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AEROSPACE
RECOMMENDED
PRACTICE

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HIGH TEMPERATURE PNEUMATIC DUCT SYSTEMS FOR AIRCRAFT

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PURPOSE AND SCOPE

This Recommended Practice is intended to outline the design, installation, testing, and field maintenance criteria for a high temperature metal pneumatic duct system, for use as a guide in the aircraft industry. These recommendations are to be considered as currently applicable and necessarily subject to revision from time to time, as a result of the rapid development of the industry.

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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 restricts 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 movements of a bellows.

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

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

Cap, Pressure - A part which can be used to cover tightly the end of a duct to 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 ducts 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. The term generally implies flexible tubing with a length to diameter ratio (L/D) of three (3) or greater.

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 (thrust) 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.

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

Load, Limit - The maximum combined load due to all internal and external pressure 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 axes 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, Autogenous Ignition - That temperature at or above which a self-sustaining combustion of a critical volume of fluid will take place without the presence of an external source of ignition, such as a spark or flame.

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 temperature 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 temperature a duct will experience under all possible operating conditions.

Tension System - A duct 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.

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1. INSTALLATION CRITERIA AND LIMITATIONS:

1.1 Introduction: Employment of high temperature pneumatic ducts in modern aircraft entails the consideration of several requirements which may be encountered during operation, maintenance, and installation assembly. The requirements are as follows:

1.1.1 Structural Deflections: The aircraft structure on which the duct installation is mounted will usually deflect sufficiently to require a flexible duct 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: Duct materials under high temperature exhibit 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 ducts 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 minimum temperature, maximum temperature, and rate of temperature rise for thermal shock should be determined by analysis based on the expected areas of aircraft operation. Usually, the extreme condition occurs with ground operation following cold soak at the minimum design temperature.

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. A shutoff valve should be located as close as possible to each engine extraction air source to provide duct or system isolation.

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 on or supported by structure.

1.1.5 (Cont'd.):

- B. The duct 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 ducts are routed.
- C. In a compression system a slight misalignment of free bellows can impose large side loads on the duct supports. Instability of the duct 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 duct 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.
- F. The duct system should be designed to withstand handling and shipping loads.

1.1.6 Typical Duct Material: For typical corrosion resistant alloys available for use in high temperature pneumatic duct systems, refer to Section 2 for detail information.

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

1.1.6.1.1 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.

- 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).

1.1.6.2 Materials used in duct manufacture should be corrosion resistant to various aircraft fluids (such as hydraulic oil) with which the duct may come in contact.

1.1.7 Fluid Flow Considerations: Considerations of thermodynamic fluid flow should be given in the duct 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 duct design. Minimum resistance in the duct should be given prime consideration to prevent turbulence which could produce resonance resulting in fatigue failure. A bellows is one component which is susceptible to severe turbulence under high velocity airflow and should be of multi-ply construction to withstand the resonance of a liner (or equivalent device) to reduce turbulence. Liners are recommended for airflows 0.2 M and above.

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- 1.1.7.3 Assure that supersonic flow is not created in the ducting downstream from duct system components, such as a flow-limiting venturi.
- 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 When a pressurized high temperature duct is routed through or adjacent to compartments where combustible fluids are present, consideration should be given to the design of the pneumatic ducts and seals to keep surface temperatures below the autogenous ignition temperature (AIT) of the fluids. Figures 1 and 2 show the AIT of various aircraft fluids obtained in a Setchkin type test apparatus (constant-temperature method). These values represent compartment conditions of supersonic aircraft where the ambient temperature approaches the duct surface temperature. A ventilated compartment will dilute any combustible mixture present and minimizes fire hazard. The duct installation and aircraft operation will determine possible deviation from these test values. As can be seen from Figures 1 and 2, an increase in the compartment pressure lowers the AIT, increasing the fire or explosive hazard if combustibles are present. Air Force Aero Propulsion Laboratory Technical Report 71-86, dated November 1971, "Ignition of Aircraft Fluids By Hot Surfaces Under Dynamic Conditions," provides data on the ignition characteristics of various aircraft fluids under conditions in which they impinge upon a hot surface in the presence of air flow similar to that possible for bleed air ducting in an engine compartment.

The thermal limitations of adjacent components could become a functional safety hazard of the aircraft, especially 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 the lower temperature.

- 1.1.8.2 Reduction of surface temperature of the duct 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. The insulation or bonding material used must not form corrosive substances at any temperature to which it may be subjected. 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. The insulation material should be capable of withstanding the effects of vibration. Some airframe companies, for conservative reasons, design to maintain surface temperatures at least 50°F lower than shown on Figures 1 and 2.
- 1.1.8.3 High temperature must be considered in the design of support methods for the ducts 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

1.1.8.3 (Cont'd.):

provided between the support and structure if the temperature can exceed structural limits.

1.1.8.4 In order to reduce the hazards associated with routing high temperature bleed air throughout the aircraft, consideration should be given to incorporating means such as a precooler heat exchanger near the engine bleed ports to reduce the bleed air temperature to a safe level. Also, provisions should be incorporated near the bleed ports of each engine to reduce the operating pressure of the bleed air system to as low a level as possible without adversely affecting performance of the systems which use bleed air. When the bleed air ducting is routed so that leakage of high temperature air from ducting and components could cause damage to vehicle structure and adjacent components, or if the leakage could result in fire and explosion hazards, provisions to detect bleed air leakage should be incorporated. When a continuous length sensing element type of leak detector is incorporated along the ducting system, it should be designed to indicate a bleed air leak within five seconds when a one-inch length of the detector element is subjected to a hot-air blast that is 100°F above the nominal detector setting.

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 ducts and supports should be given consideration in the initial design stage. Thin wall duct and insulation cover materials are quite susceptible to damage from handling during manufacture, shipping, inspection, installation, and field maintenance. Use of a heavier wall duct 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 ducts, joint couplings, and seals are requirements that are important in the initial design of the duct system.

- A. Ducts, 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 and functional checks of the system should be made. Methods for leak and functional testing of the duct system should be considered early in the design, so that necessary fittings may be incorporated.

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1.1.9.3 (Cont'd.):

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 ducts 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 duct 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 ducts 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 duct system can be a serious safety problem, similar to the case of duct surface temperature in 1.1.8.1, if it is in the vicinity of combustible fluids, vapors, or low temperature limited components. Unless the duct system has a separate tunnel of its own, it is quite likely the duct 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. Assure that all compartments through which bleed air ducting passes are adequately protected against overpressurization in the event of a duct rupture.

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.

1.1.11 (Cont'd.):

- I. Report malfunctions 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. Guard 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 duct 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. Test on individual components at critical temperatures.
 - Proof pressure
 - Burst pressure
 - Fatigue
- B. Tests on complete mock-up system, or representative critical sections.
 - Cycling (pressure, temperature, movement, and thermal shock)
 - External induced loading
 - Proof pressure
 - Flow resonance
 - Leakage
 - Ultimate structural tests on critical areas
 - Vibration testing - suitable duct subsystems
- 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,

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1.2 (Cont'd.):

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 3) 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 duct must withstand the airplane inertia weight factors applied to the weight of the duct and be adequate to deflect the duct axially, in torsion, and in bending under the effects of airplane structural deflections and duct 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 duct. (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 3) 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 resultant thermal expansion are:

- A. Fixed duct supports which can withstand 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 duct 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.

