Aircraft Cabin Smoke Control with Converging-Diverging Nozzles

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16. Abstract

The characteristics of converging-diverging nozzles are compared to those of converging nozzles for use in aircraft cabin smoke control. The peak flow flight regimes for the two different nozzles are compared by means of test data taken on a Boeing 757. The converging-diverging nozzle is shown as capable of maintaining peak volumetric flow over a wide range of airplane cabin pressure and flight altitude combinations. Sample capacities and flow schedules are presented for installation of converging-diverging nozzles in Boeing 737 aircraft.

17. Key Words Fire safety, Smoke control, Venting, Nozzles, In-flight fire, Smoke evacuation	18. Distribution Statement This document is on file at the Technical Center Library, Atlantic City International Airport, NJ 08405

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EXECUTIVE SUMMARY

Past airplane ground and flight tests have demonstrated the difficulty of controlling and evacuating smoke from the passenger cabin when in-flight fires are simulated. Buoyant smoke in particular is difficult to confine and eliminate because of its ability to spread throughout the fuselage in short periods of time. The majority of past airplane tests on cabin smoke control have used aerosol generators that had nearly neutrally buoyant outputs.

More recent tests have shown that a ventilation outflow valve in the aircraft cabin ceiling can offer improvements in venting locally produced buoyant smoke. Furthermore, when strong enough airflows are provided in an axial direction in the cabin, a buoyant plume of smoke can be confined to the locality where it is being generated. The smoke control triad consists of ventilation flow direction, ventilation flow quantity, and efficient flow removal.

This report demonstrates that use of converging-diverging nozzles for cabin smoke removal offers performance advantages over converging nozzle installations. Because converging nozzles require a large pressure ratio across the aircraft hull, they become inefficient fairly early in an emergency or rapid aircraft descent. Converging-diverging nozzles require relatively small hull pressure ratios, and with judicious use of cabin pressurization control, can be operated with peak flow all the way through descent and after touchdown.

The converging-diverging nozzles are required to have volumetric settings that accommodate the number of air packs in operation, airplane leakage, airplane pressurization, and the employment of cabin air recirculation. The sample nozzle for installation in a B737 is scheduled for volumetric flow settings between 600 and 1500 cubic feet per minute.

INTRODUCTION

PURPOSE.

Past aircraft accidents resulting from in-flight fires have almost always involved smoke spreading through the passenger cabin during aircraft descent. This smoke has caused passenger incapacitation, interfered with aircraft evacuation, and affected the flight deck crew's ability to perform essential tasks. Aircraft systems modifications or enhancements could reduce the accumulation of smoke in the cabin, and converging-diverging nozzles represent a possible approach. This report presents an evaluation of the performance capability that could be attained with the aircraft installation of one or more converging-diverging nozzles.

BACKGROUND.

Accidents resulting from in-flight fires are a small percentage of the aircraft accidents that involve fire (reference 1). Although in-flight fire and smoke incidents are frequent, few of these become serious enough to fit under the category of accident (reference 2). Past in-flight fire accidents have generally resulted in fatality for the majority of aircraft occupants. This is due to the amount of time required to bring a cruising jet from a high altitude to a landing at an airport. Typically this time is approximately twenty minutes though it has been shorter for aircraft on approach (reference 3) and can be considerably longer for aircraft over water (reference 4). These protracted times, during which no egress for the occupants is possible, are adequate for relatively small fires to grow to the point where aircraft are damaged and smoke spreads throughout the cabin. Safety improvements have been sought through fire prevention, faster response to fire, improved procedures for clearing smoke, and improved systems for smoke control. The improved systems approach could include alternate or augmented ventilation air for the cabin and additional air outflow valves on the fuselage lower hull (reference 5). Establishing an outflow valve on the upper part of the fuselage has also been tried (reference 6). This latter modification was motivated by considerations associated with the buoyant effects on smoke movement.

While nonbuoyant smoke could be confined to the region of origin by cabin ventilation flows under specific circumstances, buoyant smoke could spread throughout the passenger cabin regardless of where the smoke originated (reference 7). Installation of smoke evacuation nozzles on the upper fuselage was actually proposed much earlier in a patent awarded to Bruensicke (reference 8) and reproduced here as appendix A. In the Bruensicke patent, a series of converging nozzles are placed at the top of the hull and opened selectively near the fire source. Because of the high pressure differential across the fuselage hull and the low outside ambient pressure at cruising altitudes, the Bruensicke nozzles operate with sonic flow at their exit plane. This allows relatively small openings to discharge large amounts of air. The Bruensicke nozzles will remain sonic at the throat and thereby operate at maximum output so long as the internal hull pressure exceeds the external free stream static pressure by a factor of about 2. Once the pressure ratio across the aircraft hull drops below this ratio, the flow at the nozzle exit plane will turn subsonic and the total volumetric flow will decrease monatonically as the pressure ratio drops.

Consequently, as the aircraft descends from a cruising altitude, a point will be reached in the flight where sonic flow out the nozzle ends and the capacity of the nozzle to evacuate smoke from the aircraft will continue to diminish to zero after the aircraft lands.

Use of a converging-diverging nozzle instead of a converging nozzle provides for maintaining sonic throat conditions over a wider range of pressure ratios across the hull. In such a nozzle, the converging section performs the function of converting gas energy from pressure into velocity. The diverging section allows conversion of kinetic energy into higher pressure before discharge at the exit. This pressure recovery feature allows converging-diverging nozzles to maintain sonic throat conditions with relatively low overall pressure ratios. Well designed converging-diverging nozzles can maintain sonic throat conditions when the overall pressure ratio is between 1.1 and 1.2.

OBJECTIVE.

The performance capabilities of converging-diverging nozzles for aircraft cabin smoke evacuation will be compared with the capabilities of converging nozzles. A concept design will be developed for application to Boeing 737 aircraft.

PERFORMANCE COMPARISON

When operating with sonic throat conditions, both converging and converging-diverging nozzles pass a mass flow rate given by Fliegner's formula

$$w = KpA / \sqrt{T} \tag{1}$$

where w is the mass flow, K is a constant, p is the inlet total pressure, A is the throat area, and T is the absolute total temperature. Using the perfect gas law, Fliegner's formula can be recast as

$$V = KRA\sqrt{T} \tag{2}$$

where V is the volumetric flow leaving the upstream control volume (aircraft cabin in this discussion) and R is the gas constant for air. This shows that the volumetric flow is independent of the aircraft internal cabin pressure. As a result, these nozzles naturally match up with the characteristics of the cabin air fresh air delivery systems of jet airliners. These supply systems are generally designed to provide close to a constant volumetric (rather than mass) air delivery rate over the range of normal operating conditions

The two types of nozzles will be compared for aircraft application in three ways. The most straightforward comparison is according to present typical emergency procedures for fire or smoke in the passenger cabin. Typically, these procedures call for the flight deck crew to raise the cabin altitude to 10,000 feet and proceed to the nearest usable airport. According to the 1962 U.S. Standard Atmosphere, the ambient pressure at this altitude is 1456 lb./ft^2. In order to maintain sonic conditions, the ratio of outside pressure to cabin pressure must be less than 0.528 which corresponds to 753 lb./ft.^{2} or (or an altitude of 26,000 feet). Regardless of the initial cruise altitude, the converging nozzle will start decreasing volumetric flow once the descending aircraft passes through 26,000 feet. In contrast, if a converging-diverging nozzle were to maintain sonic throat conditions at overall pressure ratios of 0.85, then it would continue to maintain peak flow until the external pressure were 1238 lb./ft.^{2} which corresponds to an altitude of 14,000 feet.

A second way to compare the effectiveness of the two types of nozzles is through examination of a hypothetical situation where a maximum hull pressure differential of 8.5 lb./in.^{2} (1224 lb./ft.^{2}) is maintained from cruising altitude all the way to touchdown. For the converging nozzle, sonic exit conditions will continue until the ratio of external to internal pressure reaches 0.528 or

$$\frac{p_{EX}}{1224 + p_{EX}} = 0.528 \qquad (3)$$

This corresponds to an external pressure of 1369 lb./ft.^{2} or an altitude of about 12,000 feet. Under the conditions of 8.5 lb./in.^{2} pressure differential across the hull, the converging-diverging nozzle will maintain peak flow all the way to touchdown.

A third comparison of the nozzles can be made from data taken from relevant flight tests. The flight tests were those reported in reference 6 in which a B757 was used to evaluate effects of systems changes on cabin smoke evacuation during simulated emergencies. These tests involved continuous cabin smoke generation at cruise, through rapid descent, and during aircraft landing. Manual notes documented in reference 9 included hull pressure differential and airplane altitude for all nine flight tests. Of these, the two shortest and the two longest in test duration will be used for comparison of nozzle performance.

Table 1 shows the data for the four selected tests. Both the altitude and the pressure differential are plotted in figures 1 through 4. The differential pressure is read against the left vertical axis on each graph and the altitude against the right vertical axis. For both converging and converging-diverging nozzles, the previous examples showed that for every altitude's pressure there is a minimum cabin pressure below which the nozzles will no longer be sonic. Thus, a differential hull pressure can be calculated at each altitude to provide this minimum cabin pressure for sonic flow. The equations for the converging and converging-diverging nozzles respectively for the considered cases are

$$\Delta p = 0.894\, p_{EX} \qquad (4)$$

$$\Delta p = 0.176\, p_{EX} \qquad (5)$$

where p_{EX} is the external pressure at a given altitude and Δp is the required hull pressure differential.

In figures 1 through 4, these calculated differential pressures are co-located with and labeled at the appropriate altitude. The left plot in these figures shows the measured pressure differential decreasing with time. The graph on the right shows the aircraft altitude as a function of time in a given flight test. The elapsed time on the x-axis represents the time since the simulated emergency began (represented by continuous generation of smoke in the cabin). After a short time at constant altitude, the aircraft was put into a rapid descent and then landed at the selected airport.

The cabin pressure differential and altitude records in the four tests were used to evaluate nozzle performance using a procedure that will be described for figure 1. The altitudes can be matched to standard atmosphere pressures. Equation 4 then provides the minimum cabin pressure differential for sonic throat conditions for converging nozzles. The scale at the top of figure 1 that is labeled by the letter A shows the pressure differentials for the corresponding altitudes. Similarly, the scale on the lower part of the figure and labeled by the letter B shows the minimum cabin pressure differential for sonic throat conditions in a converging-diverging nozzle. The scale labeled B results from application of equation 5.

The time of nozzle effectiveness is found by finding the point in time where the cabin differential of the left hand graph matches the minimum pressure differential for the corresponding altitude displayed on the right hand graph. Since the minimum required differential rises with time and the cabin pressure differential falls with time, the match occurs at only one point. In figure 1, the converging nozzle remains at full flow rate until 5 minutes and 30 seconds of test time have elapsed. The converging-diverging nozzle remains fully effective for 15 minutes and 20 seconds. In figure 1, airplane touchdown occurs at 21 minutes after the start of the test.

If the cabin altitude selector were set at an appropriate level below the airport altitude, converging-diverging nozzles would continue their maximum flow rate until aircraft touchdown when the pressure controlling outflow valves move to the full-open position. If the outflow valves could be held in the closed position after touchdown, sonic flow conditions could persist in the converging-diverging nozzles all the way up to engine shut-down. In the four flight tests analyzed, the converging-diverging nozzle provides peak volumetric flow for periods 3 to 5 times longer than converging nozzles. Sonic flow is lost only in the last two to five minutes before touchdown.

CONCEPT DESIGN

A concept design was developed for the B737 for invention disclosure purposes and resulted in patent award for a Minimum Area Smoke Evacuation Nozzle (reference 10). The patent is reproduced in its entirety as appendix B. There are many considerations associated with such a design. Among them are nozzle capacity, nozzle location, nozzle control, nozzle sizing, weight, structural integration, and airplane ventilation characteristics.

The ventilation supply to the cabin for the B737-100 and -200 is nominally 1800 ft.^{3}/min. The design concept will involve placing one converging-diverging nozzle at the top rear of the fuselage with the divergent section of the nozzle located in the dorsal fin. In the considered aircraft model, the dorsal fin (a.k.a. fin root fillet) is removable and is approximately eight feet long and five feet high at the rear. The converging section of the nozzle would be contoured so as to have the inlet flush with the cabin ceiling panels and covered by a grill.

The flow capability of such a nozzle would have to be integrated with the airplane ventilation characteristics. The airplane has two air packs and the conditions of both or only one in operation have to be considered. Additionally, fuselage leakage at high altitude cruise with high hull pressure differential has to be considered. If the smoke evacuation nozzle exhausted at too high a rate, the airplane would be unable to maintain adequate pressurization.

Thus, the target exhaust flows for the concept valve are as follows:

- above 10,000-ft. altitude, 2 pack operation: 1200 $ft.^3$/min.
- above 10,000-ft. altitude, 1 pack operation: 300 $ft.^3$/min.
- below 10,000-ft. altitude, 2 pack operation: 1500 $ft.^3$/min.
- below 10,000-ft. altitude, 1 pack operation: 600 $ft.^3$/min.

Figure 5 shows a plug and throat combination schematic in the closed position. At the maximum flow position, the minimum area of the device would be 5.5 $in.^2$. The diffuser for the assembly would be approximately 30 inches long with an 8-inch-diameter outlet. The calculations are based on a cabin altitude of 8,000 feet and cabin temperature of 72°F. Figure 6 shows the settings that establish the flow rates for the various pack configuration and altitude conditions specified above.

DISCUSSION

For cabin smoke control and evacuation, converging-diverging nozzles have the advantage of operating over a wider range of cabin pressure and altitude conditions than converging nozzles. As with the converging nozzle, the throat is located where the nozzle passes through the pressure hull. This minimizes the structural impact on and resultant required reinforcement of the hull structure.

Installation of the divergent cone or diffuser does represent an added complication for any aircraft model. Depending on the configuration of nozzle inlets within the fuselage, the divergent cones might be located in the vertical stabilizer, dorsal fin, landing gear wells, wing dry bays, or behind the aft pressure bulkhead. Although all these represent unpressurized parts of the aircraft, additional venting provisions might be necessary to avoid damaging pressure build-up within these confined areas.

The concept design considered a single nozzle located towards the rear of the fuselage. Alternate concepts might involve several nozzles distributed along the fuselage or have a duct system with isolation valves that allows smoke collected at a specified entry point to flow to a single converging-diverging nozzle. The collection points are not necessarily placed in the ceiling for smoke control. Reference 1 clearly shows that buoyant smoke movement in an aircraft cabin can be arrested only by cabin air flowing axially in the opposite direction. Thus, in terms of smoke localization and control, a major function of a converging-diverging nozzle would be establishing axial air flow in the cabin.

