fire extinguishers into each container or into each pallet that is covered. This will provide sufficient extinguishing agent and will ensure a means to properly use that agent in containers or covered pallets.

2. Protective garments and protective breathing equipment for individuals fighting a cargo fire. This will provide protection for the individual assigned to control a cargo compartment fire.

3. Fire thermal protective covers for cockpit voice and flight data recorders, windows, safety devices, wiring, flight controls (unless it can be shown that a fire could not result in jamming or loss of affected control systems), and other equipment necessary for safe flight and landing that is located within the compartment. This is necessary to ensure that items which are not critical for continued safe flight, but are essential for the overall safe operation of the airplane, are not damaged in the event of a cargo compartment fire.

Accordingly, the final rule has been revised to include the accomplishment of the design changes and procedures specified above as an alternate method of compliance with the rule. The FAA has determined that if these items are incorporated, they will adequately address the unsafe condition. This alternative action is a logical outgrowth of the proposal and is responsive to the commenters.

Several commenters stated that discontinued use of pallets for cargo is not practical and would result in serious adverse economic consequences to the operators and to very remote communities that heavily rely upon the Combi service. Other commenters stated that cargo loads are often transferred from one airplane size to another of different size. In addition, cargo loads are transferred from airline to airline creating compatibility, logistic, and airworthiness control problems for cargo containers that have a detection and extinguisher system and meet the flame resistant liner requirements.

It is not the FAA's intent to deny the use of pallets in "Combi" aircraft. The issue is the fire control and containment capability with cargo loaded on pallets. With the present practice, in which the cargo is loaded on pallets, a deep-seated fire could develop and result in the compartment being filled with dense smoke. By revising the final rule, as described above, the FAA has addressed these concerns by requiring a means to discharge portable extinguishers into covered pallets, improved access, lighting, and protective equipment for the individual fighting the fire.

Numerous commenters indicated that the 180-day compliance time is unrealistic. After further consideration, the FAA concurs. The FAA has determined that certain of the equipment and operational changes described above (including the formulation and implementation of a training program for fighting cargo compartment fires) can be reasonably accomplished within one year after the effective date of the final rule and will provide an acceptable level of safety as an interim measure. In addition, the FAA has determined that the originally proposed alternatives or the remaining design changes described above can be reasonably accomplished within three years after the effective date and will provide an acceptable level of safety thereafter.

Several commenters provided cost estimates, based on discussions with airplane manufacturers, that indicate the cost of converting a Class B cargo compartment to a Class C cargo compartment would be approximately $2,500,000 for a wide body airplane and about $1,000,000 for a standard body. The FAA agrees that these cost estimates are reasonable, and has revised the economic impact analysis paragraph below, to incorporate these figures.

After careful review of the available data, including the comments noted above, the FAA has determined that air safety and the public interest require adoption of the rule with the changes previously described. The FAA has determined that these changes will neither increase the economic burden on any operator nor increase the scope of the AD.

There are approximately 278 Boeing Model 707, 727, 737, and 747 series airplanes and 124 McDonnell Douglas Model DC-8, DC-9, and DC-10 series airplanes of the affected design in the worldwide fleet. It is estimated that approximately 80 U.S.-registered Boeing Model 707, 727, 737, and 747 series airplanes, and 124 U.S.-registered McDonnell Douglas Model DC-8, DC-9, and DC-10 series airplanes, of U.S. registry, have been certificated to operate with a Class B main deck cargo compartment. Many of these airplanes have been permanently operated in the all-passenger configuration and are, therefore, not affected by this proposal. Approximately 40 of these airplanes are presently operated by U.S. operators in the mixed cargo/passenger configuration. Based on the estimated cost of conversion submitted by several commenters, $1,000,000 per standard body airplane and $2,500,000 per wide body airplane, the costs associated with incorporating additional design features, enhanced protective systems and equipment, and fire control procedures for the Class B cargo compartment are estimated to be $800,000 per standard body airplane and $2,200,000 per wide body airplane. (These estimated figures are based on the fact that these changes require less redesign than is required for conversion to a Class C compartment.)

