U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: PASSENGER CABIN SMOKE PROTECTION

Date: 10/24/08
Initiated By: ANM-100

AC No: 25.795-4

1. PURPOSE. This Advisory Circular (AC) provides an acceptable means of showing compliance with the requirements of Title 14, Code of Federal Regulations (CFR), part 25, § 25.795(b)(2), "Cabin smoke protection." This section requires that an airplane be designed with means to prevent passengers from being incapacitated by smoke, fumes, and noxious gases that result from detonation of an explosive or incendiary device during flight. The means of compliance described in this document provides guidance to supplement the engineering and operational judgment that must form the basis of any compliance findings relative to penetration of smoke, fumes, and noxious gases into the passenger cabin.

2. APPLICABILITY.

a. The guidance provided in this document is directed to manufacturers and modifiers of large passenger transport airplanes and repair facilities for such airplanes.

b. The material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for demonstrating compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. Furthermore, if we become aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC, and we may require additional substantiation or design changes as a basis for finding compliance.

c. The material in this AC does not change, create any additional, authorize changes in, or permit deviations from regulatory requirements.

3. RELATED SECTIONS OF 14 CFR. Part 25, §§ 25.795, 25.831, 25.855, and 25.857.

4. BACKGROUND.

a. The International Civil Aviation Organization (ICAO) adopted certain Standards and Recommended Practices related to security aspects of airplane design in Amendment 97 to Annex 8. Included is a standard that an airplane have the capability to evacuate smoke, fumes, and noxious gases—such as might be produced by an explosive or incendiary device—from the passenger cabin.

b. A draft of this AC was harmonized with the European Joint Aviation Authorities (JAA). The draft provided a method of compliance that both the Federal Aviation Administration (FAA) and JAA found acceptable. Subsequently, the European Aviation Safety Agency (EASA) was formed as the principal aviation regulatory agency in Europe. The FAA will work with EASA to ensure that this proposed AC is harmonized with ACs referred to in EASA's Certification Specifications.

5. DISCUSSION.

a. Smoke Removal, General.

(1) Prior to adoption of Amendment 25-127, there were no regulatory requirements related to removing smoke from the passenger cabin, although most manufacturers provided their customers with procedures to do so. Those procedures were based on best practices for their system, regardless of the source or intensity of the smoke.

(2) The amount of smoke that can be generated by an explosive or incendiary device is substantial, and, yet, there are limits on the capability of airplane systems to remove smoke. A regulatory requirement to remove smoke must set boundaries, based on rational premises. In that light, a general procedure for smoke removal must assume that the source of the smoke has been extinguished. Once the source has been extinguished, there is a finite quantity of smoke that must be removed from the occupied area within a certain period of time to provide acceptable environmental conditions.

b. Smoke Removal, Specific. When the fire is not extinguished, there may be acceptable procedures for removing smoke. However, due to the unknowns with a fire, there is the potential that procedures for smoke removal will worsen the situation. That is, a procedure that is acceptable in one situation may be detrimental in another. Concerns include the following:

- The location of the fire could be such that the means used to evacuate the smoke provide ventilation to the fire, thereby intensifying it.

- The dynamics of the fire itself could dramatically change normal ventilation patterns.

- Removing the smoke may convey the sense that the fire is out, even though it is continuing to burn.

c. Fire Characterization. For the purposes of this requirement, the ignition source of the fire is considered to be an explosive or incendiary device. Data from tests with these types of devices indicate that the fire that results is mostly dictated by its location in the airplane and the materials present, rather than the device itself. The fire is a function of the geometry and quantity of material available. This fact leads to the following important assumptions regarding the demonstration of compliance:

(1) The fire is a surface burning fire and, therefore, can reasonably be expected to be extinguished by personnel or by a built-in system. This is an important assumption because, as noted above, procedures for smoke removal are assumed to be effective only when the fire has been extinguished.

(2) The amount of material available to a fire can be expected to increase with the size of the airplane (i.e., the volume of the cabin), which in turn will increase the amount of smoke and gases generated. This relationship ties the quantity of smoke to the volume of the cabin. For the purposes of this guidance, the ratio of smoke quantity and cabin volume is assumed to be constant for any size of airplane. For airplanes with more than one passenger deck, each deck should be addressed independently.

6. ASSUMPTIONS. The guidance provided in paragraph 7 below, as to a demonstration of compliance with § 25.795 (b)(2), is based upon the following assumptions, as discussed in paragraph 5:

a. The airplane structure and systems are functional after the event. Therefore, no structural or systems damage or reduction in performance need be considered.

b. The airplane is operating in any phase of flight. There are foreseeable conditions when the airplane may not always be configured to provide the necessary airflow, such as during

- idle descent operations;
- short duration air conditioning "packs off" operations during take-off and initial climb;
- "packs off" operations during a "go-around;" and
- landing procedures requiring a "hold" in the descent phase.

