No. 5

Lockheed L-1011 Tristar, HZ-AHK, accident at Riyadh, Saudi Arabia, on 19 August 1980. Report dated 16 January 1982, released by the Presidency of Civil Aviation, Saudi Arabia.

SYNOPSIS

About 1808 GMT on 19 August 1980, Saudi Arabian Airlines, Flight 163, a Lockheed L-1011 Tristar, departed Riyadh, Saudi Arabia en route to Jeddah, Saudi Arabia. Flight 163 returned to Riyadh after an uncontrolled fire developed in the C-3 cargo compartment of the aircraft. The flight landed at about 1836 and then taxied clear of the runway and came to a stop on an adjacent taxiway.

While parked on the taxiway, the aircraft was destroyed by the fire and the three hundred and one persons on board the flight were killed.

The Presidency of Civil Aviation determines that the probable cause of this accident was the initiation of fire in the C-3 Cargo compartment. The source of ignition of the fire is undetermined.

Factors contributing to the final fatal results of this accident were 1) the failure of the Captain to prepare the cabin crew for immediate evacuation upon landing, and his failure in not making a maximum stop landing on the runway with immediate evacuation, 2) the failure of the Captain to properly utilize his flight crew throughout the emergency, 3) the failure of C/F/R headquarters management personnel to ensure that its personnel had adequate equipment and training to function as required during an emergency.

1. FACTUAL INFORMATION

1.1 History of the Flight

At 1332 GMT[1/] on 19 August 1980, Lockheed L-1011, HZ-AHK, owned and operated by Saudi Arabian Airlines (Saudia), departed Karachi, Pakistan. It was operating as Saudia Flight No. 163 (SV163) en route to Jeddah, Saudi Arabia, with a scheduled intermediate stop at Riyadh, Saudi Arabia.

The two hour and thirty-four minute flight from Karachi to Riyadh was uneventful. The aircraft landed at Riyadh at 1606. All passengers then disembarked with their carry-on baggage for immigration and customs clearance. Baggage for all passengers, both continuing and deplaning was also unloaded from the aeroplane for customs clearance. Fuel was added and continuing passengers, who had deplaned, were boarded along with those passengers joining the flight in Riyadh. After the baggage was loaded, the aircraft departed the gate at 1750.

The aircraft was airborne from Riyadh about 1808 with a total of 301 personnel on board. There were 287 passengers, which included 15 infants, and 14 crew members.

1/ All times contained herein are Greenwich Mean Time (GMT) based on the 24-hour clock, unless otherwise noted.

After departure, SV163 was cleared to Jeddah via green airways number 53, to cruise at an assigned altitude of 35 000 ft (FL 350). The estimated arrival time in Jeddah was 1920. The initial climb toward Jeddah was uneventful until 1814:54, 6:54 minutes after take-off, when the flight crew was alerted by both visual and aural warnings indicating smoke in the aft cargo compartment (C-3).

A total of 4 minutes and 21 seconds was spent by the flight crew in confirming the warning and when it became clear that a valid warning existed, the Captain elected to return to Riyadh. The Flight Engineer (F/E) had gone into the passenger cabin to investigate the situation and on returning to the cockpit, about 36 seconds later, at about 1820:16, he informed the Captain that there was a fire in the cabin (see Appendix D - Cockpit Voice Recorder and Figures 1 and 2).

At 1820:17 while climbing through about 22 000 ft, the First Officer contacted Riyadh and said, "163, we are coming back to Riyadh". At this time, the return to Riyadh was initiated. When queried by Riyadh as to the reason for the return, SV163 stated, "We got fire in the cabin, please alert the fire trucks". Riyadh cleared the aircraft to begin an immediate descent and gave priority for landing, at which time Riyadh advised the crew that the aircraft was then 78 miles out. Riyadh then queried if the fire was in an engine and SV163 responded at 1821:09, "negative, in the cabin". At 1821:15, Riyadh requested the number of passengers onboard. At 1821:27, SV163 replied, "don't know exactly, think we have full load".

At 1821:53, the F/E, who had just returned from the second trip to observe conditions in the cabin, informed the Captain that it was just smoke in the aft of the aircraft. The Captain acknowledged and again informed the flight deck crew that they were returning to Riyadh.

At 1822:08, the F/E stated that everyone was panicking in the back. At 1822:53, the F/E asked if the fire trucks were alerted and the Captain acknowledged that they were. At 1823:04, the Captain again asked the First Officer (F/O) to alert the fire trucks and he acknowledged that they were standing by. At that time, the Captain called for the "Landing Preliminary" checklist.

At 1824:16, there is another aural smoke detector warning, The F/E said, "what can I say"; the Captain said, "Okay" and the F/E then said, "I think it's all right now". The crew then finished the Landing Preliminary checklist.

At 1824:41, there was another aural smoke detector warning and the F/E said, "There goes A".

At 1825:26, the Captain stated that the throttle of the No. 2 engine was stuck and informed the cockpit crew that he was going to shut the engine down. Immediately thereafter, a female cabin attendant came into the cockpit and informed the crew that there was a fire in the cabin.

At 1825:55, the Captain told the F/E to inform Riyadh that there was an actual fire in the cabin now. Riyadh then advised that the fire trucks were in the standby position and were ready. One of the cabin attendants came to the flight cockpit after attempting to go the rear of the cabin and said, "there is no way I can go to the back aft of L2 and R2 because the people are fighting in the aisles".

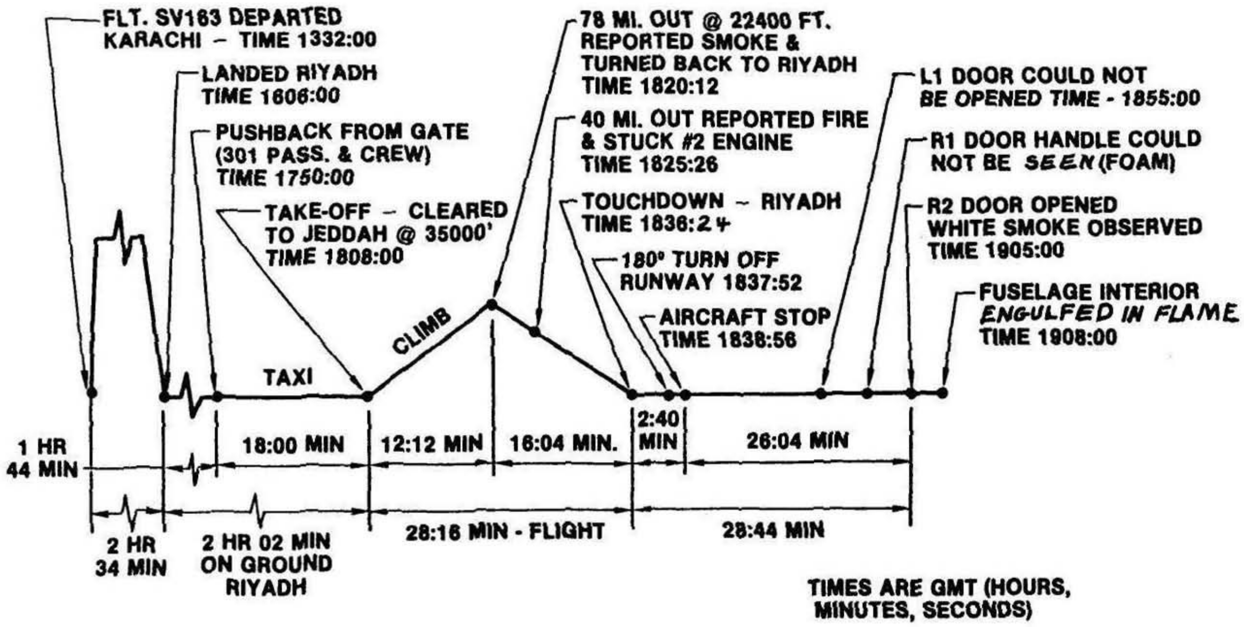

Figure 1. SV163 (S/N 1169) flight profile

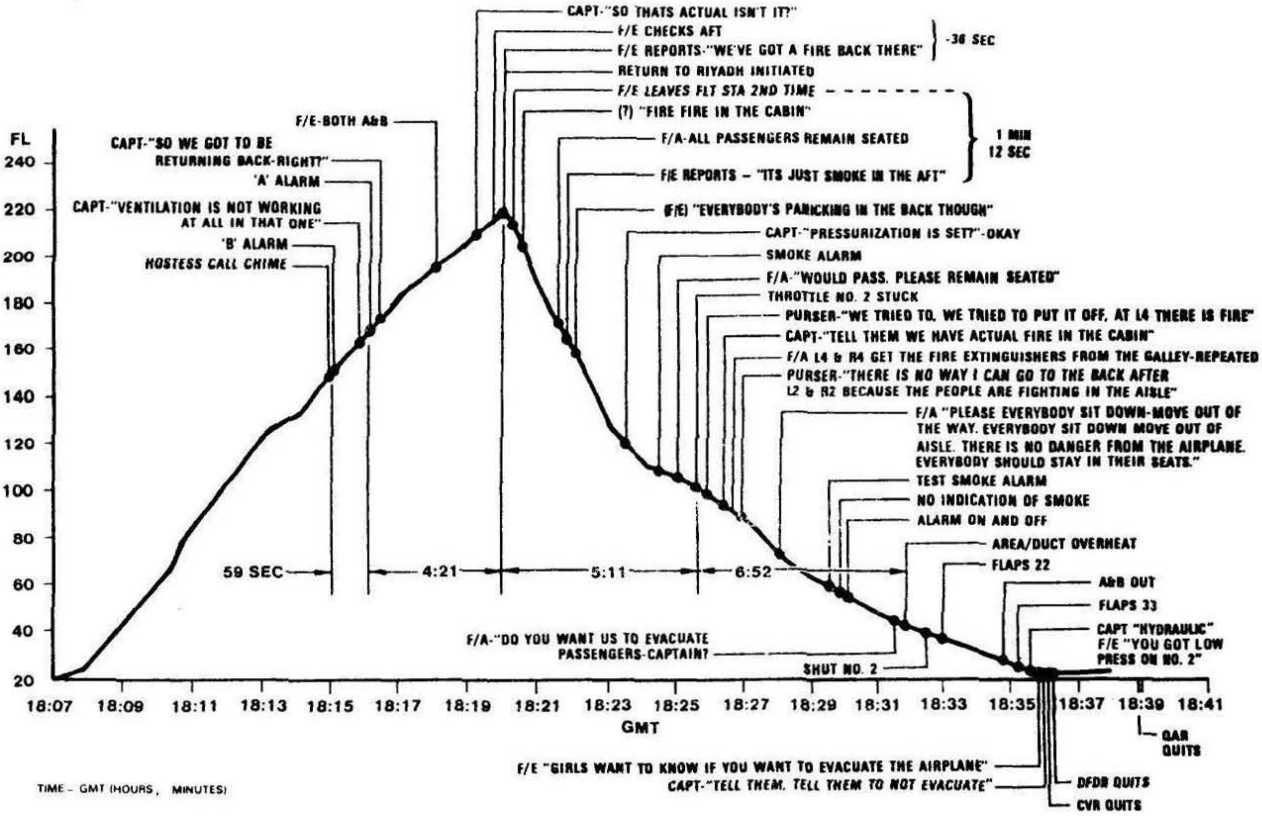

Figure 2. Flight profile and sequence of events

1827:02, the Captain said that they must get down as soon as possible.

At 1827:40, the CVR recorded announcements by the cabin crew to remain calm. They were given in English, Arabic and Urdu. The announcement was as follows:

> "Please everybody sit down, move out of the way, everybody sit down, move out of the aisle, there is no danger from the airplane, everybody should stay in their seats."

At 1828:40, the F/E asked the F/O if he informed Riyadh to have the fire trucks go to the back of the aircraft as soon as possible. The F/O replied that he had. The Captain then told the F/O to advise Riyadh about the fire trucks and the F/O complied by calling Riyadh tower and said, "please advise fire trucks to be at the tail of the aircraft after touch, please". At this time Riyadh tower contacted Fire 3 at the airport and said, "Okay, Sir, the fire on the cockpit when the aircraft land, I want you to follow them the tail, from his tail. Drive behind it from the tail. Okay, Okay, Hamad". There was then an extensive discussion between the tower and the fire trucks as to the location of the fire.

At 1829:01, a cabin attendant came forward and advised the crew that there "is too much smoke in the back". The Captain at this time, was occupied with locating the Riyadh runway. At 1829:34, the F/E said, "Okay, I am going to test the system again" and at that time there was the sound of the smoke detector. The F/E said, "Okay, there's both 'A' and 'B' loops working again and said, "and no indication of smoke". When the Captain questioned him about this statement, the F/E said there was no indication of smoke (referring to the warning devices "A" and "B") but the cabin was filled with smoke in the back.

At 1829:56, the F/E suggested that they shut No. 2 engine when they are on short final and the Captain agreed.

At 1829:59, there was another smoke warning signal and the F/E said, "there is 'A' again".

At 1830:41, the Captain called for the final check-list. At that time, the CVR picked up the cabin attendant voices trying to calm the passengers.

At 1831:30, a cabin attendant asked the Captain if they should evacuate. He responded by saying, "What". The cabin attendant repeated the question and the Captain said, "Okay".2/

At 1831:34, the Captain called for flaps 10 and then called for final check-list to the box.3/

At 1832:10, a cabin attendant again asked the Captain if he wanted them to evacuate the passengers. The Captain responded by telling the cabin attendant to take her position. At 1832:19, the F/E reported an area duct overheat condition. At that time, the Captain called for 18 degrees of flap.

At 1832:33, SV163 transmitted, "we got the runway in sight, are we cleared to land?" and Riyadh replied "affirmative, you are number one for approach and you can contact the tower, 118.1". The response from SV163 was "118.1, 163".

2/ The "Okay" was determined to be in reference to a prior non-related question.
3/ Items in a section of the check-list that have been boxed off are completed after the landing gear has been extended.

At 1832:48, the tower cleared SV163 to land and gave the wind as 320° at 5 kt. At 1832:52, the Captain stated that he is shutting down number 2 engine. At about the same time, the F/O acknowledged the clearance to land and questioned the tower again about alerting the fire trucks. The tower responded that they have been alerted.

At 1833:31, the Captain called for gear-down after which he informed his F/O that the two-engine landing procedure is the same as the three-engine landing procedure.

At 1834:02, subsequent to the shutting down of number two engine, SV163 called "Tower, SV163", and the tower responded, "go ahead 163, wind 320 at 5". At 1834:10, SV163 replied, "one six three is cleared to land, we have only one and three".

At 1834:25, the Captain requested that the F/E complete the final landing check list which he did. At 1834:44, the F/E says, "Both loops A and B are out". At this time, the CVR again picked up the attempts by the cabin attendants to calm the passengers. At 1835:17, the F/E informed the Captain that the cabin attendants wanted to know if he wanted to evacuate the aircraft. The Captain did not respond to the F/E and called for 33 flaps.

At 1835:25, there was another aural smoke warning heard and the F/E stated, "that is 'A' again". Immediately thereafter, the "C" cord aural tone was heard indicating that the aircraft was 500 ft above ground level. The aircraft at this time was on the final portion of its landing approach. At 1835:36, the Captain called, "Hydraulic" and the F/E responded that they have low pressure on number two.

At 1835:57, the Captain stated, "tell them, tell them to not evacuate". From 1836:18 until 1836:21, the CVR picked up the voice of the F/E giving his required altitude callouts of "fifty", "forty", "thirty". Immediately after the "thirty" call out, the CVR ceased to operate. The aircraft landed on Runway 01 at 1836:24.

Witnesses observed smoke coming from the rear of the aircraft while the aircraft was on a short final approach.

The aircraft continued its landing roll-out and according to DFDR and QAR[4/], it made a right 180° turn-off at the end of the runway at 1837:59 and came to a stop on the taxiway at 1839:03 which was 2 minutes and 40 seconds after touchdown. During this period of time, SV163 asked the tower if there was any fire noted in the tail of the aircraft and the tower responded after checking with the fire vehicles, that no fire was noted. This was acknowledged by the aircraft (see Appendix F).

About 1839:06, the tower asked SV163 if they wanted to continue to the ramp or to shut down. SV163 said "standby" and immediately thereafter stated, "Okay, we are shutting down the engines now and evacuating". During this time period and immediately thereafter, there were communications between tower and fire fighters regarding an increase in the fire and their requests to the crew to shutdown the engines. It should be noted that the tower did not make provisions for a common frequency between the aircraft and C/F/R personnel.

At 1840:33, after being told by the tower that they have fire in the tail, SV163 stated, "Affirmative, we are trying to evacuate now". This was the last transmission received from the aircraft.

4/ Quick Access Recorder which records identical parameters as the DFDR. The touchdown time was established by reference to the QAR, DFDR, CVR and tower times.

After further conversations by the tower and fire personnel regarding the fire and the need to have the engines shut down, the engines were shut down at 1842:18 or 3 minutes and 15 seconds after the aircraft had come to a stop on the taxiway.

Attempts by the crash, fire, rescue personnel (CFR) to enter the aircraft and open the doors were unsuccessful until the No. 2 door on the right side of the aircraft was opened at about 1905, about 23 minutes after all engines had been shut down. At 1908, the fuselage interior was observed to be engulfed in flame. (See Figures 1, 2.)

