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AEROSPACE RECOMMENDED PRACTICE

ARP 699 B

LOW PRESSURE HIGH TEMPERATURE PNEUMATIC DUCTING SYSTEMS (300 PSI AND 1000 F MAXIMUM)

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PURPOSE AND SCOPE

This Aerospace Recommended Practice is intended to outline the design, installation, testing and field maintenance criteria for a Low Pressure High Temperature Pneumatic Ducting System (300 PSI and 1000 F maximum) for use as a guide in the aircraft industry. These recommendations are to be considered as being currently applicable and necessarily subject to revision from time to time due to the rapid development of the industry.

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"This recommended practice is intended as a guide toward standard practice and its use as a basis for legal regulation is not recommended."

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TERMINOLOGY

Bellows - A convoluted unit consisting of one or more convolutions used to obtain flexibility.

Bellows, Braided - A convoluted unit surrounded by a woven wire sleeve attached to the ends which restrict the movements of the unit.

Bellows, Free - A convoluted unit which does not incorporate any device or part for the purpose of restricting movement.

Bellows, Restrained - A convoluted unit incorporating a means of restraint, other than braid, to prevent axial movement.

Bleed Air - Air extracted from the compressor of a gas turbine engine or propulsion unit.

Bleed Port - An outlet in the gas turbine compressor casing through which air is extracted or bled from the compressor.

Bracket - A support or structural part which attaches and holds a duct to the vehicle structure.

Bracket, Adjustable - A bracket that allows some freedom in the location of the duct, which it supports, during installation. After the duct is located satisfactorily, the bracket is tightened and the duct is held fixed.

Bracket, Anchor - A main duct support at a point on the duct system that remains fixed in respect to duct system expansions, contractions or deflections.

Bracket, Guide - A support designed to provide for movement of a duct in a predetermined direction while supporting it in all other directions.

Bracket, Sliding - A bracket which allows a duct to slide in a controlled direction while supporting it in all other directions.

Bracket, Swing - A linkage which supports a duct and allows movement along the arc of the swinging bracket.

Braid - Woven wire sleeving used to limit the movements of a bellows.

Bulkhead Seal - A fitting allowing the passage of a duct through a wall or bulkhead which prevents the leakage through the bulkhead around the outer periphery of the duct.

By-Pass - A duct that conveys air around a system or system component.

Cap, Pressure - A part which can be used to cover tightly the end of a duct and sustain the internal pressure.

Cap, Protective - A part used to cover an end or opening in a duct for the purpose of excluding foreign matter.

Clamp - A normally circular device which adjusts the circumferential length of the band. It is used to bind two members together by the exertion of radial pressure.

Compression System - A duct system wherein the fluid column loads due to internal pressure are reacted by the support structure.

Coupling - A fitting or clamping device that serves to join the mating ends of adjacent ducts or other components.

Deflection - A displacement of a duct or joint due to operating conditions.

Duct - An enclosed passageway made of sheet metal or other suitable material for the conveyance of fluids.

Duct Assembly - Detail parts fitted and joined together to form an integral part.

Expansion, Thermal - Duct growth due to an increase in temperature.

Flex-Section - These devices when incorporated in a duct system permit relative motion in one or more planes. The term Flex-Section may include bellows, flexible sections and flexible joints which are devices possessing flexibility resulting from the method of construction or the utilization of flexible materials.

Half Shell - Die formed duct halves.

Heat Ring - A ring or flange used between the duct and support to reduce the transfer of heat from the ducting to the supporting structure.

Hose - Tubing, either flexible by construction or made of flexible material, which is attached to the ends of adjacent ducts, tubes or fittings.

Installation - A completed set of duct assemblies and duct supports incorporated in a vehicle.

Insulation - A material applied around the duct which is used to reduce heat exchange.

Joint - A device or complete assembly which unites or establishes continuity between adjacent ducts or other components.

Joint, Ball - A joint which permits relative angular movement and rotation of two adjacent ducts.

Joint, Compensating - A pressure-compensated assembly allowing axial motion which maintains the duct walls in tension.

Joint, Expansion - Any of many types of joints which can permit axial movement without failure and therefore permit the duct system to expand or contract.

Joint, Flexible - A non-rigid joint, convoluted tubing, hose or ball joint assembly which joins two ducts and permits relative motion of the ducts in one or more planes.

Joint, Restrained - A flex-section assembly in which an angular deflection can occur with a tension load being transmitted by an external or internal device.

Joint, Rotary - A joint which permits relative rotation of two adjacent ducts.

Joint, Slip - A joint having sleeve assemblies, one sliding inside the other, to allow axial motion.

Line Mounting - Refers to a component mounted on and supported by the duct, instead of direct attachment to a support or bracket.

Linear Offset - Distance between the duct centerlines of two joining ducts.

Liner - A cylindrical part within a flex-section assembly.

Live Length - The convoluted length of a flex-section assembly.

Load - The resultant force exerted upon restraining brackets (and structure) due to internal pressure, thermal expansion or contraction, structural deflection, and component weight.

Load Limit - The maximum combined load due to all internal and external pressures and forces that a duct or duct system can encounter at any time in service.

Load, Pneumatic - The force determined by the product of the internal differential pressure and the duct cross-sectional area.

Load, Pre., - The force imposed on a duct or duct system prior to, or during, installation.

Load, Ultimate - The maximum load a duct or duct system can sustain without failure.

Misalignment - Error in alignment between the axis of two joining parts; the error may be linear, angular, or both.

Omega Bend - A bend whose shape resembles the Greek letter omega and is used to accommodate contraction or expansion in a duct system.

Pressure - A force distributed over a unit area.

Pressure, Atmospheric - The force per unit area caused by the weight of the atmosphere.

Pressure Burst - Maximum internal pressure above ambient which duct must withstand without rupture.

Pressure, Design - The selected normal operating pressure.

Pressure, Differential - The difference between the internal pressure at a point in a duct and a reference pressure (ambient) or, in a flowing system, the difference in pressure between the two points due to pressure drop.

Pressure Envelope - The range of pressures to which a part is subjected in normal operation.

Pressure, Maximum Operating - The maximum pressure a duct will experience under all possible operating conditions.

Pressure, Proof - The maximum test pressure a duct or duct installation must sustain without permanent deformation.

Rupture - A break in a duct or duct assembly.

System - A combination of ducts, duct supports, duct joints and fluid control devices which will regulate and convey fluids from a source to a point or points of use.

Temperature, Design - The selected normal operating temperature.

Temperature, Differential - The difference between the internal temperature in a duct and a reference temperature, or in a flowing system, the difference in tempreature between two points due to temperature drop.

Temperature, Envelope - The range of temperatures to which a part is subjected in normal operation.

Temperature, Maximum Operating - The maximum temperauture a duct will experience under all possible operating conditions.

Tension System - A ducting system wherein the fluid column or longitudinal forces due to internal pressure are not transmitted to the supporting structure. The fluid column loads of such a duct system are reacted by axial tension in the duct walls.

Part I Installation Criteria and Limitations

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1. INSTALLATION CRITERIA AND LIMITATIONS:

1.1 Introduction: Employment of low pressure (300 PSI), high temperature (1000 F) pneumatic ducting in modern aircraft entails the consideration of several requirements which may be encountered during operation, maintenance, and installation assembly. These requirements are as follows:

1.1.1 Structural Deflections: The aircraft structure on which the ducting installation is mounted will usually deflect sufficiently to require a flexible ducting installation. Axial, torsional, and bending deflections must be considered. Installations which traverse a wing are usually exposed to the largest deflections. In magnitude, the axial deflections may be as high as 0.06 inches per foot of duct length. Torsional deflections may require 3 deg to 5 deg rotation about the duct centerline. Bending deflections (angular) may be in the range of 3 deg to 7 deg for a typical wing installation. Paragraph 1.2 indicates some methods of compensation for structural deflection.

1.1.2 Thermal Expansion: Ducting material under high temperature exhibits a growth or expansion, which can be of considerable magnitude. If some means is not provided to compensate for this expansion, an axial compressive force tending to cause failure of the ducting or supports will be developed.

Duct connections to the engine should consider engine growth radially and axially due to dimensional increases caused by high temperatures. The motion envelope of the engine for normal operation and under airplane design limit load factors relative to its fuselage or nacelle structure should be established and considered. The difference in length due to contraction of the airframe at low temperature and expansion of the duct at high temperature usually results in the largest relative duct motion. Paragraph 1.2 indicates some methods for compensating for thermal expansion.

1.1.3 Thermal Shock: Design of the duct system should take into account the effect of thermal shock. The maximum temperature rise and rate of temperature rise should be determined from expected areas of operation. Usually, the extreme condition occurs with ground operation from a cold soak (-65 F). A test program should be established for test phases coordinated with the extreme operating conditions.

1.1.4 Space Allocation: Space allocation is another limitation in the duct installation. High priority should be given to the duct routing for the following reasons:

a. Operation - A straight duct provides a minimum pressure drop.

b. Installation Assembly - Sufficient space should be provided to make possible the easiest and cleanest installation assembly to provide structural deflection and thermal expansion compensation, and ease of maintenance and inspection.

c. Safety - Adequate space allocation can mean proper isolation of the high temperature duct from combustibles and components sensitive to high temperature. It is recommended that high temperature ducts be located above and/or isolated from ducts transporting combustible fluids by routing the ducts as far away from each other as possible or providing separate compartments.

1.1.5 Additional Duct Load Considerations: There are several additional duct loads the designer should consider in the duct installation design.

a. Duct mounted equipment items, such as valves, can create large torsional loads in local areas when subjected to vibration and should be mounted to or supported by structure.

b. The ducting systems should be capable of accommodating the external pressures which could cause collapsing. For example, provisions must be made for pressure testing a fuselage through which such ducting is routed.

c. In a compression system a slight misalignment of free bellows can impose large side loads on the duct supports. Instability of the ducting system can be caused by such a misalignment and should be avoided.

d. Installation of free bellows in a compression system requires consideration of the buckling strength of the ducting based on the compressive loads caused by the larger internal area of the bellows.

e. The duct system should be designed to withstand loads imposed by externally induced vibrations.

1.1.6 Typical Ducting Material: Some typical corrosion resistant alloys available for use in low pressure (300 PSI) and high temperature (1000 F) pneumatic duct systems are Type 321, 347, 19-9DL, AM350, 17-7PH, 15-7MO, A-286, Inconel X, René 41. Refer to Section 2 for more detail information on fabrication and design of these materials.

1.1.6.1 The ducting material and gauge selected shall be capable of satisfying the following design criteria:

a. Without Yielding - The combination stress resulting from any combination of maximum operating temperature, deflection, and maximum operating pressure times the selected proof pressure factor. A reduced allowable yield strength should be considered with respect to the life cycle expectancy.

b. Without Rupture - The combined stress resulting from any combination of maximum operating temperature, ultimate deflection, and maximum operating pressure times the selected burst pressure factor (deformation permitted).

c. Component Malfunction - The maximum combination of operating temperature and pressure levels selected should be determined from the values resulting when any single system component malfunctions.

1.1.7 Fluid Flow Considerations: Considerations of thermodynamic fluid flow should be given in the ducting system design:

1.1.7.1 A recommended design duct Mach number should be selected at 0.25 or less in order to reduce the effects of air velocity on the required distribution, noise, and duct system pressure losses. WADC Technical Report 56-187, dated September 1956, "INVESTIGATION OF AIRCRAFT DUCTING COMPONENTS AT HIGH SUBSONIC SPEEDS", provides component design information at entrance Mach numbers from M = 0.2 to 1.0.

1.1.7.2 Resonance created by high velocity airflows should be considered in the ducting design. Minimum resistance in the ducting should be given prime importance to prevent turbulences which could produce resonances resulting in fatigue failure. A bellows is one component which is susceptible to a severe turbulence under high velocity airflow and should have a multi-ply construction to withstand the resonance or a liner (or equivalent device) to reduce turbulence.

1.1.8 Environment: Environment of the duct installation should be given consideration in relation to the surface temperature of the duct.

1.1.8.1 The outside surface temperature of the duct can become a fire hazard if its routing should bring it into proximity with combustible fluids or vapors from fuel, engine, or hydraulic oils when the duct surface temperature is above the autogenous ignition point of these mediums. Location of a line, containing a combustible fluid, above or adjacent to a high temperature duct presents a fire hazard.

The thermal limitations of adjacent components could become a functional safety hazard of the aircraft, expecially items such as electrical wiring and actuators, hydraulic accumulators and actuators, and structural components which could suffer degradation of strength with high temperature.

The heat loss from the duct can present a problem for the system's proper operation if the duct is carrying air for heating purposes, or it can represent a heat load for a compartment which is being maintained at a lower temperature.

1.1.8.2 Reduction of surface temperature of the ducting system is necessary when its routing presents a safety problem as mentioned above. One method to reduce the effect of surface temperature is the use of a radiation shield for critical components. This can consist of a built-up assembly utilizing high reflectivity, low emissivity material placed between the duct and the component. Another method to reduce the effect of surface temperature is the use of insulation around the duct. There are several factors to be considered in the use of duct insulation. The insulation material must be protected from wicking of combustible fluids, crushing or tearing during fabrication, installation, maintenance, and handling, and must have low conductivity properties which will not deteriorate under high temperature. If the insulation material is protected by a cover impervious to fluids it should be vented to provide and maintain the insulation at ambient pressure.

1.1.8.3 High temperature must be considered in the design of support methods for the ducting since heat will be transferred to the supports through conduction and radiation. The support material and any fasteners or other components of the support should be compatible with the existing temperature level. Consideration should be given to possible heat transfer through the support to the structure. Insulation should be provided between the support and structure if the temperature can exceed structural limits.

1.1.9 Maintenance Requirements: Design of a low cost maintenance duct system involves consideration of durability and accessibility and replaceability of ducts, joints, couplings, and seals for field inspection.

1.1.9.1 Durability of the ducting and supports should be given consideration in the initial design stage. Thin wall ducting and insulation cover materials are quite susceptible to damage from handling during manufacture, shipping, inspection, installation, and field maintenance. Use of a heavier wall ducting or reinforcement of the insulation cover may be justified to provide additional protection from crushing and indenting.

1.1.9.2 Accessibility and replaceability of ducting, joint couplings, and seals are requirements that are important in the initial design of the duct system.

a. Ducting, where possibility of replacement exists, should not be an integral part of the aircraft structure and should be installed so a minimum of disassembly is required for removal or inspection.

b. Joint couplings that are frequently removed on the aircraft should be readily accessible, and should incorporate a quick disconnect feature with the capability of reuse without leakage. If the joint requires a seal, it should be easily removed and replaced; or it should be designed such that replacement of the seal is not required.

1.1.9.3 Field inspection of the duct system should be possible to insure component integrity. A leakage check will provide information as to existing danger points in the system, and a visual check of the system would point out potential danger spots.

a. Leakage checks of the system should be made. Methods for leak testing of the duct system should be considered early in the design, so that necessary fittings may be incorporated.

b. Visual inspection of the duct system can show up such danger points as: Torn protective covers for insulation where exposed insulation may wick and present a fire hazard, a bulging duct assembly where a weak portion of the assembly has exceeded its yield strength and is close to failure, deformed supports or duct indicating an unpredicted loading and possible malfunction, and partially failed couplings or bellows which would constitute a flight hazard; in addition to actual failures to the duct walls or duct supports.

1.1.10 Installation Tolerances: Installation tolerances for both ducting misalignment and joint leakage should be given attention. Leakage problems are aggravated if misalignment problems are not solved successfully.

1.1.10.1 Installation assembly of ducting must consider certain types of misalignment; such as axial (end points do not meet or overlap each other), offset (end point center lines offset), and angular (end point center lines meeting at an angle). Some approximate magnitudes of these misalignments occurring in normal installations are: Axial ± 0.25 inch; offset ± 0.125 inch; and Angular ± 2 degrees. Compensation for any one of these misalignments (not all at the same time) can be accomplished by appropriate use of: bellows (axial, offset, and angular); Flexible Coupling (angular); Ball Joint (angular); Ball Joint Arrangement or Combination of Ball and Slip Joints (axial, offset, and angular); Slip Joints (axial) and adjustable duct supports (axial, offset and angular).

1.1.10.2 Leakage of high temperature air from the ducting system can be a serious safety problem, similar to the case of duct surface temperature in section 1.1.8.1, if it is in the vicinity of combustible fluids, vapors, or low temperature limited components. Unless the ducting system has a separate tunnel of its own, it is quite likely the ducting will be routed in the vicinity of these critical items. Duct leakage into a sealed compartment may constitute a structural problem. A means for checking the system for leakage before operation is very important.

1.1.11 Reliability: Reliability of pneumatic duct systems is essential to aircraft airworthiness and reliable aircraft operation in service. During the inception of the design, the control specification, fabrication of components, and the duct system installation, reliability can be improved by adhering to the following:

a. Use standard, well-developed parts.

b. Select vendors whose reliability of performance is proven.

c. Provide easy maintenance accessibility.

d. Careful consideration of problem areas (pressures, temperatures, deflection, insulation, etc.).

e. Require adequate testing for qualification.

f. Select fasteners of sufficient size to hold the component in place.

g. Provide a design that is free of points of high stress concentration.

h. Inspect carefully after fabrication.

i. Report malfunctions or discrepancies to proper channels.

j. Assure corrective action is initiated.

k. Package properly to protect during shipment and storage.

l. Maintain and calibrate test equipment.

m. Avoid unnecessarily rough handling of parts.

n. Safety fasteners or other holding devices against loosening.

o. Provide sufficient clearances for adjustment and/or travel.

p. Use proper tools and fixtures to aid in assembly and installation.

q. Keep ducts and other components completely free of dirt and contamination during storage, handling and installation.

r. Require adequate production proof tests.

s. Initiate a training program in the maintenance and installation of the ducting system for shop and field personnel.

1.1.11.1 A development test program is essential for testing the installation in its actual environment so that critical weaknesses in the system can be found out and corrected. Tests should be performed on several samples in order to get a statistical spread of information. A satisfactory test program should include:

a. Tests on individual components at critical temperatures.

Proof pressure

Burst pressure

Fatigue

b. Tests on complete mock-up system.

Cycling (pressure, temperature, movement, and thermal shock)

External induced loading

Proof pressure

Flow resonance

Leakage

Ultimate structural tests on critical areas

c. Tests on systems in completed airplane.

*Proof pressure

Leakage

(*Room temperature proof pressure tests may be conducted at a higher pressure level to account for temperature effect and equivalent material stress level.)

See Section 2 for details of duct Qualification testing.

1.2 Types of Duct Systems: A duct system may be the tension, compression, or a combination tension-compression type arrangement. The tension system generally weighs the least, but it requires more space allocation for duct movement. The compression system, in addition to the pneumatic and thermal loads, must make provision for considerable side load. This, coupled with the inherent instability of free bellows, requires the system and the aircraft structure to be more sturdy. The compression-type system requires a more precise analysis because of the magnitude of types and combinations of loads which may be encountered.