However, the capability should be readily available. From the time the crew initiates the procedures to provide for cabin smoke evacuation, the airplane should be capable of providing the necessary airflow within 20 seconds.

c. The flow behavior of smoke, fumes, and noxious gases is identical to that of visible smoke. The removal of smoke is assumed to equally remove any fumes and noxious gases that are present.

d. If compliance is shown through use of a rapid air change, outside air must be used to clear the smoke from the passenger cabin. Outside air must be used for analysis or testing for the purpose of showing compliance.

e. If a smoke clearance demonstration procedure is used to show compliance, smoke may migrate to any part of the airplane, except the flight deck, before being vented overboard.

7. DEMONSTRATION OF COMPLIANCE. Requirements related to smoke protection of the flightdeck continue to apply, and actions taken in compliance with § 25.795(b)(2) should have no adverse effect on removal of smoke or minimization of the penetration of smoke into the flightdeck. Compliance may be shown with the systems and equipment, which affect cabin airflow, fully operational.

a. Cabin Airflow Performance. Based on a review of full-scale fire test data, the FAA established relationships of the hazard level within a certain volume of the passenger cabin to smoke concentration over time. Examples are given in Appendix 1. One means of demonstrating compliance is to remove smoke from the passenger cabin through uninterrupted changes of cabin air with outside air. The FAA has determined that an air change rate of at least once every 5 minutes for at least a 30-minute continuous period meets the compliance requirement and is sufficient to prevent the smoke from becoming incapacitating. Once initiated, the airplane should continue to provide the necessary average airflow over any 5-minute interval, including transient events, such as:

- transition in bleed source;
- transition in power source; or
- reduced flow for hydraulic or control surface demands.

Using an average over 5 minutes recognizes that, when following the emergency procedures in the flight manual, the instantaneous air change rate may be reduced due to transients. As noted in paragraph 6, this is not necessarily the normal operating regime of the ventilation system. The system should provide sufficient capacity for the time needed to evacuate the smoke. The system could then be restored to normal operation. Alternatively, special valves might be installed to effect evacuation, although the effect on cabin pressurization would have to be considered, so that no other hazard to occupants is created. Such hazard would include both the rate of pressure loss and the absolute cabin pressure. Demonstration of compliance for this requirement would be through analysis or tests.

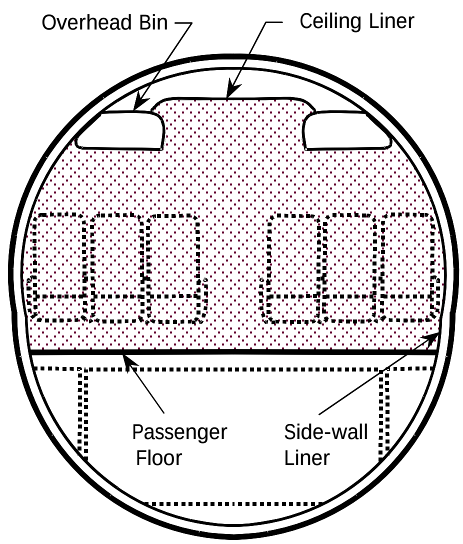
(1) Analyses. For the analyses, the applicant would need to show that the required outside air can be provided for all flight conditions, except as noted in paragraph 6b, taking into consideration variations in the capability of the air source.

(a) When performing these analyses, the applicant may do the following:

(i) Take credit for all outside air entering the passenger cabin that will aid in removing contaminants; and

(ii) Compute the passenger cabin volume from those compartments that would be expected to contain passengers and crew—excluding the flightdeck, crew rest area within the flightdeck and isolated crew rest areas (i.e., remote crew rest areas not located on the passenger deck)—during the smoke evacuation. The passenger floor, sidewall and ceiling liners, and the overhead stowage bins define the lateral boundaries of the passenger cabin volume, as illustrated in Figure 1. The fore and aft limits are defined by the flightdeck bulkhead and aft passenger cabin boundaries. Note that airplanes with more than one passenger deck may require further assessment.

Figure 1. Region within Fuselage Cross-Section that Defines the Outer Boundaries of the Passenger Cabin Volume



(b) The air change rate is defined as:

$$Air\ Rate\ Change = \frac{Passenger\ Cabin\ Volume\ (ft^3)}{Outside\ Airflow\ (ft^3/min)}$$

It is not necessary to consider individual cabin zones when computing air change rates.

