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REPORT ON THE FIRE AND EXPLOSION ASPECTS RELATING TO THE LOSS OF THE SOUTH AFRICAN AIRWAYS 747-200B "COMBI", REG. ZS-SAS ON 28TH NOVEMBER 1987 NEAR MAURITIUS

by

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1. INTRODUCTION

On 28th November 1987 a South African Airways 747 'Combi', Reg. ZS-SAS, call sign "Helderberg", crashed into the sea off Mauritius with the loss of all passengers and crew on board.

On 14th April 1989 I was instructed to travel to South Africa in order to examine the wreckage which had been retrieved. Prior to this visit I travelled to Seattle where I met with Boeing personnel. I made two trips to South Africa, one on 14th May 1989 and the other on 24th June 1989.

During both my visits I took some photographs, a selection of which I will use to illustrate my report.

2. EXAMINATION OF THE RECOVERED DEBRIS

My examination of the debris recovered from the crash site was carried out between 16th May and 22nd May 1989, and 26th June and 29th June 1989. The debris had been laid out on the floor of a South African Airways hangar at Jan Smuts Airport and had been grouped into areas relating to their original positions on the aircraft (Photographs 1 - 3).

It was clear that a decision had been made during the recovery operation to concentrate on the retrieval of items from the aft end of the aircraft i.e. aft of BS 1720. I understand that this decision was taken because of the early evidence that only items from the main deck cargo area had been affected by fire. Consequently the debris available for examination at Jan Smuts Airport was biased towards the main deck cargo compartment.

A framework had been constructed (Photographs 4 - 6) which represented the dimensions of the main deck cargo compartment from approximately the area of passenger door 4 i.e. BS 1680 to the rear pressure bulkhead, BS 2360. Skin panels with corresponding frames and stringers were fastened to the framework in their original positions and other items, e.g. the passenger/cargo partition of BS 1722 (Photograph 7); the galley block forward of this (photographs 8 and 9); the two life raft support beams, one at BS 1680-1720 (Photographs 10-11) and the other at BS 2240-2280 (Photographs 12-13); the CVR and the top of the coat closet at BS 2320 (Photograph 14); part of the main deck floor from BS 1740-1940 (Photograph 15); and part of the rear pressure bulkhead at BS 2360 (Photograph 16); had been repositioned within the compartment.

My initial examination was confined to determining whether there was any evidence that an explosion had taken place within the aircraft as a result of detonation of high explosives. I found no evidence that this had occurred. It was clear, however, that a fire had occurred in the main deck cargo compartment and my investigation was then concentrated on determining the degree of heat damage sustained by various parts of the aircraft and ultimately the seat and cause of the fire.

As the skin of the aircraft would have had the facility to lose a large amount of heat in flight, i.e. the heat sink of the outside air flow, I limited my initial examination of heat damage to items within the cargo compartment. In order to gauge the lower

end of the temperature range experienced within the compartment and therefore limit the areas which experienced any significant heat, I recorded the heat damage sustained by items which melted at relatively low temperatures, such as plastic fasteners on the insulation blankets (Photograph 17), plastic insulation on wiring and the cable stand offs.

A general pattern of damage emerged which indicated that most of the heat had been concentrated along the crown of the cargo compartment and down to lower levels on the right side of the aircraft adjacent to the position of Pallet PR. In these areas the plastic blanket fasteners had been destroyed or almost totally melted, the lowest point of heat damage occurred between BS 1800 and 1820 (Photograph 18). As the insulation blanket fastener posts melt between 200°C and 250°C the lower line where melting was observed indicated a level below which heat had not developed above these temperatures. With the exception of the area around Pallet PR there was no evidence, on the items retrieved, that temperatures in excess of 250°C had developed below the level of the top of the pallets. At BS 1800 and 1820 the blanket fasteners had partially melted down to stringer 20R but this was the lowest point of melting recorded. In particular there was no evidence of fire or smoke around the window frames i.e. at stringer 20R to 22R. Aft of BS 2200 nylon blanket fastener posts were intact on the frames of the crown and nylon clips were intact on the rear pressure bulkhead even at high level. This indicated that the area had not reached temperatures in excess of 250°C. The "Delrun" seals in the rear pressure bulkhead through which the control cables had been routed, had melted, but these typically melt at approximately 120°C.