AUTOGENOUS IGNITION
TEMPERATURE VS ALTITUDE

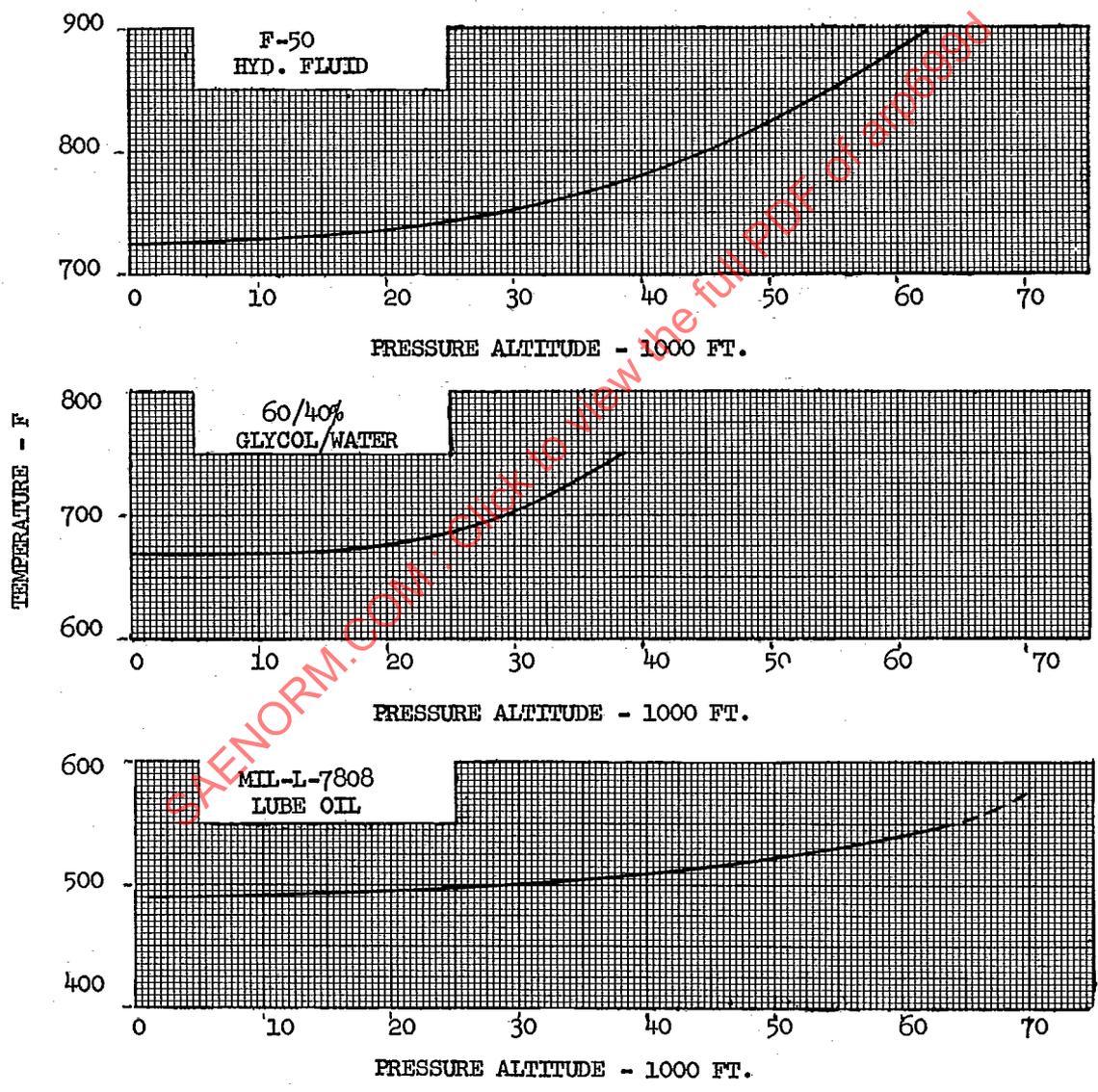


FIGURE 1

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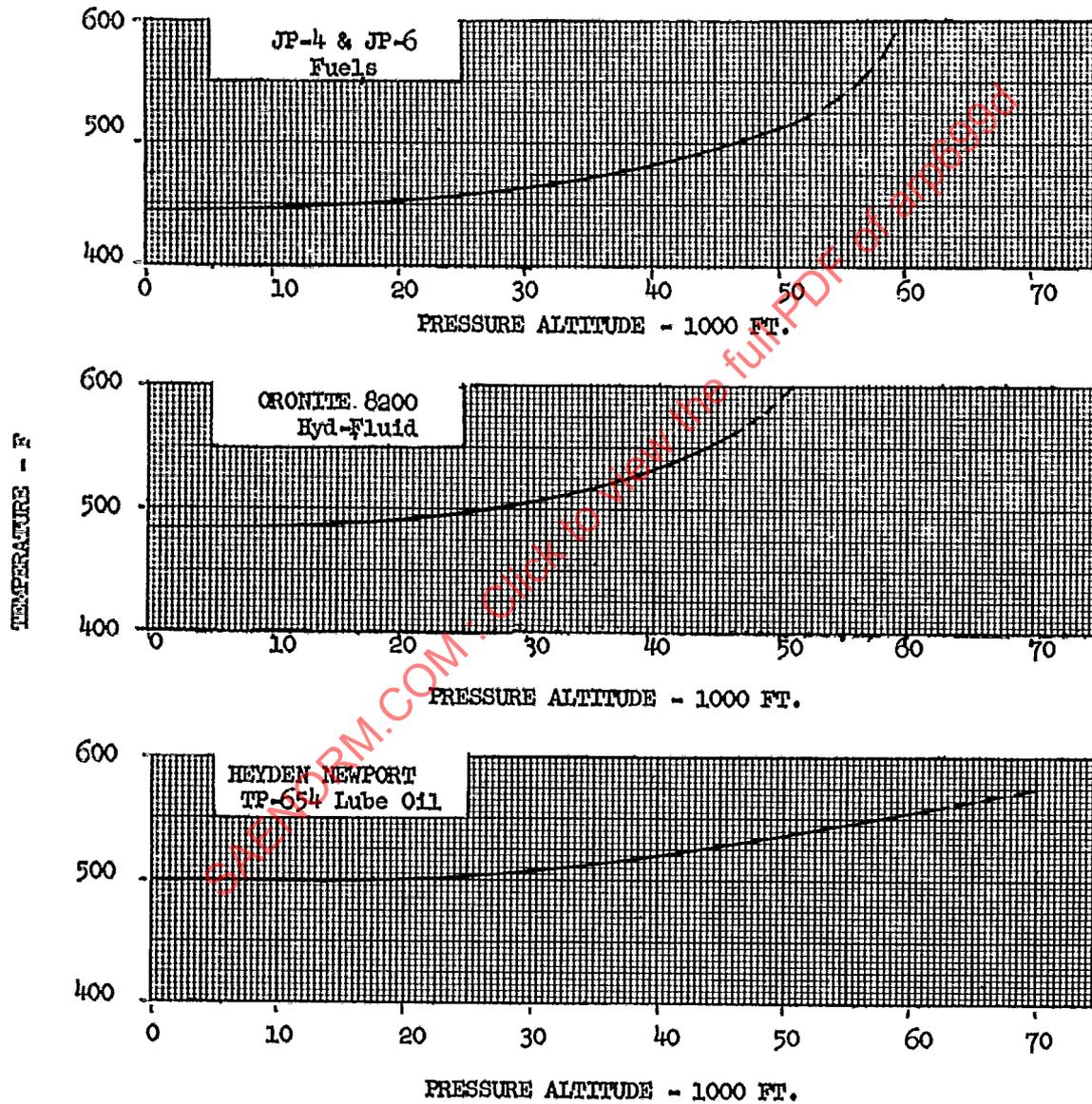
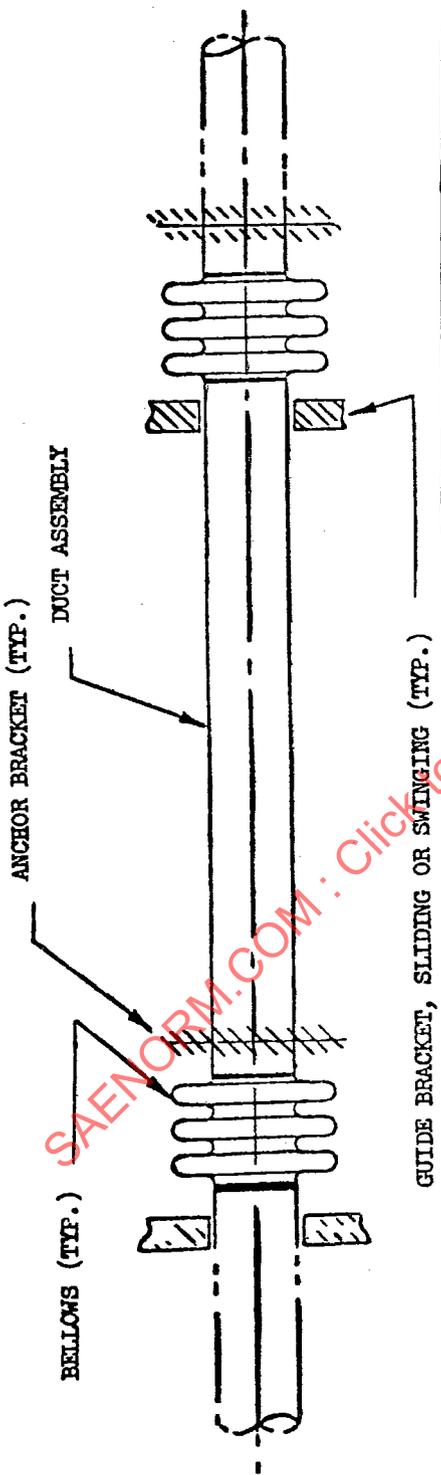
AUTOGENOUS IGNITION
TEMPERATURE VS ALTITUDE

FIGURE 2

ARP 699D

SCHMATIC - BASIC COMPRESSION SYSTEM



SCHMATIC - BASIC TENSION SYSTEM

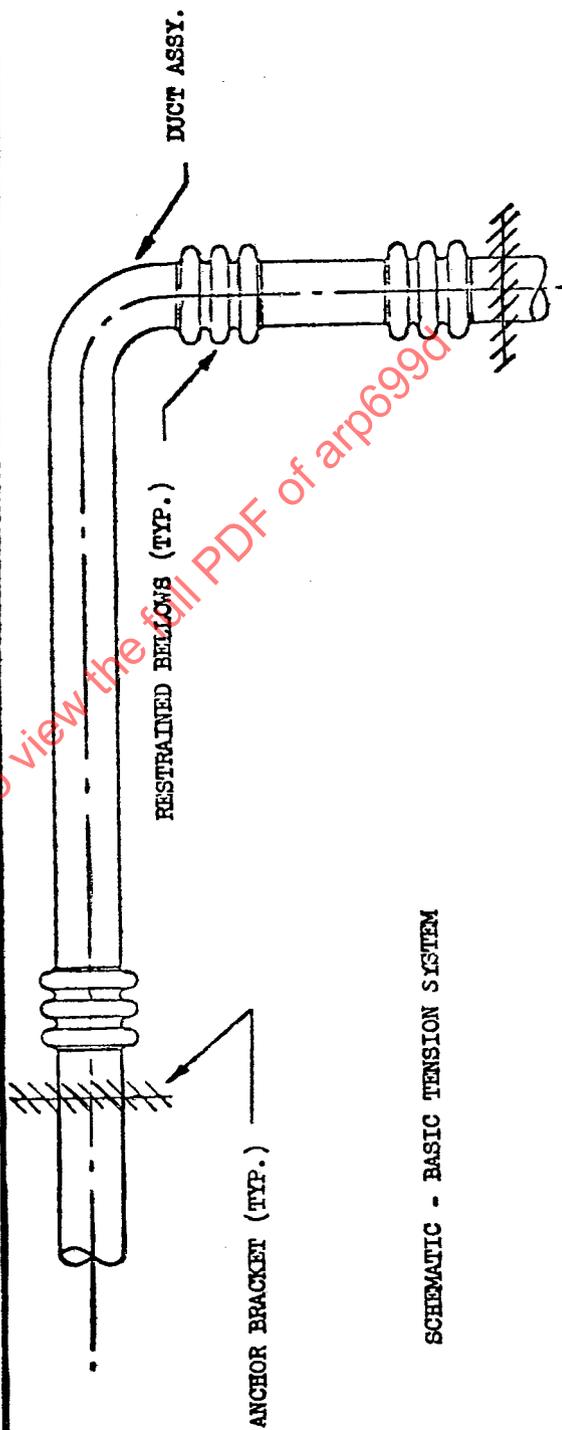


FIGURE 3

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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 ducts suitable for handling pressurized high temperature air.

2.1.1.1 Materials: Design information on these materials is presented in Figures 6 through 11 for the temperature levels shown:

Material	Maximum Continuous Operating Temperature (°F)	Comments
321/347	1600	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.
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.
PH15-7 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°F. Good corrosion resistance. Heat treatable. Over-ages above 1300°F.
Inconel 718	1300	May be welded, but must be heat treated. Formable mainly for use at 900 to 1300°F, where it is stronger than Inconel X-750. Specify Cond A (annealed) unless Cond B (coldworked) is required for higher strength.
Inconel X-750	1500	Comparable to A-286 except better strength in the range of 1200 - 1500°F. Good oxidation resistance to 1800°F.
Rene'41	1500	Higher strengths than Inconel X-750 with forming and welding somewhat more difficult than A-286 or Inconel X-750. Vacuum melted to retain hardening agents and therefore very expensive. Good oxidation resistance to 1800°F.

2.1.1.1 (Cont'd.):

CAUTION: Rubbing or chafing during installation of stainless steel ducts can result in corrosion pits on the duct OD. It is recommended that a high temperature coating be applied to the OD of stainless ducting (321/347, 21-6-9, PH 15-7 Mo, PH-7 Mo). A satisfactory coating would be Sermetel W (MIL-C-81751) or equivalent.

Material	Maximum Continuous Operating Temperature (°F)	Comments
AMS 4900	600	Commercially pure titanium, annealed, weldable, not heat treatable, except that for formed parts or fusion welded assemblies, stress relief must be specified. Primarily for applications requiring strength up to 400°F and oxidation resistance up to 600°F. Not to be electroplated.
AMS 4901	600	Stronger, but less formable than AMS 4900.
4A1-3Mo-1V	750	Use where high strength and oxidation resistance are required. Heat treatable. may be resistance welded but not fusion welded or electroplated. Difficult to form without cracking.
5A1-2.5Sn	800	Annealed. For fusion or resistance welding where strength exceeding that of commercially pure titanium is needed. Not heat treatable except that for formed parts or fusion welded assemblies, stress relief must be specified. Not to be electroplated. Difficult to form without cracking.
6A1-4V	750	Primarily for applications requiring weldability, ductility and good notch toughness. The material has attractive fatigue properties in both the annealed and aged condition. Heat treatable. Not to be electroplated. Difficult to form without cracking.
8A1-1Mo-1V	800	Use where best combination of elevated temperature, strength, stiffness, and toughness is required. Weldable. Not heat treatable. Stress relief after forming or welding must be specified. Not to be electroplated. Difficult to form without cracking.
PH14-8Mo	800	The material has strength properties at both room and elevated temperature. The outstanding advantages of this alloy are high strength coupled with high fracture toughness. The resistance of PH14-8Mo to stress corrosion is superior to that of PH15-7Mo.

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2.1.1.1 (Cont'd.):

Material	Maximum Continuous Operating Temperature (°F)	Comments
21-6-9	1000	The material combines high yield strength with good corrosion resistance. Room temperature yield strength of 21-6-9 is about twice that of 321/347. It is readily formable and can be welded by conventional welding methods. Corrosion resistance inferior to 321/347.
Inconel 625	1600	Good oxidation resistance to 1800°F. Good high temperature strength in the range of 700 - 1300°F. It is weldable and has normal formability characteristics.

NOTE: CAUTION! Use of unstabilized CRES for duct applications 800°F and above will result in carbide precipitation and intergranular corrosion.

