

Accident Board Findings

FINDINGS

The findings are statements of all significant conditions, events or circumstances in the accident sequence. The findings are significant steps in the accident sequence, but they are not always causal or do not necessarily indicate deficiencies.

1. The crew of the inbound sector from Hong Kong reported a PACK 1 failure. This failure could not be replicated on the ground in Dubai by the ground engineer.
2. The Boeing 747-400 fleet was experiencing a lower than predicted MTBF of the turbine bypass valve [TBV], which is a component of the AC PACKs.
3. A consignment of mixed cargo including a significant number of batteries, including lithium types, was loaded on the inbound flight from Hong Kong onto the pallets located at MD positions 4, 5, and 6, amongst other positions. This cargo was not unloaded in Dubai.
4. At least three shipments including lithium type batteries should have been classified and fully regulated as Class 9 materials per ICAO Technical Instructions, and thus should have appeared on the cargo manifest. These shipments were located in the cargo at MD positions 4 and 5.
5. Shippers of some of the lithium battery cargo loaded in Hong Kong did not properly declare these shipments and did not provide Test Reports in compliance with the UN Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria, Section 38.3, to verify that such these battery designs were in conformance with UN Modal Regulations.
6. The aircraft was airworthy when dispatched for the flight, with MEL items logged. These MEL items are not contributory to the accident.
7. The mass and the Center of Gravity [CG] of the aircraft was within operational limits.
8. The crew was licensed appropriately and no fatigue issues had been identified.
9. The Captains blood sample was positive for ethyl alcohol with a concentration of (11 mg/dl).
10. Currently a universal fire protection certification standard covers all transport category aircraft.
11. FAA Advisory Circular 25-9A *Smoke Detection, Penetration, And Evacuation Tests And Related Flight Manual Emergency Procedures* does not require the consideration of continuous smoke generation for cockpit smoke evacuation, the FAA recommends that the airframe design address this situation but it is not mandatory.
12. The crew were heard to confirm the oxygen mask settings during preflight, however sound spectrum analysis indicated that for unknown reasons, the First Officer's mask was set to Normal instead of 100%, which likely allowed ambient air contaminated with smoke to enter his mask.
13. The take-off at 14:50 UTC and initial climb were uneventful.
14. At 14:58 UTC, Pack 1 went off line and was reset 2 minutes later by the PM.
15. The crew acknowledged Bahrain radar and crossed into the Bahrain FIR at 15:11 UTC.
16. At some point prior to the fire warning, contents of a cargo pallet, which included lithium batteries, auto-ignited, causing a large and sustained cargo fire which was not detected by the smoke detectors when in the early stages of Pyrolysis.
17. Pallets with rain covers can contain smoke until a large fire has developed.
18. Two minutes after passing into the Bahrain FIR, Twenty one minutes after take-off there is a fire alert at 15:12 indicating a, FIRE MAIN DK FWD.
19. The Captain assumes control as Pilot Flying, the F.O begins the FIRE MAIN DK FWD non-normal checklist.
20. The Capt advises the F.O they are to return to DXB before alerting Bahrain Area East Control [BAE-C] of the fire onboard, declaring an emergency and requesting to land as soon as possible.
21. BAE-C advised the crew that Doha airport was 100 nm to the left. The turn back to DXB totaled 185 nm track distance. The likely outcome of a hypothetical diversion is inconclusive.

22. At the time the Captain decided to turn back, the crew was not yet aware of the full extent of the fire and its effects.

23. By the time that the smoke in the cockpit and fire damaged controls became apparent, diverting to Doha was no longer a feasible option.

24. The course to DXB resulted in the airplane flying out of direct radio communication with ATC, requiring a complex relay of communication and increased task saturation for the F.O.

25. In addition to the energy release from Lithium batteries resulting in combustion, there is an associated mechanical energy release. This mechanical energy release is capable of compromising the integrity of packaging and creating incendiary projectiles.

26. The control of the aircraft when in manual control was compromised due to the thermal damage to the control cable assemblies. The first indication of the deteriorated synchronization problems between the control column movement and elevator position appear when the Captain disconnects the autopilot.