Because this final rule contains a significant alternative to the proposed requirements, interested persons are invited to submit such written data, views, or arguments as they may desire regarding this AD. Communications should identify the docket number and be submitted to the Federal Aviation Administration, Northwest Mountain Region, Transport Airplane Directorate, ANM-103, Attention: Airworthiness Rules Docket No. 88-NM-80-AD, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168. All communications received by the deadline date indicated above will be considered by the Administrator, and the AD may be changed in light of the comments received.

The regulations adopted herein will not have substantial direct effects on the States, on the relationship between the national government and the States, or on the distribution of power and responsibilities among the various levels of government. Therefore, in accordance with Executive Order 12612, it is determined that this final rule does not have sufficient federalism implications to warrant the preparation of a Federalism Assessment.

For the reasons discussed above, I certify that this action (1) is not a "major rule" under Executive Order 12291; (2) is not a "significant rule" under DOT Regulatory Policies and Procedures (44 FR 11034; February 26, 1979); and (3) will not have a significant economic impact, positive or negative, on a substantial number of small entities, under the criteria of the Regulatory Flexibility Act. A final evaluation has been prepared for this action and is contained in the regulatory docket. A copy of it may be obtained from the Rules Docket.

List of Subjects in 14 CFR Part 39:

Air transportation, Aircraft, Aviation Safety, Safety.

ADOPTION OF THE AMENDMENT

Accordingly, pursuant to the authority delegated to me by the Administrator, the Federal Aviation Administration amends Part 39 of the Federal Aviation Regulations as follows:

1. The authority citation for Part 39 continues to read as follows:

   Authority: 49 U.S.C. 1354(a), 1421 and 1423; 49 U.S.C. 106(g) (Revised Pub. L. 97-449, January 12, 1983); and 14 CFR 11.89.

2. Section 39.13 is amended by adding the following new airworthiness directive:

BOEING and McDONNELL DOUGLAS: Applies to Boeing Models 707, 727, 737, 747, and 757 series airplanes; and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 series), and DC-10 series airplanes, equipped with a main deck Class B cargo compartment, as defined by FAR 25.857(b) or its predecessors, with a volume exceeding 200 cu. ft., certificated in any category. Compliance required as indicated, unless previously accomplished.

To minimize the hazard associated with a main deck Class B cargo compartment fire, accomplish the following:

A. Within one year after the effective date of this rule, or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, accomplish the following in accordance with the appropriate technical data approved by the Manager, Seattle Aircraft Certification Office (for Boeing series airplanes); or the Manager, Los Angeles Aircraft Certification Office (for McDonnell Douglas series airplanes):

   1. Revise the Limitations Section of the FAA-approved Airplane Flight Manual (AFM) to include the following:

FOR EACH FLIGHT IN WHICH CARGO IS TRANSPORTED IN THE CLASS B CARGO COMPARTMENT:

a. For airplanes having compartments with 200 square feet or less of cargo/baggagè floor area a minimum of one individual trained to fight cargo fires must be provided. (This individual is in addition to crewmembers required by the operational rules.) The training program must be approved by the FAA.

b. Prior to flight, the pilot, copilot, or individual required by paragraph A.1.a., above, must make a visual inspection throughout the Class B cargo compartment to verify access to cargo and the general fire security of the compartment after cargo door is closed and secured.

c. At intervals not to exceed 30 minutes in flight and continuously after a smoke alarm, the individual trained to fight cargo fires must conduct a visual inspection throughout the Class B cargo compartment to monitor for evidence of fire, unless an approved temperature (thermal) monitoring system is installed.

d. For airplanes having compartments with more than 200 square feet of cargo/baggage floor area provide an additional person trained to fight cargo fires to work with the individual required by paragraph A.1.a., above. (This individual may be a required flight attendant.)

e. Establish firefighting procedures for controlling cargo compartment fires.

