AEROSPACE RECOMMENDED PRACTICE

Society of Automotive Engineers, Inc.
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RECOMMENDED PRACTICE FOR THE DESIGN OF TUBING INSTALLATIONS FOR AEROSPACE FLUID POWER SYSTEMS

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1. SCOPE

This document is a compendium of recommended practices for the design of tubing systems for the transmission of liquid and gasses in fluid power systems for aerospace vehicles such as aircraft, missiles and boosters, and is considered applicable to the design of future space vehicles and other applications using aircraft technology. Primary emphasis is given to recommended practices for line sizing, tube routing, supports and clamping, stress considerations and permissible defects, and provisions for flexure through the use of flexible hoses, coiled tubes, swivel joints, and expansion glands. Fluid power systems are differentiated from the normal aircraft fuel and oil systems and the various fluid systems used for environmental control and air conditioning systems; however, the practices cited herein will in many cases be applicable to these other systems.

A section (3) regarding tubing materials and fitting types currently in use is included for reference, but particular recommendations are purposely avoided since their selection is dependent upon the specific requirements of each particular vehicle system and many other factors.

2. APPLICABLE DOCUMENTS

Specifications, standards, and drawings which are included in this document are listed in this section. Other references are listed in Section 16, Bibliography.

2.1 Specifications:

2.1.1 Federal Specifications:

F.A.R. 25 Federal Aviation Regulations, Volume III, Part 25, Airworthiness. Standards: Transport Category Airplanes.

WW-T-787 Tubing; Aluminum Alloy (Al-52) (Aluminum-Magnesium-Chromium); Round, Seamless.

2.1.2 Military Specifications:

MIL-S-4043 Steel, Corrosion-Resistant (Extra Low Carbon Type 304) Plate, Sheet, and Strip

MIL-B-5087 Bonding, Electrical, and Lightning Protection, for Aerospace Systems

MIL-H-5440 Hydraulic Systems, Aircraft, Types I and II, Design, Installation, and Data Requirements for

MIL-F-5509 Fittings, Flared Tube, Fluid Connections

MIL-J-5513 Joints, Hydraulic Swivel

MIL-P-5518 Pneumatic, Systems, Aircraft; Design, Installation, and Data Requirements for

MIL-C-5541 Chemical Films and Chemical Film Materials for Aluminum Alloys

MIL-H-5606 Hydraulic Fluid, Petroleum Base, Aircraft, Missile and Ordnance

MIL-T-6845 Tubing, Steel, Corrosion Resistant (304), Aerospace Vehicle Hydraulic Systems, 1/8 Hard Condition

MIL-T-7081 Tube, Aluminum Alloy, Seamless, Round, Drawn, 6061, Aircraft Hydraulic Quality

MIL-L-7808 Lubricating Oil, Aircraft Turbine Engine, Synthetic Base

MIL-T-8504 Tubing, Steel, Corrosion-Resistant (304), Aerospace Vehicle, Hydraulic Systems, Annealed, Seamless and Welded

MIL-T-8506 Tubing, Steel, Corrosion-Resistant (304), Annealed, Seamless, and Welded

MIL-A-8625 Anodic Coatings for Aluminum and Aluminum Alloys

MIL-C-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks, and Fuel Cell Cavities, High-Adhesion

MIL-T-8808 Tubing, Steel, Corrosion-Resistant (18-8 Stabilized) Aircraft Hydraulic Quality

MIL-H-8891 Hydraulic Systems, Manned Flight Vehicles, Type III, Design, Installation, and Data Requirements for

MIL-D-9898 Drawings, Tube Bend

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MIL-C-16173 Corrosion Preventive Compound, Solvent Cutback, Cold Application

MIL-F-18280 Fittings, Flareless Tube, Fluid Connection

MIL-C-25457 Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect

MIL-H-38360 Hose Assembly, Tetrapluaroethylene, High Temperature, High Pressure, Hydraulic and Pneumatic

2.1.3 NASA Specifications:

MSFC-SPEC-143 Fittings, Flared Tube, Pressure Connections

2.1.4 SAE Publications:

AMS 2430 Shot Peening

AMS 4943 Titanium Alloy Hydraulic Tubing, Seamless 3.0Al-2.5V, Annealed

AMS 4944 Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al-2.5V, Cold Worked, Stress Relieved

AMS 5554 Tubing, Seamless - 16.5Cr - 4.5 Ni - 2.9 Mo - 0.1N (AM-350)

AMS 5561 Steel Tubing, Seamless or Welded Corrosion Resistant, 21Cr - 6Ni - 9Mn, Hydraulic

ARP 573 Silver and Copper Alloy Brazed Joints for Aircraft Power Plants

ARP 584 Coiled Tubing

ARP 600 Torque Determination, Method of, for Tube or Hose End Fitting Connections, Flared, Flareless, or Miscellaneous Screw Thread Style

ARP 602 Hose Assemblies, Flexible Metal, Aeronautical, Medium Pressure

ARP 604 Hose Assemblies, Aircraft and Missiles, High Temperature, High Pressure

ARP 610 Synthetic or Natural Rubber Lined Pneumatic Hose Assemblies, Aircraft (Cancelled)

ARP 611A Tetrafluoroethylene Hose Assembly Cleaning Methods

ARP 614 Hose Assemblies: Aircraft and Missiles, High Temperature (450 F), High Pressure (4000 psi)

ARP 683 Installation Procedures and Torques for Fluid Connections

AS 685 Piloted Ring Seal Fluid Connection Bosses

AS 686 Piloted Ring Seal Tube Connection Assembly

AIR 737 Aerospace Hydraulic and Pneumatic Specifications and Standards

AS 756 Fitting End Assembly, Universal

AS 757 Boss, Straight Thread Gasket Seal - Standard Dimensions for

AS 758 Fittings, Installation in Straight Threaded Boss

AIR 1047 A Guide for the Selection of Quick-Disconnect Couplings for Aerospace Fluid Systems

AS 1241 Fire Resistant Hydraulic Fluid for Aircraft

2.1.5 Other Specifications:

ASTM B338	Seamless and Welded Titanium Tube (Commercially Pure)

2.2 Standards:

2.2.1 Federal Standards:

FED STD-595	Color (Requirements for Individual Color Chips)

2.2.2 Military Standards:

MIL-STD-1247	Marking, Functions and Hazard Designations, of Hose, Pipe, and Tube Lines for Aircraft, Missile, and Space Systems
MS9197	Nut, Tube Coupling, CRES, AMS 5646, Silver Plate
MS9198	Nut, Tube Coupling, CRES, AMS 5646
MS9199	Nut, Tube Coupling, AL, AMS 4121
MS9225	Ferrule, Brazing, Tube, Fitting, CRES AMS 5646
MS16142(Ships)	Boss, Gasket Seal, Straight Thread Tube Fitting, Standard Dimensions for
MS21344	Fittings, Installation of Flared Tube, Straight Threaded Connectors, Design Standard for
MS21900	Adapter, Flareless Tube to AN Flared Tube
MS21902	Union, Flareless Tube
MS21904	Elbow, Flareless Tube, 90 Deg
MS21905	Tee, Flareless Tube
MS21906	Cross, Flareless Tube
MS21907	Elbow, Flareless Tube and Universal, 45 Deg
MS21908	Elbow, Bulkhead, Universal, 90 Deg, Flareless Tube
MS21909	Tee, Bulkhead and Universal, Flareless Tube
MS21910	Tee, Flareless Tube, Internal Thread on Side
MS21911	Tee, Flareless Tube, Internal Thread on Run
MS21912	Tee, Flareless Tube, with Bulkhead on Run
MS21913	Plug, Flareless Tube
MS21914	CAP
MS21915	Bushing, Screw Thread Expander, Flareless Tube Connection
MS21916	Reducer, External Thread, Flareless Tube
MS21919	Clamp, Cushioned, Support, Loop-Type, Aircraft
MS21921	Nut, Sleeve Coupling, Flareless
MS21922	Sleeve, Coupling, Flareless
MS21923	Adapter, Flareless Tube, Bulkhead and Universal to Flared Tube
MS21924	Union, Flareless Tube, Bulkhead and Universal
MS21925	Elbow, 90 Deg. Universal, Flareless Tube, High Profile
MS21926	Elbow, 90 Deg. Universal, Flareless Tube, Low Profile

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MS21933	Fitting End, Bolt Cluster Fitting, Single Port, through Flareless
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MS21936	Contour and Mounting End, Cluster Fitting Body, Semi-Finished
MS21937	Nut, Cluster Fitting, Retainer
MS21938	Bolt, Cluster Fitting, Single Port, Flareless
MS21939	Bolt, Cluster Fitting, Single Port, through, Flareless
MS21940	Bolt, Cluster Fitting, Double Port, Flareless
MS21941	Bolt, Cluster Fitting, Double Port, through, Flareless
MS21942	Body, Cluster Fitting, One Way, Flareless
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MS21952	Bolt, Cluster Fitting, Double Port, through-Flare
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MS21959	Body, Cluster Fitting, Two Way, 90 Degrees, Internal Boss
MS21960	Body, Cluster Fitting, Three Way, Internal Boss
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MS24334	Coupling Assembly, Flareless Fitting to Internal Thread Boss
MS24335	Flange, Bulkhead Mounting, Coupling
MS24385	Fitting End, Standard Dimension for Flared Tube Connections and Gasket Seal, Precision Type
MS24386	Fitting End, Standard Dimensions for Bulkhead Flared Tube Connections, and Gasket Seal, Precision Type
MS33514	Fitting End, Standard Dimensions for Flareless Tube Connection and Gasket Seal