1.2.1 Tension: A tension System (Figure 1) is one wherein the fluid column or longitudinal forces due to internal pressure are not transmitted to the airplane structure, but are reacted by axial tension in the duct walls. Support of the ducting must withstand the airplane inertia weight factors applied to the weight of the ducting and be adequate to deflect the ducting axially, in torsion, and in bending under the effects of airplane structural deflections and ducting thermal expansion at airplane design loads. Some ways of compensating for structural deflections and thermal expansion are:

a. Duct guide supports (such as rollers, sliding, or hanger type).

b. Joint arrangements (such as ball, pressure-compensating, and restrained bellows) placed in strategic locations.

c. The use of the elasticity of the duct itself, either through the use of bends associated with its natural routing or the addition of omega or loop bends in the system.

d. Flexible attachments to the ducting. (An example is a bulkhead seal where a sliding fit or low spring rate bellows could be used on the outside of the duct.)

e. Flexible joints (such as a ball or flex-sections) can be used to compensate for bending movement.

It is important that space allocation be considered for movement of this type of system.

1.2.2 Compression: A compression system (Figure 1) is one wherein the fluid column forces due to internal pressure and thermal expansion are reacted by the support structure. Some ways of sustaining the compressive forces, and compensating for structural deflection and thermal expansion are:

a. Fixed duct supports which can withstand resultant end and side loads.

b. Joints (such as flex-sections and slip type) which provide for duct growth in the axial direction.

c. Flexible joints (such as ball or flex-sections) can be used to compensate for duct bending movement.

Column strength of the ducting must be adequate to withstand the applied compressive loads with the allowable misalignment.

1.2.3 Tension-Compression: A tension-compression type system may be used in lieu of either a tension or compression system. It would consist of placing one part of the duct system in tension and the other part in compression as described above. The fixed point of the duct section in tension will occur where it joins the duct section which is in compression. Here again space allocation for duct movement is an important requirement.

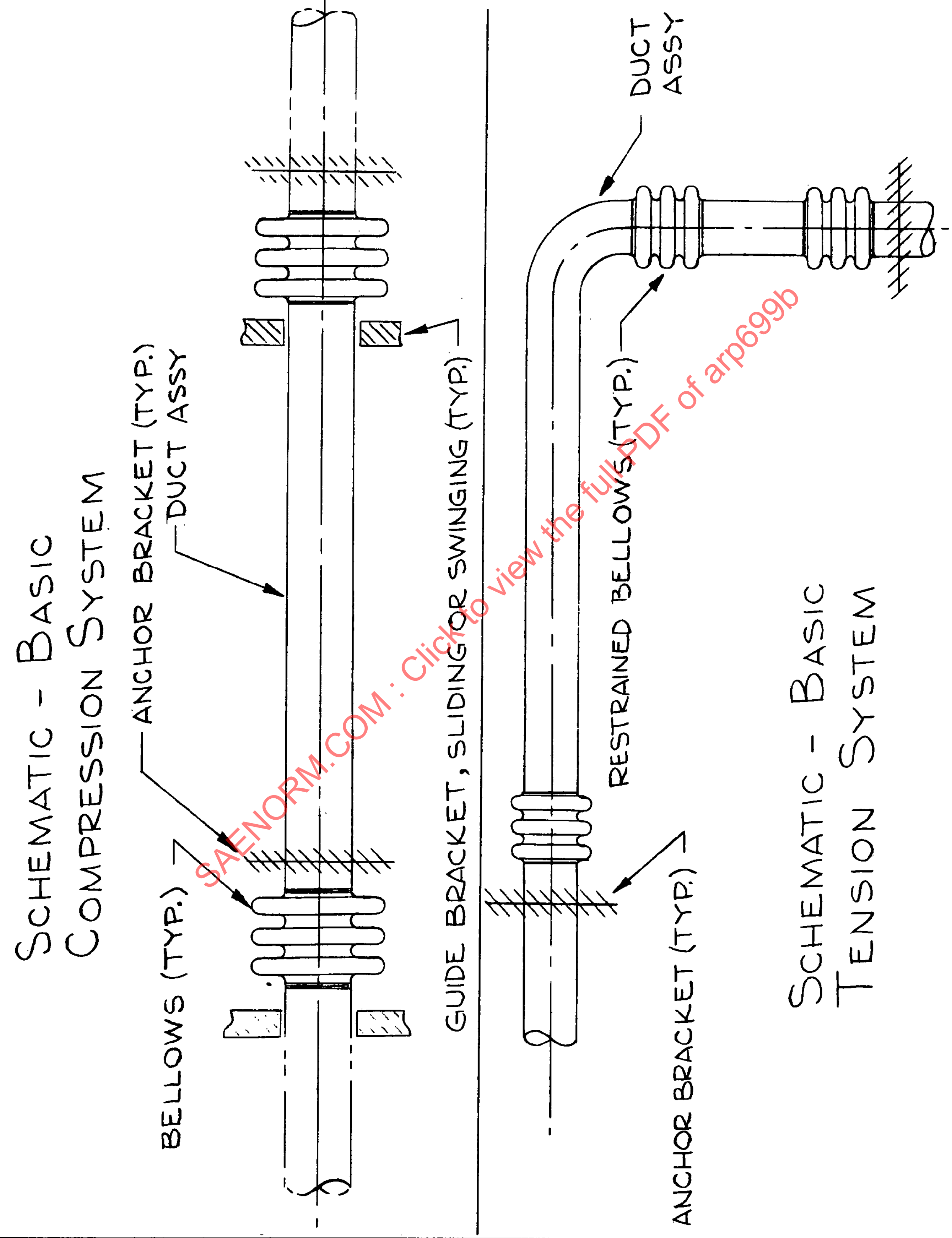
SCHEMATIC - BASIC COMPRESSION SYSTEM
ANCHOR BRACKET (TYP.)
DUCT ASSY
BELLOWS (TYP.)
GUIDE BRACKET, SLIDING OR SWINGING (TYP.)
DUCT ASSY
RESTRAINED BELLOWS (TYP.)
ANCHOR BRACKET (TYP.)
SCHEMATIC - BASIC TENSION SYSTEM

FIGURE 1

Part II Design Criteria

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Part II Index (continued)

2. Duct System and Duct Component Design:

2.1 Design Criteria: Design requirements are presented for ducts, duct couplings, duct supports, thermal insulation, and compensation devices for thermal expansion, airframe deflection and installation tolerances.

2.1.1 Ducts: The following recommendations pertain to ducting suitable for handling air at pressures up to 300 psig and temperatures up to 1000 F.

2.1.1.1 Recommended Materials: The following materials have been used extensively in duct systems. Design information on these materials is presented in Figures 1 through 13 for temperatures up to 1000 F.

Material	Maximum Continuous Operating Temp.	Comments
321/347	1600 F	Easily welded and formed. Lowest strength. Good corrosion resistance. Non-heat treatable. Good sub-zero properties. Maximum temperature limitation imposed by oxidation resistance. Type 347 has slightly higher strength at elevated temperatures.
19-9DL	1600	Higher strength than 321/347, but more expensive and requires more costly process controls. Easily welded and formed, but cold works rapidly. Non-heat treatable. Normally used in annealed condition in ducting. Deterioration of corrosion resistance if exposed to carbide precipitation temperatures.
AM 350	800	Easily weldable but work hardens rapidly. Heat treatable to higher strength than above materials, but transformation growth causes severe distortion. Good corrosion resistance. Maximum temperature limited by excess precipitation which may cause embrittlement.
17-7PH	700	Easily formed and welded. Heat treatable to high strength comparable to AM 350, but transformation growth causes distortion. Rusts superficially. Over 700 deg excess precipitation causes embrittlement. Low elongation.
15-7 MO	800	Higher strength than 17-7 and AM 350. Good formability and weldability. Good corrosion resistance. Heat treatable but subject to growth distortion. Low elongation.
A-286	1300	Weldability just fair. Good high temperature strength in the range of 700 - 1300 deg. Good corrosion resistance. Heat treatable. Over-ages above 1300 deg.

Material	Maximum Continuous Operating Temp.	Comments
Inconel X	1500	Comparable to A-286 except better strength in the range of 1200 - 1500 deg. Good oxidation resistance to 1800 deg.
René 41	1500	Higher strengths than Inconel X with forming and welding somewhat more difficult than A-286 or Inconel X. Vacuum melted to retain hardening agents and therefore very expensive. Good oxidation resistance to 1800 deg.

2.1.1.2 Fabrication Requirements: Ducts should be fabricated from tubing or sheet stock. MIL specifications or commercial specifications may be used for material and for welding techniques. These should be modified as required by detail specifications or detail drawings of the duct assembly.

2.1.1.2.1 Applicable Specifications: The following specifications may be used as material references:

AMS 5510	Steel Sheet and Strip, Corrosion and Heat Resistant (Type 321)
AMS 5512	Steel Sheet and Strip, Corrosion and Heat Resistant (Type 347)
AMS 5526	Steel Sheet and Strip, Corrosion and Heat Resistant (19-9DL)
AMS 5548	Steel Sheet and Strip, Corrosion and Moderate Heat Resistant (AM 350)
AMS 5528	Steel Sheet and Strip, Corrosion Resistant (17-7 PH)
AMS 5520	Steel Sheet and Strip, Corrosion and Moderate Heat Resistant (15-7 MO)
AMS 5525	Steel Sheet and Strip, Corrosion and Heat Resistant (A-286)
AMS 5542	Alloy Sheet and Strip, Corrosion and Heat Resistant (Inconel X)
MIL-E-5272	Environment Testing, Aeronautical and Associated Equipment, General Specification for
MIL-W-6858	Welding: Aluminum, Magnesium, Non-Hardening Steels or Alloys, and Titanium; Spot, Seam and Stitch.
MIL-W-8611	Welding, Fusion of Steels and Corrosion and Heat Resisting Alloys; Process for

2.1.1.3 Strength Requirements: The duct should be structurally adequate to resist without rupture, internal pressures of at least 2.5 times the critical combination of operating pressure and temperature. The duct should be structurally adequate to resist without permanent deformation, internal pressures of at least 1.5 times the critical combination of operating pressure and temperature. The most critical operating condition is that combination of operating pressure and temperature which results in the lowest yield strength of the duct material. The critical combination of operating pressure and temperature levels selected should be determined from the values resulting when any single system component malfunctions. Where combined loads occur, detail design of the ducting should be adequate to absorb loads from column action, structural or bracket deflection, and side loading from brackets in addition to the internal pressure loads. A reduced allowable yield strength should be considered with respect to life cycle expectancy.

2.1.1.3.1 Formed Parts: Stress level must be reduced to allow for thinning of material during forming. The degree of material thinning is dependent on the ratio of duct diameter to wall thickness, forming techniques, radius of bend and degrees of bend. Consult available design and manufacturing manuals before establishing the wall thickness.

2.1.1.3.2 Branch Duct Joints: Special attention should be given to the design and fabrication of duct joints such as tees and wyes. Flat areas, inherent in the design of tees and wyes should be kept to an absolute minimum. The areas that are normally flat should be "crowned" as much as possible. Reinforcement of the crotch area of wye sections is considered good practice. Welding technique used in the joining of duct sections must be of the highest quality.

2.1.1.3.3 Handling: Minimum wall thickness may be dictated by damage occurring during fabrication or handling. In this respect, the following minimum wall thicknesses are recommended:

Duct Diameter, Inches	Minimum Wall Thickness, Inch
Under 1.00	0.010
1.00 to 2.00	0.012
Over 2.00 to 3.50	0.016
Over 3.50 to 5.00	0.020
Over 5.00 to 6.00	0.025
Over 6.00	As required by design

2.1.1.4 Standard Sizes: The duct should be designed and fabricated to the diameters recommended below:

Outside Diameter, Inches	Size Increments, Inch
0.75 to 2.75	0.25
3.00 to 6.00	0.50
Over 6.00	1.00

2.1.1.5 Allowable Leakage: There shall be no leakage in the basic duct.

2.1.2 Compensation Devices for Thermal Expansion: The expansion of a ducting system during high temperature operation is normally absorbed by the compression or bending of bellows or special duct bends such as the "U" and Omega. Slip joints, ball joints and rotary joints may also be used for this purpose.

2.1.2.1 Free Bellows: A free bellows absorbs duct movement by the compression or extension of its convoluted portion. Bellows used in aircraft ducting systems are normally fabricated from stainless steel and may be of a single or multi-ply wall construction. A free bellows is composed of a number of working convolutions as shown in Figure 14 (a). The stroke or deflection of a given bellows (constant convolute size and wall thickness) under load is similar to a helical spring (see Figure 14 (b)). The word "load" includes any force or combination of forces applied axially to cause the bellows to compress or extend, and can therefore refer to a pressure or mechanically applied load in either direction. The stroke is also directly proportional to the number of convolutions and inversely proportional to some power of the wall thickness. In actual practice it has been found that two-plies, with a total thickness equal to a single ply, will provide at least twice the flexibility of the single ply. Multi-ply bellows can therefore be used for high pressures without excessive loss in flexibility. Two bellows used in series between anchor brackets should have the same spring rate.

2.1.2.1.1 Factors Affecting Endurance or Service Life: The cycle life of a free bellows is primarily influenced by the stress induced. The magnitude of the stress depends on the length of the stroke and the operating pressure. The closer these factors approach the maximum allowed, the shorter the cycle life. Severe or abnormal operating conditions, such as overtravel or shock loads, can also adversely affect the life characteristics of a free bellows.

2.1.2.1.2 Normal Design Practice: The following criteria should be observed for best results in the application of free bellows:

a. Compression stroke: 10 to 15% of the bellows length

b. Extension stroke: 5% of the bellows length

c. Angular deflection: $\pm 5^\circ$ (max)

d. Axial offset (if required): $\frac{.02L^2}{D}$ (Max); Where L = length of bellows D = nominal duct diameter.

e. Torsional deflection: none allowed

f. Ratio of bellows length to duct outside diameter: 1 to 1

g. Convolution height: 8 to 13% of the duct inside diameter

Although a permissible axial offset of $\frac{.02L^2}{D}$ is indicated, such practice should be avoided if possible. Axial offset induces an additional stress in the convolution which can cause premature failure. Increases in bellows length and convolution height over the values recommended above will create instability and a resultant tendency to squirm under applied load. The use of a liner, such as shown by Figure 15, will provide additional shear resistance and at the same time reduce vibration caused by high velocity flow. In the design of multi-ply bellows, consideration should be given to the elimination of moisture or air entrapped between the plies.

2.1.2.1.3 Statement of Design Requirements: Due to the highly specialized nature of free bellows design and fabrication, it is necessary that the design requirements and operating conditions be carefully outlined. The following information should normally be specified:

a. Specific function of the unit

b. Location in the system (e.g. in a straight run, adjacent to a bend, equipment, etc.)

c. Type of material

d. Minimum inside diameter

e. Maximum outside diameter

f. Type of ends and total overall length of the unit. If alignment of the end fittings is critical, an angular tolerance should be specified

g. Pressure (working, proof and burst), Temperature (maximum, minimum and ambient), and the most critical combination of temperature and pressure.

h. Maximum rate of pressure and temperature change

i. Axial deflection (compression and extension)

j. Angular deflection

k. Axial offset

l. Vibration requirements (frequency, amplitude)

m. Maximum flow velocity and allowable pressure drop

n. Minimum life cycles

o. If a liner is required, specify the minimum allowable inside diameter, minimum clearance between liner and convolutions, liner length, type of liner free end, the direction of normal air flow, and the possibility of reverse flow.

p. Qualification test requirements (to include method of duct support)

q. Production test requirements

r. Optional requirements may include the spring rate, number and height of convolutions, number of plies and wall thickness.

2.1.2.2 Restrained Bellows: A restrained bellows is similar to the free bellows except that it contains a means of limiting its axial movement. The restraint feature allows the unit to act as a tension carrying member. Thermal expansion is absorbed by locating these units in such a manner that angular deflection will occur as the ducting moves. The most common types, as shown in Figure 16, are the Gimbal, Tie Rod and Braided.

2.1.2.2.1 Gimbal Type: These units are made with internal or external gimbal supports as shown in Figure 16, and will permit angular deflection in any plane. For applications where deflection is required in one plane only, it is possible to save weight by eliminating one set of gimbal supports. Gimbal joints are utilized to absorb duct expansion in a manner similar to that illustrated in Figure 17. The primary advantage of this type unit is its ability to provide angular deflection with a small actuating force.

2.1.2.2.2 Tie Rod Type: Tie rod bellows are utilized to absorb duct expansion in the same manner as the gimbal type. These units can be made with external or internal rods to restrict axial motion. A typical tie rod bellows employing internal restraint is shown in Figure 16.

2.1.2.2.3 Braided Bellows: The use of an external braid on a bellows has been a long-accepted method of providing restraint. The primary advantages are minimum pressure drop and the small space envelope required. On the other hand, the braid restricts the angular deflection which results in a greater bending moment. The braided bellows can provide an economical means of absorbing duct expansion in stallations where the higher reaction loads can be accommodated without undue penalty. The design of these units should be such as to minimize rubbing contact between the braid and the end convolutions.

2.1.2.2.4 Normal Design Practice: The following criteria should be observed for best results in the application of restrained bellows:

a. Angular deflection: $\pm 5°$

b. Axial off et (if required): depends upon type of restraint employed $\frac{.02L^2}{D}$ (Max).

c. Torsional deflection: none allowed

d. Length of Bellows: as required to limit compression and extension to 10% of the convoluted length during angular deflection.

2.1.2.2.5 Statement of Design Requirements: Applicable information from Para. 2.1.2.1.3 should be specified as needed for restrained bellows. In addition, it may be necessary to call out a limit on the actuating force required to obtain the amount of angular deflection desired.

2.1.2.3 Compensating Joint: This type of bellows allows for duct expansion in the same manner as a free bellows. The unit can be made in longer lengths than a free bellows by installing internal slide supports at linear intervals equal to the duct diameter. By pressurization of an internal chamber, as shown in Figure 18, the tendency of the bellows to elongate under pneumatic load is eliminated and the unit functions as a tension carrying member in the duct system. By over-compensation the spring rate effect of the fully compressed unit can be cancelled; however, fixed supports within the system must be designed to withstand the spring rate force which occurs when the duct pressure decays on system shut-down. The pressure compensated assembly permits about the same degree of angular deflection as other bellows types, but axial offset is prohibited because of the rigid shell construction. The primary use of the compensating joint is to retain a tension type system in areas where limited space exists and where considerable duct expansion must be absorbed. An example would be a long duct run in a wing leading edge.

2.1.2.3.1 Normal Design Practice: The following design criteria should be observed for compensating joints:

a. Compression stroke: 10 to 15% of the total bellows length

b. Extension stroke: 5% of the total bellow length

c. Angular deflection: ±5°

d. Axial offset: none

e. Torsional deflection: none

f. Ratio of individual bellows length to duct outside diameter: unsupported length limitation same as free bellows.

