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AERONAUTICAL RECOMMENDED PRACTICE

ARP 367A

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AIRPLANE CABIN PRESSURIZATION

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 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

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.

3.1.2 Each separate source of cabin pressurizing air should independently supply sufficient air to permit the maintenance of a controllable maximum cabin differential. 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.

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 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 following formula:

$$W_s = \frac{14.7}{\sqrt{519}} \times W_m \frac{\sqrt{T_c}}{P_c} = 0.645 \quad W_m \times \frac{\sqrt{T_c}}{P_c}$$

Where:

W_s = Leakage rate in lbs/min. at standard sea level density
W_m = Measured leakage rate in lbs/min
T_c = Air Temperature in cabin (°R)
P_c = Absolute pressure in cabin (PSIA)

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.

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 and transmitted by the pressurization equipment 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.

4. CABIN AIR COMPRESSORS:

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.

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 blades occurs at a speed above the overspeed setting and below that at which either 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.

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.

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 "flow factor" 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 "flow factor". 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 "flow factor".

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 define 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:

$$\frac{P_2}{P_1}, \quad \frac{T_2}{T_1} \quad \frac{C_p \; J T_1 Y W}{HP_A} = f\left(\frac{W \sqrt{T_1}}{D^2 \; P_1}, \quad \frac{ND}{\sqrt{T_1}}\right)$$

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 discharge, inches of mercury.
T_o = Temperature of std. atmosphere at sea level, degrees fahrenheit absolute.
T_1 = Total temperature of fluid at compressor inlet, degrees fahrenheit absolute.
T_2 = Total temperature of fluid at compressor discharge, degrees fahrenheit absolute.
W = Weight of fluid inspired, pounds per minute.
HP_A = Adiabatic horsepower.
D = Impeller diameter, inches.
N = Impeller speed, revolution per minute.
k = Adiabatic exponent = $\frac{C_p}{C_v}$ = 1.395 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.
$Y = \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right]$ = Ratio of temperature rise to absolute inlet temperature in adiabatic compression.
g = Acceleration of gravity - 32.2 ft/sec.^{2}
J = Mechanical equivalent of heat - 778 ft.lbs. per BTU
HP_s = Shaft horsepower (includes bearing losses)

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.

r = Pressure ratio = $\frac{P_2}{P_1}$ (ordinate)

F_f = Flow Factor = $\frac{W\sqrt{T_1}}{D^2\ P_1}$ (abscissa)

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

HP_A = Adiabatic horsepower = $\frac{C_pJT_1YW}{33,000}$ = $0.00573\ T_1YW$

s = Adiabatic shaft horsepower efficiency = $\frac{0.00573\ T_1YW}{HP_S}$

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

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

$$\eta_m = \frac{HP_A}{\eta\,(HP_s)} = \text{mechanical efficiency}$$

$$Y = \left(\frac{P_2}{P_1}\right)^{0.283} - 1$$

4.2.1.9 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.

4.2.2 Positive Displacement Compressors:

4.2.2.1 Positive displacement 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.

4.2.2.2 The basic performance graph should consist of pressure ratio as the ordinate plotted against "flow factor" as the abscissa with a speed factor and adiabatic temperature efficiency as parameters. Mechanical efficiency of the machine should not be contained in the parameters plotted but should be defined in the nomenclature. The nomenclature defined in 4.2.1.7 may also be applied to positive displacement compressors.

4.2.2.3 A typical illustration of the recommended form for performance presentation is given in the attached Figure 6.

4.3 Cabin Air Compressor Drives:

4.3.1 Mechanically Driven - Remotely Mounted:

4.3.1.1 Power shafts for main engine driven cabin air compressor not mounted directly on engine accessory pads should be provided with full articulation within 5 degrees of the static shaft centerline. Flexibility may be obtained from spherical spines or universal yoke joints. (see ARP 259) Joint angle combinations should not cause large shaft angular deflections that would shorten the life of mating components.