2. Incorporate the following systems and equipment:

   a. Provide appropriate protective garments stored adjacent to the cargo compartment entrance for use by the designated individuals trained to fight cargo fire required by paragraphs A.1.(a) and A.1.(d) above.

   b. Provide a minimum of 30 minutes of protective breathing and an additional quantity of oxygen sufficient to conduct the inspections required by paragraph A.1.c., above. This equipment must meet the requirements of Technical Standard Order (TSO) C-116, Action Notice 8150.2A, or equivalent, and be stored adjacent to the cargo compartment entrance.

   c. Provide a minimum of 48 lbs. Halon 1211 fire extinguishant, or its equivalent, in portable fire extinguisher bottles readily available for use in the cargo compartment. At least two bottles must be a minimum of 16 lb. capacity.

   d. Provide at least two Underwriters Laboratories (UL)2A (2-1/2 gallon) rated water portable fire extinguisher, or its equivalent, adjacent to the cargo compartment entrance for use in the compartment.

   e. Provide a means for two-way communications between the following:

      (1) The flight deck and the station assigned to the individual trained to fight cargo fires.

      (2) The flight deck and the interior of the cargo compartment.

   f. Install placards in conspicuous place(s) within the cargo compartment clearly defining the cargo loading envelope and limitations that provide sufficient access of sufficient width for firefighting along the entire length of at least two sides of a loaded pallet or container. Amend the appropriate Weight and Balance and loading instructions by description and diagrams to include this information.

NOTE: In accordance with paragraph C., below, if the requirements of paragraph B.1. or B.2. are accomplished within one year after the effective date of this AD, compliance with paragraph A. of this AD is unnecessary.

B. Within three years after the effective date of this rule, or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, accomplish the requirements of paragraph B.1., B.2., or B.3., below:

1. Modify the Class B cargo compartment to comply with the requirements for a Class C cargo compartment, as defined in FAR 25.855 (Amdt. 25-60), 25.857(c) and 25.858 (Amdt. 25-54).

2. Modify all main deck Class B cargo compartments to require the following placard installed in conspicuous locations approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (for Boeing airplanes), or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (for McDonnell Douglas airplanes), throughout the compartment:

"Cargo carried in this compartment must be loaded in an approved flame penetration-resistant container meeting the requirements of FAR 25.857(c), with ceiling and sidewall liners and floor panels that meet the requirements of FAR 25, Appendix F, Part III, (Amdt. 25-60)."

3. In addition to the requirements of paragraph A., above, modify Class B cargo compartments and associated systems in accordance with technical data approved by the Manager, Seattle Aircraft Certification Office (for affected Boeing series airplanes), or the Manager, Los Angeles Aircraft Certification Office (for affected McDonnell Douglas series airplanes), to include the following:

   a. Provide a cargo compartment fire "knock down" extinguishing system that provides an initial fire extinguishant concentration of at least 5 percent of the empty compartment volume of Halon 1301 or equivalent, and a fire suppression extinguishant concentration of at least 3 percent of the empty compartment volume of Halon 1301 or equivalent, for a period of time not less than 15 minutes.

   b. Provide a smoke or fire detection system that meets the requirements of FAR 25.858 (Amdt. 25-54) and also provides an aural and visual warning to the station assigned to the individual trained to fight cargo fire. The designated station must be located adjacent to the inflight access door to the cargo compartment.

   c. Provide a means from the flight deck to shut off ventilation system inflow to the cargo compartment.

   d. Provide a temperature indication system to the flight deck and station designated for the individual trained to fight cargo fire to advise of potentially hazardous conditions within the cargo compartment.

   e. Provide a cargo compartment liner that meets the requirements of FAR 25.855, (Amdt. 25-60). The smoke/fire barrier between the occupants and cargo compartment must extend from the cargo compartment floor to the ceiling liner, or top skin of the airplane, and from the right side liner to the left side liner o the cargo compartment. The liner and barrier seals must also be constructed of materials that meet the Flame Penetration Resistance requirements of FAR 25, Appendix F, Part III (Amdt. 25-60), except that currently-installed glass fiber reinforced resin material is acceptable. In addition, provide protective covers for cockpit voice and flight data recorders, windows, wiring, and primary flight control systems (unless it can be shown that a fire could not cause jamming or loss of control), and other equipment within the compartment that is required for safe flight and landing; those covers must be constructed of materials that meet the Flame Penetration Resistance requirements of FAR 25, Appendix F, Part III (Amdt. 25-60).

f. Provide illumination in the cargo compartment as follows:

(1) General area illumination of the cargo with an average illumination of 0.1 foot-candle measured at 40-inch intervals both at one-half the pallet or container height, and at the full pallet or container height.

