AEROSPACE INFORMATION REPORT

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∅ AIR CONDITIONING OF SUBSONIC AIRCRAFT AT HIGH ALTITUDE

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1. PURPOSE

Ø This information report clarifies the special problems involved in the pressurization and air conditioning of civil subsonic transport aircraft during high altitude flight, as they relate to the physical and physiological limitations of the human body.

2. SCOPE

Ø This report is limited to the special problems of air quantity, purity, movement, pressure, temperature, and humidity which arise from the requirements of the human body during high altitude flight, together with the associated aircraft design problems.

2.1 Ø Within the purpose of this report, high altitude is defined as altitudes above 25,000 ft. (7620m) and up to 45,000 ft. (13716m).

2.2 Ø It is considered that all requirements for air conditioning of aircraft as presented in SAE ARP 367, Airplane Cabin Pressurization, and ARP 85, Air Conditioning Equipment, General Requirements for Subsonic Airplanes, exist in high altitude flight, in addition to the special requirements discussed in this AIR.

2.3 Ø It is considered that medical aspects of the physiological problems will be treated only briefly in this report. It is anticipated that Aviation Medicine and Human Factors personnel will be consulted for detailed analysis of specific problems. Refer to 3.1.6 for hypoxia information.

3. GENERAL CONSIDERATIONS

3.1 <u>Physiological Factors</u>:

3.1.1 Ø A loss of cabin pressure at high altitude encompasses possible physiological and physical hazards. The passengers may also react psychologically to rapid decompression in a manner contributing to the overall hazard.

3.1.2 Damage to ears and sinuses on rapid decompression is not likely due to the relative ease with which air can escape from the sinuses and inner ear except in individuals with upper respiratory ailments.

3.1.2.1 With rapid descent of the aircraft seeking lower altitude following decompression, ear and sinus difficulties may be experienced by many of the occupants of the airplane. Since the tolerance of individuals to recompression varies, the difficulties they experience may vary from none to temporary pain, temporary deafness, and possibly to rupture of the ear drum. This pain, which may be extreme, and the damage, which is usually repairable, must be accepted to prevent more serious impairment due to hypoxia (lack of oxygen).

3.1.3 Exposure to high altitude may result in decompression sickness, the liberation from solution within the body of nitrogen due to rapid and/or extreme pressure decreases.

3.1.3.1 The critical altitude at which decompression sickness is likely to occur, regardless of the rate of pressure change, is 30,000 ft. (9144m). Symptoms may arise, however, at altitudes as low as 23,000 ft. (7010m). The probability and severity of symptoms will increase with physical activity, age, and overweight. Usually several minutes of exposure are required before symptoms of decompression sickness begin.

3.1.3.2 Ø The frequency of occurrence and/or severity of decompression sickness is not significantly affected by the use of oxygen during decompression.

3.1.4 Ø Frostbite is a possible hazard after decompression, with possible uncontrolled ventilation at temperatures approaching -70°F (-57°C). Other physiological effects of decompression are hyperventilation and post decompression shock.

3.1.5 Personal injury may occur as a direct result of the sudden outrush of air during the decompression. The passage of air may hurl unattached objects about the cabin and, if sufficiently violent, may carry personnel through the decompression opening. Passenger injury may also occur as a result of the pilot's effort to produce rapid descent rates. This will diminish if seat belts are kept fastened and loose objects kept to a minimum.

3.1.6 Hypoxia will result from exposure to low barometric pressures of high altitudes. The low partial pressure of oxygen in the air under these conditions makes it impossible for the oxygen requirements of the body to be met. Unconsciousness and death will occur with marked rapidity if protective measures are not taken.

3.1.6.1 Hypoxia symptoms and consequences, together with the oxygen equipment and procedures required to protect against it, are detailed in the following documents:

AIR 822 - Oxygen Systems for General Aviation

AIR 825 - Oxygen Equipment for Aircraft

AIR 847 - Oxygen Equipment for Commercial Transport Aircraft Which Fly Above 45,000 Feet

AIR 1069 - Crew Oxygen Requirements Up To a Maximum of 45,000 Feet

3.2 Flight Procedures:

3.2.1 With flight at physiologically critical altitudes, the times required for recognition of emergency condition, reaction, and eventual initiation of descent become vital factors.