In order to obtain a better estimate of the temperatures experienced in the areas where the blanket fasteners had melted I examined items having higher melting points e.g. aluminium. There was no evidence that melting of aluminium had occurred to the frames on Target 267 ie crown area BS 1960-2220, but some aluminium cable brackets had melted in this area. Melting had occurred, however, to frames in an area centering around BS 1800-1820, and the damage formed roughly a V-shaped pattern. I also found melting to the aluminium structure of the forward life raft support beam between BS 1680-1720.

In addition, there was melting to the copper conductors of wiring routed over the forward life raft support beam. Some of this melting could have been caused by electrical arcing.

Further information about the degree of heat to which the skin had been exposed was given by conductivity measurements taken on the skin by Dr G Fowler. These results confirmed that the highest temperatures were experienced by the skin between BS 1800-1820 and stringers 15R-14R. In addition it was noted that the paint on the outside of the skin had been blistered and pyrolysed in this area. The skin temperature measurements were plotted over the right side of the cargo compartment and they were found to form a Y-shaped pattern, extending the original V-shape formed by melted frames, down to stringer 15R between BS 1800 and 1820.

No fire damage was observed below the main deck floor or on any of the items surrounding the lower aft cargo lobe. Similarly no fire damage was observed at low level within the cargo compartment except for isolated areas where molten aluminium had fallen onto some items. In particular the 9G cargo net was not heat affected below a level of about 4 feet from the floor (Photograph 21) and at a height of about 4 feet melting had only occurred on the right side of the centre line. There was no evidence of fire damage to the windows along the right side and consequently a fire had not burned on the right side of Pallet PR at a level below approximately stringer 19R.

Two struts which had supported the beam upon which the overhead stowage bins were fixed along the centre of the aircraft were heat blackened at high level (Photographs 22-24). These struts had been identified as having been fixed at BS 1480. There was no evidence to suggest that the skin had melted or had been breached by the fire anywhere in the aircraft.

As part of my inspection I made a detailed examination of the access door between the passenger and main deck cargo compartments. As a result of this examination I concluded that the door had been in the closed position throughout most of the fire, but there was evidence that it probably had been briefly opened at some stage. There was no evidence that a forced entry had been made through this door.

3. THE CARGO

3.1 The Cargo on the Cargo List, as produced by the DCA for Main Cargo Deck Compartment

The cargo list listed a wide variety of items as being stowed in the main cargo compartment. None of those listed, however, would have posed a particular hazard and none were considered to be 'Dangerous Goods' under the International Air Transport Association (IATA) Regulations. I understand, however, that there were a number of small batteries associated with the various electronic and computer items stored in the main deck cargo compartment, and two types were recovered:
(a) Nickel-cadmium and (b) Lithium-thionyl chloride.
It is not known whether other types were also present in the cargo. I also understand that these batteries were not stowed in bulk, but as part of the components for which they provided power, eg memory cards for small computers. The batteries were all of a small size and would have been packaged inside the electronic items.

There is some evidence that when batteries of the lithium-thionyl chloride type are subjected to abuse, they can explode. A report has been prepared by M M Thackeray outlining the problems and their relevance to this incident. It appears from his report and from other literature that, although an 'explosion' resulting from abuse of a lithium-thionyl chloride battery cannot absolutely be ruled out, such an occurrence is rare.

The other implication of having lithium batteries in the cargo is the potential fire promoting aspects which lithium possesses. Lithium like other similar metals can burn with great intensity, but the amount of lithium in the lithium-thionyl chloride batteries in the cargo is very small and consequently would probably not have a significant promoting effect if involved in fire.

In summary, therefore, I could find no potential ignition sources for this fire amongst those items listed on the cargo list as having been stowed in the main deck cargo compartment.