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MS33515	Fitting End, Standard Dimensions for Bulkhead Flareless Tube Connections
MS33611	Tube End Radii
MS33649	Bosses, Fluid Connection - Internal Straight Thread
MS33583	Tubing End - Double Flare, Standard Dimensions for
MS33584	Tubing End - Standard Dimensions for Flared
MS33656	Fitting End, Standard Dimension for Flared Tube Connections and Gasket Seal
MS33657	Fitting End, Standard Dimensions for Bulkhead Flared Tube Connection
MS33790	Bend Data, Minimum, Hydraulic, Pneumatic, Fuel and Oil Hose

2.2.3 Air Force - Navy Aeronautical Standards:

AN833	Elbow-Flared Tube and Bulkhead, Universal, 90°
AN837	Elbow-Flared Tube and Universal, 45°

2.2.4 National Aircraft Standards Committee Standards:

NAS 1095	Flareless Fitting Connections, Fabrication and Assembly

2.3 Drawings:

2.3.1 Air Force - Navy Aeronautical Design Drawings:

AND10049	Bosses - Fluid Connection, Internal Straight Threads
AND10050	Bosses - Standard Dimensions for Gasket Seal Straight Thread
AND10064	Fittings - Installation of Flared Tube Straight Threaded Connectors
AND10106	Tubing - Standard Sizes for Aluminum Alloy (5250) Round

2.4 Publications:

2.4.1 U. S. Air Force:

AFSCM 80-1	Handbook of Instructions for Aircraft Designers
AFSC DH 2-1	Design Handbook Series 2.0 Aeronautical Systems, Airframe

3. TUBING AND FITTINGS

This section is included for reference only. The types of systems wherein the various tube materials and fitting types are used are noted. However, these discussions should not be construed as recommendations for use but as a design guide only. A good point to bear in mind is that every fitting is a potential failure point in the system. It is well worth considerable design effort to eliminate even one providing that a higher risk is not introduced by incorporating more sharp-radius bends in the tubing.

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3.1 Tubing: Stainless steel and aluminum tubing are generally used for aircraft high and low pressure lines, respectively; however, titanium tubing has been selected for recent aircraft. The primary alloys currently in use are listed below, as well as other materials and alloys selected for the special applications indicated. Major physical properties are noted in Table 3-1. See also Reference 16.1.

3.1.1 Stainless Steel Tubing: Stainless steel tubing is generally used for hydraulic and pneumatic system pressure lines and for both high and low pressure lines routed on landing gear struts.

3.1.1.1 AISI Cold Worked 1/8-Hard Tubing per MIL-T-6845: This material is used on most of the current commercial airplanes and on military aircraft and missiles, except as noted below.

3.1.1.2 AISI 304L Cold Worked 1/8-Hard Tubing: AISI 304L material, indicating low carbon content, is specified where greater uniformity of properties is desired. This material is controlled by specifications MIL-S-4043 and MIL-T-8506.

3.1.1.3 AISI 304 Annealed Tubing per MIL-T-8504: This material was used on earlier commercial and military aircraft, many of which are still in use. It was superseded by the higher strength 1/8-hard tubing.

3.1.1.4 AISI 304 Tubing in Higher Hardness: Attempts have been made to use this alloy in 1/4- and 1/2-hard condition, but brittle cracking failures in flares and bends due to its lower ductility have generally resulted.

3.1.1.5 AISI 321 Cold Worked 1/8-Hard Tubing per MIL-T-8808: This material is used in systems with permanent welded or brazed connections such as on the A-7A airplane. Because of its stabilized condition, it retains its corrosion resistance after heating to fusion temperature much better than the AISI 304 alloys.

3.1.1.6 Allegheny Ludlum AM-350 Precipitation Hardened Tubing: This is a higher strength stainless steel alloy with good strength at elevated temperatures up to 800 F. It is available in two conditions: Sub-zero cooled and tempered (SCT) and cold reduced and tempered (CRT). The latter has slightly lower strength but better ductility and is of most importance. It is in use on several military airplanes. Its early limitation was that it was available only in seam-welded form and that was somewhat susceptible to stress corrosion cracking along the weld seam. Good fatigue life has been obtained in tests with tubing glass bead peened along its entire outside diameter, however. It is now available in seamless form per AMS 5554. Glass bead peening is done per AMS 2430.

3.1.1.7 Armco 21Cr-6Ni-9Mn Tubing: This is an austenitic stainless steel that combines good corrosion resistance with high strength. It is not hardenable by heat treatment but can be cold-worked and has the characteristic of relatively fast work hardening without the proportionate loss of ductility as the 304 type stainless steels. It was selected for several second generation commercial jet transports on the basis of its favorable combination of ultimate and yield tensile strengths, ductility, corrosion resistance, and cost. It is purchased to individual company specifications and AMS 5561 has been prepared.

3.1.2 Aluminum Tubing: Aluminum tubing is generally used in hydraulic system return lines, pump suction and case drain lines, and other low pressure lines, except that many companies prohibit its use in small sizes, i.e., below 1/2-inch because of its susceptability to damage.

3.1.2.1 6061-T6 (Solution Heat-Treated and Artificially Aged) Tubing per MIL-T-7081: This material is used on most of the current commercial and military airplanes.

3.1.2.2 5052 Annealed Tubing per Federal Specification WW-T-787: This alloy, formerly designated 52SO, was used on earlier commercial and military aircraft, many of which are still in use. It was superseded by the higher strength 6061-T6 tubing.

TABLE 3-1

MAJOR PHYSICAL PROPERTIES OF AEROSPACE FLUID POWER SYSTEM TUBING

TUBE MATERIAL	CONDITION	F_{T_U} ULTIMATE TENSILE STRENGTH Room Temp.	F_{T_U} ULTIMATE TENSILE STRENGTH 450°F	F_{T_Y} YIELD TENSILE STRENGTH AT 0.2% OFFSET Room Temp.	F_{T_Y} YIELD TENSILE STRENGTH AT 0.2% OFFSET 450°F	DENSITY LB/IN3	F_{T_U} at Room Temp. / DENSITY	F_{T_U} at 450°F / DENSITY	ELONGATION IN 2 INCHES MINIMUM %
Ti 6Al-4V	Annealed	130,000	104,000	120,000	86,500	.160	812,000	650,000	10
Ti 3Al-2.5V	Annealed	85,000	70,000	75,000	56,000	.162	518,000	432,000	15
Ti 3Al-2.5V	Cold worked	125,000	101,000	105,000	87,000	.162	773,000	623,000	10
Ti Cml. Pure	Grade 2	50,000	26,000	40,000	16,800	.163	306,500	159,500	20
304 CRES	1/8 HD	105,000	84,000	75,000	61,000	.290	362,000	290,000	20
304 CRES	Annealed	75,000	57,000	30,000	22,000	.290	259,000	183,000	35
21-6-9 CRES	Cold Worked	142,000	116,000	125,000	83,000	.290	490,000	400,000	20
AM 350 CRES	Cold Reduced & Tempered	185,000	165,000	140,000	119,000	.282	656,000	550,000	18 25
6061-T6 Al.	Heat Treat & Aged	42,000	10,920	35,000	8,390	.098	428,000	111,000	8
5052-O Al.	Annealed	26,000	13,800	10,000	7,000	.097	268,000	142,000	-

3.1.3 Titanium Tubing: Because of its very high strength-to-weight ratio, alloyed titanium tubing has long been considered for use in aircraft hydraulic systems but, until recently, tubing of acceptable quality has not been available. The alloys currently being evaluated by various system manufacturers are listed below, along with the commercially pure material already in use on production airplanes.

3.1.3.1 Commercially Pure Titanium Tubing per ASTM B338, Grade 2: This material has a higher strength-to-weight ratio than 304 1/8-hard tubing, but it has been its lower modulus of elasticity (on the order of 16,000,000 psi) that has led to its recent use in coiled tube assemblies, rather than stainless steel, in order to obtain the nearly 2 to 1 reduction in stresses for a given degree of deflection.

3.1.3.2 Annealed 3Al-2.5V Alloy Tubing: This material has a strength-to-weight ratio slightly greater than the 21-6-9 stainless steel alloy and approaches AM-350 in this characteristic. AMS 4943 has been published. It is being used in the F-14 hydraulic system.

3.1.3.3 Cold-Worked 3Al-2.5V Titanium Alloy Tubing: Cold working adds significantly higher strength to this material. One limitation is that, if tubes are joined by a heating operation such as welding or brazing, the material is locally annealed and the lower strength properties must be considered. AMS 4944 has been published. It was used on some early C-5A aircraft and was selected for the B-1 and F-15 airplanes and the American SST. See Reference 16.2 for a report of development work done on the SST.

3.1.3.4 Annealed 6Al-4V Titanium Alloy Tubing: This material has the highest strength of all titanium tubing alloys currently being seriously considered for aircraft use. Two major test programs to evaluate this material were:

a. The Air Force Aero Propulsion Laboratory Contract AF33(615)-5407, Hydraulic Plumbing for Advanced Aerospace Vehicles, conducted by the Los Angeles Division of North American Rockwell Corporation. This program was initiated in July 1966.