Reference 1 also indicated that the environmental control system of the typical jet transport is incapable of providing adequate volumetric flow rates to provide large enough axial cabin flow to control and confine buoyant smoke in tests to date. If practical ways of augmenting the air supply are developed, the converging-diverging venting system would also have to be resized accordingly.

The B737-100 and -200 air supply consists of 100 percent fresh air taken from engine bleed air. Later B737 derivative models and all current production transport jets recirculate a portion of used cabin air and mix it with the fresh air from the engines. Since emergency procedures call for shutting down the recirculation fans, there is considerably less air available in the newer aircraft for cabin smoke control. Aircraft with cabin air recirculation need to have this factor included in sizing of converging-diverging nozzles.

Even though converging-diverging nozzles will operate effectively at much lower pressure ratios than will converging nozzles, they will be ineffective when the pressure differential across the hull approaches zero. Even with stratified, buoyant smoke, very little will pass through a converging or converging-diverging nozzle located at the cabin ceiling during the aircraft evacuation period when cabin entry doors are open. In such a situation, the doors have so much larger an air flow capacity that any nozzles will vent a very small amount of the air exchange with the outside.

SUMMARY

A converging-diverging nozzle for aircraft cabin smoke evacuation has been compared to a converging nozzle and found to possess superior performance capabilities during aircraft descent and landing. Typical design flow requirements were developed for installation in B737-100 and -200 model aircraft. Difficulties in locating the divergent section of the nozzle were identified, and some potential installation schemes were listed. To be effective in controlling and evacuating hot buoyant smoke, the converging-diverging nozzles would have to be matched to the aircraft fresh air ventilation delivery schedule and allowances made for fuselage leakage as well as the number of air packs in operation.

REFERENCES

1. Eklund, T.I., In-Flight Cabin Smoke Control, International Colloquium on Advances in Combustion Toxicology, Civil Aeronautical Medical Institute, Oklahoma City, OK, April 11-13, 1995.

2. Reynolds, T.L., Grimstad, G.E., and Anderson, C.D., Aircraft Command in Emergency Situations (ACES) Phase I: Concept Development, Federal Aviation Administration, Report DOT/FAA/CT-90/21, prepared by Boeing Commercial Airplanes, April 1991.

3. Accident Involving the Boeing 707 PP-VJZ of the Varig Company (SAVLX-les-CHARTREUX), Board of Inquiry (France). Final Report, December 1975.

4. Hill, R.G., A Review of Recent Civil Air Transport Accidents/Incidents and Their Fire Safety Implications, AGARD sponsored International Conference on Aircraft Flight Safety, Zhukovsky, Russia, August 31-September 5, 1993.

5. Maylor, E.L., Enhanced Emergency Smoke Venting, Federal Aviation Administration, Report DOT/FAA/CT-88/22, Prepared by Boeing Commercial Airplanes, July 1988.

6. Maylor, E.L., Airplane Tests of Enhanced Emergency Smoke Venting, Federal Aviation Administration, Report DOT/FAA/CT-89/9, Prepared by Boeing Commercial Airplanes, March 1989.

7. Eklund, T.I., Generation of a Buoyant Plume of Artificial Smoke for Airplane Tests, Federal Aviation Administration, Report DOT/FAA/CT-90/9, September 1990.

8. Emergency Smoke Disposal System for Pressurized Aircraft, United States Patent 4,552,325, Issued November 12, 1985.

9. Maylor, E.L., Airplane Tests of Enhanced Emergency Smoke Venting (Supplemental Data), Federal Aviation Administration, Report DOT/FAA/CT-89/9-A, Prepared by Boeing Commercial Airplanes, March 1989.