4.3.1.2 The design of the drive shaft and its fire wall penetration points should be such as to permit simultaneous accommodation of the maximum engine roll, pitch and yaw components without a mechanical interference of any of the drive system components resulting therefrom. Sufficient installation design and manufacturing accuracy should be maintained to prevent loss of the clearances so established.

4.3.1.3 Drive shafts may require provisions for minimizing torsional vibration and shock depending upon the drive method and driven unit design.

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

4.3.1.5 Satisfactory provisions for lubrication should be made. Lubrication should not be necessary at intervals of less than 1000 hours.

4.3.1.6 Drive shafts should be free from critical vibration (resonance) periods within the range of 15 to 135% of rated speed. Shafts should be as short as possible.

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

4.3.1.8 For all cabin air compressors a shearing section should be provided in the power transmission shaft or elsewhere in the drive mechanism as close as possible to the prime mover.

4.3.1.9 Shearing section for the cabin air compressors 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.

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

4.3.1.11 A disconnect means should be provided operable in flight which will completely disconnect the drive shaft and cabin air compressor from the engine.

4.3.2 <u>Engine Mounted:</u>

4.3.2.1 Cabin air compressor configuration should be such as to result in a minimum overhang static moment on the engine mounting pads.

4.3.2.2 The mounting pads shall conform to AN or SAE six bolt generator mounting standards.

4.3.2.3 Requirements of paragraphs 4.3.1.9 through 4.3.1.12 are also applicable for engine mounted compressors.

4.3.2.4 Duct connectors or ducting should not be rigid enough to impose objectionable loads on the compressor or engine pads during normal engine operation or under conditions of maximum engine movement.

4.3.3 Turbine Drive:

4.3.3.1 The turbine portion of the unit should be designed to withstand the maximum bleed air temperatures and pressures available at the source.

4.3.3.2 Turbine inlet throttling devices should fall safe towards or in the closed position.

4.3.4 Performance Presentation - Turbine: Turbine 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.

4.3.4.1 Fixed Nozzle Area Turbine:

4.3.4.1.1 The basic performance of fixed nozzle power turbines can be conveniently expressed in terms of the following parameters:

$$\frac{HP_s}{P_2 \sqrt{T_1}} = f\left(\frac{WN}{P_2}, \frac{N}{\sqrt{T_1}}, \frac{P_1}{P_2}\right)$$

4.3.4.1.2 The performance chart for fixed area nozzle turbines should consist of a single map with the above parameters plotted on log-log coordinates as shown Fig. 3.

4.3.4.1.3 Operating limits such as maximum pressure, temperature, and speed, and choked exducer limits should be indicated on the chart.

4.3.4.2 Variable Nozzle Area Turbine:

4.3.4.2.1 The basic performance of variable area nozzle power turbines can be conveniently expressed in terms of the following parameters:

$$\frac{HP_s}{P_2 \sqrt{T_1}} = f\left(\frac{WN}{P_2}, \frac{N}{\sqrt{T_1}}, \frac{P_1}{P_2}, A_n\right)$$

4.3.4.2.2 The performance of variable nozzle turbines should be presented as a family of fixed nozzle turbine plots, each for a different nozzle area. The number of charts used should be sufficient to cover the entire range of nozzle areas with increments small enough to permit accurate interpolation between charts. Typical illustrations of the recommended form for performance presentation are shown in Figures 4 and 5, indicating plots for 100% and 50% maximum nozzle area, respectively.

4.3.4.2.3 Operating limits such as maximum pressure, temperature, and speed, and choked exducer limits should be indicated on the chart.