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 4900	Titanium Sheet Commercially Pure
AMS 4901	Titanium Sheet Commercially Pure
AMS 4912	Titanium Sheet, 4Al-3Mo-1V
AMS 4910	Titanium Sheet, 5Al-2.5 Sn
AMS 4911A	Titanium Sheet, annealed, 6Al-4V
AMS 4916	Titanium Sheet, 8Al-1Mo-1V
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 (Type 19-9DL)
AMS 5528	Steel Sheet and Strip, Corrosion Resistant (17-7 PH)
AMS 5548	Steel Sheet and Strip, Corrosion and Moderate Heat Resistant (AM 350)
AMS 5595	Steel Sheet and Strip, Corrosion and Heat Resistant (21-6-9)
AMS 5599	Nickel-base Sheet and Strip, Corrosion and Heat Resistant (Inco 625)
AMS 5603	Steel Sheet and Strip, Corrosion and Heat Resistant (PH14-8MO)

2.1.1.2.1 (Cont'd.):

AMS 5520	Steel Sheet and Strip, Corrosion and Moderate Heat Resistant (PH15-7Mo)
AMS 5525	Steel Sheet and Strip, Corrosion and Heat Resistant (A-286)
AMS 5542	Alloy Sheet and Strip, Corrosion and Heat Resistant (Inconel X-750)
AMS 5545	Sheet, Strip and Plate, Corrosion and Heat Resistant (Rene'41)
AMS 5596	Alloy Sheet and Strip, Corrosion and Heat Resistant (Inconel 718)
MIL-STD-810	Environmental Test Methods for Aerospace and Ground Equipment
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
MIL-W-27664	Welding, Spot, Inert Gas Shielded Arc

2.1.1.3 Strength Requirements: The duct system should be structurally adequate to resist without rupture a burst pressure equal to the greater of the following:

- A. Burst pressure 2.5 times the gage pressure, with the component at the associated temperature for the most adverse pressure and temperature condition that occurs during normal operation.
- B. Burst pressure 1.5 times the gage pressure, with the component at the associated temperature for the most adverse pressure and temperature condition that occurs in the event of failure of an upstream pressure or temperature control device.

The duct system should be structurally adequate to resist without permanent deformation a proof pressure equal to the greater of the following:

- A. Proof pressure 1.5 times the gage pressure, with the component at the associated temperature for the most adverse pressure and temperature condition that occurs during normal operation.
- B. Proof pressure 1.1 times the gage pressure, with the component at the associated temperature for the most adverse pressure and temperature condition that occurs in the event of failure of an upstream pressure or temperature control device.

The most adverse condition is that combination of pressure and temperature which results in the highest ratio of stress to yield strength of the duct material. Where combined loads occur, detail design of the duct 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.

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- 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 Duct Reinforcements: Consideration should be given to the use of doublers at boss and bracket attachment points. When used, doublers or other reinforcements should be continuously welded all around to the basic duct. If large temperature differentials are encountered, consideration should be given to venting the entrapped area. Circumferential stiffening devices may be utilized to prevent collapse from external pressure. Duct wall pullout should be considered for boss attachment. Circumferential stiffening devices may be utilized for bracket attachment point.
- 2.1.1.3.4 Handling: Minimum wall thickness may be dictated by damage occurring during fabrication or handling. In this respect, the following minimum wall thicknesses are recommended:

<u>Duct Diameter, Inches</u>	<u>Minimum Wall Thickness, Inch</u>
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:

<u>Outside Diameter, Inches</u>	<u>Size Increments, Inch</u>
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. Allowance shall be made for connector leakage and seal type compensator device leakage.
- 2.1.2 Compensation Devices For Thermal Expansion: The deflection of a duct system during high temperature operation is normally absorbed by axial and/or angular deflection of bellows-type flex joints or, where configuration permits, by deflection of the ducting itself. Slip joints and rotary joints may also be used to accommodate duct deflection.
- 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 duct 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 12a. The stroke or deflection of a given bellows (constant convolute size and wall thickness)

2.1.2.1 (Cont'd.):

under load is similar to a helical spring (see Figure 12b). 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-ply, 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. CAUTION! Implosion of inner plies of a multi-ply bellows used in high temperature applications is possible unless voids between plies are free of moisture or are properly vented. Two bellows used in series between anchor brackets should have the same spring rate. Free bellows have a tendency to squirm under compression loads and duct supports must be adequate to restrain sidewise motions.

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 bellows length, although up to 40% has been successfully attained; however, fatigue life will be greatly reduced.
- B. Extension stroke: 10% of the bellows length, although up to 40% has been successfully attained; however, fatigue life will be greatly reduced.
- C. Angular deflection: ± 5 degrees, although ± 15 degrees has been successfully attained; however, fatigue life will be greatly reduced.
- D. Axial offset (if required): $\frac{.02L^2}{D}$ (Max), although $\frac{.25L^2}{D}$ has been successfully attained; where L = length of bellows and D = nominal duct diameter.
- E. Torsional deflection: Preferably none.
- F. Ratio of bellows length to inside diameter: Generally, 1/2 to 1-1/2; however, exceptions can be made.
- G. Convolution height: 7 to 13% of inside diameter. Increases in bellows length and convolution height over the values recommended above can create instability and a resultant tendency to squirm under applied load. The use of a liner, such as shown by Figure 13, will provide additional shear resistance and at the same time reduce vibration by high velocity flow. The liner should be designed to prevent damaging the bellows during installation or operation. Optionally, the use of a bellows under hoop compression, also shown in Figure 13, affords the same advantages as the liner plus external protection and elimination of instability. In the design of multi-ply bellows, the elimination of moisture or air entrapped between the plies is mandatory.

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2.1.2.1.2 (Cont'd.):

Although a permissible axial offset is indicated in (D), any offset should be avoided if possible. Axial offset induces an additional stress in the convolution which can cause premature failure.

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. Minimum inside diameter.
- D. Maximum outside diameter.
- E. Type of ends and total overall length of the unit. If alignment of the end fittings is critical, an angular tolerance should be specified.
- F. Pressure (working, proof and burst), temperature (maximum, minimum and ambient), and the most critical combination of temperature and pressure.
- G. Maximum rate of pressure and temperature change.
- H. Axial deflection (compression and extension).
- I. Angular deflection.
- J. Axial offset.
- K. Vibration requirements (frequency, amplitude).
- L. Maximum flow conditions and allowable pressure drop.
- M. Minimum life cycles.
- N. Qualification test requirements (to include method of duct support).
- O. Production test requirements.

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 duct moves. The most common types, as shown in Figure 14, 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 14 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 16. 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 external restraint is shown in Figure 14 and 15. A variation of a tie-rod flex-section is one commonly referred to as "ball-strut," or "ball and socket" tie-rod. In this approach, the tension load between the internal tie rods is taken by a load-carrying ball usually of proprietary design. This approach can be used for higher pressure and temperatures, or where the angulation is beyond that which can be accommodated by the more conventional U-pin of tie-rod design.
- 2.1.2.2.3 Ball Type: The ball joint shown in Figure 5 provides angular deflection in any plane in the same manner as the gimbal type. An advantage of this type is the external ball-socket minimizes leakage in the event of bellows failure. The higher bending moment of the ball joint is sometimes offset by the use of a bearing system in the ball socket.
- 2.1.2.2.4 Hinge Type (Single Plane): The hinge joint provides angular motion in a single plane only and thus absorbs loading in the axis normal to the plane of motion. Use of hinge joints therefore improves the stability of the duct system under dynamic conditions and permits reduction in duct supports.
- 2.1.2.2.5 Braided Bellows: The use of an external braid on a bellows has been a long-accepted method of providing restraint. However, high bending moment at pressure and limited motion and cycle life restrict the use of braided bellows to primarily that of accommodating installation misalignment and/or low pressure applications.
- 2.1.2.2.6 Normal Design Practice: The following criteria should be observed for best results in the application of restrained bellows:
- A. Angular deflection: ± 5 degrees, although ± 15 degrees has been successfully attained; however, fatigue life will be greatly reduced
 - B. Axial offset: None.
 - C. Length of bellows: As required to limit compression and extension to 10% of the convoluted length during angular deflection.
 - D. Torsional deflection: Preferably none.
- 2.1.2.2.7 Statement of Design Requirements: Applicable information from 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 16, 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. Figure 4 shows a

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2.1.2.3 (Cont'd.):

compensating joint incorporated in a duct elbow. Bellows are used for seals in high temperature, high pressure applications (1000°F at 450 psig). Sliding seals are used to replace the bellows for lower pressure and temperature applications up to 60 psig at 450°F. This configuration reduces the maximum outside diameter of the component appreciably for the same amount of stroke. However, a leakage rate of .010 scfm (max) per inch of duct diameter is inherent in the sliding seal.

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PRESSURE COMPENSATING ELBOW

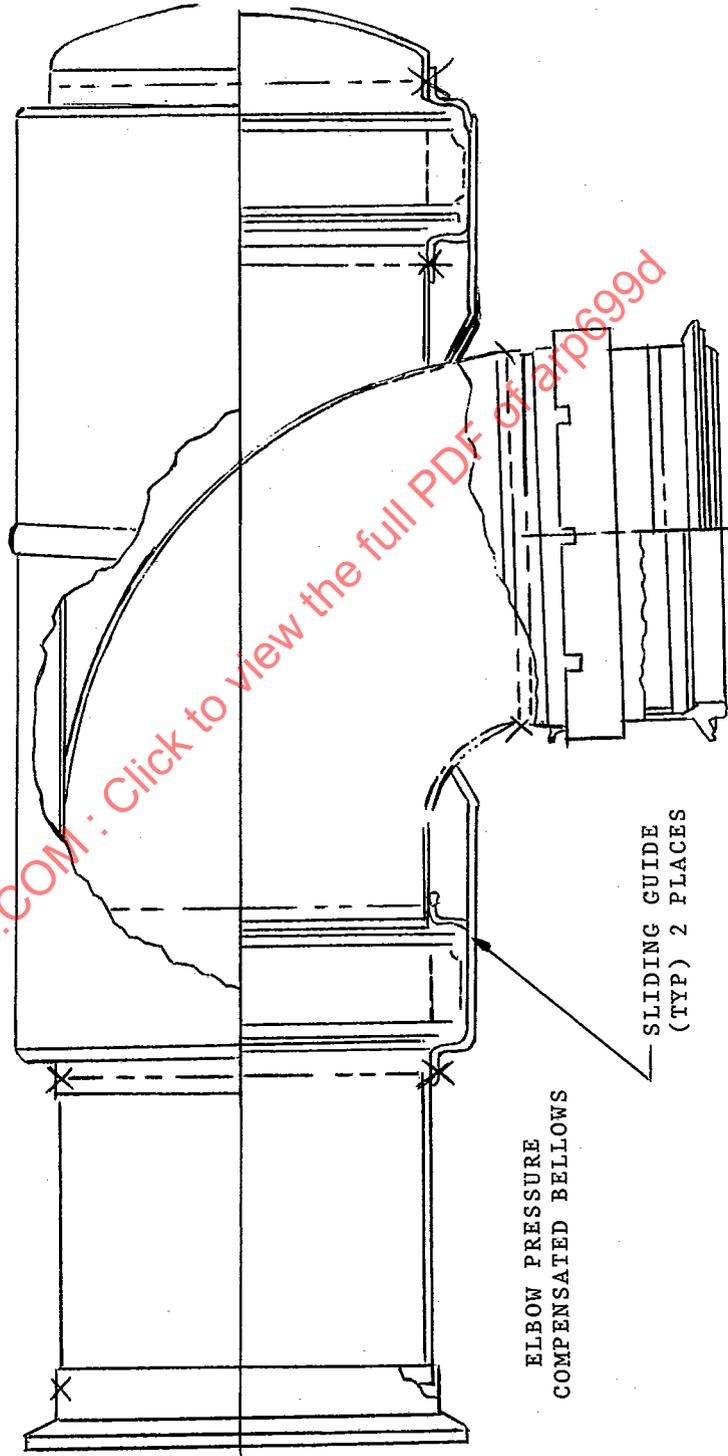
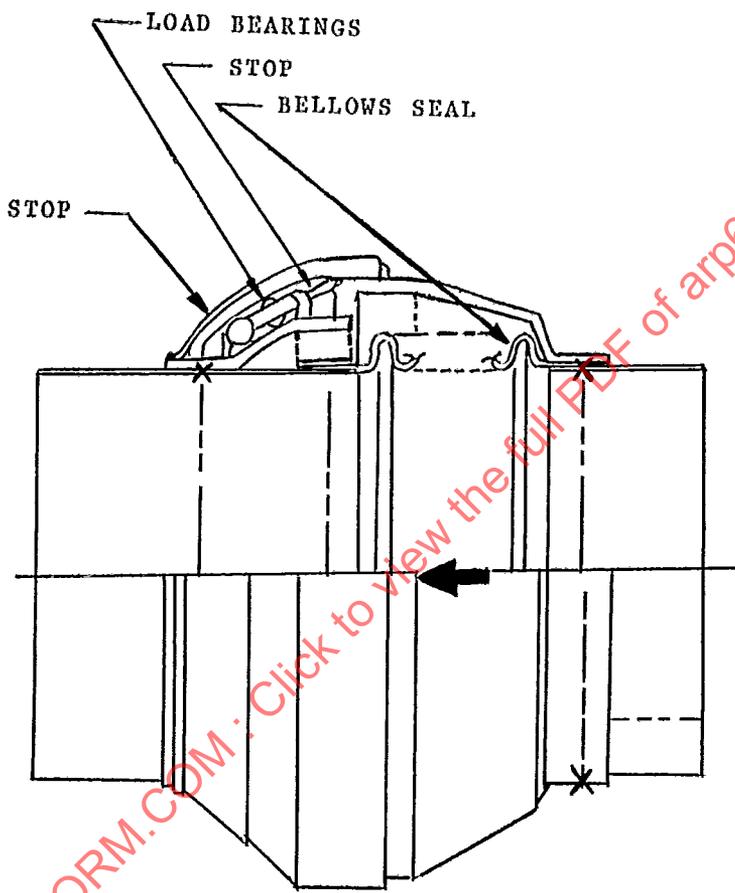


