AEROSPACE RECOMMENDED PRACTICE

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Superseding ARP699D

High Temperature Pneumatic Duct Systems for Aircraft

RATIONALE

ARP699E has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Changes in this revision are format/editorial only.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1. 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.

2. REFERENCES:

WADC Technical Report 56-187, dated September 1956, "Investigation of Aircraft Ducting Components at High Subsonic Speeds"

Air Force Aero Propulsion Laboratory Technical Report 71-86, dated November 1971, "Ignition of Aircraft Fluids by Hot Surfaces Under Dynamic Conditions"

3. 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.

3. (Continued):

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.

3. (Continued):

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.

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.

3. (Continued):

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 on 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.

3. (Continued):

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.

4. INSTALLATION CRITERIA AND LIMITATIONS:

4.1 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:

4.1.1 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 degree to 5 degree rotation about the duct centerline. Bending deflections (angular) may be in the range of 3 degrees to 7 degrees for a typical wing installation. Paragraph 4.2 indicates some methods of compensation for structural deflection.

4.1.2 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 4.2 indicates some methods for compensating for thermal expansion.

4.1.3 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.

4.1.4 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.

4.1.5 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.

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.

4.1.6 Typical Duct Material: For typical corrosion, resistant alloys available for use in high temperature pneumatic duct systems, refer to Section 5 for detail information.

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

4.1.6.1.1 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).

4.1.6.2 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.

4.1.7 Fluid Flow Considerations: Considerations of thermodynamic fluid flow should be given in the duct system design:

4.1.7.1 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.

4.1.7.2 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.

4.1.7.3 Assure that supersonic flow is not created in the ducting downstream from duct system components, such as a flow-limiting venturi.

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

4.1.8.1 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.

4.1.8.2 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.

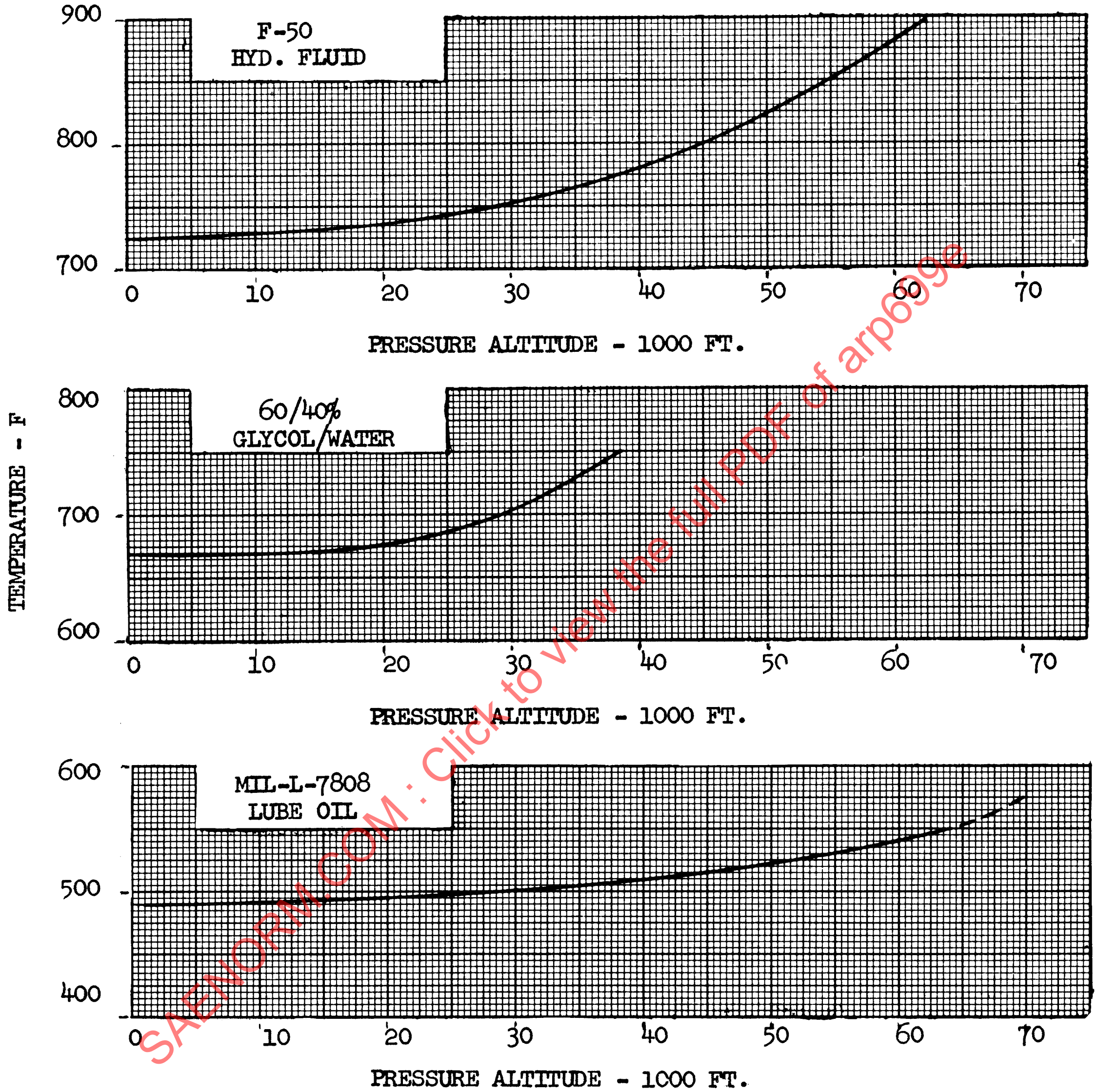


FIGURE 1 - Autogenous Ignition Temperature Versus Altitude

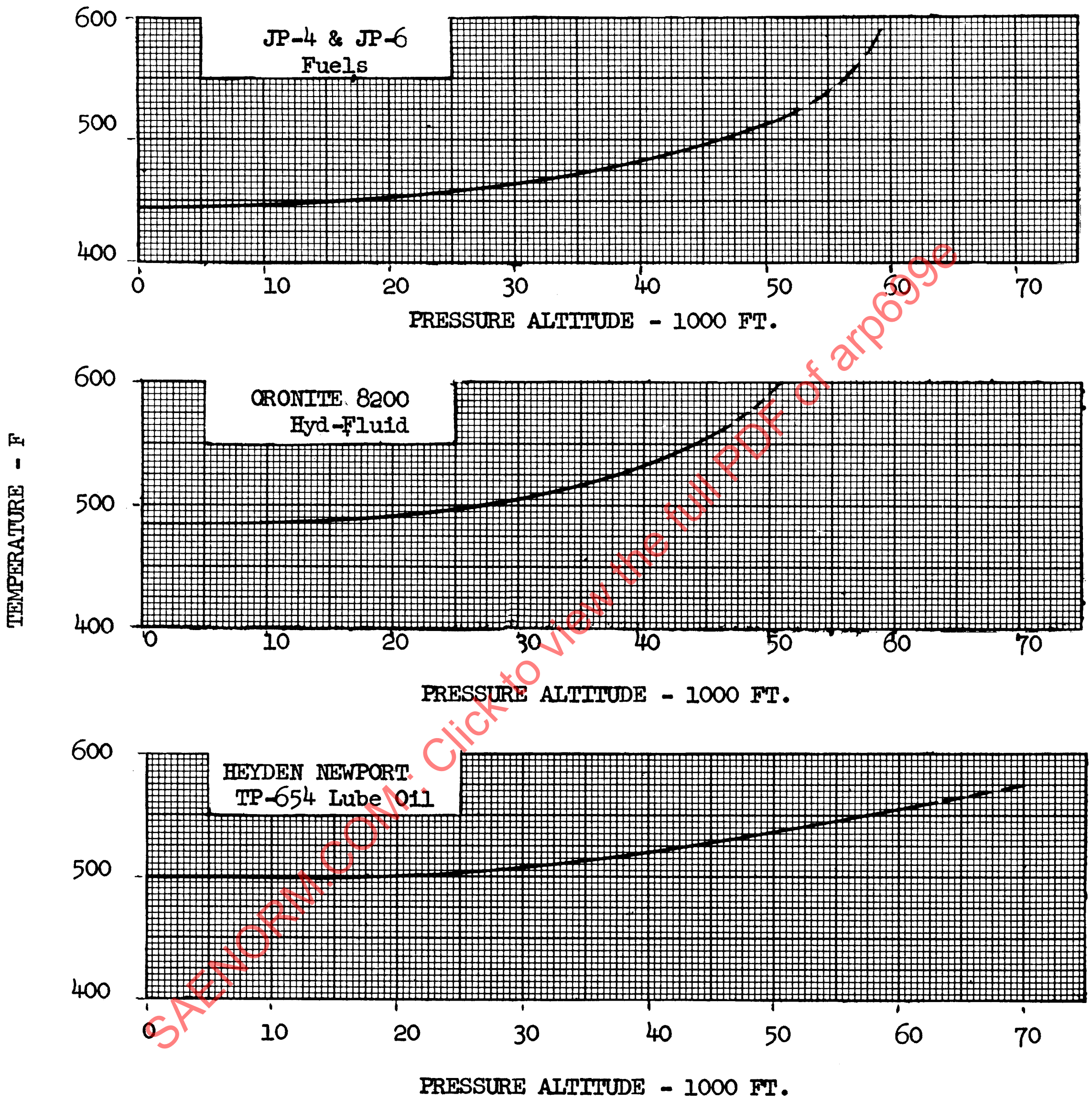


FIGURE 2 - Autogenous Ignition Temperature Versus Altitude

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

4.1.8.4 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.

4.1.9 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.

4.1.9.1 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.

4.1.9.2 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.

4.1.9.3 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.

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.

4.1.10 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.

4.1.10.1 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).

4.1.10.2 Leakage of high temperature air from the duct system can be a serious safety problem, similar to the case of duct surface temperature in 4.1.8.1, 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.

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

A. Use standard, well-developed parts.

B. Select vendors whose reliability of performance is proven.

C. Provide easy maintenance accessibility.

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

E. Require adequate testing for qualification.

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

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

H. Inspect carefully after fabrication.

I. Report malfunctions 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.

4.1.11.1 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 5 for details of duct qualification testing.

4.2 Types of Duct Systems:

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

4.2.1 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.

4.2.2 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.

4.2.3 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.

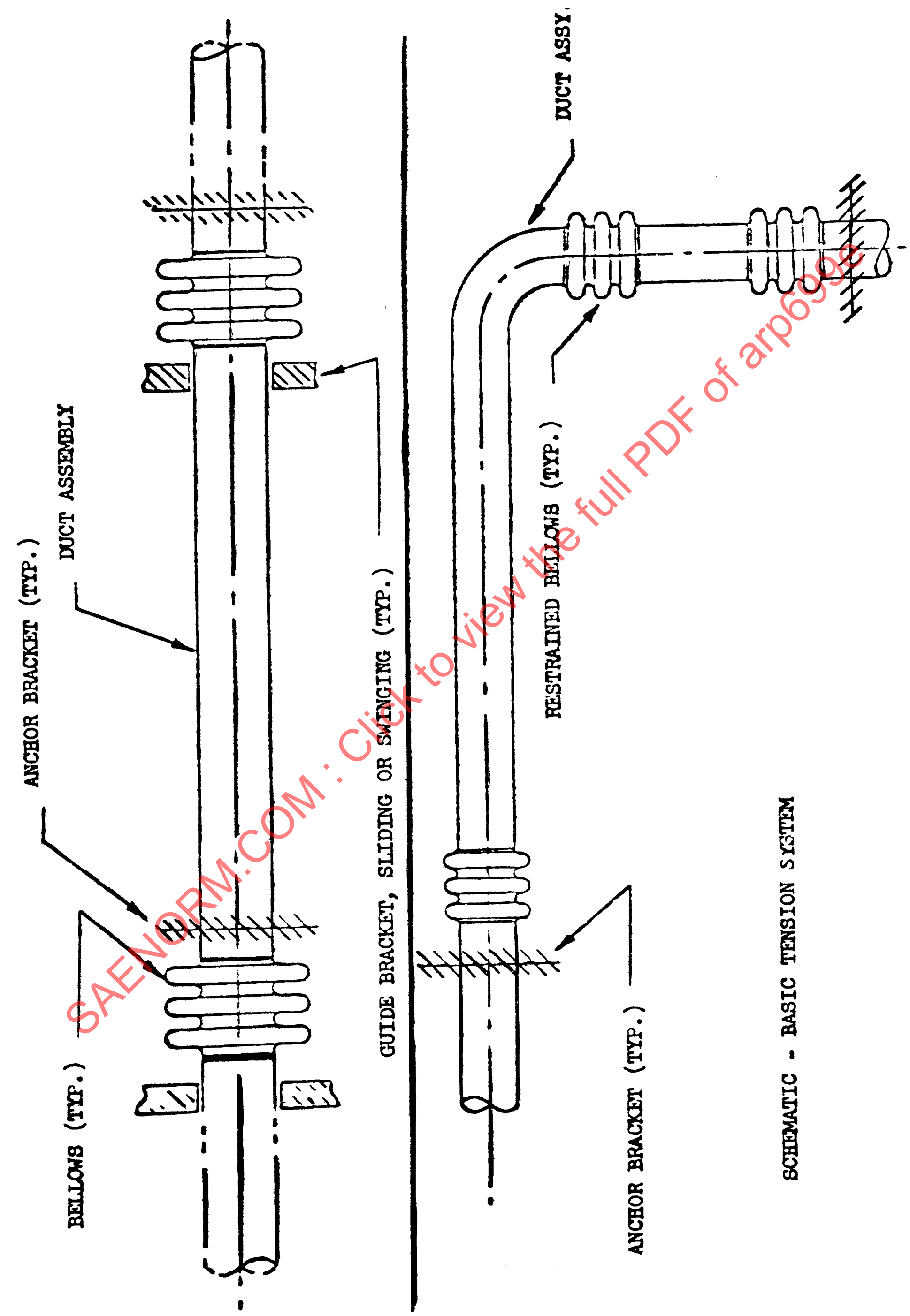


FIGURE 3 - Schematic - Basic Compression System

5. DUCT SYSTEM AND DUCT COMPONENT DESIGN:

5.1 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.

