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SOCIETY OF AUTOMOTIVE ENGINEERS, Inc.

485 LEXINGTON AVENUE
NEW YORK 17, N.Y.

AEROSPACE RECOMMENDED PRACTICE

ARP 367C

AIRPLANE CABIN PRESSURIZATION

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1. **PURPOSE:** This Aerospace Recommended Practice is intended to outline design practices and minimum performance recommendations that are based on sound engineering principles and are intended as guides for future standard engineering practices for the aircraft technology. These recommendations are to be considered as being currently applicable and necessarily subject to revision from time to time due to rapid development of the industry. The basis for these recommendations is practical engineering experience with cabin pressurization equipment in general use. The material herein is primarily applicable to multi-engine transport aircraft but in some cases may apply to any type of airplane, military or civil.
2. **SCOPE:** These recommendations cover the general field of airplane cabin pressurization equipment and are subdivided as follows:

GENERAL REQUIREMENTS FOR PRESSURIZED AIRPLANES

CABIN AIR COMPRESSORS

CABIN PRESSURE REGULATING EQUIPMENT

ENGINE BLEED AIR DUCT SYSTEMS

CABIN PRESSURE DUCTING SYSTEM

More comprehensive information may be found in the appropriate paragraphs of Sections 3E and 3H of the SAE Aerospace Applied Thermodynamics Manual, Reference 8.2.

3. GENERAL REQUIREMENTS FOR PRESSURIZED AIRCRAFT:

3.1 Air Capacity:

- 3.1.1 Cabin pressure systems for multi-engine aircraft designed for cruise operation above 20,000 feet should contain two or more pressure sources, each capable of independent continuous operation. The sources for air are either direct engine bleed or separately powered compressors.
- 3.1.2 Each separate source of cabin pressurizing air should independently supply sufficient flow to permit the maintenance of the design cabin pressure differential at maximum cruise altitude. In determining the necessary flow rate to meet this requirement, due consideration shall be given to the minimum flow required for normal operation of the cabin pressure regulating valves, cabin leakage (maximum) at full cabin pressure differential, at design cruise altitudes, and the flow rate through all essential and non-controllable overboard leakage paths such as radio rack venturi, etc. Consideration shall also be given to providing adequate flow to allow for in-service increase in leakage.



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3.1.3 All pressurized aircraft should provide for an alternate source of unpressurized air (ram) through the normal air distribution system. The quantity of air flow is to be determined by the maximum ventilation required during a low speed, low altitude, hot-day condition. Adequate ventilation for smoke evacuation shall be considered.

3.2 Air Leakage:

3.2.1 The air leakage can be estimated for design purposes using equation (1) below. Air leakage is to be stated in pounds of NACA sea level air per minute measured with maximum design pressure differential across the cabin. Air flow measured at other than sea level density may be standardized approximately by the use of the equation (2) below:

Equation for Estimating Leakage

$$W_D = \frac{123.0 P_C Z CA}{\sqrt{T_C}} \quad (1)$$

Equation for Converting Leakage to Standard Conditions

$$W_S = \frac{14.7}{\sqrt{519}} (W_M) \frac{\sqrt{T_C}}{P_C} = 0.645 W_M \frac{\sqrt{T_C}}{P_C} \quad (2)$$

Where:

W_D = Estimated design leakage rate, lbs/min

W_M = Measured leakage rate, lbs/min

k = Specific heat ratio, C_p/C_v

W_S = Leakage rate of standard sea level density, lbs/min

P_C = Cabin pressure, psia

P_A = Ambient pressure, psia

T_C = Cabin temperature, °R

CA = Equivalent leakage area, sq in, (estimated)

Z = is the function of pressure ratio between cabin and ambient defined as follows:

$$Z = \sqrt{\left(\frac{P_A}{P_C}\right)^{2/k} - \left(\frac{P_A}{P_C}\right)^{\frac{k+1}{k}}}$$

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Z = is the function of pressure ratio between cabin and ambient defined above for pressure ratios between 1.0 and 0.53. For pressure ratios equal to and below 0.53, sonic velocity occurs in the orifice, and $Z = 0.256$.

3.2.2 Leakage tests shall be made on each pressurized airplane. All pressure ducting from the air source to the pressurized area that are located in the unpressurized area as well as all ducting that discharges to ambient pressure and are located in the pressurized area are to be installed at the time the leakage test is made. All cables, tubing, harnesses, etc., that pierce pressure structure are also to be installed.