Witnesses observed SV163 to make a normal landing; however, smoke was coming from the rear of the aircraft. One witness, who responded to a call from the tower, arrived at the airport as the aircraft was approaching the runway. He stated that after the aircraft landed, he followed it down the runway and caught up with it as it passed the B-7 turn-off. The B-7 high-speed turn-off is 1 100 metres or 3 609 ft from the end of Runway 01. He stated that by that time the aircraft was taxiing slowly and it made a slow turn-off at B-8 (end of runway 01). After it stopped on the taxiway, the witness parked his car just behind and to the right of the aircraft. He observed fire through the windows on the left side of the cabin between the L-3 and L-4 doors. He said there was no fire outside the aircraft at this time.

He could not see any movement in the cockpit or cabin. He stated that just after the engines were shut down, there was a big puff of white and black smoke emitted from the aircraft belly just forward of the wings.

Most of the fire fighting personnel said that the aircraft's engines were shut down about three minutes after the aircraft stopped. Within a minute, they observed smoke rising from the top of the fuselage just forward of the No. 2 engine intake. The smoke was followed almost immediately by flames.

Another witness stated that there was a wind blowing and that the engines were wind-milling fast. This witness then observed flames coming from the aircraft near the left 3 and 4 doors (L3 and L4). He stated that attempts by the firemen to open the forward left No. 1 (L1) door were unsuccessful. The firemen then proceeded to the R1 door but upon noting that its handle could not be located due to it being covered by foam, they proceeded to the Right No. 2 door (R2). This was opened and a fireman called into the passenger cabin but received no response. Shortly thereafter, flames were observed to come out of the R2 door. About this time, witnesses noted that the fire trucks were depleting their foam.

The accident occurred at night during moonlight conditions at latitude 24°43'1"N and longitude 46°43'1"E.

1.2 Injuries to Persons

Injuries	Crew	Passengers	Others
Fatal	14	287*	0
Serious	0	0	0
Minor/None	0	0	

* Includes 15 infants

1.3 Damage to Aircraft

The aircraft was destroyed by fire.

1.4 Other Damage

None.

1.5 Personnel Information

The crew members were properly certificated for the flight and received the training required by current regulations (see Appendix B).

The crew members had been on duty about 9:45 h prior to the accident, and had 16:50 h rest time prior to reporting on duty the day of the accident.

1.6 Aircraft Information

The aircraft was certificated and maintained in accordance with existing regulations. Its centre of gravity was within the prescribed limits for the flight.

A review of the maintenance records revealed that all required inspections had been performed.

1.7 Meteorological Information

At the time of the accident, the weather at the airport was clear. The surface observations at Riyadh were as follows:

> 1800, surface aviation observation: clear, wind 360° at 6 knots, ceiling and visibility O.K., temperature 35° Centigrade, dew point 6° Centigrade, altimeter 1007 millibars.

1.8 Aids to Navigation

Riyadh International Airport is equipped with TACAN, VOR/DME, NDB and an ILS. One VOR/DME is located between Runway 01 and Runway 30. There is an ILS available for Runway 30. The navigation aids were checked after the accident and found to be satisfactory.

1.9 Communications

There were no known communications malfunctions. However, no provisions were made for direct communications between the aircraft crew and C/F/R personnel.

1.10 Aerodrome Information

Riyadh International Airport is 634 m (2 082 ft) above sea level. Runway 01 is 4 100 m (13 451 ft) in length and 45 m (148 ft) in width.

It was equipped with Medium Intensity Runway Lights (MIRL), 3-bar visual slope indicators (VASI) and SALS.

1.11 Flight Recorders

The aircraft was equipped with a Fairchild A-100 CVR, S/N 5047. The recorder was removed from the aircraft and copies of the 30-minute tape were made for immediate use by the Investigation team. The original tape was hand carried to the NTSB's laboratory in Washington, D.C. where an initial transcript was made. Another transcript was made by the investigation team in Riyadh. The two initial transcripts were combined and a final official copy was completed on 19 March 1981. The recording was considered to be excellent up to the time that the CVR ceased to function when the aircraft was about 30 ft in the air and on its landing approach.

The elapsed CVR time accuracy was derived using a 400 HZ alternator frequency which had been recorded on the tape prior to the time electrical power was lost. Elapsed time accuracy was determined to be + .005 seconds. Times appearing on the transcript are expressed in minutes and seconds from 1800 GMT. As an example, "04:46" would be "1804:46" (see Appendix D).

The aircraft was equipped with a Lockheed DFDR 209E-6, S/N 826. The recorder had been removed from the Aft Electronics Equipment Area (AEEA) and was found to be covered with a heavy coating of black soot. A sample of the soot was sent to the Federal Bureau of Investigation (FBI) for analysis and found to consist of products of combustion of urethane type material.

There was no evidence of mechanical or fire damage other than the sooting of the recorder's outer case. The DFDR operated normally and print-outs of the data in engineering units were made.

The aircraft was also equipped with a Lockheed Air Service, Model 280A, P/N 10119A 100-103 quick access recorder (QAR) which was located in the forward electronic service centre (FESC). The QAR records the same information as the DFDR from the Flight Data Acquisition Unit (FDAU). The QAR in conjunction with the Flight Data Acquisiton Unit (FDAU) samples and records data from 119 discrete signal monitors and sensors in selected aircraft systems. This data provides a record of operational parameters and is the information base for post-flight monitoring of aircraft system performance and preventive maintenance trend analysis. The Cockpit Voice Recorder ceased operation just prior to touchdown at about 1836:23. The DFDR ceased operation just after touchdown at about 1836:28.

Readouts and correlation of the DFDR, QAR and CVR recordings encompassed the entire flight from the time SV163 taxied into position for take-off at Riyadh until both the CVR and DFDR failed during the final portion of the landing phase on SV163's return to Riyadh. The QAR continued to operate and did not fail until about 2 minutes and 1 second after touchdown. The 180^{o} turn from the runway had been made and the aircraft was coming to a stop at the time of its failure. The additional QAR data provided information to perform a required brake-energy study to help determine the aircraft's ability to make a maximum performance stop on the runway.

QAR power is cut off when the rotating beacon is turned off. A witness near the aircraft stated that the rotating beacon ceased to operate as the aircraft came to a stop.

DFDR/QAR and CVR data were plotted and are reflected as profiles in Figures 1, 2, and 3 of this report.

1.12 Wreckage and Impact Information

1.12.1 Structures

Examination of the aircraft revealed that with the exception of the cockpit window surround structure, fuselage door surround structure, centre engine fixed inlet forward structure, fuselage window surround structure, and the empennage structure aft of fuselage station (FS) 1860, all of the upper fuselage structure of the aircraft had been consumed by fire.

An intense fire had been present within the cockpit and passenger area and the resultant structural damage had been largely confined within this area with the exception of the aft C-2 and C-3 cargo compartments. The floor support structure of the flight station adjacent to and forward of, the pilot's seat had collapsed. The glare shield on the co-pilot's side was essentially intact; however, most of the Auto Pilot and Flight Director components were missing with the remainder severely affected by fire. The flight station equipment and furnishing including the flight engineer's panel was severely burned and essentially destroyed.

The furnishings and equipment within the cabin areas such as the seats, class dividers, out-board overhead stowage modules, and service centre modules, were affected by fire to varying degrees ranging from heavy sooting to complete consumption.

One double seat unit on the left just aft of the L-3 door and three centre rows of seats in the centre section just aft of the service area were intact. These seats were burnt and charred to some extent and were covered with the remains of burnt ceiling panels.

A section of the floor on the left side of the forward passenger cabin had collapsed onto the containers in the C-1 cargo compartment. The collapsed section extended from about FS 429 aft to about FS 629. The centre floor structure in the overwing area of the passenger cabin from about FS 1043 aft to FS 1103 had also collapsed. The floor above the cheek area from about FS 449 to about 529 had been destroyed by fire (see Photos 2 and 3).

The centre engine fixed inlet structure and mini-skirt and saddle structure from approximately FS 1625 aft to FS 1856 had been partially consumed by fire. The forward section of the fixed inlet structure had collapsed into the aft passenger compartment.

The upper portions of the aft pressure bulkhead were destroyed by fire. Portions of the fuselage structure at FS 1860 above WL 182 had been consumed by fire. The centre engine "S" duct from approximately FS 1860 aft was intact.

A large hole was burned through the floor on the left side near the pressure bulkhead in the area of the aft lavatory installations.

There was evidence of an intense fire on the left side of the aft passenger section which extended from FS 1545 aft to FS 1763. This area encompassed 6 dual seat configurations. Floor structure beneath the six seat section over the cheek area and a section of floor in the adjacent passenger aisle over the C-3 cargo compartment had been destroyed by fire. (See Photos 4 and 5).

The centre cargo compartment C-2 (containerized) and the aft cargo compartment C-3 are located beneath the aft passenger section. The C-2 compartment extends from FS 1363 aft to FS 1625. The C-3 compartment extends from FS 1625 aft to FS 1792. The Nomex blow-out panels located on the left wall of the C-2 compartment between FS 1625 and FS 1545 had been partially destroyed by fire. The heat exchanger air outlet screen assembly duct installations had been consumed by fire, however, the screen assemblies remained in their relative positions.

The vertical support at FS 1605 was fractured at a point 12 in down from its attachment to the BL 80 longitudinal support. The upper portion of the vertical support at FS 1685 showed evidence of buckling and exposure to fire and heat at the BL 80 attachment point.

The C-3 cargo compartment left side wall and adjacent fuselage structure (cheek area) had been severely affected by fire. The FS 1625 bulkhead aluminium face sheet and aluminium core at the left upper corner was split open exposing the core. The surrounding area in that corner extending from the upper horizontal cross support downward about 4 feet and inboard to the blow-out grill was intact. The balance of the bulkhead exhibited random charring and sooting but with no significant damage.

The hole in the ceiling of the forward left side of the C-3 compartment extended from about FS 1675 aft to about FS 1725 and from BL 80 inboard about 40 in. The cabin floor material above the hole was also burned away. The initial observation of the material surrounding the hole from the C-3 into the cabin revealed a "shingle" type pattern of the debris. That is, the material was burned away more at the bottom and less at the top generally in a tapered manner. Such a burn pattern indicates fire from the inside of C-3 burning upward and outward into the cabin area.

The Nomex fabric ceiling liner was burned away from the left longitudinal support (BL 80) inboard about 60 in and in the aft direction from FS 1625 to FS 1725. The left side wall Nomex blow-out panels were also fire and heat damaged.

The C-3 left wall upper longitudinal support in the vicinity of FS 1645 was consumed by fire. An 18-in section of the associated horizontal cross beam lower cap was burned away. The vertical support at FS 1645 showed a partial fracture and buckling 3 in down from longitudinal support BL 80 (FS 1676) attachment point. A burned section of the longitudinal support lower cap which measured about 14 in in length remained attached to the vertical support. A concaved area showing a diameter of about 5 in with a depth of 1-1/2 in existed of the FS 1665 horizontal support beam lower cap at a point 30 in inboard from BL 80. The web area adjacent to the above was buckled in the aft direction.

Examination of the aft bulkhead of the C-3 cargo compartment showed a skin burnoff at its inboard corner at about BL 13. The back skin panel (aft side of C-3) had a burn off of about one square foot. The honeycomb structure between the two aluminium sheets was in place. The forward skin panel (in C-3 compartment) had about 1 to 2 sq. in. of the aluminium burnt away. This area had been protected by "close out" angles of 775T6 aluminium material. Examination indicated that this had occurred late in the fire sequence.

The upper end of the vertical support at FS 1685 had fractured and was bent 180 degrees in the outboard direction. The fracture occurred about 4 in down from the transverse floor beam attachment point. The vertical support at FS 1705 was attached to the lower cap section of the transverse support beam. The web and upper cap of the support beam were missing. The vertical support at FS 1778 had been consumed by fire with the exception of the lower 8 in. The transverse beam was bent downward and twisted in the forward direction. The bend and twist started at a point 15 in outboard of the aircraft centre line.

The fuselage skin above and below WL 200 in the left cheek area was severely affected by fire.

The stringers and associated vertical support members below WL 200 in an area outboard of the C-3 compartment between FS 1645 and FS 1685 were severely affected by fire. Additional damage to posts and stringers occurred from FS 1785 to FS 1792.

The protective covering over the pneumatic manifold and heat exchanger located outboard of the C-3 compartment's left wall had been consumed by fire. The fibre glass ducts leading to the 5 cargo heating air supply vents had fallen downward and were in various positions within the burned debris behind the compartment left wall.

1.12.2 Systems

1.12.2.1 Environmental Control System (ECS)

None of the equipment in either of the Environmental Control System bays showed signs of fire or smoke damage. The turbine bypass valves were all in the pre-position setting which is about 37 degrees open. This was determined by noting the valve position indicators on packs 1 and 3 and by removing and inspecting the valve on pack 2. The indicator does not affect valve operation. The pre-position valve setting is a position established by the temperature control system when a pack is shut down. This action requires AC power. Such a valve setting indicates that all three packs were shut off and the valves pre-positioned before engines were shut down and AC power was lost.

The controllable exhaust and outflow valves and their positions were found as:

Forward electrical service centre	- Closed
Mid electrical service centre	- Closed
Galley venting	- Closed
C-3 cargo venting	- Closed
Forward outflow valve	- Closed
Aft outflow valve	- Slightly Open (3/8") (0.4")

1.12.2.2 Pneumatic System

Ducting was inspected in detail in all fire damaged areas from No. 2 engine and APU forward and no evidence of pneumatic duct rupture or leakage was found. The 8-in line running through the cheek area alongside the C-3 cargo compartment did not appear to have suffered any structural damage. All the duct insulation was burned away or mechanically destroyed along the outerside of the C-3 compartment. Forward of the severely burned area, the insulation was intact.

1.12.2.3 Overheat Detection System

An overheat detector system is installed adjacent to the pneumatic ducting to detect and annunciate Bleed Air Leaks. Resistance checks were made of the "J" area loop, which is the loop adjacent to the aft engine bleed duct in the left-hand cheek. The resistance of the "B" channel of the "J" loop was 62 ohms. This indicates that the sensor was permanently alarmed and had been exposed to temperatures of at least 1 500°F. At any resistance less than 100 ohms the circuit will alarm. Normal resistance is greater than 1 000 ohms. Channel "O", a wing loop, was checked for reference and had a resistance of 1 600 ohms.

1.12.2.4 Pressurization

The cabin pressure control panel was recovered from the wreckage but was severely fire damaged. Some of the Indicator positions were found as follows

- Altitude Set	26 000 flt/2 000 ft. cabin alt.
- Baro Set	29.9 in Hg/1 012 mb
- Mode Set	Standby (note 1 and 2)
- Manual Select	Manual (note 3)

Notes :

1. Dials were burned off. Position determined by set screw location.

2. Switch was loose - may not be actual position at time of fire.

3. Switches, if depressed, will release if the Teflon detent latching system is destroyed.

The Lockheed California Company prepared a pressurization system summary as the result of on-site findings and subsequent testing. It is quoted, in part:

"Summary, Pressurization System

- A pressure profile consistent with the final aircraft configuration would develop from the following sequence of events:

  - Normal procedures were followed during climb and descent. Descent rate from flight altitude was relatively rapid and a suitable cabin descent rate was selected to reach zero differential at touchdown.

  - During approach, with the cabin altitude at 2 000 ft, STANDBY mode was selected with a HOLD rate.

  - At some time, probably during the later stages of the flight, the avionics and galley overboard vent valves were closed.

  - Just prior to engine shutdown, the ECS packs were closed down, thereby effectively eliminating any ventilation air for the fuselage interior. This could have triggered a flash fire with a burst of smoke projecting downward out of the OFV as the valve continued closing during engine shutdown.

  - There is no evidence of any valve or pressure controller malfunction.5/"

1.12.2.5 Cargo Compartments

The L-1011 has three pressurized cargo compartments. The forward compartment (C-1) extends from the rear of the ECS bay and nose wheel well to the galley. The mid compartment (C-2) extends from the main gear wells and hydro bay to FS 1625. The aft compartment (C-3) abuts the mid and extends aft to FS 1792 (Figure No. 5).

5/ There was, however, fire damage to the wires controlling the aft outflow valves (OFV) which could have influenced the final valve position.