2.1.2.3.2 Statement of Design Requirements: Applicable information from Para. 2.1.2.1.3 should be specified as needed for compensating joints. The following additional requirements are usually necessary:

a. Spring rate at design compression stroke

b. Amount of pneumatic compensation. Usually expressed as the axial force required to hold unit in any position from neutral to fully compressed under pressurized conditions

c. Mounting details (in case of support bracket).

2.1.2.4 Duct Expansion Bends: Various simple and special bends can be used to absorb thermal growth in a duct system. Some of the common type bends employed for this service are shown in Figure 19. The following information shows the comparative expansion values of several type bends:

a. A simple "U" bend has twice the expansion value of a quarter bend

b. An expansion "U" bend has twice the expansion value of a simple "U" bend

c. An Omega has 2.50 times the expansion value of a simple "U" bend

A tension type system is generally preserved by the use of bends because of the pneumatic force (fluid column action) exerted at the duct bend. Disadvantages of this method of allowing for thermal expansion are the amount of space required and the increase in fluid pressure losses. Bends made with too small a radius will have very little expansion value, inasmuch as buckling of the walls will occur. Refer to Para. 2.1.1.3 for strength requirements applicable to ducts used in expansion bends.

2.1.2.5 Slip Joint: This unit absorbs duct expansion by means of linear motion similar to that of a telescoping joint. Relatively large axial motion is possible within a fairly small envelope and with a low actuating force. Sealing and alignment are critical in order to maintain leakage at an acceptable level. Because of pneumatic loading and the seal concentricity required, this unit must be supported and used in the same manner as a free bellows. The slip joint has not been used extensively at the pressures and temperatures dealt with in this document because of sealing and alignment problems.

2.1.2.6 Ball Joint: Ball joints can be made to absorb duct thermal expansion in the same manner as a restrained bellows. Angular deflections as great as 10 to 15 degrees are possible. Since no axial motion can occur, this unit will function as a tension carrying number in the ducting system. The ball joint is heavier and larger than a comparative restrained bellows, and therefore its use has been limited to special applications where torsional deflections or large angular deflections must be absorbed. Some of the problems inherent to ball joint design are leakage, wear and high actuating forces.

2.1.2.6.1 Combination Ball and Slip Joints: A ball and slip joint combination unit may be used to absorb duct expansion in certain applications where torsional motion must be also handled.

2.1.2.7 Rotary Joint: A single rotary joint will not absorb thermal expansion in a duct system; however, the use of two or more rotary joints as shown in Figure 20 will allow for thermal expansion in a duct system, provided certain design and installation practices are observed. Figure 22 shows two rotary joints interconnected by a "U" shaped duct.

a. The axial center lines of the rotary joints must be at right angles (normal) to the run of ducting to permit true rotation without inducing bending or non-uniform loading of the rotation surfaces.

b. When only two rotary joints are used, the duct runs adjacent to each rotary joint must permit some movement in a plane parallel to the rotation surfaces of each rotary joint since the rotary joints are at a fixed distance apart by virtue of the "U" interconnecting ducts, and thermal expansion in the duct runs will cause displacement or movement axially of each duct run. This movement will resolve into rotary motion of each rotary joint and movement of each rotary joint and connecting "U" duct through an arc sufficient to accommodate the amount of thermal expansion.

2.1.3 Compensation Devices for Airframe Deflection, Growth and Contraction from Temperature Effects, and Installation Tolerances: In general, the normal practice is to utilize the previously described thermal expansion units to absorb deflections of the airframe, growth and contraction due to temperature effects, and to compensate for various forms of duct misalignment which occur during installation. When such a practice is followed, a conservative approach is to allow approximately 30% of the design motion for installation tolerances. The following two subparagraphs apply to the specific use of various devices to compensate for airframe torsional deflection and installation tolerances.

2.1.3.1 Airframe Torsional Deflection: The ball joint, rotary joint and possibly the slip joint, can be used solely to absorb torsional deflection of ducting. Nonmetallic type joints are capable of absorbing a small amount of torsional deflection in the pressure and temperature range for which designed.

2.1.3.2 Installation Tolerances: The braided bellows provides a simple means of compensating for angular and offset misalignment during installation of the ducting system. By the addition of an adjustable end-piece, the braided unit can also be utilized to compensate for axial tolerances. Adjustable duct supports may be used to obtain proper angular and offset alignment. Finally, some types of duct couplings will tolerate a small amount of angular misalignment. It should be noted that there is no substitute for accurate tooling in duct fabrication and installation. Adherence to good tooling practices will minimize the necessity of adjustment during installation. Additional recommendations on tooling are presented in Para. 2.1.5.2.4.

2.1.4 Duct Coupling Requirements: A coupling is considered to be an assembly of all parts required to join two pieces of ducting together, such as shown in Figures 23 and 24. The parts required may include flanges, clamps, bolts, nuts, washers, gaskets, seals and other parts peculiar to a supplier's design. The duct coupling requirements stated herein are to be considered as minimum acceptable requirements.

2.1.4.1 Structural Loads: A duct coupling, as a component of a duct system must have sufficient strength to preserve the duct system integrity and continuity without experiencing permanent deformation when subjected to loads or combination of loads caused by the following conditions:

a. High temperature (up to 1000 F)

b. Low temperature (-65 F)

c. Pressure (normal, proof and burst) - same as for the basic duct

d. Pressure Cycling - The duct coupling shall be capable of withstanding repeated pressure loading with the internal air temperature equal to the normal operating air temperature.

e. Bending Moment - The allowable bending moment is a function of the duct diameter and wall thickness. The coupling should be designed to withstand repeated applications of bending loads without any damage and without exceeding the allowable leakage specified in Para. 2.1.4.2.

f. Torsion - The coupling should be designed to withstand repeated torsional loading without any damage and without exceeding the leakage specified in Para. 2.1.4.2.

g. Vibration - The coupling should remain structurally intact and not exceed the allowable leakage when exposed to the vibration conditions specified in MIL-E-5272 or the applicable drawing.

2.1.4.2 Allowable Leakage: The maximum allowable leakage per coupling should not exceed 0.01 CFM of Standard Air per inch of duct diameter.

2.1.4.3 Safety Features: Safety features are design details or innovations which are incorporated in a duct coupling to provide a degree of safety not usually associated with the basic coupling. The safety design may be a structural safety device or a visual safety device. Several examples are described below:

2.1.4.3.1 Structural Safety Device:

2.1.4.3.1.1 Add an additional coupling strap over the Tee bolt. The strap is retained in proper loading position by means of a cotter pin, and thereby maintains joint integrity in the event the Tee bolt fails.

2.1.4.3.1.2 Add a rachet tang which will engage a slot in the coupling band and maintain joint integrity in the event of Tee bolt failure.

2.1.4.3.2 Visual Device:

2.1.4.3.2.1 Install a cotter pin through the Tee bolt which incorporates a hole at a location corresponding to the correct nut torque valve. Visually inspect to see that the cotter pin is installed.

2.1.4.3.2.2 With the added coupling strap of Para. 2.1.4.3.1.1, if the cotter pin is not installed the added strap will act as a visual device, since the strap will not conform to the "safetied" contour.

2.1.4.4 Disconnect Features: The incorporation of a disconnect feature in a coupling design other than the normal method of connecting and disconnecting should be determined on the basis of coupling function. The incorporation of "quick" disconnect features in a coupling should be justified by its use in the duct system, where definite advantages are gained by its use over the normal coupling. An example might be the duct connection to a piece of equipment requiring frequent removal from the system. The time thus saved in removal and reinstallation of the equipment may justify the use of the "quick" disconnect coupler. Special disconnect features generally add some weight to the coupling.

2.1.4.5 Installation and Handling Requirements: The following requirements pertaining to the installation and handling of duct couplings should be given careful consideration:

a. Dimensional inspection before and after attachment. This may include compatibility of the duct outside diameter with the inside diameter of the flange, angular relation of flange face to the duct axis and flatness of the flange face.

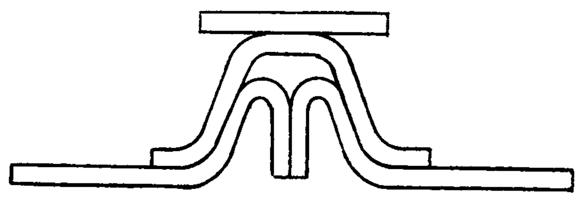
b. Handling precautions to prevent damage

c. Installation techniques

2.1.4.6 Duct Coupling Methods: This section presents a series of common duct coupling methods. Specific information regarding the intended use, the leakage allowed, the temperature range, the pressure range, and the bending load or deflection requirements should be furnished to the coupling manufacturer.

2.1.4.6.1 "V" Band Couplings:

Type "A"



Materials: Corrosion Resistant Steel

Tools to Install: Torque Wrench

Duct Sizes: 1 inch through 6 inches diameter in 0.50 inch diameter increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 300 psig or greater for sizes 1 inch through 3 inches diameter. For sizes 3 inches through 6 inches, the maximum operating pressure decreases as diameter increases.

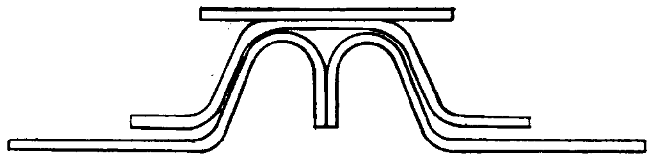
Maximum Operating Temperature: The maximum operating air temperature is 800 F for all couplings.

Remarks:

a. Available with fail-safe feature.

b. V-band coupling indexes flanges on skirt of flange.

Type "B"



Materials: Corrosion Resistant Steel

Tools to Install: Torque Wrench

Duct Sizes: 1 inch through 6 inches diameter in 0.50 inch diameter increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 300 psig or greater for sizes 1 inch through 3.25 inches diameter. For sizes 3.50 inches through 6 inches diameter, maximum pressure decreases as diameter increases.

Maximum Operating Temperature: The maximum operating air temperature for all coupling sizes is 1000 F.

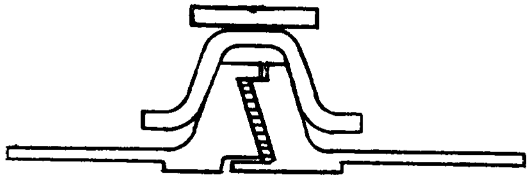
Remarks:

a. Available with fail-safe feature.

b. Coupling indexes flanges on O.D. of flange.

c. Available in heavy duty series for higher bending loads.

Type "C"



<u>Materials:</u> Corrosion Resistant Steel, Metallic Gasket

<u>Tools to Install:</u> Torque Wrench

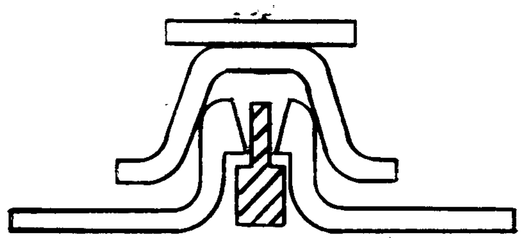
<u>Duct Sizes:</u> 1 inch through 5 inches diameter in 0.50 inch increments. Some sizes available in 0.25 inch increments.

<u>Maximum Operating Pressure:</u> 300 psig or greater for sizes 1 inch through 3.50 inches diameter. For sizes 4 inches through 5 inches, maximum operating pressure decreases as diameter increases.

<u>Maximum Operating Temperature:</u> The maximum operating air temperature for all coupling sizes is 1000 F.

<u>Remarks:</u> Available in heavy duty series for higher bending loads with operating pressures greater than shown. Various types of gaskets available depending on temperature.

Type "D"



Materials: Corrosion resistant steel, metallic gasket

Tools to Install: Torque wrench

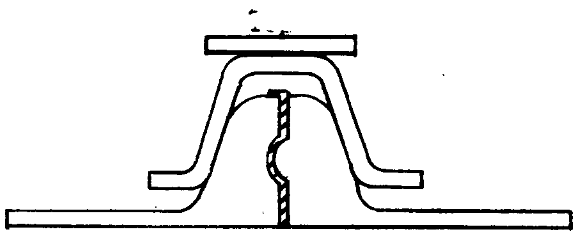
Duct Sizes: 1 inch through 12 inches diameter in 0.50 inch increments from 1 inch to 6 inches and 1 inch increments from 6 inches to 12 inches. Some sizes available in 0.25 inch increments.

Maximum Operating Pressure: 300 psig or greater for sizes 1 inch through 3.50 inches diameter. For sizes 4 inches through 12 inches, the maximum operating pressure decreases as diameter increases.

Maximum Operating Temperature: The maximum operating temperature for all coupling sizes is 1000 F.

Remarks: Various type gaskets available depending on temperature.

Type "E"



Materials: Corrosion resistant steel, metallic gasket.

Tools to Install: Torque wrench.

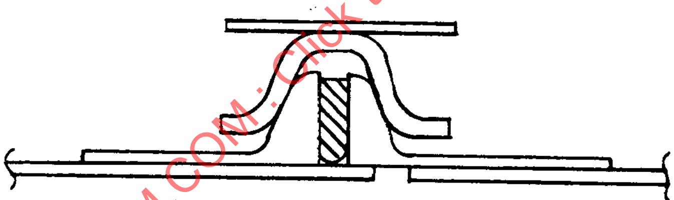
Duct Sizes: 1 inch and 2.50 inches diameter only two sizes established.

Maximum Operating Pressure: 300 psig or greater for both sizes.

Maximum Operating Temperature: 1000 F maximum for 1 inch size and 750 F for 2.50 inch size.

Remarks: None.

Type "Special"



Material: Corrosion resistant steel

Tools to Install: Torque wrench

Duct Sizes: As required

Maximum Operating Pressure: As required

Maximum Operating Temperature: As required

Remarks:

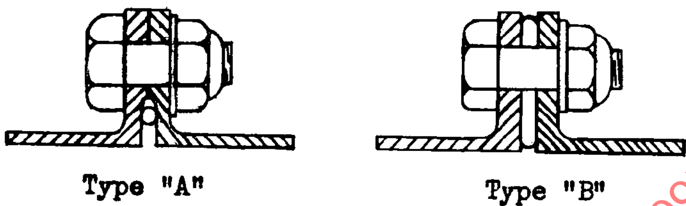
a. Typical machined flanges.

b. Pressures and temperatures dependent on gasket used.

c. Infinite number of special shapes available to customer specification.

2.1.4.6.2 Bolted Couplings:

Types "A" and "B"



Materials: Corrosion resistant steel

Tools to Install: Standard wrenches

Duct Sizes: Type "A" couplings are available in the following sizes: 1.75", 2.50", 2.75", 3.50", 4.00" 4.50", 5.00".

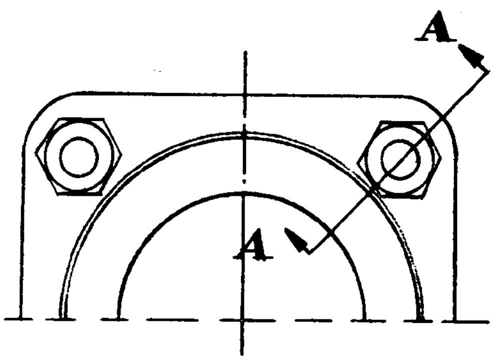
Type "B" couplings are available in 2" and 3" sizes only.

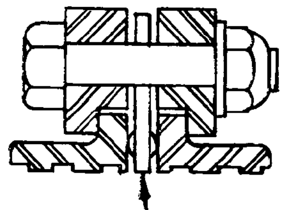
Maximum Operating Pressure: 205 psig for all sizes both types of couplings.

Maximum Operating Temperature: 750 F for all sizes both types of couplings.

Remarks: Maximum operating temperature is 750 F when steel gaskets are used.

Type "C"





Section A-A

Materials:

a. Corrosion resistant steel ferrules and flanges.

b. Gasket materials dependent on maximum operating temperatures.

Tools to Install: Ferrules are mechanically attached (no welding) to tubes by special hand or power tools supplied by manufacturer.

Duct Sizes: 1 inch through 7 inch diameter. 1 inch through 4 inches in 0.50 inch increments, 4" through 7" in 1.00" increments.

Maximum Operating Pressure: 300 psig or greater for all coupling sizes.

Maximum Operating Temperatures: 1000 F for all sizes.

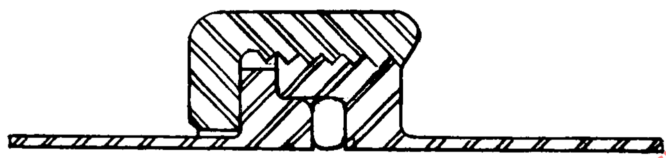
Remarks:

a. Number of bolt holes increases as nominal diameter increases.

b. A similar coupling without ferrules is available for welding to the duct.

2.1.4.6.3 Threaded Couplings:

Type "A"



Materials: Ring nut, threaded flange and flange ring made from corrosion resistant steel.

Gasket materials dependent on operating temperatures.

Tools to Install: May be installed with a standard strap wrench. Special wrenches are available from manufacturer.

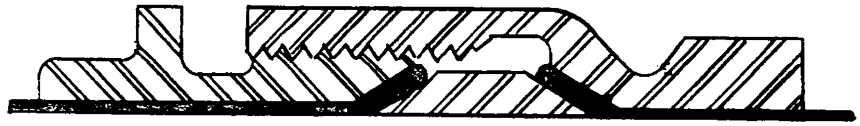
Duct Sizes: 1 inch through 7 inches diameter, in 0.50 inch increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 300 psig or greater for sizes 1 inch through 5 inches diameter. For sizes 6 inches through 7 inches, the maximum operating pressure decreases as diameter increases.

Maximum Operating Temperature: 1000 F for all coupling sizes with metallic gasket.

Remarks: Optional methods available for locking ring nut in place.

Type "B"



Materials: Nut, coupling and ring, corrosion resistant steel - heat treated.

Tools to Install: Standard type wrenches.

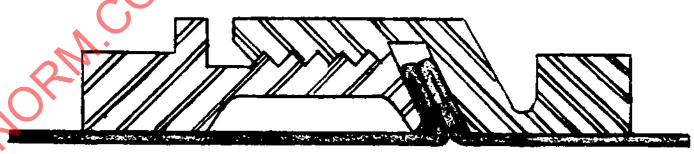
Duct Sizes: 0.25 inch through 4 inches diameter. From 0.25 inch to 1.50 inches sizes are in 0.25 inch increments. From 1.50 inches to 3 inches sizes are in 0.50 inch increments. A 3.50 inch size has not been established.

Maximum Operating Pressure: 300 psig or greater for all coupling sizes.

Maximum Operating Temperature: 700F for all sizes.