(2) Illumination of the access pathways required by paragraph A.2.f., above, under visibility conditions likely to be encountered after fire and discharge of the fire extinguishant, and prior to the decay of extinguishant concentration below 3 percent, must provide an average of 0.1 foot-candle measured at each 40-inch interval, with not less than 0.05 foot-candle minimum along a line that is within 2 inches of and parallel to the floor centered on the pathway.

g. Provide a safe means to effectively discharge portable fire extinguishers into each container or into each pallet that is covered.

h. Demonstrate the following features and functions during flight tests:

(1) Fire Extinguishant Concentration, required by paragraph B.3.a., above.

(2) Smoke or Fire detection system, required by paragraph B.3.b., above.

(3) Prevention of smoke penetration into occupied compartments. [Refer to FAR 25.857(b)2 and 25.855(e)2.]

(4) Compartment temperature indication, required by paragraph B.3.d., above.

(5) Cargo accessibility, required by paragraph A.2.f., above.

(6) Firefighting procedures, required by paragraph A.1.e., above.

i. Items specified in paragraphs B.3.h(5) and B.3.h(6), above, must be evaluated under reduced visibility conditions representative of those likely to occur with cargo fires.

C. Compliance with the requirements of paragraphs B.1. or B.2., above, constitutes terminating action for the requirements of paragraph A., above.

D. An alternate means of compliance or adjustment of the compliance time, which provides an acceptable level of safety, may be used when approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region.

NOTE: The request should be forwarded through an FAA Principal Maintenance Inspector (PMI), who will either concur or comment, and then send it to the Manager, Seattle Aircraft Certification Office.

E. Special flight permits may be issued in accordance with FAR 21.197 and 21.199 to operate airplanes to a base in order to comply with the requirements of this AD.

All persons affected by this directive who have not already received the appropriate service information from the manufacturer may obtain copies upon request to Boeing Commercial Airplanes, P. O. Box 3707, Seattle, Washington 98124, or McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846, Attention: Director, Publications and Training, C1-750 (54-60). This information may be examined at the FAA, Northwest Mountain Region, Transport Airplane Directorate, 17900 Pacific Highway South, Seattle, Washington; the Seattle Aircraft Certification Office, FAA, Northwest Mountain Region, 9010 East Marginal Way South, Seattle, Washington; or the Los Angeles Aircraft Certification Office, 3229 East Spring Street, Long Beach, California.

This amendment becomes effective September 25, 1989.

Issued in Seattle, Washington, on August 10, 1989.

Leroy A. Keith, Manager
Transport Airplane Directorate
Aircraft Certification Service

U.S. Department of Transportation
Federal Aviation Administration

AIRWORTHINESS DIRECTIVE REVISION

AVIATION STANDARDS NATIONAL FIELD OFFICE
P.O. BOX 26460
OKLAHOMA CITY, OKLAHOMA 73125

The following Airworthiness Directive issued by the Federal Aviation Administration in accordance with the provisions of Federal Aviation Regulations, Part 39, applies to an aircraft model of which our records indicate you may be the registered owner. Airworthiness Directives affect aviation safety. They are regulations which require immediate attention. You are cautioned that no person may operate an aircraft to which an Airworthiness Directive applies, except in accordance with the requirements of the Airworthiness Directive (FAR 39.3).

89-18-12 R1 BOEING and MCDONNELL DOUGLAS: Amendment 39-6301 as amended by Amendment 39-6557. (Docket No. 88-NM-80-AD)

Applicability: Boeing Models 707, 727, 737, 747, and 757 series airplanes; and McDonnell Douglas Models DC-8, DC-9 (includes MD-80 series), and DC-10 series airplanes, equipped with a main deck Class B cargo compartment, as defined by FAR 25.857(b) or its predecessors, with a volume exceeding 200 cu. ft., certificated in any category.

Compliance: Required as indicated, unless previously accomplished.