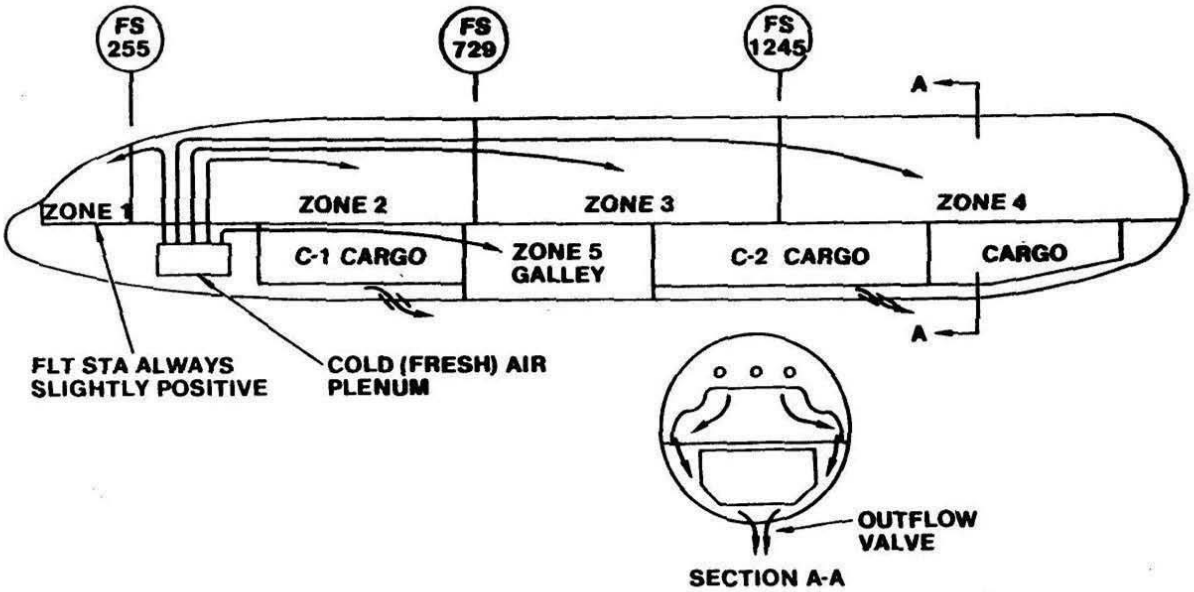

Figure 5. Ventilation schematic

The forward and mid compartments for HZ-AHK were designed for palletized or container cargo. The aft compartment (C-3) is used for bulk baggage/cargo and animal transport.

C-1, C-2 and C-3 cargo compartments are Class "D" compartments. Each compartment is heated by a closed loop recirculation system in which compartment air is circulated over the bleed air ducts in a low effectiveness heat exchanger.

No fresh air was supplied to the C-1 or C-2 compartments; but 165 CFM of cabin exhaust air (controllable either manually or automatically) could be circulated through C-3 of HZ-AHK to provide cooling and ventilation for animal transport (see Appendix L). An additional fixed flow of 10 CFM was supplied to the C-3 compartment.

a. Normal Operation - Heating and Ventilation

The heating system can be selected on by the F/E at the ECS monitor panel. If on, the heating system is fully automatic and will cycle a fan to maintain a selectable C-3 temperature between 50°F and 65°F. If cargo temperature reaches 95°F, a "hot" light will illuminate on the F/E panel. All sensors are located in the fan inlet.

The aft cargo vent system is controlled at the ECS monitor panel. When the system is turned on, overboard valve (A), and inlet valve (D) will open and vent fan (E) will come on. Valve (B) will remain closed. The close light on the switch light will extinguish when any valve opens. Valve (C) will maintain the 165 CFM overboard flow. Valve (C) is a preset flow control valve with no manual control (see Figure 16, Appendix L). Valve (D) is a fixed (10 CFM) flow which is operative at all times.

b. Cabin Pressurization

In event of depressurization, the F/E can unlatch the Cool Air OVBD switchlite which will open valve (B) and close overboard valve (A). Valve (D) and fan (E) will not be affected. In this mode, air is directed under the C-2 floor and to the aft out-flow valve.

c. Smoke Detector Operation

If either the A or B smoke detector alarms, there will be an aural warning; valves (A), (B), and (D) will close; and fan (E) will stop. When all valves are closed, the "Close" legend will illuminate in the cargo vent switchlite. If the smoke detector clears, valves will not reopen automatically, but must be recycled manually to be opened.

d. Aft Electronics Equipment Centre (AEEC) Venting

To provide cooling for the AEEC, a portion of the cabin exhaust air passes through the compartment and is exhausted through the fuselage overflow valves. An AEEC overheat sensor alarms at 125°F.

In the course of the investigation Valves (A), (B) and (D) and fan (E) were removed from AHK on 24 August 1980. All valves are motor operated. Valve (A) was fully closed and tightly sealed. Valve (B) was nearly closed. Valve (D) was open and had a heavy deposit of carbon on the upstream (inlet) side of the butterfly. The fan had a heavy deposit of carbon on the blades, spinner and a dense material on the side walls. Valves (B) and (D) were tested at Saudia Maintenance at Riyadh Airport. Valve (D) was operated with 28 VDC power. Valve operation was normal in both opening and closing. Position switch was normal and gave a valve closed signal when closed. Valve (B) which was about 5 degrees open was given a 28 V close signal. It closed in less than 1/2 second. The valve was cycled open and closed and operated normally in all respects.

The fan (S/N 1119) was removed and found to be seized. The fan was sprayed with LPS-3 lubricant and a solvent cleaner which removed some of the tar material on the fan inner wall. The fan then was free to turn and a resistance check of all three phases show motor resistance to be normal. The fan had a deposit of soot on the blades and spinner.

1.12.2.6 Smoke Patterns

Heavy deposits were found on the aft outflow valve (OFV). There was heavy streaking behind the continuous drains in the aft fuselage. The streaking diminished and essentially disappeared on the forward fuselage.

The forward OFV had some carbon build up; however, it was restricted to the aft gate and was not streaked along fuselage skin.

Investigation revealed that the fire in the aft of the aircraft started in flight whereas the forward fuselage fire occurred while on the ground after the aircraft came to rest.

1.12.2.7 Electrical

Examination of the Cockpit electrical panel revealed the following switch positions:

- Generator switches and indications-undetermined
- Generator field (GF) and breaker (GB) switches-undetermined
- Bus tie breaker (BTB) switches-undetermined
- Essential bus selector - B3 Manual
- DC bus isolation switch-undetermined
- Standby power switch-undetermined
- Battery switch - ON
- AC voltmeter selector - Gen 1
- DC voltmeter selector - BAT

In the mid electrical service centre (MESC) the physical position of switch gear was observed:

GB1, GB2, GB3 - Contacts open
BTB, BTB2 - - - Contacts open
BTB3 - - - - - Contacts open
Battery cockpit feeder current limiter - Open AC Hyd. Pump System A and B - Open

Wire bundles in the cabin overhead were destroyed by fire and no data could be obtained.

In the left cheek adjacent to the C-3 cargo compartment varying degrees of wire damage existed. Following removal of debris, the ECS bleed air duct, and hydraulic lines, detailed examination of wire bundles was accomplished.

Generator feeders from the No. 2 engine and the APU contain aluminium conductors. These were melted by the heat.

Other bundles through the area evidenced almost total loss of insulation material in the more severe fire damaged areas. Wire insulation material is Kapton which resists heat decomposition except in the event of direct flame contact.

One of the No. 8 gauge wires (P.N. 2436-6B8) was apparently severed by electric arcing and approximately 1 in of the bare copper conductor was missing. The forward end of the severed wire had all strands of the conductor fused in a relatively smooth flat face. The aft end was fused. This wire is oriented at 6:00 o'clock on the outside of the bundle. Several other wires were severed at this same general location.

At FS 1700 this same No. 8 gauge wire showed evidence of arcing for a length of approximately 1 in but was not severed. The other wires in the bundle did not appear to have arced. At FS 1625 several small wires were severed at the forward edge of a metal loop clamp. A segment of this wire bundle was removed intact for laboratory analysis. The segment was removed from FS 1500 to FS 1725 disconnect panel.

Examination of the wire bundle revealed no evidence of "wet wire arcing". The broken wire end globules were not flat or concave as found when wire-to-wire arcs occur in the presence of moisture. Duplication of the actual broken wire ends found on HZ-AHK was accomplished in a laboratory test by burning a duplicate harness which was electrically energized. A gas torch was used as the fire source.

1.12.2.8 Hydraulic System

The hydraulic reservoirs were drained to measure the fluid.

Results in U.S. gallons:

	A System	B System	C System	D System
AS FOUND	2.6	Empty	5.88	4.7
NORMAL OPERATION	3.1	2.8	5.7	2.2
RESERVOIR CAPACITY	5.7	5.7	12.5	5.7

Note: (1) "D" reservoir was overfull.

Hydraulic service centre accumulator readings were taken prior to draining the reservoirs.

Results: (Direct reading gauges)

B System Brake	1 000 psi
B Reservoir	800 psi
A Reservoir	1 000 psi
C Brake	2 400 psi
C Reservoir	1 000 psi
D Reservoir	1 400 psi

The investigation showed fire effects on systems "A" and "B". Only system "B" reservoir was depleted. "A" shows a loss of part of its fluid quantity. "A" and "B" systems run through the left lower cheek area of the fuselage. System "A" pressure and return lines also run aft to power the rudder (one of three systems to the rudder). System "A" is one of four systems powering the stabilizer. System "B" pressure, return and suction lines also run aft to the engine driven pump, stabilizer and the rudder. The stainless steel pressure lines were still intact in the areas of high fire damage but the aluminium return line (System A) and the aluminium suction and return lines (System B) were burned through at about FS 1753 (Figure 7). System "B" suction line shows a petal type burst forward of the C-3 sidewall burn through areas at about FS 1629. This area is along the left hand side outboard of the C-3 baggage compartment liner. The petal rupture showed no signs of fire damage.

The "C" System lines going forward along the L.H. cheek area to the nose landing gear passed through a fire and high heat area outboard of the C-1 baggage liner. These lines were blackened by the fire but show no visual breaks (Stainless steel and aluminium). The "C" System reservoir contained a normal quantity of fluid. Nose steering thus was not affected, nor was landing gear extension. The parking brake was mechanically set. The ram air turbine (RAT) was not deployed. There was dripping hydraulic fluid from the aft lower fuselage drains and from around the aft pressurization outflow valve.

The "B" System pressure line from FS 1575 aft to the pressure bulkhead was removed and pressure tested with water and air at 3 000 psi. It did not leak. The remaining hydraulic lines that passed through the rear fire area were visually inspected for signs of cracks or pinholes. None were found to indicate leakage.

The emergency fuel shut-off valves to No. 2 engine were determined to be open. These two shut-off valves (primary and secondary) would normally be open unless the flight crew shut down the No. 2 engine with the fire-pull handle. Other evidence also indicated the No. 2 engine was shut down by the normal fuel/ignition switch. This was that the "B" and "C" Hydraulic firewall shut-off valves were in the open position.

The No. 2 engine driven pump was removed and no evidence of fluid overheat was found. The air turbine motor, hydraulic case drain filter was checked. The filter showed no signs of contamination nor overheated fluid. Also the "B" System return filter was checked and found to be free of any abnormalities.

Examination of the APU did not reveal any evidence of fire or overheat. Based on the aircraft records, the APU was placarded inoperative.

The main landing gear brakes were observed to be "off" approximately 10 h after the accident. In order to determine why the brake pressure had bled off, the System "B" brake return line shut-off module, for parking brakes, was removed for testing. The module tested satisfactorily. The brake shuttle valves were removed and found to be in the "B" System position. When the shuttle valves were removed, some hydraulic fluid was in evidence. The reason the brakes were not in the "ON" position, although the parking brake lever was set, was not determined. For further details, see Figures 7, 8, and 9.

1.12.2.9 Control Systems

Review of the CFR and DFDR indicates that there were two control system anomalies during the descent and approach to Riyadh. These were a "stuck" engine No. 2 throttle and a slow retraction of No. 4 left spoiler.

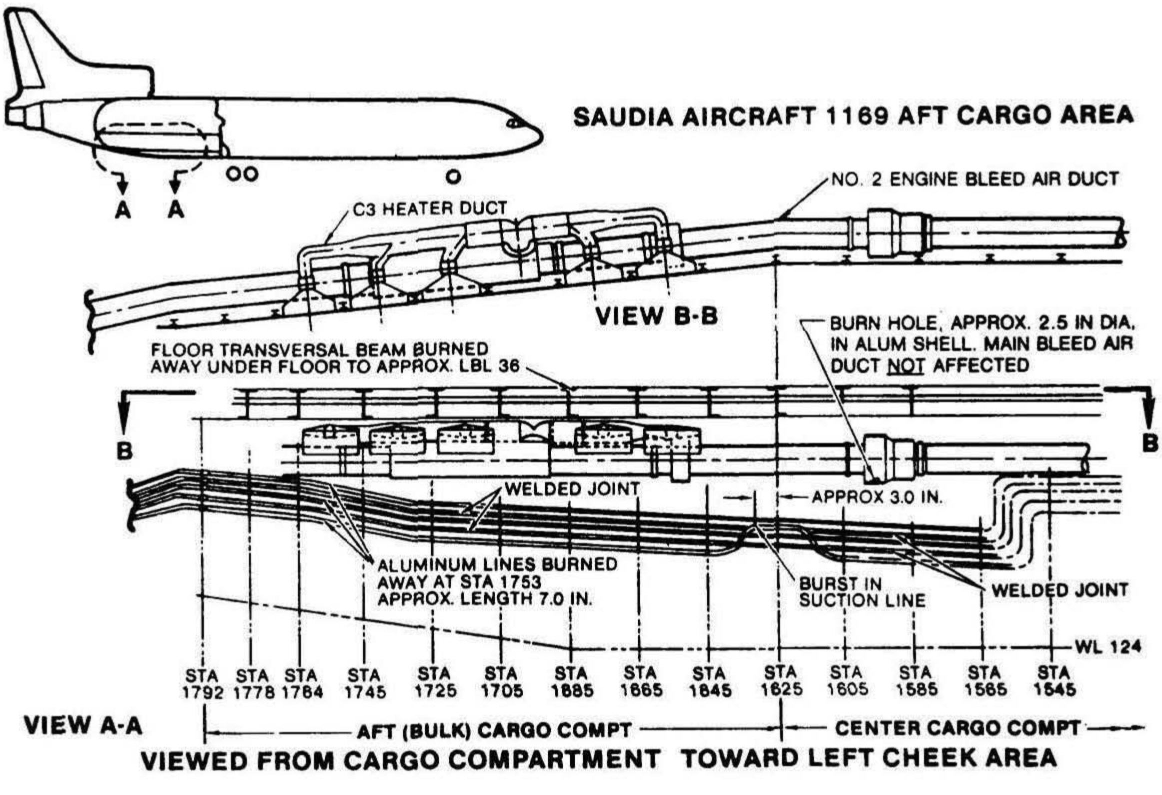

Figure 7. Aircraft system configuration aft cargo area

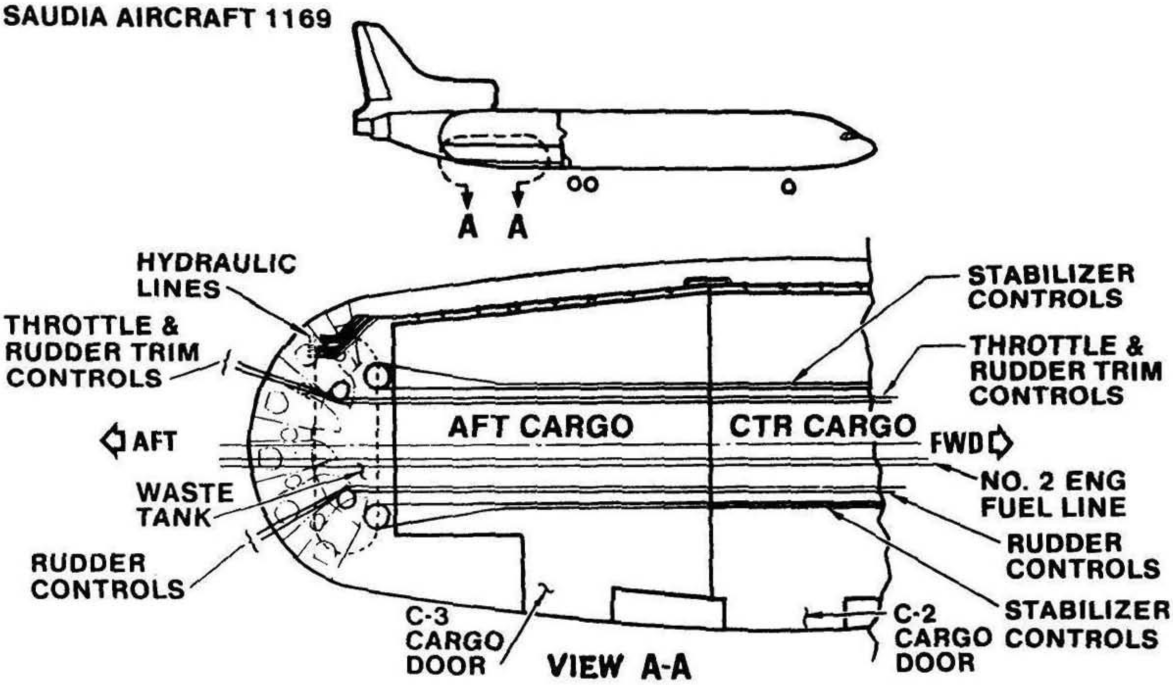

Figure 9. Aircraft system configuration - plan view

Testing revealed that the slow retraction of No. 4 spoiler was associated with the decay of "B" hydraulic system pressure after the shut down of No. 2 engine.

Testing also revealed that heating and subsequent slight cooling of the throttle control cable rollers and/or seals could cause a stuck throttle condition.

There were no other control problems or anomalies during the flight.

1.13 Medical and Pathological Information

A review of the flight crews' medical records revealed that there was no pre-existing medical problem which would have affected their ability to conduct the flight safely.

All deaths occurred as the result of smoke inhalation and fire. The Captain and F/O were in their seats and had sustained charring burns. Their bodies were buried before autopsy authorization was received. The body of the F/E, who was found in his seat, was autopsied as were the bodies of 10 identified cabin crew members.

Not all of the passengers' bodies were viewed by the investigation team but many were, and none showed evidence of impact or crushing type injuries. The only bone fractures noted were those associated with heat-induced muscle contractions. Some bodies were fully clothed and showed burns of 1st degree only on the exposed surfaces. Some bodies had no burns while others were severely charred.