27. The time interval between fire detection and the onset of aircraft system failures was two minutes and thirty seconds at the point of detection. In all probability the fire had damaged the control cables prior to autopilot disconnection.

28. The aircraft begins to turn on to a heading for DXB and descends. As it was dusk, the aircraft is now descending to the east and back into an easterly time zone where there is limited available ambient solar light.

29. The cargo compartment liner failed as a fire and smoke barrier under combined thermal and mechanical loads.

30. Consequently, the damaged cargo compartment liner exposed the area above the cargo bay in fire zone 3 to sustained thermal loading either breaching the cargo compartment liner or causing the aluminium structure retaining the liner to collapse, exposing the area above and adjacent to the breach to continuous thermal loading.

31. Consequently, the damaged cargo compartment liner exposed the supernumerary and cockpit area to sustained and persistent smoke and toxic fumes.

32. Based on the NTSB pallet and container testing results, it is now known that the growth rate of container fires after they become detectable by the aircraft's smoke detection system can be extremely fast, precluding any mitigating action and resulting in an overwhelming fire that cannot be contained.

33. The high thermal loading damaged or destroyed the supporting trusses for the control cables directly affecting the control cable tension. The control column effectiveness was significantly reduced, subsequently the movement of the elevators, speed brake, rudders, brakes and landing gear control had been compromised.

34. The high thermal loading caused damage to the ECS ducting,

35. The ACARS/AHM data indicates a series of sensor failures and fire wire loops tripping to active in the area of the fire, the fault timing and the fire warning are corollary.

36. The crew donned their oxygen masks, and experienced difficulty hearing each other.

37. The oxygen masks had a required setting of 100% and in emergency for smoke in the cockpit.

38. The oxygen selector position cannot be viewed when the mask is on. The technique used to determine the selector position when the mask was on was not an operator technique or reinforced through training scenarios and non-cognitive muscle memory techniques.

39. The mask settings remain unchanged for the duration of the flight.

40. The main deck fire suppression system was activated and the cabin depressurized.

41. Lithium-metal cell thermal stability and reactions that occur within a cell with elevated temperatures, up to the point of thermal runaway are not oxygen dependent. Electrolyte or vent gas combustion properties and the fire hazards associated with thermal runaway reactions do not respond to the FL250 assumed hazard mitigation methodology.

42. The Class E cargo compartment fire suppression strategy of preventing venting airflow in to cargo compartment, depressurization and maintaining 25,000ft cabin altitude may not be effective for Class D metal fires.

43. For unknown reasons Pack 1 went off and was not mentioned by the crew. The cockpit smoke prevention methodology when the fire suppression is active is to have pack one on low flow pressurizing the cockpit area to a higher than ambient pressure, preventing smoke ingress.

44. It is unknown in this instance that if Pack one had been active this method would have worked as described based on the volume and flow of the smoke The Capt requests a descent to 10,000ft

45. The QRH Fire Main Deck checklist does not address the key factor of descend or divert decision making. The checklist fire suppression methodology advises the crew to remain at 25,000 cabin pressure altitude to suppress a fire or land at nearest suitable airport. It does not provide guidance for when or how to transition to landing or the fact that descending early might provide more atmospheric oxygen to the fire. There is no intermediate step to verify or otherwise assess the condition of the fire and to evaluate the risk to the aircraft if a decent is initiated.

46. The Class E certification standards for fire suppression does not require active fire suppression.

47. Within three minutes of the fire alarm, smoke enters the cockpit area. This smoke in the cockpit, from a continuous source near and contiguous with the cockpit area, entered with sufficient volume and density to totally obscure the pilot's view of the instruments, control panels and alert indicating systems for the duration of the flight.

48. Once the liner had been breached, the openings in the liner would progressively expand, allowing an increase in the volume of dense noxious smoke, fire and combustion by-products to escape the cargo compartment.

49. The cargo compartment liner structure certification does not include extreme heat and other input loads such as vibration, multi-axial loading, intermittent pressure pulses, thermo mechanical loadings based on differential materials coefficients, acoustic and ballistic damage testing.

50. The crew made several comments concerning their inability to see anything in the cockpit. The crew in the smoke environment had reduced visibility and could not view the primary instruments such as the MFD, PFD, Nav Displays or the EICAS messages.