4.3.4.3 Nomenclature:

P_1 = Turbine inlet air total pressure, PSI absolute
P_2 = Turbine exit air static pressure, PSI absolute
T_1 = Turbine inlet air total temperature, ^oR
T_2 = Turbine exit air total temperature, ^oR
W = Turbine airflow, lb/sec.
N = Turbine speed, RPM
HP_s = Turbine shaft horsepower

$$\eta = \frac{HP_s}{HP_{ad}} = \text{Turbine shaft horsepower efficiency}$$

$$HP_{ad} = \frac{W C_p J \, T_1}{550}\left[1-\left(\frac{P_2}{P_1}\right)^{.283}\right] = 1{,}415 \, W \, C_p \, T_1 \left[\frac{Y}{Y+1}\right]$$

J = 778 ft-lb/btu
C_p = .243 btu/lb °F, specific heat of air
K = Specific heat ratio = 1.395 for air
$\frac{K-1}{K}$ = .283 for air

$$Y = \left[\left(\frac{P_1}{P_2}\right)^{\frac{K-1}{K}} - 1\right] = \left[\left(\frac{P_1}{P_2}\right)^{.283} - 1\right]$$

$$\frac{Y}{Y+1} = \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}\right] = \left[1 - \left(\frac{P_2}{P_1}\right)^{.283}\right]$$

A_n = Turbine Nozzle Area, Sq. in.

5. CABIN PRESSURE REGULATING EQUIPMENT:

5.1 Cabin Pressure Regulators:

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

5.1.2 The cabin pressure regulating outflow valves should have sufficient capacity to pass the normal rated airflow at sea level at a pressure differential not in excess of 0.20 in. Hg.

5.1.3 A cabin altitude selector should be provided that includes a selector knob and indicating dial permitting selection of any cabin pressure altitude within the range of -1000 ft. to + 10,000 feet. The absolute cabin pressure altitude during isobaric operation shall be within ± 350 feet of that selected on the dial, when the airflow is within ± 10% of the system normal capacity. Within this tolerance the maximum rate of change of cabin altitude shall not exceed 50 ft/min. When selecting cabin pressure altitude equivalent to airport altitude the cabin absolute pressure shall not vary by more than ± 100 feet of the corrected barometric airport pressure.

5.1.4 A cabin pressure rate of change selector should be provided. The rate of change shall be selectable from 1000 ± 200 feet per minute to 65 ± 35 feet per minute.

5.1.5 Leakage through the outflow valves in the full closed position should be kept to a minimum.

5.1.6 Means should be provided to functionally check the maximum differential and to fully close the valves on the ground without removing the units from the airplane.

5.1.7 The outflow valves should be located in an area where airplane altitude or external configuration will not adversely affect their operation.

5.1.8 The cabin pressure regulating system and components should be designed so that no single failure can cause loss of cabin pressure to an altitude in excess of 15,000 feet.

5.2 <u>Cabin Pressure Relief Valves:</u>

5.2.1 Relief valve(s) should be provided which will prevent excessive differential pressure across the cabin in event of failure of the cabin pressure regulating valve(s). The relief valve setting should be established at a value above the pressure regulator maximum differential. Consideration should be given for the minus tolerance of the relief valve and plus tolerance of the regulator to preclude an overlapping of operation when establishing the relief valve setting.

5.2.2 The relief valve should include a negative relief function to prevent structural damage in event of a negative pressure differential.

5.2.3 The valve should be capable of passing sufficient airflow from outside to inside the cabin during a maximum allowable rate of descent from maximum normal altitude to sea level to prevent the negative differential from exceeding a safe value. All normal inflow air to the cabin is to be shut off during this condition.

5.2.4 An emergency manual method of relieving cabin pressure should be provided. This may be accomplished through the relief valve(s), outflow valve(s) or an auxiliary valve(s). This may be accomplished mechanically, electrically or pneumatically.

5.2.5 Each relief valve should have sufficient capacity to pass the normal rate air flow without exceeding the limit of paragraph 5.2.1.

5.2.6 Leakage through the relief valve below cracking pressure should be kept to a minimum.

5.2.7 Relief valves should be located in an area where airplane attitude or external configuration will not adversely affect their operation.