FIGURE 4



BALL JOINT

FIGURE 5

- 2.1.2.3.1 Normal Design Practice: The following design criteria should be observed for bellows type compensating joints:
- A. Compression stroke: 10 to 15% of the total bellows live length, although up to 40% has been successfully achieved; however, fatigue life will be greatly reduced.
 - B. Extension stroke: 10% of the total bellows live length, although up to 40% has been successfully achieved.
 - C. Angular deflection: Preferably none.
 - D. Axial offset: None.
 - E. Torsional deflection: Preferably 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 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 Compensating Joint, Seal Type: This device shown in Figure 18 is similar to the bellows type compensating joint except it utilizes seals rather than bellows for sealing purposes. This permits almost unlimited axial stroke capability with minimum actuating force. Seals, usually of proprietary design, are non-metallic, thereby limiting use of this device to applications below 700°F. The design accommodates unlimited torsional deflection. Normally, over-compensation is not required as there is no spring rate to overcome in this design.
- 2.1.2.4.1 Normal Design Practice: The following design criteria should be observed for seal type compensating joints:
- A. Axial stroke - Limited only by available envelope.
 - B. Angular deflection: None.
 - C. Axial offset: None.
 - D. Torsional deflection: Unlimited.
- 2.1.2.4.2 Statement of Design Requirements: Applicable information from 2.1.2.1.3 should be specified as needed for compensating joints. The following additional requirements are usually necessary:
- A. 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.
 - B. Mounting details (in case of support bracket).
- 2.1.2.5 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 20. 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.

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2.1.2.5 (Cont'd.):

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

C. An omega has two and a half 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 2.1.1.3 for strength requirements applicable to ducts used in expansion bends.

2.1.2.6 Slip Joint: The slip joint shown in Figure 19 absorbs duct expansion by means of linear motion similar to that of a telescoping joint. It should only be used in a compression system.

Relatively large axial motion is possible within a fairly small envelope and with a low actuating force. Because of pneumatic loading, this unit must be supported and used in the same manner as a free bellows. It is limited to pressure and temperature applications up to 60 psig at 450°F.

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 21 will allow for thermal expansion in a duct system, provided certain design and installation practices are observed. Figure 23 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 duct 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 running 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 Deflections, 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 the duct. Nonmetallic type joints are capable of absorbing a small amount of torsional deflection in the pressure and temperature range for which designed. For higher temperatures requiring bellows type joints, a gimbal type joint is recommended to avoid torsion load on the bellows.

- 2.1.3.2 Installation Tolerances: The braided bellows provides a simple means of compensating for angular and offset misalignment during installation of the duct 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 2.1.6.1.4.
- 2.1.4 Duct Coupling Requirements: A coupling is considered to be an assembly of all parts required to join two pieces of duct together, such as shown in Figures 24 and 25. 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's integrity and continuity without experiencing permanent deformation when subjected to loads or combination of loads caused by the following conditions:
- A. High temperature - Maximum flange to clamp transient differential temperature should be considered in the coupling design, especially for large diameter and high temperature.
 - B. Low temperature.
 - 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 coupling should be designed to withstand repeated applications of bending loads without any damage and without exceeding the allowable leakage specified in 2.1.4.2. Couplings are generally weaker in bending than the basic duct for lightweight aircraft systems and maximum bending load plus pressure load must be known.
 - F. Torsion - The coupling should be designed to withstand repeated torsional loading without any damage and without exceeding the leakage specified in 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-STD-810 or equivalent specification noted on the applicable drawing.
- 2.1.4.2 Allowable Leakage: For bleed air system couplings, the maximum allowable leakage per coupling should not exceed 0.01 CFM of standard air per inch of duct diameter. Ram air system couplings often allow 5-10 times more leakage.
- 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 on the following page.

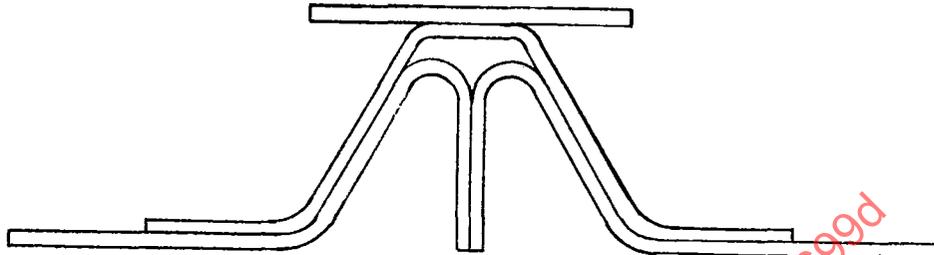
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- 2.1.4.3.1 Structural Safety Device: These measures are effective only if the safety device is in parallel with the weakest element of the coupling in hoop tension (usually the tee bolt).
- 2.1.4.3.1.1 Add an additional coupling strap over the tee 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 ratchet tang which will engage a slot in the coupling band and maintain joint integrity in the event of tee bolt failure.
- 2.1.4.3.1.3 Add a secondary bail or link which will engage a slot in the coupling band and maintain joint integrity in the event of the bolt failure.
- 2.1.4.3.2 Visual Device: The added coupling strap of 2.1.4.3.1.1 will act as a visual device since the strap will not conform to the "safetied" contour if the tee bolt fails.
- 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. It should be noted that angular misalignment will induce bending loads in the coupled joint.
 - 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 Joints:

Type "A".

Materials: Corrosion resistant steel.Tools to Install: Wrench, torque type if torque device not provided.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: 405 psig or greater at room temperature with no bending load for sizes 1 inch through 3 inches diameter. For sizes 3 inches through 6 inches, the maximum operating pressure decreases as diameter increases. Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M in.-lbs.

Maximum Operating Temperature: The use of special materials permits operating temperatures to 1200°F.

Remarks:

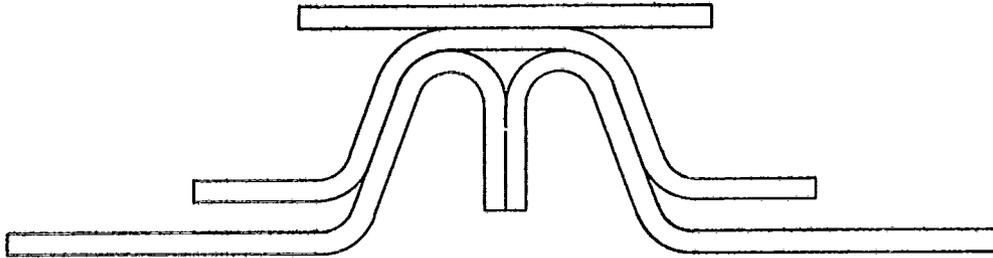
- A. Available with fail-safe feature.
- B. V-Band coupling indexes flanges on skirt of flange.
- C. For pressures, temperatures and diameters in excess of the above, contact the supplier for changes in material and thicknesses.
- D. Available in titanium at reduced temperature and pressure conditions. Contact supplier for detail information.

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2.1.4.6.1 (Cont'd):

Type "B"



Materials: Corrosion resistant steel.

Tools to Install: Wrench, torque type if torque device not provided.

Duct Sizes: 1 inch through 8 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 8 inches diameter, maximum pressure decreases as diameter increases. Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M in.-lbs.

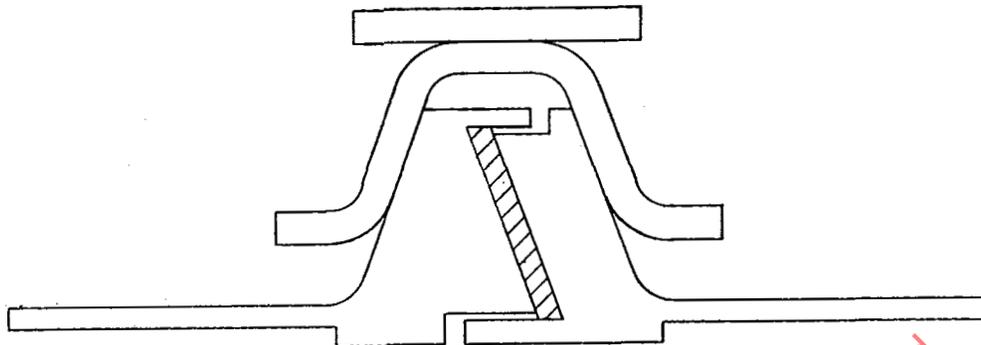
Maximum Operating Temperature: The use of special materials permits operating temperatures to 1200°F.

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.
- D. For pressures and temperatures in excess of the above, i.e., 300 psi and/or 1200°F, contact the supplier for changes in material and thicknesses.
- E. Available in titanium at reduced temperature and pressure conditions. Contact supplier for detail information.

2.1.4.6.1 (Cont'd):

TYPE "C"



Materials: Corrosion resistant steel, metallic gasket.

Tools to Install: Torque wrench.

Duct Sizes: 1 inch through 5 inches diameter in 0.50-inch diameter increments. Some sizes available in 0.25-inch diameter increments.

Maximum Operating Pressure: 500 psig or greater at room temperature with no bending load for sizes 1 inch through 3.50 inches diameter. For sizes 4 inches through 5 inches, maximum operating pressure decreases as diameter increases. Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment

M in.-lbs.

Maximum Operating Temperature: The maximum operating air temperature for all sizes is 1200°F.

Remarks:

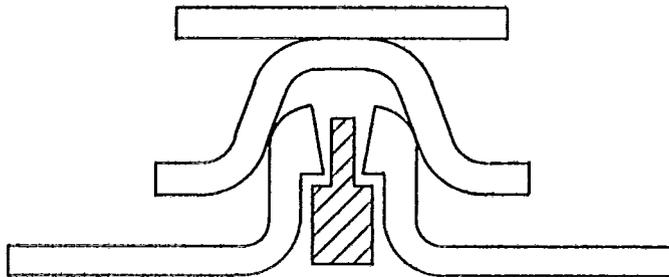
- A. Available in medium duty series to 12 inch diameter for high bending loads with operating pressures 66% greater than shown. Various types of gaskets available depending on temperature.
- B. For pressures and temperatures and diameters in excess of the above, contact the supplier for changes in material thickness.
- C. Individual duct removal restricted.

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2.1.4.6.1 (Cont'd.):

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 diameter increments from 1 inch to 6 inches and 1-inch diameter increments from 6 inches to 12 inches. Some sizes available in 0.25-inch diameter 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. Also reduce operating pressures by $\frac{16M}{D^3}$ to allow for maximum applied bending moment M in. lbs.