Remarks: Designed for installation on AND-10061 Tube Flare, except for very thin wall tubing which must be double flared.

Type "C"



Materials: Nut and body corrosion resistant steel, heat treated.

Tools to Install: Standard type wrenches.

Duct Sizes: 2 and 3 and 4 inch diameters.

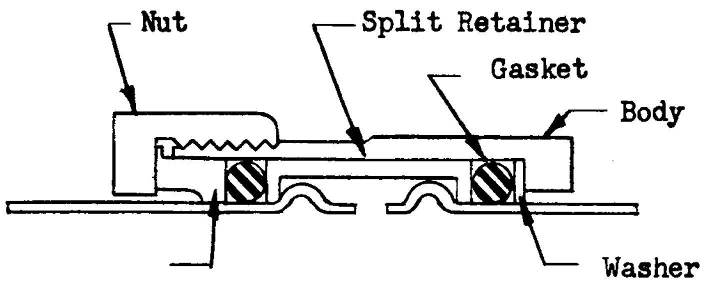
Maximum Operating Pressure: 300 psig or greater for all coupling sizes.

Maximum Operating Temperature: 700 F for all coupling sizes.

Remarks: Necessary to double flare thin wall tubing to obtain good seal.

2.1.4.6.4 Flexible Couplings:

Type "A"



Materials: Corrosion resistant steel, elastomer gasket.

Tools to Install: Standard wrenches.

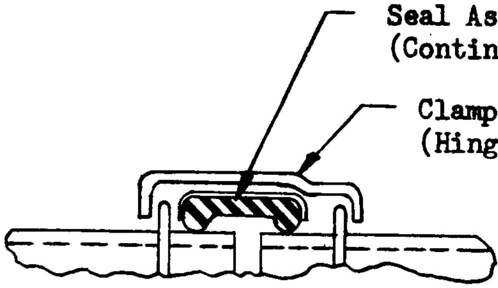
Duct Sizes: 0.75 inch through 6 inches diameter in 0.50 inch increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 300 psig or greater for all coupling sizes.

Maximum Operating Temperature: 500 F for all coupling sizes.

Remarks: Allowable angular deflection ± 4°. Capable of absorbing some rotary and axial motion.

Type "B"



Materials: Corrosion resistant steel or aluminum clamp assembly, elastomer seal with cadmium plated copper case or aluminum.

Tools to Install: Screwdriver.

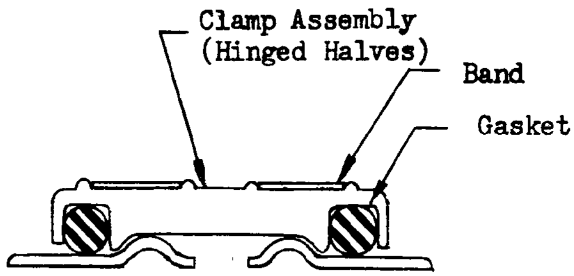
Duct Sizes: 1 inch through 4.25 inches diameter in 0.25 inch diameter increments, except a 3.625 size replaces the 3.750 size.

Maximum Operating Pressure: 125 psig for all coupling sizes.

Maximum Operating Temperature: 480 F for all coupling sizes.

Remarks: Allowable angular deflection ± 4°. Capable of absorbing some rotary and axial motion.

Type "C"



Materials: Aluminum clamp, corrosion resistant steel bands, elastomer gasket.

Tools to Install: Torque wrench.

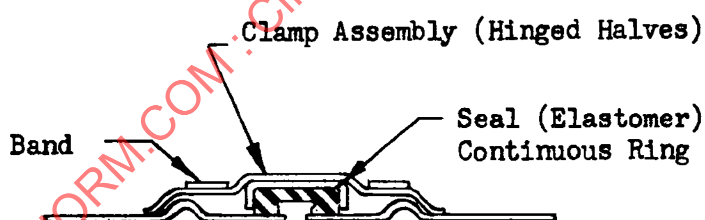
Duct Sizes: 0.75 inch through 4 inch diameter in 0.25 inch diameter increments to 2 inch size. 0.50 inch increments from 2 inch through 4 inch size.

Maximum Operating Pressure: 125 psig for all coupling sizes.

Maximum Operating Temperature: 400 F for all coupling sizes.

Remarks: Allowable angular deflection ± 4°. Capable of absorbing some rotary and axial motion.

Type "D"



Materials: Aluminum clamp assembly, corrosion resistant steel bands, elastomer seal in aluminum case.

Tools to Install: Torque wrench.

Duct Sizes: 1 inch through 4.50 inches diameter in 0.50 inch increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 160 psig for all coupling sizes.

Maximum Operating Temperature: 400 F for all coupling sizes.

Remarks: Allowable angular deflection ± 4°. Capable of absorbing some rotary and axial motion.

2.1.5 Duct System Design Loads:

2.1.5.1 Design Operating Conditions: All ducts must be designed to withstand Proof and Burst Pressure conditions as outlined in Para. 2.1.1.3.

2.1.5.2 Bending Loads: In-flight bending loads may be caused by airframe deflection, thermal expansion and/or pneumatic loads which may be imposed on ducts by junctions, bends and pressure pulsations.

2.1.5.3 Column Loads (Compression Systems): Column loads may be imposed on the ducts by end reactions of flex-sections or slip joints, or by the longitudinal reaction of supporting brackets. A duct section in compression being acted upon by these forces will exhibit all the characteristics of a pin-ended Euler column. Consequently, the distance between supports must be sufficiently short to prevent unstable column failure.

2.1.5.4 Thermal Expansion: Design of a duct system must include a consideration of differences of thermal expansion between system components caused by differences in thermal expansion coefficients and by differences in operating temperatures of physically attached components. In making provisions for thermal expansion it is assumed that the system components and the structure are installed at 70 F. Normally, the greatest expansion differential occurs on a winter day with the structure cooled to -65 F and the ducting being heated to the maximum operating temperature possible for the winter day condition. However, the design should include a survey to determine whether any operating condition might possibly cause more serious expansion differentials.

2.1.5.5 Pneumatic Loads: These loads include dynamic pulse loads resulting from rapidly opening and closing valves and pneumatic thrust loads at duct terminal points and bends.

2.1.5.6 Installation Loads: Manufacturing and installation tolerances of duct assemblies and supports can result in initial misalignments. Loads created by misalignment should be accounted for in the duct and bracket design.

2.1.5.7 Duct Ovality: One of the most important and difficult factors to define by design limits is the allowable out-of-roundness or ovality of a duct segment. Pressure and temperature cannot be established as the sole criteria for establishing duct wall thickness; they do however, establish a minimum allowable gauge. Final acceptance of any straight, curved, or branched section will necessarily be based on fatigue tests of out-of-round sections. On this basis it may be found that wall thickness may differ for drawn and fusion welded ducts and for initial degrees of ovality and induced ovality due to airframe deflection.

2.1.5.8 Maximum Stresses in Ducts: To determine the maximum principal stresses consider the combined stresses of shear, axial fiber tension and/or compression and hoop tension due to internal pressure by applying the method of Mohr's Circle. Each principal stress (tension, compression and shear) so obtained multiplied by a factor of 1.5 must be below its corresponding Yield Strength x 1.5 or below its Ultimate Strength for the material considered, whichever is lower.

2.1.5.9 Vibration Loads: While almost any part may be susceptible to fatigue failure, duct assemblies in particular should be especially investigated since they are exposed to several types of vibration loading. The designer should be aware of the mechanism by which a duct or duct system may be induced to vibrate so that he may intelligently design against their occurrence and effects. Resonant conditions should particularly be avoided. Vibration may be induced by internal air flow excitation, external air flow excitation, and transmission through structural members and supports.

2.1.6 Duct System Supports:

2.1.6.1 Compression Systems:

2.1.6.1.1 Types of Support Brackets: Fixed (anchor) brackets should be used to absorb loads resulting from thermal expansion or internal pressure. Anchor brackets must also absorb side loads due to duct misalignment, the spring rate force of compressed flex-sections, and the duct section pressure drop loads. Movable (guide) brackets should be used for intermediate or end support of the ducting.

2.1.6.1.2 Location of Supports: Straight ducts should have a minimum of two supports. Additional supports should be used to provide rigidity in critical clearance areas, to minimize duct vibration, and to prevent elastic buckling or column failure. The distance between the duct and supporting structure should be kept as small as possible.

2.1.6.1.2.1 Expansion Devices: Supports should be provided on each side of device to insure axial loading and minimize "squirm". They should be placed as close to the device as practical with 1/2 duct diameter or 3" as a maximum distance. Only one support may be fixed. If intermediate anchors are used on the duct to provide for temperature growth of individual duct sections, both supports at the expansion device may be movable.

2.1.6.1.2.2 Change in Direction: Anchor brackets should be provided at all points at which the duct routing direction is changed and at which point a thrust load must be absorbed. If the direction of change is greater than 30 degrees, use of fixed supports adjacent to the tangency points of the bend will minimize eccentric loading on the brackets.

2.1.6.1.2.3 Other Supports: Tees and similar duct fittings should be rigidly supported in order to eliminate lateral motion which would result from duct expansion. Where duct ends are capped or closed off by a valve, the duct should be anchored or provisions made for duct growth.

2.1.6.1.3 Support Strength Requirements: Anchor brackets should be strong enough to resist a total load equal to the vector sum of all loads which occur in each duct leading to the anchor point. The loads will result from a combination of internal duct pressure times the effective area, the load required to compress the bellows, installation preload, and the thrust resulting from change in direction of the moving fluid. (The last load is small and can usually be neglected. Intermediate anchor brackets should be designed for the same loads as end anchor brackets in order to handle a failure which may subject the intermediate brackets to full pneumatic load. Guide brackets should be strong enough to resist any combination of loads resulting from structural deflection or misalignment, and from any side duct loading which may occur, including that resulting from a duct rupture.

2.1.6.1.3.1 Design Values for Internal Pressure Loads: In computing bracket loads at the anchor point or normal to the duct axis, a pressure twice the maximum operating pressure should be used. In computing bracket loads along the duct axis, a pressure equal to one-half the maximum operating pressure should be used. Anchor bracket deflection under application of normal operating loads should be kept to a minimum in order to insure adequate rigidity. A maximum allowable deflection of 0.0625 inch is recommended.

2.1.6.1.4 Method of Accurately Locating Supports: Tooling should be used to locate all ducting supports. Sufficient adjustment should be provided in the brackets to allow for installation tolerances. Duct support brackets should not be used to force the ducting into position.

2.1.6.2 Tension Systems:

2.1.6.2.1 Types of Support Brackets: Anchor brackets should be provided for major duct sections. Intermediate supports should be used to stabilize the duct as required, or to limit duct vibration. Anchor brackets should also be located at items of equipment which are not designed to absorb tension loads. Intermediate guide brackets should be designed to accommodate any motion resulting from growth of the ducting system between anchor points.

2.1.6.2.2 Support Strength Requirements: Anchor and guide brackets should be strong enough to resist the load equal to the vector sum of all loads occuring in each duct. All supports should be strong enough to resist any combination of loads resulting from duct growth, structural deflection, and bending of restrained bellows. Consideration should also be given to side loads resulting from duct rupture.

2.1.6.2.2.1 Design Values: For guide bracket loads, the product of the duct weight supported by the bracket times the airplane load factor should be used. Use a stress factor of 1.5 for loads resulting from duct growth or deflection. For anchor bracket loads, refer to previous recommendations in Para. 2.1.6.1.3.1. In areas where brackets may be inadvertently used as "hand-holds" or steps, the minimum design load should be 200 pounds in all directions.

2.1.6.2.3 Method of Accurately Locating Supports: Tooling should be used to locate all ducting supports. Sufficient adjustment should be provided in the brackets to allow for installation tolerances. Duct support brackets should not be used to force the ducting into position.

2.1.7 Thermal Insulation: High temperature duct systems may be insulated to prevent overheating of adjacent equipment and structure and to reduce the heat loss from the duct walls and through support brackets. Insulation may also be used to minimize or eliminate autogenous ignition hazards. Insulation materials should have low wicking characteristics or be suitably protected.

2.1.7.1 Ducts: Duct insulation should consist of an insulating medium enclosed in a moisture and/or vapor impervious cover as required.

2.1.7.1.1 Materials: Normally the cost of insulating materials increases with temperature requirements. Material selection should be made with this in mind. A comparison of the various coverings and insulating materials is shown in the following tables. The temperature limits are given for insulating materials without binders.

A. Metallic Foil Coverings:

TEMP. LIMIT	MATERIAL	ADVANTAGES	DISADVANTAGES
400 F	Aluminum	Light Weight, Low Cost	Poor durability and formability
1600 F	Stainless Steel	Formability Durability	Weight, medium cost
1800 F	Inconel	Formability Strength Corrosion Resistant	Weight and high cost

B. Coated Fabric Coverings:

TEMP. LIMIT	FABRIC	COATING	ADVANTAGES	PRIMARY DISADVANTAGE
175 F	Glass, cotton or synthetic	Vinyl Plastic	Low cost, fuel and oil resistance, good abrasion resistance.	Low temperature limit
275 F	Glass	Neoprene Rubber	Weather and oil resistance, good abrasion resistance	Low temperature limit
275 F	Glass	Nitrile Rubber	Good fuel and oil resistance, good abrasion resistance	Poor weather resistance
500 F	Glass	Silicone Rubber	High temperature and good weather resistance.	Poor abrasion and fuel resistance.

C. Insulating Materials:

TEMP. LIMIT	MATERIAL	DENSITY LB/FT³	ADVANTAGES	DISADVANTAGES
700 F	Steel Wool	6 - 30	Med. Weight	High Cost
1100 F	Glass Fibers	3 - 9	Light Weight	High Cost
1200 F	Asbestos	15 - 25	Med. Cost	Weight
1600 F	Mineral Wool	8 - 12	Low Cost	Weight
2000 F	Quartz Micro-fibers	3 - 9	Light Weight	High Cost

2.1.7.1.2 Removable Type: Removable insulation generally consists of two types; namely, preformed and wrap around. The preformed type is usually made up of two half shells, while the wrap on type consists of a flat piece which is formed around the duct at the time of installation. Of the two types, the wrap around insulation is more economical but it is usually limited to straight sections. The preformed insulation lends itself well to irregular sections and joints. Fabric covered insulation is made using one of the insulation materials listed above, and covered on one or both sides with a fabric. The outer fabric covering should be a durable moisture and/or vapor impervious material. The edges should be adequately sealed. Insulation must have a vent, located on the lower surface of the duct as installed, to allow for equalization of pressure. Foil covered insulation is fabricated using one of the inorganic fibers, either preformed or flat, covered both sides with a metallic foil. The foil may be texturized to afford better forming and handling characteristics. The edges should be hermetically sealed by welding, crimping or taping. This type duct insulation must also have a vent to allow for equalization of pressure. Insulation blankets are attached to ducts by snap fasteners, straps, and lacing, sewing or taping.

2.1.7.1.3 Integral Type: Integral insulation may be fabricated by attaching the insulating batt directly to the duct by wrapping with a cover material and processing the cover to form a unitized construction. Covers of metallic foil welded to the duct at each end, and suitably supported by the insulation, can be used throughout the temperature range indicated in this document. Fiberglass cloth impregnated with high temperature resins can be wrapped around duct insulation and cured to form a satisfactory cover for lower temperatures. A pressure-equalizing vent must be provided in the same manner as for the removable type.

2.1.7.2 Equipment and Components: Insulation for items such as valves, couplings and flex-sections is fabricated using the same materials and techniques as for ducts. The irregular shapes encountered in these components require more complicated patterns and tooling. Insulation may be attached using the normal duct insulation attachment techniques. Insulation for flex-sections must incorporate the required flexibility.

2.1.7.3 Support Brackets: Insulation may be incorporated to minimize the amount of heat loss through support brackets. It is desirable that such insulation be placed as close as possible to the heat source in order to limit the bracket temperature.

2.1.7.3.1 Insulating Materials: Several of the insulating materials which can be used to reduce heat loss through duct supports are as follows:

TEMP. LIMIT	MATERIAL	CONDITION	GENERAL APPLICATIONS
400 F	Hi temp thermo setting resin impregnated glass cloth	Rigid Sheet	Insulation at structural attachment.
500 F	Silicone impregnated glass cloth	Rigid Sheet	Insulation at structural attachment.
1000 F	Compressed Mineral Board	Rigid Sheet	Insulation shield (very little structural strength)
1100 F	Glass Fibers	Batting	Wrap-around insulation between duct and support
1200 F	Asbestos	Rigid Sheet	Insulation shield (very little structural strength)
1200 F	Asbestos	Heavy Fabric	Wrap-around insulation between duct and support
2000 F	Quartz Fibers	Batting	Wrap-around insulation between duct and support

2.2 Qualification Requirements: Qualification requirements are presented for duct components and for the complete pneumatic duct system.

2.2.1 Qualification of Components: The following test requirements are for ducts, couplings, flex-sections, joints and insulation. The maximum allowable tolerance on the test conditions should be as follows:

a. Temperature: ± 5 F up to 250 F
± 10 F up to 500 F
± 15 F above 500 F

b. Pressure: ± 3% of absolute value

c. Flow: ± 5%

d. Vibration Amplitude: ± 5%

e. Vibration Frequency: ± 2%

2.2.1.1 Duct Qualification Tests: Qualification tests may be conducted by the duct fabricator, the airframe manufacturer, or by a commercial laboratory deemed suitable by the airframe manufacturer. Upon satisfactory qualification the vendor shall submit a reproducible certified copy of the test results. Qualification tests shall be conducted on one (1) production sample and consist of the following tests in the order listed:

a. Leakage test

b. Proof pressure test

c. Endurance test

d. Vibration test

e. Burst pressure test

Burst pressure tests may be conducted on a separate sample in order to expedite the test program.

2.2.1.1.1 Test Conditions:

2.2.1.1.1.1 Ambient Temperature and Pressure: Unless otherwise specified on the applicable drawing, the equipment shall be tested at an ambient temperature of 70 F and an ambient pressure of approximately 29.9 inches of mercury.

2.2.1.1.2 Tests:

2.2.1.1.2.1 Leakage Test: Leakage tests shall be conducted at room temperature and proof pressure as indicated in Para. 2.2.1.1.2.2. No leakage of the basic duct shall be permitted.

2.2.1.1.2.2 Proof Pressure Test: The duct shall be proof pressure tested at 1.5 times the pressure at the most critical combination of pressure and temperature occuring in the duct with a simgle component malfunction. Ducts with operating pressure below 2 psig shall be proof pressure tested to at least 3 psig. No part of the duct shall fail, take any permanent set, or be damaged in any manner as a result of the above test.

