Society of Automotive Engineers, Inc.
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AERONAUTICAL RECOMMENDED PRACTICE

ARP 367

AIRPLANE CABIN PRESSURIZATION

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Revised

1. PURPOSE: This Aeronautical 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 industry. 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 currently 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 commercial.

2. SCOPE: These recommendations cover the general field of airplane cabin supercharging equipment and are subdivided as follows:

2.1 GENERAL REQUIREMENTS FOR PRESSURIZED AIRPLANES:
Dealing with air flow quantities, pressure differentials, allowable leakage rates, desirable design features and typical equipment.

2.2 CABIN SUPERCHARGERS:
Dealing with operating characteristics, standard performance presentation, design features, drive shafts, mounting pads.

2.3 AUXILIARY EQUIPMENT:
Dealing with pressure control valves, pressure and vacuum relief valves, check valves, instrumentation.

2.4 MISCELLANEOUS PROVISIONS:
Dealing with air ducts, water traps, turbo supercharger bleed systems.

3. GENERAL REQUIREMENTS FOR PRESSURIZED AIRPLANES:

3.1 Air Capacity:

3.1.1 Air capacity should be stated in terms of weight flow of air per minute at sea level and 59 F. It may be referenced in terms of air volumes under the same conditions.

3.1.2 Source(s) of pressurized air should be capable of supplying a minimum of 1.0 lbs per minute of outside air per occupant at maximum design cabin altitude and maximum design pressure differential. Depending on the effectiveness of the distribution system and on the amount of mechanical refrigeration available, it may be necessary to provide as much as 1.2 lbs per minute per occupant of additional air in order to obtain reasonable comfort during hot weather or heavy smoking. This additional ventilation may be provided either by the primary pressure source(s) or by re-circulation, provided due allowance is made for efficiency of purification apparatus used in the re-circulation system.

3.1.3 Wherever practicable supercharged air supply systems for multi-engined aircraft should contain two or more pressure sources, each capable of independent continuous operation.

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3.1.4 In all pressurized aircraft provisions should be made for a minimum alternate supply of at least 1.0 lbs of unpressurized (ram) air per minute per occupant during all normal flight conditions. Considerably higher alternate air flow rates may be required for low altitude operation during hot weather, depending on the effectiveness of the air distribution system and the amount of mechanical refrigeration available.

3.1.5 Air flow rates given in this section should be increased by a factor of 1.5 for crew members on the flight deck unless independent temperature control both for heating and cooling is available to these occupants.

3.2 Air Leakage:

3.2.1 Air leakage should be stated in pounds of NACA sea level air per minute measured with maximum design pressure differential across the cabin. Airflow measured at other than sea level density may be standardized approximately by use of the following formula:

$$W_s = \frac{0.277\, W_m}{\sqrt{\rho_m}}$$

where:

W_s = Standardized leakage rate in lbs/min

W_m = Measured leakage rate in lbs/min

ρ_m = Measured cabin air density in lbs/cu ft

3.2.2 Standardized leakage rate, W_s, should be subtracted from total pressurized airflow at sea level, W_p, to determine airflow available for pressure regulation, W_a. Designating the minimum steady flow required through the pressure regulator(s) for stable control at maximum design differential as W_r, the percentage W_a/W_r may be called the regulation factor, or F_r.

W_s = Standardized Leakage Rate in lbs/min
W_p = Pressurized air available in lbs/min
$W_a = W_p - W_s$ in lbs/min
W_r = Minimum flow for regulation in lbs/min

Then $F_r = W_a/W_r$ = regulation factor.

3.2.3 Leakage tests should be run on all new pressurized aircraft and the regulation factor, F_r, should not be less than 3.0.

3.2.4 For aircraft which have been in service, overhaul and resealing will be desirable if the regulation factor becomes less than 2.0.

3.2.5 Two alternate methods of leakage testing are recommended:

3.2.5.1 With cabin pressurized on the ground to design pressure differential, measure the air input required to maintain this differential.