10. Minimum Area Smoke Evacuation Nozzle, United States Patent 5,312,072, Issued May 17, 1994.

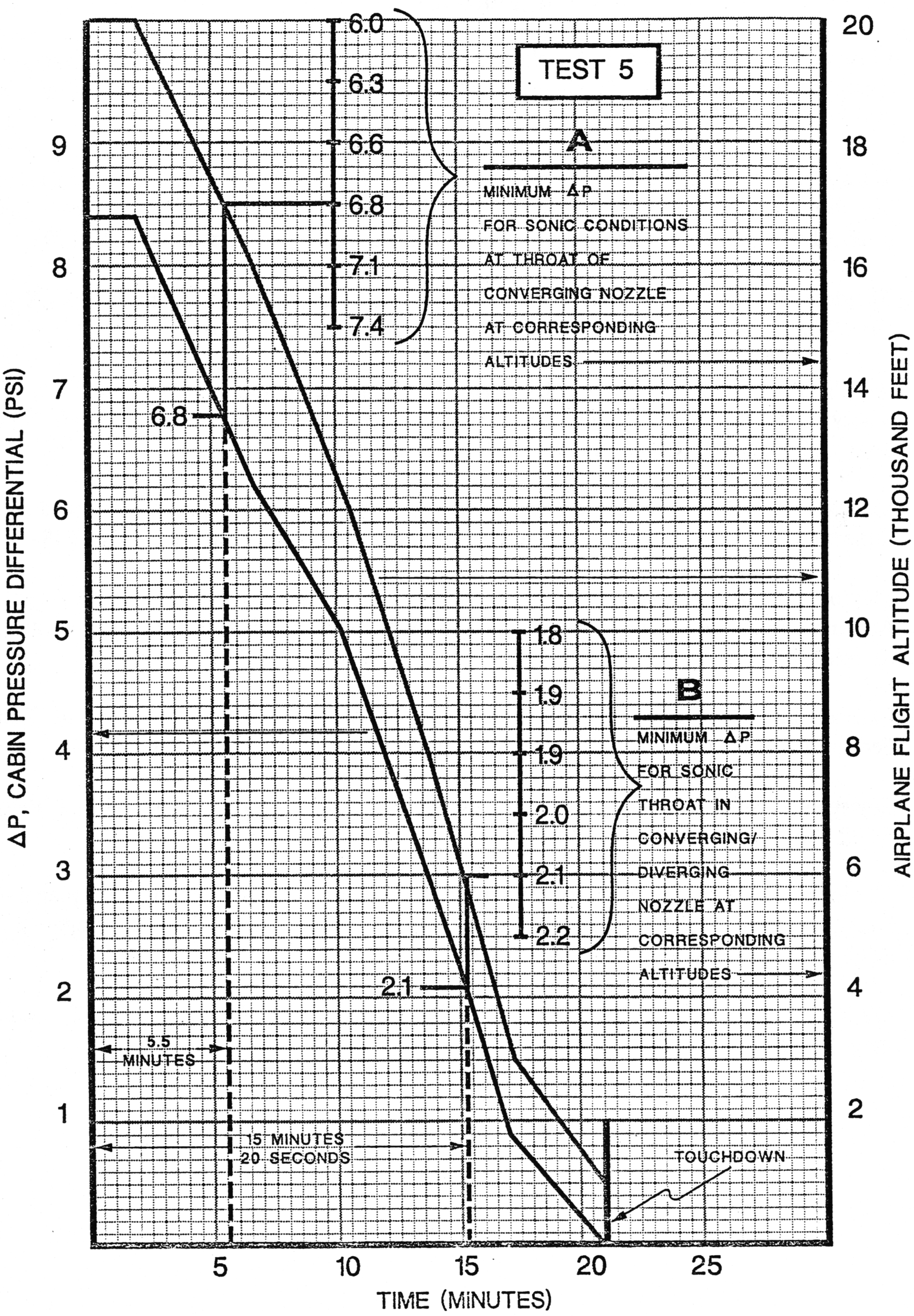


FIGURE 1. TEST NO. 5 PRESSURE DIFFERENTIAL

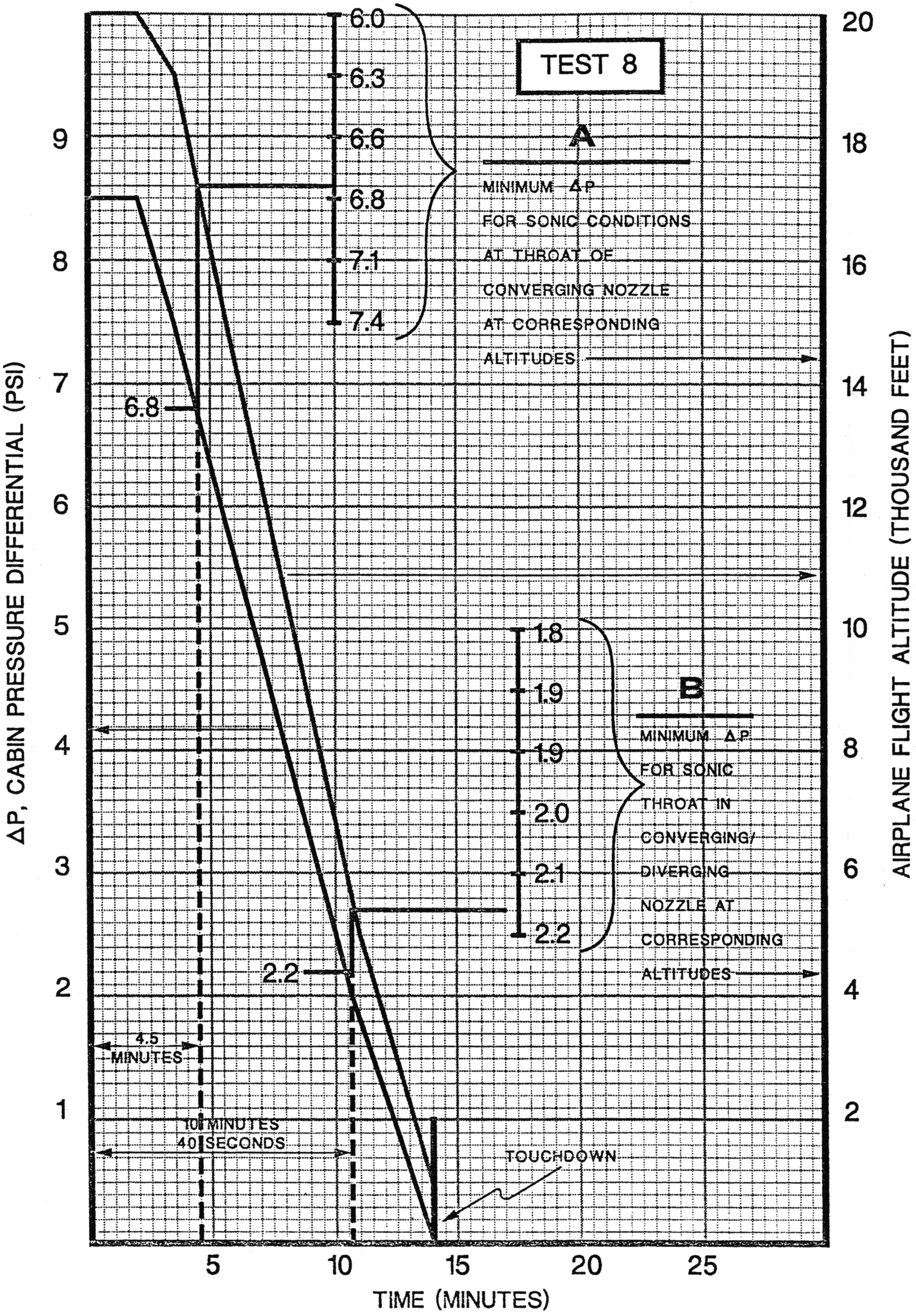


FIGURE 2. TEST NO. 8 PRESSURE DIFFERENTIAL

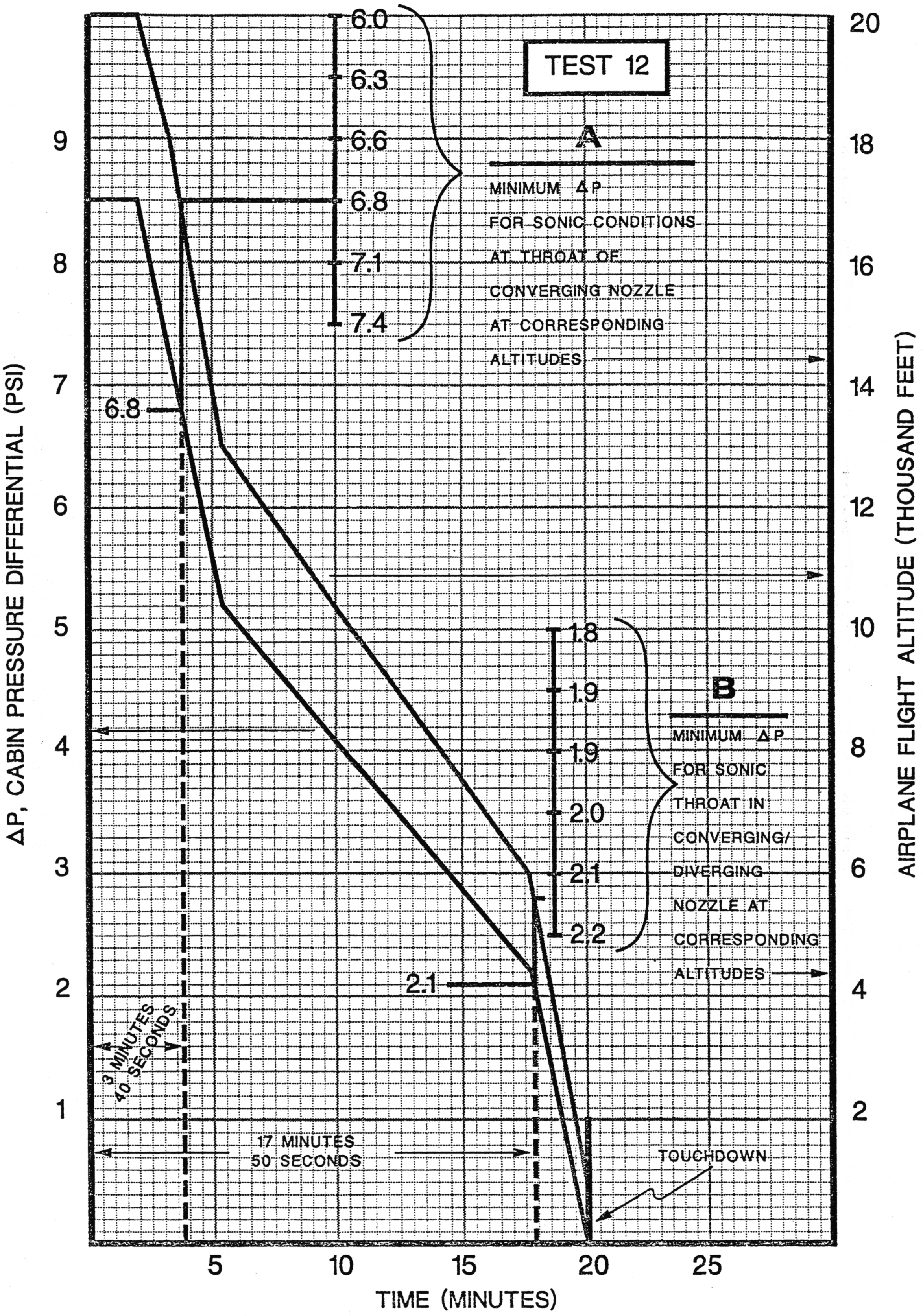


FIGURE 3. TEST NO. 12 PRESSURE DIFFERENTIAL

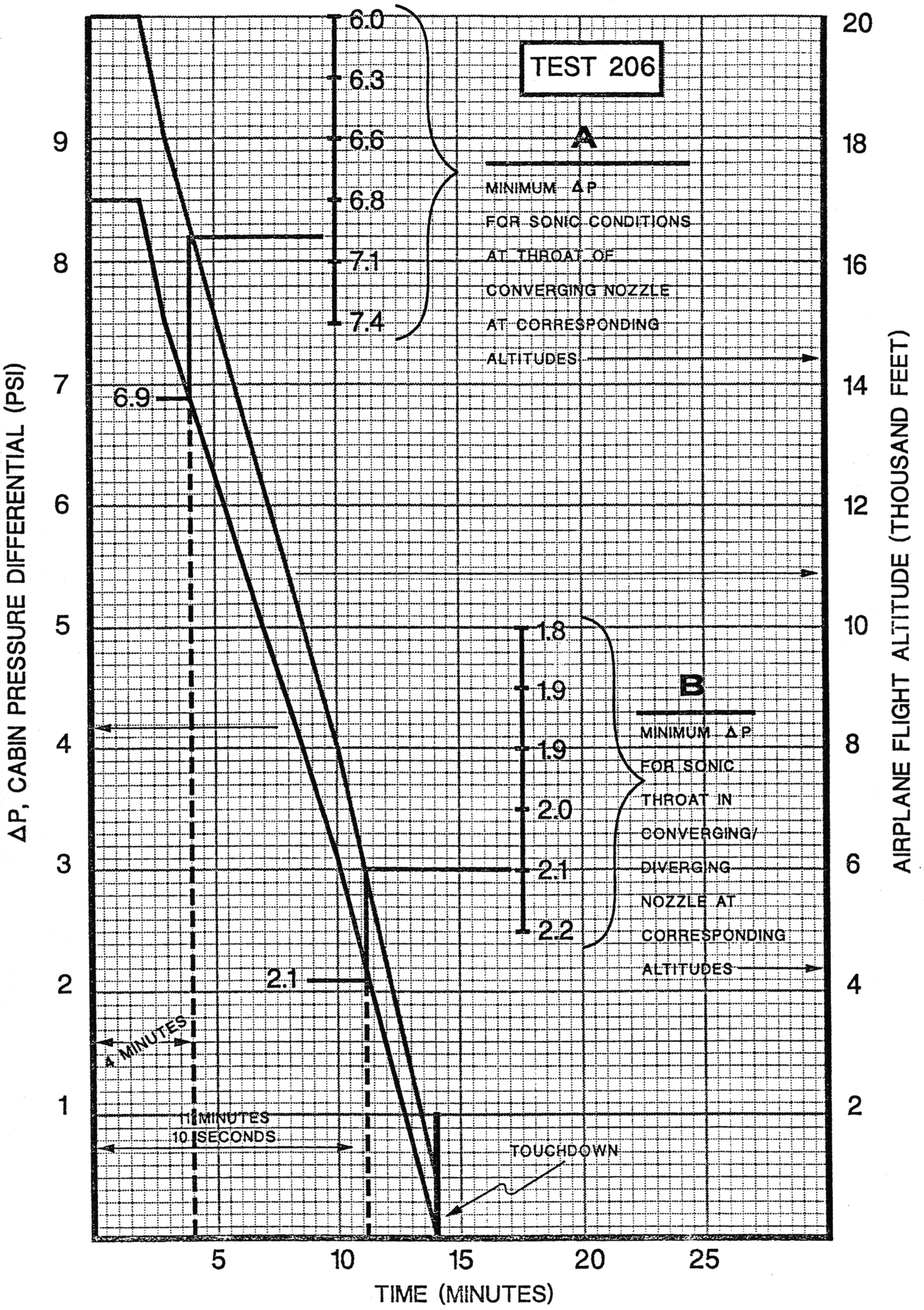


FIGURE 4. TEST NO. 206 PRESSURE DIFFERENTIAL

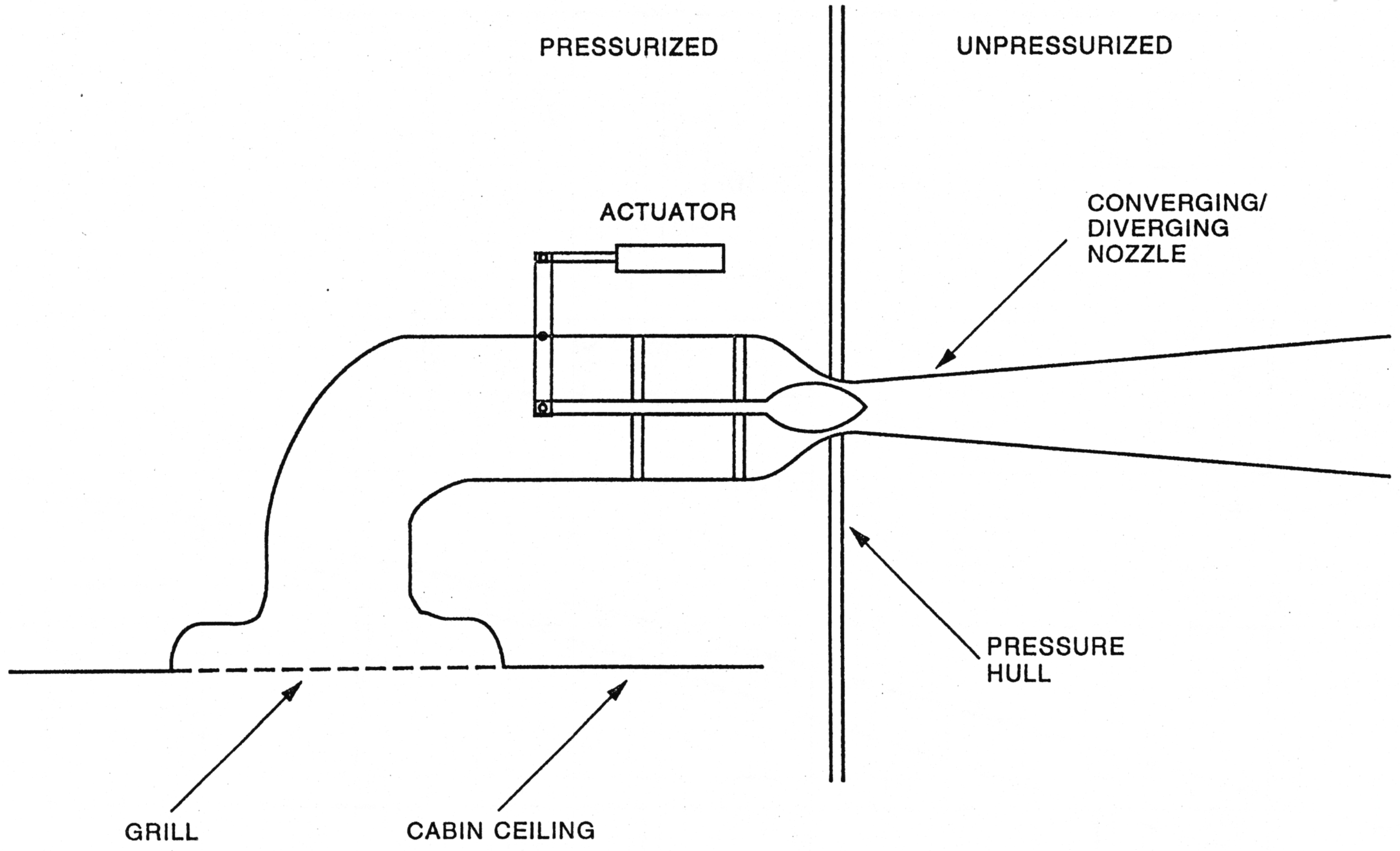


FIGURE 5. CONVERGING-DIVERGING NOZZLE SCHEMATIC

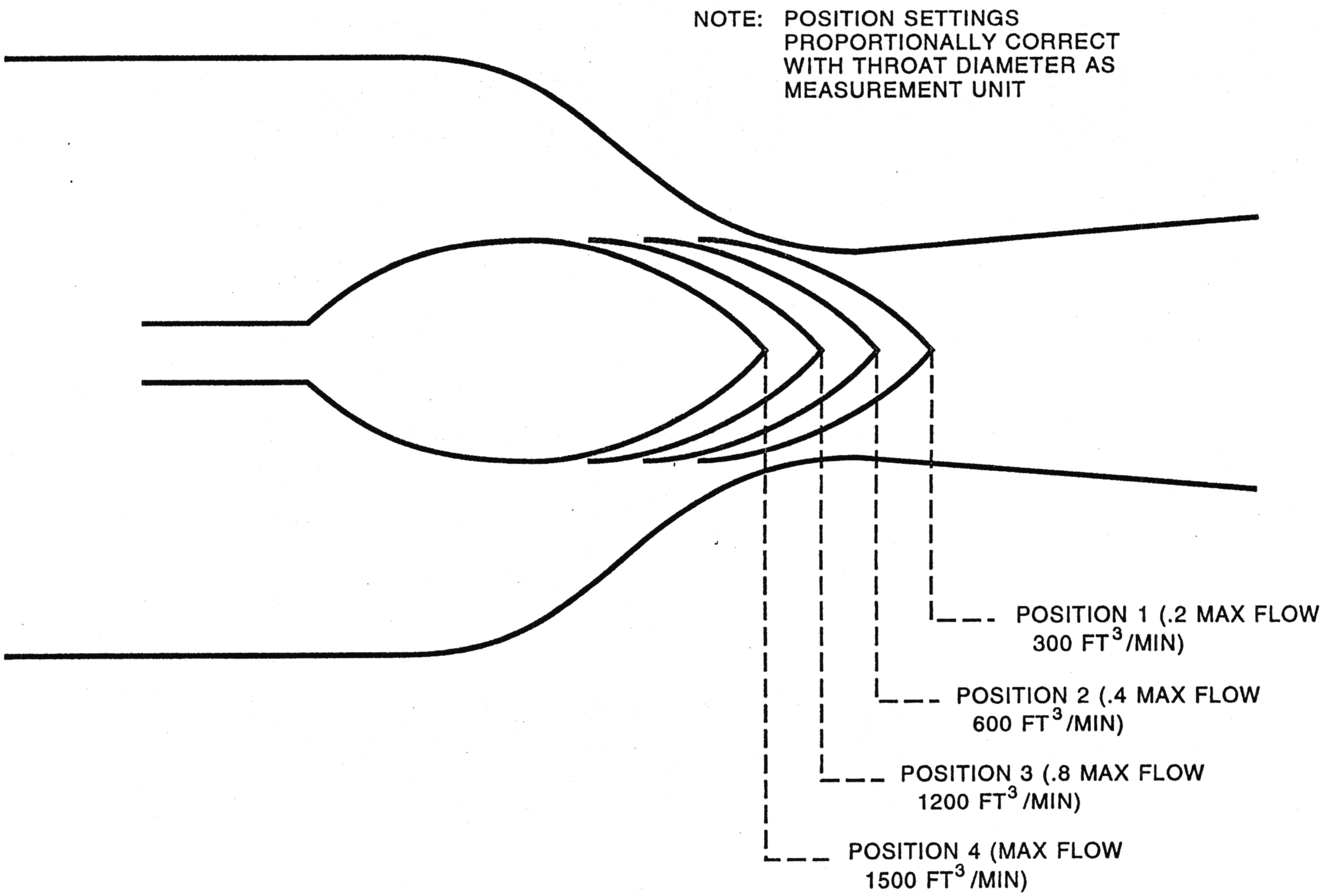


FIGURE 6. PROPORTIONAL NOZZLE PLUG POSITIONS

TABLE 1. TEST PARAMETERS

TEST NO.	ELAPSED TIME (MIN:SEC)	PRESSURE DIFFERENTIAL (PSI)	AIRCRAFT ALTITUDE (FEET)
5	0	8.4	20,000
5	2:00	8.4	20,000
5	6:40	6.2	16,000
5	10:20	5.0	12,300
5	13:40	3.0	8,000
5	17:10	0.9	3,000
5	21:03	0	TOUCHDOWN (1160)
8	0	8.5	20,000
8	2:05	8.5	20,000
8	3:25	7.5	19,000
8	10:55	2.0	5,000
8	14:05	0	TOUCHDOWN (1160)
12	0	8.5	20,000
12	2:17	8.5	20,000
12	3:30	7.2	18,000
12	5:23	5.2	13,000
12	17:37	2.2	6,000
12	20:07	0	TOUCHDOWN (1160)
206	0	8.5	20,000
206	2:04	8.5	20,000
206	20:10	7.5	18,000
206	22:44	5.6	13,000
206	26:50	3.1	8,000
206	31:00	0	TOUCHDOWN (1160)

APPENDIX A—UNITED STATES PATENT: EMERGENCY SMOKE DISPOSAL SYSTEM FOR PRESSURIZED AIRCRAFT

United States Patent [19]
Bruensicke

[11] **Patent Number: 4,552,325**
[45] **Date of Patent: Nov. 12, 1985**

[54] **EMERGENCY SMOKE DISPOSAL SYSTEM FOR PRESSURIZED AIRCRAFT**

[75] Inventor: **Wilhelm A. Bruensicke**, Santa Monica, Calif.

[73] Assignee: **Lockheed Corporation**, Burbank, Calif.