2.2.1.1.2.2.1 Optional Proof Pressure Test: Duct may be proof pressure tested at room temperature provided the proof test pressure is increased to compensate for the stress reduction for the duct material at the higher operating temperature. This new pressure is to be equivalent to the proof test pressure at the selected operating temperature and can be obtained by multiplying the pressure by a conversion factor. This factor is the ratio of the tensile yield strength of the duct material at room temperature to the tensile yield strength of the duct at the elevated temperature.

2.2.1.1.2.3 Endurance Test: The duct shall be subjected to a pressure cycling test at operating temperature and pressure as specified on the applicable drawing. Alternately, the test may be conducted at room temperature provided the test pressure is increased to compensate for the reduction in allowable stress which would occur at the operating temperature level. The duct shall be cycled between the specified test pressure and a pressure level within 10% of the specified minimum pressure for a minimum of 5000 cycles at a minimum rate of one cycle in 10 seconds. The maximum number of pressure cycles should be determined on the basis of the number of functional cycles expected during the life of the part. No part of the duct shall fail, take any permanent set or be damaged in any manner as a result of this test.

2.2.1.1.2.4 Vibration Test: The duct (only those incorporating welded brackets used for support) shall be vibration tested in accordance with MIL-E-5272, Procedure I, or an equivalent specification noted on the applicable drawing.

2.2.1.1.2.5 Burst Pressure Test: The duct shall be burst pressure tested at 2.5 times the pressure at the most critical combination of pressure and temperature occurring in the duct with a single component malfunction. Room temperature air may be used for this test provided an alternate equivalent burst pressure for this reduced temperature condition is used. The duct shall not repture during this test. Deformation resulting from this test shall be permitted and the part need not be functional after test.

2.2.1.2 Qualification Tests of Compensation and Deflection Devices:

2.2.1.2.1 Restrained Bellows Qualification Tests: Qualification tests shall be conducted on one (1) or more samples as required and consist of the following tests:

a. Leakage Test

b. Flow Resonance Test

c. Proof Pressure Test

d. Pressure Drop Test

e. Endurance Test

f. Vibration Test

g. Deflection Force Test

h. Burst Pressure Test

2.2.1.2.1.1 Test Conditions:

2.2.1.2.1.1.1 Ambient Temperature and Pressure: Same as Para. 2.2.1.1.1.1.

2.2.1.2.1.2 Tests:

2.2.1.2.1.2.1 Leakage Test: Same as Para. 2.2.1.1.2.1.

2.2.1.2.1.2.2 Flow Resonance Test: This test shall be conducted on one sample assembled into a test duct. The assembly shall be subject to the range of flows at the pressure and temperature specified on the applicable drawing to determine the flow rate at which the most severe resonance condition occurs. Subject the assembly to the flow at which the most severe resonance occurred for 50 hours. If no resonance condition is encountered over the flow range specified, discontinue the test.

2.2.1.2.1.2.3 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.1.2.4 Pressure Drop Test: The pressure drop test shall be conducted on one sample. The total or static pressure drop shall not exceed 20% of the velocity head at the design duct Mach number.

2.2.1.2.1.2.5 Endurance Test: The endurance test shall be conducted on one sample of the bellows while at the operating temperature and pressure specified on the applicable drawing. Cyclically deflect one end of the assembly through the angular motion, number of cycles and cycle rate specified on the applicable drawing. It is suggested that a cycle should consist of plus 5 degrees to minus 5 degrees from normal and back to normal, and that 10,000 cycles should be applied between the frequency of 20 to 40 cycles per minute. In the same manner, cycle the unit for an equal number of cycles in a plane 90 degrees from that in which the previous cycling was conducted. Before and after the endurance test the assembly shall be subjected to proof pressure test of Para. 2.2.1.2.1.2.3 and the deflections force test of Para. 2.2.1.2.1.2.7. The initial deflection plane used for the cyclic tests should be the plane requiring the maximum deflection force. Record the moments required to deflect the bellows for both tests. There shall be no leakage or evidence of permanent deformation or galling of working surfaces as a result of this test.

2.2.1.2.1.2.6 Vibration Test: The bellows shall be vibration tested in two planes in accordance with MIL-E-5272a, Procedure I, or an equivalent specification as noted on applicable drawings. Airflow should be used during the resonance survey to determine if it contributes to the vibration. If airflow does produce excitation, the remainder of this test should be conducted at the critical velocity condition.

2.2.1.2.1.2.7 Deflection Force Test: The deflection force test shall be conducted on one sample of the bellows to determine the moment required to deflect the unit 5 degrees in any direction. The maximum moment allowable for each diameter shall not exceed the value specified on the applicable drawing.

2.2.1.2.1.2.8 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.2 Free Bellows Qualification Tests: Qualification tests shall be conducted on one (1) or more samples as required and consist of the following tests:

a. Leakage Test

b. Flow Resonance Test

c. Proof Pressure Test

d. Endurance Test

e. Vibration Test

f. Burst Pressure Test

2.2.1.2.2.1 Test Conditions:

2.2.1.2.2.1.1 Ambient Temperature and Pressure: Same as Para. 2.2.1.1.1.1.

2.2.1.2.2.2 Tests: During the following tests the bellows shall be restrained at both ends to prevent buckling and movement along the longitudinal axis.

2.2.1.2.2.2.1 Leakage Test: Same asPara. 2.2.1.1.2.1.

2.2.1.2.2.2.2 Flow Resonance Test: Same as Para. 2.2.1.2.1.2.2. If the unit incorporates a liner, a reverse flow test should also be conducted unless the unit is marked for flow in one direction only.

2.2.1.2.2.2.3 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.2.2.4 Endurance Test: The endurance test shall be conducted on one sample of the bellows while at the operating temperature and pressure specified on the applicable drawing. It is recommended that the assembly be flexed for 20,000 cycles at a stroke of 15% compression and 10% extension based on the normal active length (L) of the bellows. The assembly shall be mounted with the longitudinal axis of one end offset parallel with respect to the other end. This offset shall be equal to $.02L^2/D$; where L is the bellows length and D is the nominal duct diameter, as shown in Figure 21. A flexing cycle is defined as a change in duct length from the compressed position to the extended position and return to the compressed position. The cycling frequency shall be between 20 and 40 cycles per minute.

2.2.1.2.2.2.5 Vibration Test: Same as Para. 2.2.1.2.1.2.6.

2.2.1.2.2.2.6 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.3 Compensating Joint:

Qualification Tests: Qualification tests shall be conducted on one (1) or more samples and consist of the following tests:

a. Leakage

b. Proof Pressure

c. Vibration

d. Flexure and Endurance

e. Compensation Valve

f. Burst Pressure

Burst pressure test may be conducted on a separate sample in order to expedite the test program.

2.2.1.2.3.1 Test Conditions:

2.2.1.2.3.1.1 Ambient Temperatures and Pressures: Same as Para. 2.2.1.1.1.1.

2.2.1.2.3.2 Tests:

2.2.1.2.3.2.1 Leakage Test: Same as Para. 2.2.1.1.2.1.

2.2.1.2.3.2.2 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.3.2.3 Vibration Test: The unit shall be supported unpressurized by its mounting bracket and/or its coupling flanges and shall be vibration tested in accordance with MIL-E-5272, Procedure I or equivalent specification as noted on applicable drawings.

2.2.1.2.3.2.4 Flexure and Endurance Test: The unit shall be compressed axially from its normal unstressed, unpressurized position to its full design compressed position while subjecting it to the internal operating pressure and temperature specified on the applicable drawing. One flexure cycle shall consist of compressing the unit axially from the normal position to the full design compressed position and return to the normal position. At the specified operating conditions the unit shall be subjected to a total number of cycles and at a cycle frequency specified on the applicable drawing. It is recommended that 15,000 cycles be used with a cycle rate of 20 to 40 cycles per minute. One-third of the cycles shall be run with the compensator in its normal position; one-third of the cycles shall be run under a deflective bending moment as specified by the applicable drawing; the remaining third of the cycles shall be run under a deflective bending moment as specified by the drawing and in the opposite direction as the other bending moment. Upon completion of this test the unit shall meet the proof pressure requirements of Para. 2.2.1.2.3.2.2, the leakage requirements of Para. 2.2.1.2.3.2.1 and the dimensional requirements.

2.2.1.2.3.2.5 Compensation Value Test: With the unit at operating pressure and at normal installed length the amount of over or under compensation (axial load) shall be recorded.

2.2.1.2.3.2.6 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.4 Expansion Bends (Omega, U, etc.) Qualification Tests: The following qualification tests, except the Burst Pressure Test, shall be conducted on the complete ducting system. Burst Pressure Tests shall be conducted on only the expansion bends.

a. Endurance

b. Leakage

c. Proof Pressure

d. Burst Pressure

2.2.1.2.4.1 Test Conditions:

2.2.1.2.4.1.1 Ambient Temperature and Pressure: Same as Para. 2.2.1.1.1.1.

2.2.1.2.4.2 Tests:

2.2.1.2.4.2.1 Endurance Test: Pressure and temperature cycling tests shall be conducted on a complete ducting system utilizing production ducting, expansion bends, and components, supported in such a manner as to simulate actual aircraft installation and structure rigidity. Subject the entire system to a minimum of 5000 pressure and temperature cycles, or to the maximum number of cycles equivalent to the expected service life of the system. The test is to be conducted with air at the operating temperature and pressure specified on the applicable drawing. One cycle shall consist of the following:

a. Open all system valves and introduce hot air to the system until all components have reached the stabilized operating temperature specified.

b. Close all system valves and pressurize to the operating pressure specified.

c. Open all system valves and allow system to decay to ambient temperature and to between zero and 10% of the maximum pressure.

2.2.1.2.4.2.2 Proof Pressure Test: The entire duct system shall be proof pressure tested per Para. 2.2.1.1.2.2 following the test of Para. 2.2.1.2.4.2.1.

2.2.1.2.4.2.3 Leakage Test: The leakage test shall be conducted on the entire ducting system per Para. 2.2.1.1.2.1 except leakage as specified on the applicable drawing shall be permitted.

2.2.1.2.4.2.4 Burst Pressure Test: The burst pressure test per Para. 2.2.1.1.2.5 shall be conducted on the individual expansion bends and duct sections.

2.2.1.2.5 Optional Expansion Bends (Omega, U, etc.) Qualification Test: Qualification tests shall be conducted on one (1) sample of each configuration and consist of the following tests:

a. Endurance

b. Leakage

c. Proof Pressure

d. Burst Pressure

2.2.1.2.5.1 Test Conditions:

2.2.1.2.5.1.1 Ambient Temperatures and Pressures: Same as Para. 2.2.1.1.1.1.

2.2.1.2.5.2 Tests:

2.2.1.2.5.2.1 Endurance Test: Subject the test sample to a minimum of 5000 pressure and temperature cycles, or to the maximum number of cycles equivalent to the expected service life of the part. The bend shall be installed in a test setup simulating aircraft installation as specified on the applicable drawing. The test shall be conducted with air at the operating temperature and pressure and with a mechanically induced load as specified on the applicable drawing. The mechanical load shall simulate the expansion caused by the system in which this unit is used. One cycle shall consist of the following:

a. Subject the unit to air at the operating temperature and pressure until it has reached a stabilized temperature.

b. Apply mechanical load.

c. Dump pressure and remove the mechanical load.

2.2.1.2.5.2.2 Leakage Test: Same as Para. 2.2.1.1.2.1.

2.2.1.2.5.2.3 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.5.2.4 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.6 Ball Joints: Qualification Tests on units similar in material gage and construction shall be conducted on one (1) sample of the largest and smallest diameter, and consist of the following tests:

a. Leakage

b. Proof Pressure

c. Vibration

d. Deflection Moment

e. Endurance

f. Burst Pressure

2.2.1.2.6.1 Test Condition:

2.2.1.2.6.1.1 Ambient Temperatures and Pressures: Same as Para. 2.2.1.1.1.1.

2.2.1.2.6.2 Tests:

2.2.1.2.6.2.1 Leakage Test: Leakage shall be determined at the specified operating temperature and proof pressure. The value specified on the applicable drawing shall not be exceeded.

2.2.1.2.6.2.2 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.6.2.3 Vibration Test: The unit shall be vibration tested in two planes in accordance with MIL-E-5272, Procedure I, or equivalent specification as noted on applicable drawing.

2.2.1.2.6.2.4 Deflection Moment Test: The deflection moment test shall be conducted with the unit pressurized to the operating pressure and temperature to determine the moment required to deflect it in any direction to the angle specified on the applicable drawing. The maximum moment allowable for each diameter shall not exceed the value specified on the applicable drawing.

2.2.1.2.6.2.5 Endurance Test: The endurance test shall be conducted with the unit at the operating temperature and pressure specified on the applicable drawing. Angularly deflect one end of the assembly through the angular motion, number of cycles, and cycle rate specified by the applicable drawing in the plane of one of the struts (when used). It is suggested that a cycle should consist of a plus and minus 5 degree deflection from normal and back to normal, and that 10,000 cycles should be applied between the frequency of 20 to 40 cycles per minute. In the same manner cycle the unit for an equal amount of cycles in a plane 90 degrees from that in which the previous cycling was conducted. Before and after the endurance test the assembly shall be subjected to proof pressure test of Para. 2.2.1.2.6.2.2 and the deflection test of Para. 2.2.1.2.6.2.4. Record the moments required to deflect the bellows assembly for both tests. There shall be no evidence of permanent deformation or galling of working surfaces as a result of this test. Leakage shall not exceed the value specified on the applicable drawing.

2.2.1.2.6.2.6 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.7 Slip Joint Qualification Tests: Qualification tests on units similar in material gage and construction shall be conducted on one (1) sample of the largest and smallest diameter, and consist of the following tests:

a. Leakage

b. Proof Pressure

c. Endurance

d. Vibration

e. Burst Pressure

2.2.1.2.7.1 Test Conditions:

2.2.1.2.7.1.1 Ambient Temperatures and Pressures: Same as Para. 2.2.1.1.1.1.

2.2.1.2.7.2 Tests:

2.2.1.2.7.2.1 Leakage Test: Same as Para. 2.2.1.2.6.2.1.

2.2.1.2.7.2.2 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.2.7.2.3 Endurance Test: The endurance test shall be conducted with air cycled at the specified operating temperature and pressure for the number of cycles and cycle rate specified by the applicable drawing. It is suggested that 10,000 cycles be applied at a rate between 20 to 40 cycles per minute. One cycle shall consist of stabilizing the unit at the operating temperature, pressurizing to operating pressure and dumping pressure. Immediately following endurance test subject the unit to the leakage test of Para. 2.2.1.2.6.2.1.

2.2.1.2.7.2.4 Vibration Test: Same as Para. 2.2.1.2.6.2.3.

2.2.1.2.7.2.5 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.2.8 Rotary Joint Qualification Tests: Qualification tests shall be conducted on one or more samples as required and consist of the following:

a. Examination of product

b. Leakage Test

c. Flow Resonance Test

d. Proof Pressure Test

e. Pressure Drop Test

f. Endurance Test (Service Life)

g. Vibration Test

h. Burst Pressure Test

i. Sand - Dust

j. Torque

k. Fire Test

2.2.1.2.8.1 Test Condition:

2.2.1.2.8.1.1 Ambient Temperature and Pressure: Same as Para. 2.2.1.1.1.1.

2.2.1.2.8.1.2 Tests:

2.2.1.2.8.1.3 Examination of Product: Each test sample shall be carefully examined to determine conformance with the specifications and the suppliers detail drawings for dimensions, tolerances, weight, workmanship, design, marking, cleanliness, and any visible defects.

2.2.1.2.8.1.4 Leakage Tests: Same as Para. 2.2.1.2.6.2.1.

2.2.1.2.8.1.5 Flow Resonance Tests: At least one test sample shall be subjected to flow tests to determine resonance conditions. The test sample shall be subjected to the complete range of flows and temperatures as shown on the applicable drawings or specification. If a resonant condition is found, the test sample shall be subjected to a 50 hour test using the flow rate and temperature producing the most severe resonance. The test sample shall show no structural deterioration at the end of the 50 hour test period and successfully pass the Leakage requirements stated in Para. 2.2.1.2.8.1.4.

2.2.1.2.8.1.6 Proof Pressure Test: Each test sample shall be subjected to at least an air pressure of 1.5 times the normal operating pressure and an air temperature equal to the maximum temperature specified on the applicable drawings or specification.

If desired and mutually agreed to, the proof pressure test may be conducted using air at 70 F providing the test pressure is increased to compensate for the allowable stress reduction in test sample material at the maximum operating temperature. The test sample shall withstand the proof pressure conditions without failure of any part or without exhibiting permanent set or experiencing any damage which would preclude operation at normal operating conditions.

2.2.1.2.8.1.7 Burst Pressure Test: At least one representative production test sample shall be subjected to a burst test pressure of at least 2.5 times the maximum bleed pressure while at the maximum temperature specified on the applicable drawings or specification. The test sample shall not rupture, however, deformation and non-operation after the above burst test shall not be reasons for failure to pass this test.

2.2.1.2.8.1.8 Pressure Drop Test: A pressure drop test shall be conducted on one test sample if it is determined by review of cross sectional drawings that the design of the rotary joint would cause additional pressure drop greater than an equivalent length of ducting and of the same I.D. as the system ducting incorporating the rotary joint. The pressure drop shall not exceed 20% of the velocity head at the design duct system Mach number.

2.2.1.2.8.1.9 Endurance Test: An endurance test shall be conducted on one test sample which should consist of the two rotary joints and the interconnecting "U" duct, as shown in Figure 22. The degree of rotary motion for each rotary joint should be at least 15° or equivalent to the rotation required to satisfy the thermal expansion of the ducting under consideration.

Prior to the start of the endurance test, the test sample shall be subjected to the following tests:

a. Leakage

b. Proof Pressure

c. Torque

The endurance test shall consist of inducing rotary motion in each of the two joints as required above for 20,000 cycles. The test sample shall be subjected to the normal operating temperatures and pressures as required by detail drawings. The amount of Torque required to produce rotary motion shall be recorded continuously or at least every 100 cycles.

Criteria of failure may be one or more of the following:

a. Excessive part wear

b. Leakage above maximum allowable

c. Excessive Torque

d. Permanent deformation

2.2.1.2.8.1.10 Vibration Test: The test sample shall be vibration tested in accordance with MIL-E-5272, Procedure I, or to special conditions noted on detail drawings. The Vibration Test and Flow Test may be combined if mutually agreed upon.

2.2.1.2.8.1.11 Sand and Dust: The Test sample shall be tested for Sand and Dust in accordance with MIL-E-5272, Procedure I, except that at the conclusion of the test the sample shall be subjected to the normal operating pressure and temperature and shall be rotated through 10 cycles. The torque required for rotation shall be noted. If the Torque is in excess of the maximum allowed by the Specification, the unit shall be considered as failing to meet the operational requirements after sand and dust testing.

If mutually agreed upon, the internal surfaces of the test sample may be isolated and only the external surfaces subjected to the above sand and dust test.