(2) Tests. If a test is chosen to demonstrate compliance, relevant portions of the smoke removal procedures in AC 25-9A may be followed. Small amounts of smoke are allowed to remain in parts of the passenger cabin, since complete homogeneous mixing of outside air with smoke would not be expected.

b. Protective Breathing. An applicant would have to define to the satisfaction of the FAA how the applicant would accomplish either b(1) or b(2) of this section. The objective of any alternative approach should be to keep the fractional effective dose below 1, as described in Appendix 1. To that end, a definition of initial conditions is needed that is consistent among models. Appendix 2 provides data from testing and the resulting initial conditions that should be used, if alternative methods of compliance are utilized.

(1) An alternative to direct evacuation of smoke from the passenger cabin is to provide cabin occupants with protective equipment to avoid the hazard. Under this alternative, the equipment would need to provide protection for the duration of the flight, assuming worst-case diversion times. Any protective devices for in-flight use should not compromise passenger evacuation. Generally, this would mean that the devices would be accessible only when necessary in flight. Various studies have shown that protective breathing devices can increase evacuation times because passengers devote considerable time to donning the equipment rather than exiting the airplane.

(2) A combination of smoke evacuation and protective equipment for the occupants might also be an option. In this case, procedures would need to be developed to account for various scenarios, such that the combination would be effective. Appendix 1 shows a typical Fractional Effective Dose (FED) curve from a combination of protective breathing equipment for passengers and smoke evacuation.

c. Additional Alternatives. If another method of compliance is used for any airplane configuration, § 25.795(b)(2) requires that the applicant must show that the applicant's method will prevent the FED value (as explained in Appendix 1) from reaching 1.0 with an initial combined volumetric concentration of 0.59% carbon monoxide and 1.23% carbon dioxide in the passenger cabin. The value provided in Appendix 2 may be used in supporting the applicant's method.

d. Combination Passenger/Cargo Arrangements. The basic assumptions used to establish smoke quantity and air change rates were based on typical passenger carrying arrangements. For combination passenger/cargo ("combi") arrangements, the same approach would tend to yield higher initial concentration values and, therefore, a higher rate of air change required to maintain an FED below 1.0. This is because the volume of the cargo compartment is large with respect to the volume of the passenger compartment. For the purposes of § 25.795(b)(2), however, the assumptions used to arrive at the required air change rate for passenger airplanes are considered acceptable for combi airplanes, and the methods of paragraphs 7a and 7b are acceptable for those airplanes as well.

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Appendix 1

Hazard Assessment

1. INTRODUCTION. Determining an acceptable means of compliance requires knowledge of several parameters as well as establishing suitable criteria of success. The following discusses each of the relevant parameters and the means of establishing environmental conditions that will prevent incapacitation, defined by a Fractional Effective Dose (FED) of 1.0.

2. HAZARD PARAMETERS. The hazards to passengers from cabin smoke can be characterized by the toxic gases and the time variation of their concentrations. If one assumes that the airflow patterns within the passenger cabin maintain a steady outflow with uniform mixing of outside air, then the variation of smoke concentration over time will be in the form of an exponential decay, as shown in Chart 1 of this appendix. This decay is described by the equation:

$$C(t) = C_o e^{-(t/\tau)}$$

Where,
$C(t)$ is the percentage concentration of smoke by volume, as a function of time
C_0 is the initial percentage concentration of smoke by volume
t is passenger smoke exposure time (in minutes)
τ is the time for one cabin air change (in minutes)

a. As noted above, a number of simplifying assumptions have been made in defining this relationship. For example, the effects of diffusion within a space are not considered, as these will vary from airplane to airplane and significantly complicate the calculation. However, preliminary analyses, which consider diffusion, indicate that the simplified approach correlates sufficiently well to define a compliance approach.

b. Assuming that the passenger-cabin air change rate, τ, is known, the initial concentration will establish the concentration reductions for all other times. This concentration model describes the time relationship for a specific gas in a given volume. Each gas that is considered hazardous is assumed to behave in the same manner. Carbon monoxide and carbon dioxide are two consistently common by-products of combustion and are used to characterize all hazardous by-products from a fire. The time variation in concentrations of each is modeled separately to assess their combined effect on human tolerance. Establishing the basis for this initial concentration level is pivotal to the basic problem of smoke evacuation. The following provides the rationale used:

c. A review of available test data reveals that the most relevant data relates to cargo compartment fires. The FAA has data available to characterize the concentrations of smoke and gases produced by such a fire at the time it was extinguished. The cargo compartment fire is considered a good basis for assessing hazards because it can be readily detected and extinguished if it is a surface fire. In addition, the cargo compartment is considered a possible location for an explosive or incendiary device.