5.1.1 Ducts: The following recommendations pertain to ducts suitable for handling pressurized high temperature air.

5.1.1.1 Materials: Design information on these materials is presented in Figures 4 through 9 for the temperature levels shown:

TABLE 1

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.

TABLE 1 (Continued)

Material	Maximum Continuous Operating Temperature (°F)	Comments
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.

5.1.1.1 (Continued):

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.

TABLE 2

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.
4Al-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.
5Al-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.
6Al-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.

TABLE 2 (Continued)

Material	Maximum Continuous Operating Temperature (°F)	Comments
8Al-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.
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.

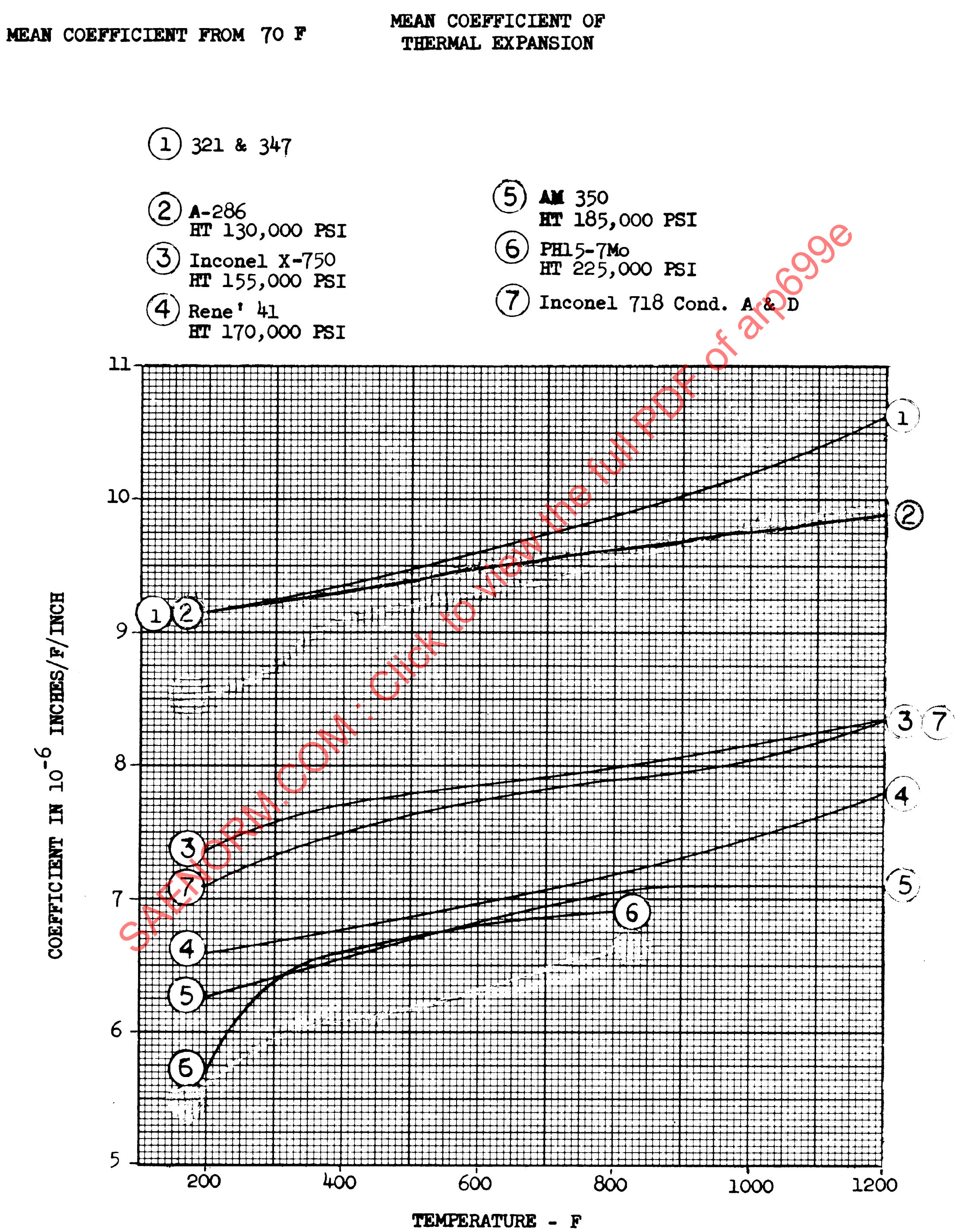

MEAN COEFFICIENT FROM 70 F
MEAN COEFFICIENT OF THERMAL EXPANSION
1 321 & 347
2 A-286 HT 130,000 PSI
3 Inconel X-750 HT 155,000 PSI
4 Rene' 41 HT 170,000 PSI
5 AM 350 HT 185,000 PSI
6 PH15-7Mo HT 225,000 PSI
7 Inconel 718 Cond. A & D
COEFFICIENT IN 10-6 INCHES/F/INCH
TEMPERATURE - F
11
10
9
8
7
6
5
200
400
600
800
1000
1200

FIGURE 4

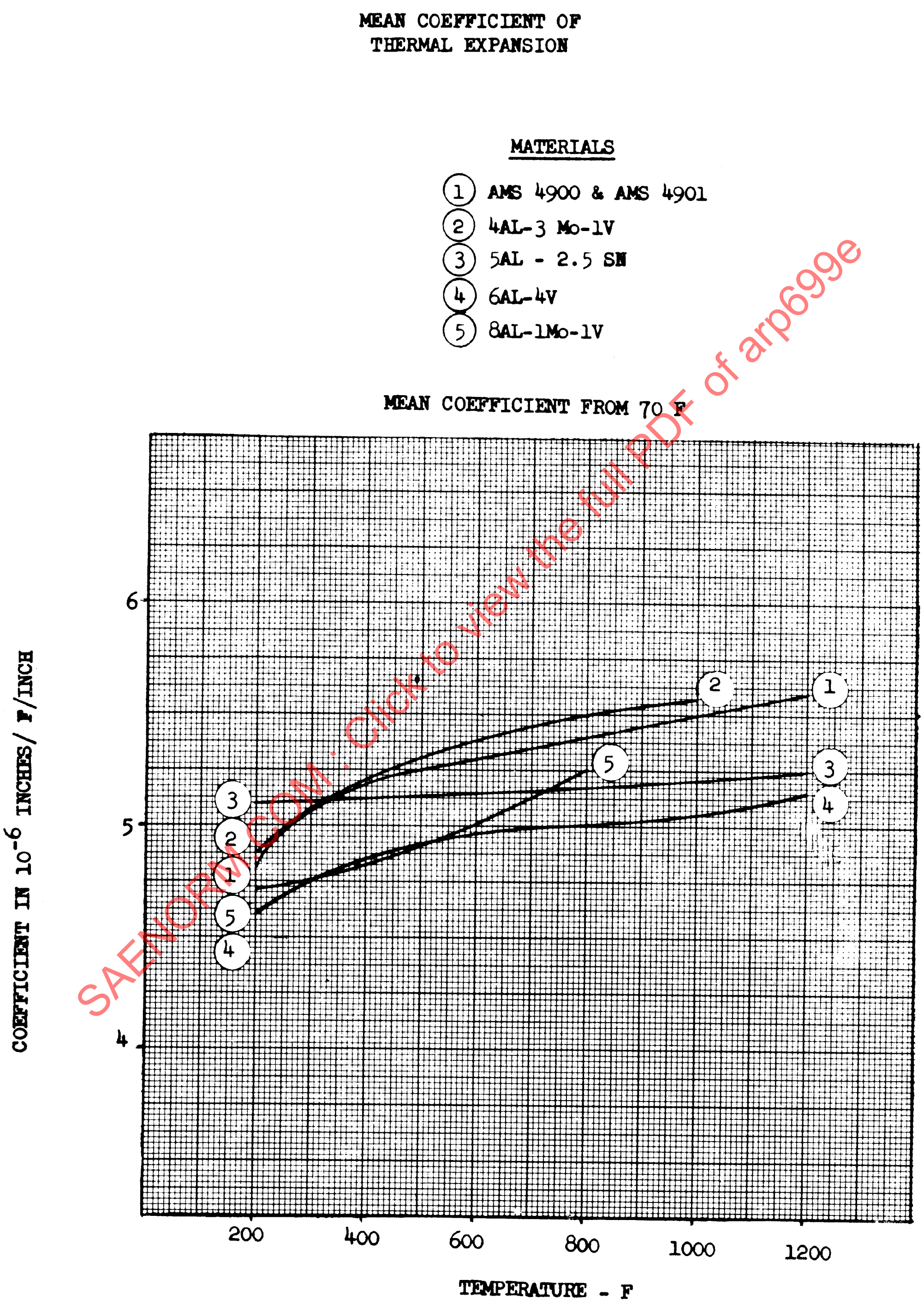

MEAN COEFFICIENT OF
THERMAL EXPANSION
MATERIALS
1 AMS 4900 & AMS 4901
2 4AL-3 Mo-1V
3 5AL - 2.5 SN
4 6AL-4V
5 8AL-1Mo-1V
MEAN COEFFICIENT FROM 70 F
COEFFICIENT IN 10-6 INCHES/ F/INCH
6
5
4
200
400
600
800
1000
1200
TEMPERATURE - F
1
2
3
4
5

FIGURE 5

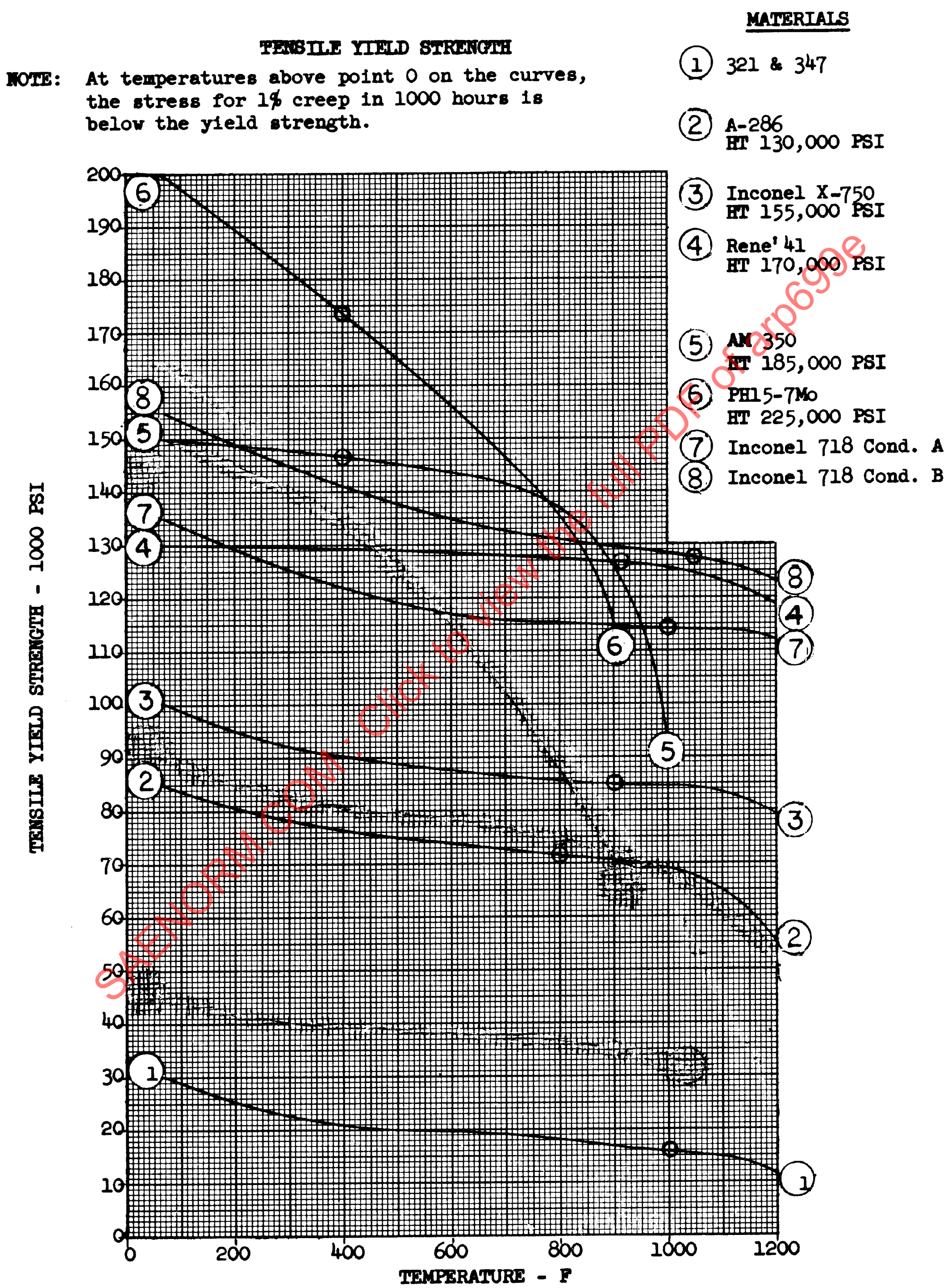

TENSILE YIELD STRENGTH
NOTE: At temperatures above point O on the curves, the stress for 1% creep in 1000 hours is below the yield strength.
MATERIALS
1 321 & 347
2 A-286 HT 130,000 PSI
3 Inconel X-750 HT 155,000 PSI
4 Rene' 41 HT 170,000 PSI
5 AM 350 HT 185,000 PSI
6 PH15-7Mo HT 225,000 PSI
7 Inconel 718 Cond. A
8 Inconel 718 Cond. B
TENSILE YIELD STRENGTH - 1000 PSI
TEMPERATURE - F
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
0
200
400
600
800
1000
1200