   The final report of the North American Rockwell program is available from Defense Documentation Center, Alexandria, Virginia. See Reference 16.3.

b. Evaluation for use on the American Supersonic Transport by The Boeing Company. See Reference 16.4 for final report available from The Department of Transportation.

In a program to develop manufacturing methods for this tubing, the Wolverine Tube Division of Calumet and Hecla [1] in a development program for the Metallurgical Processing Branch, Manufacturing Technology Division, Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, has established that the ELI (Extra-Low-Interstitial) grade of this material has better ductility than the regular grade. See Reference 16.5. The Nuclear Metals Division of the Whittaker Corporation[2] has developed a rotary ball swaging method of obtaining fine internal and external finishes on both seamless and seam-welded tubing. See References 16.6 and 16.7.

3.1.4 Tubing Wall Gages: The standard wall gages listed in MIL-F-18280 and MS33611 are recommended for 3000 psi hydraulic system pressure lines for Types I and II systems (-65 to +275 F). For low-pressure lines, for high pressure lines used at other conditions, and for other materials than those noted therein, wall gages should be selected on the basis of laboratory tests under applicable conditions per approved methods such as specified in ARP 899. As a minimum, pressure impulse tests, flexure fatigue tests, and burst tests of bent tube specimens are recommended.

3.1.4.1 Typical Tube Wall Formulae: The simple thin wall formula shown below is useful for initial calculations:

$$S = \frac{Pd}{2t}$$

where S = hoop stress
P = pressure
d = tube diameter
t = tube wall

(1) Wolverine Tube Division, Calumet and Hecla Corporation, 17200 Southfield Road, Allen Park, Michigan 48101.

(2) Nuclear Metals Division, Whittaker Corporation, West Concord, Massachusetts 01781.

3.1.4.1 (Continued)

Using the criteria of MIL-H-5440, which requires that tubing burst pressure be at least 400% of the nominal operating pressure, minimum allowable tube wall gages can be calculated as follows:

$$t_{min} = \frac{4Pd}{2F_{t_u}}$$ where F_{t_u} = Specified minimum ultimate tensile strength of the material.

The following formulae, which are generally considered more precise, may also be used. However, it should be recognized that the generally available strength values usually reflect longitudinal strength only; and, in some materials, the transverse strength (which is important to hoop strength) and the fatigue properties may be significantly different. Therefore, final selections should be verified by adequate testing.

3.1.4.1.1 Formula for Thin-Wall Tubes:

$$t = \frac{P_{burst} \times O.D.}{2KF_{tu} + 1.4\,P_{burst}},$$

where

P_{burst} = 4 times rated operating pressure

$K = 0.6 + 0.4 \dfrac{F_{ty}}{F_{tu}}$

F_{t_y} = specified minimum tensile yield strength of the material

F_{t_u} = specified minimum ultimate tensile strength of the material

The foregoing holds for all cases except where F_{t_y} is less than 1/2 F_{t_u}, then

$$t = \frac{P_{proof} \times O.D}{2KF_{t_y} + 1.4\,P_{proof}},$$

where P_{proof} = 2 times rated operating pressure

3.1.4.1.2 Formula for Thick-Wall Tubes: Where the tube wall gage closely approaches or exceeds 0.10 x the ID, then the Lame formula for thick wall cylinders should be used, where:

$$S = P\,\frac{OD^2 + ID^2}{OD^2 - ID^2}$$ where S = hoop stress, P = internal pressure

Then $$t = \frac{OD}{2}\left(1 - \sqrt{\frac{F_{t_u} - P_{burst}}{F_{t_u} + P_{burst}}}\right)$$

3.2 Standard Reconnectable Fittings: Only those fittings which have become government or industry standards for aircraft use are listed here. Other fittings which have been successfully used on one or more aircraft, but which as yet have not achieved standardization, are listed in Section 3.3. Installation and torquing information is listed in ARP 600 and ARP 683.

3.2.1 Standard Flared Fittings: There are currently three flared fitting types standardized for aircraft use. In two of these the flared end of the tubing is held in tight contact with the conical end of the mating fitting body. In the third, a brazed-on ferrule rather than the flared tube end, is held in connection with the standard flared fitting. Several non-standard flared fittings, as noted in Section 3.3.1, are also in use.

3.2.1.1 AN/MS Flared Fitting: The three-piece 37 deg - flare-angle assembly, consisting of fitting body, sleeve, and nut shown in Figure 3-1a, has been in standard use on military aircraft and missiles for many years. Commonly known as the AN flared fitting, it was also used on most early commercial aircraft and on some jet transport models. Dimensional tolerances and surface finish requirements have been tightened in recent years and it is now controlled by specification MIL-F-5509. Drawings of all AN/MS flared fittings shapes are listed in AIR 737. The male fitting end designs are controlled by MS33656 Flared Tube Connection and Gasket Seal, and MS33657 Bulkhead Flared Tube Connection. MS33649 Boss, Fluid Connection - Internal Straight Thread, is the design standard for the female port connection. Two tubing end flare design standards are available, MS33583 Double Flare and MS33584 Single Flare. The double flare is recommended for use with the softer (5052) aluminum type tubing only, since high tensile strength tubing cannot be satisfactorily double flared. Assembly and installation requirements are specified in MS21344 Installation of Flared Tube, Straight Threaded Connectors. The torque values are for 5052 aluminum and annealed 304 CRES tubing and have not been updated to include modern tube materials or current part numbers. However, the fitting and seal installation requirements are applicable.

3.2.1.2 NASA Marshall Center Flared Fittings: This is a closer tolerance three-piece 37 deg flare-angle assembly of the same design configuration as the AN/MS flared fitting. It is used by NASA on their space booster rockets and is controlled by MSFC-SPEC-143, Fittings, Flared Tube, Pressure Connections. The prime intent of this specification is to produce "Premium Quality" aluminum and corrosion-resistant steel fittings by the use of Marshall Space Flight Center specifications for control.

Approved sources of supply for these parts may be obtained from George C. Marshall Space Flight Center, Huntsville, Alabama.

3.2.1.3 Standard Ferrule, Braze Flared Fitting: This fitting assembly consists of a ferrule, nut, and body fitting as shown in Figure 3-1b. It is generally used on engine fluid lines interchangeable with the standard flared fitting assembly. The ferrule is brazed on to the tube end, and when connected to a standard fitting body, the ferrule creates the seal against the cone end of the fitting in the same manner as the flared tube end of the AN/MS flare assembly. However, no flaring of the tube end is required. The brazing is performed in accordance with ARP 573.

The nut design is controlled by Drawings MS9197, MS9198 and MS9199. The ferrule control drawing is MS9225. The nut and ferrule assembly can be attached to either fitting end standard connections MS33656 or MS33657 and MS24385 or MS24386, and is used with steel tubing.

3.2.1.4 Universal Fittings - Cluster Installation: The Universal Fittings part numbers MS21932 through MS21960 may be used in many combinations to permit the joining of a number of different size hydraulic lines at one or more common locations.

The standard sheet MS21931 shows the assembly and installation of a number of the combinations that may be used; however, the combinations are not necessarily limited to those shown as long as the basic assembly procedure outlined in the standard is observed.

The fittings are fully qualified and have been used on a number of aircraft. However, since two "O" rings are required in each body to create a seal between the bolt and the body the use of these type fittings are limited to 3000 psi pressure and temperatures of -65 F to 160 F.

These fittings may be obtained from most of the aircraft fitting manufacturers, fabricated in either aluminum alloys or stainless steel.

3.2.2 Standard Flareless Fittings: The three-piece flareless fitting assembly, consisting of fitting body, sleeve, and nut shown in Figure 3-2a, has been in standard use on most commercial jet transport airplanes and on some military aircraft. It was originally known as the Ermeto fitting and is now commonly known as the MS flareless fitting. It is controlled by specification MIL-F-18280 and the fitting ends by Standards MS33514 for the regular end and MS33515 for the bulkhead end. Fittings are controlled by MS21900 through MS21916, MS21923, and MS21924, the nut by MS21921, and the sleeve by MS21922. Fittings and nuts are made from the following materials:

(a) Aluminum alloys: 2024-T6 or -T851 bar stock, and 2014-T6 forgings anodized and sealed in a potassium dichromate solution giving all the parts a yellow color.

(b) Carbon steel alloys: C-1137 or C1141 bar stock and forging, and AISI 4130 and 4140 bar stock and forging with a chromate cadmium finish. It should be noted that cadmium plated fittings should not be used at temperatures above 350 F, however.

(c) Stainless steels: AISI 304, 316, and 347 bar stock and forgings given a passivation treatment.

(d) In addition, individual companies such as Boeing have standardized flareless fittings made of the 6Al-4V alloy of titanium. They are controlled by individual company standard drawings.

In the flareless fitting, sealing is obtained by the nut forcing the sleeve into tight contact with the inside sealing diameter of the fitting body. The sleeve is retained to the tubing by a presetting operation during which the cutting edge of the sleeve is swaged onto the tube, cutting into the metal surface. Slight collapse of the tubing wall under the ring cut may be evident. A slight rotation of the sleeve on the tubing can be tolerated but it should not be possible to move it forward or backward on the tube over 1/64 inch. A tube wall of sufficient thickness to withstand the gripping action of the sleeve is necessary. The minimum wall thicknesses recommended for various tube materials and using standard assembly procedures are shown in Table 3-2. NAS-1095 specifies recommended fabrication and assembly techniques. Automatic presetting machines are generally used for production line presetting of flareless sleeves. Hardened tool steel hand presetting tools are available for bench presetting; and, when such tools are not available, standard steel flareless fittings can be used to a maximum of five times as presetting tools but no more than once per fitting is recommended.