The post-mortem examinations of the bodies of the F/E and the cabin attendants were conducted at the Riyadh Central Hospital. These showed some degree of charring burn on various parts of the body. All autopsied bodies had sustained 2nd and 3rd degree burns, with exception of one body which was 100 per cent charred. A few of the bodies were partially clothed, thus the unburned clothing provided some protection and only 1st degree burns were noted under the covered areas. No internal injuries or abnormalities were noted. Soot was present in every trachea. Blood samples from each of the examined bodies were taken for analysis, as well as one additional blood sample which was obtained from the body of a passenger.

Tests conducted to determine carbon monoxide levels revealed that the F/E's CO level was 48 per cent. The CO level in the other eleven blood samples ranged from 42 per cent to a high of 58 per cent. The sample which produced the highest percentage level (58 per cent) was taken from the body of the purser.

The effects of carbon monoxide (CO) would have varied from person to person according to:

a) Their CO base-line state, i.e. smoker/non-smoker and the degree of possible CO poisoning prior to landing - according to their location in the aircraft.

b) Their level of activity affecting heart respiratory rate. When the carbon monoxide saturation level reaches 45-50 per cent the subject is incapable of exertion; he is confused and on the verge of unconsciousness. Vision becomes dim; clear thinking becomes difficult and the individual is likely to have difficulty in rising from his chair or walking without assistance. Even at lower levels, around 30 per cent, there is impaired judgement and some loss of vision. These effects are all aggravated in an 'exercise' situation.

Some of the toxic gases that most likely were present in the cabin and cockpit are nitrous oxide, hydrogen cyanide, formic acid, acrolein, sulphur dioxide, halogen acids, ammonia, aldehydes and azo-bis-succinonitride. The detrimental effects of these gases would add to the complications of the effects of CO.

Most of the bodies in the cabin were located forward of L2 and R2 doors (see Figure 10).

1.14 Fire

The first indication of a problem of Flight 163 was at 1814:54 when the C-3 cargo bin smoke detector alarmed and the F/E reported, "B aft cargo". The second "A" smoke detector alarmed at 1815:54. When the F/E returned from inspecting the cabin about 1820:16, he reported, "we've got a fire back there". It was not determined whether he actually saw fire or saw smoke and smelled odours which led him to conclude that there was a fire. About one minute later, at 1820:37, a cabin attendant came into the cockpit and said, "Fire ... fire in the cabin". The F/E made a second trip into the cabin and at 1821:53 reported "... just smoke in the aft".

The precise location of the initial fire was not determined. The only remarks made by the F/E and cabin attendant were in generalities about the smoke and fire being "in the back of the cabin". There was no indication of smoke being observed by anyone prior to the warning of the smoke detector. There was evidence of intense fire on the left side of the aft passenger section aft of the L-3 door. The burn-through of the cabin floor structure in this area was localized beneath the second through sixth row of dual seat units forward of L-4. The aisle floor adjacent to the sixth seat unit was burned through, causing a hole which extended nearly to the left floor track of the left row of the centre seat units. The cabin floor that was most severely burned and was destroyed by fire extended from fuselage station (FS) 1545 aft to FS 1763. The "cheek" area outboard of this area and that area aft to the rear bulkhead was open and severely damaged by fire. All cabin wall liner material and overhead storage units were destroyed by fire in the same area.

The aircraft was equipped with fire extinguishers, one each positioned in the following locations:

> Six CO_2 fire extinguishers located at the flight deck (left side), L-1, L-2, galley, L-3 and L-4.
>
> One dry chemical extinguisher positioned in the galley.
>
> Four H_2O (water) extinguishers, one each positioned near R-1, R-2, R-3 and R-4.

Three of the CO_2 bottles were found under the first left-hand seat aft of L-3 door. One of the three bottles was a larger size and was identified as the one from the flight deck. The safety wire on that bottle was broken and the bottle discharged. The safety wire on one of the remaining two CO_2 bottles was also broken and the bottle discharged. The third bottle had a little pressure left in it and the safety wire was still intact, however, the wire was loose enough that the bottle could have been discharged without breaking the wire. The fourth CO_2 bottle was found on the first seat aft of the L-3 aisle seat. The extinguisher was under debris from the ceiling. The safety wire was broken and bottle discharged. The fifth bottle was found in the hole in the floor just forward of L-4. The bottle showed extreme heating. The safety wire was intact and the bottle was empty. The sixth CO_2 bottle was found just forward of R-3. The safety wire was broken; however, the bottle was only partly discharged.

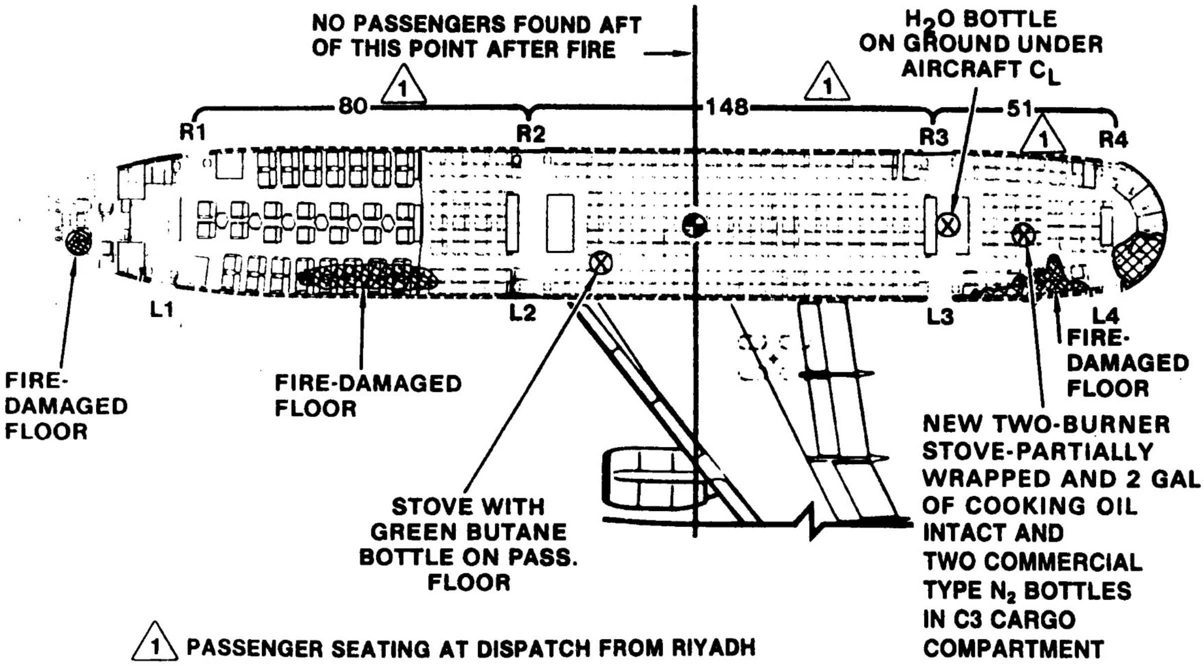

Figure 10. Passenger placement, fuselage fire damage (floor) and significant articles

The dry chemical extinguisher from the galley was located under the first seat aft of L-3, centre side of the left side aisle. The discharge nozzle was burnt completely off and the bottle was completely empty.

Three of the four water extinguishers were found. One of the bottles was positioned in its normal location at R-3, fully charged. The other two were found in the area around R-2. One of the bottles was empty and the safety wire was broken, the other was blown open from overpressure, and the safety wire was still intact (see Figure 11).

The aircraft is equipped with 12 portable oxygen packs. Six O_2 packs were found in their cases, stowed in their brackets and unused. The six remaining packs were not found nor were their cases or mounting brackets.

At 1824, the Riyadh Airport fire station received the alarm through the ATC direct telephone that Flight 163 was returning to the airport. This message was logged in the fire station as a TriStar L-1011 returning to airport with fire in the cockpit and about 50 miles from the airport with a full load of passengers. Fire equipment was dispatched to the taxiway B intersections to standby. Nine units took positions at intersections along the taxiway. Each of the fire units turned out in pursuit as the aircraft passed the intersection where they were waiting. Some, but not all of the fire personnel, reported seeing smoke as the aircraft rolled by. A few of the others said that they smelled smoke. Nothing else unusual was noted about the aircraft as it taxied onto the taxiway at the B-8 intersection.

Most of the fire fighting personnel state that the aircraft engines were shutdown about 3 min after the aircraft parked. When the aircraft parked, the fire trucks assumed positions which correspond with clock positions of 2, 4, 7, 10 and 11.

Those personnel who were in a position to observe the rear portion of the aircraft after it came to a stop noted a puff of heavy white smoke coming from beneath the aircraft aft of the wings. Most of them said that in less than a minute after their trucks were positioned, they observed smoke rising from the top of the fuselage just forward of the No. 2 engine intake. This smoke was followed almost immediately by flames (see Figure 12). All fire personnel reported that when this smoke and flame was sighted at the top of the fuselage, their monitors (turret discharge nozzle assemblies) were put into action and their agent was applied at a high rate. Those near the fire applied their agent against the fire. Those that were at the front half of the aircraft applied their agent along the fuselage from the cockpit back as far as their monitor pressure would reach. They stated that their purpose was to cool the fuselage. There were two exceptions:

1) The driver of truck No. 5, which was positioned on the dirt some distance from the taxiway and at the 4 o'clock position of the aircraft had problems with his truck and was unable to re-position. He applied all of his agent at low rate on the right side of the fuselage and the top of the wing.

2) The other exception was truck No. 8. Initially, No. 8 was positioned at the 12 o'clock position and in the words of one of the fire officers, the driver was starting to panic and to apply his agent onto the cockpit area. The officer manned the truck and moved it just forward of the right wing and applied its agent against the fire which was near the No. 2 engine inlet. The Fire Department Log shows that truck No. 8 was the first one to return to the station to refill. The time was 1932. At 1907, Fire Control requested that the Civil Defense come to the airport. The first Civil Defence units were logged in at 1918.

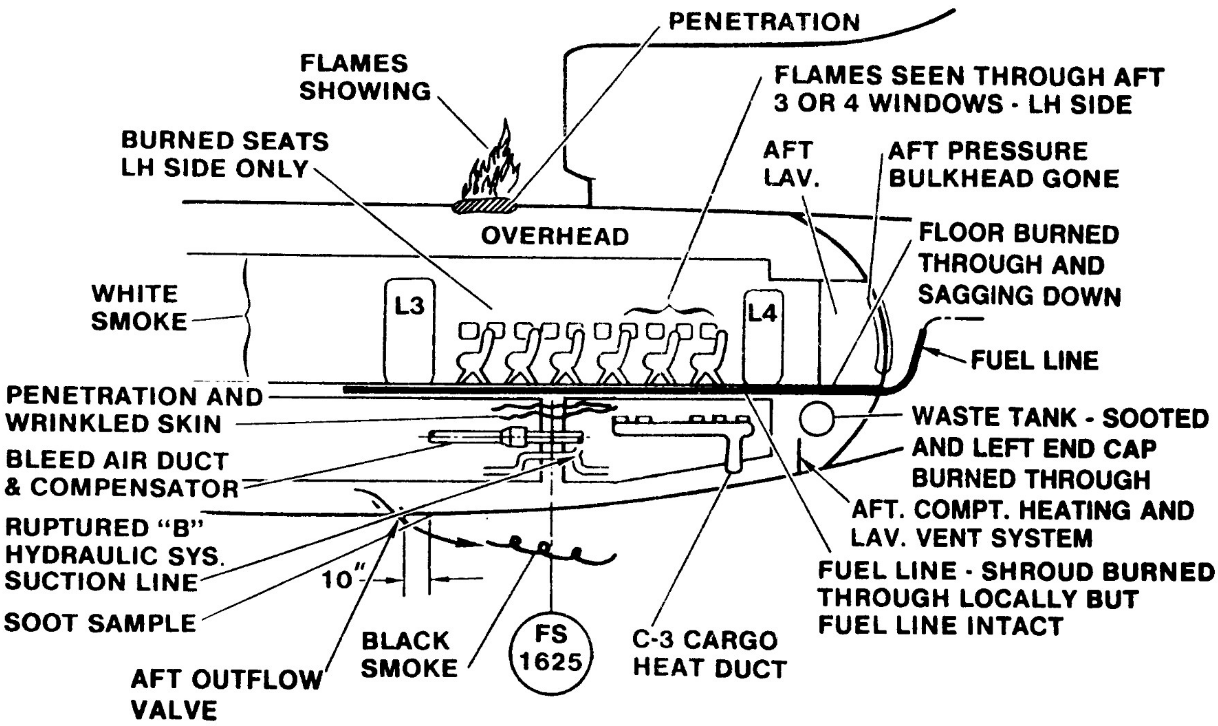

Figure 12. Aft fuselage conditions witnessed on ground

There were nine units from the airport which participated and 17 personnel; 16 units and 50 personnel from Civil Defence, and 2 units and 10 personnel from the RSAF. One thousand two hundred sixty gallons of foam (AFFF) were used. Use of other agents is unknown. The last airport fire unit returned to the station at 0512. At 0645, the Fire Chief informed the ATC Tower that the fire station was ready for the airport to open.

Airport fire fighting equipment which initially responded were two Chubb Pathfinders, three Chubb Patrollers, one Gloster unit, two Ramchargers, and one Walter Pursuer.

Thirteen fire fighters who initially responded to the incident were interviewed to determine their actions and their knowledge of fire fighting and rescue procedures. Most of them had never fought an actual aircraft fire nor a training fire. They all stated that their initial attack on the L-1011 fire was with the monitors. They each said that they began dispensing agent (AFFF and water) when smoke or fire was first sighted at the top of the fuselage in the area forward of the No. 2 engine intake. Those within monitor range began pumping agent toward that area. Those who were not within monitor range of the affected area, began dispensing their agent on other areas of the fuselage.

When questioned about aircraft exits, in particular those on the L-1011, it was evident that their knowledge on the subject ranged from limited to non-existent.

Two fire fighters said that a Saudia maintenance man had shown them how to operate the cabin door on the L-1011 approximately six months prior to this accident. They both said that the operation of the door was explained to them but that they were not allowed to perform the actual operation. Additional questioning revealed that none of the firemen were aware of any doors below the cabin. None of the interviewed firemen knew at the time of the accident how many doors, emergency or otherwise, were available to gain entry to the aircraft. None of the other fire fighters were knowledgeable of the number of or operation of doors on any of the other passenger-carrying aircraft which use the airport.

A review of the training records of the fire personnel who were initially involved in the fire fighting activities revealed that only four of them had received training from the Fire Academy in Jeddah. Three of these were fire officers who had attended the Fire Officer Course. The other, a Fireman/Driver had attended the Basic and Advanced Course at the Fire Academy. None of the other fire personnel had attended any formal training other than training which was conducted at the fire station. The courses which were taught at the station consisted of lectures and practical operation of the equipment. The courses were taught by the fire station training officer, fire officers, or more experienced personnel. Course material for the station training was furnished by the Fire Academy. It was reported that courses at the Fire Academy had not been taught in about 3 years. None of the course material which was reviewed during the investigation was found to pertain to rescue operations or procedures.

In a non-related circumstance to the accident, it should be noted that the airfield was not initially closed when fire fighting equipment was occupied with SV163. This resulted in operating aircraft traffic not being afforded fire fighting protection. In another instance, the tower failed to inform the on-scene rescue personnel of the assigned frequency of the accident aircraft so that direct contact could be made.

1.15 Survival Aspects

The accident was survivable. The first door was opened about 23 min after all engines had been shutdown. The first rescue attempt was conducted at L-1 door.

Most witness statements agree in content but differ slightly in the time factor element. A witness who participated in the first two efforts to open the doors stated that he was aboard fire truck No. 4 as it was positioned near the left rear portion of the aircraft. He observed thick white smoke flowing from the bottom rear fuselage. At that time the aircraft engines were still running. A few seconds later, he observed smoke near the top of the fuselage, forward of the No. 2 engine inlet. According to him, this smoke was followed almost immediately by flames in the same area. As the driver of No. 4 started applying agent via the monitor, the witness dismounted and moved toward exit L-1. His route was outboard of No. 1 engine which he thought was still running. On approaching L-1, he observed the fire chief and other people attempting to reach the L-1 emergency handle via a ladder which was placed on top of fire truck No. 6. While fire personnel steadied the ladder, he climbed up and pulled the emergency handle. He was not certain if the door moved or not. An additional effort was attempted while he held onto and rode the monitor. While on the monitor, he pushed on the door to no avail. Most of the group then moved to R-2 where another ladder had been positioned by other firemen. A fireman then climbed the ladder, operated the handle and the door opened in the emergency mode. The cabin was observed to be full of smoke and no life was observed nor were any human sounds heard. R-2 door was opened at 1905 - 26 min after the aircraft came to a stop and 23 min after the shutdown of all engines.

Shortly after (about 3 min) R-2 was opened, flames were seen progressing forward from the rear section of the cabin.

1.16 Tests and Research

1.16.1 C-3 Cargo Smoke Detection System Test

A test was conducted to determine if the C-3 aft cargo smoke detection system had operated properly and was not defective. The detectors were tested and it was found that they operated as prescribed.