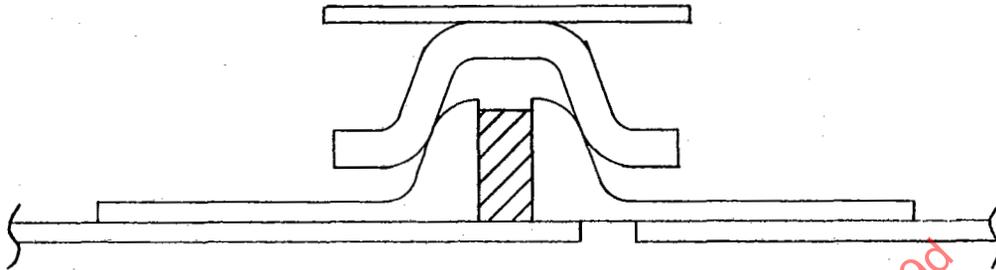
Maximum Operating Temperature: The maximum operating temperature for all sizes is 1000°F.

Remarks:

- A. Various type gaskets available depending on temperature.
- B. For pressures and temperatures in excess of the above, i.e., 300 psig and/or 1000°F, contact the supplier for changes in material and thicknesses.
- C. Individual duct removal restricted.

2.1.4.6.1 (Cont'd.):

TYPE "SPECIAL"



Material: Corrosion resistant steel.

Tools to Install: Torque wrench.

Duct Sizes: As required.

Maximum Operating Pressure: Consult manufacturer.

Maximum Operating Temperature: Consult manufacturer.

Remarks:

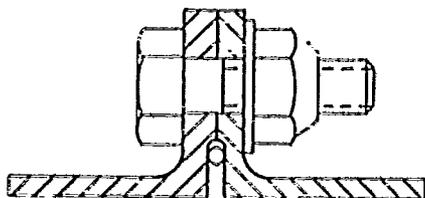
- A. Typical machined flanges.
- B. Pressures and temperatures dependent on gasket used. Generally requires heavy clamp to generate sufficient gasket load for sizes over 2 inch.
- C. Infinite number of special shapes available to customer specification.
- D. Individual duct removal restricted.

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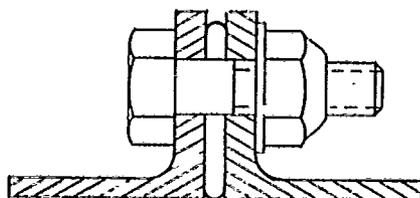
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2.1.4.6.2 Bolted Joints:

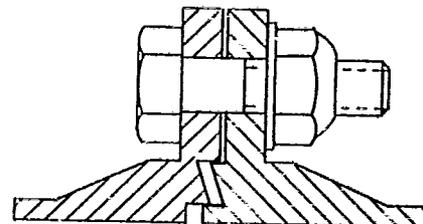
TYPES "A", "B", AND "D".



TYPE "A"



TYPE "B"



TYPE "D"

Materials: Corrosion resistant steel.Tools to Install: Torque wrenches.Duct Sizes: Type "A" joints are available in the following sizes: 1.75", 2.50", 2.75", 3.50", 4.00", 4.50", 5.00".

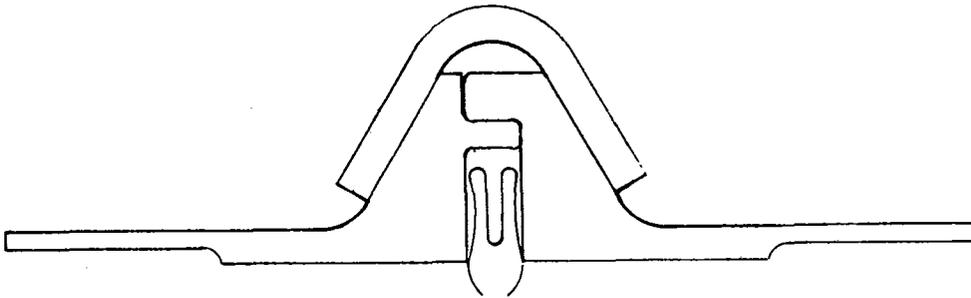
Type "B" joints are available in 2" and 3" sizes.

Type "D" joints are available in same sizes as type "A" plus sizes to 12 inch diameter in 1-inch diameter increments.

Maximum Operating Pressure: 205 psig for all sizes of types "A" and "B". See page 38 for pressures applicable to type "D". Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M in.-lbs.Maximum Operating Temperature: 750°F for all sizes of types "A" and "B". See page 38 for the temperature applicable to type "D".Remarks: Maximum operating temperature is 750°F when steel gaskets are used with types "A" and "B".

2.1.4.6.2 (Cont'd):

"FORGED TYPE" AND "WROUGHT TYPE"



Materials: Inconel and A-286.

Tools: Torque wrench.

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

Maximum Operating Pressure: 460 psig for all sizes. Also reduce operating pressure by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M in. lbs.

Maximum Operating Temperature: 1125°F for all sizes.

Remarks:

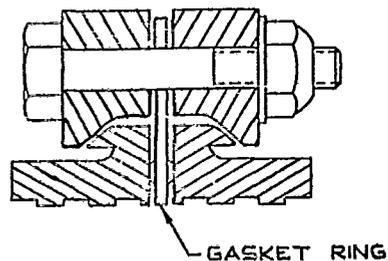
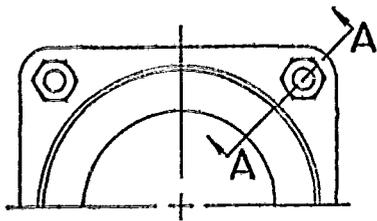
- A. Coupling incorporates a fail-safe feature.
- B. Available in low profile at reduced temperature and pressure conditions. Contact supplier for detail information.
- C. Individual duct removal restricted.

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2.1.4.6.2 (Cont'd.):

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. Torque wrenches.

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

Maximum Operating Pressure: Consult manufacturer.

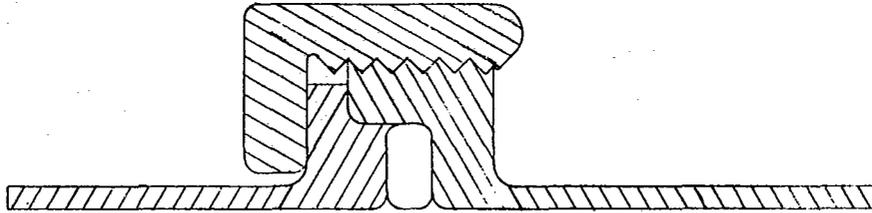
Maximum Operating Temperatures: 1000°F for all sizes.

Remarks:

- A. Number of bolt holes increases as nominal diameter increases.
- B. A similar flange without ferrules is available for welding to the duct.

2.1.4.6.3 Threaded Joints:

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 diameter 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. Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M in. lbs.

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

Remarks:

- A. Optional methods available for locking ring nut in place.
- B. Recommended only for small sizes (up to 2") due to high torque required to seat metallic gaskets.

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2.1.4.6.3 (Cont'd.):

TYPE "B"



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

Tools to Install: Standard type wrenches.

Duct Sizes: 0.25 inch through 2 inches diameter. From 0.25 inch to 1.50 inches, sizes are in 0.25-inch diameter increments.

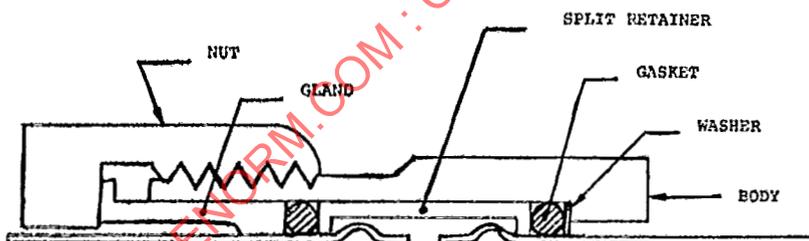
Maximum Operating Pressure: 300 psig or greater for all joint sizes.

Maximum Operating Temperature: 700°F for all sizes.

Remarks: Designed for installation on MS 33584 tube flare, except for very thin wall tubing which must be double flared.

2.1.4.6.4 Flexible Joints:

Type "A"



Materials: Corrosion resistant steel, elastomer gasket.

Tools to Install: Standard wrenches.

Duct Sizes: 0.75 inch through 4 inches diameter in 0.50-inch diameter increments. Some sizes available in 0.25-inch diameter increments.

Maximum Operating Pressure: 125 psig or greater for all joint sizes.

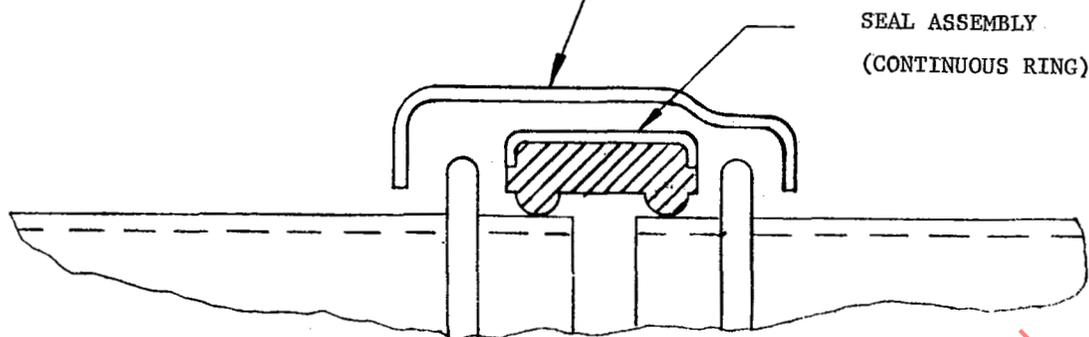
Maximum Operating Temperature: 500°F for all joint sizes.

Remarks: Allowable angular deflection + 4°. Capable of absorbing some rotary and axial motion. Tube bead strength may limit performance in tension systems.

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CLAMP ASSEMBLY
(HINGED HALVES)

TYPE "B"



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

Tools to Install: Screwdriver.

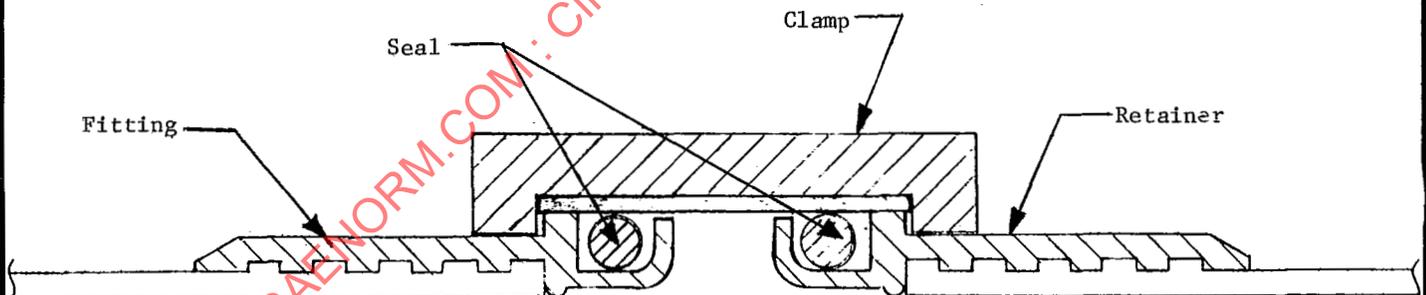
Duct Sizes: 1 inch through 4.25 inches diameter in 0.25 inch diameter increments, except a 3.625 size replaces the 3.750 size.

Maximum Operating Pressure: 125 psig for all joint sizes.

Maximum Operating Temperature: 480°F for all joint sizes.

Remarks: Allowable angular deflection $\pm 4^\circ$. Capable of absorbing some rotary and axial motion.

TYPE "C"



Materials: Aluminum alloy and/or corrosion resistant steel clamp assembly, swaged or welded end fittings, seal ring and fluoro elastomer seals.

Tools to Install: Hand installation no tools required.

Duct Sizes: 0.50 inch through 4.00 inch diameter in 0.25-inch diameter increments to 2.00 inch size; 0.50-inch diameter increments from 2.00 inch through 4.00 inch size.

