# EVALUATION OF TRANSPORT AIRPLANE MAIN DECK CARGO COMPARTMENT FIRE PROTECTION CERTIFICATION PROCEDURES

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1. EXECUTIVE SUMMARY

a. Purpose

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

b. Problem:

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

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

c. Investigation:

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

d. Conclusions:

The Team concluded the following:

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

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

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

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

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

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

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

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

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

e. Recommendations:

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

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

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

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

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

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

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

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

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

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3. INTRODUCTION

a. Purpose:

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

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

b. Scope:

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

The following subjects were encompassed by the investigation.

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

c. Background:

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

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

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

4. SYNOPSIS OF MEETINGS

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

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

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

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

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

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

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

Subjects addressed were :

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

## 4. FACTS, ANALYSIS, AND DISCUSSION

### A. Federal Aviation Regulations (FAR) Applicable to Combi's For Cargo Compartments

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

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

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

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

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

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

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

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

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

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

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

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

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

b. Regulatory History

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

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

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

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

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

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

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

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

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

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

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

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

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

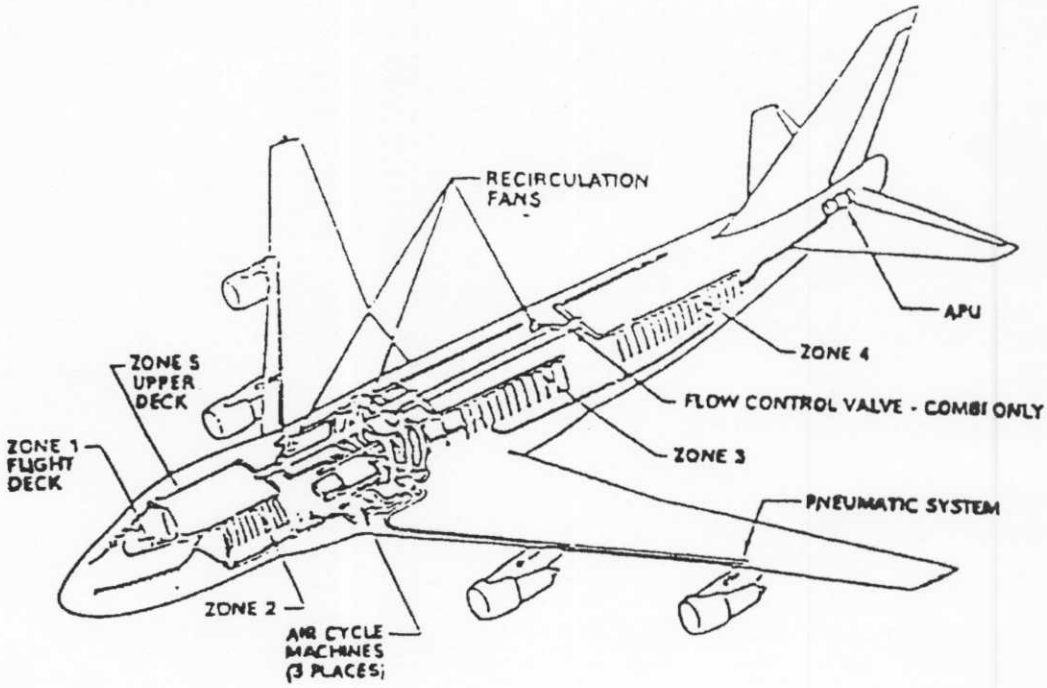
c. Combi Air Flow-Control

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

Example of an Air-Conditioning Duct System

AIR-CONDITIONING DUCT SYSTEM

(PASSENGER, CONVERTIBLE & COMBI AIRPLANES)



d. Combi Compartment Sizes

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

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

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

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

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

e. Smoke Detection System

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

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

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

f. Cargo/Passenger Fire/Smoke Barriers

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

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

g. Fire Extinguishers for Combi Airplanes

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

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

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

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

h. Fire Containment of Cargo Containers

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

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

i. Cargo Compartment Liners

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

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

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

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

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

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

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

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

k. Crew Training

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

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

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

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

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

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

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

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

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

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

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

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

Appendix I

List of Participants

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| | | |
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