To minimize the hazard associated with a main deck Class B cargo compartment fire, accomplish the following:

A. Within one year after the effective date of this rule, or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, accomplish the following in accordance with the appropriate technical data approved by the Manager, Seattle Aircraft Certification Office (for Boeing series airplanes); or the Manager, Los Angeles Aircraft Certification Office (for McDonnell Douglas series airplanes):

1. Revise the Limitations Section of the FAA-approved Airplane Flight Manual (AFM) to include the following:

FOR EACH FLIGHT IN WHICH CARGO IS TRANSPORTED IN THE CLASS B CARGO COMPARTMENT:

a. For airplanes having compartments with 200 square feet or less of cargo/baggage floor area a minimum of one individual trained to fight cargo fires must be provided. (This individual is in addition to crewmembers required by the operational rules.) The training program must be approved by the FAA.

b. Prior to flight, the pilot, copilot, or individual required by paragraph A.1.a., above, must make a visual inspection throughout the Class B cargo compartment to verify access to cargo and the general fire security of the compartment after cargo door is closed and secured.

c. At intervals not to exceed 30 minutes in flight and continuously after a smoke alarm, the individual trained to fight cargo fires must conduct a visual inspection throughout the Class B cargo compartment to monitor for evidence of fire, unless an approved temperature (thermal) monitoring system is installed.

d. For airplanes having compartments with more than 200 square feet of cargo/baggage floor area provide an additional person trained to fight cargo fires to work with the individual required by paragraph A.1.a., above. (This individual may be a required flight attendant.)

e. Establish firefighting procedures for controlling cargo compartment fires.

2. Incorporate the following systems and equipment:

a. Provide appropriate protective garments stored adjacent to the cargo compartment entrance for use by the designated individuals trained to fight cargo fire required by paragraphs A.1.a. and A.1.d. above.

b. Provide a minimum of 30 minutes of protective breathing and an additional quantity of oxygen sufficient to conduct the inspections required by paragraph A.1.c., above. This equipment must meet the requirements of Technical Standard Order (TSO) C-116, Action Notice 8150.2A, or equivalent, and be stored adjacent to the cargo compartment entrance.

c. Provide a minimum of 48 lbs. Halon 1211 fire extinguishant, or its equivalent, in portable fire extinguisher bottles readily available for use in the cargo compartment. At least two bottles must be a minimum of 16 lb. capacity.

d. Provide at least two Underwriters Laboratories (UL)2A (2-1/2 gallon) rated water portable fire extinguisher, or its equivalent, adjacent to the cargo compartment entrance for use in the compartment.

e. Provide a means for two-way communications between the following:

(1) The flight deck and the station assigned to the individual trained to fight cargo fires.

(2) The flight deck and the interior of the cargo compartment.

f. Install placards in conspicuous place(s) within the cargo compartment clearly defining the cargo loading envelope and limitations that provide sufficient access of sufficient width for firefighting along the entire length of at least two sides of a loaded pallet or container. Amend the appropriate Weight and Balance and loading instructions by description and diagrams to include this information.

<u>NOTE</u>: In accordance with paragraph C., below, if the requirements of paragraph B.1 or B.2 are accomplished within one year after the effective date of this AD, compliance with paragraph A. of this AD is unnecessary.

B. Within three years after the effective date of this rule, or prior to carrying cargo in a Class B cargo compartment, whichever occurs later, accomplish the requirements of paragraph B.1., B.2., or B.3., below:

1. Modify the Class B cargo compartment to comply with the requirements for a Class C cargo compartment, as defined in FAR 25.855 (Amdt. 25-60), 25.857(c) and 25.858 (Amdt. 25-54).

2. Modify all main deck Class B cargo compartments to require the following placard installed in conspicuous locations approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (for Boeing airplanes), or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (for McDonnell Douglas airplanes), throughout the compartment:

"Cargo carried in this compartment must be loaded in an approved flame penetration-resistant container meeting the requirements of FAR 25.857(c), with ceiling and sidewall liners and floor panels that meet the requirements of FAR 25, Appendix F, Part III, (Amdt. 25-60)."