3.2 IATA Dangerous Goods Regulations

The transportation of all 'dangerous goods', whether by land, sea or air is governed by international regulations and recommendations. The regulating body for

air transport is the International Air Transport Association (IATA) and their "Dangerous Goods Regulations" cover all aspects of the transportation of hazardous items by air. The basic Regulations take into account all relevant international and national regulations in setting an acceptable minimum standard, but any state or operator can register variations to these Regulations and impose additional requirements as thought necessary. An example of such an operator variation is a requirement stipulated by British Caledonian Airways in the 1986 Regulations which states that "In accordance with Article 8 of the Warsaw Convention, an Air Waybill must contain a description of the 'nature of the goods' in addition to the information specified in sub-Section 8.2".

This implies that British Caledonian Airways required a fuller description of the nature of the goods rather than just a general title.

In general, 'dangerous goods' are divided into various classes and divisions according to the hazard they present. Many 'dangerous goods' are too dangerous to be carried by aircraft (e.g. organic peroxides, explosives), some may be carried on cargo aircraft only (e.g. some pesticides, petroleum gases), and others are acceptable on both passenger and cargo aircraft. A detailed list of individual commodities is published which indicates the class and division into which each commodity falls as well as its acceptability for transport by air, the relevant packing and labelling requirements, and the quantity limitations and other provisions.

The Regulations also outline the responsibilities of both shipper and operator for the provision of correct information, the checking and inspection of the dangerous goods and the compliance with the regulations. As no 'Dangerous Goods' were listed on the Helderberg's cargo list these Regulations would not have applied to the operators in this incident, but if undeclared dangerous goods had been loaded, the shipper, according to the IATA Regulations, would have been in breach of these Regulations.

3.3 Cargo Handling

In addition to Regulations concerning the transport of 'Dangerous Goods', IATA also publish an "Airport Handling Manual" which makes recommendations as to the correct procedures for cargo handling, loading and securing; and for the segregation of incompatible substances. With regard to the latter, some 'dangerous goods' may react dangerously with one another and therefore during transit they must

be physically separated, sometimes in different holds. Lashing and securing arrangements must be carried out in accordance with the operator's instructions.

None of the substances listed on the cargo list as having been stowed in the main deck cargo compartment, would have in my opinion, reacted with one another to cause a fire under the conditions of stowage in the aircraft. Similarly there was nothing listed which would have been prone to self heating during storage.

4. CALCULATIONS

Tests carried out by Dr G Fowler indicated that the skin between BS 1800-1820 and as low as the panel between str 15R-14R, had reached temperatures between 288° C and 300°C. The air flow across the outside of the fuselage during flight would have had a substantial cooling effect on the skin and so in order to estimate the energy required to heat the skin to these temperatures it was necessary to quantify this cooling effect.

The calculations made to date took into account the fact that only a small area between BS 1800-1820 was being heated and this provided a minimum figure for heat loss in this area of approximately 100 Kilowatts per square metre (100 KW/m^2) which is 10 watts per square centimetre (10 W/cm^2).

Calculations were also made in order to predict the size of fire which could develop and reach a steady state, given the ventilation conditions typical for this type of aircraft. Based on ventilation information provided by Boeing, calculations showed that, depending on the circumstances the fire would probably have reached a steady state heat output from about 250 KW to about 1 Megawatt (MW). This is assuming that 5% of the oxygen in the air was consumed. This size of fire would be equivalent to a fire involving an armchair at the low end or a large settee at the higher end.

5. DISCUSSIONS

5.1 The Origin of the Fire and Fire Spread

The extent and intensity of the fire damage to items of debris recovered indicated that the fire started in Pallet PR, which was on the front right side of the main deck cargo compartment, and all the heat damage observed is consistent with fire spreading from this area.

Due to the limited amount of debris recovered from the pallets and due to the complexity of predicting fire spread within such a configuration, it was not possible to determine the exact position in which the fire started with absolute certainty. There were, however, features of the damage which precluded certain areas of the pallet from being the seat of the fire.