3.2.2 In the event of accidental or intentional loss of cabin pressure at high altitude, it is essential that the airplane descend to an altitude of 8,000 ft. (2438 m). If terrain or other conditions do not permit continued flight at such low altitude, then the revised altitude schedule may be adjusted to a level where the available oxygen equipment will meet the needs of the passengers and crew. (Refer to F.A.R 121.329 (c)). To prevent or alleviate the incidence of eardrum injuries due to high rate of descent, the descent rate should be reduced to less than 1500 f.p.m. (7.6 m/s) below 1500 feet (4,572m), consistent with other operational requirements.

3.2.3 With sudden decompression, (loud noises occur,) fog formation occurs which is often mistaken for smoke, unusual wind gradients are developed, and general confusion borne of fear is generated, particularly in untrained personnel.

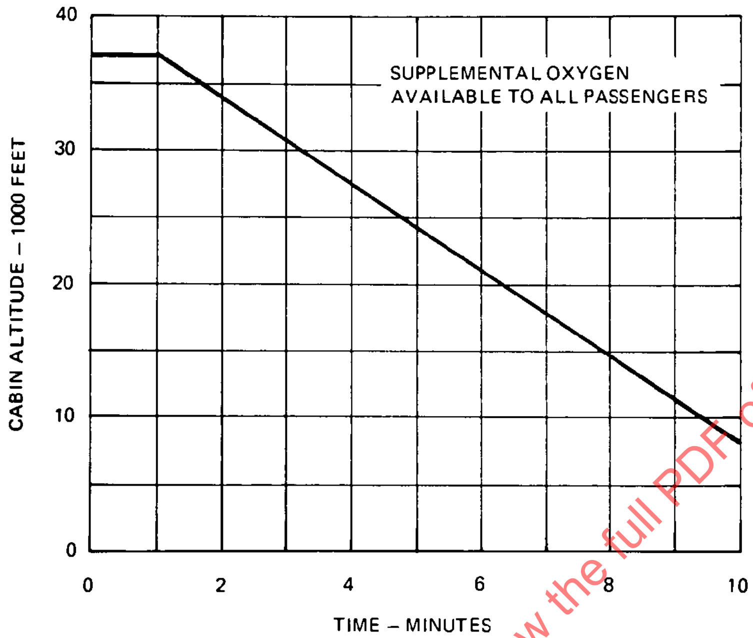
4. PRESSURIZATION DESIGN GUIDELINES

The design of aircraft structure, including windows, doors, and hatches must be such as to make the possibility of an uncontrolled decompression in flight as remote as the possibility of a major structural failure.

4.1 Pressure Altitude and Controls:

4.1.1 The cabin pressure altitude should be no greater than 8000 ft. (2438m.) during normal flight at the maximum cruise altitude of the airplane. The cabin pressure control system should be designed so that no single failure results in a loss of control. Furthermore, the control system should include a means of automatically limiting cabin altitude to 15,000 ft. (4572 m) in the event of a failure or failures which causes the outflow valve (s) to open. Large outflow valves, required to minimize cabin pressure buildup on the ground, should be actively prevented from opening inadvertently during pressurized flight. Refer to ARP 1270 for further details on cabin pressure control system requirements.

4.1.2 In the event of the loss of a window or a skin panel, or penetration of the pressurized area by a high
Ø velocity object, the cabin altitude profile during descent should be maintained within the limits shown in Figure 1. Figure 1 is taken from the F.A.A.'s Tentative Airworthiness Standards for Supersonic Transports, dated 1 January 1971.