3.2.3 The following methods of measuring leak rates are recommended:

- a) With cabin pressurized on the ground to design pressure differential, measure the air input required to maintain this differential, or
- b) With the cabin pressurized to design differential pressure, shut off the air supply, measure the time to reach lower pressure differential and calculate the leakage rates. This value is to be established experimentally on the first aircraft that has an acceptable leakage rate as determined by a).

3.2.4 For aircraft which have been in service, leakage testing shall be accomplished at intervals established by service experience.

3.3 Decompression: Blow-out panels and/or sufficient flow areas should be provided between compartments as required to prevent injury to crew and passengers and to prevent structural failures in the event of sudden decompression.

3.4 Desirable Design Features:

- 3.4.1 The cabin structure, windows, doors, seals, ducting and pierce points through the pressurized area should be designed for minimum leakage.
- 3.4.2 Overboard venturis for ventilating radio and electrical compartments, lavatories, buffets, etc., should be designed for a minimum flow commensurate with needs.
- 3.4.3 Self-energizing type of door seals should be considered whenever possible.
- 3.4.4 Alternate cabin air compressor air intakes should be provided where necessary in the event the normal air intake ices over.
- 3.4.5 The location of air compressor inlet scoops should be such as to preclude the possibility of entrance of oil, fuel, exhaust fumes, water, snow, ice and foreign objects into the system.

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- 3.4.6 Noise level specifications for crew or passenger compartments state the maximum allowable noise as contributed by all aircraft noise sources. Thus, the noise level design requirements for the ventilation system alone, will generally have to be set lower (made more stringent) than the governing total noise specification in the compartment, since ventilation noise is only one of a number of contributing noise sources. The "margin" between the total noise specifications and ventilation design requirements, dependent upon the relative difficulty in controlling the noise from the different sources, should be set early in design.

Noise level specifications have conventionally, at least to the present time, been stated in terms of maximum overall sound pressure level and/or maximum sound pressure levels in octave frequency bands. Such specifications cannot adequately cover "pure tones" or "pitched noise" (such as the whine from high speed rotating equipment, whistles or duct rumble). While these noises may be of lower intensity than the overall or octave band specifications, they could be objectionable to the crew or passengers.

To insure that the system is below the desired overall noise level and that objectionable noises are eliminated, a test program on a representative portion of the system should be conducted.

Consideration should be given early in design in keeping the noise level generated by the pressurization equipment and transmitted through ducting or structure to an acceptable minimum. The following should be carefully considered in the system design.

- a) Location of noise generating equipment relative to the occupied compartments.
- b) Low air velocities in the ducting.
- c) Insulation treatment to ducting and components as required for sound attenuation.
- d) Avoid sharp edges, abrupt directional changes and direct impingement in duct design.
- e) Use of isolators in mounting noise generating equipment to break the path of noise transmission through structure.

4. CABIN AIR COMPRESSORS:

Selection of the compressor type should be based on a trade-off study of weight, efficiency and pressure ratio required by the particular application. A description of the various classes of compressors and the associated controls may be found in Section 3H of Reference 8.2.

4.1 Design Requirements:

- 4.1.1 The cabin air compressor should provide stable flow for any or all conditions of operation up to design altitude. The output of the cabin air compressor should not be adversely affected by engine management during normal operation.

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- 4.1.2 A flow control device should schedule the total air flow from sea level to maximum cruising altitude and should be compatible with the ventilation requirements and the intent of Paragraph 3.1.2.
- 4.1.3 A reliable overspeed mechanism, preferably sensing shaft speed, should be provided to override the normal controls. For turbine driven compressors, the overspeed device should shut the unit down by closing the turbine bleed air valve.

For mechanically driven compressors, the overspeed device should provide governing of the unit speed through a "topping" type speed control system. Consideration should be given to selection of gear ratios which will minimize the maximum wheel speeds attainable.

- 4.1.4 Containment of wheel burst fragments in high speed rotating equipment is an essential design consideration.

For turbine driven units, consideration should be given to the design of the turbine blades so that failure of the turbine blades occurs at a speed above the overspeed setting and below that at which either compressor blade or hub failure of the compressor wheel may be expected to occur.

The compressor and turbine scrolls should be designed to contain blade fragments at the overspeed condition.

Since trans-hub failures due to fatigue are possible, it would be desirable to provide containment of a hub segment at maximum normal rpm if the weight penalty imposed is justifiable.