5.3 <u>Instrumentation:</u>

5.3.1 A cabin pressure rate of change indicator should be provided.

5.3.2 A cabin absolute pressure indicator should be provided.

5.3.3 A cabin pressure differential gauge should be provided. The maximum normal cabin differential should be identified on the gauge.

5.3.4 A visual or audible warning should be provided when the cabin altitude exceeds a safe value for passengers and crew.

5.4 <u>Control and Sensing Lines:</u>

5.4.1 Static sensing ports should be located in area where airplane attitude or external configuration will not adversely affect the true readings. Duplication of sensing ports is desirable in event of blockage of one of the lines or ports.

5.4.2 All lines should be routed in such a manner as to prevent water traps and drainage toward valves where the freezing of condensation will affect operation of the system. Drainage toward the static sensing ports is desirable.

5.4.3 Line sizes should be carefully selected to prevent sluggish operation of the system.

6. <u>ENGINE BLEED AIR DUCTING SYSTEM:</u>

6.1 <u>Definition:</u>

6.1.1 The engine bleed air ducting are those ducts that carry high temperature air from the compressor section of the main engines to the turbine of the turbocompressor. For aircraft using bleed air directly into the cabin the bleed air ducting system will terminate at the inlet to the refrigeration unit.

6.2 Design Requirements: A flow limiting device should be provided in the branch duct from each source to avoid the loss of excessive quantities of engine bleed air in event of failure of the ducting system. The flow limiting device should be located as close to the source as possible. For engines that have provisions for limiting flow internally, a flow limiting device in the ducting system is not required.

6.2.1 Where multiple sources of bleed air are used, the ducting system should be manifolded and valved in such a manner that full cabin pressurization can be maintained at cruise altitude in event of a duct rupture or failure of one or more of the bleed air sources (engine).

6.2.2 The detail design of the ducting, thermal expansion provisions, supports, joints, insulation and testing should be in accordance with the committee's document on "Low Pressure High Temperature Pneumatic Ducting" when published.

6.2.3 Careful consideration should be given to duct design in order to minimize pressure drop in the system. Duct sizes should be determined by the minimum engine pressures available and the minimum pressures required by the turbocompressors or refrigeration unit to meet the pressurization performance requirements.

6.2.4 Common usage of the bleed ducting by other systems should not have an adverse affect on the pressurization system.

6.2.5 Indicators should be provided in the flight deck as required to detect abnormal condition in the ducting system or valves. Indicators should provide area identification as comprehensible as possible.

6.2.6 Shut off and check valves should be provided at each bleed air source if multiple air sources are used.

6.2.7 The ducting system downstream of the section where pressure and temperature have been regulated to a lower value should be designed to withstand the maximum pressures and temperatures available at the source.

7. CABIN PRESSURE DUCTING:

7.1 Definition:

7.1.1 All air ducts from the cabin air compressor to the point of entry into the pressurized compartment. When engine bleed air is used directly into the cabin these ducts are from the refrigeration unit discharge to the point of entry into the pressurized compartment.

7.2 <u>Design Requirements:</u>

7.2.1 Ducts and duct couplings should not introduce objectionable odors into the cabin.

7.2.2 On installation where the cabin pressure ducts are located between the firewall and the engine, adequate provision should be made to retain the integrity of the firewall and to preclude the spreading of the fire to another fire zone through the cabin pressure ducts. This may be accomplished by one or more of the following methods depending on the particular system design:

a) Fireproof ducts between the firewall and the air source.
b) Firewall shut off valves.
c) Fireproof ducting downstream of the firewall.

7.2.3 Pressure drop in the ducting system should be kept to a minimum.

7.2.4 Where multiple air sources are used the cabin pressure ducts should be manifolded and valved in such a manner that full pressurization can be maintained at cruise altitude in event of duct rupture or failure of any one of the air sources.

7.2.5 Check valves should be provided at the pressure bulkhead to prevent sudden decompression in event of complete loss of the pressurization air source.