[21] Appl. No.: **422,934**

[22] Filed: **Sep. 24, 1982**

[51] **Int. Cl.^{4}** **B64D 13/00; B64D 25/00**
[52] **U.S. Cl.** **244/118.5**; 244/129.2; 15/313; 52/1; 98/19
[58] **Field of Search** .... 244/53 B, 121, 119, 244/118.5, 129.1, 129.2, 129.4; 98/1.5, 2, 43, 33, 119, 19; 15/313; 52/1; 89/1 B; 169/61, 16, 62, 11, 45, 91; 137/68 A

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,146,751	7/1915	Davis	98/19
2,085,658	6/1937	Hoffbauer	169/16
2,299,668	10/1942	Webster	15/313
2,306,420	12/1942	Allen	172/36
2,373,916	4/1945	Replogle	15/313
2,399,326	4/1946	Crot	98/1.5
2,408,774	10/1946	Goddard et al.	137/68 A
2,641,985	6/1953	Jensen	98/1.5
2,641,986	6/1953	Arthur	98/1.5
2,661,804	12/1953	Haessler	169/11
2,694,537	11/1954	Reichert	244/118.5
2,811,090	10/1957	Davis et al.	98/1.5
3,069,993	12/1962	Allgood et al.	98/119
3,195,439	7/1965	Stratton	98/2
3,393,884	7/1968	Zumbiel	244/129
3,410,191	11/1968	Jackson	98/1.5
3,418,914	12/1968	Finkin	98/2
3,428,022	2/1969	Ledley	116/137
3,461,789	8/1969	Texidor	98/1.5
3,486,410	12/1969	Drexelius et al.	89/1 B
3,486,562	12/1969	Goodloe et al.	169/11
3,511,161	5/1970	Schindelman	98/1.5
3,567,162	3/1971	Lea	244/121
3,826,180	7/1974	Hayashi	98/43
3,955,323	5/1976	Harmathy	52/1
3,964,390	6/1976	Medlock	89/1 B
3,983,892	10/1976	Hardesty	89/1 B
4,049,221	9/1977	Fountain	244/118
4,057,205	11/1977	Vensel	244/118
4,068,568	1/1978	Moss	98/33
4,121,790	10/1978	Graham	244/118
4,194,521	3/1980	Banta	137/67

OTHER PUBLICATIONS

Edward L. Lopez, "Smoke Emission from Burning Cabin Materials and the Effect on Visibility in Wide–Bodied Jet Transports, Mar. 1974, p. 13.

Primary Examiner—Galen L. Barefoot
Attorney, Agent, or Firm—Louis L. Dachs

[57] **ABSTRACT**

The present invention provides a convenient and reliable means to evacuate smoke from an interior cabin (30) of a pressurized aircraft (20) by providing a normally closed smoke evacuation outlet (102) in the skin (108) of the aircraft in fluid communication with a relatively large area smoke disposal chute (114) extending upwardly from the cabin's ceiling (50), whereby upon the activation of the outlet, the smoke (106) (that otherwise would rise to and collect below the ceiling of the cabin until the whole cabin is full of smoke) will be discharged into the external airstream, with the differential pressure between the relatively high pressure in the cabin and the relatively low pressure in the external atmosphere (particularly at the high cruising altitudes associated with the operation of modern transport aircraft) providing the actual motive power. Preferably, the outlet is designed to be opened automatically (110, 124) in response to smoke in the vicinity of the smoke disposal chute being detected by means of a conventional type of smoke detector (120). The chute between the ceiling and the outlet on the skin may also be provided with a manual means (132, 134) for blocking the further outflow of pressurized air through the skin outlet opening in the event that the apparatus has been activated inadvertently or in the event that the emergency is over.

9 Claims, 11 Drawing Figures

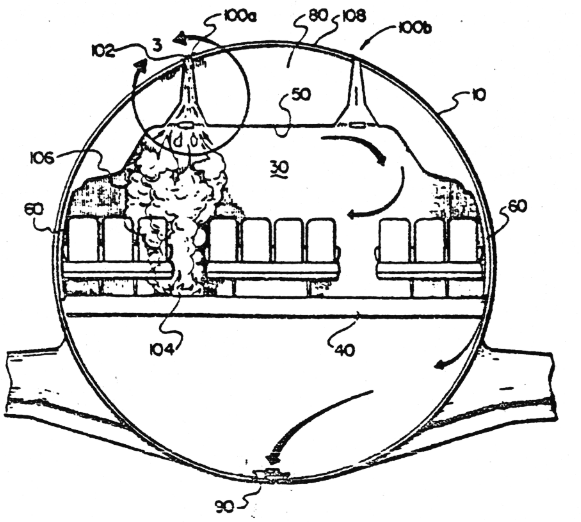
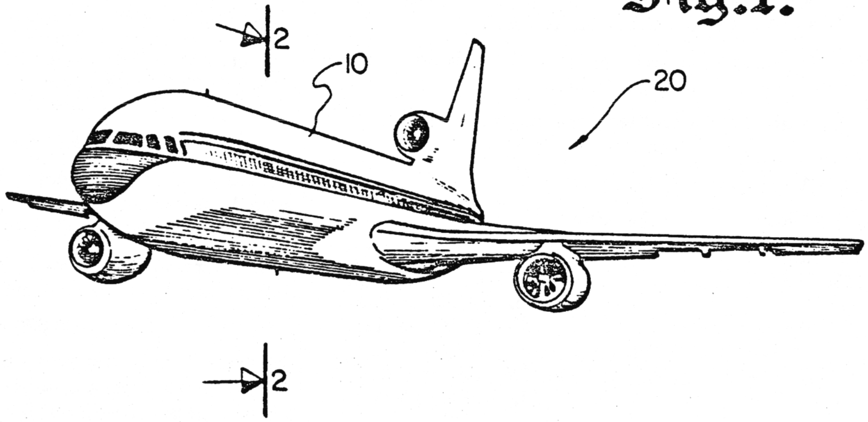


Fig.1.



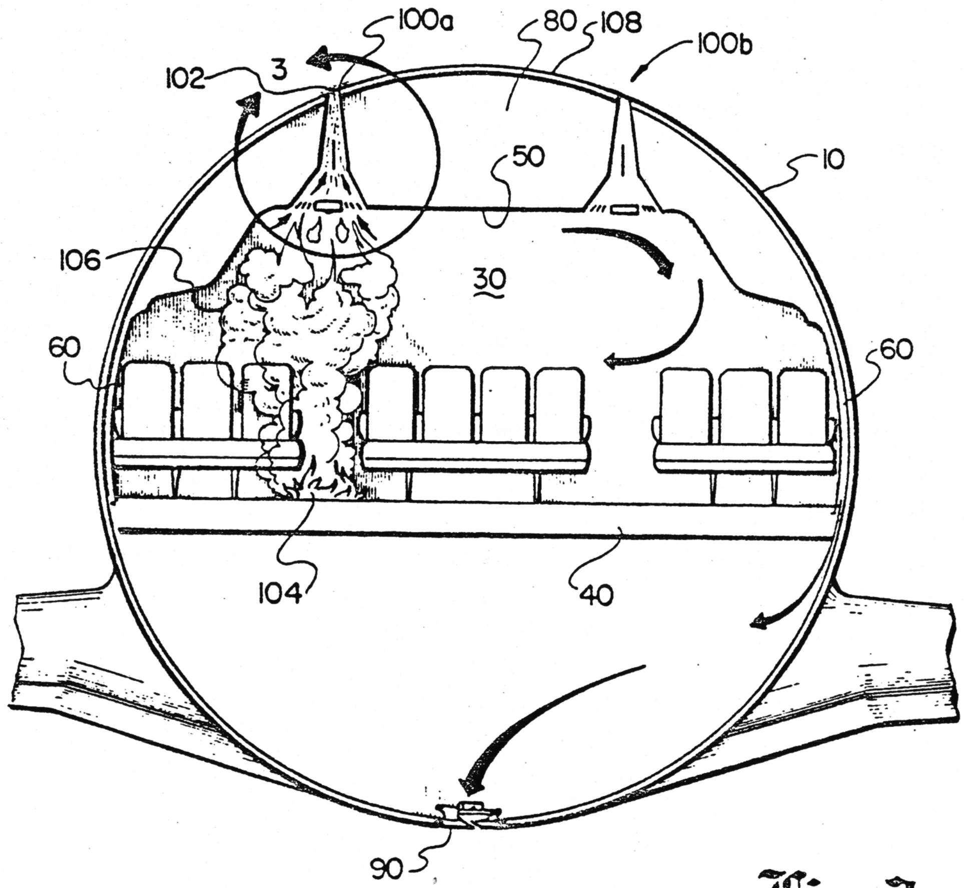


Fig.2.

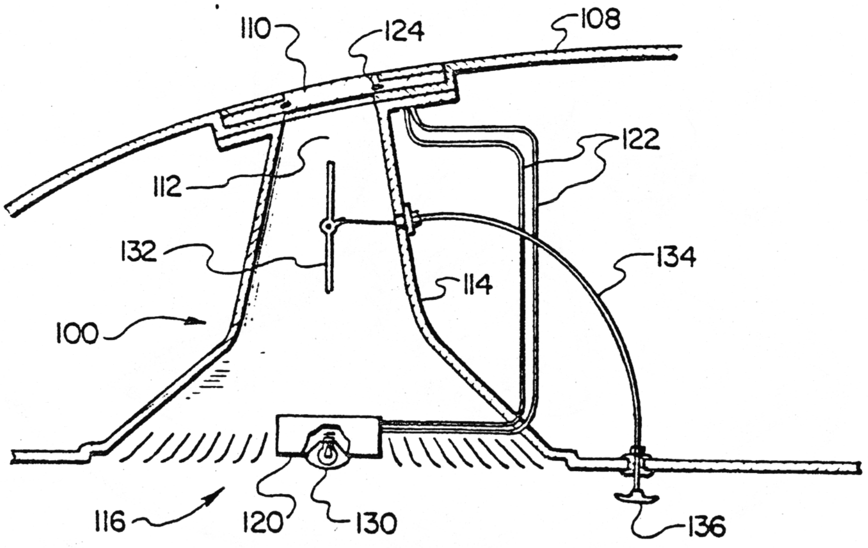

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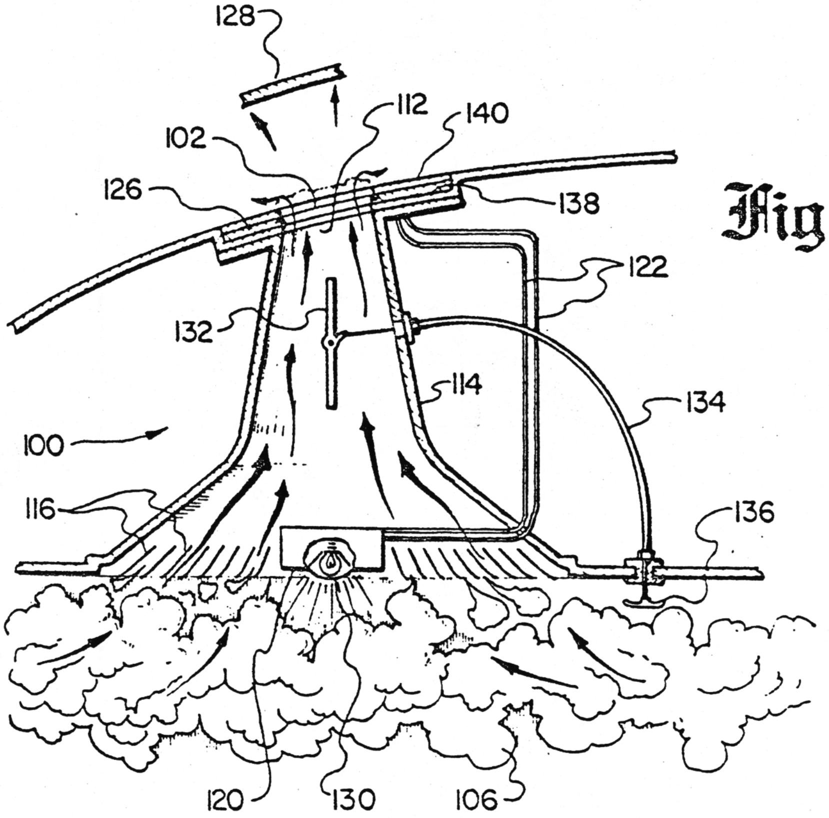
Fig. 3.


128
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130
106

Fig. 4.

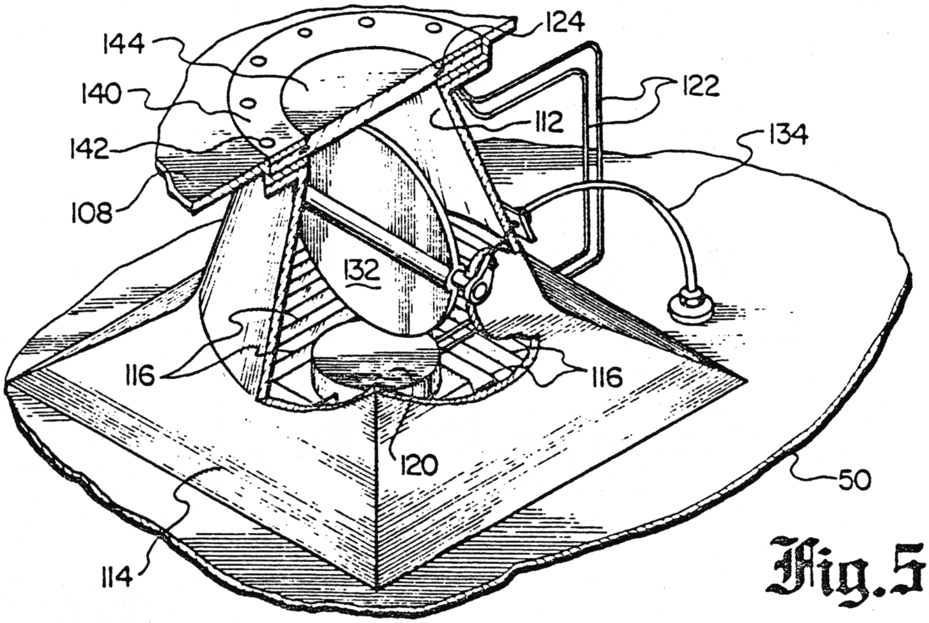

124
144
122
140
112
134
142
108
132
116
116
120
50
114

Fig.5.