FIGURE 6

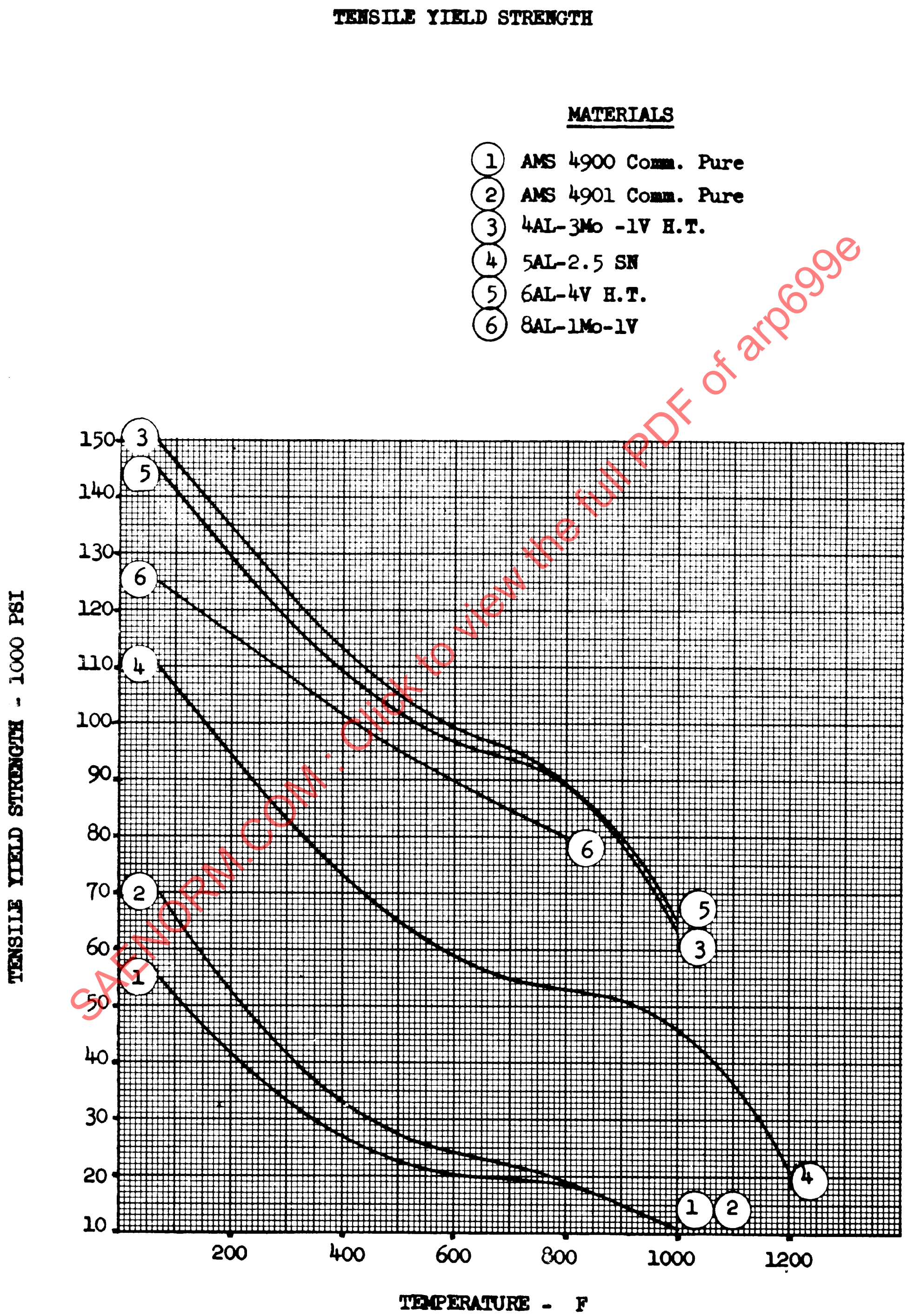

TENSILE YIELD STRENGTH
MATERIALS
1 AMS 4900 Comm. Pure
2 AMS 4901 Comm. Pure
3 4AL-3Mo -1V H.T.
4 5AL-2.5 SN
5 6AL-4V H.T.
6 8AL-1Mo-1V
TENSILE YIELD STRENGTH - 1000 PSI
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
200
400
600
800
1000
1200
TEMPERATURE - F

FIGURE 7

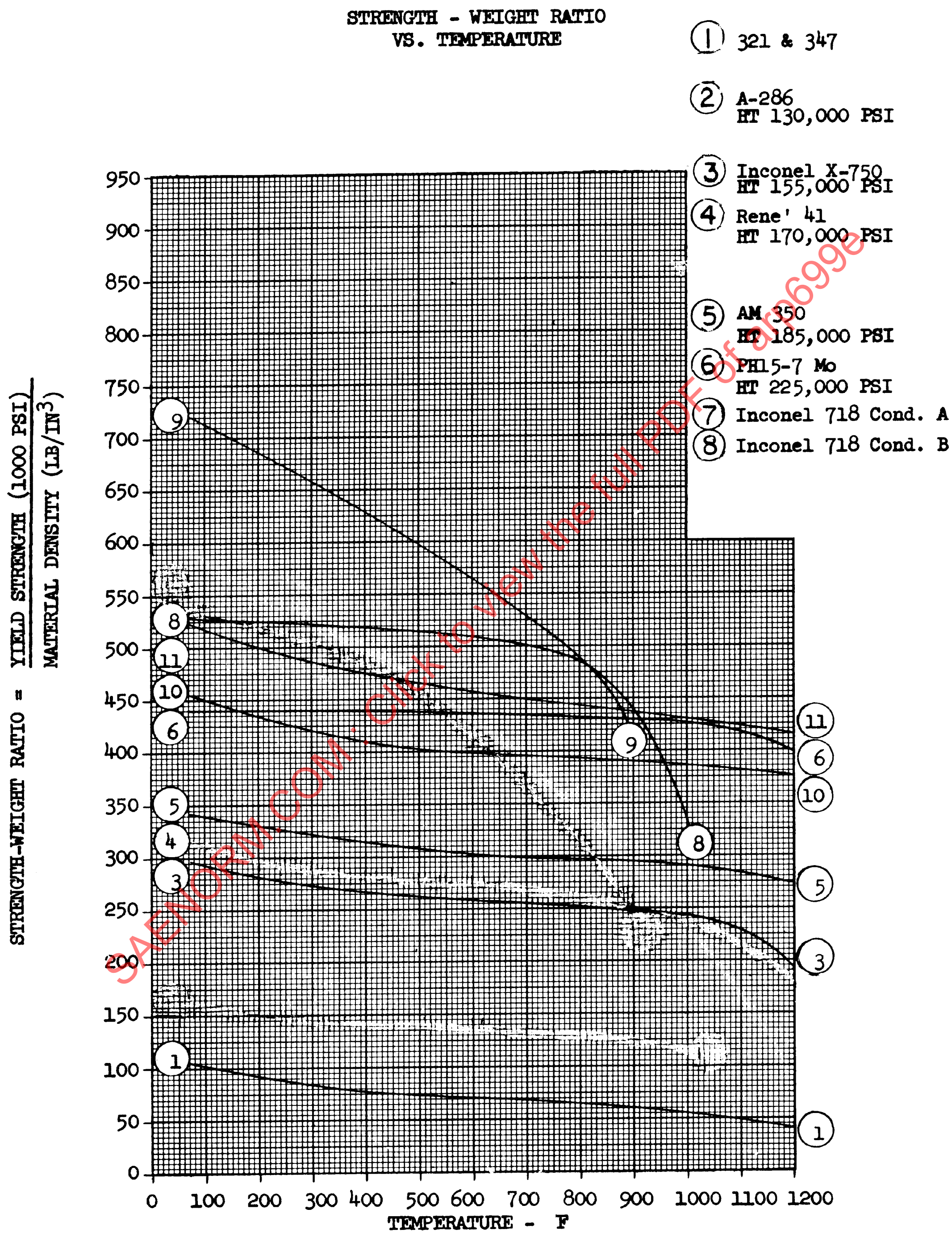

STRENGTH - WEIGHT RATIO
VS. TEMPERATURE
1 321 & 347
2 A-286
HT 130,000 PSI
3 Inconel X-750
HT 155,000 PSI
4 Rene' 41
HT 170,000 PSI
5 AM 350
HT 185,000 PSI
6 PH15-7 Mo
HT 225,000 PSI
7 Inconel 718 Cond. A
8 Inconel 718 Cond. B
STRENGTH-WEIGHT RATIO = YIELD STRENGTH (1000 PSI) / MATERIAL DENSITY (LB/IN3)
TEMPERATURE - F
0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
9 8 11 10 6 5 4 3 1

FIGURE 8

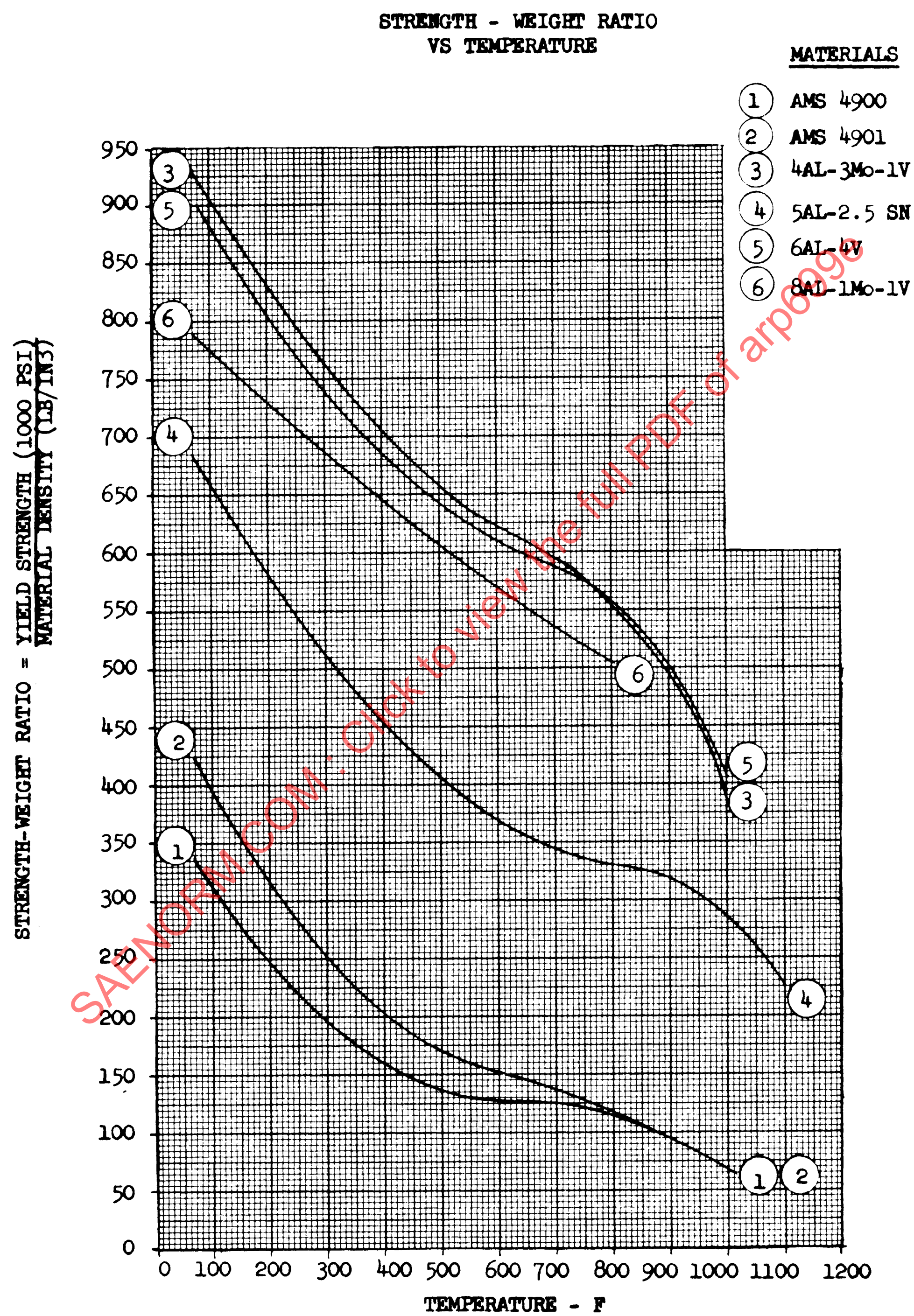

STRENGTH - WEIGHT RATIO
VS TEMPERATURE
MATERIALS
1 AMS 4900
2 AMS 4901
3 4AL-3Mo-1V
4 5AL-2.5 SN
5 6AL-4V
6 8AL-1Mo-1V
STRENGTH-WEIGHT RATIO = YIELD STRENGTH (1000 PSI) / MATERIAL DENSITY (LB/IN3)
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200
TEMPERATURE - F

FIGURE 9

5.1.1.1 (Continued):

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

5.1.1.2 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.

5.1.1.2.1 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)
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)

5.1.1.2.1 (Continued):

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

5.1.1.3 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.

5.1.1.3.1 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.

5.1.1.3.2 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.

5.1.1.3.3 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.