1.16.2 Tests of Materials at London Police Forensic Science Laboratory

Some debris and soot samples from the C-3 cargo compartment; the areas in the vicinity of the compartment and from the area of the aft outflow valve were sent to the Metropolitan Police Forensic Science Laboratory in London. Examination of these materials did not reveal any evidence of products of an incendiary mixture or device.

1.16.3 Examination and Tests to Determine if Incendiary Materials were Present

A Specialist qualified in the detection of aircraft sabotage participated in the investigation to determine if there was any evidence of sabotage in the wreckage.

The examination of the baggage and other items that had been removed from the C-3 cargo compartment disclosed that the baggage was scorched and burnt in various degrees. There was no evidence found to suggest damage from the detonation of an explosive device, and there was nothing to suggest burning originating from an incendiary device in any of the baggage. A 4-litre can, labelled Caltex Diesel engine lubricating oil was found to be sooted but had not leaked and was full of fluid (see Appendix I).

The Specialist submitted an addendum to his report after he had received the analysis of the burst hydraulic pipe. He states that he was unable to conclude the cause of the fire; however, he found no evidence of "a positive nature of criminal activity".

1.16.4 Examination by the British Royal Aircraft Establishment

In April 1981, an examination of the burst B system hydraulic pipe was completed by the Materials Department of the Royal Aircraft Establishment located in England.

The general conclusion was that the pipe had been subjected to a period of heating which caused a reduction in its strength leading to a burst. They stated that there was no evidence of fatigue and the intergranular nature of the fracture strongly suggested hot tearing conditions. They also stated that the fracture surfaces suggested that no flame had been playing on them for any appreciable time after the burst had occurred. (see Appendix K).

1.16.5 Selected Tests and Research by the Lockheed-California Co. and F.A.A. Technical Center

1.16.5.1 Tests of Phosphate Ester Hydraulic Fluid

The Lockheed California Company conducted tests to determine the ignition behaviour of the type of hydraulic fluid used on the aircraft. The fluid was tested in the form of a stream, a pool and a mist. Ignition sources were a flame, an electric arc and a hot surface.

Findings from the tests were:

1) Ignition of phosphate ester hydraulic fluid;

- Mist will ignite and burn at room temperature. Liquid must be heated to 350°F to burn.
- The temperature of hot metal must be in excess of 1 000°F to ignite fluid. An electrical arc or open flame will ignite a mist at room temperature.

2) Conditions influencing combustion:

- An air flow is needed to sustain combustion. In still air, the fluid tends to self-extinguish in the products of combustion.
- Heat transfer affects burn time.

"These findings imply that sudden release of hydraulic fluid (no mist) through a tube rupture would not provide a prolonged contribution to the cheek fire. Hydraulic fluid was found to be draining from the area of the burst pipe during the onsite inspection".

1.16.5.2 Landing Performance Tests

An analysis of aircraft stopping performance was made using data from the QAR to provide an estimate of the difference between the time actually experienced in bringing the aircraft to a stop and the time that would have been required had maximum wheel braking been employed. Also considered was the question of whether any wheel braking had been applied because the roll-out after touchdown was of such long duration.

It was concluded from the deceleration profile that some wheel braking had been applied, but braking levels were not at a moderate or a maximum level. It was estimated from the analysis that the aircraft could have been stopped 2.4 min sooner had maximum braking been employed. However, the deceleration rate would have approached 0.5g and the pilot might have been reluctant to execute such severe braking. With braking limited to moderate (0.25g deceleration) the stop would have been much faster than normal, but would have required only a few seconds more than for a stop with maximum braking.

Regarding the availability of braking, Lockheed states:

"It is pertinent in considering braking during the actual landing that the B hydraulic system pressure (not fluid) had been lost because of events associated with shutdown of engine No. 2. When B system pressure is lost, the B-brake accumulator provides adequate pressure to permit maximum braking to be applied and released four times. However, procedures to be observed when B system pressure is lost call for selection of ALTERNATE brakes (associated with C-system) in lieu of NORMAL brakes (B-system). Selection of ALTERNATE brakes was not evident from conversations recorded by the CVR nor by the available evidence. The onsite inspection found the brake selector switch in the NORMAL (B-system) position and the brake selector valves in the NORMAL position.

Witnesses indicated that when the aircraft reached the taxiway and was brought to a stop, it then rolled about 5 ft further before being brought to a final stop. This additional movement possibly prompted the flight crew to select the parking brakes (hydraulic pressure for parking brakes supplied by B-system brake accumulator). The aircraft parking brake controls were found set by the onsite inspection members.

Regardless of whether NORMAL or ALTERNATE brakes were selected during landing at Riyadh, procedures to be observed would provide adequate hydraulic power (pressure and flow) for a maximum braking stop."

1.16.5.3 Electrical Testing of Wire Harness

A segment of a wiring harness from the left-hand cheek area was removed and transported, in accordance with procedures established with the NTSB, to the Rye Canyon Research Laboratory, Plant 2, for analysis. The segment was subjected to visual examination to determine if wire faults were the source of ignition. Conclusions were:

1) No pre-existing wire damage had existed.

2) No ground faults to metal harness clamps were present.

3) No evidence of wet-wire faults was disclosed.

A facsimile of the harness segment was fabricated and subjected to fire testing conducted as follows:

1) Molten aluminium at 1 200°F to 1 500°F was poured from a ladle over the electrically energized harness. No electrical arcing resulted.

2) A flame 6-in in diameter at 1 800°F was applied to the harness and caused wire insulation to burn and char. Arcing occurred between conductors. After approximately 5 min, the arcing caused wire conductor fusing, severing, and blocking. Arcing and small flames from insulation continued after removal of the flame until circuit breakers tripped.

The fire test duplicated wiring harness damage observed in the cheek area. It was concluded, from the testing, that the fire caused wire insulation damage and resulting arcing between wires.

Three wires removed from the electrical harness were submitted to the Rye Canyon Research Laboratory for analysis of the wire insulation for evidence of phosphate ester hydraulic fluid. Analysis revealed a high phosphorus content on two of three wires. This condition was judged to be consistent with spillage of phosphate ester hydraulic fluid but could also be attributed to the AFFF fire fighting agent used during the fire fighting effort.

1.16.5.4 Tests and Conclusions by Lockheed regarding Fuselage Doors and Hatches

Post-accident inspection of the aircraft revealed the forward outflow valve closed, the aft outflow valve substantially closed, and all cool air overboard valves closed. Such valve positions are unusual after touchdown. With the valves thus positioned, the effect of cabin residual pressure on door opening characteristics was considered. Two tests were conducted after the accident to validate the previous certification testing to define door-opening pressure.

In the first test series, the cabin pressure was lowered slowly (approximately 200 ft per minute) by use of a small cabin inflow (one ECS pack) and a fixed outflow opening.

During this test, the door unseated, moved inboard in several separate, finite movements, then travelled upward. The upward movement was in a smooth and continuing motion once it had begun. The combination of a low air inflow and a fixed outflow valve position led to a marked pressure decay once the door had unseated. Determining the door-opening pressure, therefore, was subject to interpretation.

To more closely define door opening pressure, the second test series were run with high ECS air inflow (three ECS packs), minimum uncontrolled outflow (cool air overboard valves closed), and the pressurization system used to maintain a constant test pressure within the limits of its capability. Doors L-1 and R-2 on the test aircraft were used. Door L-1 opened at a pressure differential of 0.20 pounds per square inch differential (psid). Door R-2 opened with some delay at a cabin differential pressure of 0.35 psid and opened rather rapidly at a 0.30 psid.

Consideration of all available evidence indicates that there was little or no pressurization differential between the cabin and ambient pressure at the time of touchdown and that the doors could have been opened immediately after touchdown.

1.16.5.5 Oxygen System Research and Tests

Research indicates that the flight station oxygen system and the passenger oxygen system were not utilized during the flight.

1.16.5.6 Research Conducted to Determine Centre of Gravity Shift as Related to Passenger Movement

Significant in-flight passenger movement could provide an indication of the progress of the cabin fire to determine whether the passenger movement had occurred in flight using the effect on pitch trim, information from the DFDR was analysed. Two salient conclusions are :

1) There is no indication of a major movement of passengers either prior to or immediately after initial operation of the smoke detector system and aural warning.

2) Although some passenger movement occurred while the aircraft was airborne, the final massive forward movement apparently occurred after the aircraft had landed.

These findings indicate that, despite the early reported presence of smoke[6/] and, later, flames in the aft cabin, the cabin environment was such that the cabin crew was successful in keeping passenger movement to a minimum. After landing, however, the cabin conditions altered and a passenger movement forward took place.

1.16.5.7 Cabin and Cargo Compartment Flame Testing

In an attempt to determine the origin of the fire and to examine the probable nature of its progression, flame tests were conducted with partial simulation of the cabin and C-3 cargo compartment. These tests were directed toward the cabin flooring support beams, cargo compartment liners, and passenger seats. In addition, a test was conducted simulating the C-3 cargo compartment by utilizing a converted bus. Testing was as follows:

1. Cabin Carpet/Floor Panel Test (Lockheed)[7/] - To examine how various fuel sources possibly present in carry-on baggage could be ignited and the effect of the associated fire on carpet and flooring panel. Carpet and floor panel were the same as those on the accident aircraft. The results of the tests showed that spilled fuel fluids burning on carpeted floors self-extinguish with only superficial damage.

2. Cabin Floor/Cargo Ceiling Burn (Lockheed) - To consider liquid fuel spilled on carpet and leaking through on to the cargo compartment ceiling liner. The test set-up implied a discontinuity in the floor panelling (discontinuities are not common). The test used 100 mL of white gasoline on the carpet and 50 mL on the cargo ceiling. Test 2 of this series used 150 mL of kerosene on the carpet and 100 mL on the cargo floor. The results showed that spilled fluids in the quantities mentioned burning on the cabin floor and the cargo compartment ceiling simultaneously self-extinguish with only superficial damage to the cabin floor but with penetrations of the ceiling liner possible.

3. Cargo Compartment Ceiling Liner/Cabin Floor Tests (Lockheed) - To consider the penetration of the compartment ceiling liner and (in some tests) the cabin floor panel/carpet from an open flame from below. The results were that a 1 300°F 6" diameter butane flame will penetrate the ceiling liner of .030 Nomex in 43 seconds and a 1 500°F similar flame will penetrate it in 36 seconds. No penetration occurred during the period of the tests when these tests were conducted using .020 twoply fiberglass instead of Nomex. The over-all conclusions were that upward burning penetrates the cargo ceiling liner and cabin floor in a short period of time.

4. Cargo Compartment Sidewall Liner/Blowout Panel Tests (Lockheed) - Open flame was applied to the cargo compartment liner, with and without blowout panels. The results indicated that the blowout panel remains secure under severe flame or heat exposure; however, the corner and ceiling confines heat and creates hot spots.

6/ Acrid smoke such as generated by a hydraulic fire could not have been tolerated and passengers would have been forced to move forward early in the flight sequence.

7/ All tests and research conducted by the Lockheed California Company were in co-ordination with the U.S. NTSB and FAA and were reviewed by either both or one of these governmental agencies.

5. Cabin Floor and Floor Beam (Lockheed) The FS 1 685 floor support beam which is located above the C-3 cargo compartment was consumed by a high intensity fire outboard from left butt line (LBL) 40 to the fuselage skin. The test was conducted to determine the heat/flames involved in this event. The test flame caused damage to the beam and floor panel above, but not to the same degree as the fire damage observed on the aircraft. The beam/floor panel damage on the aircraft was the result of fire from below as determined by the reverse-single burn-away of the beam and the flooring materials. It was not positively determined whether this was the result of the original fire or the general fire condition after the aircraft was brought to a stop.

6. Seat Row Ramp Test (Lockheed) - A test to examine the ignition of a fuel spill under a passenger seat. The test was conducted with the floor panel inclined at an 18 degree slope to take into account the nose-high attitude of the aircraft at rotation on take-off and during the subsequent climb. Eighteen degrees was experienced at rotation; however, this exceeds the normal climb attitude. The objective of the test was to determine if liquid products from burning of the polyurethane seat materials would flow rearward to collect in a pool at the lower end of the ramp. At the completion of the test, 1 quart of liquid had collected. Flames from the burning seat material were abundantly evident, being 5 to 6 ft high. Similar flames, had they been present in the aircraft, should have been obvious to the cabin crew.

7. Simulated C3 Cargo Compartment Fire Test. (FAA Technical Center) A test series approximating possible conditions in the C3 compartment was conducted at the FAA Technical Center. A 750-cubic foot simulated cargo compartment was used. This test series was conducted to determine the effects of airflow shut off on a small cargo fire in a compartment similar in volume to the C3. The tests are outlined in Figure 14. The tests indicated that a small cargo fire, such as one started by a match or cigarette on or in a bag could easily reach a temperature that would penetrate the L-1011 Nomex liner. They also indicated that a slow growing fire, in a compartment the size of C-3, could burn for a long duration before the O_2 would be reduced enough to cause a major reduction in flaming.

8. Class "D" Cargo Compartment Fire Simulation. (FAA Technical Center) The FAA at their Technical Center is conducting (December 1981) a test programme to determine what design features and materials are necessary to safely contain likely fires in class D cargo compartments. (Refer to Appendix H). The results of the entire test programme when completed will be documented in a technical report by the FAA. However, because of the similarities of the first test set up and the C-3 cargo compartment the results were released to the accident investigation team for their use. The following is a description of the test and summary of results:

The test compartment used was the same as shown in Figure 13, with the following modifications:

1) A drop ceiling was installed approximately 12 in below the bus roof. The ceiling was constructed of Lockheed Nomex cargo liner fastened to aluminium structure.

2) Airflow in the cargo compartment was supplied by a fan forcing air through an adjustable orifice. This airflow was 130 CFM until smoke detection, at which time it was terminated. The outlet for the airflow system consisted of an opening with a check valve to prevent air being induced into the compartment after airflow shut off.

3) Airflow above the compartment was simulated using a fan at one end to draw air through that section, from an opening at the other. Airflow was 260 CFM, and continued for the entire test.

4) A smoke detector of the same type as used in the C-3 compartment was installed using a C-3 mounting panel supplied by Lockheed.

5) The volume of the compartment was approximately 620 cu. ft.

The test was conducted using a combination of boxes and actual baggage as a fire load. The compartment was approximately 1/3 full. The fire was ignited in a canvas type bag using two packs of matches set off by a spark from an igniter. Airflow in the compartment was shut off when the smoke detector activated. The total test duration was approximately 10 minutes. The fire was not completely extinguished in the baggage for approximately 2 hours.

The following are pertinent test results:

1) A large amount of smoke was needed to alarm the detector.

2) Burn-through of the Nomex liner occurred around the same time as smoke detection, shortly after flame impingement.

3) The fire intensity oscillated during the test. High intensity for a minute or so after burn-through, then subsiding as O_2 in the compartment was consumed. Then as fresh air entered the compartment through the rupture, the fire would gain intensity thus again consuming the O_2. This was vividly demonstrated by the smoke exiting from above the compartment. At, and shortly after burn-through, large quantities of smoke poured against the airflow, out the air inlet above the ceiling (this would be into the cabin). This smoking stopped, with all smoke then exiting out the fan outlet (outlet valve on aircraft). After a short period smoke again exited the inlet. This oscillation occurred 3 or 4 times during the test.

4) The smoke detector came on at 2 min 59 s and went out at 5 min 44 s. It was determined that soot deposits on the lens of the detector caused the warning to go out. Subsequent tests also showed that heating of a detector can cause intermittent alarms.

5) Temperatures of significant magnitude and duration to penetrate a floor panel, were measured in the area above the ceiling liner.

6) The temperatures above the liner oscillated during the test with the highest peak being the first one just after burn-through.

7) The hole burnt through the Nomex liner was very similar in size and nature to that of the one in C-3.

8) Damage in the compartment was confined to the hole in the liner and baggage directly under the hole.

9) Cabin Fire Simulation. (FAA Technical Center). The FAA, at their Technical Center, conducted a test in conjunction with a cabin materials programme, simulating an inflight cabin fire. This test points out the development spread and hazards associated with an inflight fire; a full report on this test will be included in a technical report on full-scale fire tests issued shortly by the FAA.

The test was conducted in a C-3 aircraft modified to resemble a wide body aircraft. (Refer to Report No. FAA-NA-79-42) Measurements of heat, smoke, oxygen, and toxic gases were taken at various locations in the fuselage. Six sets of triple aircraft seats and a small portion of carpet were the only combustible aircraft materials used in the cabin.

A fire was started in a "carry on" bag under one of the seats. (This could also represent flame coming through a hole in the floor.) A simulated inflight airflow system was used in the cabin, changing the air approximately once every 4 min. When one seat of the triple became fully involved in the fire (only a few minutes after the bag was ignited), the airflow to the cabin was shut off.

The following are the results of the test:

1) Seats rapidly became involved in the fire.

2) Smoke from the burning bag went up to the ceiling before being drawn down through the ventilation system.

3) The burning of one triple seat produced vast amounts of smoke and gas.

4) Shutting of the ventilation system produced clearing of smoke and gas at lower levels because stratification resulted.

5) A flash fire occurred a few minutes after airflow shut off. Conditions in the adjacent section of the cabin went from very good (little heat, some smoke and gases at high levels), just prior to the flash fire, to a completely non-survivable condition within less than 30 seconds.