(i) There was no evidence of burning to the floor around Pallet PR and consequently no fire had burnt at low level around the sides of the pallet nor had burning debris fallen down from the pallet, with the exception of molten material falling down behind the 9G net.

(ii) There was no fire damage around the window frames on the right side of Pallet PR which indicated that no fire had burnt on the right side lower than about stringer 19R. If fire had developed at this point or if debris had fallen down, flames would have burnt through the polycarbonate 'pull down' shade over the window with relative ease and also destroyed the plastic windows, producing traces of that burning on the window frames. No such traces were found.

(iii) In my opinion if the fire had started towards the left side of the pallet it would have involved Pallet PL at a fairly early stage and it is likely that debris from the edges of these pallets would have fallen down causing heat damage to the floor area.

(iv) The intense heat which was experienced by the skin between BS 1800-1820 at a level of stringer 15R indicated that a localised fire had burnt adjacent to this area. If a fire had started lower down towards the centre of the pallet I would have expected it to have spread upwards and outwards towards the top of the pallet. In order to have caused the localised damage seen between BS 1800-1820

it would have been necessary to have artificially channelled the fire towards that area.

It is possible that the fire adjacent to BS 1800-1820 caused the insulation blanket to fall away between these two frames and the blankets on either side of this bay could have remained intact for longer. Alternatively all the blankets in this area could have fallen away at about the same time. In both scenarios a localised source of heat was necessary to either cause the one blanket to fail without the others or to cause the localised heat seen on the skin down the foot of the Y-shaped pattern.

Consequently I am of the opinion that the fire started towards the top right side of Pallet PR in the area around BS 1800-1820.

In my opinion the flames spread up the side of the fuselage on the right side and across the crown. There is also evidence that flames had spread over the forward life raft support beam, between 1680-1720. Hot gases would have built up along the length of the compartment beneath the crown and some insulation blankets would have become detached during this time. There was no evidence, however, of further fires developing in areas other than Pallet PR and the heat damage towards the rear of the compartment was relatively minor and was concentrated at high level.

In my opinion the flames from Pallet PR died back after a short time due to the depletion of oxygen and/or extinguishment action by the crew, and a relatively steady state fire burned in Pallet PR. It is possible that flames were persistent throughout the remainder of the flight until impact, but the fire size would have been limited to the size of a burning armchair or large settee depending on the ventilation available at various times.

5.2 The Nature of the Fire

According to the transcript of the Cockpit Voice Recorder (CVR), the Fire Alarm bell first sounded at 28.31 and the CVR first became affected by the fire at 29.40. (ie 800Hz Test tone signal commenced). The recording ended at 29.52. Therefore the wiring to the CVR which was routed along both sides of the crown became involved in fire about 1 minute to 1 minute 20 seconds after smoke detection.

Consequently by the time that detection had occurred the fire was developing rapidly and in my opinion flames had probably already reached the crown.

There are two scenarios which would theoretically explain fire attack to the CVR wiring shortly after activation of the smoke detectors.

(i) A normal diffusion flame fire involving only the materials listed on the cargo list which had been burning and producing smoke for some time, but for some reason had not been detected.

(ii) A promoted or accelerated fire which would have developed very rapidly after initiation and would have produced intense heat immediately following ignition. This type of fire could have been caused by either an incendiary device or by some chemical reaction within cargo not listed on the cargo list.

The normal diffusion flame fire, fuelled only by the type of substances listed in the cargo list and the associated packaging, can only reach certain temperatures and emit certain levels of energy. This is due to the fact that they are restricted by the speed at which the fuel can combine with oxygen in the surrounding air i.e. the combination can only take place at the edges of the flame. Consequently the rate of burning would be less and therefore the energy emitted would be smaller than if the oxygen was mixed with the fuel before ignition ie premixed flame.