Non-standard flareless fittings in current use, including special sleeves and nuts are noted in Section 3.3.

3.3 Non-Standard Reconnectable Fittings: Reconnectable fittings which have been successfully used in fluid power systems on one or more model aircraft, but which have not been standardized by the government or the industry, are included herein.

3.3.1 Non-Standard Flared Fittings:

3.3.1.1 Close Tolerance Flared Fittings: At least one airframe company, General Dynamics Fort Worth Division, uses flared fittings in the same basic configuration as the AN/MS design but with tighter control of certain tolerances and finishes. They deviate from the standard in the following major respects:

(a) Fitting cone and finish

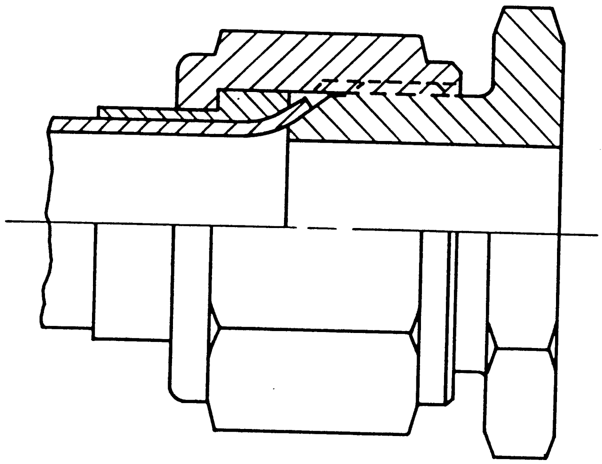
General Dynamics finish: 32 microinches RHR (same as MS24385 & 6); MS finish: 100 microinches RHR max.

(b) Hex sealing face side

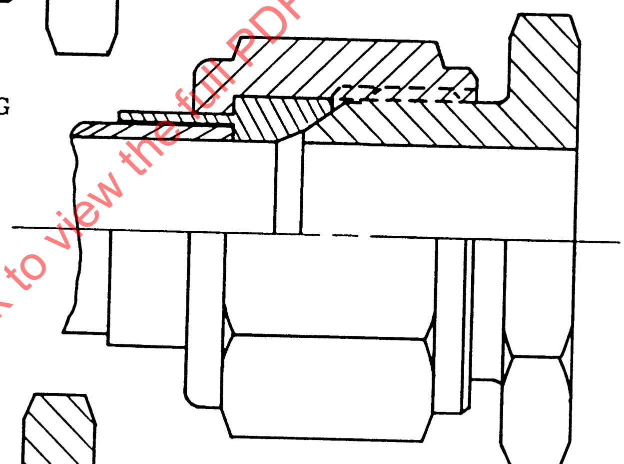
General Dynamics finish in area of seal: 32 microinches RHR, remaining surfaces 100 microinches RHR (same as MS24385 & 6); MS33656: total surface 100 microinches RHR

(c) Perpendicularity of hex sealing face to thread axis

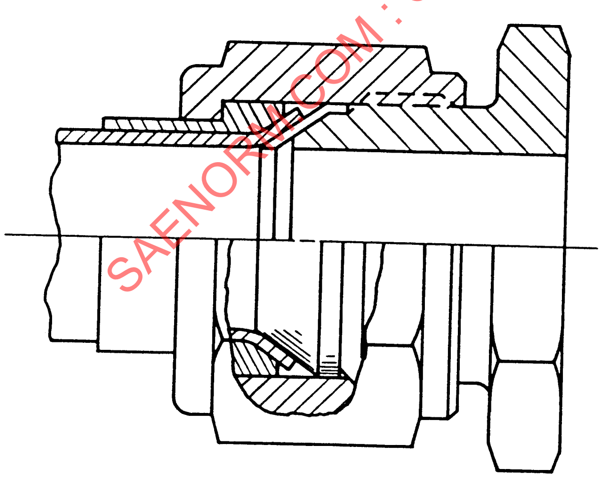
General Dynamics: 0.002 TIR; MS33656: 0.005 TIR up to -10 size, 0.008 TIR for -12 to -48 sizes



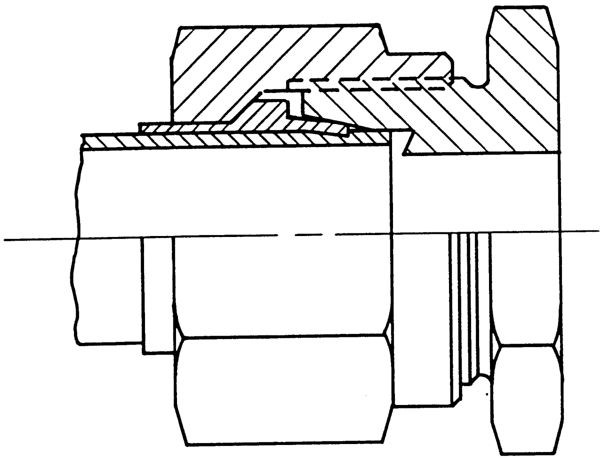
AN/MS FLARED FITTING
FIGURE 3-1a



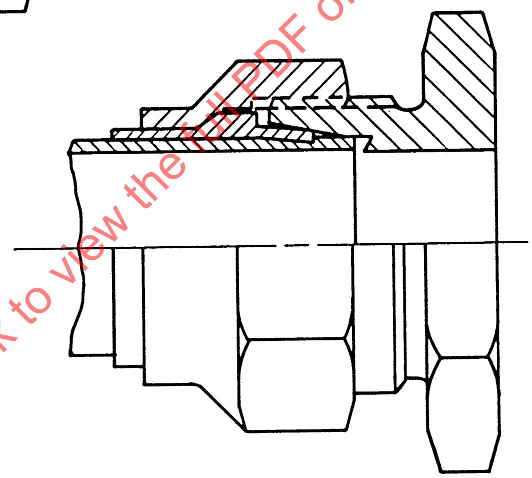
STANDARD FERRULE, BRAZED FLARED FITTING
FIGURE 3-1b



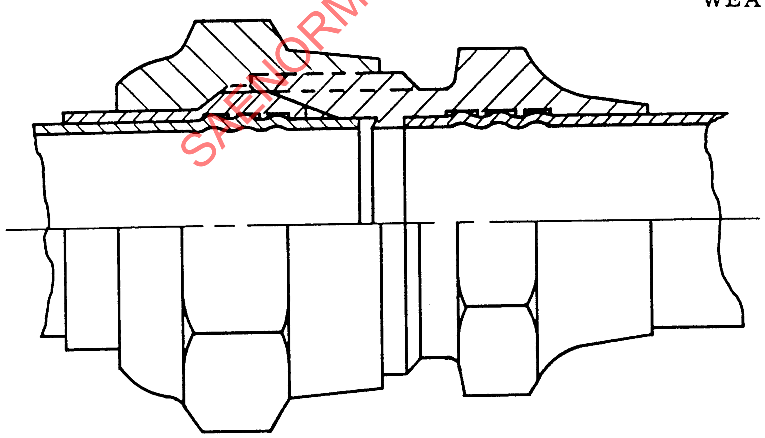
VOI-SHAN FLARED CONICAL SEAL
FIGURE 3-1c



MS FLARELESS FITTING
FIGURE 3-2a

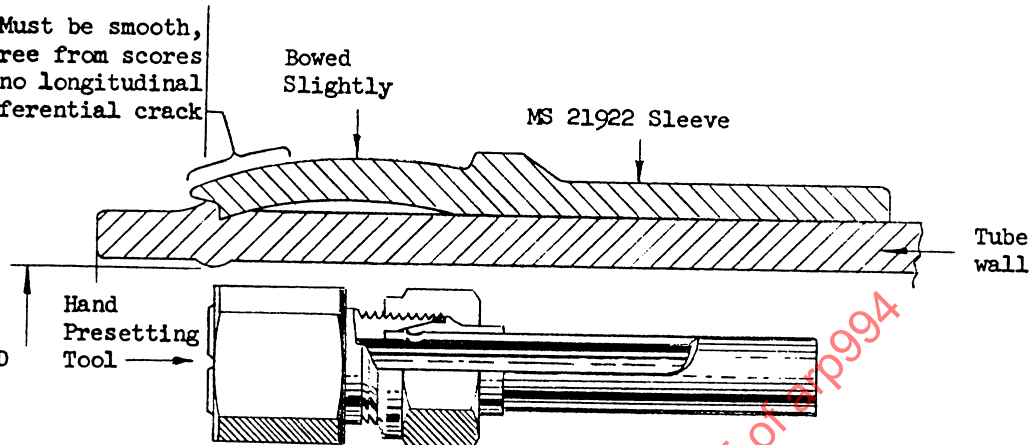


WEATHERHEAD MINIATURIZED
FLARELESS FITTING
FIGURE 3-2b



BOEING AND LOCKHEED SWAGED FLARELESS
SLEEVE WITH LIGHTWEIGHT UNION AND NUT
FIGURE 3-2c

TABLE 3-2



Size	Tube O.D. Size Nom.	ALUMINUM 6061-T6 MIL-T-7081 Wall	Min. I.D. After Presetting	Working PSI	CRES 1/8 - 1/4 HARD MIL-T-6845 Wall	Min. I.D. After Presetting	Working PSI	CRES ANNEALED MIL-T-8504 Wall	Min. I.D. After Presetting	Working PSI
2	1/8	.020	.060	3000	.016	.070	3000	.020	.060	3000
3	3/16	.028	.095	3000	.018	.110	3000	.020	.115	3000
4	1/4	.035	.150	3000	.020	.165	3000	.028	.155	3000
5	5/16	.049	.180	3000	.022	.225	3000	.028	.225	3000
6	3/8	.049	.240	3000	.025	.290	3000	.035	.270	3000
8	1/2	.065	.330	3000	.028	.400	3000	.049	.380	3000
10	5/8	.083	.420	3000	.035	.485	3000	.058	.475	3000
12	3/4	.095	.530	3000	.042	.610	3000	.065	.590	3000
16	1	.065	.830	1500	.065	.840	1500	.083	.800	1500
20	1 1/4	.083	1.050	1500	.065	1.080	1500	.065	1.080	1500
24	1 1/2	.095	1.280	1500	.065	1.330	1500	.065	1.330	1500
32	2	.156	1.650	1500	.065	1.830	1500	.095	1.780	1500