3.2.5.2 With cabin pressurized on the ground to design pressure differential, shut off the air supply, measure the time to reach a lower pressure differential, and calculate the leakage rate. For this calculation it will be acceptable to assume isothermal expansion of the air.

3.3 Desirable Design Features

3.3.1 Alternate supercharger air intakes should be provided if there is any danger of the normal intake icing over.

3.3.2 High frequency noise from the superchargers should not be transmitted into the cabin through the air ducts.

3.3.3 Purity of air delivered into cabin should be assured free from oil vapors, deicing vapors, water, snow, ice, and dirt from taxiing.

3.4 Equipment - In general pressurizing equipment should include the following components:

3.4.1 Pressure source(s) capable of maintaining cabin pressure equivalent to 8000 feet or lower altitude at the cruising altitude of the airplane.

3.4.1.1 Cabin supercharger(s) meeting the requirements of Section 4 of this specification.

3.4.1.2 Bleed air from gas turbine engines. (see note)

3.4.1.3 Engine turbo supercharger bleed system(s) meeting the requirements of Section 6.3 of this specification.

Notes:

(a) Where either (3.4.1.2) or (3.4.1.3) are the sources of pressure a flow limiting means should be provided in the individual bleed circuit from each source to avoid the loss of excess quantities of air in event of an excessive leak in the system.

(b) Where either (3.4.1.2) or (3.4.1.3) are the source of pressure, automatic fire dampers should be provided in each pressure source at the point where the bleed air duct penetrates the first fire barrier and at the point where the pressure supply duct enters the fuselage. Where (3.4.1.1) is the source of pressure a fire damper need only be provided at the points where the pressure supply ducts enter the fuselage if the supercharger is so located that no fire barriers are penetrated. If the supercharger is so located that either the inlet or discharge duct penetrates the firewall an additional fire damper should be installed at that point.

(c) Where multiple sources of pressure are employed check valves should be provided in the individual circuits to prevent the loss of air in the event one or more sources become inoperative.

3.4.2 A cabin pressure regulating system meeting the requirements of Section 5.1 of this specification.

3.4.3 Emergency pressure relief valve(s) meeting the requirements of Section 5.2 of this specification.

3.4.4 Vacuum relief valve(s) meeting the requirements of Section 5.3 of this specification.

3.4.5 Check valves meeting the requirements of Section 5.4 of this specification.

3.4.6 Instrumentation meeting the requirements of Section 5.5 of this specification.

4. CABIN SUPERCHARGERS:

4.1 Operating Characteristics:

4.1.1 The supercharger should provide stable flow under any or all conditions of operation up to design altitude.

4.1.2 Cabin supercharger should be replaceable as a unit.

4.1.3 The supercharger oiling system should be inherently reliable.

4.1.3.1 Supercharger oiling systems should be so designed as to eliminate frequent servicing operations. Replacement should not necessarily occur more frequently than every 100 hours of operation.

4.1.3.2 Supercharger oiling systems should function satisfactorily under any conditions suitable for main engine operation.

4.1.3.3 Oil leakage should be kept to a minimum so that oil reservoir capacity is not excessive.

4.1.4 The supercharger should be provided with a suitable oil seal to preclude oil vapors being carried to the cabin.

4.1.5 Safety factors employed in the structural elements of the supercharger should be sufficiently high to prevent occurrence of structural failures which might endanger crew or passengers directly.

4.1.6 Rated Capacity---The rated capacity of the cabin supercharger should be defined as the available flow in CFM at specified maximum continuous RPM and pressure ratio, an inlet temperature of 59 F and no ram.

4.1.7 Rated Speed---The definition of rated speed should be as follows: Rated speed of the supercharger is the impeller revolutions per minute required to develop rated capacity. Ratio of gearing supplied with the supercharger assembly should be specified simultaneously.

4.1.8 Critical Altitude---Critical altitude of a cabin supercharger in a given airplane is that altitude above which maximum normal operating pressure differential cannot be maintained across the fuselage at rated air flow.