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

TABLE 3

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

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

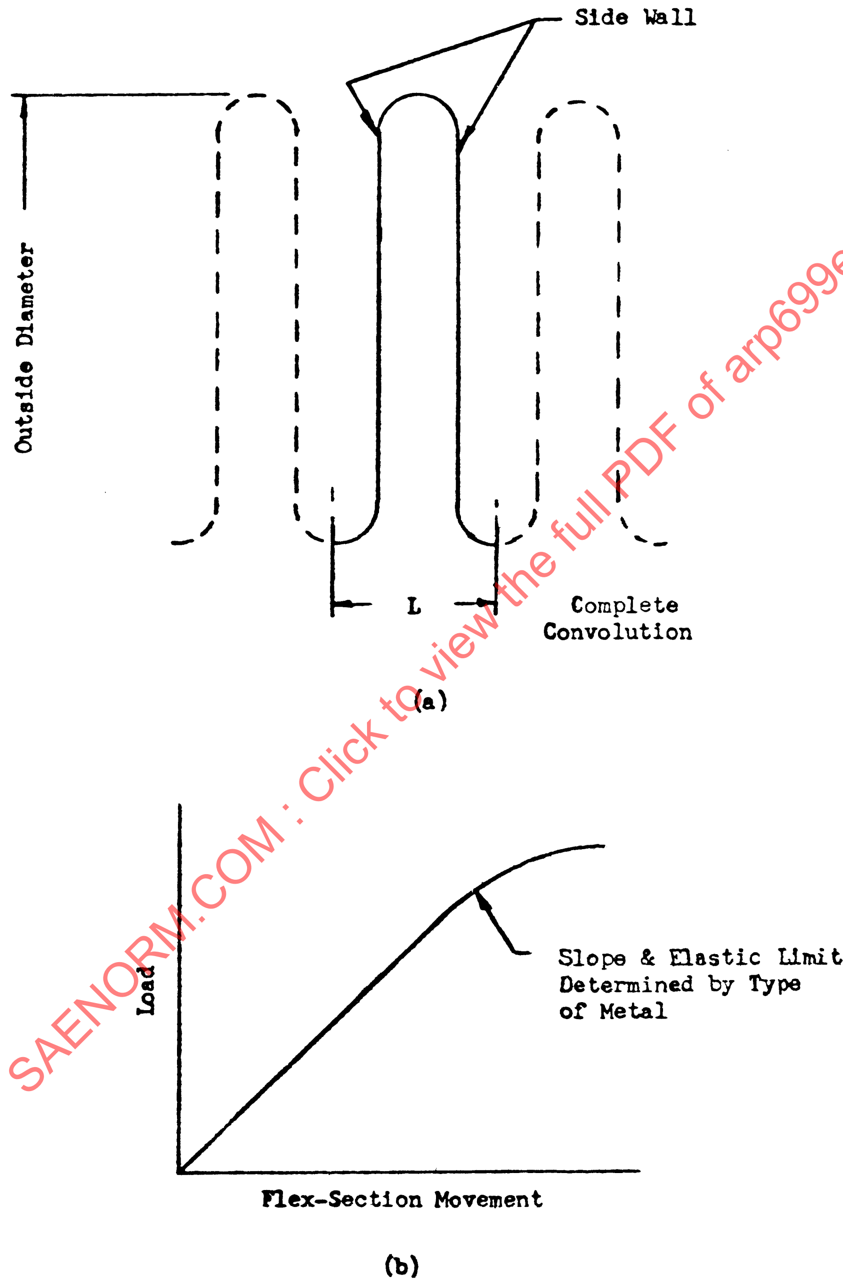
TABLE 4

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

5.1.1.5 Allowable Leakage: There shall be no leakage in the basic duct. Allowance shall be made for connector leakage and seal type compensator device leakage.

5.1.2 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.

5.1.2.1 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 10a. The stroke or deflection of a given bellows (constant convolute size and wall thickness) under load is similar to a helical spring (see Figure 10b). The word “Load” includes any force or combination of forces applied axially to cause the bellows to compress or extend, and can therefore refer to a pressure or mechanically applied load in either direction. The stroke is also directly proportional to the number of convolutions and inversely proportional to some power of the wall thickness. In actual practice it has been found that two-plies, with a total thickness equal to a single ply, will provide at least twice the flexibility of the single ply. Multi-ply bellows can therefore be used for high pressures without excessive loss in flexibility. 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.



FREE BELLOWS DATA

FIGURE 10

5.1.2.1.1 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.

5.1.2.1.2 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.

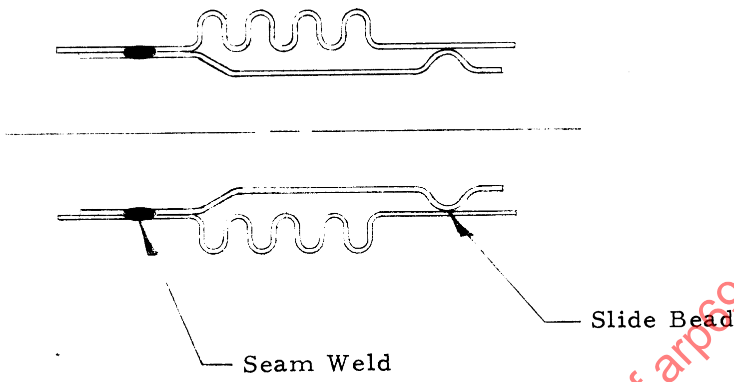
D. Axial offset (if required): $\frac{.02L^2}{D}$ (Max), although $\frac{.25L^2}{D}$ has been successfully attained; where L = length of bellows and D = nominal duct diameter.

E. Torsional deflection: Preferably none.

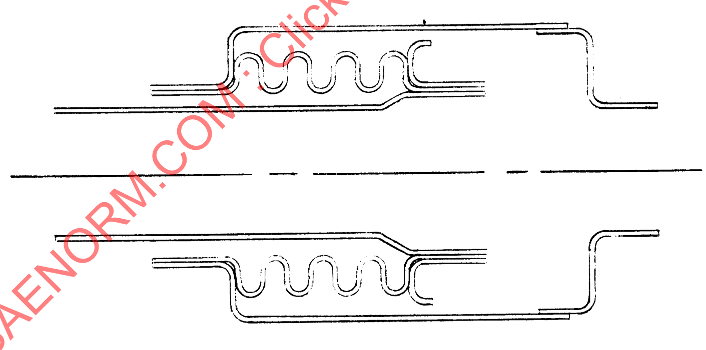
F. Ratio of bellows length to inside diameter: Generally, 1/2 to 1-1/2; however, exceptions can be made.

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 11, 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 11, 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.

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.



LINED FREE BELLOWS



COMPRESSION SYSTEM BELLOWS

FIGURE 11

5.1.2.1.3 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.

5.1.2.2 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 12, are the gimbal, tie rod and braided.

5.1.2.2.1 Gimbal Type: These units are made with internal or external gimbal supports as shown in Figure 12 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 13. The primary advantage of this type unit is its ability to provide angular deflection with a small actuating force.

5.1.2.2.2 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 12 and 14. 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.

5.1.2.2.3 Ball Type: The ball joint shown in Figure 15 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.

5.1.2.2.4 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.

5.1.2.2.5 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.