3.3.1.2 Titanium Flared Fittings: General Dynamics, Fort Worth has also for years used their close tolerance flared fittings in titanium alloy. They have been used on both the 350 F, 3000 psi hydraulic system on the B-58 bomber and on the 275 F, 3000 psi hydraulic system on the F-111 all purpose fighter. The 6Al-4V alloy, in the annealed condition treated with a fluoride phosphate coating after machining, is used. Dry film lubricant on the B-nut threads is recommended in order to obtain multiple reconnect capability without galling.

3.3.1.3 Voi-Shan(3) Flared Conical Seal: This seal is used with the three-piece 37 deg flare angle assembly as shown in Figure 3-1c, installed between the inside diameter of the flared tube and the conical face of either male fitting MS33656 or MS33657. It was developed by General Dynamics Astronautics Division for use on the Atlas intercontinental ballistic missile high pressure helium systems. Frequently, in laboratory test systems, when minor leakage occurs as the result of scratches or small inclusions on either the inside face of the flare or on the conical face of the male fitting, installation of this seal is used to stop the leakage and prevent replacement of the fitting or tube assembly.

The design of this seal is controlled by a Voi-Shan drawing. They are made from nickel alloy, copper, aluminum alloy, and stainless steel. Special platings finishes may be applied if required.

3.3.2 Nonstandard Flareless Fittings:

3.3.2.1 Weatherhead(4) Miniaturized (ER) Flareless Fitting*: The miniaturized fitting is of the same design configuration as the standard MS flareless fitting consisting of the fitting body, sleeve, and nut, but are reduced in size and weight while retaining the flareless method of sealing. The fitting designs are controlled by a series of Weatherhead drawings. Figure 3-2b shows the relative size of the standard and miniaturized configurations. The fittings are made from titanium. Either the MS21922 flareless steel sleeve or a Weatherhead standard sleeve may be used with the miniaturized fittings.

3.3.2.2 Boeing and Lockheed Swaged Flareless Sleeve and Lightweight Fittings: The Commercial Airplane Division of The Boeing Company and The Georgia Division of Lockheed have cooperated in the development of the swaged-on sleeve for use with standard MS flareless fittings. This swaged-on sleeve and a swaged-on lightweight union and nut are shown in Figure 3-2c. They were introduced on the Lockheed C-5A and the Boeing 747 airplane hydraulic systems.

The design concept and connection of the fittings are similar to the standard MS flareless, and can be used interchangeably, in field repair, with the standard MS flareless. The prime benefits derived from this design are: weight saving, reduced size, and a positive stop when joining, eliminating torque control. The design of the sleeve is such as to create a more positive engagement on the tubing than obtained in the MS sleeve, greatly reducing the tendency for rotation, loosening, or failure due to over-torquing.

The fitting can be used with all tubing materials currently in use on commercial and military aircraft, including the high strength thin wall tubing.

Tooling for swaging the sleeve to the tube may be obtained from Harrison Manufacturing Company(5) and Haskel Engineering and Supply Company(6)

3.3.2.3 McDonnell-Douglas Brazed-on Flareless Sleeves: Douglas Aircraft Division of the McDonnell-Douglas Corporation has implemented brazed piping systems into high production on both military and commercial aircraft. The remaining B-nut connections, necessary for removal of equipment and major components in service, employ heavy-duty brazed sleeves with light-weight B-nuts.

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(3) Voi-Shan Division of VSI, 18249 Euclid Street, Fountain Valley, California.

(4) The Weatherhead Company, 300 East 131st Street, Cleveland, Ohio 44108. (Fitting no longer available.)

(5) Harrison Manufacturing Company, 3020 Empire Avenue, Burbank, California 91504.

(6) Haskel Engineering & Supply Company, 100 East Graham Place, Burbank, California 91502.

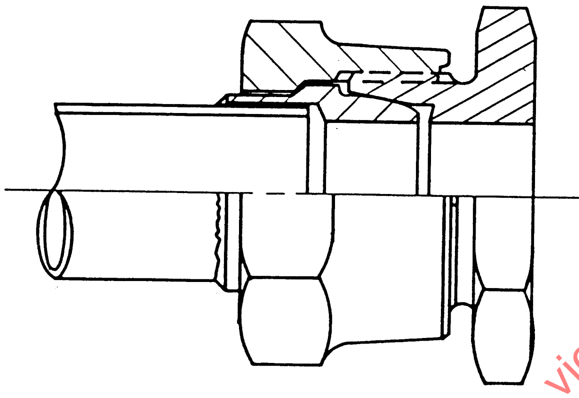
* This fitting is no longer available.

3.3.2.3 (Continued)

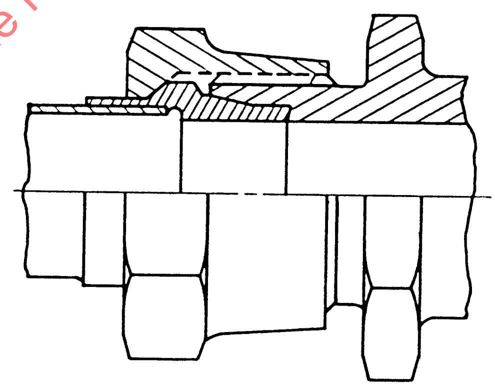
This design is similar to the standard MS flareless connection and couples to the MS33514 male fitting end standard. See Figure 3-2d.

The brazed sleeve provides more cross-sectional, parent material at the sealing end of the sleeve. The increased strength matches the ruggedness of a hose nipple. The tail of the sleeve is brazed to the tube support and eliminates moisture entrapment under the sleeve. The reliability of this joint relative to leakage, is greatly increased since the extra leakage path inherent to other flareless sleeves is non-existent.

3.3.2.4 Aeroquip[7] Globe Seal Sleeve: Aeroquip also has developed a brazed-on flareless sleeve which is available in both 21-6-9 stainless steel and 6Al-4V titanium alloy. It is being used (in the 21-6-9 alloy) on the S3A airplane. See Figure 3-2e.



McDONNELL-DOUGLAS BRAZED-ON
SLEEVE FLARELESS FITTING
FIGURE 3-2d



AEROQUIP GLOBE SEAL
SLEEVE FLARELESS FITTING
FIGURE 3-2e

3.3.3 Mil-Flo[8] Miniflare Fitting: This fitting, shown in Figure 3-3a, is an aerospace refinement of the Flodar Corporation[9] Self-Flare Fitting. The three-piece assembly consists of a fitting body with pressed-in flaring insert, a sleeve similar to the flareless fitting sleeve except with four collet slots on the skirt away from the sealing end, and nut. It is currently in use on the Sikorsky CH-53 and S-64 helicopters and the Hughes Tool Company 369A and LOH helicopters, in Zytel 42 Nylon on nylon tubing, and was selected by Boeing for use on the X-20 (Dyna-Soar) manned re-entry space vehicle for the hydraulic system on AM-350 tubing, for the cryogenic hydrogen and oxygen systems on 6061-T6 tubing, and the hydrogen peroxide system on AISI 316 tubing.

(7) Aeroquip Corporation, Jackson, Michigan 49203
(8) Mil-Flo, Incorporated, 1900 W. Dorothy Lane, Dayton, Ohio 45439
(9) Flodar Corporation, 16919 St. Clair Avenue, Cleveland, Ohio

3.3.3 (Continued)

The Miniflare fitting sleeve is retained to the tube by its crimping action at the base of a moderate flare in the tube end. Sealing is accomplished in three stages in series, anyone of which will satisfactorily seal high and low pressures. The first stage is at the tube flare to body insert (similarly to the flareless fitting), and the third stage is at the outside edge of the flared tube end where it seats in the fitting body. The collet slots provide a semi-flexible sleeve end which prevents an abrupt stress concentration at the point of last support, thereby increasing the resistance of the tubing to fatigue failures resulting from structural deflections and/or vibration.

Portable presetting machines are available from the manufacturer for swaging the sleeves to the tube assemblies. They can also be set in place and the tubing properly flared by coupling a standard fitting and nut together for emergency repair.

Although as yet not standardized, NAS standards were initiated several years ago and would presumably be completed upon further acceptance and use by the aerospace industry.