4.2 Performance Presentation

4.2.1 Supercharger performance information should be plotted on dimensionless coordinates in order to simplify comparison and operating analyses.

4.2.1.1 The basic performance graph should consist of compression ratio as the ordinate plotted against "flow factor" as the abscissa with a speed factor, temperature efficiency, and shaft power efficiency as parameters. Where all the required information cannot be combined conveniently in one graph, the various factors may be plotted separately against "flow factor". (See 4.2.2.2)

4.2.1.2 The units used for the variables in the performance presentation should be those which are readily measured during tests.

4.2.1.3. Since the factor of impeller speed is a primary independent variable, it should not appear in the dimensionless "flow factor".

4.2.1.4 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.

4.2.2 The system of presentation similar to that in Reference 7.1 meets the above requirements and is recommended as an industry standard.

4.2.2.1 The basic dimensionless equation is as follows:

$$\frac{P_2}{P_1} \quad \frac{T_2}{T_1} \quad \frac{C_p \quad JT_1 YW}{P_s} = \phi\left(\frac{W\sqrt{T_1}}{D^2 \; P_1} \quad \frac{ND}{\sqrt{T_1}}\right)$$

NOMENCLATURE

P_o = Absolute pressure of std. atmosphere (29.92 in. H_g).
P_1 = Total absolute pressure at compressor inlet, inches of mercury.
P_2 = Total absolute pressure at compressor discharger, inches of mercury.
T_o = Temperature of std. atmosphere at sea level, degrees fahrenheit absolute.
T_1 = Temperature of fluid at compressor inlet, degrees fahrenheit absolute.
T_2 = Temperature of fluid at compressor discharge, degrees fahrenheit absolute.
W = Weight of fluid inspired, pounds per minute.
P_s = Shaft horsepower
D = Impeller diameter, inches.
N = Impeller speed, revolutions per minute.
k = Adiabatic exponent = $\frac{C_p}{C_v}$ = 1.3947 for normal air.

C_p = Specific heat at constant pressure, BTU/lb/°F = 0.243 for normal air.
C_v = Specific heat at constant volume, BTU/lb/°F = 0.174 for normal air.

$$Y = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1$$ = Ratio of temperature rise to absolute inlet temperature in adiabatic compression

g = Acceleration of gravity = 32.2 ft/sec²
J = Mechanical equivalent of heat = 778ft. lbs per BTU

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

$$r = \text{Compression ration} = \frac{P_2}{P_1} \quad \text{(ordinate)}$$

$$F_f = \text{Flow factor} = \frac{W\sqrt{T_1}}{D^2 \; P_1} \quad \text{(ordinate)}$$

$$M = \text{Speed factor} = \frac{ND}{11230 \times \sqrt{T_1}}$$

$$P_s = \text{Adiabatic horsepower} = \frac{C_p J T_1 Y W}{35{,}000} = 0.00573\ T_1 Y W$$

$$\eta_s = \text{Adiabatic shaft horsepower efficiency} = \frac{0.00573\ T_1 Y W}{P_s} \quad \text{(contour or ordinate)}$$

$$\text{Temperature ratio (actual)} = \frac{T_2}{T_1} \quad \text{(ordinate)}$$

$$\eta = \text{Adiabatic temperature efficiency} = \frac{T_1 Y}{T_2 - T_1} \quad \text{(contour)}$$

4.2.2.3 Typical illustrations of the recommended forms for performance presentation are given in the attached Figures 1 and 2.

Figure 1. Typical plot of temperature ratio vs. flow factor with speed factor as parameter.

Figure 2. Desired combined performance plot--compression ratio vs. flow factor with speed factor as parameter and adiabatic efficiency as contours.

4.3 Testing Requirements:

4.3.1 Prototype units of new cabin supercharger designs should be required to pass a 500 hour mechanical endurance test simulating conditions of load, cycling, vibration and temperature which would normally be encountered in service.

4.3.2 A prototype unit of each new impeller design should be required to pass an overspeed test of 125% of the maximum speed expected in service.