2.2.1.2.8.1.12 Torque: The torque characteristics of the test sample shall be determined by testing at the normal operating temperature and pressures. The allowable torque shall be stated in the detail specification or on the applicable drawings. The allowable Torque should be compatible with the adjoining duct wall crippling stresses under conditions of axial movement induced by Thermal expansion or contraction.

2.2.1.2.8.1.13 Fire Test: A test sample shall be subjected to a fire test if required by installation requirements.

2.2.1.3 Duct Coupling Qualification Tests: Qualification tests shall be conducted on one (1) or more samples as required and consist of the following tests:

Required Tests

a. Proof Pressure

b. Leakage

c. Endurance (Bending Moment)

d. Repeated Load

e. Vibration

f. Burst Pressure

Optional Tests

a. Repeated Assembly

b. Initial Misalignment

c. Temperature Shock

d. Torsional Moment

2.2.1.3.1 Test Conditions:

2.2.1.3.1.1 Ambient Temperature and Pressure: Same as Para. 2.2.1.1.1.1.

2.2.1.3.2 Tests:

2.2.1.3.2.1 Proof Pressure Test: Same as Para. 2.2.1.1.2.2.

2.2.1.3.2.2 Leakage Test: The coupling should be assembled on a test vessel (Figure 24 or similar) and pressurized to the level at which leakage is to be determined. After the temperature of the air in the test vessel is stabilized the pressure decay shall be recorded each minute for 5 minutes. The leakage in SCFM shall be calculated and compared with the allowable specified in Para. 2.1.4.2.

2.2.1.3.2.3 Endurance Test (Bending Moment): The endurance test shall be conducted on one (1) sample of the duct coupling while at the temperature and pressure specified on the applicable drawing. For this test the coupling shall be mounted as shown in Figure 23. The free end of the assembly shall have a bending moment of the magnitude specified on the applicable drawing applied alternately in opposite directions for a total number of cycles and at a cycle rate as specified by the drawing. It is suggested a total of 20,000 cycles be applied at a cycle rate between 10 and 40 cycles per minute. One cycle shall consist of applying the load in one direction, then in the opposite direction and back to normal. There shall be no permanent deformation of the coupling or leakage in excess of the permissible amount specified on the applicable drawing as a result of this test. Leakage requirements shall be met with the allowable bending moment applied and when relaxed to zero. Record the clamp torque at the end of each 5000 cycles.

2.2.1.3.2.4 Repeated Load Test: The duct coupling shall be assembled for this test as shown in Figure 24 and subjected to a cycling test at the pressure and temperature specified on the applicable drawing. The maximum pressure shall be applied and relieved to between zero and 10% of the maximum pressure for a minimum of 20,000 cycles at a cycle rate between 10 and 40 cycles per minute. There shall be no permanent deformation of the coupling or leakage in excess of the amount specified on the applicable drawing.

2.2.1.3.2.5 Vibration Test: The duct coupling shall be assembled as shown in Figure 24 and be subjected to a vibration test in accordance with MIL-E-5272, Procedure I, or equivalent specification as noted on the applicable drawing. During this test the assembly shall be pressurized to the value specified on applicable drawing.

There shall be no permanent deformation of the coupling or leakage in excess of the amount specified on the applicable drawing.

2.2.1.3.2.6 Burst Pressure Test: Same as Para. 2.2.1.1.2.5.

2.2.1.3.2.7 Repeated Assembly Test: The coupling should be connected to and disconnected from the pressure test vessel, (Figure 23 or similar) fifteen successive times. The joint should be actually taken apart so that the mating parts are disturbed, rather than merely loosened. After the 3rd, 6th, 9th, and 12th assembly the coupling should be subject to the pressure for which initial coupling leakage was determined (Para.

2.2.1.3.2.2) After the 15th assembly, the test pressure should be held for 15 minutes and the leakage determined. In no case should the leakage exceed that specified on the drawing.

2.2.1.3.2.8 Initial Misalignment Test: The two halves of the pressure test vessel (Figure 24 or similar) should be installed in a jig with a spacer .031 inches diameter inserted radially between the flanges on one side so as to separate them at this point, with the flanges in contact at the point diametrically opposite the spacer. The spacer should then be removed and the jig locked so as to maintain the condition of misalignment thus provided. With this arrangement the misalignment of the flanges will range from approximately 0.4° for the 5 inch size to 1° for the 2 inch size. The test coupling should be installed on the pressure vessel flanges and subjected to the pressure for which initial leakage was determined (Para. 2.2.1.3.2.2). The leakage should be determined, and should not exceed the amount specified on the applicable drawing.

2.2.1.3.2.9 Temperature Shock: The pressure test vessel with the test coupling installed should be soaked at -65 F until stabilized. Air at the maximum operating temperature expected during engine starting should then be allowed to flow through the test vessel until the coupling temperature reaches 65% of stabilized temperature of the air. The rate of temperature rise should be in accordance with the anticipated operating condition. The discharge airflow should then be reduced so that the pressure in the test vessel builds up to that specified on the applicable drawing. The leakage should then be determined. The test vessel should then be depressurized and the cycle repeated 4 times. Leakage should not exceed that specified on the applicable drawing.

2.2.1.3.2.10 Torsional Moment Tests: The coupling should be mounted on a test fixture similar to Figure 23, but arranged so that a torsional load may be applied to one end of test vessel. The test vessel should be pressurized to the value at which the coupling leakage was initially determined (Para. 2.2.1.3.2.2) and the leakage checked. A torque should then be applied to the fixture and the point at which coupling rotation occurs (break-away torque) should be determined. Following this test, leakage should be rechecked. Leakage should not exceed that specified on the applicable drawing.

2.2.1.4 Insulation Qualification Tests:

2.2.1.4.1 Qualification Tests of Fabric Covered Insulation: Qualification tests shall be conducted on one (1) or more samples as required and consist of the following tests:

a. Thermal Conductivity Test

b. Low Temperature Test

c. Solvent Resistance Test

d. Simulated Service Test

e. Flammability Test

2.2.1.4.1.1 Test Conditions:

2.2.1.4.1.1.1 Ambient Temperatures: Ambient temperatures shall be 70 F ± 15 unless otherwise specified on the applicable drawing.

2.2.1.4.1.2 Tests:

2.2.1.4.1.2.1 Thermal Conductivity Test: The thermal conductivity test shall be conducted on a specimen of the basic insulating material by the Guarded Hot Plate Method described by test C 177-52 in the 1952 Edition of ASTM Standards.

2.2.1.4.1.2.2 Low Temperature Test: The specimen shall consist of a one foot long cylindrical section. The specimen shall be subjected to a temperature of -54 C (-65 F) for a total of 24 hours after stabilization. At the conclusion of this test the specimen shall be examined. Deterioration due to the low temperature exposure shall not be acceptable.

2.2.1.4.1.2.3 Solvent Resistance Test: The specimens shall consist of three (3) one foot long cylindrical sections with both ends sealed. Each specimen shall be weighed to the nearest 0.1 gram before and after the test. Weighing shall be done in such a manner as to permit determination of the per cent increase in weight of the cover and the insulation independently. The insulation weight increase shall be zero per cent. The fluids to be used for this test are MIL-F-5624 (JP4) fuel, MIL-L-7808 lubricating oil, MIL-O-5606 hydraulic fluid and Skydrol if applicable. The test shall be performed by allowing each of the above fluids to flow over its own specimen for a period of ten (10) minutes at the rate of 1.5 liter per hour. The fluid temperature shall be maintained at 250 F while each specimen is at room temperature.

After the completion of the above tests each specimen shall be wiped clean of any excess fluid before reweighing. Reweighing shall be done within 15 minutes after the completion of the test.

2.2.1.4.1.2.4 Simulated Service Test: The specimen shall consist of a one foot long insulated duct section. The duct shall be heated internally to the maximum operating temperature specified on the applicable drawing for a duration of 50 hours. The ambient temperature shall be maintained at a level representative of service conditions. At the completion of this test the insulation shall show no evidence of deterioration.

2.2.1.4.1.2.5 Flammability Test: The specimen shall be subjected to a flammability test in accordance with method 2022 of Federal Specification L-P-406 and shall meet the flammability requirements specified on the applicable drawing.

2.2.1.4.2 Qualification Tests on Metal Covered Insulation: Qualification tests shall be conducted on one (1) or more samples as required and consist of the following tests:

a. Thermal Conductivity Test

b. Simulated Service Test

c. Leakage Test

2.2.1.4.2.1 Test Conditions:

2.2.1.4.2.1.1 Ambient Temperatures: Same as Para. 2.2.1.4.1.1.1.

2.2.1.4.2.2 Tests:

2.2.1.4.2.2.1 Thermal Conductivity Test: Same as Para. 2.2.1.4.1.2.1.

2.2.1.4.2.2.2 Simulated Service Test: Same as Para. 2.2.1.4.1.2.4.

2.2.1.4.2.2.3 Leakage Test: Seal vents in the cover and pressurize to 2 psig. No leakage shall occur.

2.2.2 System Qualification: The following test requirements apply to the complete ducting system mock-up.

2.2.2.1 Test Set-up: The duct system qualification must use a test setup that is representative of the system to be installed in the aircraft. All ducting, ducting supports, and purchased equipment shall be production articles. Insofar as possible the skeleton test structure should approximate the airframe structure with respect to strength and stiffness. The test setup should include the identical system instrumentation and system controls as planned for the airplane. These elements should be oriented as to distance, elevation, etc., as in the airplane. The test setup should include instrumentation to indicate system operation and to aid in checking original system calculations. The system should include instrumentation in purchased mechanical equipment to indicate operation under all conditions of duct system operation. The test setup should include purchased equipment which has been successful in passing production functional tests. Faulty purchased equipment can delay and result in erroneous duct system test data. The test setup should provide a suitable structure which will permit the accurate installation of the ducting system and associated equipment. The location of duct supports should be identical to the aircraft. The duct supports should be the same supports as designed and manufactured for aircraft use.

2.2.2.2 Test Requirements:

2.2.2.2.1 Pressures and Temperatures: To avoid personnel injury in event of a failure, the system test setup should be reviewed by responsible safety engineers and their approval secured. A schedule of pressure and temperatures should be established which will operate the system at the lowest possible energy level, to permit leakage inspection, minor support adjustments and observation of equipment operation.

The source of temperature and pressure may be insufficient to accurately follow the system changes. The desired degree of response to system changes should be determined during the formulationof the test program and suitable test facilities secured. The duct system integrity should be demonstrated by subjecting the total system (purchased equipment and duct) to a proof pressure of at least 1.5 times the normal working pressure. This test should be conducted using air at operating temperature. This test should be performed early in the test program to eliminate any possibility of testing a system which does not have sufficient safety margin.

2.2.2.2.2 Air Flow Rate: Air flow rates to be used during system testing should be compatible with the airplane air source. The air temperature and pressure associated with various air flow rates must be coordinated. The system should be subjected to the full range of air flows expected on the airplane system and also at the rates of change of air flow expected on the airplane system. The effect of changes in air flow rates and system modulation on ducts, duct supports and equipment should be observed.

2.2.2.2.3 Pressure and Temperature Cycling: The system shall be subjected to a pressure or temperature cycling test for a total number of cycles equivalent to the expected service life of the system. The choice as to whether to conduct these tests at constant pressure with varying temperature or at constant temperature with varying pressure depends primarily upon the type of thermal expansion provisions utilized. It should be noted that a temperature cycling test requires considerable more time to conduct than pressure cycling at constant temperature. Temperature cycling tests have previously been recommended for expansion bends as described in Para. 2.2.1.2.4.2.1.

2.2.2.2.4 Thermal Shock: The system shall be tested for the effect of thermal shock. The test shall consist of temperature cycling the complete ducting system based on the maximum thermal shock operation of the system. A temperature cycle shall consist of raising the temperature of the ducting system from a stabilized temperature to a specified higher temperature and held there until the temperature is stabilized, then cooled to the original temperature. The rate of temperature rise should be based on the corresponding airflow expected at this condition, and the number of cycles should be based on expected operation. A check of the system should be made at the completion of the test for malfunctions.

2.2.2.2.5 Simulation of Airplane Vibration: The simulation of airplane vibration as induced in a duct system and components is desirable, however, the simulated vibration, (frequency and amplitude) should be realistic and based on the best available vibration data and experience of comparable systems.

The simulation of airplane vibration on large ducting systems may be expensive and unrealistic due to differences in test setup support structure and actual airplane structure. The inclusion of equipment in the duct system will require induced vibration characteristics in order that the total system be compatible.

2.2.2.2.6 Simulation of Airframe Deflection: Airframe deflection data may be simulated on the system test. Airframe deflections at limit load which will affect duct system loading should be simulated. Tests may be conducted to simulate the amount, direction and frequency of deflection loading on the duct system and supporting brackets. These tests should be conducted with the duct system at normal operating pressure and temperature to insure that thermal expansion and internal duct air loads will be correctly simulated.

2.2.2.2.7 Duration of Tests: The actual time span for a duct system test can vary a great deal and depends upon the degree to which an airframe manufacturer desires to use the ground test setup.

Three time spans may be considered, Minimum, Normal, and Maximum. The Minimum time span would be the least amount of test time required to subject the system to one cycle of the system performance requirements and proof pressure test. The Normal time span would be the simulated airplane cycle of operation for a number of operating hours after conducting the system performance requirements and proof pressure test. The number of simulated airplane operating hours can be correlated to the overhaul period or warrantee period of the major mechanical equipment items of the duct system. The Maximum time span would be a test conducted on a duct system to determine the life expectancy of the ducts, supports, etc. The value of such a test is questionable, since the life span of a duct is quite long compared to the mechanical equipment operating life span, and since fatigue test results show a wide scatter.

The duct system qualification endurance test time should be based on the service span desired plus a margin of service. The service span may be considered system operating time in hours or cycles of operation. Test time to prove the duct system may be shortened by recognizing the factors which affect ducting life and concentrating a greater portion of test time on these factors. These factors, in general, are associated with transitions in air flow, pressure and temperature.

2.2.2.2.8 Leakage: The duct system allowable leakage must be computed from the known leakages of all components and joints in the total system. Leakage may be classified as to internal, external and control. Internal leakage is a factor in system operation and is generally associated with the leakage past valve port closures of purchased components. The internal leakage of such components should be determined from inspection tests. External leakage is associated with air lost from the system through duct joints, seals at duct connections to components, clearances around shafts and wear of shafts and seals.

Control leakage is associated with duct system components which use pneumatic control elements and require air "bleed-off" for proper control element operation.

The air used or lost for operation of control elements may be insignificant, however, when a total system leakage is being considered the accumulated control element bleed-off air should be accounted for in determining the total allowable system leakage.

2.3 Production Inspection Requirements: Inspection test requirements are presented for production components and for the installed system.

2.3.1 Duct Components or Assemblies of Components: Each unit shall be inspected for quality of materials, workmanship and conformance to the detail requirements set forth in this document. In addition, the following tests shall be performed:

a. Leakage Test per Para. 2.2.1.1.2.1.

b. Proof Pressure Test per Para. 2.2.1.1.2.2.

c. Any routine manufacturing tests which are required to ensure uniformity of the product and conformance with the approved design and detail requirements of this document.

2.3.2 Insulation: Each unit shall be inspected for quality of materials, workmanship and conformance to the detail requirements set forth in this document.

2.3.3 Installed System: The installed duct system should be inspected for the following:

a. Completeness of system, including components, and control elements.

b. Duct connections - inspect for proper torque, installation of gaskets, safety devices, insulation.

c. Ducting - inspect for damage due to handling, installation or improper clearance.

d. Ducting - inspect for acceptable alignment. Inspect support structure and ducting. Check movable type brackets for proper location in relation to system expansion.

e. Leakage - inspect the total system for leakage. Use ground air source at a pressure level considerable less than normal operating to aid in discovering points of excessive leakage. After repair of leakage points, the system should be pressurized slowly up to the proof pressure level with air at the normal operating temperature if possible.

f. System Operation - After duct system integrity and leakage has been checked, a system operational test should be conducted.