51. The Captain selected the Autopilot on and leveled out following the pitch control problems. The aircraft remained in a stable steady state when controlled via the AP. There was no communication between the Captain and the F.O. that the controllability problem was resolved using the AP.

52. Effective elevator and rudder control was only available with the autopilots. The aircraft was controllable with the AP as the servos are electrically controlled and hydraulically actuated, which for pitch control is in the tail section aft of the rear pressure bulkhead, and the fire had not compromised the electrical cabling to the actuators.

53. The PF was not fully aware of the extent of the control limitations, could not see the EICAS messages and was not aware of all of the systems failures.

54. The Captain called for the smoke evacuation handle to be pulled as the smoke accumulated in the cockpit. The smoke evacuation handle when pulled opens a port in the cockpit roof, which if the smoke is sustained and continuous, will draw smoke through the cockpit as the pressure is reduced by the open port venturi effect compounding the problem. The smoke evacuation handle remained open for the remainder of the flight.

55. There are several instances of checklist interruption at critical times at the beginning of the emergency. The speed and quick succession of the cascading failures task saturated the crew. The smoke in the cockpit, combined with the communications problems further compounded the difficult CRM environment. With the incapacitation of the captain, the situation in the cockpit became extremely difficult to manage.

56. One factor when dealing with the QRH and running checklists is that the B747 does not have a hot microphone function. This caused increasing difficulty managing cascading failures and high workload.

57. The crew was unable to complete the Fire Main Deck checklist. The aircraft was not leveled off at 25,000 ft. Directly descending to the 10,000 ft may have exacerbated fire and smoke problem due to the extra available oxygen.

58. The Captain instructed the F.O. to input DXB RWY12L into the FMC. This action was completed with difficulty due to the smoke. There was no verbal confirmation of the task completion, however, the aircraft receivers detected the DXB Runway 12L glide slope beam when approaching Dubai.

59. Captain made a comment mentioning the high cockpit temperature, almost immediately the Captains oxygen supply abruptly stopped without warning, this occurred seven minutes six seconds after the first Main Deck Fire Warning.

60. The Captain's inability to get oxygen through his mask was possibly the result of the oxygen hose failure near the connector. The high thermal loading was conducted through the supplementary oxygen stainless steel supply lines heating the supplementary oxygen directly affecting the flexible hose connector causing the oxygen supply line to fail.

61. Systems analysis indicates that the oxygen supply is pressure fed, therefore venting oxygen could be released by a failed oxygen hose which could then discharge until the oxygen line fails or the oxygen supply is depleted.

62. The Captain requests oxygen from the F.O. several times over approximately one minute. The First Officer due to possible task saturation was not able to assist the Captain.

63. The oxygen requirement of the Captain became critical, the Captain removes the oxygen mask and separate smoke goggles and leaves the seat to look for the supplementary oxygen. The Captain did not return. The Captain was in distress locating the supplementary oxygen bottle and could not locate it before being overcome by the fumes.

64. The Captain was incapacitated for the remainder of the flight. A post-mortem examination of the Captain indicates that the cause of death was due to carbon monoxide inhalation.

65. A full face emergency oxygen supply is available in the cockpit. Oronasal masks are available in the lavatory, jump seat area and crew bunk area.

66. Due to the Captain's incapacitation the F.O became P.F. for the remainder of the flight, operating in a single pilot environment. Exposure to this type of environment in a controlled training environment could have been advantageous to the remaining crew member.

67. The FO had breathing difficulties as the aircraft descended as the normal mode function of the mask supplies oxygen at a ratio to atmospheric, ambient air. The amount of oxygen supplied was proportional to the cabin altitude.

68. The cockpit environment remained full of smoke in the cockpit, from a continuous source near and contiguous with the cockpit area for the duration of the flight.

69. As the flight returned towards DXB, the crew were out of VHF range with BAE-C and should have changed VHF frequencies to the UAE FIR frequency 132.15 for the Emirates Area Control Center [EACC]. Due to the smoke in the cockpit the PF could not view the audio control panels to change the frequency selection for the duration of the flight.