4.3.3 A prototype of each new supercharger design should be required to pass a test at 115% of the maximum speed to be encountered in service, for two minutes, without permanent deformation or mechanical failure.

4.3.4 All complete new supercharger units should be required to pass a test at full rated capacity and speed for 1 hour and 10% of the units should be tested at 110% of rated speed for 5 minutes.

4.4 Desirable Design Features:

4.4.1 Automatic supercharger flow control should maintain relatively constant mass flow of air up to maximum design cruising altitude of the airplane. Variation of flow proportional to the square root of the cabin air density is satisfactory throughout the normal altitude range.

4.4.2 Means should be provided either in the compressor design or in the pressure regulating system to avoid surging due to overload.

4.4.3 Manual means of adjusting supercharger flow are desirable.

4.5 Supercharger Drives:

4.5.1 Power shafts for main-engine driven superchargers not mounted directly on engine accessory pads should be provided with full articulation within 5 degrees of the static shaft center line. Flexibility may be obtained from spherical splines or universal joint yokes.

4.5.2 Drive shafts should have provisions for minimizing torsional vibration and shock.

4.5.3 Drive shafts should be provided with dirt and grease tight covers.

4.5.4 Satisfactory provisions for lubrication should be made. It should not be necessary to disassemble or remove the drive shaft for lubrication more frequently than every 1000 hours.

4.5.5 Drive shaft drive requirements at the engine shall conform to AN or SAE six bolt generator mounting standards.

4.5.6 When drive shafts are employed, they should be free from critical vibration (reasonance) periods within the range of 15 to 135% of rated speed. Shafts should be as short as possible.

4.5.7 The power transmission shaft should remain within satisfactory unbalance limits at 135% of rated speed.

4.5.8 Shearing section: For all superchargers, a shearing section should be provided in the power transmission shaft (if used) or elsewhere in the drive mechanism as close as possible to the prime mover.

4.5.8.1 Shearing section for supercharger drive shaft should be designed to shear at a safe margin below the power transmission torque allowable to provide protection to the prime power source.

4.5.8.2 Failure of the shearing section should not result in secondary damage to any part of the supercharger, or drive mechanism.

4.5.9 A disconnect means should be provided operable in flight which will completely disconnect the drive shaft and supercharger from the engine.

4.6 Mounting Pads on Engine:

4.6.1 Supercharger mounting pads on new engines should be designed to carry a maximum overhung static moment of 350 inch pounds.

4.6.2 Allowable power for supercharger drive pads at engine idling speed should be at least 75 horsepower.

5. Auxiliary Equipment:

5.1 Cabin Pressure Regulating System:

5.1.1 Normal operation of the cabin pressure regulating valve(s) should be automatic, but an emergency over-ride system accessible to flight personnel should be provided.

5.1.2 The cabin pressure regulating valve(s) should have sufficient capacity to pass the normal air flow being supplied to the cabin from the pressure source(s) at sea level at a pressure differential not in excess of 0.25 inches of H_g.

5.1.3 A differential over-ride control should be provided which can be permanently adjusted to cause the cabin pressure regulator to limit differential across the pressurized structure to a safe value, regardless of the settings of other controls.

5.1.4 A cabin absolute pressure selector should be installed in the control cabin. This should preferably be calibrated in feet from -1500 to 15,000 feet with equivalent calibration in inches of H_g from 0 to 5000 feet for barometric adjustment to airport pressure.

5.1.5 The cabin absolute pressure control should regulate to within $\pm$ 1% of the preselected value in inches of H_g with the extreme variation occurring in cycles of not less than 2 minutes at all flow rates from the nominal rating of the regulating valve(s), per 5.1.2, to 10% of the nominal rating.

5.1.6 A rate of pressure change selector should be installed in the control cabin.

5.1.7 The rate of change control should regulate the rate of change of absolute pressure within the cabin to within $\pm$ 10% of the control setting at all flow rates from the nominal rating of the regulating valve(s), per 5.1.2, to 10% of the nominal rating.

5.1.8 Valves should be so located that no venturi action of flaps or wheel well doors will affect the flow through the valves.