1.16.5.8 Throttle Control Cable Heat/Flame Tests

Throttle control cable tests were conducted to determine the extent of increased drag experienced in throttle cable operation if fairlead nylon rollers and/or bulkhead seals are heated to the plastic state and subsequently are cooled.

The throttle cables for the No. 2 engine are routed aft through fairleads in the floor support beams and through seals in the aft pressure bulkhead. Fairlead rollers and the aft pressure bulkhead seals are fabricated from nylon thermoplastic impregnated with molybdenum disulphide.

The tests were conducted on a mock-up of the throttle control cables from approximately FS 1383, above the C-2 cargo compartment, to FS 1862 aft of the pressure bulkhead. Production control cables, fairleads, pulleys, and pressure seals were used. Because transient heat applied to the rollers and seals tended to dissipate into surrounding support bracketry, the mockup tests were supplemented with tests involving use of rollers attached to individual brackets. With individual brackets, heatsoak and cooling conditions were more easily controlled.

Heat was applied to the fairlead rollers by a propane torch directed downward from above. The test was repeated with a heat source below the rollers. Maximum break-away force developed during the repeated tests was 48 lb.

The throttle cables are 3/32 in diameter and are Lockclad when routed through the floor beam fairleads, but are bare at the aft pressure bulkhead seals.

Melt temperatures for the nylon thermoplastic material is 460 to 470°F. Under melt temperatures, no increase in drag was experienced in the simulated throttle cable. After heading to 500°F and full cool down, break-away force for a single bulkhead seal ranged from 8 to 95 lb. Break-away force for fairlead roller was 12 to 80 lb. Rollers are installed above and below the cable at each fairlead. Break-away force for the cable at the fairlead roller varied according to the extent that the cable routing brought the cable in contact with the rollers and the degree of flow of the nylon material around the cable. The pilot exercises a 2.6 mechanical advantage at the No. 2 engine power lever over drag loads imposed on the throttle cable.

Impeded movement of the control cables requires that the nylon material be heated to the melt temperature and then cooled. It is postulated that cooling would occur under some altered draft conditions encountered as the fire progressed. It should be noted that sufficiently high temperatures would cause the nylon to flow downward and away from the cable so that little or no increased drag would be experienced as the cable travelled over the bare steel roller hub. Rollers in fairleads further forward or aft probably would be subjected to melt temperatures leading to encumbered cable travel.

Other cables routed through the floor support beams in addition to the throttle cables are control cables for the rudder and stabilizer and for rudder and stabilizer trim. These cables also pass through aft bulkhead pressure seals except for stabilizer control cables which convert to control rods forward of the bulkhead.

There is no evidence that the pilot experienced increased drag in cables associated with the rudder and stabilizer. The rudder trim cables possibly were affected, but the condition apparently was not detected by the pilot either because no attempt was made to adjust rudder trim or the bare cable (no Lockclad) provided less surface for involvement with the melted plastic material. Probably, because of frequent or nearly continuous movement of rudder cables, stabilizer cables, and stabilizer trim cables, no increased drag or seizing of these cables occurred. Movement of the cables would cause a 'broaching' action of the cables as they travelled back and forth through the nylon material while it cooled to a solid state.

A phenolic pulley was tested to determine if fire-damage could lead to a "cable jam" condition. The pulley was the same as those installed at FS 1 808 except for a difference in bearing seals which was inconsequential for purposes of the test. At a temperature of 720°F, after the pulley flanges were destroyed by fire, the simulated throttle cable slipped from the pulley and came to rest on the bolt through the pulley hub. As installed on the aircraft, the pulley hubs for the throttle cables, but not the rudder trim cables, abut one another. It is considered that a cable jam could occur if pulley warpage and/or flange damage permitted the cable to slip toward or between these abutting hubs.

1.16.5.9 J Smoke Detector System Testing

To evaluate the response of the smoke detector system to smoke in the aft passenger cabin, testing was performed by use of the arrangement depicted in Figure 14. Test results confirmed that smoke in the aft cabin can cause actuation of the smoke detector system. However, other tests previously mentioned show that the majority of the smoke from a fire under a seat would rise to the cabin ceiling before being drawn down through the ventilation system. The test provided a dense smoke condition directly connected to the cabin inlet to the ventilation system ducting. Under actual aft cabin fire conditions, smoke would be less dense in early stages of the fire, particularly if the fire origin were remotely located from the duct inlet.

The test was accomplished with the C3 cargo compartment loaded with 150 cu. ft of simulated luggage (total compartment volume is 750 cu. ft) and the fuselage pressurized to 4 psid. A colour video camera was mounted in the compartment to record smoke patterns against a target panel. In addition, an acrylic plate was installed to permit direct viewing of the compartment from the cabin. A smoke box was installed in the cabin to inject smoke directly into the grille (ventilation system inlet) at FS 1735. The smoke density was measured at a light transmission meter as it entered the cargo compartment. Smoke was generated by use of a smoke candle.

Both A and B smoke detector loops annunciated within 31 seconds. A puff of smoke flowed through the inlet duct causing the light transmission meter to peak at approximately 30 per cent. This condition actuated the smoke detectors and caused the ventilation system's valves to close and the fan to stop. At the completion of the test, smoke was visible in the compartment as a light haze.

1.17 Additional Information

1.17.1 Training

Saudia L-1011 Initial/Transition Training is conducted as follows:

Captains: Attend ground school in Jeddah, then go to either TWA or Lockheed for simulator training. Following simulator training, TWA gives the flight training required for their type rating and initial proficiency check. They then return to Jeddah for a Differences Check Ride; then on to their line training.

First Officers: Attend ground school in Jeddah, then go to either TWA or Lockheed for simulator training. They receive a simulator check only, then return to Jeddah where they fly 8 hours as an observer, followed by 8 hours at the controls (2 hours of which is their Proficiency Check).

Flight Engineers: Attend ground school in Jeddah, then go to TWA or Lockheed for simulator training, and then return to Jeddah for flight training.

Recurrent Training is given in Jeddah.

1.17.2 Examples of Incidents Causing Fires in Baggage (In Part).

The following are a few instances of fires being caused by matches in luggage. These examples were extracted from a British Flight Safety Focus of October 1980:

Case 1 - 1st September 1979 - BAC 1-11-500

"During baggage loading in the rear hold, a suitcase burst into flames. The case was removed quickly from the aircraft and the fire extinguished..." The case contained, apart from scorched underwear, six large boxes of "Ship" brand matches, one box of which had ignited."

Case 2 - 23rd December 1979 - BAC 1-11-500

"While unloading baggage at Buton, handlers noticed a strong smell of burning. After being unintentionally hit by another case, the suitcase in question gave off billows of smoke and an acrid smell. The suitcase was removed to the Fire Training Ground and the passenger was brought to identify the case which was then opened. Several boxes of Italian/Spanish type matches were found, one box of which had ignited."

Case 3 - 25th August 1980 - BAC 1-11-500

"During baggage loading a loader noticed smoke billowing out of a suitcase he had just loaded. He quickly removed the case from the aircraft and informed the crew. A Fireman opened the case and found that one of six large boxes of "Safety Matches", loosely wrapped in a lady's personal belongings, had ignited."

The above three instances happened to the same operator. That operator already had a "Restricted Articles" notice in small print on tickets issued. Subsequently they have increased the publicity on restricted articles.

There have been other instances of cargo compartment fires inflight from matches and other combustibles.

1.17.3 Post-Accident Remedial Actions Taken by Manufacturer

The following modifications for L-1011 aircraft have been released by Lockheed-California Company subsequent to the accident. The first three, a) through c) were in progress prior to the accident. The last d) is a direct result of testing carried out during the accident investigation:

a) The lavatory vent bleed air line was rerouted to move it 1 in away from the skin insulation and a protective clip was added. Service Bulletin 093-21-197 released 10/15/81.

b) The C-2 and C-3 Cargo Heat Exchange insulation was changed from a Tedlar (Polyvinyl Fluoride) cover to Kapton (Polyamide) cover. Service Bulletin 093-21-201.

c) Insulation was removed from the fuselage skin under the aft lavatories to reduce the possibility of corrosion. No Service Bulletin. This is a production change only.

d) To improve the fire resistance of L-1011 C-3 cargo compartment ceiling panels, Nomex laminate panels have been replaced by high strength glass laminate panels. Service Bulletin 093-25-377 released 17 June 1981.

1.17.4 Aircraft Fire Fighting and Rescue Procedures

Chapter 12 of ICAO Doc 9137-AN/898, Part 1 refers to Crash/Fire/Rescue Procedures that are the established criteria for such procedures in Saudi Arabia. Some of Chapter 12's most appropriate paragraphs pertaining to this accident are as follows:

12.1.10 "All personnel operating directly in involved area of the crash should be provided with adequate protective clothing, etc..."

12.1.13 "Rescue operations should be accomplished through regular doors and hatches wherever possible but rescue and fire fighting personnel must be trained in forcible entry procedures and be provided with the necessary tools."

12.1.14 "Rescue of aircraft occupants should proceed with the greatest possible speed. While care is necessary in the evacuation of injured occupants so as not to aggravate their injuries, removal from the fire threatened area is the primary requirement."

12.1.17 "Aircraft windows may often be used for ventilation. Some are designed to be used as emergency exits. On all aircraft these exits are identified and have latch release facilities on both the outside and inside of the cabin. Most of these exits open towards the inside. Most cabin doors are used as emergency exits except those incorporating air-stair facilities. With a few exceptions these doors open outwards. When exits are used for ventilation they should be opened on the down-wind side."

12.3.20 "b) Rescue and fire fighting personnel: It will be their duty and responsibility to assist crew members in any way possible. Since crew members' visibility is restricted, rescue and fire fighting personnel should make immediate appraisal of the external portion of the aircraft and report unusual conditions to the crew members. Protection to the over-all operation is the primary responsibility of the rescue and fire fighting personnel. In the event crew members are unable to function, the rescue and fire fighting personnel will be responsible for initiating necessary action."

1.17.5 Saudia Flight Manual Procedure in the Event of Aft Cargo Smoke Warning

The following is a quote, in part, for flight crew procedures to be followed in the event of smoke indications by the A and/or the B aft cargo smoke detectors. This was extracted from the L-1011 Flight Handbook dated 15 May 1975. It states, as follows:

"Consideration should be given to proceeding to the nearest suitable airport and landing, particularly with any animals in the compartment".

1.17.6 Comparison of a Fire Incident Occurring on a TWA L-1011 in 1976 with the Saudia HZ-AHK Accident.

The circumstances of an inflight fire incident which occurred on a TWA L-1011 in 1976 were reviewed during the course of this investigation. The review was conducted in an effort to determine if there were any pertinent similarities; however, no significant similarities were noted. Some of the factors reviewed are as follows:

a) On the TWA incident the AREA OVERHEAT warning was the very first indication of the fire and pin-pointed the source location. On HZ-AHK the AFT CARGO smoke detector warning was the first indication of the fire, and 16 min and 15 s elapsed before the AREA OVERHEAT alarmed.

b) Fire damage on the TWA incident was located in the unpressurized area of the fuselage aft body where significant moisture and condensation may be present which could affect wires with damaged insulation. On HZ-AHK, the principle fire damage occurred in the left cheek within the pressurized fuselage which has no source of moisture, as does the aft body area.

c) Hydraulic fluid was ignited in both instances. However, in the TWA incident, the source of the fluid leak which produced a misty vapour was positively determined. In the case of HZ-AHK, no such misty vapour leak was ever discovered.

d) Oil soaked wires were not cited as the cause of the TWA incident. Hydraulic fluid misty vapour directed onto damaged wires was ignited by electric arcs generated by the wet wire fault phenomenon. In HZ-AHK, there was no evidence discovered to suggest a misty vapour hydraulic leak. To the contrary, the "B" system hydraulic line experienced a petal rupture due to overpressure or weakening of the tubing due to excessive heat of the fire.

e) Hydraulic system "B" was involved in both incidents; however, in the TWA case, system "B" was involved because of a leaking servo transfer line. Saudia system "B" was involved when fire caused a rupture "petal" burst of the "B" suction line which caused a loss of fluid.

1.17.7 Cargo Compartment Classifications (In Part)

The following is a quote in part of cargo compartment classifications as reflected by Part 14 of the U.S. Aeronautics and Space Code of Federal Regulations:

"Cargo Compartment Classification.

a) "Class A. A Class A cargo or baggage compartment is one in which (1) The presence of a fire would be easily discovered by a crewmember while at his station; and (2) Each part of the compartment is easily accessible in flight."

b) "Class B. A Class B cargo or baggage compartment is one in which (1) There is sufficient access in flight to enable a crewmember to effectively reach any part of the compartment with the contents of a hand fire extinguisher; (2) When the access provisions are being used, no hazardous quantity of smoke, flames, or extinguishing agent will enter any compartment occupied by the crew or passengers; (3) There is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station."

c) "Class C. A Class C cargo or baggage compartment is one not meeting the requirements for either a Class A or B compartment but in which (1) there is a separate approved smoke detector or fire detector system to give warning at the pilot or flight engineer station; (2) There is an approved built-in fire extinguishing system controllable from the pilot or flight engineer stations; (3) There are means to exclude hazardous quantities of smoke, flames, extinguishing agent, from any compartment occupied by the crew or passengers; (4) There are means to control ventilation and drafts within the compartments so that the extinguishing agent used can control any fire that may start within the compartment.

d) "Class D. A Class D cargo or baggage compartment is one in which (1) A fire occurring in it will be completely confined without endangering the safety of the airplane or the occupants; (2) There are means to exclude hazardous quantities of smoke, flames, or other noxious gases, from any compartment occupied by the crew or passengers; (3) Ventilation and drafts are controlled within each compartment so that any fire likely to occur in the compartment will not progress beyond safe limits; and (4) [Reserved]. Consideration is given to the effect of heat within the compartment on adjacent critical parts of the airplane. For compartments of 500 cu. ft. or less, an airflow of 1 500 cu. ft. per hour is acceptable."

In its recommendations resulting from the investigation of this accident, the U.S. National Transportation Safety Board states, in part:

"The Safety Board notes that its predecessor Civil Air Regulation 4B.383, "Cargo Compartment Classification," contained the following regarding Class D compartments: "Note: For compartments having a volume not in excess of 500 cu. ft. an airflow of not more than 1 500 cu. ft. per hour is acceptable. For larger compartments lesser airflow may be applicable." This guideline at least suggested more conservative criteria should be followed for larger compartments while the existing rule does not address the airflow allowance in compartments larger than 500 cu. ft."

"The volume of the C-3 compartment of the L-1011 is 700 cu. ft.. Safety Board investigators have been advised by FAA that the L-1011 C-3 compartment was approved as "Class D" by "extrapolations" from the 500 cu. ft. volume and 1 500 cu. ft. per hour airflow guidelines in 14 CFR 25.857 (d) (5). However, the theoretical concept of a Class D compartment is that a fire within the compartment would be extinguished by oxygen depletion, preventing its propagation. This concept apparently has been successfully applied in a narrow-bodied aircraft with limited volume compartments. However, the Safety Board is concerned that it may not be a valid concept for larger volume compartments, such as the L-1011 C-3 compartment, because much greater volumes of oxygen are available to support combustion prior to depletion and "snuffing." The additional air supply can readily support a fire for sufficient time to allow penetration of the compartment lining, thereby providing access to an unlimited oxygen supply to support propagation of the fire."

"In fact, preliminary tests conducted at the FAA Technical Center, using a 620 7/ cu. ft. simulated Class D compartment, illustrated that a fire of sufficient intensity to penetrate the L-1011 C-3's ceiling liner in less than 1 minute burned for more than 10 minutes after the compartment airflow was shut off."

7/ Correction to quote as it was a 620 cu. ft. compartment.

"The Safety Board is aware that the type of flames used in the tests at Lockheed and at the FAA Technical Center do not duplicate the type of flame (bunsen burner) used to certify flammability characteristics of cargo and baggage compartment interior materials (14 CFR 25.855). However, the Safety Board believes that a small fire in a piece of baggage could generate localized intense heat similar to that from the propane burner used in the recent tests and that the fire could penetrate the ceiling before the oxygen supply is depleted."

"The penetration of the L-1011 C-3 compartment ceiling carries extremely hazardous consequences because numerous major aircraft components are routed between the ceiling of the compartment and the floor of the cabin. Among these items are the No. 2 engine throttle cables, the No. 2 fuel line, and flight control cables. Fire reaching these components could easily endanger the entire aircraft, and therefore, the design does not comply with the intent of 14 CFR 25.857 (d) (5). Moreover, once such a fire reaches the cabin, the cabin furnishings will become involved, and the fire will be difficult to extinguish."

"The Safety Board is aware of several instances of fire in checked baggage from ignition of matches and other items. In most of these instances, fires ignited while the aircraft were on the ground and the aircraft were not damaged. However, the possibility of such a fire while in flight and the questionable capability of the L-1011 C-3 compartment to contain a fire by "snuffing" to keep it from spreading suggest that the "Class D" certification of the C-3 compartment should be re-evaluated."

In answer to the recommendation by the NTSB that the Class D certification of a compartment be re-evaluated, the FAA stated:

"The L-1011 is not unique in having a large Class D type cargo compartment that has been demonstrated to be in compliance with the requirements of FAR 25.857 (d). For this reason, the Federal Aviation Administration (FAA) does not believe specific action pertaining to the L-1011 as a special case is appropriate. Neither do we find that the limited tests cited by the Board are sufficient in themselves to justify the recommended action. In the research program discussed under Recommendation A-81-13, detection, extinguishment, and flammability of cargo compartment liners will be evaluated. Since the intent of this recommendation is embodied in the FAA research program discussed under Recommendation A-81-13, we intend no further action on Safety Recommendation A-81-12." (See Appendix H for details.)