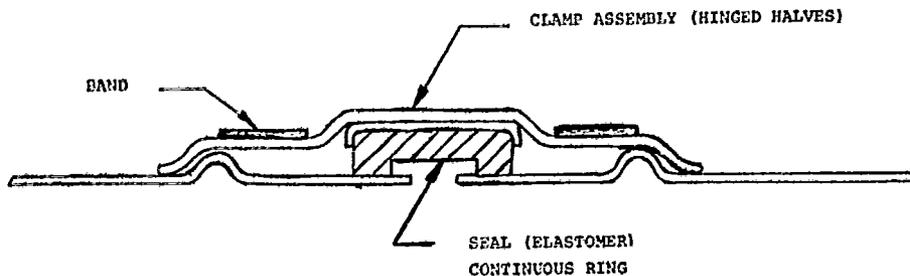
Maximum Operating Pressure: 125 psig for all joint sizes.

Maximum Operating Temperature: 400°F for all joint sizes.

Remarks: Allowable angular deflection $\pm 4^\circ$. Capable of absorbing some rotary and axial motion.

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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 diameter increments. Some sizes available in 0.25 inch diameter increments.

Maximum Operating Pressure: 160 psig for all joint sizes.

Maximum Operating Temperature: 400°F for all joint sizes.

Remarks: Allowable angular deflection $\pm 4^\circ$. Capable of absorbing some rotary and axial motion.

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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 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 failures.
- 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 cold day with the structure cooled to the design minimum low temperature and then the duct is heated to the maximum operating temperature possible for the cold day condition. However, the design should include a study to determine whether any other 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 and Sonic Fatigue 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.

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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 duct.
- 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 duct supports. Sufficient adjustment should be provided in the brackets to allow for installation tolerances. Duct support brackets should not be used to force the duct 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 duct 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 occurring 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 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 duct supports. Sufficient adjustment should be provided in the brackets to allow for installation tolerances. Duct support brackets should not be used to force the duct 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. All adhesives should be checked for their high temperature stability and possible effects on the duct system.
- 2.1.7.1 Ducts: Duct insulation should consist of an insulating medium enclosed in a moisture and/or vapor impervious cover as required. The use of metallic foil covering on the inner surface of insulation blankets next to metallic ducts should be avoided where fretting action may destroy the corrosion preventive film.
- 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

<u>Temp. Limit</u>	<u>Material</u>	<u>Advantages</u>	<u>Disadvantages</u>
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

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2.1.7.1.1 (Cont'd.):

B. Coated Fabric Coverings

<u>Temp. Limit</u>	<u>Fabric</u>	<u>Coating</u>	<u>Advantage</u>	<u>Primary Disadvantage</u>
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	Phenolic resin or silicone rubber	High temperature and good weather resistant	Poor abrasion and fuel resistance

C. Insulating Materials

<u>Temp. Limit</u>	<u>Material</u>	<u>Density lb/ft³</u>	<u>Advantages</u>	<u>Disadvantages</u>
700°F	Air	.076	Light weight	Only fair insulating quality, needs more support for cover
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
1600°F	Glass fibers leached	3-1/2 & 6	Light weight	High cost
2000°F	Quartz microfibers	3 - 9	Light weight	High cost

*CAUTION - Asbestos is a health hazardous material; approved safety guidelines should be followed.

2.1.7.1.2 Removable Types: 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 other 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

2.1.7.1.2 (Cont'd.):

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:

<u>Temp. Limit</u>	<u>Material</u>	<u>Condition</u>	<u>General Applications</u>
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
1600°F	Glass fibers leached	Batting	Wrap-around insulation between duct and support
2000°F	Quartz fibers	Batting	Wrap-around insulation between duct and support

*Asbestos is a health hazardous material; approved safety guidelines should be followed.

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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: $\pm 5^{\circ}\text{F}$ up to 250°F | D. Vibration amplitude: $\pm 5\%$ |
| $\pm 10^{\circ}\text{F}$ up to 500°F | E. Vibration frequency: $\pm 2\%$ |
| $\pm 15^{\circ}\text{F}$ above 500°F | |
| B. Pressure: $\pm 3\%$ of absolute value | |
| C. Flow: $\pm 5\%$ | |

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 | D. Vibration Test |
| B. Proof Pressure Test | E. Burst Pressure Test |
| C. Endurance 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 test shall be conducted at room temperature and proof pressure as indicated in 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 the most critical combination of pressure and temperature as determined by the requirements of 2.1.1.3. 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 this 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. Buckling considerations may preclude the use of a room temperature equivalent proof pressure test.

- 2.2.1.1.2.3 Endurance Test: The duct shall be subjected to a pressure cycling test at pressure and temperature values equal to or exceeding those values that, in combination, will result in the highest ratio of stress to yield strength in the material. 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. Some manufacturers have subjected pneumatic components to as many as 600,000 cycles. Before and after the endurance test, the assembly shall be subjected to proof pressure test of 2.2.1.1.2.2. 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-STD-810, or equivalent specification noted on the applicable drawing. A random vibration test should be considered for jet aircraft equipment.
- For long ducts or ducts incorporating flex joints, the vibration induced by jet engine noise and by aerodynamic effects in the aircraft is applied to the full length of the duct. To apply this level of vibration at duct end points or attach points only may lead to unrealistic bending resonances and test failures. In this case, additional vibration test input clamps and brackets should be used such as at each end of flex sections.
- 2.2.1.1.2.4.1 Random Vibration Tests: Random vibration tests cited throughout this section for ducts and duct components are generally recommended for diagnostic purposes rather than qualification. The reason for this is the difficult problem of simulating in-service dynamic mounting of the ducts together with fabrication of test fixtures that simulate aircraft installed damping and stiffness. However, if a valid, overall, random vibration environment can be simulated, then random vibration tests should be conducted during qualification.
- 2.2.1.1.2.4.2 Vibration Pressurization: Ducts and duct components that are not always pressurized need not be pressurized for the complete vibration test period. As a general rule, it is recommended that one half of the test time be conducted pressurized and the other half unpressurized.
- 2.2.1.1.2.5 Burst Pressure Test: The duct shall be burst pressure tested at the most critical combination of pressure and temperature as determined by the requirements of 2.1.1.3. 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 rupture during this test. Deformation resulting from this test shall be permitted and the part need not be functional after the test.

2.2.1.2 Qualification Tests of Compensation and Deflection Devices:

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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 | E. Endurance Test |
| B. Flow Resonance Test | F. Vibration Test |
| C. Proof Pressure Test | G. Deflection Force Test |
| D. Pressure Drop 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 2.2.1.1.1.

2.2.1.2.1.2 Tests:

2.2.1.2.1.2.1 Leakage Test: Same as 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 for 50 hours to the flow at which the most severe resonance occurred. 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 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 a minimum of 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 2.2.1.1.2.2 and the deflection force test of 2.2.1.2.1.2.7. The initial deflection plane used for the cycle 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-STD-810 or 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 conditions. A random vibration test should be considered for jet aircraft equipment.

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 through a specified angle. 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 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 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 as 2.2.1.1.2.1.

2.2.1.2.2.2.2 Flow Resonance Test: Same as 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 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 a minimum of 20,000 cycles of compression and extension strokes based upon the applicable specification requirements. 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 that recommended in 2.1.2.1.2, where "L" is the bellows length and "D" is the nominal duct diameter, as shown in Figure 22. 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. Before and after the endurance test the assembly shall be subjected to proof pressure test of 2.2.1.1.2.2.

2.2.1.2.2.2.5 Vibration Test: Same as 2.2.1.2.1.2.6.

2.2.1.2.2.2.6 Burst Pressure Test: Same as 2.2.1.1.2.5.

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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
- 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 2.2.1.1.1.1.

2.2.1.2.3.2 Tests:

2.2.1.2.3.2.1 Leakage Test: Same as 2.2.1.1.2.1.

2.2.1.2.3.2.2 Proof Pressure Test: Same as 2.2.1.1.2.2.

2.2.1.2.3.2.3 Vibration Test: The unit shall be supported by its mounting bracket and/or its coupling flanges and shall be vibration tested in accordance with MIL-STD-810 or equivalent specification as noted on applicable drawings. A random vibration test should be considered for jet aircraft equipment.

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 a minimum of 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 2.2.1.1.2.2, the leakage requirements of 2.2.1.1.2.1 and the dimensional requirements.

2.2.1.2.3.2.5 Spring Rate and Compensation Value Test: (A) With the unit unpressurized, measure the force to compress the unit through its design stroke. (B) 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 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 duct system. Burst pressure tests shall be conducted on only the expansion bends.

- | | |
|--------------|-------------------|
| A. Endurance | C. Proof Pressure |
| B. Leakage | D. Burst Pressure |

2.2.1.2.4.1 Test Conditions:

2.2.1.2.4.1.1 Ambient Temperature and Pressure: Same as 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 duct system utilizing production duct 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 2.2.1.1.2.2 following the test of 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 duct system per 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 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 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 2.2.1.1.1.1.

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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 installations 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 2.2.1.1.2.1.

2.2.1.2.5.2.3 Proof Pressure Test: Same as 2.2.1.1.2.2.

2.2.1.2.5.2.4 Burst Pressure Test: Same as 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 | D. Deflection Moment |
| B. Proof Pressure | E. Endurance |
| C. Vibration | F. Burst Pressure |

2.2.1.2.6.1 Test Conditions:

2.2.1.2.6.1.1 Ambient Temperatures and Pressures: Same as 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 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-STD-810, or equivalent specification as noted on applicable drawing. A random vibration test should be considered for jet aircraft equipment.

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 double amplitude deflection, based upon the applicable specification, from normal and back to normal, and that a minimum of 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 and deflection moment test. 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 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 2.2.1.1.1.1.
- 2.2.1.2.7.2 Tests:
- 2.2.1.2.7.2.1 Leakage Test: Same as 2.2.1.2.6.2.1.
- 2.2.1.2.7.2.2 Proof Pressure Test: Same as 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 a minimum of 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, cycling the slip motion and dumping pressure. The amount of slip motion used in the test should satisfy the thermal expansion or motion of the duct under consideration. Immediately following endurance test, subject the unit to the leakage test of 2.2.1.2.6.2.1. Before and after the endurance test, the assembly shall be subjected to the proof pressure test of 2.2.1.1.2.2.
- 2.2.1.2.7.2.4 Vibration Test: Same as 2.2.1.2.6.2.3.
- 2.2.1.2.7.2.5 Burst Pressure Test: Same as 2.2.1.1.2.5.

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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 | G. Vibration Test |
| B. Leakage Test | H. Burst Pressure Test |
| C. Flow Resonance Test | I. Sand - Dust |
| D. Proof Pressure Test | J. Torque |
| E. Pressure Drop Test | K. Fire Test |
| F. Endurance Test (Service Life) | |

2.2.1.2.8.1 Test Conditions:

2.2.1.2.8.1.1 Ambient Temperature and Pressure: Same as 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 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 resonance 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 2.2.1.2.6.2.1.

2.2.1.2.8.1.6 Proof Pressure Test: Each test sample shall be proof pressure tested per 2.2.1.1.2.2.

2.2.1.2.8.1.7 Burst Pressure Test: At least one representative production test sample shall be burst pressure tested per 2.2.1.1.2.5.

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 duct and of the same I.D. as the system duct 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 23. 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 duct under consideration.

2.2.1.2.8.1.9 (Cont'd.):

Prior to the start and at the conclusion 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-STD-810, or to special conditions noted on detail drawings. The vibration and flow test may be combined if mutually agreed upon. A random vibration test should be considered for jet aircraft equipment.

2.2.1.2.8.1.11 Sand And Dust: The test sample shall be tested for sand and dust in accordance with MIL-STD-810, 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.

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2.2.1.3 Duct Joint 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 2.2.1.1.1.1.

2.2.1.3.2 Tests:

2.2.1.3.2.1 Proof Pressure Test: Same as 2.2.1.1.2.2.

2.2.1.3.2.2 Leakage Test: The joint should be assembled on a test vessel (Figure 25 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, or the leakage rate, shall be recorded. The leakage in SCFM shall be calculated and compared with the allowable specified in 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 joint while at the temperature and pressure specified on the applicable drawing. For this test the joint shall be mounted as shown in Figure 24. 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 minimum of 25,000 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 joint 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 500 cycles.

2.2.1.3.2.4 Pressure Cycle Test: The duct joint shall be assembled for this test as shown in Figure 25 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 25,000 cycles at a cycle rate between

2.2.1.3.2.4 (Cont'd.):

10 and 40 cycles per minute. There shall be no permanent deformation of the joint or leakage in excess of the amount specified on the applicable drawing.