Ø FIGURE 1

ALLOWABLE CABIN ALTITUDE PROFILE FOLLOWING A DECOMPRESSION

4.2 <u>Redundant Pressure Sources:</u>

4.2.1 The cabin pressurization source should be duplicated to such an extent as to eliminate the possibility of a single failure resulting in any loss of pressurization capabiltiy. In the event of any single failure, there should be sufficient inflow remaining to maintain an 8,000 ft. (2438m) cabin altitude at the
Ø maximum cruise altitude. In the event of a double failure, there should be sufficient inflow remaining to maintain a cabin altitude of 8,000 ft. (2438m) at the minimum cruise altitude acceptable from an airplane range standpoint. Examples of double failures are as follows:

a. Two air conditioning systems, including the controls.

b. One air conditioning system and a pressurized duct rupture.

c. One air conditioning system or a duct rupture, plus a door seal blowout or a 12-in. (305 mm) skin puncture.

Flight at altitude above 25,000 ft. (7620m) is not recommended with only one pressurization source operable.

4.2.2 With the loss of one or more pressurization sources, when flight must be continued for an extended
Ø period, cooling and ventilation should be provided for essential electronic equipment.

4.3 Window Design:

4.3.1 Cabin windows shall be sufficiently redundant as to preclude the uncontrolled loss of pressure as a result of the failure of a single panel. The windshield and flight station windows must be designed
Ø with safety margins to preclude failure from any cause.

4.3.2 Window design factors must consider the deterioration of materials involved due to aging, cleaning agents, insecticidal spray solvents, weather, high and low temperatures, vibration, and damage due to aircraft equipment.

4.3.3 Maintenance inspection procedures must be such as to insure an acceptable margin of safety in window strength during exposure to deterioration in service.

4.4 Door and Hatch Design:

4.4.1 Attachment means and operating mechanism of doors and hatches must be such as to prevent inadvertent opening during flight. Large, outward opening cargo doors, if opened inadvertently
Ø while pressurized, can produce catastrophic decompression rates. Such rates may cause collapse of the cabin floor with the possible destruction of vital control and power systems.

4.4.2 Cabin and cargo door seals should be designed to seal tighter with increasing pressure differential.
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4.5 Structural Design:

4.5.1 The fuselage pressure shell should have "rip stops" to limit crack propagation.
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4.5.2 Blowout panels or adequate openings in the air conditioning system must be provided for equalization of pressure in the various compartments during decompression at the maximum possible rate, without causing further damage to personnel or aircraft equipment.

4.5.3 Structural damage due to small arms gunfire, hail impingement, and bursting of pneumatic ducts or
Ø high pressure containers should not be sufficient to cause loss of cabin pressure.

4.5.4 Design of rotating machines should include containment of fragments after blade failure or wheel
Ø burst at maximum operating speed.

4.6 Pressure Relief System:

4.6.1 Design of the pressure relief system should be adequate to vent overboard all air from a "worst case"
Ø duct rupture without exceeding the maximum pressure for which the fuselage is designed.

5. TEMPERATURE FACTORS

The basic temperature requirements of the human body are unaffected by any of the conditions encountered in high altitude flight. However, consideration must be given to the increased significance of humidity effects as encountered at high altitude.

5.1 Air supplied to the cabin at high altitude normally has low humidity because of the low ambient temperatures encountered at altitude. This tends to increase to the rate of vaporization of moisture on the surface of the body and from the lungs at room temperature, which results in greater cooling of the body. Higher air temperatures must be used in accordance with the Comfort Charts published by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

5.2 The net transfer of heat due to radiation from a portion of the body near a window or other cold surfaces
Ø at high temperature difference may make more difficult the problem of maintaining human comfort.

5.3 Operation of refrigeration equipment at high altitude may be required due to:

a. Rapid climb to altitude before the cabin is cooled. This, of course, would be alleviated by pre-cooling the aircraft prior to take-off.

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b. Decreased effectiveness of heat exchangers due to low density cooling air.

c. High temperature of the supply air brought about by compression to the level of cabin pressure.