A premixed flame or a chemically promoted fire is capable of producing very intense localised flames which could develop very rapidly. Such a chemical would typically have its own oxygen source ie it would release oxygen as a by product of its own combustion, and in the context of this fire would probably be capable of self igniting or causing ignition due to spillage. An example of such a substance is one of the organic peroxides which can cause ignition if spilled onto other substances and will burn with a very fierce and violent flame. Other examples include metal fires e.g. sodium, finely divided magnesium, or some of the finely divided metal catalysts which rapidly oxidise on exposure to air.

The heat damage observed on the skin just above stringer 15R between BS 1800-1820 was localised and intense and in my opinion the energies required to produce that damage were unlikely to have been attained by a normal diffusion flame fire considering the geometry of this case i.e the distance and angle between the pallet

edge and stringer 15R. Consequently I am of the opinion that the fire was promoted in some way in the early stages, but it is probable that once the promoting fuel was exhausted then the fire continued as a ventilation controlled fire, fuelled only by the packaging materials and substances listed on the cargo list.

5.3 Possible Causes of the Fire

Fires in aircraft compartments can normally be associated with carelessly discarded smokers' materials or a malfunction of electrical or heating equipment on board. In the Helderberg incident the position in which the fire started i.e. high level in Pallet PR, indicates that carelessly discarded smokers' materials were not the ignition source. If a carelessly discarded match or cigarette fell onto the floor it would have to have first ignited paper or rubbish on the floor before igniting the cardboard of the packaging boxes. There was no evidence of a low level fire around the Pallet PR and therefore in my opinion carelessly discarded smokers' materials can be ruled out as a cause of this fire.

The only electrical wiring which was routed across Pallet PR was raceway H and in order for these wires to have caused a problem the insulation covering one of them would have to have abraded away and it would have to have contacted something of a different electrical potential. This would probably have to have been another wire of a different potential which also had its insulation abraded away. Even if this had occurred it is unlikely, in my opinion, that arcing on these wires could have produced sufficiently large globules of molten copper to fall down on to the pallet and still remain sufficiently hot to ignite the cardboard.

The 'eyebrow' lights which were fitted on top of each window in the 'reveal', may have been on at the time of the fire, but as there was no heat or smoke damage to the skin or frames in these areas I discounted them as being a cause of the fire. Consequently even without the evidence of an intense localised fire at BS 1800-1820, I have ruled out the aircraft's electrical equipment as a cause of this fire. There was no other potential ignition sources associated with the aircraft's equipment in the immediate area of Pallet PR.

I am therefore of the opinion that the cause of the fire was something in the cargo stowed on pallet PR. This could have been an incendiary device which was deliberately planted in the cargo or it could have been a chemical which was

mis-declared and caused ignition when spilled or when contaminated by some other substance.

5.4 Extinguishment

The main deck cargo compartment was equipped with a 16 lb (7.25Kg) Halon 1211 extinguisher but other Halon extinguishers and water extinguishers were also available on board the aircraft. Halon 1211 (BCF) extinguishes flames by interfering with the chain reaction in flames and consequently Halon would be effective on fires involving normal packaging materials and most flammable liquids. If Halon is used on fires involving oxidising agents or metals as the fuel, however, then the Halon can react with the burning metal or oxidiser and produce an exothermic reaction which emits a large quantity of heat, thus promoting the fire instead of extinguishing it. Water would have a similar effect on metal fires unless sufficient spray could be applied to cool the area. This is unlikely from a limited source such as a portable fire extinguisher.

6. CONCLUSION

The fire on board the South African Airways 747, Registration ZS-SAS which crashed off Mauritius on 28th November 1987 started in Pallet PR, which was situated at the front right side of the main deck cargo compartment.

In my opinion the fire started as a rapidly developing flaming fire towards the top right side of the pallet, and flames extended across the crown of the aircraft and over the forward life raft support beam at BS 1680-1720. The heat damage decreased as the distance from BS 1800-1820 increased.

It is also my opinion that the fire was caused by something in the cargo stowed on Pallet PR which promoted a rapidly developing fire at an early stage. This could have been either an incendiary device or a hazardous substance within the cargo which had apparently not been declared. Many such substances have the ability to ignite and promote an intense fire if spilled on to suitable substrates.

G McGuiness