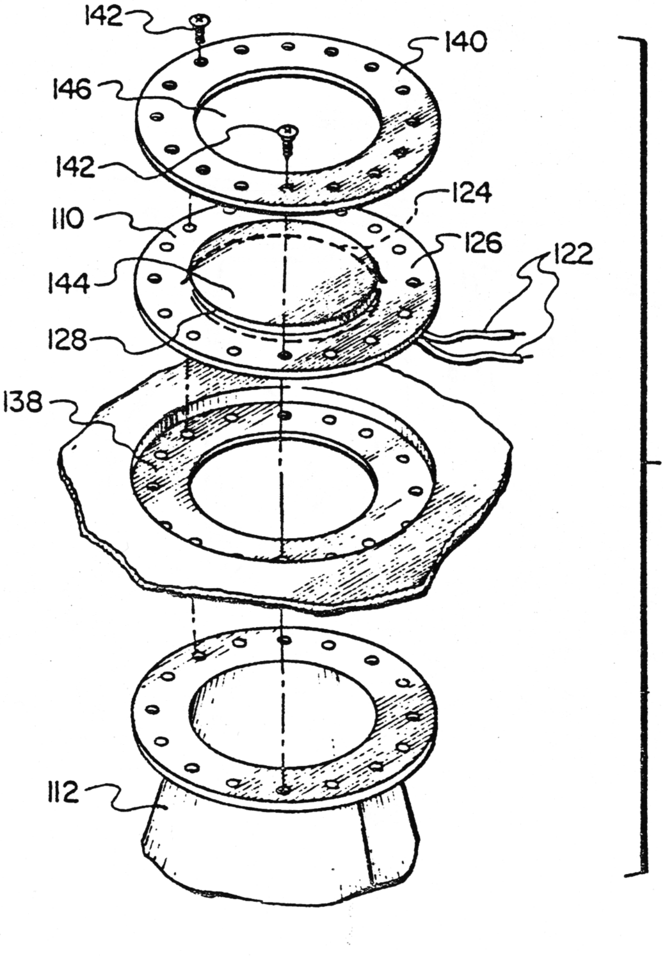

142
140
146
142
124
110
126
122
144
128
138
112

Fig.6.

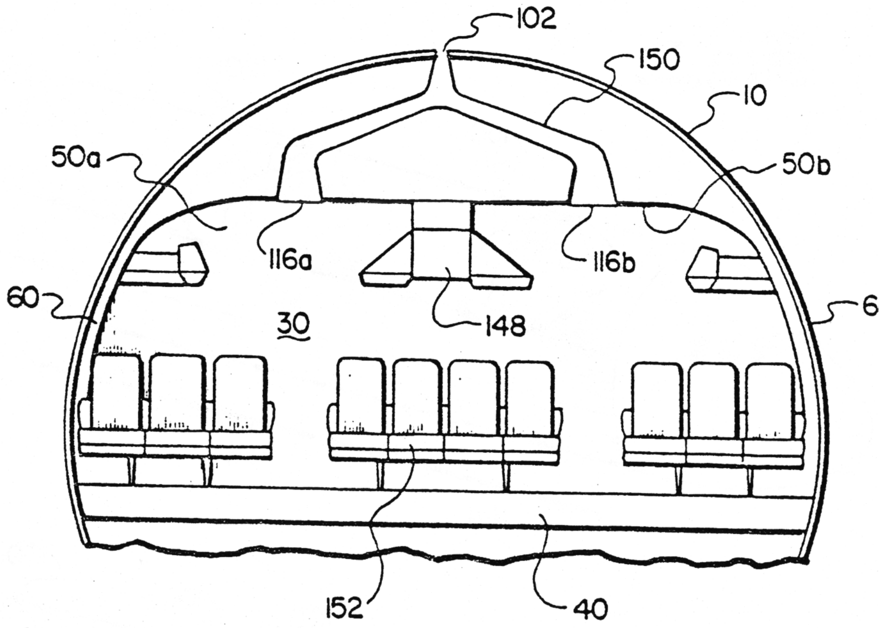

102
150
10
50a
50b
116a
116b
60
148
30
60
152
40

Fig.7.

Fig.8.

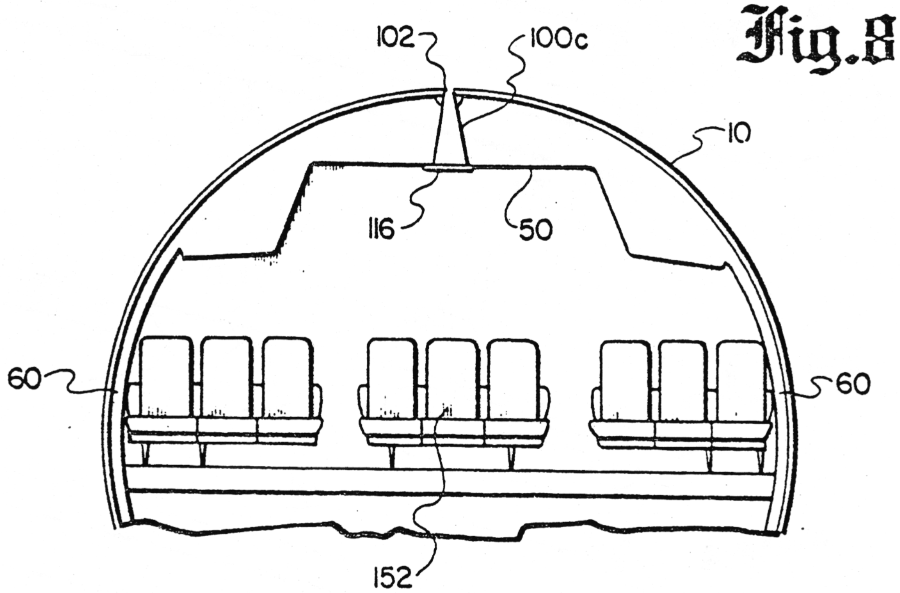

102
100c
10
116
50
60
60
152

Fig. 9.

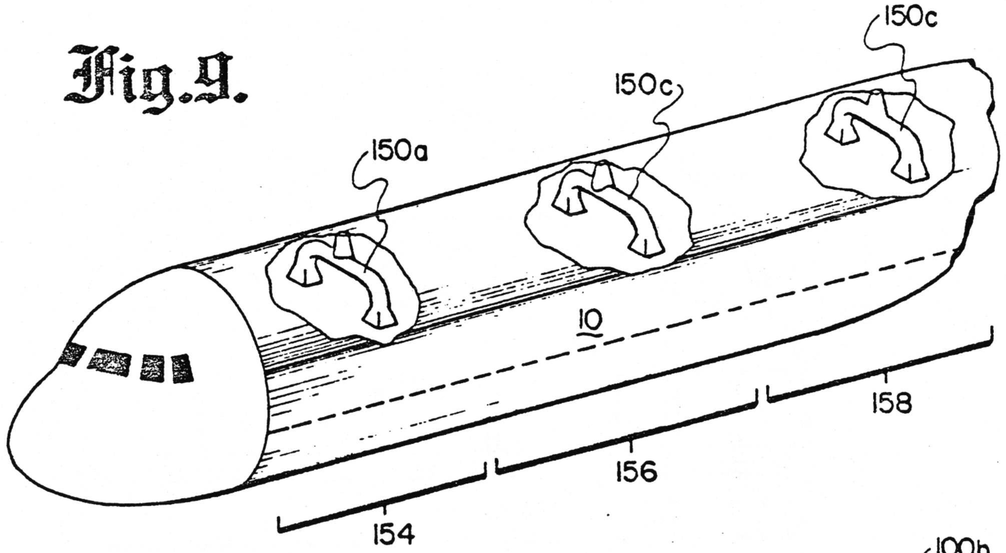


Fig. 10.

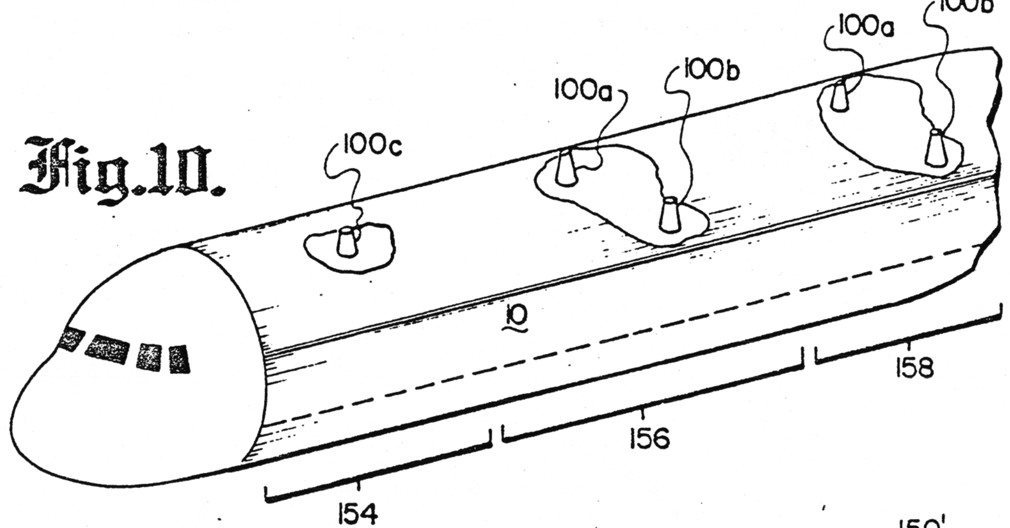
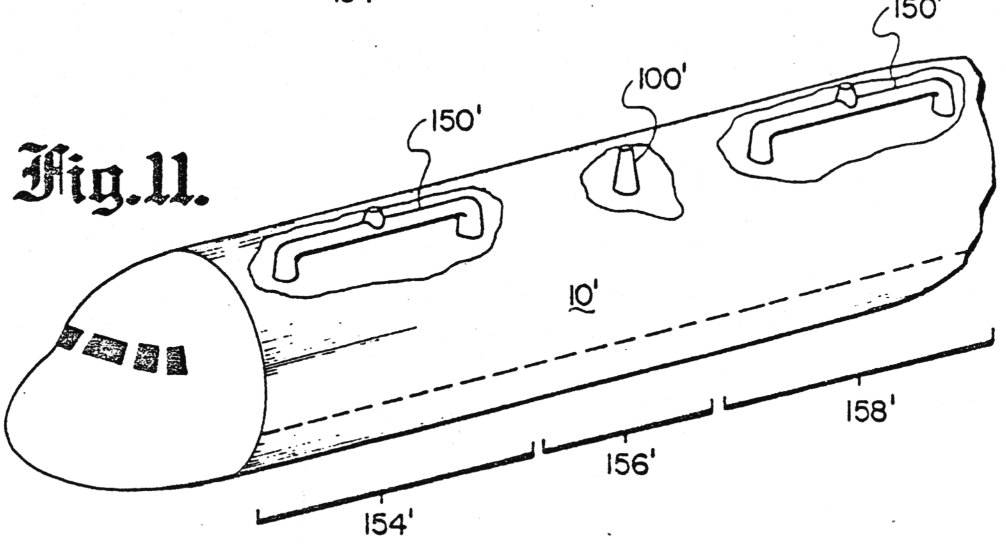


Fig. 11.



EMERGENCY SMOKE DISPOSAL SYSTEM FOR PRESSURIZED AIRCRAFT

TECHNICAL FIELD

The present invention relates generally to aircraft fire suppression apparatus and more particularly to apparatus for evacuating smoke from the interior of a pressurized aircraft during an in-flight fire emergency.

BACKGROUND OF THE INVENTION

As is well known, the smoke produced in a fire emergency can pose the greatest hazard to human life, since the occupants adjacent the area wherein the combustion is occurring will be unable to locate emergency exits or otherwise escape to safety, nor (in the event that escape is not feasible) will they even be able to locate and use any available fire suppression equipment such as portable fire extinguishers, blankets and the like. Particularly in a moving enclosed space such as the interior of a large passenger transport aircraft, the smoke will also result in an apparent loss of equilibrium, and will inevitably heighten the panic environment that would be expected under such conditions. Furthermore, the smoke is frequently accompanied by noxious fumes which may further impair visual acuity by irritating the delicate tissues of the human eye as well as impairing respiratory functions.

Cabin materials utilized in the construction of wide-bodied jet transport aircraft are normally tested for smoke emission values in accordance with U.S. National Bureau of Standards procedures utilizing a smoke chamber for providing a numerical measure of a particular material's propensity for impairment of visibility within the aircraft cabin as a result of the emission of smoke when the material is combusted. The combustion of certain types of such materials may also produce irritating gases which further impair human visual acuity. A report dated March 1974 entitled "Smoke Emission From Burning Cabin Materials And The Effect On Visibility In Wide-Bodied Jet Transports," Report No. FAA-RD-73-127 authored by Edward L. Lopez and prepared by the Lockheed-California Company Division of Lockheed Corporation under contract with the Department of Transportation, Federal Aviation Administration, Contract. No. DOT FA 72 NA-665, and published by the National Technical Information Service, Springfield, Va., lists smoke emission values for various types of aircraft cabin materials and details particular tests of human visual acuity during the combustion of materials having particularly high and low smoke emission values in a full-size mock-up of a section of a wide-bodied cabin.

As reported on page 13 of said Report, under the heading "Visibility Tests with Ventilation," the peak smoke densities and the smoke stratification effects during the combustion of smoke-emitting materials were somewhat reduced as a result of the normal air ventilation patterns within the cabin, with the air inlets located in the vicinity of the floor of the cabin and the outlets in the ceiling, but eventually the entire cabin would have severely restricted visibility.

To some extent, the deleterious effects of smoke occurring as a result of a fire aboard the aircraft may be suppressed by means of a mist of water such as is provided by my Stowable Fire Suppression System For Aircraft Cabins And The Like, disclosed and claimed in Co-pending application Ser. No. 335,228 filed on Dec. 28, 1981; however, for maximum effectiveness, the mist needs to be aimed at the source of the smoke. Also of interest is U.S. Pat. No. 4,391,017, "Device for Removing Incendiary Matter from the Interior of an Aircraft," by Applicant. Here, a flexible hose and nozzle are coupled to an outlet in the passenger compartment which is connected to the lower pressure external airstream allowing incendiary material to be "sucked" overboard.

Accordingly, there remains a need for an effective way to evacuate smoke from the interior of a passenger transport aircraft in flight promptly and efficiently so as to prevent any loss of visual acuity or equilibrium that otherwise would occur in the aircraft's occupants, thereby facilitating a proper response to the emergency and in any event reducing the panic conditions that could otherwise be expected to occur under such circumstances.

DISCLOSURE OF THE INVENTION

The present invention provides a convenient and reliable means to evacuate smoke from an interior cabin of a pressurized aircraft by providing a normally closed smoke evacuation outlet in the skin of the aircraft in fluid communication with a relatively large area smoke disposal chute extending upwardly from the cabin's ceiling, whereby upon the activation of the outlet, the smoke (that otherwise would rise to and collect below the ceiling of the cabin until the whole cabin is full of smoke) will be discharged into the external airstream, with the differential pressure between the relatively high pressure in the cabin and the relatively low pressure in the external atmosphere (particularly at the high cruising altitudes associated with the operation of modern transport aircraft) providing the actual motive power.