5.2 Pressure Relief Valve(s):

5.2.1 Relief valves should be installed which will positively prevent the differential pressure across the fuselage from exceeding 110% of the normal maximum operating differential.

5.2.2 Flow capacity of relief valve(s) should be large enough to pass the maximum rate of flow delivered by the cabin pressure source(s) without exceeding the limit of 5.2.1.

5.2.3 Relief valve leakage at the normal maximum cabin pressure differential should not exceed 1% of full-rated flow capacity.

5.2.4 Relief valve springs should be so designed as to eliminate the possibility of any permanent set due to maximum movement of the valve.

5.2.5 Icing of relief valves should be guarded against. Special care should be exercised to locate relief valves where they will not ice up due to:

5.2.5.1 External icing conditions.

5.2.5.2 Condensation settling into valve and freezing there with valve not operating.

5.2.6 Special consideration should be given to valve and seat design to avoid possibility of sticking. High and low temperature effects, tobacco smoke, tar, dust deposits, and deterioration of materials should be kept in mind in this regard.

5.2.7 An emergency manual method of relieving cabin pressure should be available. This may be accomplished through the normal relief valve(s), outflow valve(s), or an auxiliary valve.

5.2.8 Relief valves should be opened and closed by hand occasionally and otherwise governed by API and ASMS codes when applicable.

5.2.9 Valves should be so located that no venturi action of flaps or wheel well doors will affect the flow through the valves.

5.3 Vacuum Relief Valves:

5.3.1 Suitable vacuum relief valve(s) should be installed to prevent collapse or damage of the pressure cabin due to negative pressure differential. These should be installed above the ditching water line on airplanes to be certified for ditching.

5.3.2 Vacuum relief valve(s) shall be capable of passing sufficient air from outside to inside the cabin at the maximum normal cabin operating altitude to prevent the pressure differential from exceeding a value of 0.25 psi during a maximum permissible rate of descent of the airplane.

5.3.3 The vacuum relief valve(s) should be so designed as to preclude sticking or freezing.

5.3.4 The vacuum relief valve(s) should be so designed as to prevent outward leakage during normal operation.

5.3.5 Extreme temperature variations should not deteriorate the materials employed, nor cause malfunctioning of the valve(s).

5.4 Check Valves:

5.4.1 Check valves should be used to prevent back flow in case of compressor failure.

5.4.2 Check valves should be designed to preclude freezing or sticking.

5.4.3 Check valves should have minimum pressure drop.

5.5 Instrumentation:

5.5.1 A standard rate of climb indicator, responsive to cabin atmosphere, should be installed at the pressure controls panel.

5.5.2 A cabin altitude indicator should be provided adjacent to the pressurization control in the cockpit.

5.5.3 A cabin differential pressure gauge should be provided adjacent to the pressurization controls in the cockpit. Special warning should be available in the event maximum design pressure is exceeded.

5.5.4 Oil temperature indication or other warning of incipient supercharger failure should be provided.

6. Miscellaneous Provisions:

6.1 Air Ducts:

6.1.1 Ducts should be fire-proof material forward of the engine firewall.

6.1.2 No objectionable odors should be introduced into the airstream from ducts or duct joints.

6.1.3 Ducts shall be suitably reinforced at the joints to prevent buckling when clamps and seals are tightened.

6.1.4 Manually or thermally operated check dampers should be provided to prevent powerplant or supercharger fires from being conducted into the cabin.

6.1.5 Suitable reinforcement should be provided to prevent drumming and reverberation of the duct walls.

6.1.6 Ducts should be insulated sufficiently to avoid excessive heat transmission and to reduce the tendency of the ducts to become a sound carrier.

6.1.7 Pressure drop between the air intake and the supercharger should not exceed 1/2 in. H_g and should be as small as possible compatible with ram available at rated flow capacity of the system and indicated flight speed.

6.2 Water Separators:

6.2.1 Water traps should be provided in supercharger inlet ducts.

6.2.2 Pressure drop shall be a minimum.