MEAN COEFFICIENT OF
THERMAL EXPANSION

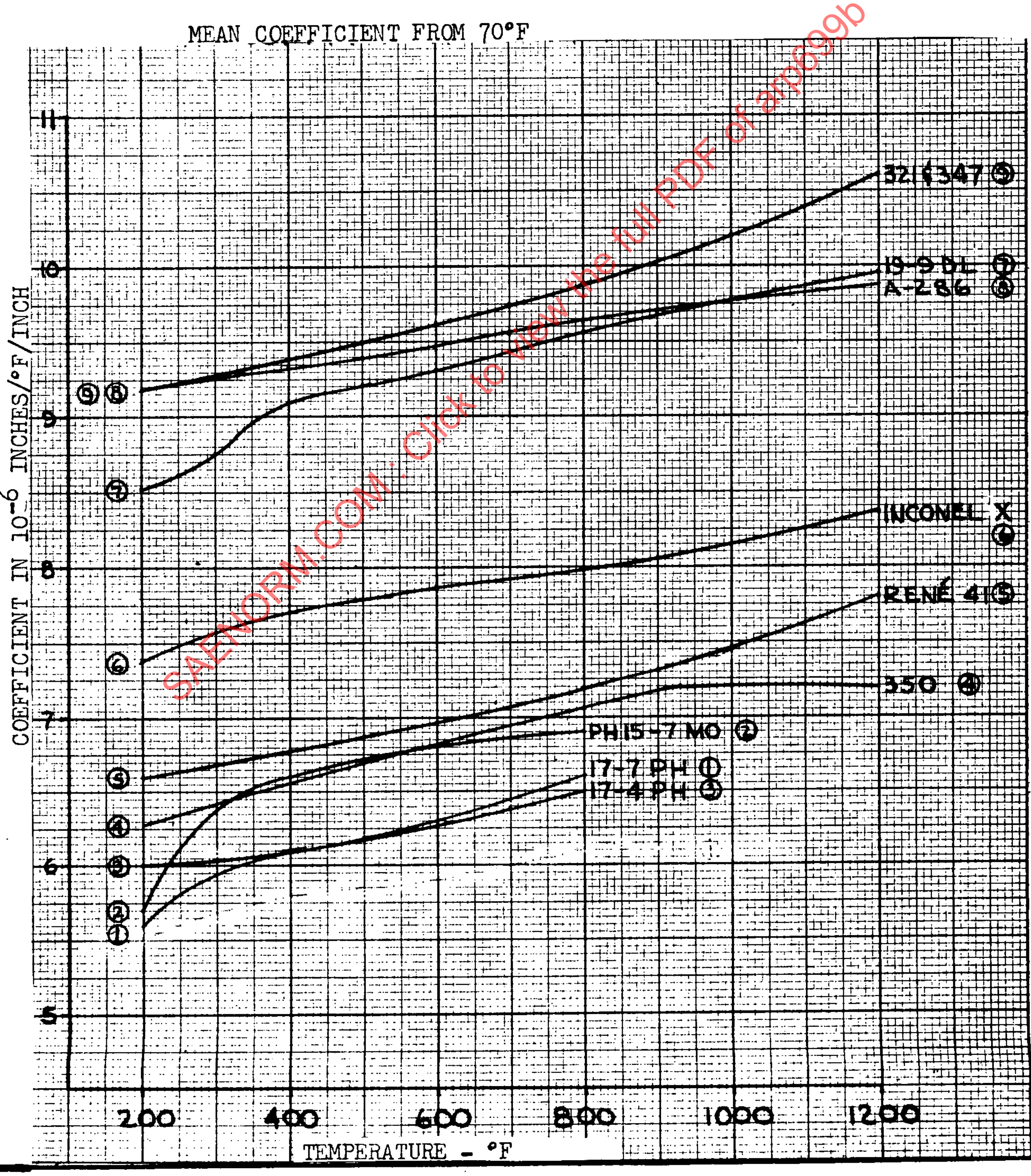


FIGURE 1

TENSILE YIELD STRENGTH

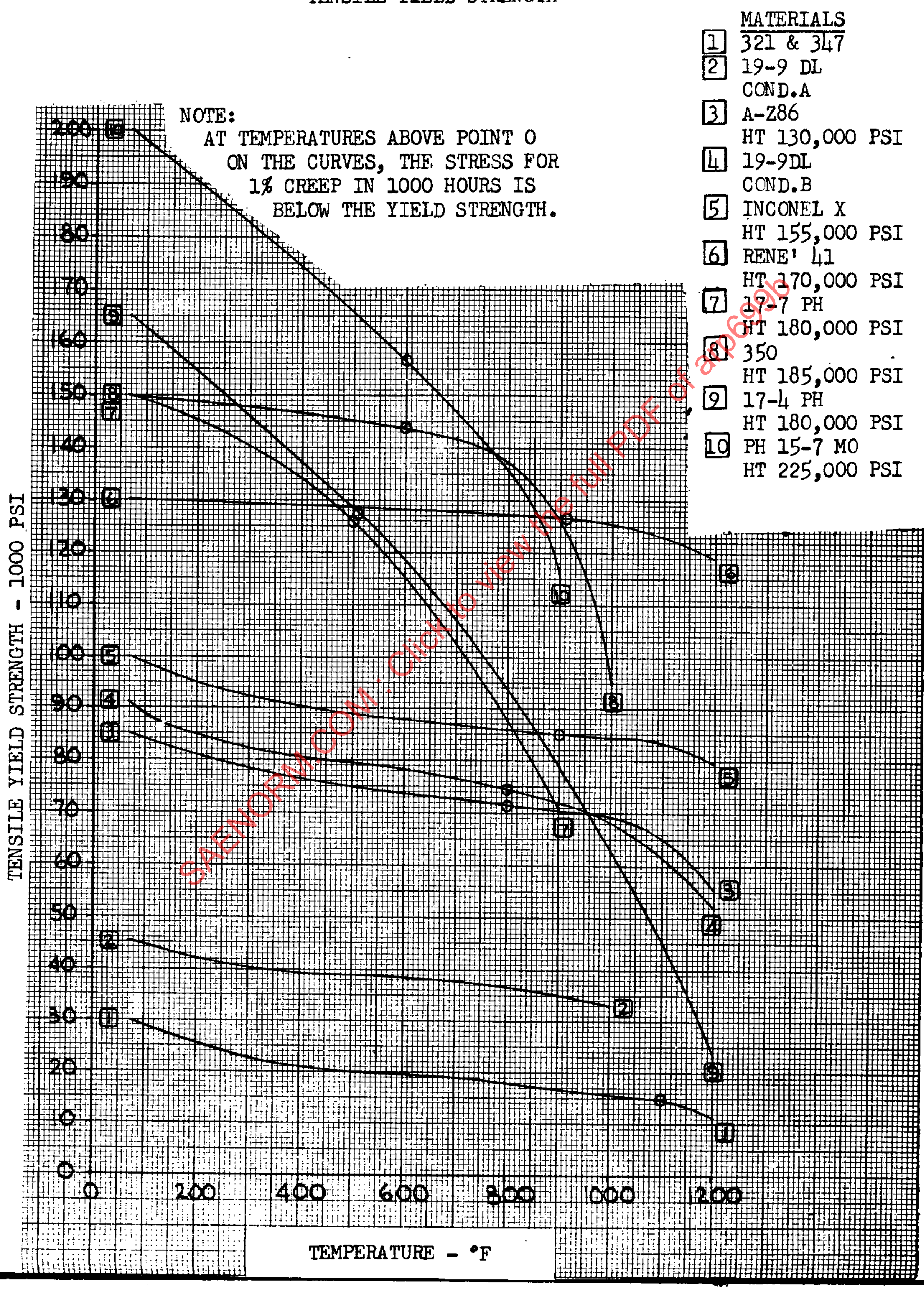


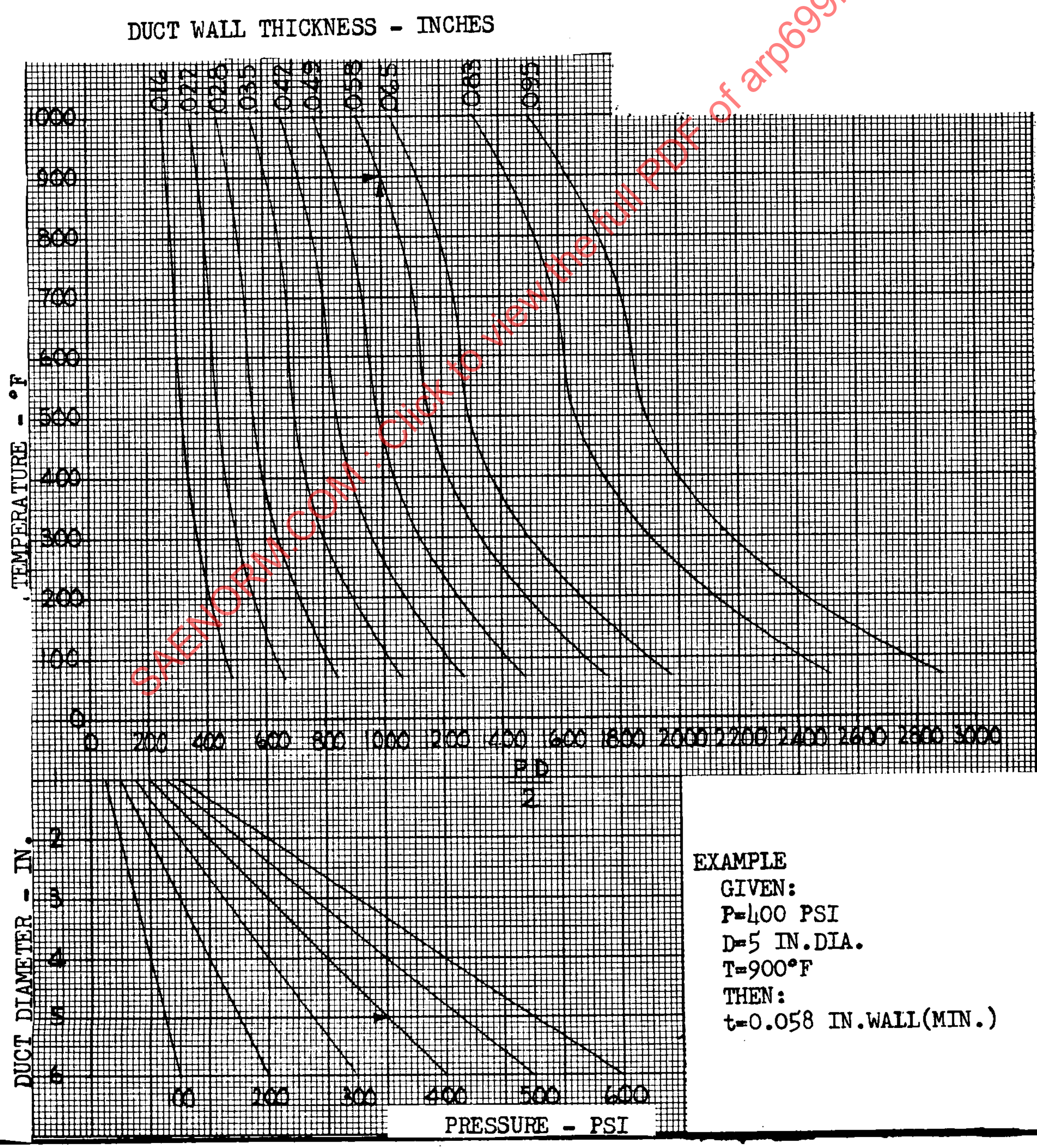
FIGURE 2

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE 321 & 347 STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS HAS NOT BEEN CONSIDERED.
4. EQUATION USED: $SH = \frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (IN.)
t = WALL THICKNESS (IN.)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.058 IN.WALL(MIN.)

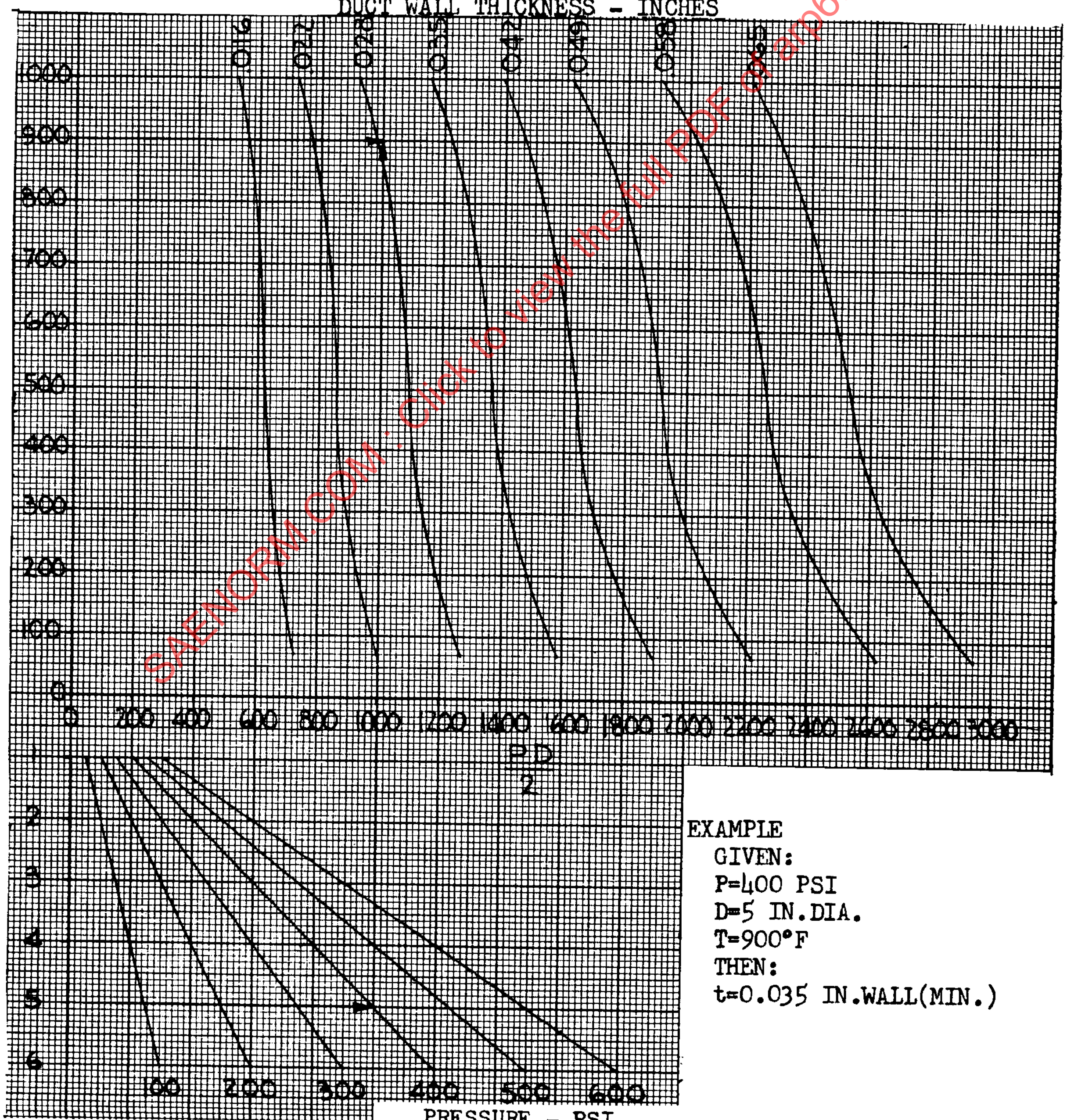
FIGURE 3

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE 19-9 DL(AMS 5538) COND.A STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS HAS NOT BEEN CONSIDERED.
4. EQUATION USED: $SH=\frac{PD}{2t}$ (HOOP STRESS).

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (IN.)
t = WALL THICKNESS (IN.)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.035 IN.WALL(MIN.)

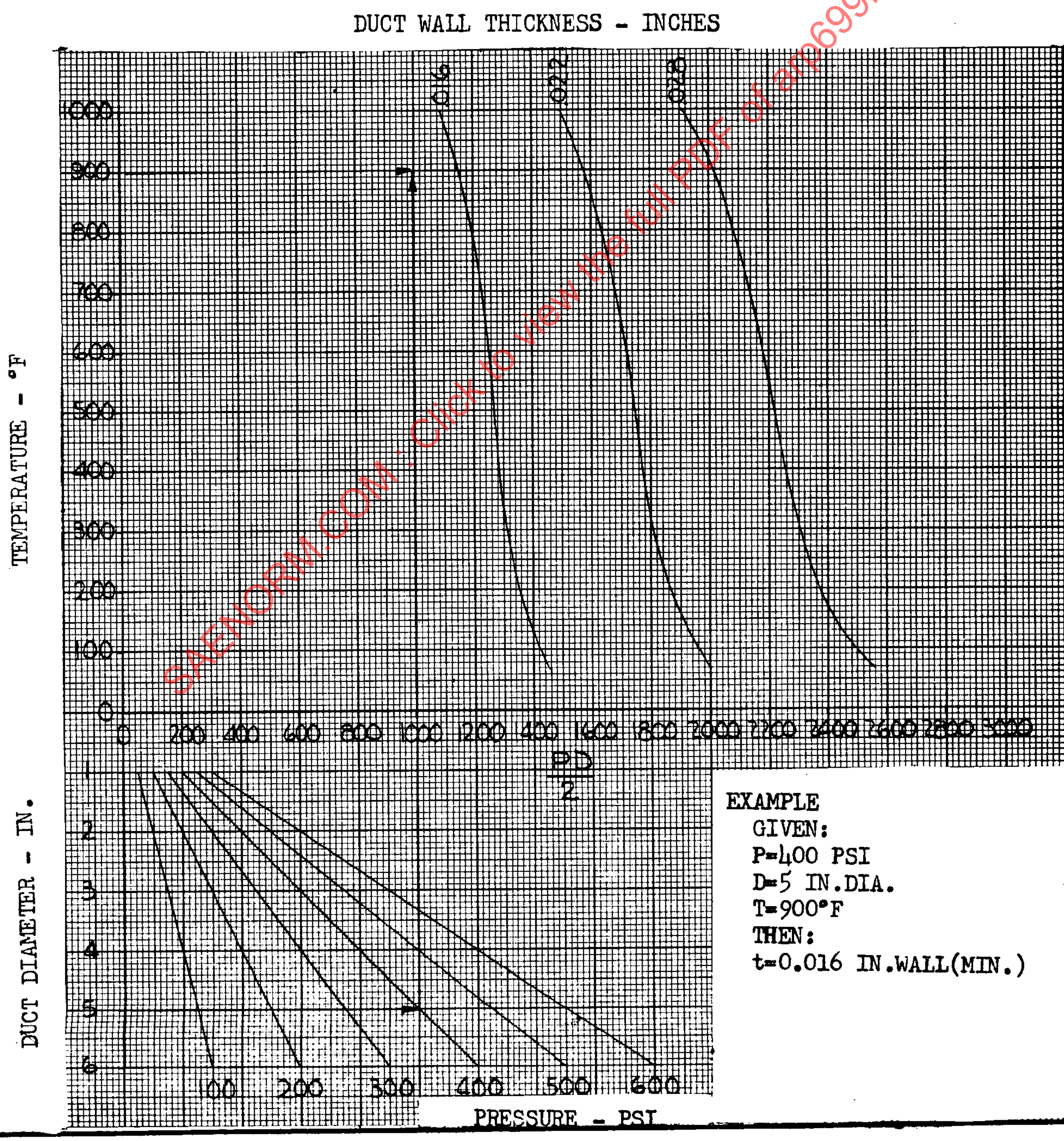
FIGURE 4

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE 19-9 DL(AMS 5539) COND.B STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS HAS NOT BEEN CONSIDERED.
4. EQUATION USED $SH=\frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCHES)
t = WALL THICKNESS (INCHES)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