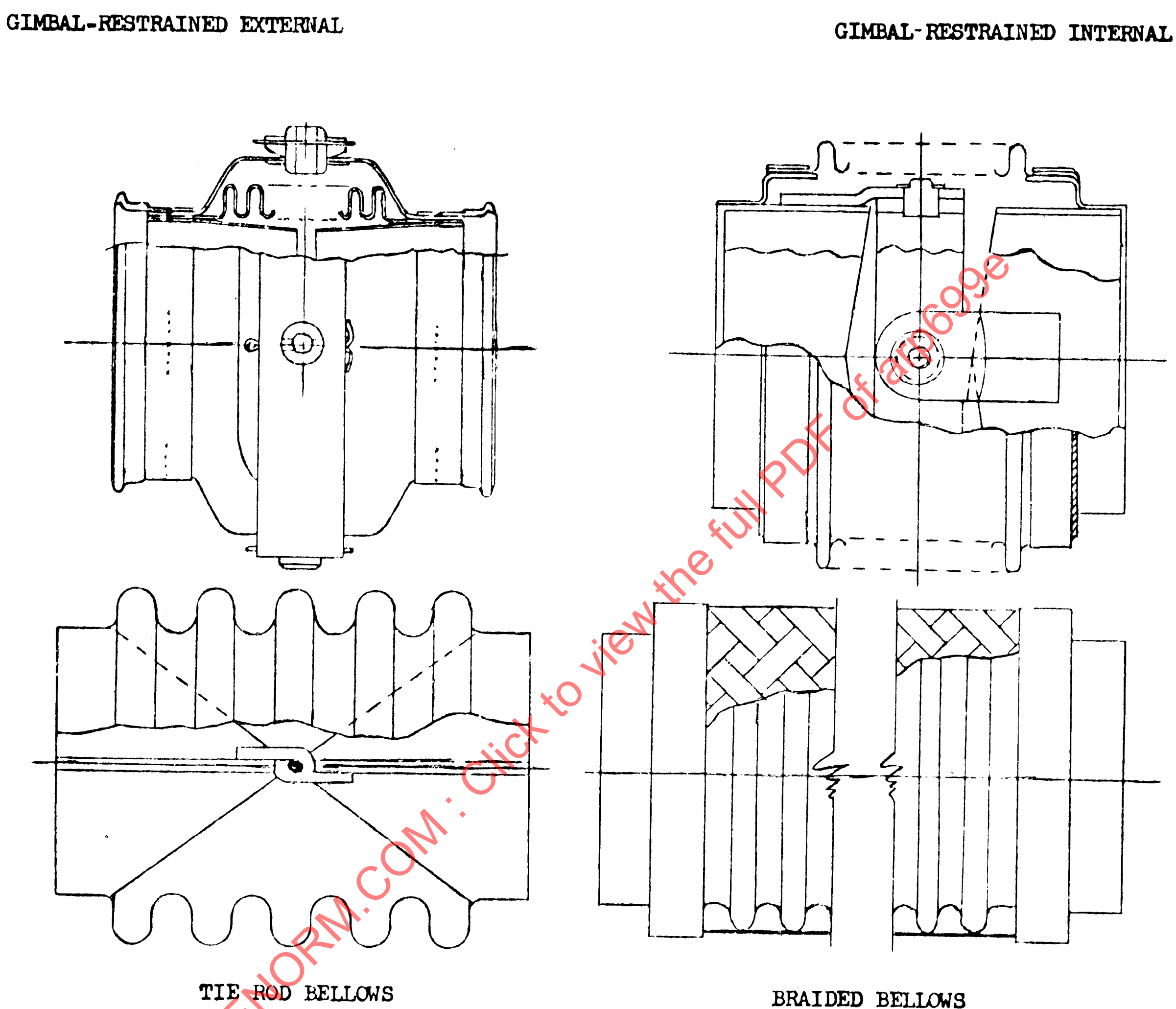

GIMBAL-RESTRAINED EXTERNAL
GIMBAL-RESTRAINED INTERNAL
TIE ROD BELLOWS
BRAIDED BELLOWS

FIGURE 12

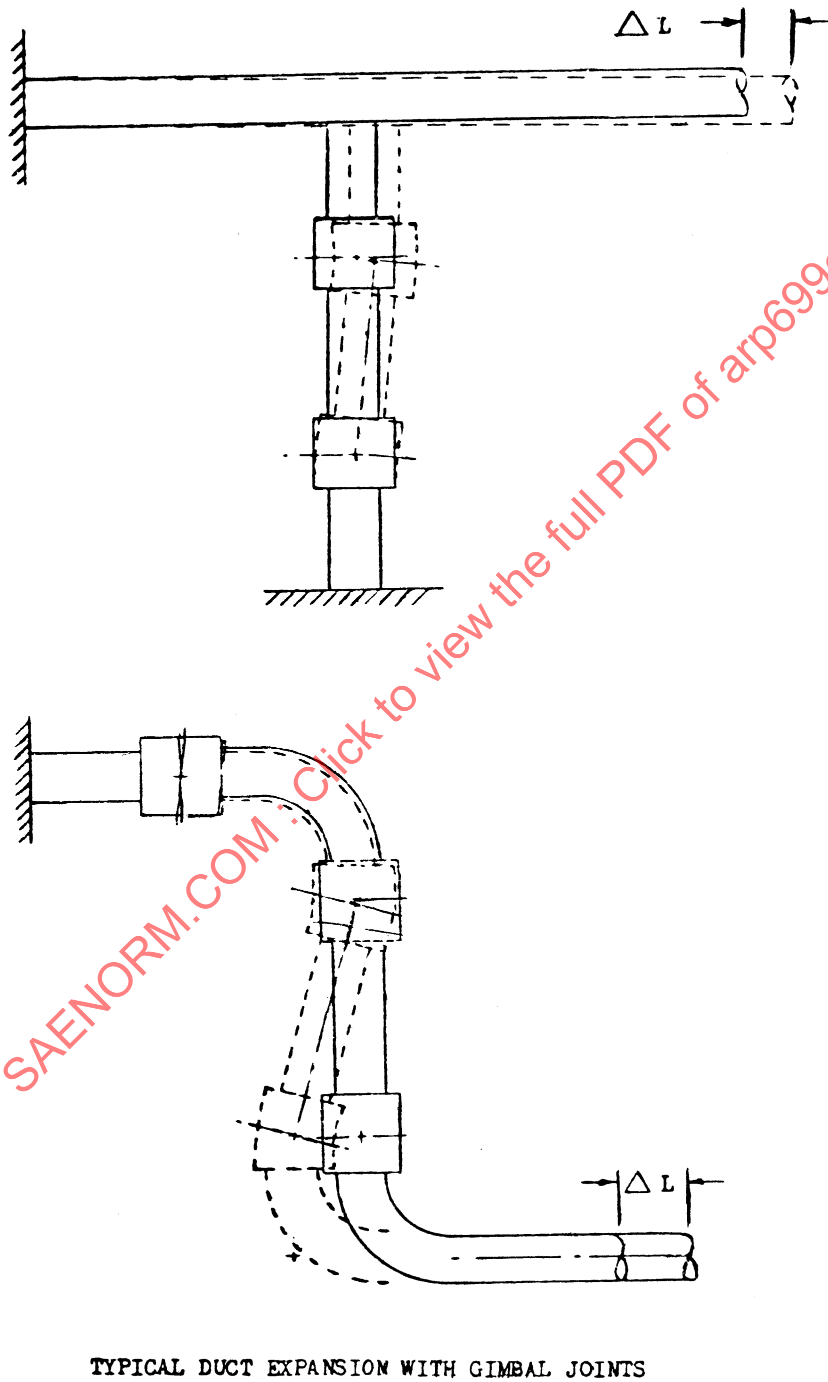


FIGURE 13 - Typical Duct Expansion With Gimbal Joints

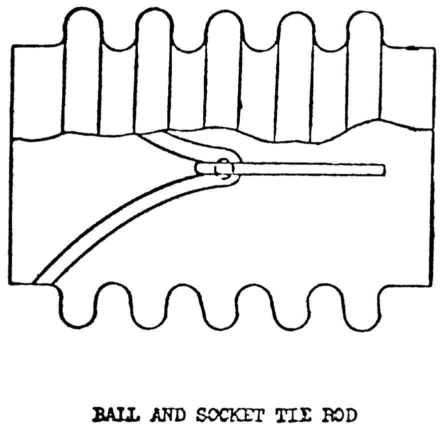


FIGURE 14 - Ball and Socket Tie Rod

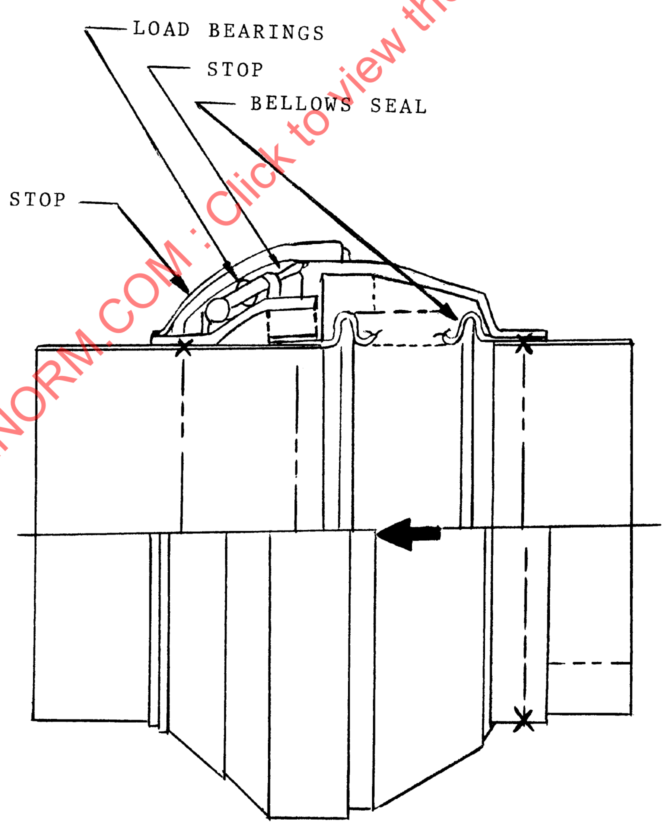


FIGURE 15 - Ball Joint

5.1.2.2.6 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.

5.1.2.2.7 Statement of Design Requirements: Applicable information from 5.1.2.1.3 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.

5.1.2.3 Compensating Joint (Figure 16): 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 13, 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 17 shows a 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.

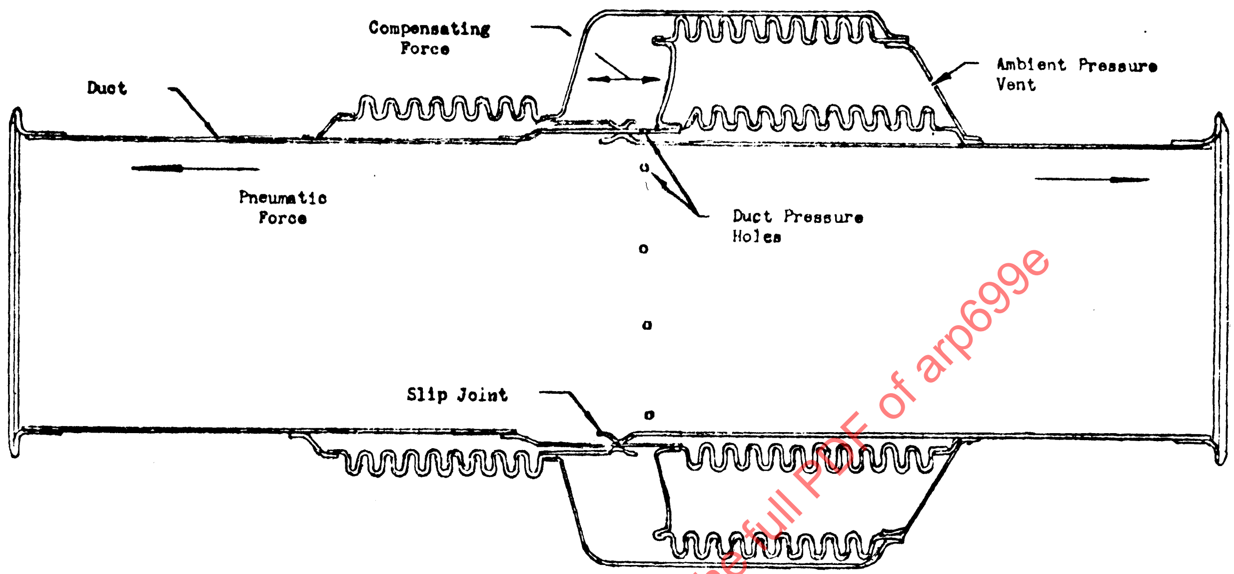


FIGURE 16 - Pressure Compensating Bellows

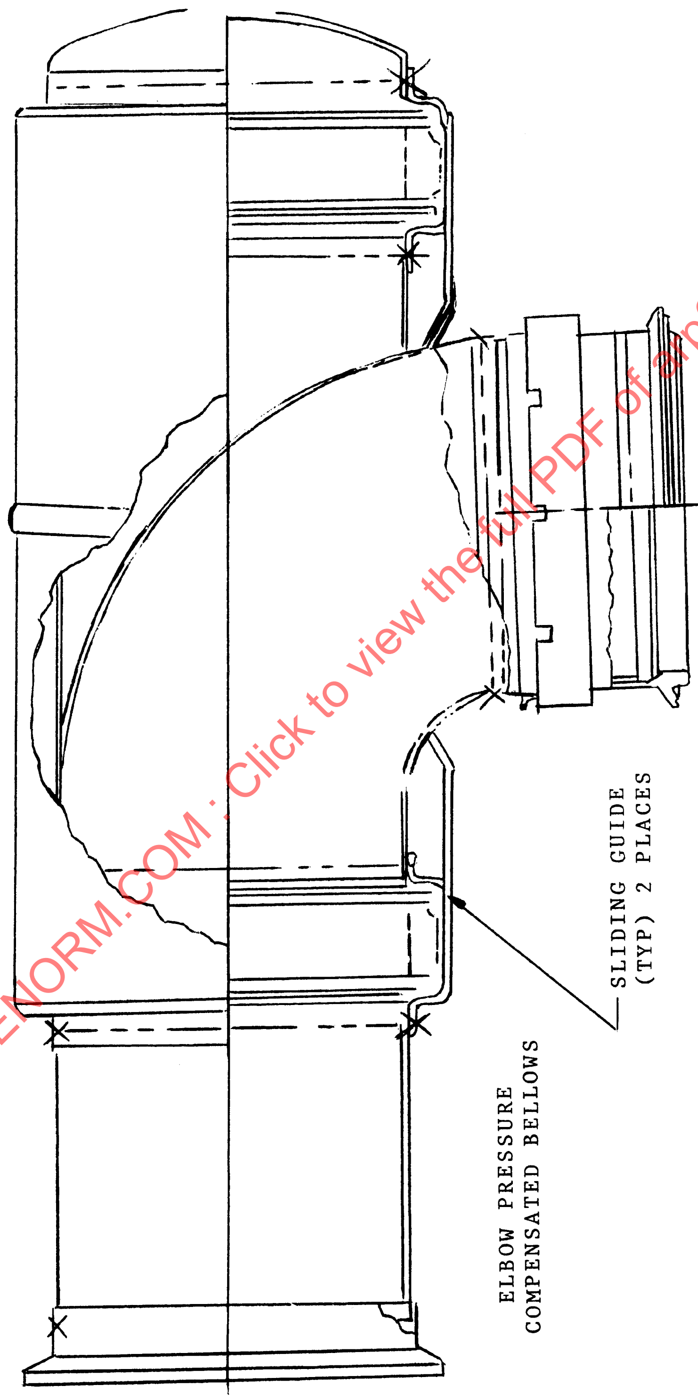


FIGURE 17 - Pressure Compensating Elbow

5.1.2.3.1 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.

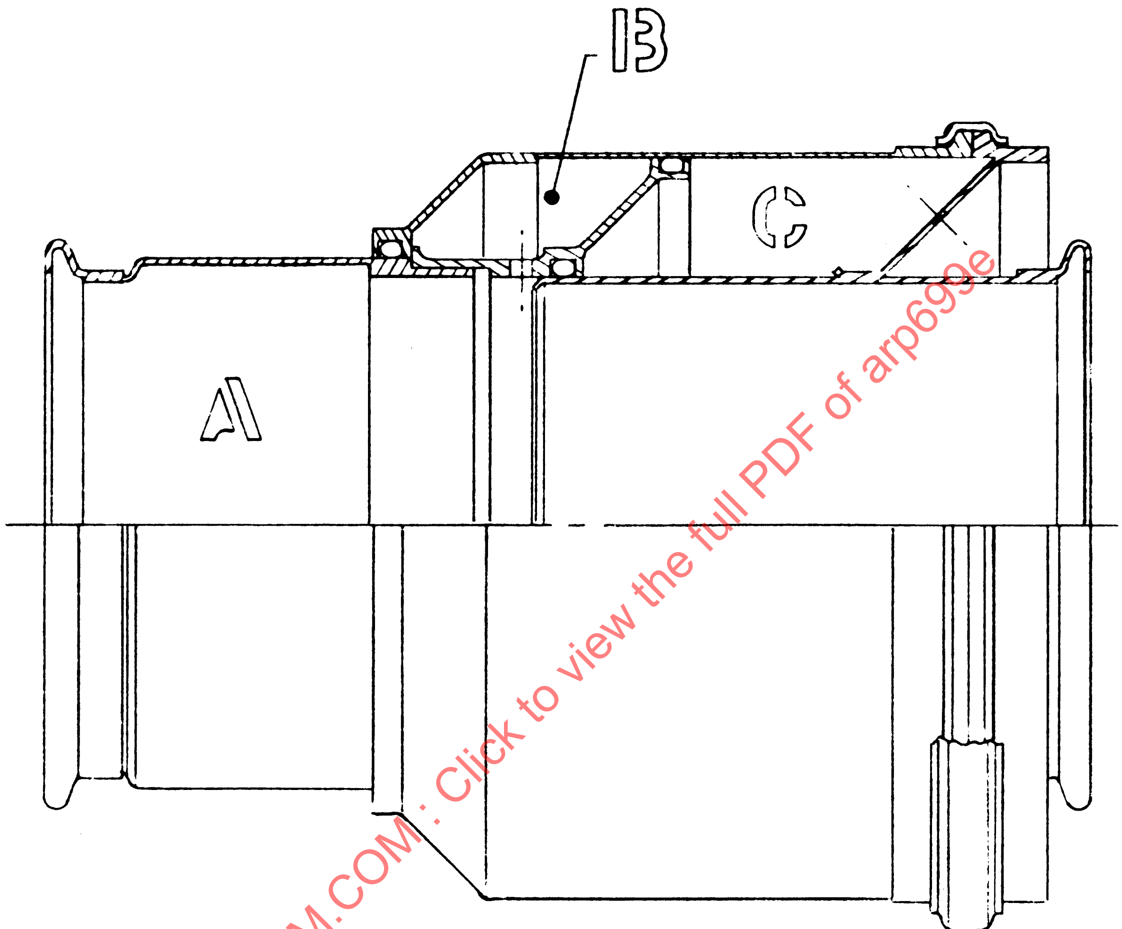
5.1.2.3.2 Statement of Design Requirements: Applicable information from 5.1.2.1.3 should be specified as needed for compensating joints. The following additional requirements are usually necessary:

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).

5.1.2.4 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.



AREA "A" = DUCT OR LINE SIZE

AREA "B" = BALANCE CHAMBER

AREA "C" = VENT CHAMBER

FIGURE 18 - Seal Type Pressure Compensator

5.1.2.4.1 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.

5.1.2.4.2 Statement of Design Requirements: Applicable information from 5.1.2.1.3 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).

5.1.2.5 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 19. The following information shows the comparative expansion values of several type bends:

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

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

C. An omega has 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 5.1.1.3 for strength requirements applicable to ducts used in expansion bends.