3. In addition to the requirements of paragraph A., above, modify Class B cargo compartments and associated systems in accordance with technical data approved by the Manager, Seattle Aircraft Certification Office (for affected Boeing series airplanes), or the Manager, Los Angeles Aircraft Certification Office (for affected McDonnell Douglas series airplanes), to include the following:

a. Provide a cargo compartment fire "knock down" extinguishing system that provides an initial fire extinguishant concentration of at least 5 percent of the empty compartment volume of Halon 1301 or equivalent, and a fire suppression extinguishant concentration of at least 3 percent of the empty compartment volume of Halon 1301 or equivalent, for a period of time not less than 15 minutes.

b. Provide a smoke or fire detection system that meets the requirements of FAR 25.858 (Amdt. 25-54) and also provides an aural and visual warning to the station assigned to the individual trained to fight cargo fire. The designated station must be located adjacent to the inflight access door to the cargo compartment.

c. Provide a means from the flight deck to shut off ventilation system inflow to the cargo compartment.

d. Provide a temperature indication system to the flight deck and station designated for the individual trained to fight cargo fire to advise of potentially hazardous conditions within the cargo compartment.

e. Provide a cargo compartment liner that meets the requirements of FAR 25.855, (Amdt. 25-60). The smoke/fire barrier between the occupants and cargo compartment must extend from the cargo compartment floor to the ceiling liner, or top skin of the airplane, and from the right side liner to the left side liner of the cargo compartment. The liner and barrier seals must also be constructed of materials that meet the Flame Penetration Resistance requirements of FAR 25, Appendix F, Part III (Amdt. 25-60), except that currently-installed glass fiber reinforced resin material is acceptable. In addition, provide protective covers for cockpit voice and flight data recorders, windows, wiring, and primary flight control systems (unless it can be shown that a fire could not cause jamming or loss of control), and other equipment within the compartment that is required for safe flight and landing; those covers must be constructed of materials that meet the Flame Penetration Resistance requirements of FAR 25, Appendix F, Part III (Amdt. 25-60).

4 89-18-12 R1

f. Provide illumination in the cargo compartment as follows:

(1) General area illumination of the cargo with an average illumination of 0.1 foot-candle measured at 40-inch intervals both at one-half the pallet or container height, and at the full pallet or container height.

(2) Illumination of the access pathways required by paragraph A.2.f., above, under visibility conditions likely to be encountered after fire and discharge of the fire extinguishant, and prior to the decay of extinguishant concentration below 3 percent, must provide an average of 0.1 foot-candle measured at each 40-inch interval, with not less than 0.05 foot-candle minimum along a line that is within 2 inches of and parallel to the floor centered on the pathway.

g. Provide a safe means to effectively discharge portable fire extinguishers into each container or into each pallet that is covered.

h. Demonstrate the following features and functions during flight tests:

(1) Fire Extinguishant Concentration, required by paragraph B.3.a., above.

(2) Smoke or Fire detection system, required by paragraph B.3.b., above.

(3) Prevention of smoke penetration into occupied compartments. [Refer to FAR 25.857(b)2 and 25.855(e)2.]

(4) Compartment temperature indication, required by paragraph B.3.d., above.

(5) Cargo accessibility, required by paragraph A.2.f., above.

(6) Firefighting procedures, required by paragraph A.1.e., above.

i. Items specified in paragraphs B.3.h(5) and B.3.h(6), above, must be evaluated under reduced visibility conditions representative of those likely to occur with cargo fires.

C. Compliance with the requirements of paragraphs B.1. or B.2., above, constitutes terminating action for the requirements of paragraph A., above.

D. An alternate means of compliance or adjustment of the compliance time, which provides an acceptable level of safety, may be used when approved by the Manager, Seattle Aircraft Certification Office, FAA, Northwest Mountain Region (for Boeing series airplanes); or the Manager, Los Angeles Aircraft Certification Office, FAA, Northwest Mountain Region (for McDonnell Douglas series airplanes).

NOTE: The request should be forwarded through an FAA Principal Maintenance Inspector (PMI), who will either concur or comment and then send it to the Manager, Seattle Aircraft Certification Office or to the Manager of the Los Angeles Aircraft Certification Office, as appropriate.

E. Special flight permits may be issued in accordance with FAR 21.197 and 21.199 to operate airplanes to a base in order to comply with the requirements of this AD.

All persons affected by this directive who have not already received the appropriate service information from the manufacturer may obtain copies upon request to Boeing Commercial Airplanes, P.O. Box 3707, Seattle, Washington 98124, or McDonnell Douglas Corporation, 3855 Lakewood Boulevard, Long Beach, California 90846, Attention: Director, Publications and Training, C1-750 (54-60). This information may be examined at the FAA, Northwest Mountain Region, Transport Airplane Directorate, 17900 Pacific Highway South, Seattle, Washington; the Seattle Aircraft Certification Office, FAA, Northwest Mountain Region, 9010 East Marginal Way South, Seattle, Washington; or the Los Angeles Aircraft Certification Office, 3229 East Spring Street, Long Beach, California.