2. ANALYSIS

The flight crew was certificated properly for the flight. They had received the off-duty time required by regulations and there was no evidence of medical factors that might have affected their performance except that the F/E was affected by dyslexia.

The aircraft was equipped and maintained in accordance with regulations and approved procedures.

The investigation and analysis of this accident explored and concentrated primarily in four major areas. Those areas are the 1) fire origin or the causal area; 2) the flight and actions by the crew; 3) actions by Crash/Fire/Rescue services and, 4) survival aspects. In addition, the investigation went beyond these areas and probed such areas as crew background and Air Traffic Control actions.

2.1 Fire Origin

Four assumed probable areas for the origin of the fire were developed. They were based on the fire originating in the, 1) passenger cabin, 2) cheek area adjacent to the C-3 cargo compartment, 3) area immediately aft of the C-3 cargo compartment and, 4) C-3 cargo compartment.

In exploring these possible areas of fire origin, a review of the investigation findings regarding the aircraft systems are appropriate. Investigation revealed that all aircraft systems functioned normally except for anomalies associated with the fire effects of the accident. There was no detectable evidence that the fuel system leaked or that there were any pre-fire faults in the electrical, hydraulic, or pneumatic systems. Evidence indicated that the fire caused the sticking throttle which resulted in the Captain's decision to shutdown the No. 2 engine. When the engine was shut down, the engine-driven B-system hydraulic pumps began to run down which caused the low B-system pressure during the last portion of the approach to the landing. The fire also resulted in the burst of the B-system suction line and the duct over-heat signal that came on late in the flight.

In an effort to determine the exact location of the origin, fuel source or ignition of the fire, the logical analytic approach for evaluating the suspect areas was to assume that a fire started in each of the four areas and then evaluate them against the known sequence of events. These events were taken from information gained from the DFDR, QAR, CVR, ATC Tape, eyewitness reports and test findings.

2.1.1 Possible Origin in Passenger Cabin

The passenger cabin is not considered as the originating area of the fire for the following reasons:

a) No reports of fire or smoke in the cabin were made by the cabin crew until about 5 minutes after the C-3 compartment smoke warning.

b) It is improbable that a large enough amount of smoke to alarm the smoke detectors could enter the C-3 compartment from the cabin without a fairly large fire being visible in the cabin.

c) The flight and cabin crew initial reports of only smoke in cabin are not consistent with the intensity of a fire needed to penetrate the cabin floor from above. In fact tests to cause such a penetration were unsuccessful.

d) A stuck throttle cable from a cabin fire effect is improbable without the fire penetrating the cabin floor which is inconsistent with testing results.

e) The duct overheat signal would require cabin floor penetration as detectors are located approximately 12 in below the floor and thus initially protected from a cabin fire effect.

f) Tests show that a cabin fire involving the seats would progress too fast for it to occur early in the fire sequence.

2.1.2 Possible Origin in Cheek Area

a) It is improbable that smoke from the cheek area enters the C-3 cargo compartment to activate the smoke detectors.

b) There is insufficient fuel in the cheek area for a fire of early intensity.

c) The cheek area is too remote from the throttle cable to cause a stuck cable early in the fire.

d) The duct overheat signal timing is too late in the flight, therefore, is inconsistent for a fire originating in cheek area.

e) No evidence was found to indicate that hydraulic lines in the cheek area initially were involved with fire during the flight as all hydraulic systems were normal until the last portion of the flight.

f) The electrical wire harness fire damage in the cheek area was duplicated in a laboratory flame test in approximately 5 min, whereas the elapsed time of the airplane fire was about 21 min before similar wire damage caused various events, such as the C-1 cargo door open warning.

g) The laboratory analysis of the accident airplane's wire harness from the cheek area did not find any prefire insulation damage, wet wire faults or ground faults that could have been ignition sources. Thus, there does not seem to be any probable ignition sources for a fire to originate in the cheek area.

h) Laboratory analysis also showed that the "B" system rupture in the cheek area was caused by heating and that "No flame had been playing on this part for any appreciable time after the burst had occurred".

Arguments supporting the origination of fire in the cheek area are that it has ingredients for a fire source such as electrical wires, hydraulic lines and pneumatic lines. However, there is no supporting evidence that a fire did start in this area. In fact, all evidence indicates that the fire source was elsewhere.

2.1.3 Possible Origin in Area immediately aft of the C-3 Cargo Compartment

a) It is improbable that smoke from a fire aft of C-3 could enter C-3 in a large enough quantity to activate the detector without producing smoke in the cabin.

b) It is improbable that any smoke generated in this area would enter the cabin area and then seek its way down into the C-3 compartment without initially alerting the cabin crew prior to any detector alert. If the fire was intense enough to generate the smoke required to enter the cabin and then progress into the C-3 area, it would have been hot enough to cause an early alarm of the "J" area overheat detection loop. In addition, if smoke had been forced to the ceiling above the panels it would have been drawn off through the OFVs.

c) There was no evidence found to indicate any hydraulic leaks in the area or possible ignition sources.

d) The duct overheat signal timing is too late inflight, therefore, is inconsistent for a fire originating aft of C-3.

e) There is no mention or indication of an acrid substance in the smoke which would indicate hydraulic fluid as the fuel for the fire. If such a fire happened in flight, the passengers would not have been able to tolerate the acrid smoke and would have moved forward. Such an occurrence was not detected by the C.G. study. It was concluded that the major movement took place after the aircraft landed.

f) The fire damage in the C-3 compartment cannot be accounted for with a fire origination aft of C-3.

g) The lavatories are directly over the area aft of C-3 however, there was no mention of a lavatory fire.

h) Fire was seen in windows between L3 and L4. Had a fire began in the area of the lavatories and progressed forward to that point, the smoke should have precluded the fire from being visible. This would, most likely, have made the entire fuselage non-survivable before the aircraft landed.

i) There was no evidence of flame propagation between the cargo ceiling and cabin floor from aft of C-3 to the cabin floor from aft of C-3 to the area of burn-through in the ceiling of the C-3 cargo compartment.

2.1.4 Possible Origin in C-3 Cargo Compartment

To evaluate the possibility of a fire starting in the C-3 compartment, an assumption will be made that evidence of the source of ignition was consumed by the fire.

For clarity, the analysis will follow the chronological order of events that are considered to be pertinent.

At 1815, following fire ignition, smoke was generated in sufficient quantity to set off the "B" system smoke detector. The actuation of the "B" smoke detector secured the pet ventilation air inflow and outflow valves as well as disrupting power to the inflow fan (This fan was inoperative at aircraft dispatch and was listed in the ship's log). As the smoke continued the "A" system detector was triggered about one minute later, confirming the presence of smoke in C-3 cargo compartment.

Approximately four minutes elapsed before the aircraft was turned back to Riyadh. During some of this period, the flight engineer left and returned to the cockpit with a report "fire back there". A short time later at 18:21:33, he left the cockpit again and upon return to the cockpit reported "it's just smoke in the aft". These inputs could indicate that the C-3 ceiling penetration happened early and that the burning material was near the top of the C-3 compartment.

Penetration of the C-3 compartment liner permits access to an eight-inch space between the cargo compartment ceiling and the bottom of the passenger floor. This space is open across the aircraft (left to right hand sides) between each 20-inch spaced transversal. Smoke can be driven through these channels to the cabin sidewall exhaust grill and can enter the cabin.

The Captain reported a stuck No. 2 engine throttle lever at about 18:25. It can only be assumed, at this point, that the fire penetrated the cargo ceiling liner left of the aircraft centre line, in line with or near to the throttle cable run located at BL35L. The throttle control cables are routed in this area between the cargo compartment ceiling and the passenger floor and are threaded through holes in each transversal. The controls consist of lockclad cables (carbon steel core with a swaged aluminium jacket) suspended between fairlead nylon rollers approximately every 8 ft apart along the cable run. As determined by laboratory tests the fairlead rollers soften and melt at approximately 500°F and adhere to the lockclad cable causing substantial increase in system friction. This can occur with a small amount of cooling.

About 18:26, 11 minutes after the first smoke alarm, a cabin attendant reported seeing fire in the left rear cabin. It can be assumed that the heat and flame, initially unable to penetrate the passenger floor, has followed the same path as the smoke between the transversals to the sidewall of the aircraft. Even with the pet air ventilation system closed, the fire will propagate much the same as was demonstrated in the FAA testing with a simulated compartment.

At 18:32:19, the area duct overheat signal came on. The overheat sensor is installed in the aircraft to detect hot air leaks in the high pressure pneumatic system. The system has dual loop eutectic sensors for redundancy that trigger at 255°F plus or minus 15°F. The dual loop is located outside the left hand sidewall of the C-3 compartment between the sidewall liner and the pneumatic duct and below the five compartment heating inlet ducts which penetrate the top of the sidewall liner.

This sensor location shields the sensors from direct impingement from above. Radiated heat from the eight-inch space above or sufficient fire progression would be required to trigger the sensor. This is contrary to a fire that had its origin low in the cheek area which would burn up to the exposed sensor.

At 18:32:52 the Captain elected to shut down No. 2 engine which secured the "B" and "C" engine driven hydraulic pumps. Each of these systems are backed up by Air Turbine Motor (ATM) driven pumps; however, the pneumatic air source to each can be isolated by a shut off valve. When this valve is closed, as would be the corrective action for a duct area overheat, the "B" system ATM is isolated from the high pressure pneumatic drive source, causing the "B" system to stagnate or have a zero flow condition. In this state, there is no heat transfer from external heat sources and the systems' aluminium lines would be subject to damage. At 18:35:06 the Flight Engineer reported "Aft cargo door is open, Sir." The electric harness powering this circuit was damaged at this point providing a false signal in the cockpit because the C-3 cargo door was found closed and latched.

At 18:35:42, thirty-six seconds after the cargo open light in response to a call of "Hydraulics" by the Captain, the F/E reports "Okay, that's good you got low pressure on number two". This statement is not specific enough to determine whether it is engine oil pressure, as No. 2 engine is shut down, or hydraulic oil pressure because the pneumatic isolation valve is closed.

At 18:42, an eye witness reportedly saw flames in the aft three windows between L4 and L3 doors and finally at 18:46 a witness reported seeing flames through the fuselage skin top and aft, also through the fuselage skin on the left side, aft and below the window line.

In summary, a fire starting in the C-3 Cargo Compartment is entirely probable as it lends itself to total agreement with the time sequence of events and facts in that:

a) The smoke detectors located in the C3 cargo compartment actuated and gave the first warning of smoke/fire.

b) Initial reports as corrected by the F/E, described smoke in the cabin, not fire, suggesting that the actual fire was not yet in sight.

c) The stuck throttle cable-run is above the C-3 cargo compartment and is accessible to a fire originating in the C-3 compartment after the compartment liner is penetrated by the fire.

d) The bleed air duct overheat detector location (in the cheek area) could be actuated by heat (225°F) radiating from a fire that has breached the C-3 cargo compartment liner and is passing outboard, under the floor, and over the adjacent cheek area.

e) There is an extensive history of fires originating in aircraft in cargo compartments where loose baggage and cargo are carried.

f) A full scale test shows that known facts can easily support a fire originating in C-3.

These facts include but are not limited to:

1) Ease of penetration of Nomex liner from below and evidence of fire from C-3 to cabin.

2) Fluctuation of the smoke detection signals.

3) Long duration of a fire before cabin hazard levels significantly increased.

4) Temperatures in area between the cargo ceiling and cabin floor reached a peak just after the liner burned through and then decreased, thus causing the throttle to stick.

5) Lack of damage in the C-3 compartment similar to that of the C-3 compartment of the accident aircraft. This was due to the fluctuation of oxygen levels.

2.1.5 Summary

In summary, the Presidency has been unable to determine the ignition source of the fire; however, evidence strongly supports fire origination in the C-3 cargo compartment. Evidence that the fire did not start in the cabin area or the cheek area is conclusive and there is considerable evidence that it did not start in the area just aft of the C-3 cargo compartment.

2.2 The Flight and Actions by the Crew

According to CVR information, initial system warning of smoke in the C-3 cargo compartment occurred 6:54 minutes after take off from Riyadh and while climbing through 15 000 ft en route to Jeddah. Four minutes and 21 seconds was spent by the crew in confirming the warning.

Saudia procedures state that in the event of a single or double smoke warning, diversion to the nearest suitable airfield should be considered. Due to the complexity of electronic systems in later generation wide-bodied aircraft it is possible to have a spurious warning occur. Therefore, unless there is immediate evidence that an actual emergency exists, system checks should be accomplished prior to flight diversion decisions.

It should be noted, however, that about 3 min were spend by the crew in looking for the aft cargo smoke warning procedure. Evidence indicated that this difficulty was the result of a split of the Emergency and Abnormal procedures into Emergency, Abnormal and Additional. The crew apparently believed that the correct procedures were in the Abnormal section while it was actually in the Emergency section. Another factor which possibly contributed to the time required to find the location of the proper procedures was that the Flight Engineer was affected by "Dyslexia". The manifestation of such a condition can cause confusion of switches, actions, etc.

The Presidency believes that Saudia should revise their checklists by reducing the divisions and providing an index identifier as in a Quick Reference Handbook.

Confirmation that a fire actually existed occurred after the aircraft had begun its return to Riyadh. An expedited descent was initiated shortly thereafter and an emergency was declared by alerting Riyadh's tower and crash/fire/rescue equipment.

The flight crew's action up to the point of turn around can be considered normal; however, thereafter their actions began to deteriorate. During the descent, the Captain appeared to devote his entire attention to flying the aircraft. He could have reduced his workload by using the F/O to fly the aircraft in order to allow himself time to properly evaluate the situation.

During this same period, the actions of the F/E may have confused the Captain by underestimating the seriousness of the situation. The F/E kept saying "No problem" when a severe problem existed. The F/E may have been saying this to bolster his own confidence that all would end well but, in doing so, he presented to the Captain an incorrect view of what was actually occurring. The F/E's actions may have contributed to the Captain's apparent lack of effective and appropriate assertive action when such action was imperative.

Notwithstanding the preceding, the Captain had numerous other warnings that there was a fire, which is one of the most critical of aviation in-flight emergencies. The Captain should have instructed his cabin crew to prepare for an evacuation immediately upon landing. He should have called for the use of oxygen by his cockpit crew and instructed his cabin crew to use oxygen when needed. The inhalation of toxic gases, at times, is insidious and causes physical and mental impairment which would be alleviated by the proper use of oxygen.

The F/O failed in that he was there to assist the Captain and monitor the safety of the aircraft. His limited time in the aircraft is no excuse for throughout his training he, as well as every other pilot, has been trained to act as a team member. However, in this case, it is obvious that he failed to assert himself in a manner that is so necessary of a team member when an emergency occurs.

Based on the evidence derived from the CVR and physical evidence showing non-use of O_2 or smoke masks, it is concluded that the cockpit crew was not affected by the toxic gases during the return flight and the descent into Riyadh. In addition the positive pressure of the cockpit ventilation system would tend to prevent entry of cabin air (smoke) into the cockpit.

During this same period, all evidence indicates that the cabin crew functioned normally, in fact they acted commendably. They attacked the fire as well as they could and, at the same time, did everything that they could to calm the passengers. They also made every attempt to keep the Captain advised of the very serious nature of events occurring in the passenger cabin, and to extract from him the essential order to evacuate immediately upon landing.

After landing, the Captain should have stopped his aircraft as soon as possible and initiated an emergency evacuation. However, he wasted critical time in taxiing the aircraft clear of the runway.

The Captain had numerous and strong indications that a critical fire situation existed prior to his landing, yet none of his actions, at this time, gave evidence of such knowledge. He appeared to reject the seriousness of the situation. The reason or reasons for such a rejection remain undetermined.

The question arises whether the aircraft could have been brought to a stop within minimum certification distance after touchdown. In this respect, the evidence showed that maximum braking capability was available and that the aircraft could have been brought to a stop on the runway with a saving of about 2 min time as compared to the time it took to taxi to a stop. The Presidency believes that these two minutes were significant with respect to survivability. This is especially so, if coupled with an immediate evacuation.

During this time period, the flow of fresh air was reduced thus causing greater depletion of oxygen with an accompanying increase of toxic and combustible gases. The combination of these factors resulted in a flash fire which impaired both the flight and cabin crew to the degree that they became both physically and mentally incapable of performing their evacuation duties. Their impairment evidently occurred at a point in time just after engine shutdown but prior to initiating an evacuation.

A question arose as to the possibility that a pressurization differential prevented evacuation after the aircraft came to a stop. The evidence shows that the inside emergency door handle of R-2 was never operated. It is reasonable to assume that the flight attendants who were originally stationed at exits L-3, L-4 and R-3, R-4 had moved forward because of fire near those exits. Therefore, there is a strong possibility that exit R-2 was manned by not only its regularly assigned flight attendant but possibly one or more flight attendants who had moved forward from the rear exits. If any of these flight attendants had operated the inside emergency handle while the fuselage was pressurized, the door would have opened later when fire breached through the fuselage.