2.2.1.3.2.5 Vibration Test: The duct joint shall be assembled as shown in Figure 25 and be subjected to a vibration test in accordance with MIL-STD-810, or equivalent specification as noted in the applicable drawing. During this test the assembly shall be pressurized to the value specified on the applicable drawing. A random vibration test should be considered for jet aircraft equipment.

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

2.2.1.3.2.6 Burst Pressure Test: Same as 2.2.1.1.2.5.

2.2.1.3.2.7 Repeated Assembly Test: The joint should be connected to and disconnected from the pressure test vessel, (Figure 24 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 joint should be subjected to the pressure for which initial joint leakage was determined (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 25 or similar) should be installed in a jig with a spacer .031 in. 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 with a known restraining force so as to maintain the condition of misalignment thus provided. With this arrangement the misalignment of the flanges will range from approximately 0.4 degree for the 5-inch size to 1 degree for the 2-inch size. The test joint should be installed on the pressure vessel flanges and subjected to the pressure for which initial leakage was determined (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 joint installed shall be soaked until stabilized at the low temperature value as determined from the analysis cited in 1.1.3. Air at the maximum expected temperature, as determined from 1.1.3, shall then be allowed to flow through the test vessel until the joint temperature has stabilized. 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 joint should be mounted on a test fixture similar to Figure 24, 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 joint leakage was initially determined (2.2.1.3.2.2) and the leakage checked. A torque should then be applied to the fixture and the point at which joint 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.

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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 | D. Simulated Service Test |
| B. Low Temperature Test | E. Flammability Test |
| C. Solvent Resistance Test | F. Corrosion Resistance Test |

2.2.1.4.1.1 Test Conditions:

2.2.1.4.1.1.1 Ambient Temperature: Ambient temperatures shall be $70^{\circ}\text{F} \pm 15$ 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 test specimen shall consist of a one foot long cylindrical section. The specimen shall be subjected to the design minimum low temperature 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 accepted.

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 percent increase in weight of the cover and the insulation independently. The insulation weight increase shall be essentially zero percent. 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 AS 1241 if applicable. The test shall be performed by allowing each of the above fluids to flow over its own specimen for a period of forty eight (48) hours 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 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.

- 2.2.1.4.1.2.6 Corrosion Resistance Test: Ducting with integral insulation or adhesive coatings shall be subjected to a corrosion resistance test as defined by the airframe manufacturer's procurement specification.
- 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 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 2.2.1.4.1.2.1.
- 2.2.1.4.2.2.2 Simulated Service Test: Same as 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 duct system mock-up.
- 2.2.2.1 Test Setup: The duct system qualification must use a test setup that is representative of the system to be installed in the aircraft. All ducts, duct 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 duct system and associated equipment. The location of duct supports should be identical to those on 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 formulation of the test program and suitable test facilities. The duct system integrity should be demonstrated by subjecting the total system (purchased equipment and

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2.2.2.2.1 (Cont'd.):

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 or 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 cycling test at pressure and temperature values equal to or exceeding those values that, in combination, will result in the highest ratio of stress to yield strength in the material. The test shall be conducted 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 considerably more time to conduct than pressure cycling at constant temperature. Temperature cycling tests have previously been recommended for expansion bends as described in 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 duct system based on the maximum thermal shock operation of the system. A temperature cycle shall consist of raising the temperature of the duct 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: For realistic random vibration criteria readily adaptable to the flight vehicle, location within the vehicle, and flight environmental condition to be encountered, see MIL-STD-810C.

2.2.2.2.6 Simulation of Airframe Deflection: Airframe deflections 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 the 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.

2.2.2.2.7 (Cont'd.):

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 warranty 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 duct 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 leakage 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 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 2.2.1.1.2.1.
- B. Proof Pressure test per 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.

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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. Ducts - Inspect for damage due to handling, installation or improper clearance.
- D. Ducts - Inspect for acceptable alignment. Inspect support structure and duct. 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 considerably 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.

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MEAN COEFFICIENT FROM 70 F

MEAN COEFFICIENT OF
THERMAL EXPANSION

① 321 & 347

② A-286
HT 130,000 PSI③ Inconel X-750
HT 155,000 PSI④ Rene' 41
HT 170,000 PSI⑤ AM 350
HT 185,000 PSI⑥ PHL5-7Mo
HT 225,000 PSI

⑦ Inconel 718 Cond. A & D

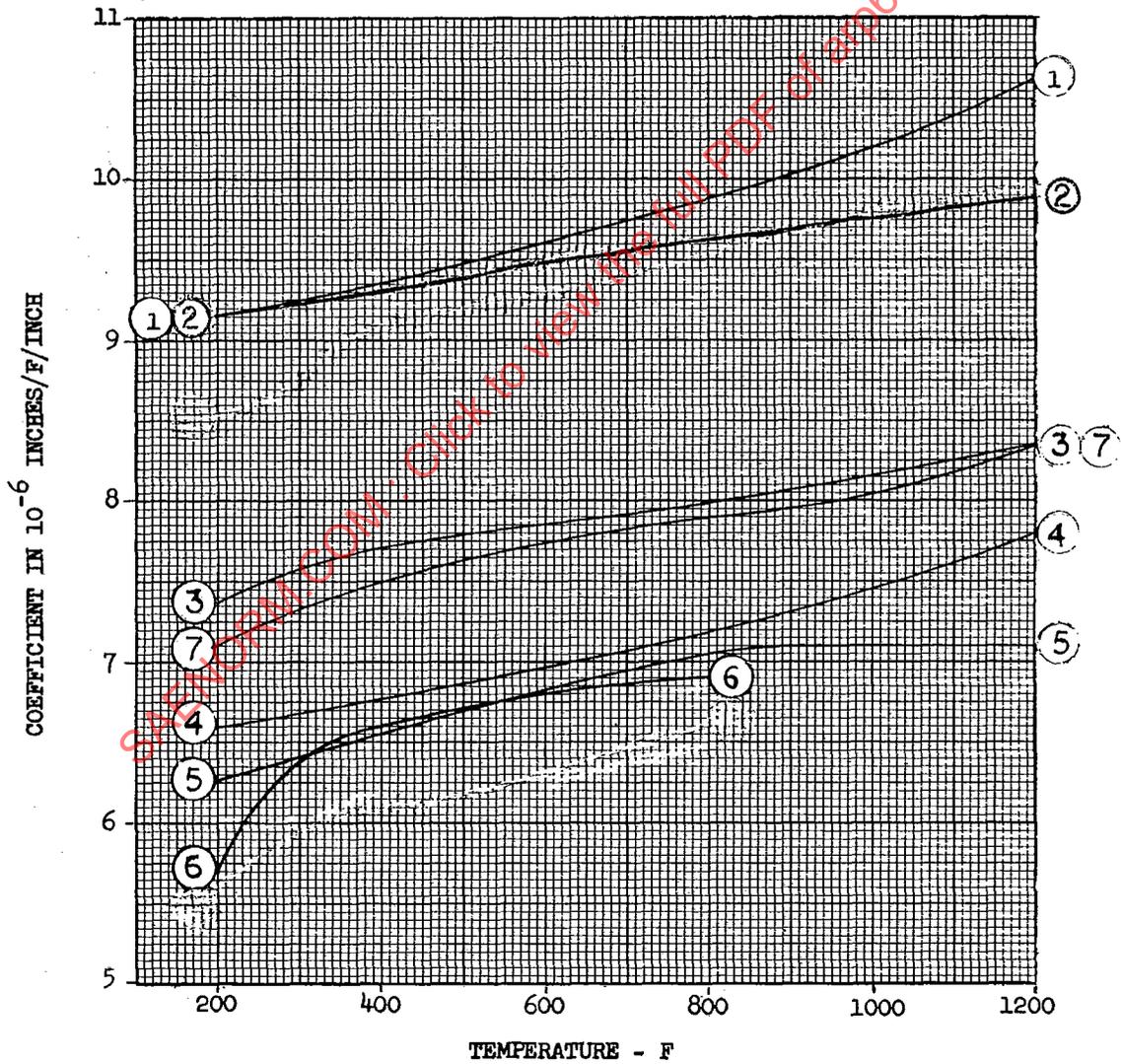


FIGURE 6

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MEAN COEFFICIENT OF
THERMAL EXPANSIONMATERIALS

- ① AMS 4900 & AMS 4901
- ② 4AL-3 Mo-1V
- ③ 5AL - 2.5 SN
- ④ 6AL-4V
- ⑤ 8AL-1Mo-1V

MEAN COEFFICIENT FROM 70 F*

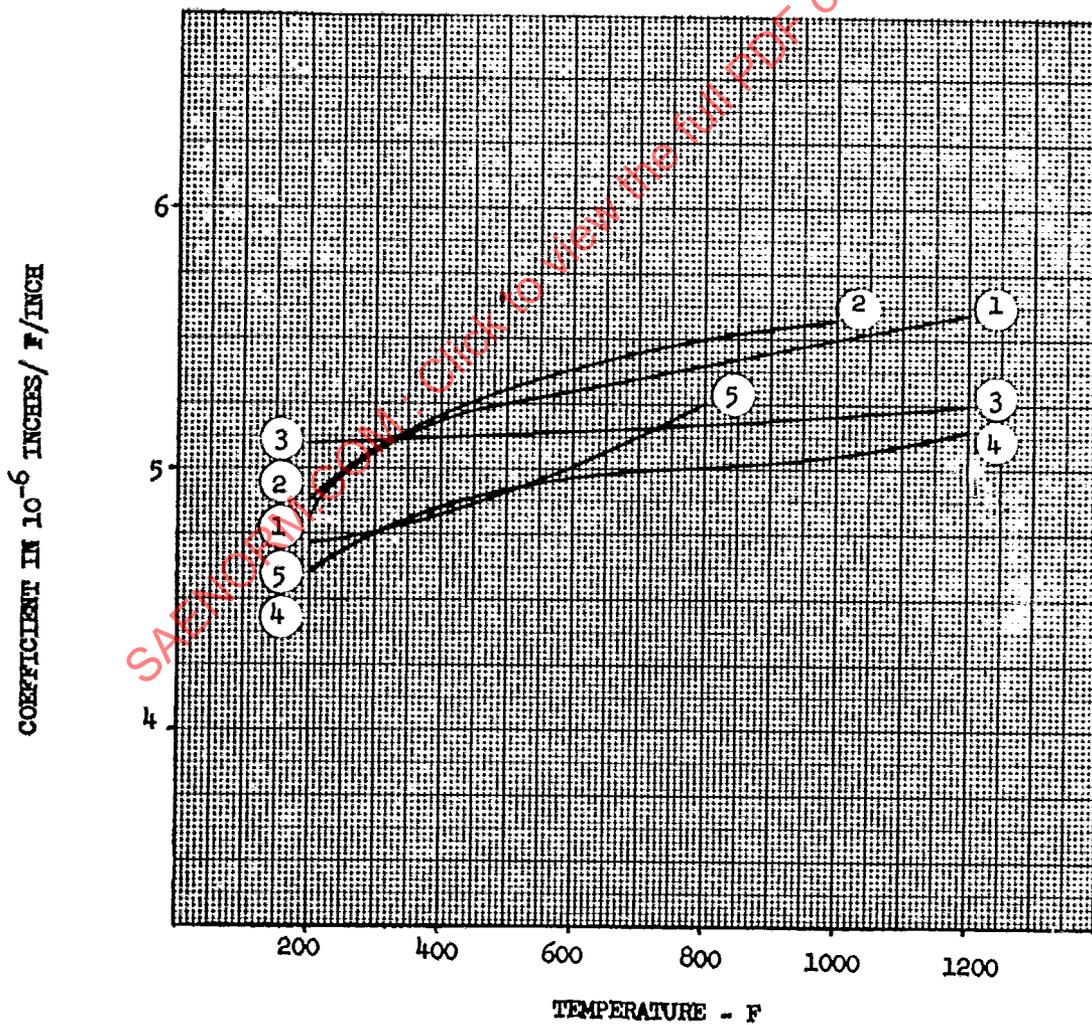


FIGURE 7

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TENSILE YIELD STRENGTH

NOTE: At temperatures above point O on the curves, the stress for 1% creep in 1000 hours is below the yield strength.