5.1.2.6 Slip Joint: The slip joint shown in Figure 20 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.

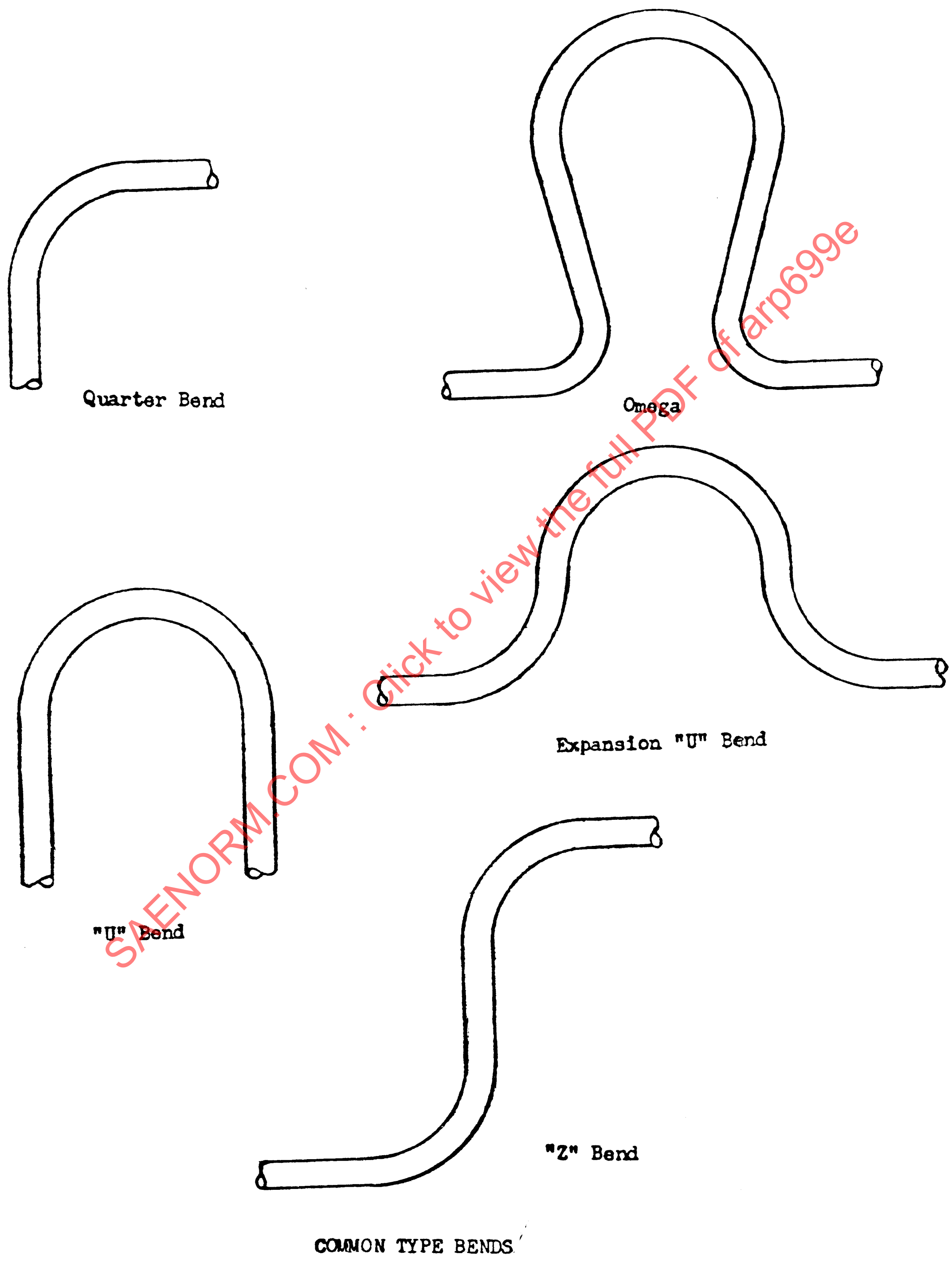
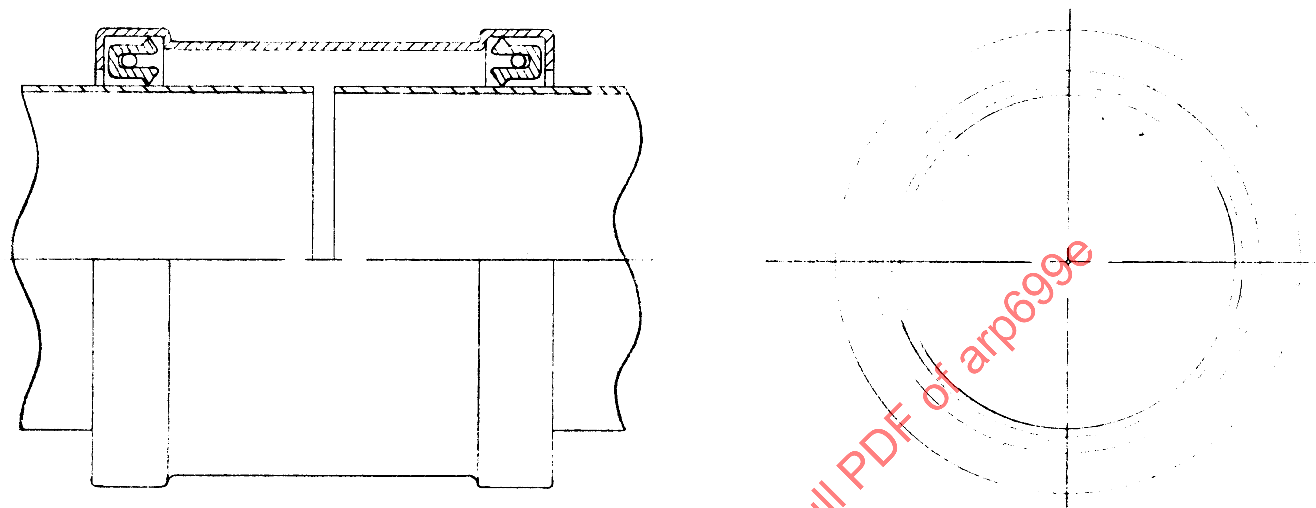


FIGURE 19 - Common Type Bends



FLEXIBLE DUCT CONNECTOR

MATERIAL: CRES/TEFLON
PRESSURE: 125 PSIG
TEMPERATURE: -60° TO 500°F

FIGURE 20

5.1.2.7 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 22 shows two rotary joints interconnected by a “U”-shaped duct.

A. The axial center lines of the rotary joints must be at right angles (normal) to the run of 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.

5.1.3 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.

5.1.3.1 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.

5.1.3.2 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 5.1.6.1.4.

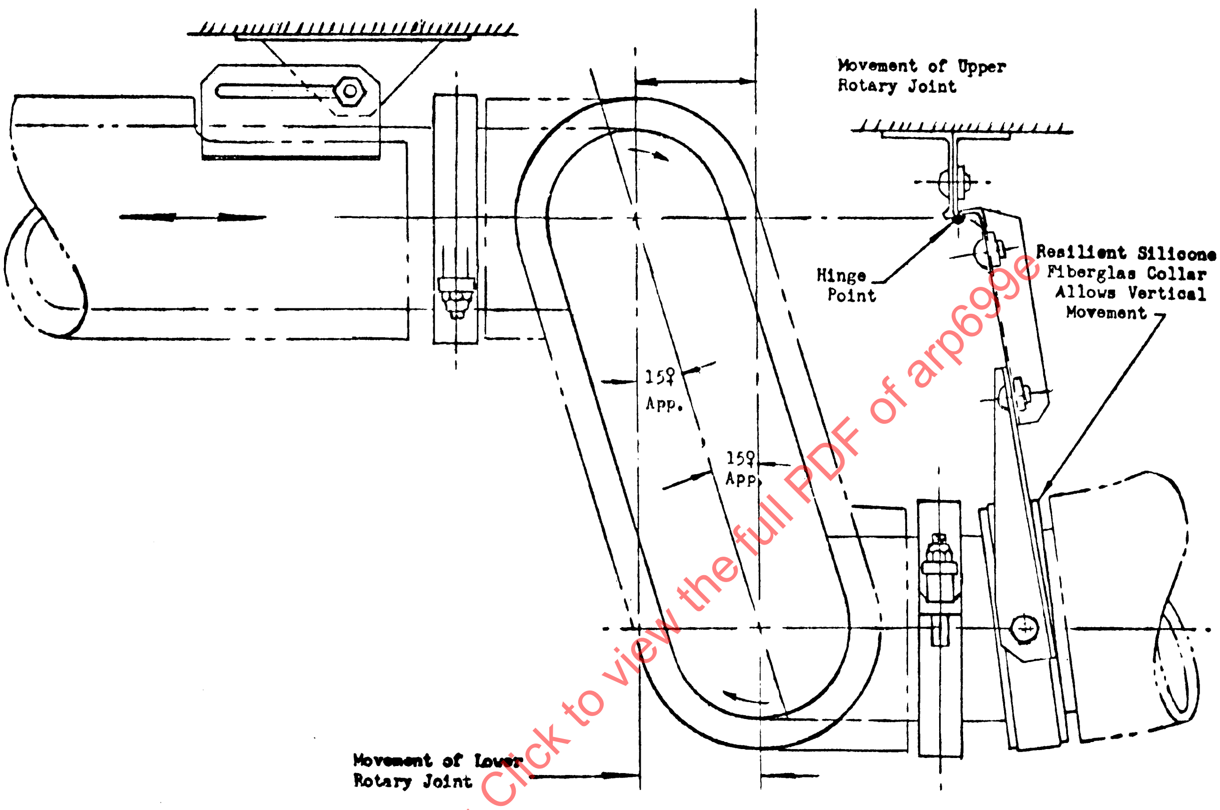


FIGURE 21 - Rotary Joint Installation Typical

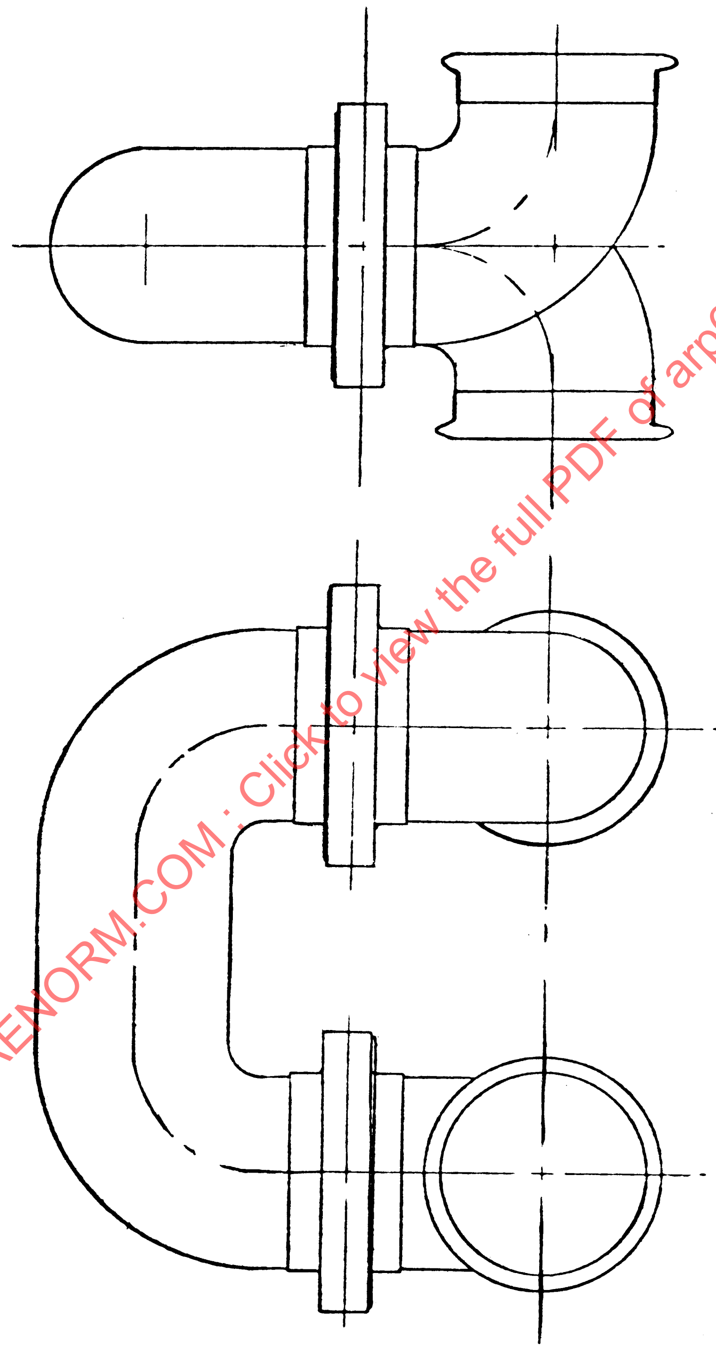


FIGURE 22 - Rotary Joint Assembly for Endurance Test

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

5.1.4.1 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 5.1.4.2. 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 5.1.4.2.

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.

5.1.4.2 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.

5.1.4.3 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.