Amendment 39-6301,(AD 89-18-12) became effective on September 25, 1989.

This Amendment 39-6557 becomes effective on May 3, 1990.

FOR FURTHER INFORMATION CONTACT:

Mr. Donald Kurle (Boeing airplanes) Systems & Equipment Branch, ANM-130S, FAA, Northwest Mountain Region, Seattle Aircraft Certification Office, 17900 Pacific Highway South, C-68966, Seattle, Washington 98168, telephone (206) 431-1576; or Mr. Kevin Kuniyoshi (McDonnell Douglas airplanes), Systems & Equipment Branch, ANM-130L, FAA, Northwest Mountain Region, Los Angeles Aircraft Certification Office, 3229 East Spring Street, Long Beach, California 90806, telephone (213) 988-5337.

OXYGEN SUPPLY SELECTIONS

The cockpit crew oxygen regulators had 3 different supply selections available, viz:

(1) NORMAL

(2) 100%

(3) EMERGENCY

NORMAL: This selection supplied a mixture of cabin air and oxygen on demand; the ratio being dependant on the cabin height. At a cabin height of 14000 feet, the ratio was approximately 1:1.

100%: This was the usual selection for all flights and supplied 100% oxygen on demand.

EMERGENCY: This selection delivered a pressurised supply of 100% oxygen at a constant flow. This selection would have prevented the ingress of toxic gases into the mask.

National Transportation Safety Board
Washington, D.C. 20594

March 9, 1990

Mr. J. N. J. Van Rensburg
Rooth & Wessels
P. O. Box 208
Pretoria, 001
REPUBLIC OF SOUTH AFRICA

Dear Mr. Van Rensburg:

On behalf of the National Transportation Safety Board (NTSB), thank you for the opportunity to review the report of the investigation of the accident involving the Helderberg. I also appreciate the opportunity the Board of Inquiry has provided to the advisors to the NTSB to review and comment on the draft report. The comments of the Boeing Company and the Federal Aviation Administration, which represent the views of those organizations and not of the NTSB, are enclosed for your review.

The efforts of the investigative team of the Republic of South Africa to gather evidence to enable the Board of Inquiry to determine the probable cause of this accident have made a real contribution to accident investigation and to aviation safety. I believe that the team, under the firm direction of Mr. R. W. Van Zyl, consistently placed the needs of the investigation above its own personal needs despite considerable personal sacrifice. I am honored to have been able to assist the team to a small extent.

The draft report is an excellent compendium of the facts of the investigation. The NTSB agrees with all conclusions, recommendations and the probable cause, with the exception of Recommendation No. 6.1 which states:

> The Combi type of configuration, with passengers and cargo on the same deck and provision for fire fighting on the cargo deck based on, inter alia, crew access to the seat of the fire and hand fire extinguishers to fight the fire, should be prohibited as creating an unacceptable risk to life and property.

The Safety Board has issued Safety Recommendations A-88-61 through 63 to address what it considered to be deficiencies in the fire detection and suppression methods used in class B cargo compartments, the type found on the main deck of the Boeing 747 Combi. In response to these recommendations and as a result of its own review into the safety of class B compartments, the FAA has issued a Notice of Proposed Rulemaking (NPRM) in advance of its issuance of an airworthiness directive. The NPRM and the Safety Recommendations have been included in the draft report as Appendices G and E, respectively. The airworthiness directive that was issued as a result of the NPRM, airworthiness directive No. 88-NM-80-AD, effective September 25, 1989, effectively upgrades the fire detection and control capabilities of class B compartments considerably beyond those in effect at the time of the Helderberg accident. Although I agree in principle with Recommendation 6.1, I believe that it should be revised to address the fire suppression and fire detection capabilities that will be in place in the main deck cargo compartments of Combi aircraft following implementation of the airworthiness directive.

Again, thank you for the opportunity to review the draft. I look forward to receiving the final report.

Sincerely,

Barry Strauch
U.S. Accredited Representative