d. In order to quantify the initial density of smoke in passenger cabins from test results, it is necessary to equate the smoke data from cargo compartments to passenger cabins. This can be accomplished by compensating for the volume differences between the two. For example, if the initial concentration for a particular gas were 2% by volume in a 100-ft^3 cargo compartment, this would translate to a concentration of 0.2% in a 1000-ft^3 passenger compartment. However, because the explosive device is a localized event, it is likely that the smoke and gases would initially be restricted to a confined area of the cabin before they had time to disperse. While the resultant distribution of smoke and gases over time would likely involve the entire cabin, by treating the local area as an independent volume from which the smoke and gases must be evacuated, a conservative assessment of the hazard can be made. It is, therefore, assumed that the smoke and toxic gases are confined to 1/4 of the cabin volume. So, in the example above, the initial concentration used for the hazard assessment would be 4 times 0.2%, or 0.8% by volume. This initial smoke concentration value, C_0, would then be used to calculate the concentration decay over time.

e. Based on the test data and this volumetric relationship between the sizes of cargo compartments and passenger cabins, the FAA has determined that the initial combined volumetric concentrations of 0.59% carbon monoxide and 1.23% carbon dioxide should be assumed in the passenger cabin when determining occupant protection against smoke incapacitation. These initial conditions are also contained in Appendix 2.

f. There is no distinction between smoke, its constituents, and other potentially hazardous products of combustion in terms of their dissipation rates over time. That is, all particulates and gases are assumed to maintain their relative percentages within the smoke, even though their absolute percentages relative to the cabin air diminish with time.

3. PASSENGER HAZARD CHARACTERIZATION. There are numerous methods available to assess hazard and numerous variations of each of them. One generally accepted method is a FED hazard model. FED considers the cumulative effects of varying exposures to various contaminants over time. There are several parameters of FED that include temperature, smoke density, and various gases. However, these parameters largely depend on the associated products of combustion for any particular fire. Since there is no way to predict the fuel for the fire, it is necessary to use representative data to establish a standard. The FED is described in the general form:

$$FED = \Sigma_1^n FED_i$$

Where,
FED_i is the fractional effective dose for a given hazard, and
n is the total number of hazards considered

Each product of combustion has its own relationship to toxicity over time. An FED value of 1.0 or greater would indicate passenger incapacitation for these assessments. According to data from the FAA's fire testing program, carbon monoxide has the greatest contribution to FED. Carbon dioxide causes increased respiration rates, which magnifies the effect of carbon monoxide. These two combustion products tend to dominate the FED calculation in the data used by the FAA in developing this guidance. See Chart 2 in this appendix for graphical examples of FED calculations. Further information on the concept of FED can be found in the following:

- Society of Fire Protection Engineers "Handbook of Fire Protection Engineering," Second Edition, dated 1995.

- FAA report DOT/FAA/AR-95/5, "Toxicity Assessment of Combustion Gases and Development of A Survival Model," dated July 1995.

4. SAMPLE CURVES.

a. Chart 1 shows an example of the exponential decay of hazardous gases over time and the change in oxygen concentration that results.