3.3.4 Parker[10] Lo-Torque Fitting: This reconnectable tube assembly consists of three pieces: adapter, sleeve, and nut shown in Figure 3-3b. These fittings were developed by North American Aviation for use on the RS-70 4000 psi hydraulic system. They were made from AM 355 stainless steel bar stock heat-treated to condition SCT 900 and passivated, and were attached to AM-350 stainless steel tubing.

The adapter and sleeve are attached to the tube ends by a silver-copper lithium braze alloy, using a special induction brazing tool. When joining tube assemblies, the nut, which is shouldered on the sleeve, threads on to the male thread of the adapter engaging the conical metal lip seal of the sleeve with the internal female conical face of the adapter creating the seal. No specific torquing is required since the fittings assemble to a positive stop. Some weight saving is attained with this type fitting since a union such as MS21902 is not required to join two tube assemblies. Special elbows, tees and cross type fitting bodies machined to accept the sealing lip of the sleeve-tube coupling, are required when a reconnectable threaded joint is used.

The design of these fittings are controlled by Parker drawings.

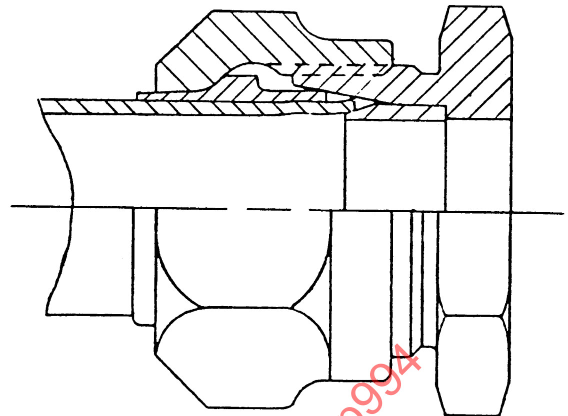
3.3.5 Resistoflex[11] Dynatube Fittings: The fitting assembly is made up of a shoulder (sleeve) and nut which threads onto a male threaded shoulder (connector) as shown in Figure 3-3c. It is in use on a number of space vehicles, a rocket motor, and the General Electric J93 engine primarily in low pressure fuel systems and is being evaluated for use on high pressure aircraft applications and has been selected for the early F-14, F-15, B-1, and L-1011 airplanes.

The shoulder (sleeve) has a diaphragm sealing lip that bears against the connector face when the two are joined, creating the seal. The sealing force of the diaphragm lip is increased at higher pressures. The shoulder (sleeve) may be attached to the tube by three different processes: roll-swage, brazing or welding. Damage to the sealing lip by overtightening is prevented because the stress on the sealing surface is controlled by the dimensional design and the fact that the nut and sleeve shoulder against the connector fitting when fully assembled, preventing further torquing of the nut. Some weight saving is attained in this design over the standard MS flare and flareless fitting. Special elbows, tees and cross type fitting bodies machined to accept the sealing lip of the sleeve-tube coupling, are also available.

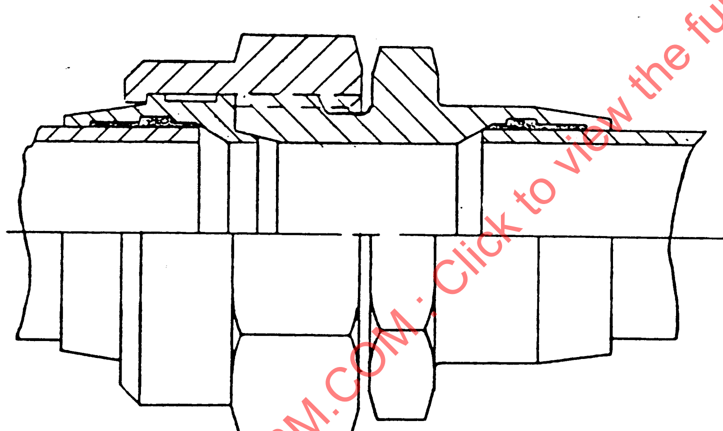
Fitting assemblies sizes -3 through -12 are designed to allow the nut to be loose on the shoulder and can be slid back on the tube. Fitting assemblies sizes -16 and larger have the nut locked to the shoulder. These designs apply to both the rigid tube assemblies as well as the flex hose fitting assemblies, and are controlled by Resistoflex drawings. Tooling for attachment of both the swaged and brazed type fittings is available from the manufacturer or from the Aeroquip Corporation, which is a licensee of Resistoflex for the manufacture of the Dynatube fitting.

(10) Parker Aircraft Co., 5827 West Century Blvd., Los Angeles, California

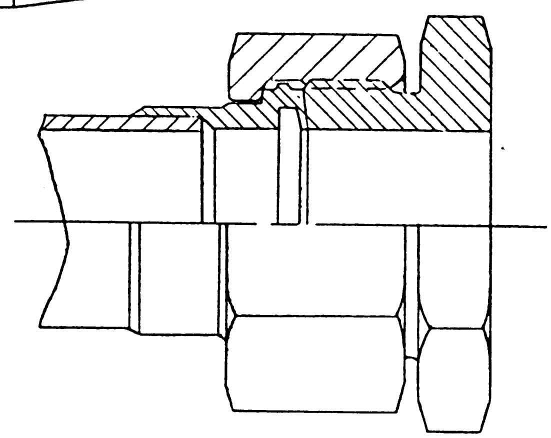
(11) Resistoflex Corporation, Roseland, New Jersey 07068



MIL-FLO MINIFLARE FITTING
FIGURE 3-3a



PARKER LO-TORQUE FITTING
FIGURE 3-3b



RESISTOFLEX DYNATUBE FITTING
FIGURE 3-3c

3.3.6 Aeroquip Universal Boss Fitting: This universal boss fitting is a compact, lightweight method of connecting fluid lines to boss outlets per AND 10050. They may be manufactured from either forgings or using tubing to which the threaded fittings are brazed, and can be used with either rigid tubing or flex hose.

The boss end of the fitting consists of a hex head male thread which is designed to receive the tubular end of the elbow. The portion of this tubular end that protrudes beyond the bottom end of the threaded fitting has circular grooves to which a collar is permanently attached; this creates a seal between the inside diameter of the threaded end and the tube when the fitting is torqued-up in the boss. Prior to final torquing, the elbow is rotated to the desired position for alignment with the fluid line assembly. A hex jam nut on top of the male threaded hex is threaded onto the upper portion which locks the fitting to prevent rotation after assembly. A standard "O" ring boss seal can be used under the hex.

As shown in Figure 3-3d, this fitting has a smaller drop dimension, and permits closer boss spacing since it eliminates the swing clearance required for the AN833 and AN837 elbows. They are manufactured in both stainless steel and aluminum in sizes -8 through -24, for operating pressures to 3000 psi and temperature of -65 F to +450 F depending on boss seal design and material.

The design is controlled by Aeroquip Corporation and is qualified for use on both military and commercial aircraft such as Bell Aircraft Helicopters, UH 1B, ID and IE, General Dynamics F-111, General Electric engines, Lockheed C-5A, and Boeing Aircraft 720B and others.

3.3.7 Boeing Swivel Elbow Fitting: This design was developed for Boeing commercial jet transport airplanes and has replaced nearly all the bulkhead elbows and banjo fittings formerly used. As shown in Figure 3-3e, it has a standard flareless fitting fixed end(s) and a captive nut and a machined globe seal fitting on the swivel and which attaches directly to a straight union fitting installed in a standard boss. It has been standardized in the following shapes and is controlled by Boeing standard drawings which specify a choice of carbon steel, stainless steels, aluminum alloys, and 6Al-4V titanium: 90 deg elbow reducer; 45 deg elbow reducer; Tee reducer with swivel on run; Tee reducer with swivel on side; and cross reducers.

3.3.8 McDonnell-Douglas Metal-Seal Tube-to-Component Fittings: This fitting, as shown in Figure 3-3f, consists of a union or reducer with a standard flared end per MS33656 or a standard flareless end per MS33514 on one end and a simple straight-threaded end on the other but with a metal lip seal machined under the torquing hex. For the DC-10, aluminum alloy fittings with MS33514 tube ends are used on all aluminum alloy bosses except hydraulics. Titanium fittings are used with steel and aluminum bosses and all steel hydraulic lines except oxygen. All bosses are per MS33649. Dimensions for the fittings are controlled by Douglas drawings and several manufacturers are approved.

On the SST program, Boeing found that this design, when used on titanium fittings with titanium housings, was subject to fretting failure during pressure impulse testing.

3.3.9 Boeing Recessed Boss Seal Fittings: The Boeing approach to reducing boss seal leakage is the recessed boss seal fitting, as shown on Figure 3-3g, which was introduced on the 747. The boss end has a groove for a standard diametral-seal O-ring and backup ring, and a boss seal O-ring is used under the hex to keep moisture out of the threads. Dimensions are controlled by Boeing drawings which have been made for straight unions, reducers, and expanders, 45 deg elbows, and 90 deg elbows. Several manufacturers have been approved.