Preferably, the outlet is designed to be opened automatically in response to smoke in the vicinity of the smoke disposal chute being detected by means of a conventional type of smoke detector. The chute between the ceiling and the outlet on the skin may also be provided with a manual means for blocking the further outflow of pressurized air through the skin outlet opening in the event that the apparatus has been activated inadvertently or in the event that the emergency is over.

With a typical modern wide-body passenger transport aircraft operating under typical high altitude cruise conditions, a smoke disposal outlet opening having an active area of approximately six sq. inches in the aircraft's outer skin will permit approximately 75 pounds (34 kg) (approximately 1,280 cu. feet (150 m^3)) per minute of smoke-laden air to be evacuated without any apparent loss in cabin pressurization.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a typical modern passenger aircraft in flight;

FIG. 2 is a cross section through the aircraft of FIG. 1, showing a typical installation of an emergency smoke disposal apparatus in accordance with the present invention, with smoke from a fire inside the cabin being evacuated by means of said apparatus;

FIG. 3 is an enlarged view of a portion of the smoke evacuation system shown in FIG. 2 with the outlet in the aircraft's outer skin closed;

FIG. 4 is a view similar to FIG. 3 but shows the outlet being opened and smoke evacuated therefrom;

FIG. 5 is an isometric partially cut-away view showing the apparatus of FIG. 3 as it would be seen from outside the aircraft;

FIG. 6 is an exploded view corresponding generally to FIG. 5 and showing the construction of the smoke outlet;

FIGS. 7 and 8 are cross-sectional views through other types of aircraft showing alternative arrangements of the smoke evacuating apparatus; and

FIGS. 9, 10 and 11 are partially cut-away isometric views of a typical passenger transport aircraft showing different embodiments of the invention installed at various locations within the aircraft's interior.

BEST MODE OF PRACTICING INVENTION

Referring now to FIGS. 1 and 2, it will be seen that the fuselage portion (10) of a typical modern passenger transport aircraft (20) has a generally constant circular cross section of about 20 feet in diameter (6.1 m) with an interior passenger cabin (30) being defined by a load-bearing floor (40), a cabin ceiling (50) and a pair of side walls (60), the latter generally conforming to the semicircular configuration of the fuselage portion (10). Below the floor (40) there is provided a hold area which may include one or more cargo holds as well as various areas for mechanical and electrical equipment. Above the ceiling (50) there is provided a plenum (80), which may contain various duct work, control cables, hydraulic lines and the like, but which nevertheless is for the most part unused space resulting from the fact that the external circular cross section of the fuselage is preferable for withstanding the differential pressure between the interior of the aircraft and the external airstream, while a lower generally horizontal ceiling results in a more aesthetically pleasing interior configuration for the passengers and gives the illusion of more spaciousness.

As is well known, by operating the aircraft at higher altitudes where the atmosphere is much less dense than at sea level, considerable operating efficiencies result. Thus, a typical cruising altitude will be 37,000 feet (11,300 m). On the other hand, the human organism will have difficulty functioning at altitudes much above 10,000 feet (3,050 m), principally as a result of the lack of sufficient oxygen. Accordingly, modern aircraft are pressurized on the inside while in flight to a "cabin altitude" that is normally below 8,000 feet (2,400 m), with the actual pressure profile during the course of the flight being determined by the respective elevations of the departure and arrival air fields as well as the maximum planned cruising altitude.

In addition to maintaining such a differential pressurization between the cabin and the external airstream, the aircraft's environmental control system is also required to control temperature within a normal comfort range and also to introduce fresh air into the cabin. These various functions are conventionally handled by redundant air conditioning packs, each driven by intermediate pressure (45 psig) (3.2 kg/cm^2) engine bleed air. Each air conditioning pack thereby has the capability to provide an independent source of pressurized air at a predetermined temperature and flow rate. The conditioned air is mixed in an air distribution manifold and introduced into the various cabin zones through air outlet grilles in the cabin ceiling so as to produce a gentle circulation pattern within the cabin. Air is optionally also introduced through individual air outlets directed at particular seat positions. The cabin air is normally exhausted into the side walls (60) at floor level, whereupon it eventually is discharged overboard through outflow valves (90). The outflow valves (90) are servo controlled during flight so as to maintain a predetermined cabin pressure within a cabin pressurization envelope whose outer boundaries are determined by the maximum permissible differential pressure between the interior of the cabin and the external airstream and also by the maximum permissible cabin altitude. Prior to landing, the pressurization is slowly adjusted so that at some time prior to touchdown the differential pressure will drop to zero; thus there will be no pressure differential tending to lock the emergency exits in their closed positions once touchdown has been achieved.

It will be appreciated that such a system is capable of providing a much higher inflow of conditioned air than is required to maintain the desired cabin pressurization and to compensate for any air leakage which is inherent in the aircraft. In particular, in a typical installation aboard a Lockheed L-1011 aircraft at a cruising altitude of 37,000 feet (11,300 m) and operating in the automatic pressurization mode with only two of the three air conditioning packs in operation, but taking into account the inherent leakage of the aircraft in its "as delivered" condition, the system will deliver an excess of 100 pounds per minute (45 kg/min.) of conditioned pressurized air with the outflow valves fully closed. Under normal equilibrium conditions with the inflow equal to the combined outflow through the outflow valves and through inherent leakage, at a cruising altitude of 37,000 feet (11,300 m) and a cabin altitude of 8,000 feet (2,400 m), the outflow valves will have an activated area of approximately 8 sq. inches (51.6 cm^2); with all three packs in operation, the corresponding figures are 226 pounds per minute (103 kg/min.) excess available inflow, which is equivalent to approximately 18 sq. inches (116 cm^2) of activated outflow valve area at equilibrium.

Thus, it will be appreciated that a considerable volume of smoke-laden air can be evacuated from the cabin if only an effective discharge flow path were to be provided. The present invention provides such a flow path by means of the smoke evacuation apparatus such as the smoke evacuation units shown in FIG. 2 (100*a*, 100*b*) with only the first such unit (100*a*) being activated. From the above discussion of the mass flow characteristics of the aircraft's pressurization system, it will be appreciated that by limiting the skin opening (102) associated with each individual unit (100) to a maximum of 8 sq. inches (51.6 cm^2), 100 pounds per minute (45 kg/min.) of smoke-laden air may be evacuated without any noticeable loss of cabin pressurization. This equates to approximately 1660 cu. feet (47 m^3) per minute. By providing a number of such smoke evacuation units (100) and activating only the particular unit (100*a*) closest to the combustion source (104), it will be appreciated that the smoke (106) from this combustion source will tend to rise and gather at the ceiling level (50) in the vicinity of that particular smoke evacuation unit (100*a*) and that, accordingly, substantially all of the smoke (106) from the combustion source (104) may be evacuated.

Reference should now be made to FIG. 3, which it wil be recalled is an enlarged view of an individual smoke evacuation duct assembly (100). In particular, it will be seen that mounted flush with the external fuselage skin (108) is a breakaway outlet plate (110) that covers the skin outlet opening (100) adjacent the upper end (112) of a smoke evacuation chute (114) that leads downwardly to a grille (116) provided in the ceiling (50). The cross-sectional area of the upper end of the duct (112) is approximately 8 sq. inches (51.6 cm^2) in area, but the duct increases in cross-sectional area significantly in the direction of the ceiling grille (116). Thus, once the outlet plate (110) has been broken off and ejected, as shown in FIG. 4, the smoke-laden air (106) will be accelerated gradually as it travels up through the chute (114) until it is ejected through the opening (102). As noted previously, even though the smoke evacuation opening (102) is only approximately 8 sq. inches (51.6 cm^2) in area, it may nevertheless accommodate a flow of 1,660 cu. feet per minute (47 m^3) with only two air conditioning packs in operation. (This equates to a flow velocity of approximately $1{,}660\times 144\div 8$ feet per minute (47 $m^3\div 0.00516$ $m^2=9{,}100$ m/min. in the vicinity of the fuselage skin (108).)

As shown in FIGS. 3 and 4, there is preferably provided an automatic smoke detector circuit (120) that is so mounted that it will detect any smoke in the vicinity of the ceiling grille (116), and upon such detection will by means of an appropriate electrical connection (122) activate a pyrotechnic fuse (124) provided about the periphery (126) of the outlet plate (110), thereby permitting the differential pressure to eject an inner breakaway portion (128) and exposing the skin opening (102).

As a further refinement, the smoke detector (120) may be provided with a visible indicating means such as a neon light (130) that will be illuminated only so long as smoke is actually present in the vicinity of the device, and the smoke chute (114) may be provided with a butterfly valve (132) connected to a suitable manual closing means such as a bowden cable (134) terminated with an operating handle (136), whereby upon the cessation of the emergency condition being indicated by means of the extinguishment of the indicator means (130), the chute (114) may be manually closed from the interior of the cabin, thereby interrupting the further flow of air out through the opening (102) and permitting the resumption of normal operation of the aircraft's air conditioning and pressurization system.

FIG. 5 is another view showing the appearance of the outlet cover plate (110) as it would be seen from the exterior of the aircraft. From this figure it may be seen in particular that the outlet plate (110) is mounted flush within a slight depression (138) formed in the skin (108), by means of an annular reinforcing plate (140) and a plurality of suitable fastening means such as recess head machine screws (142).

Referring specifically to FIG. 6, it may be seen that the peripheral portion (126) is somewhat thinner than the raised inner portion (128) of the outlet plate (110), with the outer diameter of the raised portion (128) being slightly smaller than the open interior (146) of the annular retaining plate (140), and with the height of the raised portion (128) relative to the peripheral portion (126) of the plate (110) being approximately equal to the thickness of the retaining plate (140). Furthermore, the depression of the well (138) with respect to the surrounding fuselage skin (108) is approximately equal to the combined thickness of the retaining plate (140) and the peripheral portion (126) of the plate (110). Thus, in their assembled configuration, an essentially smooth uninterrupted surface is provided by the outer fuselage skin (108), the upper surface of the retaining plate (140) and the outer surface (144) of the plate's raised central portion (128).

Still referring to FIG. 6, it will be seen that there is shown in dotted lines the location of the pyrotechnic fuse (124) which is molded about the periphery of the raised inner portion (128) of the plate (110) and which is electrically connected to the wires (122) from the smoke detector (120) such that when an appropriate electrical potential is applied across the pair of wires (122), an annular notch is formed about the periphery of the raised portion (128) which permits it to be separated from the peripheral portion (126) of the cover plate (110), as a result of the differential pressure between the interior of the aircraft and that of the external airstream

At maximum cruising altitude (43,000 feet) (13,000 m), this differential pressure will be on the order of 8 pounds per sq. inch (0.56 kg/cm^2) and thus for a cover plate (110) providing a smoke evacuation opening (102) having an effective area of about 8 sq. inches (51.6 cm^2), the force tending to remove the central portion (128) of the cover plate (110) will be on the order of 64 pounds (29 kg). Thus, it is not necessary that the pyrotechnic fuse (124) completely separate the plate's inner portion (128) from its periphery (126) but only that the connection therebetween be sufficiently weakened that such differential pressure will be effective to result in the ejection of a central portion of the plate, thereby exposing the required outlet opening (102) in the aircraft's outer skin (108) (see also FIG. 4).

FIGS. 7 and 8 show alternative arrangements to that shown in FIG. 2. In particular, in FIG. 7 it will be seen that the aircraft cabin interior (30) is provided with a central overhead baggage compartment (148) which effectively divides the ceiling area of the cabin into a right-hand portion (50*a*) and a left-hand portion (50*b*) with which are respectively associated a pair of ceiling outlet grilles (116*a*, 116*b*) branching from a common skin outlet opening (102) by means of a Y-shaped smoke chute manifold (150).

As a result of this branched or "Y" form of construction, upon the activation of the skin outlet opening (102), air will be vented simultaneously through both outlet grilles (116*a*, 116*b*). As a consequence, the flow through each of the two grilles (116*a*, 116*b*) would be somewhat less than half that associated with the arrangement of FIG. 2 in which each of the two grilles has its individual associated skin opening. However, such a flow should still be more than adequate to evacuate the smoke-laden air resulting from a fire within the cabin and, particularly, if the fire is in the vicinity of the central seating area (152), it will be appreciated that smoke from the fire will rise to and be trapped in both the right-hand ceiling area (50*a*) and the left-hand ceiling area (50*b*) and therefore it may be advantageous to have active smoke outlet grilles in both of the ceiling regions (50*a*, 50*b*) simultaneously activated.

FIG. 8 shows an alternative embodiment generally similar to the embodiment shown in FIG. 2. However, in place of the two somewhat smaller outlet smoke evacuation duct assemblies (100*a*, 100*b*), there is provided a larger unit (100*c*) having a central duct. Such an arrangement would be particularly advantageous in a larger aircraft in which a considerable volume of cabin air could be discharged without affecting the proper operation of the automatic cabin pressurization system and thus, rather than a plurality of individual smaller outlet openings of perhaps 6 sq. inches (39 cm^2), there were provided a fewer number of larger outlet openings, each of perhaps 12–18 sq. inches (77–116 cm^2) in area, thereby ensuring that even if the fire were confined to a relatively remote portion of the cabin, there would be an adequate outflow of smoke-laden air.

Typically, a modern large transport aircraft will be subdivided into several distinct cabins by means of fixed service centers and movable interclass barrier screens. Other interior fixtures, such as overhead coat stowage cabinets and lounge areas, may serve further to divide the aircraft's interior into distinct regions. Accordingly, it is generally preferable to include several independent smoke evacuating systems throughout the length of the aircraft.

Referring specifically to FIG. 9, it may be seen that the forward cabin area (154) is provided with a first branched smoke evacuation unit (150*a*) generally similar to that described previously with respect to FIG. 7. A second such unit (150*b*) is provided in the center or main cabin area (156), while a third unit (150*c*) is associated with the aft cabin (158).

In the embodiment shown in FIG. 10, a single smoke evacuation unit (100*c*) such as shown in FIG. 8 is associated with the relatively small forward cabin (154), while pairs of such units (100*a*, 100*b*) are associated with each of the relatively large center and aft cabins (156, 158), each arranged generally as was shown in the cross-sectional view of FIG. 2.

In the embodiment shown in FIG. 11, it will be seen that units utilizing branched chute manifolds (150′) generally similar to that shown in the cross-sectional view of FIG. 7 have been included in the forward and rear cabins (154′, 158′), while the center or main cabin (156′) is provided with a single, somewhat more efficient unit (100′); however, the two branched manifolds (150′) are oriented longitudinally rather than laterally (as was shown in FIG. 9). Such an arrangement may be particularly advantageous for aircraft with a standard sized fuselage (10′) having a single central aisle.