A pressure profile was made which depicted the crew following normal pressurization procedures during the climb out of Riyadh and during the initial part of the return and descent. However, during descent a cabin altitude of 2 000 ft had been selected to correspond to the field elevation of 2 082 ft at Riyadh. For Saudia, the usual descent rate is 240 fpm. In this instance a higher than usual rate was selected to ensure zero differential pressure at touchdown. This was necessary since the descent time was reduced due to the altitude versus the distance to go to touchdown.

The condition of the aircraft found by the investigating team leads to the most probable conclusion that the aircraft was not pressurized after it landed at Riyadh.

Just prior to landing, the Captain told the cockpit crew not to evacuate; however, it is not clear if such information was relayed to the cabin crew. Saudia cabin crews have the authority to initiate an evacuation should the situation dictate it. Even if the cabin crew had decided that the situation warranted breaking their procedures, they were prevented from doing so by the Captain. The Captain by allowing the engines to continue to operate after he stopped the aircraft effectively prevented the cabin crew from initiating the evacuation on their own. There was no evidence that shows that an evacuation procedure was initiated.

Based on information obtained during the investigation, there is no evidence obtained to indicate that the doors were not fully operational at the time the aircraft was brought to a stop. There was no evidence to indicate any of the door interior emergency handles had been pulled. This lack of action by the cabin crew may have been that the order by the Captain not to evacuate had been received by the cabin crew. A second and possible factor in the failure of anyone of the crew to open the doors was the fact that by the time the aircraft came to a stop the passengers were in total panic and had rushed to and against the doors which would have prevented the doors from moving inboard the necessary few inches prior to opening. However, it is more likely that the cabin crew were physically impaired by the flash fire which occurred. Since the flight crew were found still at their duty stations, it is doubtful that the evacuation command was ever issued.

Evidence was conclusive that the environmental control system (ECS) packs were shut down before the engines were shut down. This is a normal post-landing procedure. This action resulted in the loss of any ventilation air being introduced within the fuselage. The closed and almost closed positions of the forward and aft outflow valves initially were unexplainable for they should have automatically gone to open on touch-down.

Based on standard operating procedures at turn around, the two outflow valves were regulating; the overboard vent valves were in their normal in-flight position, that is, the forward electronic equipment compartment and the mid-electronic equipment compartment valves were closed and exhaust air was discharged through the forward outflow valve. The galley vent valve was open exhausting oven air overboard. The cabin pressurization system had been reset for Riyadh altitude and all three (3) cycle machines were operating.

The mode of operation used to control the outflow valve during short final portion of the flight cannot be determined. However, the system was found in the standby operation mode, with the standby rate set at the hold or zero rate of change position. The outflow valves by design will go to the full open position only when the system is set in the normal operating mode in actuation of the airplane squat switch. Since this did not happen, it can be concluded that at some point in the short final phase of the flight, the system operating mode was switched from normal to standby. At any time during this period, a loss of AC power to the actuator or loss of DC power which is needed to keep the actuator brake released, would lock the valve in the position in which it was found. The harnesses supplying power to the aft outflow valve are routed through the reported fire area, along the side of the C2-C3 cargo compartment. Damage to these harnesses during this period is probable.

Following the power interrupt, the f[illegible]d outflow valve would be modulating to maintain pressure control. With the control in standby and at a hold rate setting, the forward valve would continue to open to maintain a 2 000 ft altitude within the cabin. At some point after the cabin reached 2 000 ft altitude and prior to shutting down engines, the packs were turned off. This probably occurred during rollout which accounts for the reduction in the smoke trail from the airplane aft outflow valve seen by the eye witnesses.

It is further confirmed by finding all three (3) pack turbine bypass valves in their pre-position. The pre-position setting or system start-up position is automatically attained after system shutdown and requires 30 seconds of AC power to drive the motor operated valves.

To summarize the outflow valve investigation, it is known that the pressurization system operating mode was changed from normal to standby during the final phase of descent before touchdown. It is also known the aft outflow valve was open during the flight phase because of the reported smoke trail from the aft end of the aircraft, reported by eye witnesses, and the soot stained underside aft of the valve.

2.3 Actions by Crash/Fire/Rescue Services

Evidence indicated that the actions by the Riyadh crash/fire/rescue personnel were both inadequate and disorganized. Evidence also showed a lack of adequate training for the firemen and lack of useful fire protective clothing and fire fighting equipment.

Chapter 12 of ICAO Doc 9137-AN/898, Part 1 establishes the criterion for C/F/R procedures which Saudi Arabia has adapted; yet, in this case all of the pertinent criteria were not followed by Airport C/F/R Services. The firemen were not properly clothed in protective clothing although they had ample warning that an aircraft on fire was approaching. They were not equipped with the tools for forcible entry nor were they trained in forcible entry procedures. They were not trained in opening the L-1011 doors and were not knowledgeable of any entry areas below the cabin doors. They had not received actual fire fighting training nor actual training on L-1011 aircraft.

It should be noted that fire was sighted in the aft of the aircraft as it came to a stop on the taxi-way yet the firemen failed to take immediate entry action. This can be excused by the fact that the two wing engines were still running and the firemen had no direct communication with the crew; therefore, they were awaiting crew action. However, no excuse can be given for the failure of C/F/R action after the engines stopped 3 min later and until the first door was opened about 26 min after the aircraft came to a stop.

There is no doubt that the individual firemen on-scene did as well as they were able to, but they lacked the training and equipment to accomplish their task, a fact which is attributable to C/F/R management at the time of the accident. With this in mind, the Presidency was extremely concerned and since the date of the accident has updated the training and equipment throughout Saudi Arabia.

2.4 Survival Aspects

Post-mortem examinations and toxicological findings revealed that the deaths in this accident were attributable to the inhalation of toxic gases and/or exposure to the effects of the fire, heat and lack of oxygen. There were no unusual forces transmitted to the aircraft occupants as the landing and subsequent roll-out were normal.

In all cases examined, the trachea was covered with carbon particles which extended into the bronchiotes of the lung. In the majority of the cases the soot deposit was heavy and the carbon monoxide (CO) levels varied from 42 per cent to 58 per cent.

It is clear, both from the state of the bronchial tree of the deceased and the levels of carbon monoxide in all of the blood samples, that the deceased breathed heavily smoke-filled contaminated air before they died.

There was no evidence that oxygen was used by either the flight or cabin crew. Therefore, it is a safe assumption that the occupants were incapacitated prior to exposure to heavy smoke. Such incapacitation could have occurred from at least two causes. One cause could have been by the inhalation of one or a combination of fast acting toxic gases. Another cause could have occurred as a result of a flash fire which would consume almost all of the available oxygen thus causing immediate incapacitation.

Initially, during the period from first smoke detection until after landing when the outflow valves closed and the airconditioning packs were shut down, the crew and passengers were exposed to mild and virtually insignificant hypoxia due to exposure to a cabin altitude of about 5 000 ft. This was combined in the passenger cabin with increasing amounts of carbon monoxide and other toxic agents from the combustion of aircraft and other materials.

During this period, the occupants of the passengers' cabin of the aircraft were undoubtedly exposed to these hazards, but at levels which were insufficient to severely affect them. Evidence indicates that during this period the cockpit crew was exposed to little or none of the hazards until after the aircraft landed.

After landing, the seriousness of the situation and potential hazard accelerated rapidly as the fire began burning more aircraft materials. The situation was further aggravated when the F/E shutdown the conditioning units, and the outflow valves closed, thus collecting heat and combustible gases at the ceiling of the cabin. Hazardous conditions in the aircraft increased as the fire increased; however, they were still survivable until a flash fire occurred in the cabin just after engine shut down occurred. This caused a very rapid build-up of hazards in the cabin and cockpit (lack of O_2, toxic gases, smoke, heat), inducing almost immediate incapacitation of the passengers and crew and thereafter - death.

Based on the foregoing, this accident was survivable. The actions by the Captain in not preparing his cabin crew for evacuation and then not stopping as soon as possible on the runway to evacuate the aircraft, and the actions of C/F/R personnel contributed to the ultimate fatal results.

2.5 Other Areas

Review of the background of the cockpit crew raises some areas of concern. Both the F/O and F/E had, at one point in their careers, been dropped from the training programme, or had been terminated and then reinstated. Their actions or lack of action during this accident sequence were not helpful to the Captain. Reinstatement in a flight position of terminated crew men is not desirable.

The performance of ATC in this accident can be considered, in most cases, standard, but an error in judgement was made by not closing the airfield immediately when all C/F/R vehicles were occupied at the accident scene. In this case, however, it had no effect on the outcome of the accident. In another instance, the tower and the officer-in-charge of the fire fighting personnel did not make preliminary co-ordination to provide the fire fighters with the frequency of the aircraft. Direct communication between rescue personnel and an aircraft in distress is essential.

As the result of this accident, the US NTSB made two recommendations to the US FAA. The NTSB's basis in making both recommendations is logical and the Presidency believes the recommendations merit positive and expedited action. The NTSB noted that the L-1011 C-3 compartment was approved as a "Class D" compartment by "extrapolations" from the 500 cu.ft volume and the 1 500 cu.ft per hour airflow guidelines in 14 CFR 25.857 (d) (5).

The concept of a Class D compartment is that a fire within it would be controlled by oxygen depletion. This concept as it relates to the L-1011 compartment of 700 cu.ft using a Nomex ceiling liner volume has been subsequently disproved by FAA tests.

The NTSB recommended that the "Class D" certification of the L-1011 C-3 cargo compartment be re-evaluated yet the FAA responded that it has been demonstrated that a large class D type cargo compartment is in compliance with the requirements of FAR 25.857 (d). In view of the results of the FAA testing, the Presidency is concerned with the FAA's answer. There is certainly evidence that the C-3 compartment did not meet the intent of the FAR and that the FAR was inadequate for the purpose intended.

Two of the other three requirements for classification of a Class D Cargo Compartment were also not met by the C-3 cargo compartment. Therefore, it is believed that the FAA should reconsider its stand on this recommendation and take immediate positive action. (See Section 4 and Appendix H.)

3. CONCLUSIONS

3.1 Findings

1) The flight crew was properly certificated to conduct the flight, and the aircraft was properly maintained in accordance with prescribed procedures.

2) A fire probably started in the C-3 cargo compartment.

3) The fire did not start in the cabin area.

4) The fire did not start in the left cheek area.

5) The majority of the evidence indicates that the fire did not start in the area aft of the C-3 cargo compartment.

6) The ignition source for the fire was not determined.

7) The initial fuel for the fire was probably baggage and cargo in the C-3 cargo compartment.

8) There was no detectable evidence of a pre-fire fault in the aircraft systems.

9) The Operator's Emergency and Abnormal checklist procedures were not adequately indexed for rapid identification.

10) During the descent to Riyadh, the Captain did not brief the cabin crew regarding plans to evacuate.

11) The Captain did not fully utilize his flight deck crew during the emergency.

12) Upon landing, the cabin and ambient differential pressure was negligible.

13) The aircraft had adequate braking capability available to make a maximum stop on the runway.

14) The Captain elected to taxi off the runway prior to bringing the aircraft to a stop.

15) Toxic fumes, including carbon monoxide, were being produced by burning materials and were inhaled by the aircraft occupants.

16) Autopsy findings indicated that the occupants had inhaled a high percentage of carbon monoxide.

17) There was no evidence of an attempt to open the doors from inside the aircraft by the emergency method.

18) Crash/Fire/Rescue personnel were not properly equipped or trained. This resulted in their actions being inadequate and disorganized for the situation at hand.

19) The degree of seriousness of the accident is directly related to the actions of the Captain, and C/F/R services.

20) Investigative evidence and testing indicates that the C-3, class D compartment of the L-1011 did not meet the intent of FAR 25.857 (d) and that the FAR is inadequate for the purpose intended.

3.2 Probable Cause

The Presidency of Civil Aviation determines that the probable cause of this accident was the initiation of fire in the C-3 cargo compartment. The source of the ignition of the fire is undetermined.

Factors contributing to the final fatal results of this accident were 1) the failure of the Captain to prepare the cabin crew for immediate evacuation upon landing and his failure in not making a maximum stop landing on the runway, with immediate evacuation, 2) the failure of the Captain to properly utilize his flight crew throughout the emergency 3) the failure of C/F/R headquarters management personnel to ensure that its personnel had adequate equipment and training to function as required during an emergency.

4. SAFETY RECOMMENDATIONS

4.1 National Transportation Safety Board

As the result of findings in this accident the US National Transportation Safety Board made two recommendations to the US Federal Aviation Administration. These recommendations together with the FAA response are contained in Appendix H of this report.

The Presidency of Civil Aviation requests that the FAA reconsider its action regarding NTSB's recommendation A-18-12 and take expedient corrective action.

4.2 Presidency of Civil Aviation

Following the accident, the Presidency made a series of recommendations to Saudia. They were, in part, as follows:

4.2.1 FLIGHT CREW TRAINING AND STANDARDIZATION

1. Revise existing training programmes and initiate additional programmes to ensure that flight crews are given adequate instruction for their immediate and aggressive response to any problems relative to safety of flight. Such programmes should include instructions for immediate action to be taken upon the activation of any aircraft's fire and smoke warning devices and/or upon receipt of any information that fire or smoke has been observed aboard an aircraft. If smoke is confirmed, the instructions should dictate a landing as soon as possible at a suitable airfield.

2. Amend Saudia's crew training programme to include additional assertive and command training for junior Saudia Captains and for First Officers.

3. Establish a system so that flight crews are matched to ensure that the cockpit experience level and competence is at a desirable level. Such a procedure would eliminate the scheduling of junior Captains and junior First Officers for the same flight.

4. Amend Saudia's personnel policy and practices to stop the rehiring of flight crew members for a flight crew position after they have been removed from another flight crew because of substandard performance.

5. Review and amend emergency procedures and check lists for all aircraft to separate and clarify the emergency landing evacuation procedures to prevent possible confusion of the specific steps to take in such emergencies.

6. Review Saudia's Standard Operating Procedures to ensure that they are precise and contain detailed instructions and procedures. Clear, concise and easily understandable instructions should eliminate deviations and ensure standardization.

4.2.2 SURVEILLANCE AND HANDLING OF CARRY-ON BAGGAGE, CHECKED BAGGAGE

1. Saudia provide personnel to oversee the check-in security inspection and boarding on all Saudia flights. In addition, Saudia personnel should spot check for security purposes checked baggage and cargo.

2. Saudia take the necessary action to improve their surveillance and direction of the cargo handlers in regard to the methods and materials that are placed in aircraft cargo compartments.

Some of the remedial actions that Saudia has taken to date to improve their operations are:

1. Emergency check lists and procedures for all Saudia aircraft have been, or are being revised, to insure that flight crews have the information available to them so that they can take immediate decisive action whenever an emergency occurs.

2. An extensive review of crew training procedures has been accomplished to improve any areas that may be deficient.

3. Emphasis has been placed on improving any deficient areas in evacuation training.

4. The airline has incorporated all of its pilot training records into a computer system. This system will allow immediate access to crew records so that Training and Line Supervisory personnel can make prompt, comprehensive evaluations for improving the effectiveness of the training for the individual crew member, among other benefits.

5. The C-3 cargo compartment (Class D) of all Saudia L-1011 aircraft has been sealed off in an effort to confine any fire that may occur within it. The compartment no longer has the capability to transport animals.

4.2.3 OTHER AREAS

In addition to the recommendations made to Saudia, the Presidency evaluated areas for improvement within Civil Aviation, in particular, PCA Fire Services. Immediate remedial action was taken which has resulted in the Kingdom's present Fire Services now exceeding, in most cases, the international criteria established by ICAO. Further improvement in capability is planned and presently in progress.

ICAO Note: A number of photos, figures and appendices were not reproduced.

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APPENDIX A

NOTIFICATION AND FORMATION OF THE INVESTIGATION

Upon the occurrence of this accident, the Kingdom of Saudi Arabia in the exercise of its powers and in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation designated an aviation consultant from the United States to act as the Investigator-in-Charge of the accident. The Investigator-in-Charge was instructed by the Kingdom to conduct a complete and comprehensive investigation. He was informed that all functions of the Government of the Kingdom would render any necessary assistance and support. The Kingdom invited participation by personnel of the State of Manufacture and appropriate aviation experts of other governments. Accordingly, the United States immediately dispatched to the scene of the accident an Accredited Representative and Advisors from the National Transportation Safety Board. The American Accredited Representative was assisted by other advisors which were selected from the US Federal Aviation Administration, the Lockheed Aircraft Corporation and Trans World Airlines Inc. The Government of Great Britain provided immediate technical assistance and subsequently an Accredited Representative was designated from the Department of Trade, Accidents Investigation Branch. In addition, the carrier involved, Saudi Arabian Airlines provided immediate technical assistance to the investigation.

Upon his arrival on-scene, the Investigator-in-Charge held an organization meeting and investigative groups were established for Operations/Air Traffic Control/ Weather, Aircraft Structures, Aircraft Systems, Maintenance Records, Human Factors, Witnesses, and Cockpit Voice Recorder. During the initial stages of the investigation, an expert in aircraft sabotage detection was called upon to assist.

Subsequent to the accident numerous tests and extensive research were conducted in efforts to determine the origin of the fire. All tests and research by the United States and its advisers were either conducted by U.S. Government bureaux or under the observation of those bureaux.

In accordance with Chapter 6, Section 6.11 of Annex 13 to the Convention on International Civil Aviation, a meeting was called and the States involved in the investigation were afforded the opportunity to review and comment on the draft Final Report of this accident. United States Government personnel attended and the substance of their comments is included in this report.