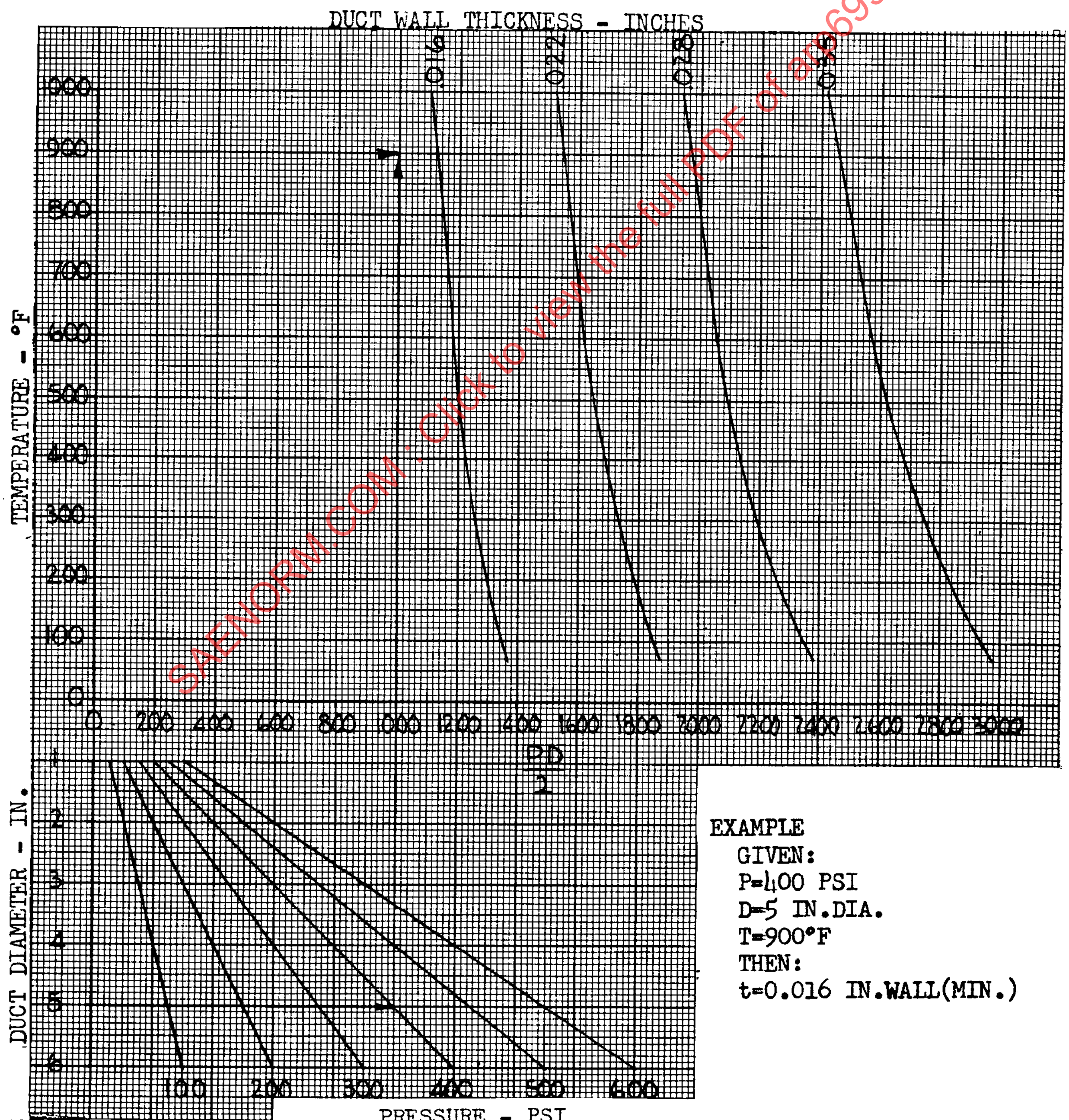
FIGURE 5

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE A-286 STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS DATA HAVE NOT BEEN CONSIDERED.
4. EQUATION USED: $SH = \frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCH)
t = WALL THICKNESS (INCH)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

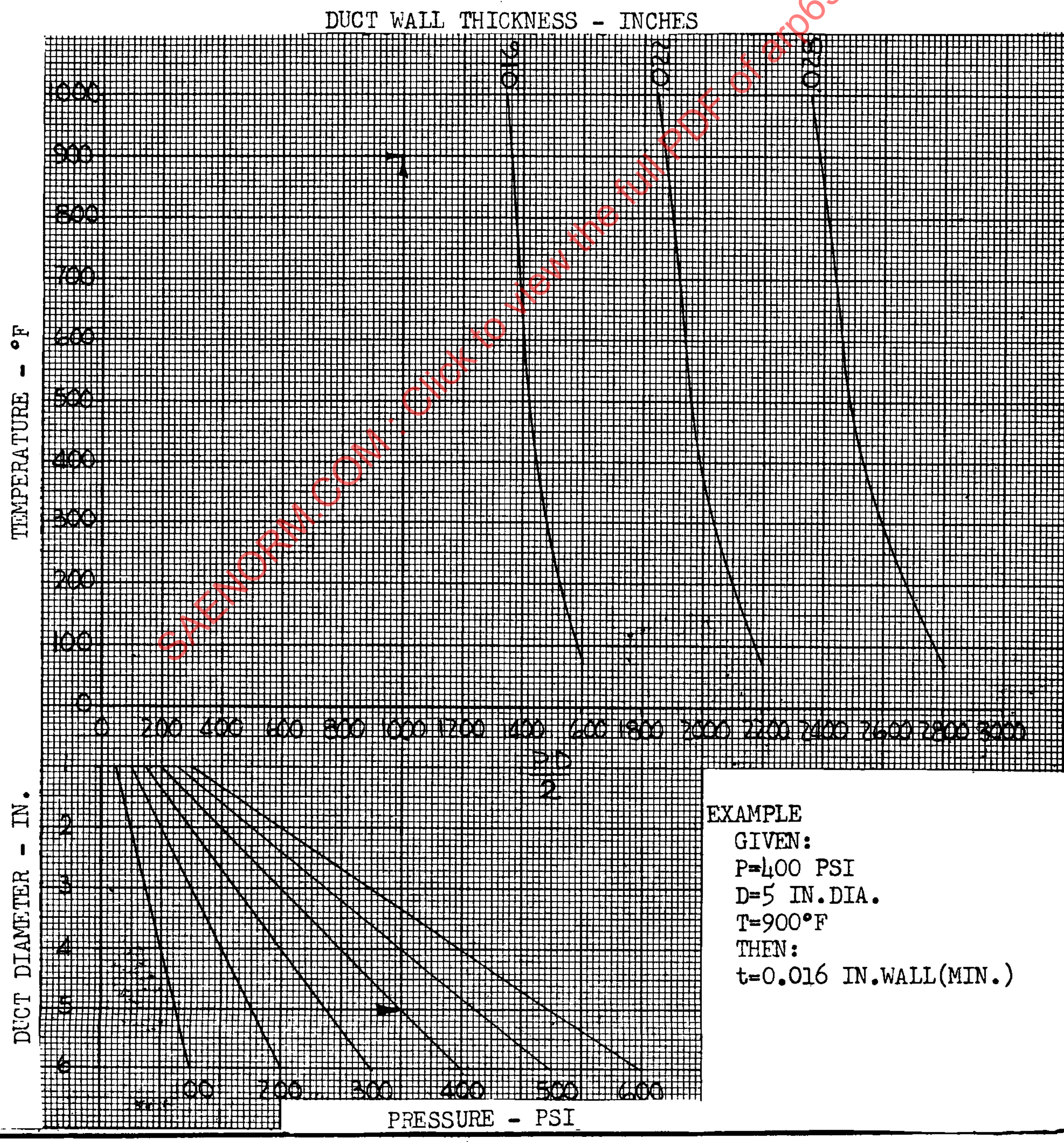
FIGURE 6

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE INCONEL X STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS DATA HAVE NOT BEEN CONSIDERED.
4. EQUATION USED: $SH = \frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCHES)
t = WALL THICKNESS (INCHES)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

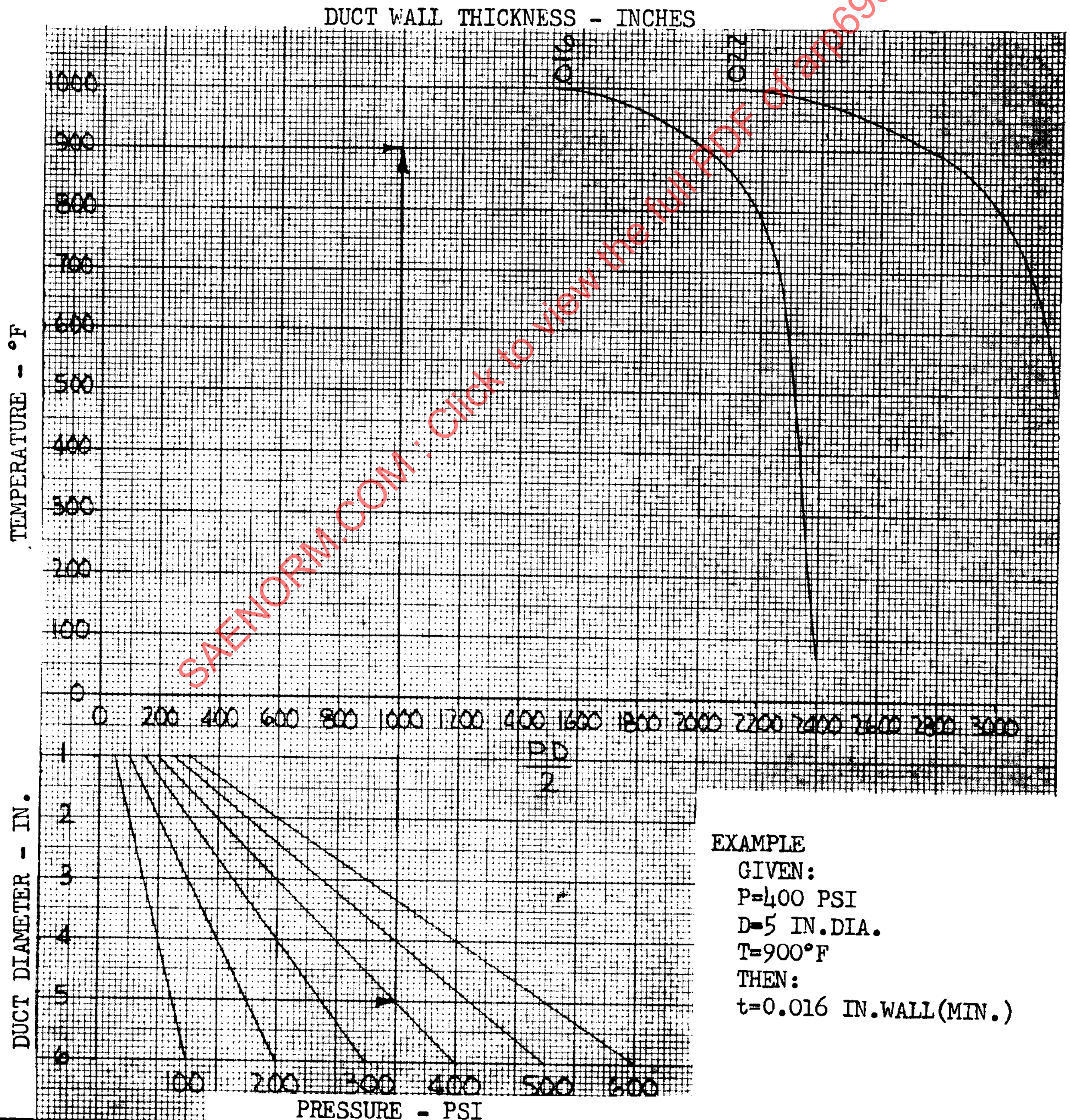
FIGURE 7

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE 350 STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS DATA HAVE NOT BEEN CONSIDERED.
4. EQUATION USED: $SH=\frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCHES)
t = WALL THICKNESS (INCHES)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

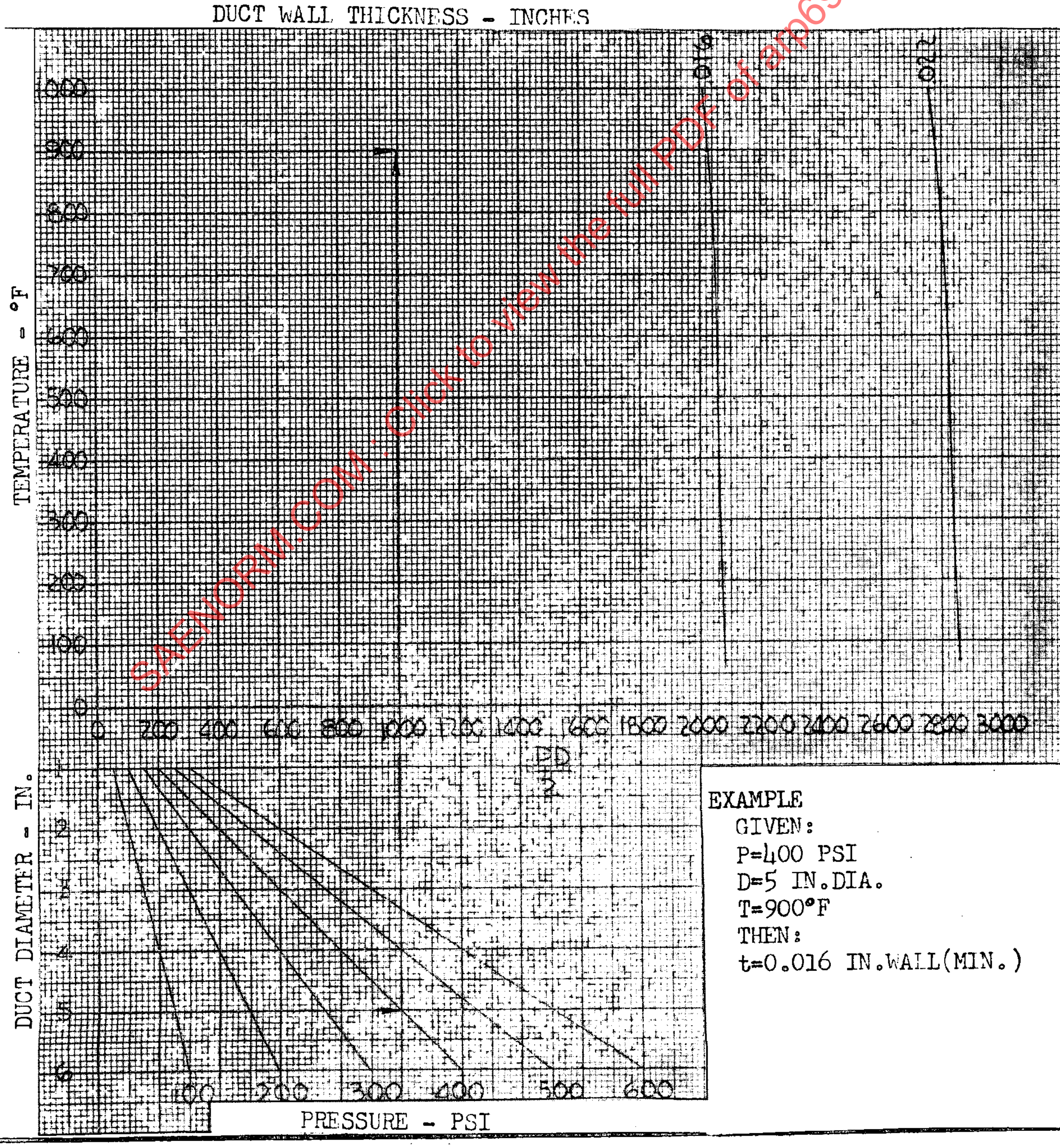
FIGURE 8

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE RENE 41 STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS HAS NOT BEEN CONSIDERED.
4. EQUATION USED: $SH = \frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCHES)
t = WALL THICKNESS (INCHES)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

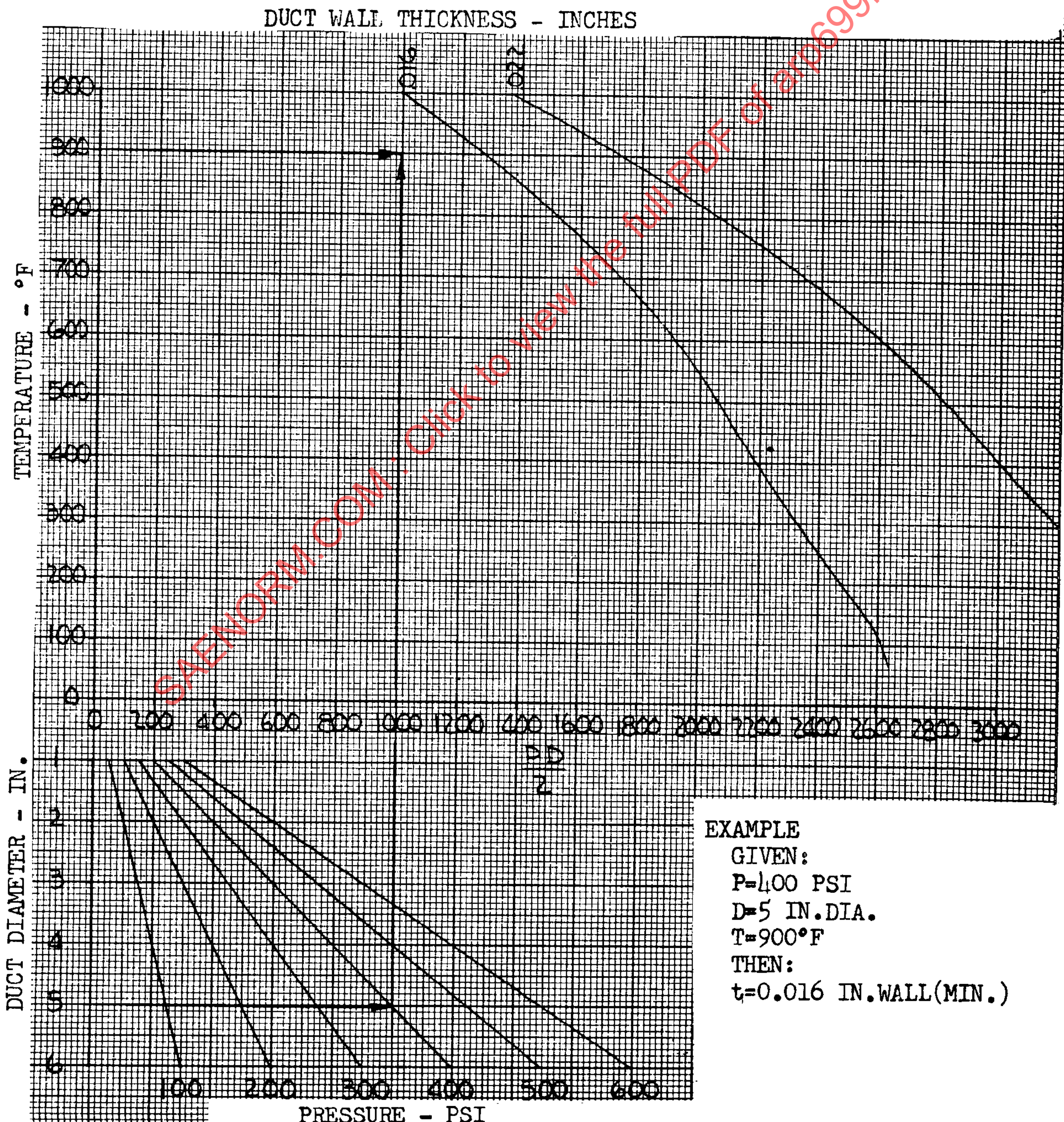
FIGURE 9

MINIMUM DUCT WALL THICKNESS
PROOF PRESSURE & TEMPERATURE
TYPE 17-4 PH STEEL

NOTES:

1. CURVES ARE FOR INTERNAL PROOF PRESSURE LOADS ONLY.
2. EXTERNAL LOADS MUST BE ACCOUNTED FOR INDEPENDENTLY.
3. CREEP STRESS HAS NOT BEEN CONSIDERED.
4. EQUATION USED: $SH=\frac{PD}{2t}$ (HOOP STRESS)

P = PROOF PRESSURE (PSI)
D = DUCT DIAMETER (INCHES)
t = WALL THICKNESS (INCHES)



EXAMPLE
GIVEN:
P=400 PSI
D=5 IN.DIA.
T=900°F
THEN:
t=0.016 IN.WALL(MIN.)

FIGURE 10