6. VENTILATION

Ø Ventilation requirements are not sugnificantly changed at cabin altitudes involved in normal pressurized flight (Refer to ARP 85 and ARP 367).

7. HUMIDITY FACTORS

In the absence of sweating, humidity does not appreciably affect the thermal comfort of the occupants of air-conditioned passenger airplanes. However, some of the cabin occupants may experience discomfort from drying of respiratory mucous membranes if the humidity of the cabin air is very low. In the absence of proper air conditioning of the cabin, which would result in high cabin air temperature, high humidity, and insufficient ventilation, active sweating may produce discomfort.

7.1 At high altitudes, the atmospheric temperatures are low and, therefore, little moisture is contained in the air. An increase in cabin humidity can be obtained by either adding water to the incoming air and/or recirculating air to minimize the amount of dry ambient air introduced into the cabin.

7.2 The humidity of the cabin air should not be allowed to rise to such a level that the dew point temperature will be higher than the temperature of exposed surfaces of cabin lining, soundproofing, insulation, or essential flight equipment or structure which could be adversely affected by moisture accumulations.

7.2.1 The thermal isolation from the airplane skin of essential flight equipment may prevent the loss of heat to such a degree as to materially raise the surface temperatures of these components.

7.2.2 Cabin lining, soundproofing, and insulating materials may either be made nonhygroscopic and non-wicking or may be protected from contact with cabin air by moisture impervious materials. Protection must also be provided against absorption of moisture from condensation on the skin which may drip onto the lining, soundproofing, or insulation.

7.2.3 Cabin air may be prevented from contacting the airframe skin or other structure in contact with the skin by the use of water impervious insulating materials. Provisions should be made for draining and disposing of any moisture that is collected.

7.3 It is expected that the compromise reached on the above items will result in the use of lower cabin relative humidity values than those shown on the Comfort Charts of the ASHRAE. Some of the cabin occupants may experience discomfort from drying of the respiratory mucous membranes due to low humidity air.

8. DETERMINATION OF CABIN LEAKAGE

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8.1 The effective leakage area, in square inches, A_e, may be determined experimentally. A standard method is to first determine the leakage in pounds per minute, M, at a given pressure by determining the flow necessary to hold that cabin pressure. The value of leakage thus determined may then be used to determine the effective leakage area, A_e, by use of the appropriate curve of Figure 2. Having established A_e, which is assumed not to vary with pressure, the other curves of Figure 2 may then be used to determine the leakage rate that will exist at any other combination of cabin pressure and airplane altitude. Any one of the following factors may be determined if the remaining factors are known:

Effective leakage area
Leakage rate
Cabin pressure
Ambient altitude

8.2 The following is an example of a calculation to determine leakage rate at a condition other than that measured, namely 8,000 feet cabin altitude and 40,000 feet airplane altitude.

Assuming

M having been measured as 165 lb/min. with a cabin pressure of 21 psia at sea level ambient.

Determine

1. From Figure 2, $\frac{M_{SL}}{A_e} = 27$ lb/min./in.^{2}

2. From calculation, $A_e = \frac{M_{SL}}{27} = \frac{162}{27} = 6$ in.^{2}

3. Cabin pressure equivalent to 8,000 ft is 10.92 psia

4. From Figure 2, $\frac{M_{40,000}}{A_e} = 15.1$ lb/min/in^2

5. From calculation, $M_{40,000} = 15.1A_e$
$= (15.1)(6)$
$= 90.6$ lb/min.

8.3 The following is an example of a calculation to determine the maximum cabin pressure obtainable at any ambient altitude.

Assuming

1. $A_e = 6$ in.^{2}

2. Leakage and air supply are equal at 72 lb/min.

3. Airplane altitude = 20,000 ft

Determine

1. From calculations, $\frac{M_{20,000}}{A_e} = \frac{72}{6} = 12$ lb/min./in.^{2}

2. From Figure 2, cabin pressure = 9.5 psia (11,000 ft cabin altitude)