70. The flight remained on the Bahrain frequency 132.12 MHz on the left hand VHF ACP for the duration of the flight. To solve the direct line of communication problem, BAE-C requested traffic in the vicinity to relay communication between crew and BAE-C.

71. The PF made a blind Mayday call on 121.5 MHz at 15:21 UTC.

72. The PF had to relay all VHF communication through other aircraft. The radio communication relay between the PF, the relay aircraft and the ANS stations resulted in confusion communicating the nature and intent of the PF's request for information with the required level of urgency.

73. The PF requested from the relay aircraft immediate vectors to the nearest airport, radar guidance, speed, height and other positional or spatial information on numerous occasions to gauge the aircraft's position relative to the aerodrome and the ground due to the persistent and continuous smoke in the cockpit.

74. The relay aircraft did not fully comprehend or communicate to the BAE-C controller the specific nature of the emergency and assistance required, particularly towards the end of the event sequence.

75. There was a multi-stage process to complete a standard request for information between the accident flight and the destination aerodrome via the relay aircraft and the ATCU.

76. The flight crew did not or could not enter the transponder emergency code 7700, however all ATCUs were aware that the airplane was in an emergency status.

77. DXB controllers were aware that the flight was in an emergency status, however were not aware of the specific nature of the emergency or assistance required, due to the complex nature of the relayed communications.

78. There was no radar data sharing from the UAE to Bahrain ATC facilities. Bahrain had a direct feed that goes to the UAE but there was no reciprocal arrangement. This lack of data resulted in the BAE-C ATCO not having radar access the SSR track of the accident flight.

79. The ATC facilities are not equipped with tunable transceivers.

80. The accident aircraft transmitted on the Guard frequency 121.5 Mhz. The transmissions were not heard by the EACC or DXB ATC planners due to the volume of the 121.5 Mhz frequency being in a low volume condition.

81. The PF did not respond to any of the calls from the ACC or the relay aircraft on 121.5 MHz, which were audible on the CVR, after the Mayday transmission.

82. During the periods when direct radio communications between the pilot flying and the controllers was established, there was no negative effect. Therefore it is likely that if direct 121.5 contact had been established the communications task could have been simplified.

83. The relay aircraft hand off between successive aircraft caused increasing levels of frustration and confusion to the PF.

84. All Dubai aerodrome approach aids and lighting facilities were operating normally at the time of the accident.

85. There is no requirement for full immersion smoke, fire, fumes cockpit training for flight crews.

86. The PF selected the landing gear handle down. The landing gear did not extend, likely due to loss of cable tension.

87. The flaps extended to 20°. This limited the auto throttle power demand based on the max flap extension placard speed at 20° Flaps.

88. The PF was in radio contact with a relay aircraft, who advised the PF through BAE-C that Sharjah airport was available, and a left hand turn onto a heading of 095° was required.

89. The PF made an input of 195° into the MCP for an undetermined reason when 095° was provided. The aircraft overbanked to the right, generating a series of audible alerts. It is probable that the PF, in the absence of peripheral visual clues, likely became spatially disorientated by this abrupt maneuver.

90. The aircraft acquired 195°, the AP was selected off. The throttle was retarded and the aircraft began a rapid descent.

91. The PF was unaware of the large urban area directly in the airplane's path. The aircraft began a descent without a defined landing area ahead.

92. Spatial disorientation, vestibular/somatogyral illusion due to unreliable or unavailable instruments or external visual references are a possibility. The PF was unaware of the aircraft location spatially. The PF may have been attempting an off airfield landing, evidenced by numerous control column inputs.

93. The control column inputs to the elevators had a limited effect on the descent profile. The pilot made a series of rapid column inputs, in response to GPWS warnings concerning the sink rate and

terrain. The inputs resulted in pitch oscillations where the elevator response decreased rapidly at the end of the flight

94. The available manual control of pitch attitude was minimal, the control column was fully aft when the data ends, there was insufficient trailing edge up [nose up] elevator to arrest the nose down pitch. Control of the aircraft was lost in flight followed by an uncontrolled descent into terrain.

95. The aircraft was not equipped with an alternative viewing system to allow the pilot(s) to view the instruments and panels in the smoke filled environment.