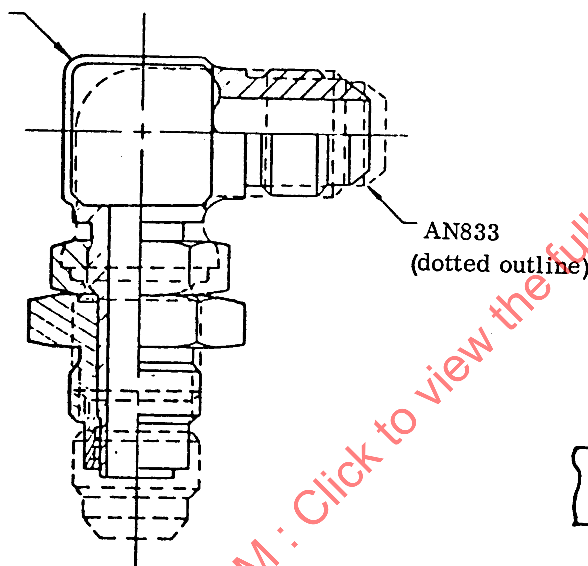
3.3.10 Rosan[12] Fluid Port Adapters: These adapters are threaded into special bosses and installed by torquing to a range of predetermined values and then secured by means of a serrated lock ring pressed into a serrated counterbore broached into the face of the housing boss as shown in Fig. 3-3h. Sealing is metal-to-metal backed up by a standard AS 568 Class I O-ring.

They have been selected for the B-1, F-14, F-15, YF-17, P-600, and S-3A aircraft and the UTTAS helicopter. Design and installation are controlled by AS 1299, AS 1300, and AS 1301.

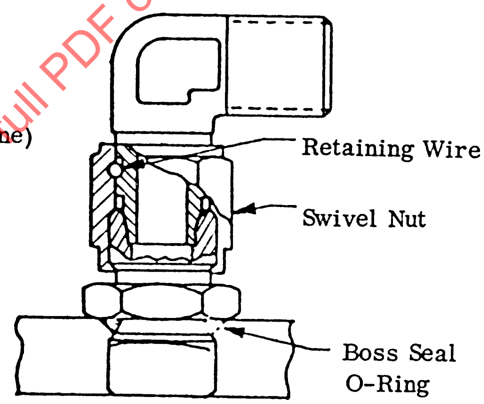
(12) Rosan, Inc., 2901 West Coast Highway, Newport Beach, California 92663

3.3.11 Wiggins[13] Suction Line Fitting: This is an adaptation of a fuel system line connector to low pressure hydraulic applications. The design shown in Figure 3-3i illustrates a Wiggins half connector connected to a male adapter for connection to a standard boss. The connection consists of a machined ferrule swaged to the tube, an O-ring and two metal washers on the ferrule, a spacer ring, and coupling nut which is torqued hand tight to the adapter.

The Georgia Division of Lockheed has standardized this connector in several fitting body shapes for use in the hydraulic pump suction lines on the C-5A.

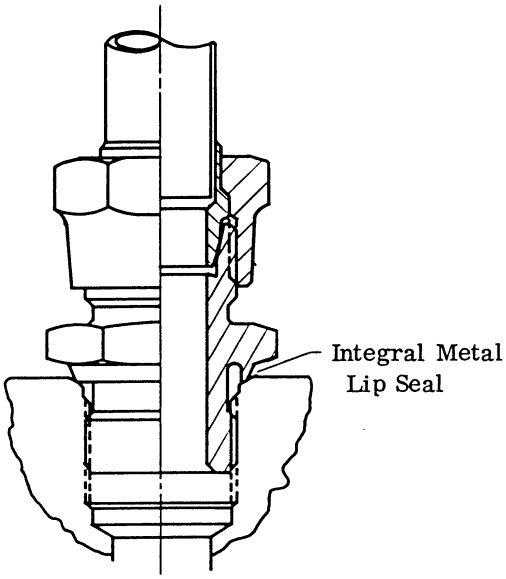


AEROQUIP UNIVERSAL BOSS FITTING
AND AN FITTING COMPARISON
FIGURE 3-3d

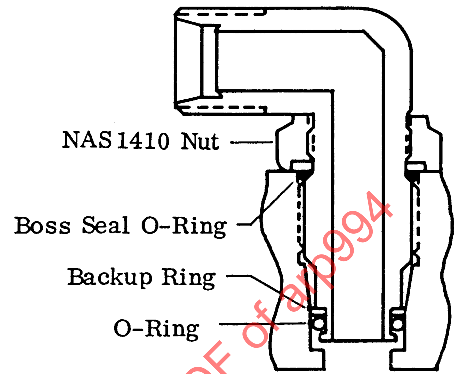


BOEING SWIVEL ELBOW FITTING
CONNECTED TO STANDARD UNION
IN MS33649 BOSS
FIGURE 3-3e

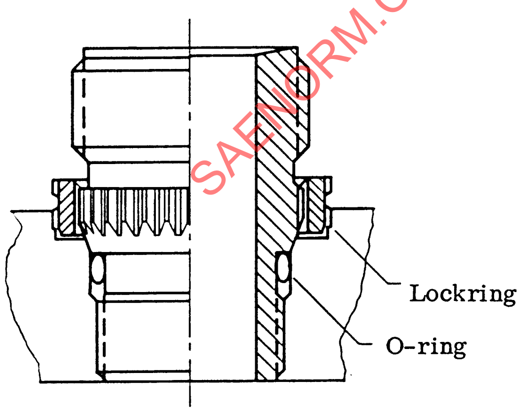
(13) E. B. Wiggins, Inc., 5000 Triggs Street, Los Angeles, California 90022



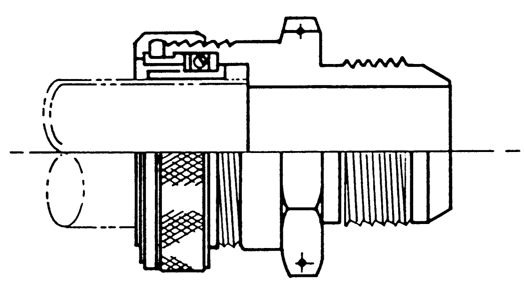
McDONNELL-DOUGLAS METAL SEAL
TUBE-TO-COMPONENT FITTING
FIGURE 3-3f



BOEING 90° ADAPTER FITTING
INSTALLED IN RECESSED SEAL BOSS
FIGURE 3-3g



ROSAN FLUID PORT ADAPTER
FIGURE 3-3h



WIGGINS SUCTION LINE FITTING
FIGURE 3-3i

3.4 Permanent Joints: There is an increasing desire within the industry to reduce the number of leak points in the airborne fluid power systems, especially in those aircraft with larger complex systems. An obvious means to this end is to reduce the number of reconnectable fittings in the transmission lines by the use of permanent joints in as many places as possible, i.e., except at removable components and structural production breakpoints. Four major types have been seriously considered, i.e. brazed joints, welded joints, swaged joints, and heat shrunk joints. Several forms of brazed joints have been developed and are in service on experimental and production airplanes and space vehicles.

3.4.1 Brazed Joints:

3.4.1.1 North American Induction Brazed Joint: North American Aviation developed a brazed joint system for the 450 F, 4000 psi, RS-70 aircraft hydraulic system utilizing both induction and furnace brazing. The North American brazed joint consists of a union (sleeve) tapered at both ends and containing two silver-copper lithium braze alloy preformed rings as shown in Figure 3-4a. The AM-350 tube ends are sized to a close diametral tolerance to ensure a close fit in the sleeve and positive capillary flow of the braze alloy. An electrical induction coil is assembled in a tool which holds the union and tube ends in proper alignment during the brazing operation. After inserting the two tube ends an equidistance into the union, argon gas is allowed to flow through the brazing tool and between the union and tube to purge the braze area before heat is applied to create the braze joint. After brazing, the joint has a structural strength equal to or greater than the unbrazed area of the tubing. The design is controlled by North American drawings. The union is made from stainless steel AM 355 bar stock and passivated.

3.4.1.2 North American Furnace Brazed Joint: The furnace brazed joint was used in two types of joint assemblies: tube to manifold and tube to tube. The tube to manifold consisted of either a straight or bent tube inserted in a female port boss in a fluid manifold or valve plate per Figure 3-4b using a nickel braze alloy preformed ring.

The tube to tube joint consists of a union and two preformed rings.

Use of the manifold or valve plate permits the attachment of hydraulic valves and components to a single or cluster of fixed hydraulic lines, and allows removal and replacement of the components without disturbing the line assemblies and installation.

The hydraulic lines were fabricated from annealed AM-350 stainless steel tubing. Proper heat-treatment of the tubing and the AM 355 manifold material is attained as a part of the furnace braze operation. Since the tubing is in the annealed condition before brazing, smaller bend radii may be used when bending the tubing and the union may be installed much closer to the bend as the result of not requiring a specific length of straight tubing either side of the union for attaching the induction brazing tool. Therefore, the tube to tube furnace brazed line assemblies generally require less installation space than other tube and fittings.

The unions and manifold were made from AM 355 bar stock passivated after machining. Other stainless steels may be used for the manifold; however, care should be taken to ensure they are fully compatible with the tubing when furnace brazed.

3.4.1.3 Deutsch Pyrobraze Joint: The union (sleeve) used to form this permanent joint was similar to the North American induction brazed union in that it was a sleeve with reduced wall thickness at each end and containing two preformed braze alloy rings as shown in Figure 3-4c. The union was packaged in an exothermic material with two small electrical wires protruding from the package.

To perform the braze, the tube ends were inserted equidistances into the package. The exothermic material was ignited by connecting the two wires to a small 9 volt battery, the heat generated by the exothermic reaction melting the eutectic type braze alloy. Prior to and during the brazing operation, a flow of argon gas was passed through the tubes to purge the braze area to prevent the forming of oxides.