8. <u>REFERENCES:</u>

8.1 "Presentation of Centrifugal Compressor Performance in Terms of Non-Demensional Relationships" by B. E. Del Mar, Douglas Aircraft Company, Santa Monica, California (Presented at Meeting of Aviation Division, A.S.M.E., Los Angeles, California, June 5-9, 1944).

M = MACH NO. = $\frac{ND}{11{,}230\sqrt{T_1}}$

$\frac{T_2}{T_1}$ = TEMP RATIO = $\frac{Y}{n} + 1$

F_F = FLOW FACTOR = $\frac{W\sqrt{T_1}}{D^2 P_1}$

T_1 = INLET TEMP – °F ABS

T_2 = OUTLET TEMP – °F ABS

P_1 = INLET PRESS – IN. HG ABS

n = ADIABATIC EFFICIENCY – %

W = AIR FLOW – LB/MIN

N = SPEED – RPM

$Y = r^{.283} - 1$ (r = PRESSURE RATIO)

D = IMPELLER DIAMETER – INCHES

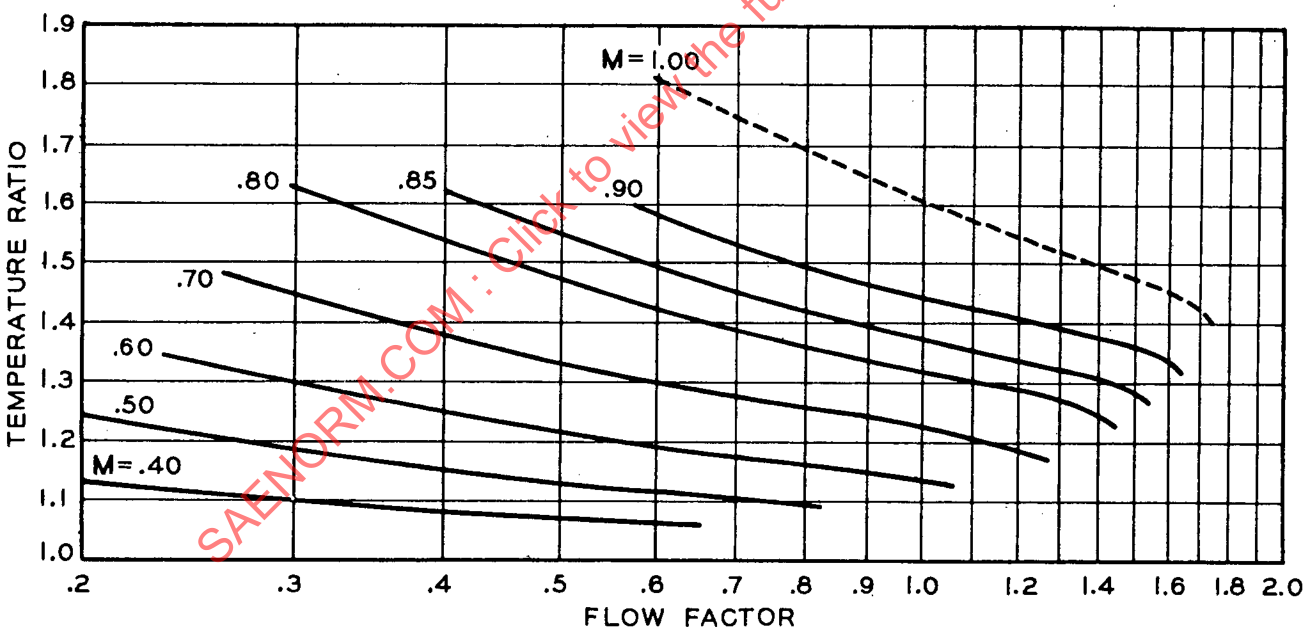

FIGURE I

$$Y = \left(\frac{P_2}{P_1}\right)^{0.283} - 1$$

η = ADIABATIC EFFICIENCY = $\frac{T_1 Y}{T_2 - T_1}$

~~η = ADIABATIC EFFICIENCY - %~~

M = MACH NO. = $\frac{ND}{11{,}230\sqrt{T_1}}$

F_F = FLOW FACTOR = $\frac{W\sqrt{T_1}}{D^2 P_1}$

r = PRESSURE RATIO = $\frac{P_2}{P_1}$

P_1 = INLET PRESS - IN. HG ABS

P_2 = OUTLET PRESS - IN. HG ABS

T_1 = INLET TEMP - °F ABS

N = SPEED - RPM

W = AIR FLOW - LB/MIN

D = IMPELLER DIAMETER - INCHES

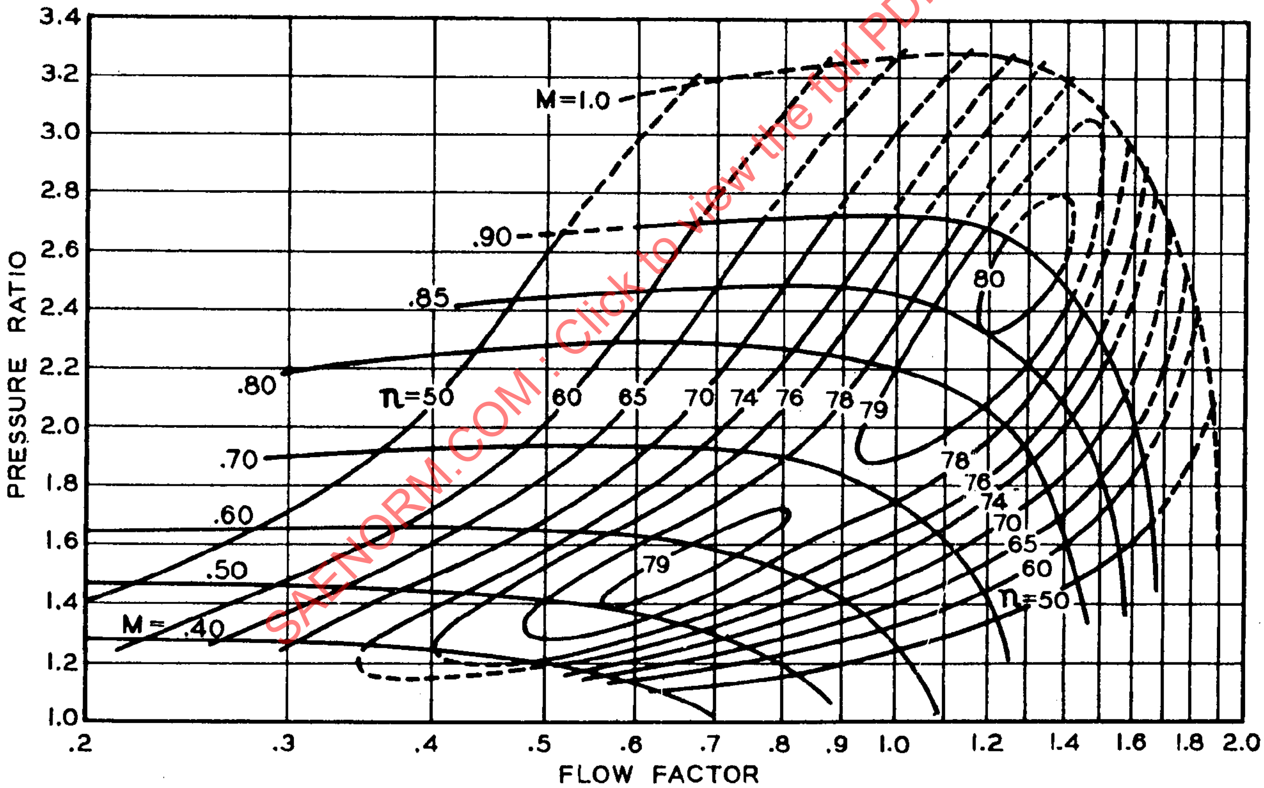

FIGURE 2