MATERIALS

- ① 321 & 347
- ② A-286
HT 130,000 PSI
- ③ Inconel X-750
HT 155,000 PSI
- ④ Rene' 41
HT 170,000 PSI
- ⑤ AM 350
HT 185,000 PSI
- ⑥ PH15-7Mo
HT 225,000 PSI
- ⑦ Inconel 718 Cond. A
- ⑧ Inconel 718 Cond. B

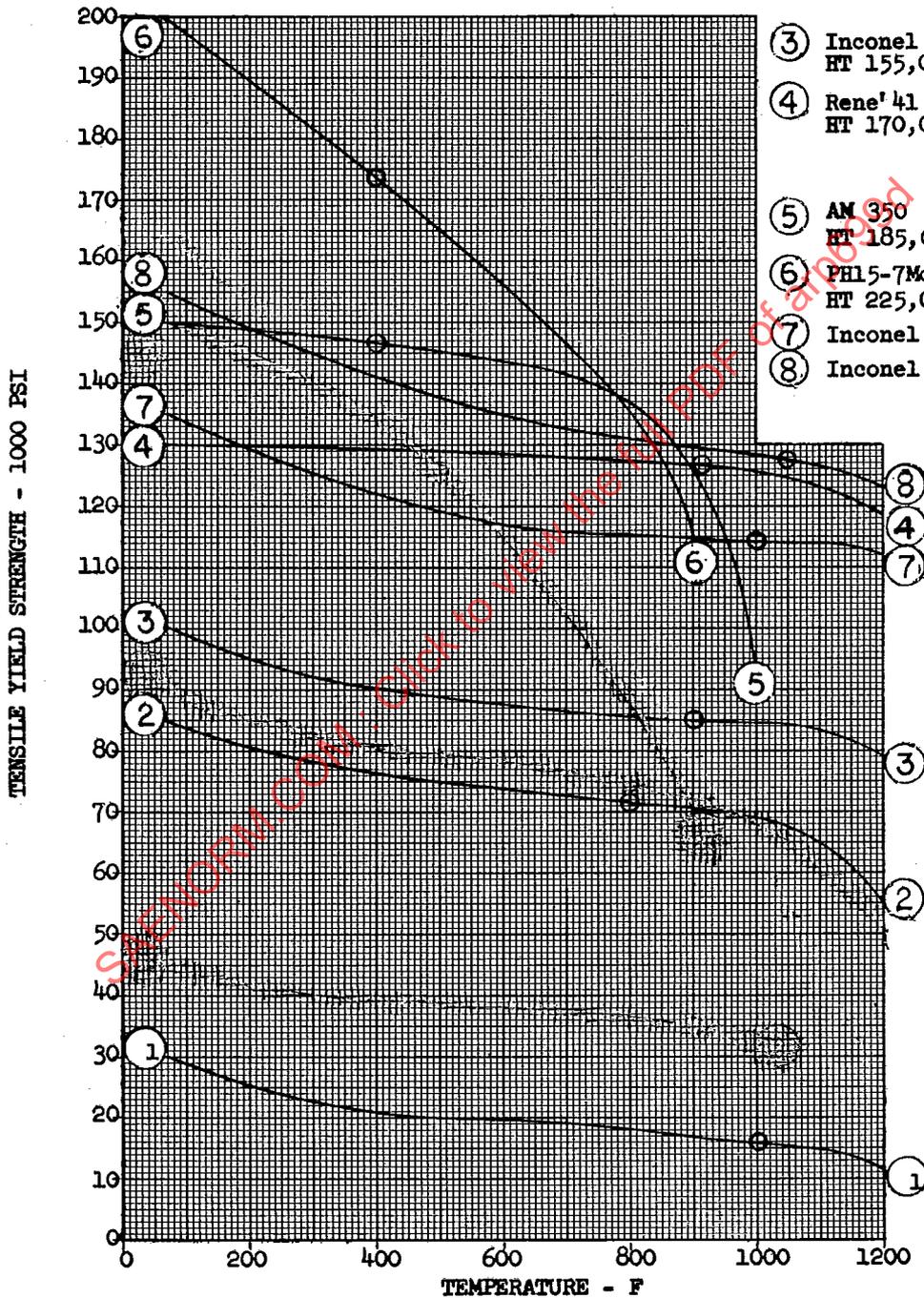


FIGURE 8

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TENSILE YIELD STRENGTH

MATERIALS

- ① AMS 4900 Comm. Pure
- ② AMS 4901 Comm. Pure
- ③ 4AL-3Mo -1V H.T.
- ④ 5AL-2.5 SN
- ⑤ 6AL-4V H.T.
- ⑥ 8AL-1Mo-1V

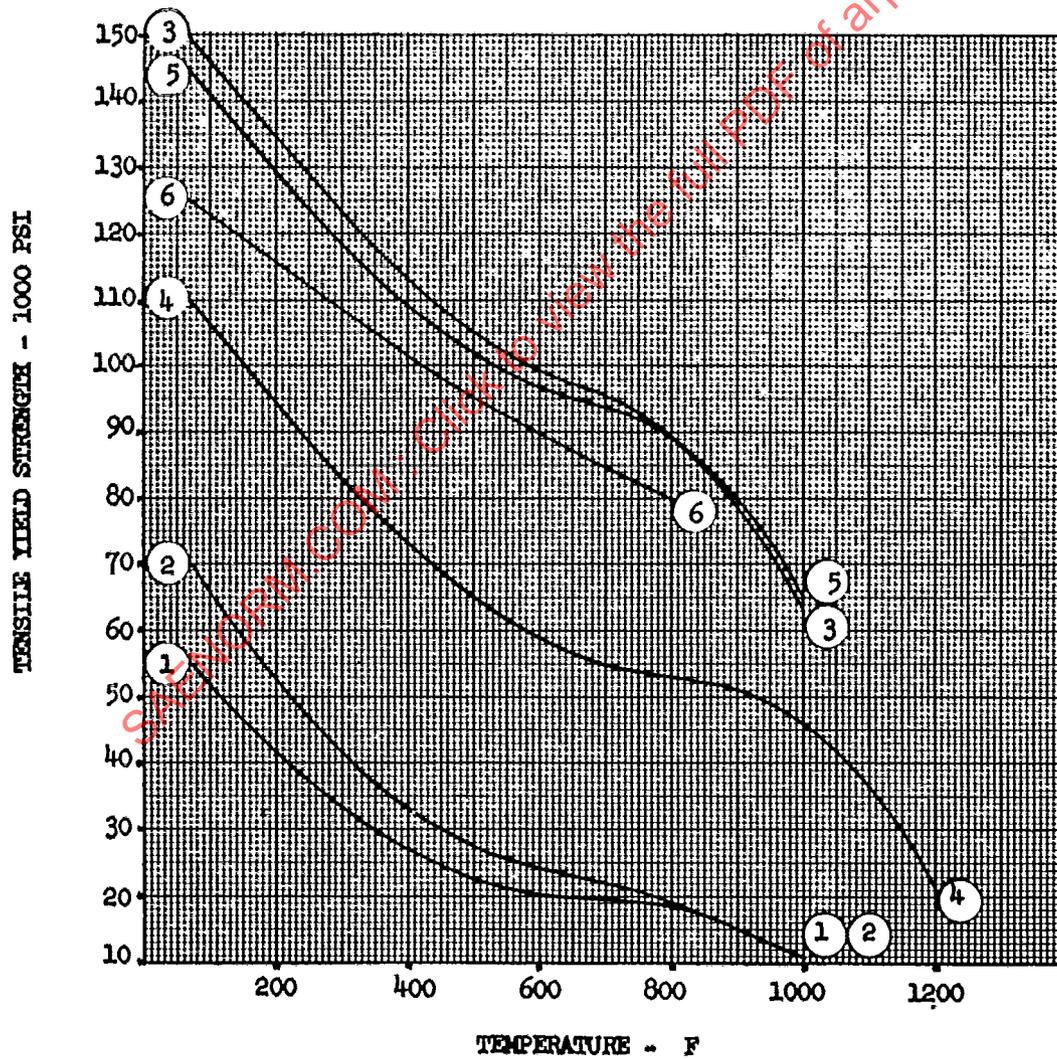


FIGURE 9

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STRENGTH - WEIGHT RATIO
VS. TEMPERATURE

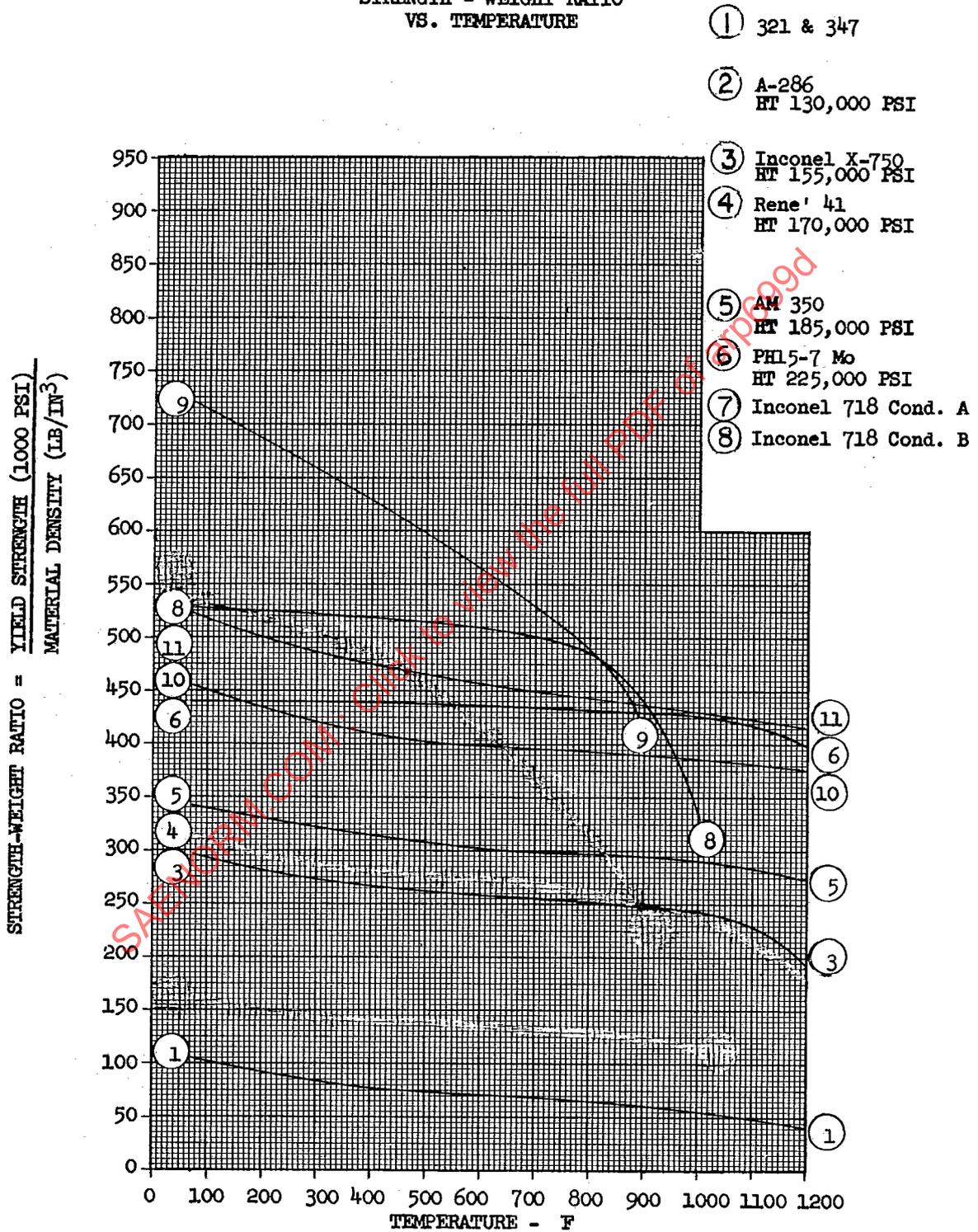


FIGURE 10