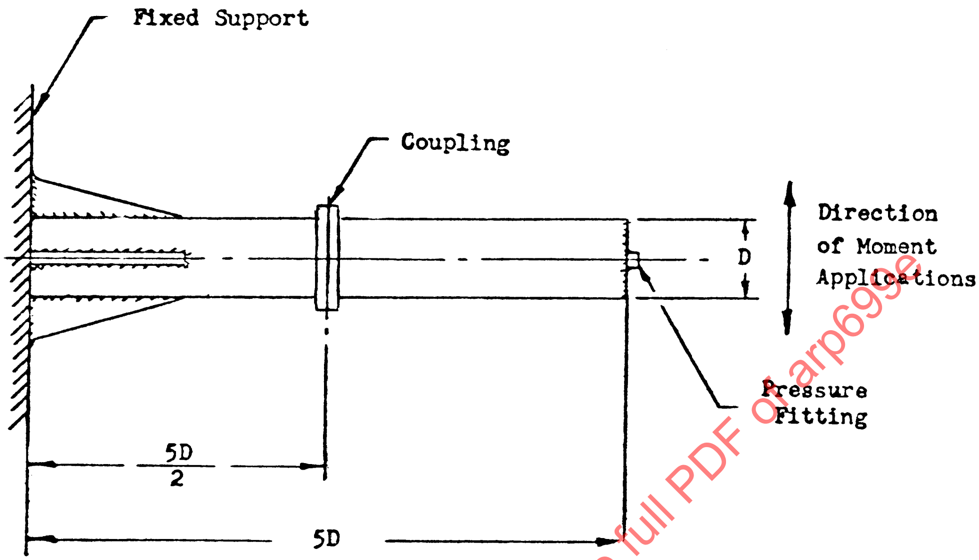


FIGURE 23

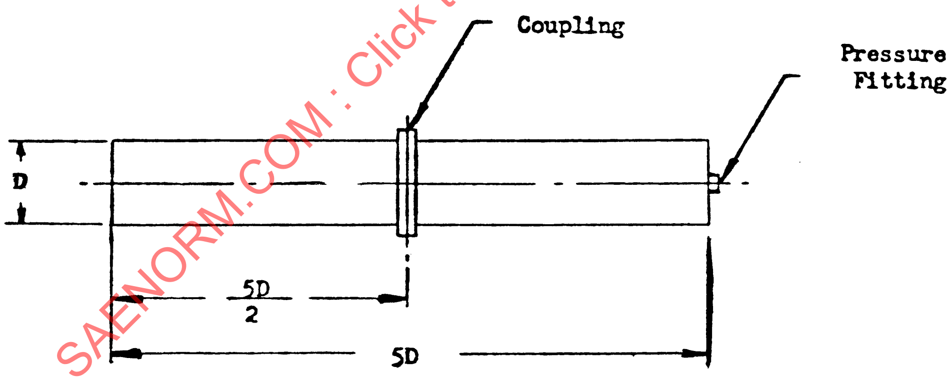


FIGURE 24

5.1.4.3.1 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).

5.1.4.3.1.1 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.

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

5.1.4.3.1.3 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.

5.1.4.3.2 Visual Device: The added coupling strap of 5.1.4.3.1.1 will act as a visual device since the strap will not conform to the “safetied” contour if the tee bolt fails.

5.1.4.4 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.

5.1.4.5 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.

5.1.4.6 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.

5.1.4.6.1 "V" Band Joints:

Type "A"

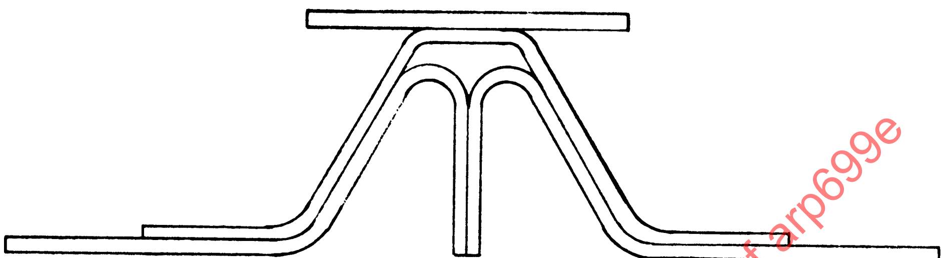


FIGURE 25

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 inches-pounds.

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.

5.1.4.6.1 (Continued):

Type "B"

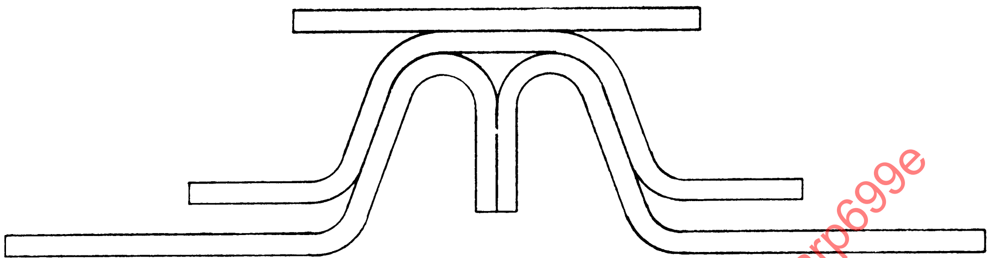


FIGURE 26

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 inches-pounds.

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.

5.1.4.6.1 (Continued):

Type "C"

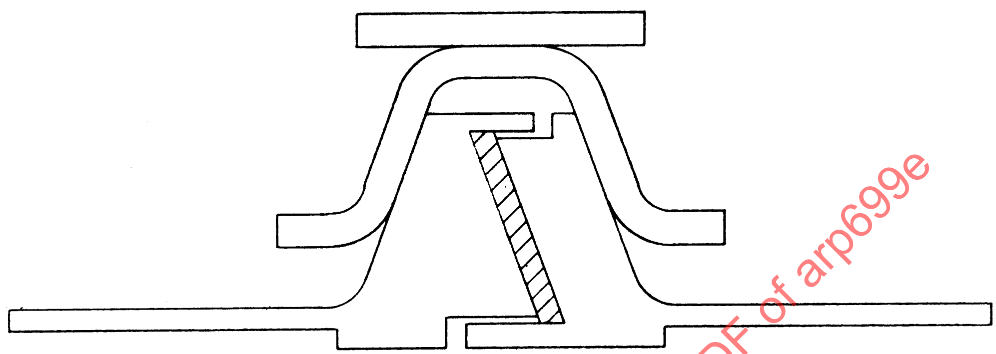


FIGURE 27

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 inches-pounds.

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.

5.1.4.6.1 (Continued):

Type “D”

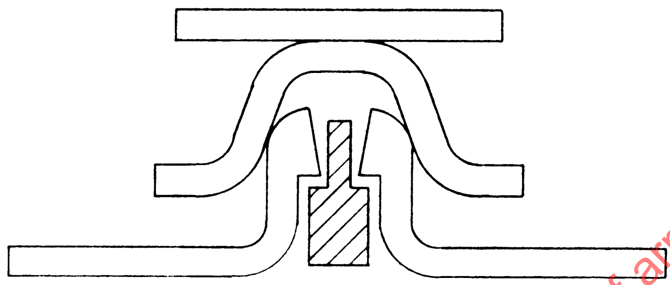


FIGURE 28

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 $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M inches-pounds.

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.

5.1.4.6.1 (Continued):

Type “Special”

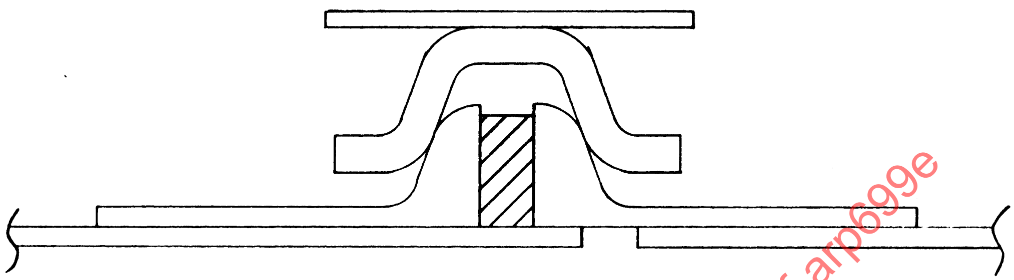


FIGURE 29

Materials: 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.

5.1.4.6.2 Bolted Joints:

Type “A”, “B”, and “D”.

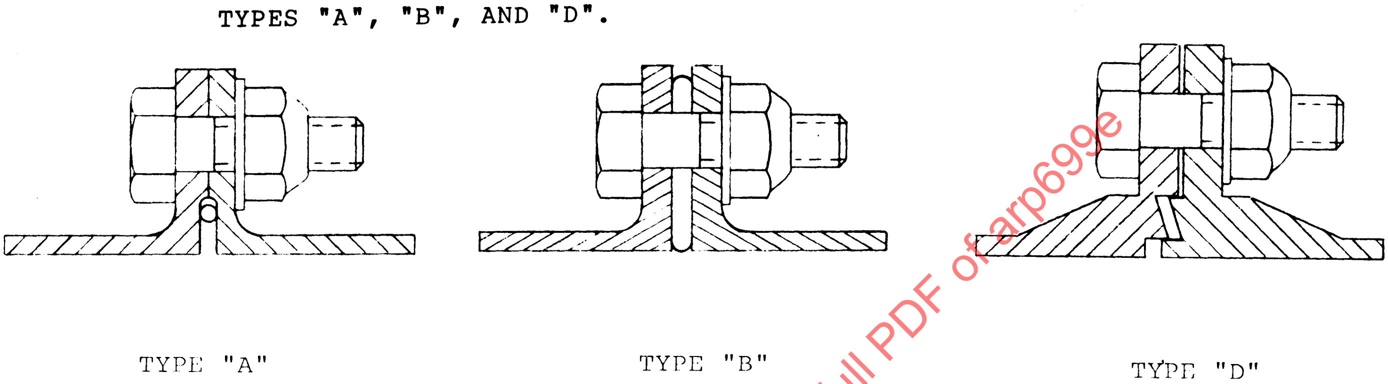


FIGURE 30

Materials: Corrosion resistant steel.

Tools to Install: Torque wrenches.

Duct Sizes: Type “A” joints are available in the following sizes: 1.75 inch, 2.50 inch, 2.75 inch, 3.50 inch, 4.00 inch, 4.50 inch, 5.00 inch.

Type “B” joints are available in 2 inch and 3 inch 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 57 for pressures applicable to type “D”. Also reduce operating pressures by $\frac{16M}{\pi D^3}$ to allow for maximum applied bending moment M inches-pounds.

Maximum Operating Temperature: 750 °F for all sizes of types “A” and “B”. See page 57 for the temperature applicable to type “D”.

Remarks: Maximum operating temperature is 750 °F when steel gaskets are used with types “A” and “B”.

5.1.4.6.2 (Continued):

"Forged Type" and "Wrought Type"

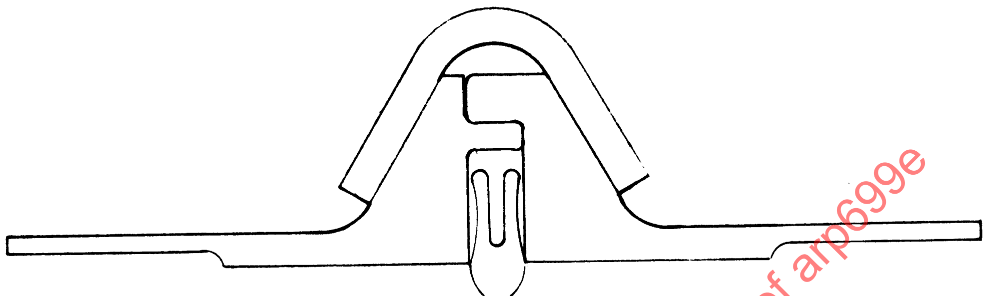


FIGURE 31

Materials: Inconel and A-286.

Tools to Install: 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 inches-pounds.

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.

5.1.4.6.2 (Continued):

Type “C”

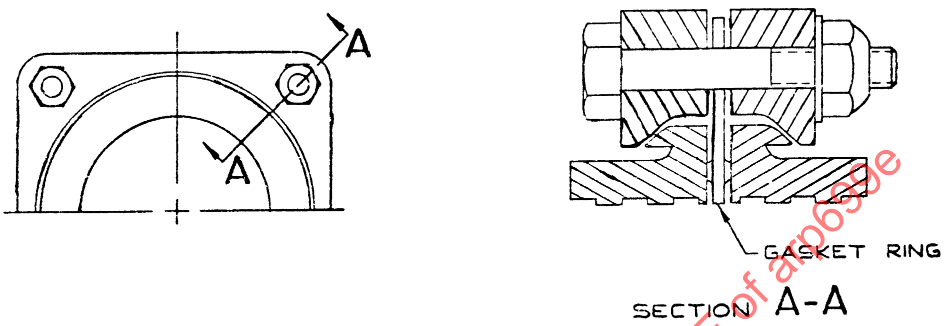


FIGURE 32

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 Temperature: 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.

5.1.4.6.3 Threaded Joints:

Type “A”.

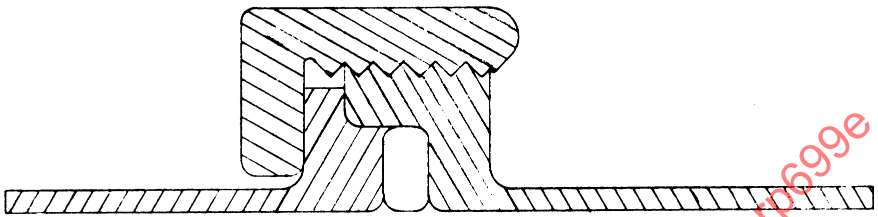


FIGURE 33

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 inches-pounds.

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 inches) due to high torque required to seat metallic gaskets.

5.1.4.6.3 (Continued):

Type "B".

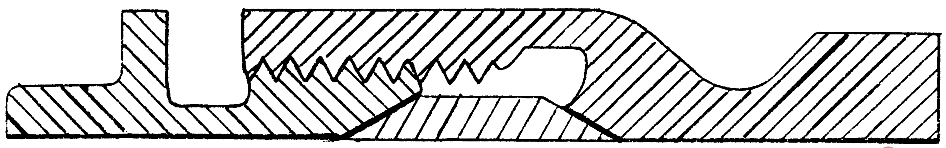


FIGURE 34

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.

5.1.4.6.3 (Continued):

Type “A”.