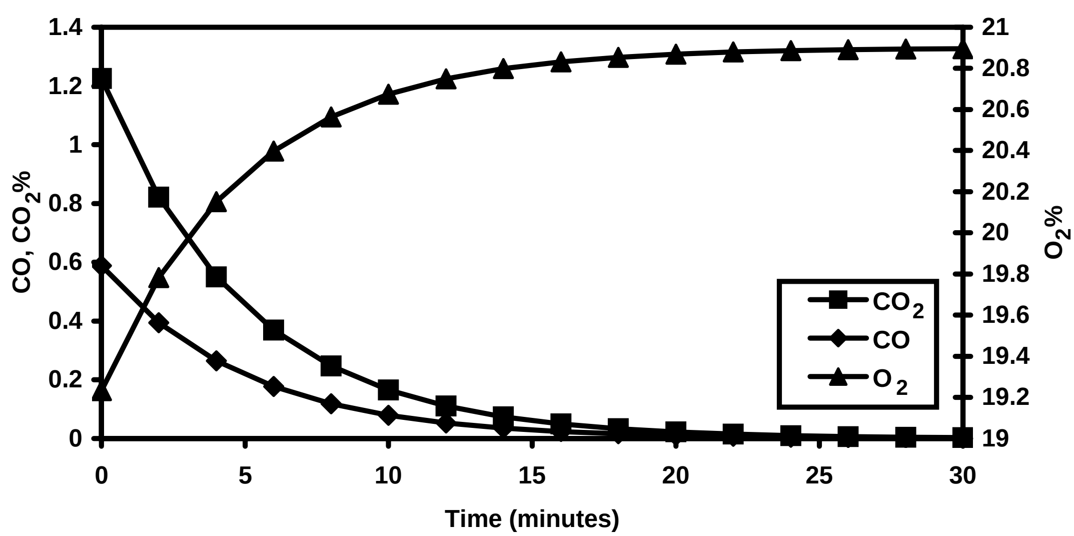

Chart 1. Decay of toxic gas concentrations with an associated increase in oxygen concentrations over time from a smoke evacuation with a five-minute air change rate.

b. Chart 2 shows an example of both an acceptable and an unacceptable FED profile, while using the same baseline data. Note that a small increase in time for an air change is sufficient to drive FED above 1.0. Also included is an FED curve showing the effect of two minutes of use of protective breathing equipment by passengers before exposure to the cabin air.

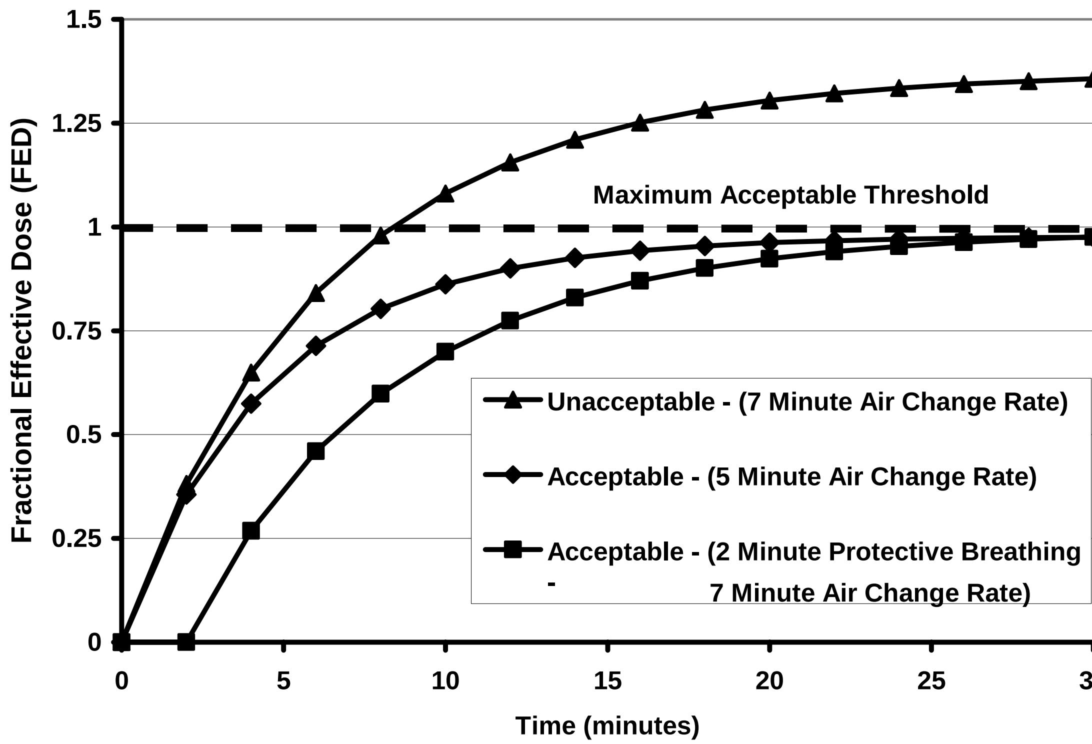

Chart 2. FED accumulation curves for a smoke evacuation with a seven-minute air change rate (unacceptable), a five-minute air change rate (acceptable), and a seven-minute air change rate using protective breathing equipment for the first two minutes (acceptable).

Appendix 2

Initial Concentration Data

The FED curves in Appendix 1 are based on empirical data from full-scale fire tests. In the absence of other rationally generated data, the initial concentrations that should be used in assessing alternative methods of compliance are shown in the right-most column (Initial Concentration in Cabin Area) below:

Constituent	Initial Concentration from Tests (% Volume)	Initial Concentration in Cabin Area (% Volume)
CO	1.20	0.59
CO_2	2.50	1.23
O_2	17.50	19.23

The data for initial concentrations in the cabin area are based on the volumetric relationship between passenger compartments and cargo compartments. While this relationship is not a constant among all airplanes, there is a range of values, and the FAA has selected an acceptable value within this range on which to base these concentrations.