It is apparent that there has been provided with this invention a novel Emergency Smoke Disposal System for Pressurized Aircraft which fully satisfies the objects, means and advantages set forth hereinbefore. While the invention has been described in combination with specific embodiments thereof, other permutations and combinations of the individual components comprising the invention will be apparent to the skilled artisan in accordance with the practical requirements of a particular installation on a particular type of aircraft. Accordingly, this specification is intended to embrace all such alternatives, modifications and variations as fall within the spirit and broad scope of the appended claims.

I claim:

1. A smoke evacuation system for a vehicle comprising:

a skin opening defined in an outer skin separating an interior compartment within said vehicle from an exterior environment surrounding said vehicle, said interior being capable of being maintained at a positive differential pressure with respect to said exterior;

a cover plate for covering said opening and thereby preventing any flow of air therethrough;

means for ejecting said cover plate from said opening; and

a smoke disposal chute having a first end in fluid communication with a region within said compartment at which smoke may be expected to collect and a second end in fluid communication with said opening;

whereby when said cover plate is ejected from said opening, any smoke-laden air in said region will be forced through said opening and evacuated into said external environment as a result of said positive pressure differential.

2. The system of claim 1 further comprising a grille in the vicinity of said first end for preventing the blockage of said chute by foreign objects.

3. The system of claim 1,

wherein said vehicle is a transport aircraft provided with an air conditioning pack for conditioning air from said external environment and introducing it under pressure into said interior compartment and with an overflow vent for providing an opening having a variable cross-sectional area in said skin of said aircraft for permitting a portion of said pressurized air to be controllably released to said external environment, and

wherein the effective cross-sectional area of said opening after said cover plate has been ejected is less than the effective area of said vent during normal operation of said pack, whereby even after said cover plate has been ejected and said smoke evacuation system opening activated, said air conditioning pack will be able to continue to maintain the conditioned air inside said compartment at a predetermined normal pressure.

4. The system of claim 1 wherein said ejecting means is activated in response to an electrical signal.

5. The system of claim 4 wherein said ejection means comprises an electrically activated pyrotechnic fuse embedded in said cover plate so as to separate a central portion of said cover plate from a peripheral portion upon said electrical signal being applied to said fuse.

6. The system of claim 4 further comprising a smoke detector circuit for generating said electrical signal upon the detection of smoke in said region.

7. The system of claim 1 further comprising means for at least partially blocking said chute after said cover plate has been ejected.

8. The system of claim 1 wherein the effective cross-sectional area of said second end is sufficiently small that said interior compartment will remain pressurized even after said cover plate has been ejected and said opening exposed.

9. The system of claim 8 wherein the effective cross-sectional area of said first end is substantially larger than the cross-sectional area of said second end whereby the velocity of said smoke-laden air will be significantly less in the vicinity of said region compared to that at said opening.

* * * * *

APPENDIX B—UNITED STATES PATENT: MINIMUM AREA SMOKE EVACUATION NOZZLE

US005312072A

United States Patent [19]
Eklund

[11] **Patent Number:** **5,312,072**
[45] **Date of Patent:** **May 17, 1994**

[54] **MINIMUM AREA SMOKE EVACUATION NOZZLE**

[75] Inventor: **Thor I. Eklund**, Haddonfield, N.J.

[73] Assignee: **The United States of America as represented by the Secretary of Transportation**, Washington, D.C.

[21] Appl. No.: **564,514**

[22] Filed: **Aug. 9, 1990**

[51] **Int. Cl.⁵** **B64D 13/00**
[52] **U.S. Cl.** **244/118.5**; 244/129.2
[58] **Field of Search** 244/118.5, 129.2; 417/198, 196; 98/1.5

[56] **References Cited**

U.S. PATENT DOCUMENTS

284,962	9/1883	Huston	417/198
2,299,668	11/1942	Webster	244/118.5
2,980,033	4/1961	Waddington et al.	417/196
3,545,886	12/1970	Chalom	417/196
4,166,477	9/1979	Duthion et al.	137/561 R
4,382,569	5/1983	Boppe et al.	244/199
4,552,325	11/1985	Bruensicke	244/129.2

OTHER PUBLICATIONS

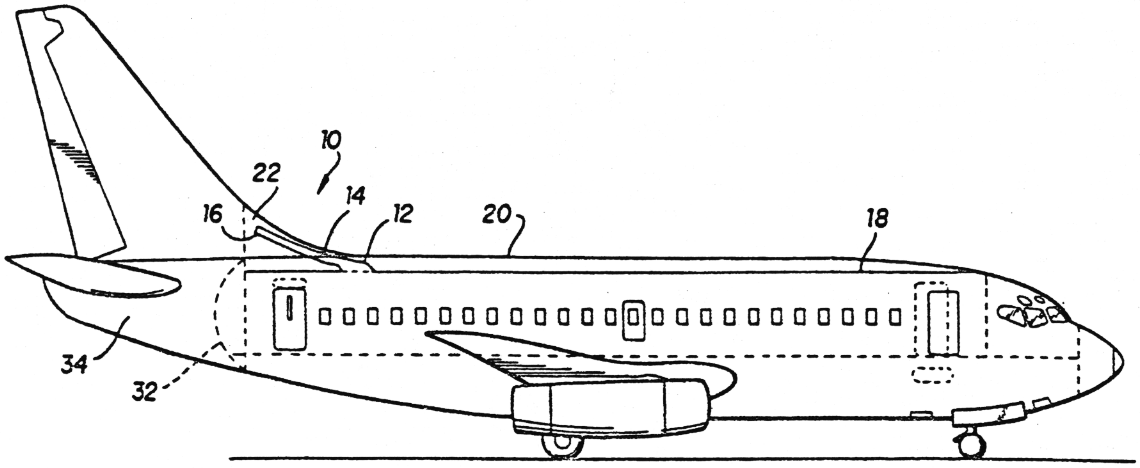
Potter and Foss, *Fluid Mechanics*, 1982, pp. 490–497.
Elements of Gasdynamics, Chapter 5, Flow in Ducts and Wind Tunnels, Liepmann et al., May 1967, pp. 124–143.

Primary Examiner—Michael S. Huppert
Assistant Examiner—Anne E. Bidwell
Attorney, Agent, or Firm—O. M. Wildensteiner

[57] **ABSTRACT**

A smoke evacuation nozzle for an airplane having minimum diameter at the fuselage pressure hull exit for minimum structural integrity disruption. The nozzle is a converging-diverging nozzle which maintains sonic flow down to a very low altitude, thereby obtaining maximum airflow through it at all times. The throat is located at the point where the nozzle goes through the fuselage pressure hull so that the penetration through the fuselage pressure hull is minimal.