To minimize the possibility of trans-hub failures, the hubs should be designed for low operating stresses. Careful attention should be given in detail design to avoid stress risers.

- 4.1.5 When applicable, means should be incorporated to prevent surge of the cabin air compressor under any normal flow conditions and damage to the compressor under any abnormal flow condition.
- 4.1.6 Cabin air compressors should be provided with suitable oil seals to preclude oil vapors being carried to the ducting system. Provisions must be made to preclude oil vapors, emitted by the compressor oil sump or system vents, from being injected by the compressor inlets.
- 4.1.7 The lubricant should be suitable for use throughout the operating and environmental range of the aircraft. The unit should be designed to preclude the need for frequent lubrication service. A design objective of 500 hours between servicing is recommended. The lubricant reservoir whenever possible should be an integral part of the cabin air compressor.
- 4.1.8 Service time of 2500 hours of operation between overhaul should be a design objective.



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4.2 Performance Presentation - Compressor:4.2.1 Centrifugal Compressors:

- 4.2.1.1 Compressor performance information should be plotted on a coordinate system which consists of directly measured quantities so that parameters may be expressed in their most workable form.
- 4.2.1.2 The basic performance graph should consist of pressure ratio as the ordinate plotted against corrected flow as the abscissa with a speed factor and adiabatic temperature efficiency as parameters. Where all the required information cannot be combined conveniently in one graph, the various factors may be plotted separately against corrected flow. Mechanical efficiency of the machine should not be contained in parameters plotted but should be defined in the nomenclature.
- 4.2.1.3 The units used for the variable in the performance presentation should be those which are readily measured during tests.
- 4.2.1.4 Since the factor of impeller speed is a primary independent variable, it should **not** appear in the corrected flow.
- 4.2.1.5 Choice of factors and units should be such as to give maximum clarity and spread in the plotted results and well defined limits of operation and surge.
- 4.2.1.6 The system of presentation similar to that in Reference 8.1 meets the above requirements and is recommended as an industry standard.
- 4.2.1.7 The basic equation is as follows:

$$\left(\frac{P_{t2}}{P_{t1}}\right) \left(\frac{T_{t2}}{T_{t1}}\right) \left(\frac{C_p J T_{t1} W_c}{HP_{ad}}\right) = f \left(\frac{W_c \sqrt{T_{t1}}}{D^2 P_{t1}} \frac{ND}{\sqrt{T_{t1}}} \right)$$

NOMENCLATURE

P_a	= Absolute pressure of standard atmosphere (14.7 psia)
P_{t1}	= Total absolute pressure at compressor inlet, psia
P_{t2}	= Total absolute pressure at compressor discharge, psia
T_a	= Temperature of standard atmosphere at sea level, °R
T_{t1}	= Total temperature of fluid at compressor inlet, °R
T_{t2}	= Total temperature of fluid at compressor discharge, °R
W_c	= Compressor weight flow, lb/sec



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NOMENCLATURE (Continued)HP_{ad} = Adiabatic horsepower

D = Impeller diameter, feet

N = Impeller speed, rpm

k = Adiabatic exponent = $\frac{C_p}{C_v}$ = 1.395 for normal airC_p = Specific heat at constant pressure, BTU/lb/°R = 0.243 for normal airC_v = Specific heat at constant volume, BTU/lb/°R = 0.174 for normal air

$$Y = \left[\left(\frac{P_{t_2}}{P_{t_1}} \right)^{\frac{k-1}{k}} - 1 \right]$$

J = Mechanical equivalent of heat - 778 ft-lbs/BTU

4.2.1.8 From the constants, definitions, and the basic equation, the following relationships may be established for general use when air is the fluid.

k = Adiabatic exponent for normal air = 1.395

C_p = Specific heat at constant pressure for normal air =
0.243 BTU/lb/°RC_v = Specific heat at constant volume for normal air =
0.174 BTU/lb/°Rr = Pressure ratio = $\frac{P_{t_2}}{P_{t_1}}$ (ordinate)Corrected flow = $\frac{W_c \sqrt{\Theta}}{\delta}$ (abscissa)Θ = Temperature correction factor = $\frac{T_{t_1}}{519}$ δ = Pressure correction factor = $\frac{P_{t_1}}{14.7}$ M = Speed factor = $\frac{ND}{936 \sqrt{T_{t_1}}}$ (contour)