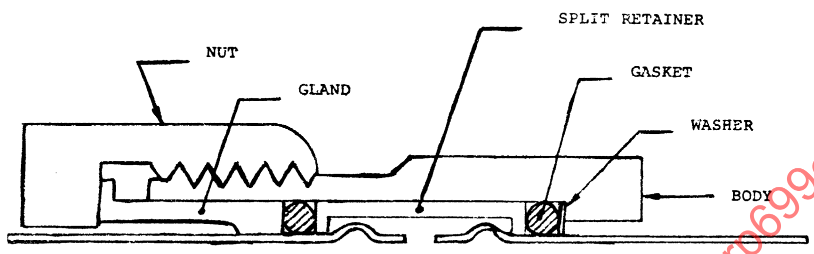


FIGURE 35

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.

5.1.4.6.3 (Continued):

Type "B".

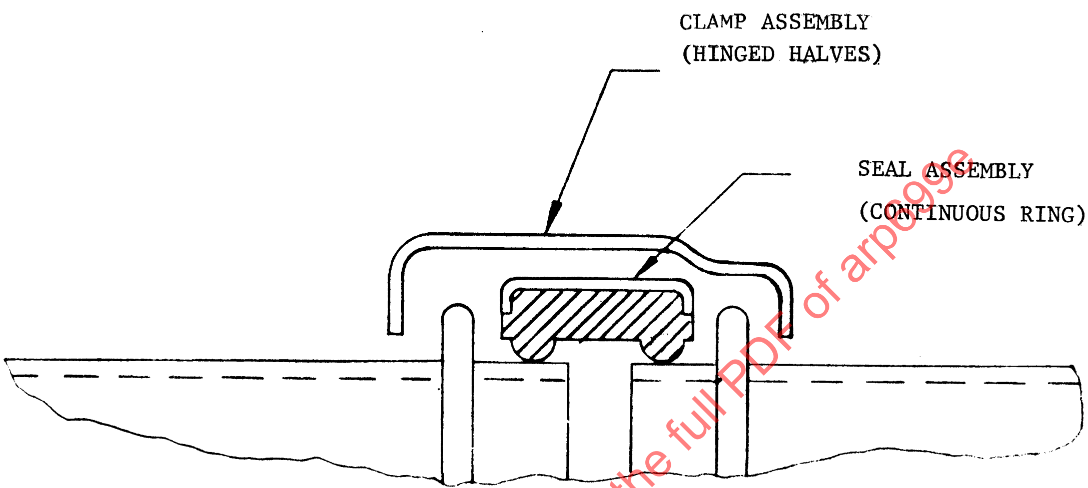


FIGURE 36

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 ±4°. Capable of absorbing some rotary and axial motion.

5.1.4.6.3 (Continued):

Type “C”.

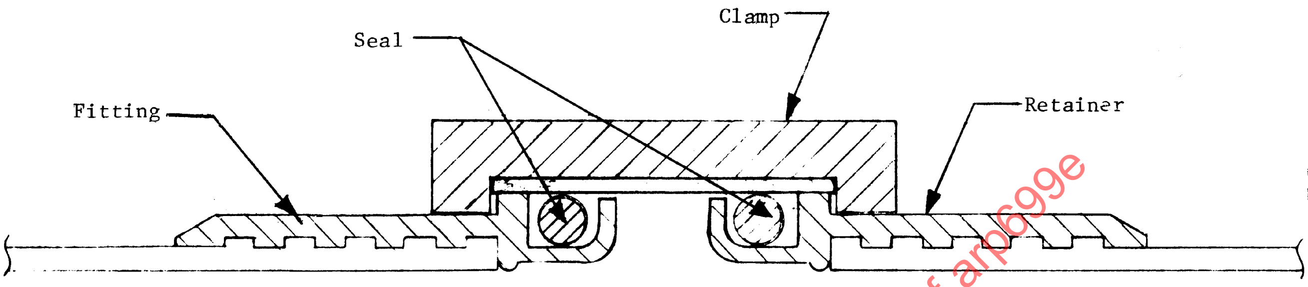


FIGURE 37

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 ±4°. Capable of absorbing some rotary and axial motion.

5.1.4.6.3 (Continued):

Type “D”.

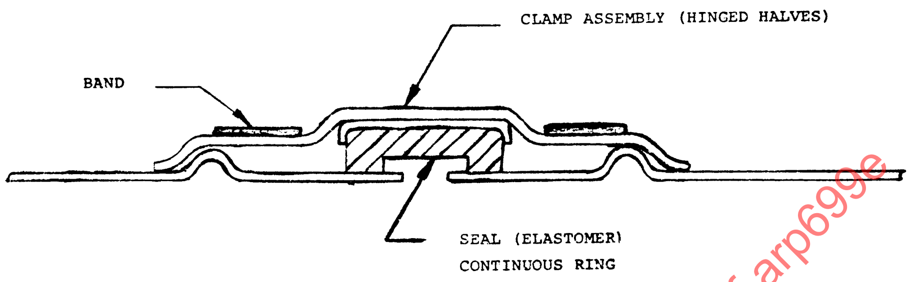


FIGURE 38

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 ±4°. Capable of absorbing some rotary and axial motion.

5.1.5 Duct System Design Loads:

5.1.5.1 Design Operating Conditions: All ducts must be designed to withstand proof and burst pressure conditions as outlined in 5.1.1.3.

5.1.5.2 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.

5.1.5.3 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.

5.1.5.4 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.

5.1.5.5 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.

5.1.5.6 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.

5.1.5.7 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.

5.1.5.8 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.

5.1.5.9 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.

5.1.6 Duct System Supports:

5.1.6.1 Compression Systems:

5.1.6.1.1 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.

5.1.6.1.2 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.

5.1.6.1.2.1 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 inches 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.

5.1.6.1.2.2 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.

5.1.6.1.2.3 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.

5.1.6.1.3 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.

5.1.6.1.3.1 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.

5.1.6.1.4 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.

5.1.6.2 Tension Systems:

5.1.6.2.1 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.

5.1.6.2.2 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.

5.1.6.2.2.1 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 5.1.6.1.3.1 in areas where brackets may be inadvertently used as “hand-holds” or steps, the minimum design load should be 200 pounds in all directions.

5.1.6.2.3 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.

5.1.7 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.

5.1.7.1 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.

5.1.7.1.1 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

TABLE 5

Temp. Limit	Material	Advantages	Disadvantages
400 °F	Aluminum	Light weight, low cost	Poor durability and formability
1600 °F	Stainless Steel	Formability Durability	Weight, medium cost
1800 °F	Inconel	Formability Strength Corrosion resistant	Weight and high cost

5.1.7.1.1 (Continued):

B. Coated Fabric Coverings

TABLE 6

Temp. Limit	Fabric	Coating	Advantage	Primary Disadvantage
175 °F	Glass, cotton or synthetic	Vinyl plastic	Low cost, fuel and oil resistance, good abrasion resistance	Low temperature limit
275 °F	Glass	Neoprene rubber	Weather and oil resistance, good abrasion resistance	Low temperature limit
275 °F	Glass	Nitrile rubber	Good fuel and oil resistance, good abrasion resistance	Poor weather resistance
500 °F	Glass	Phenolic resin or silicone rubber	High temperature and good weather resis-tant	Poor abrasion and fuel resistance

5.1.7.1.1 (Continued):

C. Insulating Materials

TABLE 7

Temp. Limit	Material	Density lb/ft^3	Advantages	Disadvantages
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.

5.1.7.1.2 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 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.

5.1.7.1.3 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.

5.1.7.2 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.

5.1.7.3 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.

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

TABLE 8

Temp. Limit	Material	Condition	General Applications
400 °F	Hi-temp thermo setting resin impregnated glass cloth	Rigid sheet	Insulation at structural attachment
500 °F	Silicone-impregnated glass cloth	Rigid sheet	Insulation at structural attachment
1000 °F	Compressed mineral board	Rigid sheet	Insulation shield (very little structural strength)
1100 °F	Glass fibers	Batting	Wrap-around insulation between duct and support
1200 °F	Asbestos*	Rigid sheet	Insulation shield (very little structural strength)
1200 °F	Asbestos*	Heavy fabric	Wrap-around insulation between duct and support
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.

5.2 Qualification Requirements:

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

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

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

B. Pressure: ±3% of absolute value

C. Flow: ±5%

D. Vibration amplitude: ±5%

E. Vibration frequency: ±2%

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

A. Leakage Test

B. Proof Pressure Test

C. Endurance Test

D. Vibration Test

E. Burst Pressure Test

5.2.1.1.1 Test Conditions:

5.2.1.1.1.1 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.

5.2.1.1.2 Tests:

5.2.1.1.2.1 Leakage Test: Leakage test shall be conducted at room temperature and proof pressure as indicated in 5.2.1.1.2.2. No leakage of the basic duct shall be permitted.

5.2.1.1.2.2 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 5.1.1.3. 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.

5.2.1.1.2.2.1 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.

5.2.1.1.2.3 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 5.2.1.1.2.2. No part of the duct shall fail, take any permanent set or be damaged in any manner as a result of this test.

5.2.1.1.2.4 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.

5.2.1.1.2.4.1 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.

5.2.1.1.2.4.2 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.

5.2.1.1.2.5 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 5.1.1.3. 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.

5.2.1.2 Qualification Tests of Compensation and Deflection Devices:

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

A. Leakage Test
B. Flow Resonance Test
C. Proof Pressure Test
D. Pressure Drop Test
E. Endurance Test
F. Vibration Test
G. Deflection Force Test
H. Burst Pressure Test

5.2.1.2.1.1 Test Conditions:

5.2.1.2.1.1.1 Ambient Temperature and Pressure: Same as 5.2.1.1.1.

5.2.1.2.1.2 Tests:

5.2.1.2.1.2.1 Leakage Test: Same as 5.2.1.1.2.1.

5.2.1.2.1.2.2 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.

5.2.1.2.1.2.3 Proof Pressure Test: Same as 5.2.1.1.2.2.

5.2.1.2.1.2.4 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.

5.2.1.2.1.2.5 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 5.2.1.1.2.2 and the deflection force test of 5.2.1.2.1.2.7. 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.

5.2.1.2.1.2.6 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.

5.2.1.2.1.2.7 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.

5.2.1.2.1.2.8 Burst Pressure Test: Same as 5.2.1.1.2.5.

5.2.1.2.2 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

5.2.1.2.2.1 Test Conditions:

5.2.1.2.2.1.1 Ambient Temperature and Pressure: Same as 5.2.1.1.1.1.

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

5.2.1.2.2.2.1 Leakage Test: Same as 5.2.1.1.2.1.

5.2.1.2.2.2.2 Flow Resonance Test: Same as 5.2.1.2.1.2.2. 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.

5.2.1.2.2.2.3 Proof Pressure Test: Same as 5.2.1.1.2.2.

5.2.1.2.2.2.4 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 5.1.2.1.2, where "L" is the bellows length and "D" is the nominal duct diameter, as shown in Figure 39. 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 5.2.1.1.2.2.

5.2.1.2.2.2.5 Vibration Test: Same as 5.2.1.2.1.2.6.

5.2.1.2.2.2.6 Burst Pressure Test: Same as 5.2.1.1.2.5.

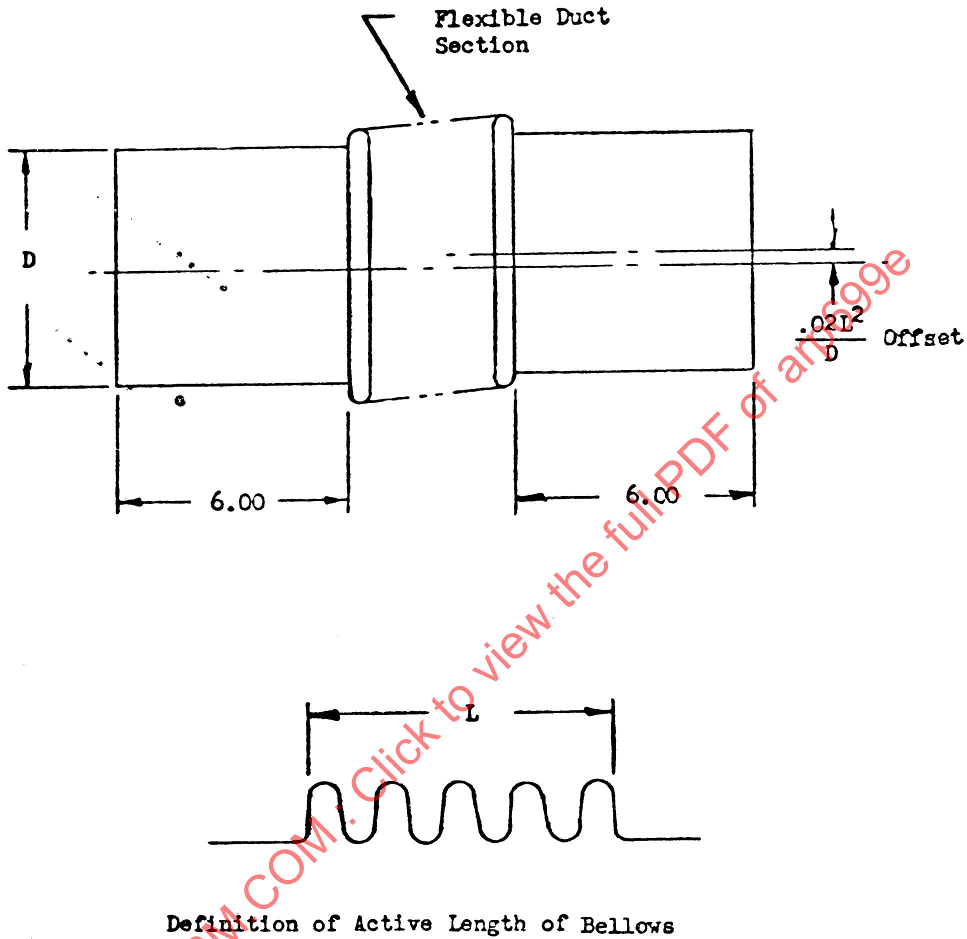


FIGURE 39 - Endurance Test Set-Up for Free Bellows