13 Claims, 3 Drawing Sheets



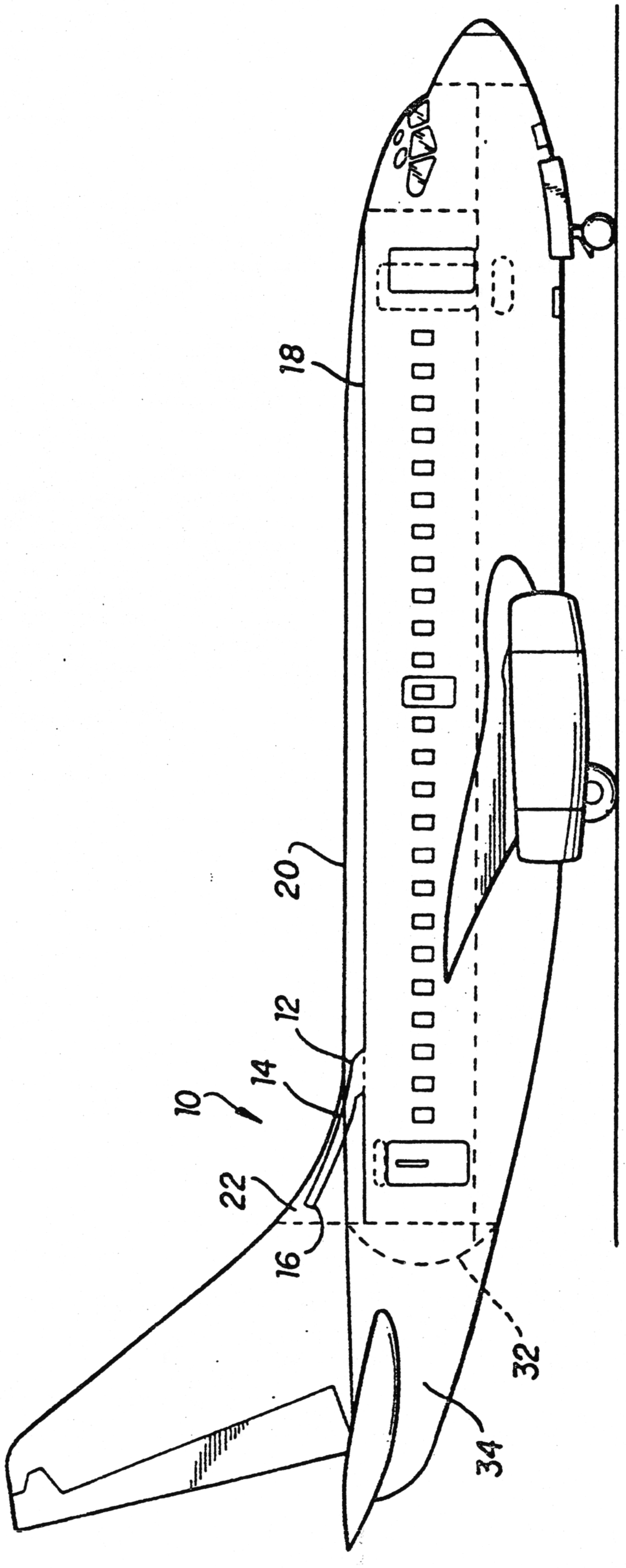


FIG. 1

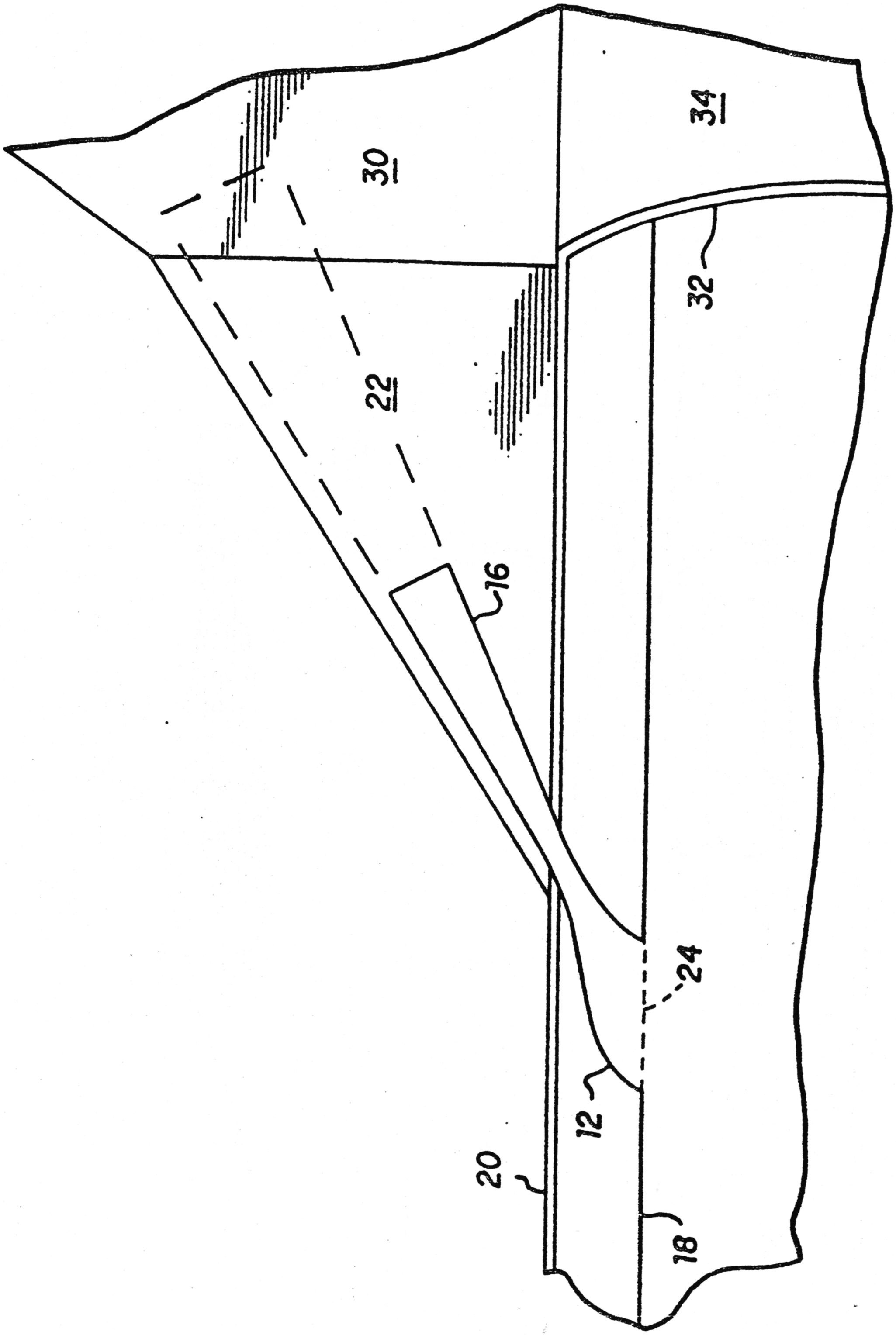


FIG. 2

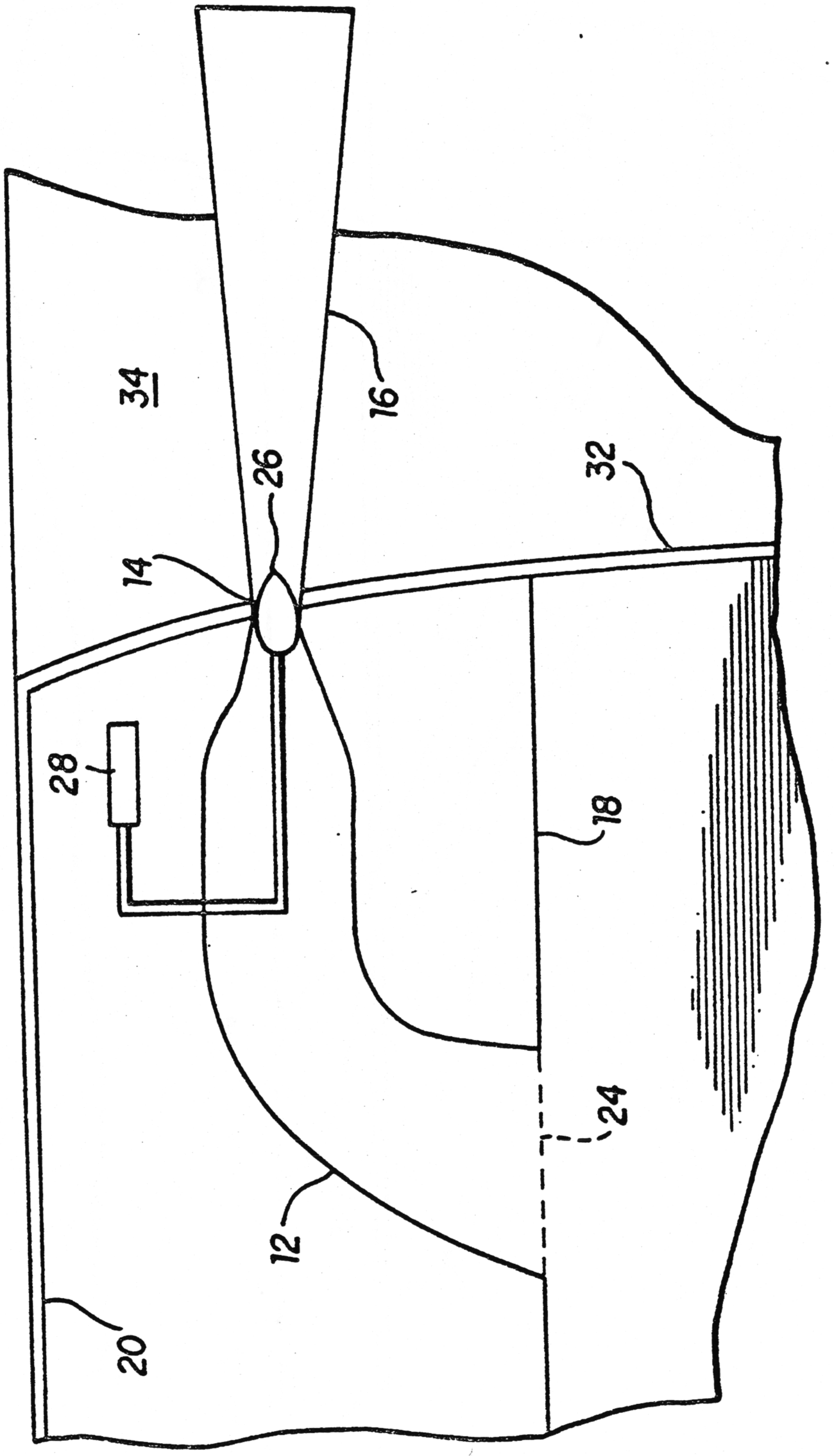


FIG. 3

MINIMUM AREA SMOKE EVACUATION NOZZLE

STATEMENT OF GOVERNMENT INTEREST

The present invention may be made or used by or for the Government of the United States without the payment of any royalties thereon or therefor.

BACKGROUND

Smoke evacuation nozzles that have been proposed for use in aircraft are special nozzles that are normally closed; they would be opened in the event of fire, and used to remove the smoke from the passenger cabin. Studies have shown that such nozzles would be most effective if placed on or near the top of the fuselage along its centerline. As is true for most components of an airplane, the design of such a nozzle is a trade-off; in this case the trade-off is between flow capability on the one hand and weight on the other. A large nozzle will have a large flow capability, but will be heavy; and the large opening in the fuselage to accommodate it will require a considerable amount of reinforcing, which will cause its own weight penalty.

On the other hand, a small nozzle will not have the above weight penalty, but will not have the flow capability.

It is well known that a sonic orifice or nozzle flows the most fluid per unit area, and it is intuitive that such is desirable for a smoke evacuation nozzle given the above trade-off. However, the prior art has failed to produce such a nozzle that would remain effective at lower altitudes.

For example, the patent to Bruensicke, 4,552,325, shows a smoke evacuation nozzle that has a converging entrance section leading to the exit through the fuselage pressure hull. This nozzle will have sonic flow through its minimum area or throat only at higher altitudes where the ratio between the cabin pressure and the ambient pressure at a given altitude is greater than 2. At lower altitudes the flow will be subsonic, and hence the nozzle will not be as effective as a sonic nozzle.

OBJECTS OF THE PRESENT INVENTION

Accordingly, it is an object of the present invention to provide a smoke evacuation nozzle for an airplane which removes the maximum amount of smoke for its size.

It is a further object to provide such a nozzle which also requires the minimum diameter penetration through the aircraft fuselage pressure hull.

It is a further object to provide such a nozzle which maintains sonic flow at both high cruising and low descent altitudes.

It is a further object to provide such a nozzle which does not impose an additional aerodynamic drag penalty on the aircraft.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the location of the smoke evacuation nozzle of the present invention in an airplane.

FIG. 2 shows a more detailed view of the nozzle in the dorsal fin of a representative airplane.

FIG. 3 shows the details of the smoke evacuation nozzle of the present invention, with the diverging portion of the nozzle extending into the tailcone of an airplane.

SUMMARY

Briefly, the present invention is a converging-diverging smoke evacuation nozzle in an airplane. The entrance to the converging portion is preferably flush with the passenger cabin ceiling and is covered by a grille. The throat is located where the nozzle penetrates the fuselage pressure hull, and the diverging portion is located within the dorsal fin and/or vertical stabilizer. When not in use the throat is closed by an aerodynamic plug in the converging portion. During operation, the flow through the nozzle can be controlled by movement of the aerodynamic plug to compensate for altitude changes.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 shows nozzle 10 of the present invention installed in a representative airplane. Nozzle 10 comprises a converging portion 12, a throat 14, and a diverging portion 16. As can be seen, converging portion 12 is located in the space between passenger cabin ceiling 18 and fuselage pressure hull 20, and diverging portion 16 is located within dorsal fin 22. Throat 14 of nozzle 10 is located at the point where nozzle 10 goes through fuselage pressure hull 20, thereby requiring the minimum size penetration through fuselage pressure hull 20.

The design of nozzle 10 is well known in the art; it is a smoothly contoured converging-diverging nozzle with no disruptions to the flow on its interior walls. It can be a simple conical nozzle, or it can be designed by the method of characteristics or any other well known nozzle design criteria.

The entrance to nozzle 10 at the cabin ceiling should be covered by grille 24 (see FIGS. 2 and 3), both for esthetic reasons and to prevent debris from being sucked into nozzle 10 and clogging it during operation. When not in operation, flow through nozzle 10 is preferably prevented by an aerodynamic plug 26 in converging portion 12 just upstream of throat 14 and which seats in throat 14. Such a closure is the smallest, hence lightest and most easily operated. During operation of nozzle 10 plug 26 can be moved upstream and downstream by plug actuator 28 to vary the effective area of throat 14 as the altitude of the airplane changes. Plug actuator 28 can be of any design, but is preferably automatic in operation rather than manual (but may provide for emergency manual operation as a safety measure).

FIG. 2 shows a representative vertical stabilizer 30 and dorsal fin or fin root fillet 22 with diverging portion 16 shown in it; the dimensions are approximately to scale. The actual placement of diverging portion 16 will be a function of its size and the size of the dorsal fin and vertical stabilizer of a given aircraft. A short diverging portion will be lighter in weight, hence may extend only into the dorsal fin; however, a longer diverging portion may be required in order to get the desired performance. Additionally, not all aircraft have adequately large dorsal fins, in which case diverging portion 16 will extend instead into the vertical stabilizer as shown in the dotted lines. Alternatively, diverging portion 16 could be extended through aft pressure bulkhead 32 into tailcone 34 as shown in FIG. 3 since the tailcone of an airplane has sufficient room to accommodate the diverging portion of a smoke evacuation nozzle.

Placing diverging portion 16 in dorsal fin 22 and/or vertical stabilizer 30 will require cutting away the central parts of some of the internal members. However, making diverging portion **16** out of fairly rigid material and incorporating it as part of the internal structure of dorsal fin **22** or vertical stabilizer **30**, whichever it passes into, may be sufficient to restore any lost structural strength.

The flow from nozzle **10** exits into the interior of dorsal fin **22**, vertical stabilizer **30**, or tailcone **34**, each of which enclosed spaces is at approximately ambient pressure for that altitude. However, if there is a fire on board and nozzle **10** is put into use, the pressure in the enclosed space will undoubtedly rise; therefore it may be necessary to put some exhaust louvers on the outside skin of dorsal fin **22**, vertical stabilizer **30**, or tailcone **34** to help remove the smoke and keep the back pressure from rising.

FIG. **3** shows a representative smoke evacuation nozzle for installation at any point in the pressure hull. Throat **14** is located in aft pressure bulkhead **32**. Diverging portion **16** is located in tailcone **34** and converging portion **12** is located between passenger cabin ceiling **18** and fuselage pressure hull **20**. Grille **24** covers the entrance to converging portion **12** which leads to throat **14**. Aerodynamic plug **26** seats in throat **14** to form an airtight seal when nozzle **10** is not in use. Aerodynamic plug **26** is translated fore and aft by actuator **28** which can be of any design to fit the physical constraints of a particular installation.

Although the prior art smoke evacuation nozzles such as in the patent to Bruensicke will have sonic flow through them at higher altitudes because of the lower outside ambient pressure, the flow will not remain sonic as the airplane descends through lower altitudes. Sonic flow is established when the pressure upstream of the throat is approximately twice the outside ambient pressure (for air). When this nozzle pressure ratio drops below 2, the flow becomes subsonic. Thus if a fire breaks out on board an airplane flying at 35,000 feet and the valve of Bruensicke is opened, the pressure ratio will be 3.45 (based on an 8.5 psi cabin pressure differential and the U.S. standard altitude pressure of 3.47 psia at 35,000 feet). As the plane descends, which is the prescribed response in case of a cabin fire, the pressure ratio will decrease due to the increasing outside ambient pressure. If the cabin altitude is set at 6,000 feet, the pressure ratio will fall below 2 when the plane descends below 23,000 feet, and the valve will not flow as much as it would if the flow were still sonic at the throat of the valve.

The present invention, since it has a diverging pressure-recovery section downstream of the throat, converts the velocity of the air downstream of the throat back to pressure. This means that the flow at the throat remains sonic at nozzle pressure ratios of less than 2. Tests on a well-designed and -manufactured venturi, which had a diverging pressure-recovery section downstream of its throat, showed that such a nozzle remained sonic at its throat down to an overall pressure ratio of 1.12. Although this cannot be correlated with a definite altitude since the pressure ratio across the fuselage pressure hull varies according to cabin pressure, it is an altitude about ⅓ that at which a nozzle such as that shown in Bruensicke stops being a sonic nozzle. Thus the present nozzle will remove smoke at its maximum rate for a far longer time than prior art nozzles. See also FIG. 5.23 and associated text of "The Dynamics and Thermodynamics of Compressible Fluid Flow", Volume I, by Ascher H. Shapiro, The Ronald Press Co., 1953.

With a converging-diverging nozzle with throat sonic flow capability down to an overall pressure ratio of 1.12, an airplane with cabin altitude set at 6,000 feet would continue to flow maximum air through the nozzle until it descended below 9,000 feet. Furthermore, if a fuselage pressure differential of 2.6 psi were maintained after the airplane descended below 10,000 feet, the smoke evacuation nozzle of the present invention could maintain sonic throat velocity all the way to sea level touchdown.

A specific example of an airplane for which the nozzle of the present invention could be put into the dorsal fin is the Boeing 737-100 or -200. These airplanes have dorsal fins that are much larger than needed for the installation of such a nozzle. Further, the dorsal fins are removable, which allows the diverging portion of the nozzle to be fairly easily integrated into the airplane's structure.

As is well known in the art, cabin air is supplied from "air packs" that take air from the engine compressors, condition it, and supply it to the cabin. At higher altitudes more of this air leaks out of the cabin than at lower altitudes due to the higher pressure differential at the higher altitudes. Therefore any smoke evacuation nozzle must have an adjustable opening since the proper flow area for lower altitudes will result in depressurization at higher altitudes. Therefore actuator **28** should be capable of settings that are intermediate fully open and fully closed.

Although the present invention is shown as a nozzle in the cabin ceiling that exhausts into the dorsal fin, vertical stabilizer, or tailcone, it could also be designed to exhaust smoke from the cabin floor or the cargo area into a wheel well or any other enclosed space that is exposed to outside ambient air pressure. As with the dorsal fin, vertical stabilizer, and tailcone, however, it may be necessary to add louvers to the wheel well covers or other enclosed space to remove the smoke from the wheel well or other enclosed space.

I claim:

1. In an airplane having a cabin ceiling, a fuselage pressure hull, and a vertical stabilizer, the improvement which comprises a smoke evacuation nozzle which maintains sonic flow at its throat at a nozzle pressure ratio of less than 2.

2. The smoke evacuation nozzle of claim **1** comprising a converging portion, a throat, and a diverging portion.

3. The smoke evacuation nozzle of claim **2** wherein said converging portion is located within said fuselage pressure hull, said diverging portion is located outside of said fuselage pressure hull, and said throat is located in said fuselage pressure hull.

4. The smoke evacuation nozzle of claim **3** wherein said diverging portion is located within said vertical stabilizer.

5. The smoke evacuation nozzle of claim **3** wherein said airplane futher includes a dorsal fin.

6. The smoke evacuation nozzle of claim **5** wherein said diverging portion is located within said dorsal fin.

7. The smoke evacuation nozzle of claim **6** wherein said diverging portion is located in said dorsal fin and said vertical stabilizer.

8. The smoke evacuation nozzle of claim **3** wherein said converging portion is located between said cabin ceiling and said fuselage.

9. In an airplane having a pressurized compartment subject to being filled with smoke, said pressurized compartment being defined by physical boundaries, and a space enclosed within the outer envelope of the airplane but exposed to ambient air pressure, the improvement which comprises means for conducting the smoke from said pressurized compartment to said enclosed space.

10. An airplane as in claim **9** wherein said means for conducting smoke comprises a nozzle having a converging portion, a throat, and a diverging portion.

11. An airplane as in claim **10** wherein said converging portion is located in said pressurized compartment.

12. An airplane as in claim **11** wherein said diverging portion is located in said enclosed space.

13. An airplane as in claim **12** wherein said throat is located in one of said boundaries of said pressurized compartment.

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