3.4.1.3 (Continued)

A number of these joints were used on the North American RS-70, 4000 psi, 450 F hydraulic system with AM-350 stainless steel tubing. However, due to lack of additional interest and concern about an uncontrolled pyrotechnic reaction, further promotion of this fitting has been discontinued.

3.4.1.4 Aeroquip Space-Craft Brazed Joint: The Aeroquip induction brazed joint consists of a close tolerance tubular union (sleeve) with two formed ring cavities, containing the preformed braze alloy rings, see Figure 3-4d. After inserting the two tube ends into the union, the joint is brazed by attaching a portable plier-type induction brazing tool to the joint and applying the heat by means of the induction coil in the tool. Inert gas piped into the head of the tool provides an inert atmosphere around the joint during brazing to prevent forming of oxides that could contaminate the braze.

This process can also be used to join the tubing to special tubular tee's and elbows. The ends of the fittings contain a single braze ring cavity and alloy in which the tube is inserted for brazing.

Considerable weight and space saving is attained with this joint compared to the AN and MS type of fitting. In-place brazing can be performed which permits the installation and replacement of lines in the air vehicle. The reliability of this joint relative to leakage, is greatly increased since the leakage paths inherent in the flared or flareless joints do not exist.

The joints may be made using most any of the 300 series and 21-6-9 stainless steels as well as titanium tubing. They have been used on Gemini, LEM, Agena, Lunar Orbiter, A7A, S3A, Concorde, and F-14 vehicles.

All fabrication, assembly and installation tooling may be obtained from the Aeroquip Corporation.

3.4.1.5 Linair [14] Production - Brazed Tube Fittings: The Linair brazed fittings were designed by McDonnell-Douglas for induction brazing to various types of stainless steel and titanium tubing. They may be attached by using a multiple cavity bench tool or for in-place brazing inside a vehicle a portable powered hand-held tool can be used.

There are two general types of fittings: permanent and detachable. The permanent fittings consist of unions, reducers, elbows, tees and crosses that are permanently attached to the tube assembly; whereas, the detachable fittings of the same type have a standard male thread or "B" nut on one end to permit the attachment and removal of a component or another line assembly. See Figure 3-4e.

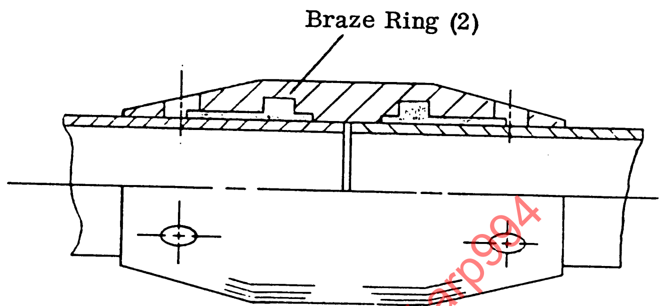
These fittings are supplied pre-cleaned, with brazing material in the form of a ring installed in a cavity inside the fitting. The brazing tool, which is clamped around the area of the fitting to be brazed to the tube, incorporates a metal plate induction coil and a tube chill block, both water-cooled. The heating cavity is purged with a flow of inert gas prior and during the braze operation. An acceptable brazed joint is determined by a visible fillet of alloy on the tube at the end of the fitting.

Multi-cavity, induction brazing tools were designed to braze 10 joints at a time. These include positionable tee and elbow assemblies. They can be racked and indexed to a working master part which totally eliminates the need for individual holding fixtures in production.

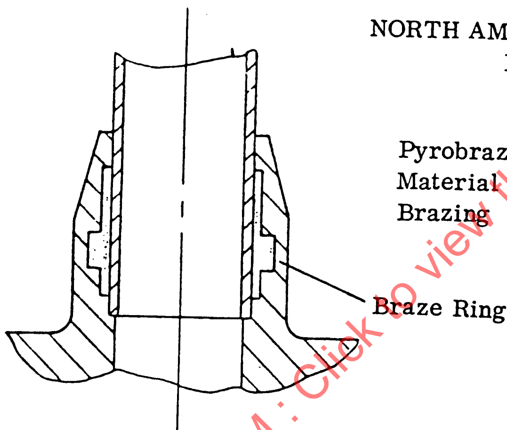
Fittings are of CRES, 304-L material, and accommodate tube sizes from 3/16 O.D. through 1-1/4 O.D. When high strength CRES 21-6-9 tubing is used to save weight, gold-nickel preformed brazing rings are used as the brazing alloy. 3000 psi pressure lines range through the 1 in. O.D. size, and return lines range through the 1-1/4 O.D. sizes.

Fitting types can be provided which directly replace detachable flared or flareless connections and meet all the applicable requirements of MIL-F-18280C. The fittings are currently being used on the A-4, DC-10, and the S-3A.

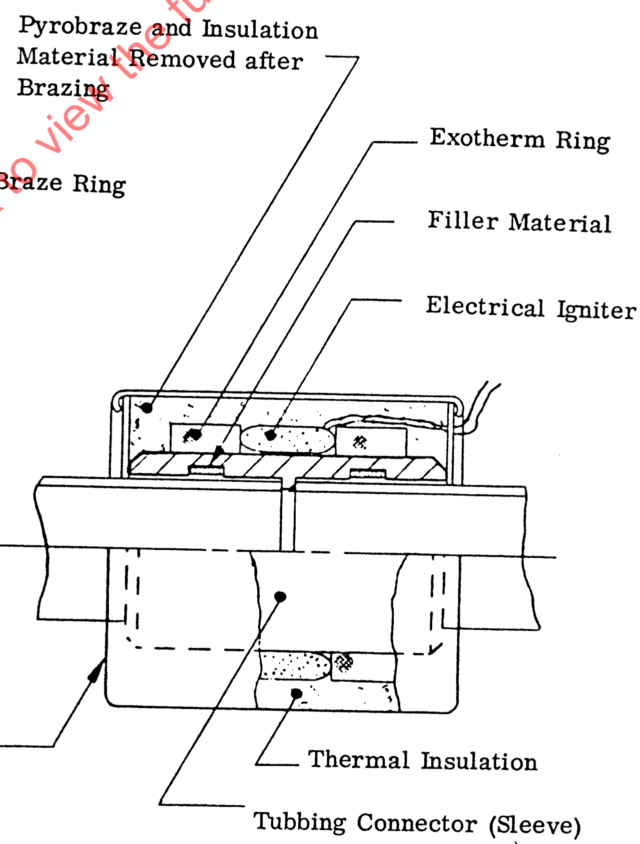
(14) Linair Engineering, 651 West Knox Street, Gardena, California 90247



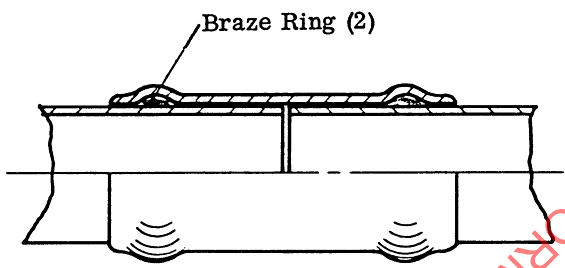
NORTH AMERICAN INDUCTION-BRAZED JOINT
FIGURE 3-4a



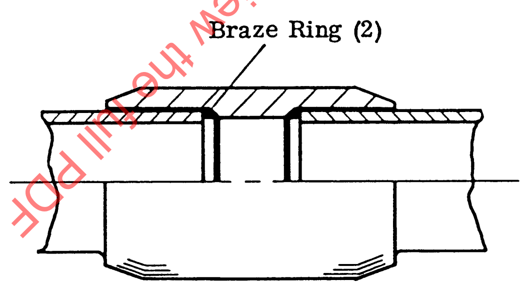
NORTH AMERICAN
FURNACE-BRAZED JOINT
FIGURE 3-4b



DEUTSCH PYROBRAZE JOINT
FIGURE 3-4c



AEROQUIP SPACECRAFT BRAZED JOINT
FIGURE 3-4d



LINAIR PRODUCTION-BRAZED TUBE FITTING
FIGURE 3-4e

3.4.1.5 (Continued)

The design of these fittings is controlled by Linair Engineering drawings conforming to the McDonnell-Douglas design specification drawings and are made from either carbon steel alloys or stainless steel material. A variety of materials is available for the prepositioned braze ring.

3.4.2 Welded Joints: Machine welding by the tungsten inert gas (TIG) method is used to join basic aircraft structure and similar techniques can be used for hydraulic tubing. The development of portable welding tools, power supplies, instrumentation, and procedures for in-place welding of tubes in an airplane system has proceeded to the point where acceptable butt welds can be repeatedly made with the standard AISI 304, AM-350, and the 21-6-9 stainless steels and the titanium alloys of interest, i.e. 6Al-4V and 3Al-2.5V. The joint designs considered most promising are shown in Figure 3-5 and are described below.

3.4.2.1 Square Butt Weld Joint: The square butt weld (Figure 3-5a), wherein the tube ends are butted together and welded in one pass without filler material, is the simplest and lightest weld joint design and lends itself best to radiographic inspection. Since the tube interface is visible to the operator, initial alignment of the welding tool is relatively easy. With proper end fitup, 100% weld penetration is more sure than with sleeve-type joints since only one thickness of material must be penetrated. Tests of well-aligned butt welds have been eminently successful and have proven as strong as the tube itself in most of the pressure impulse and flexure fatigue tests. Its primary disadvantage is that very little end gapping can be tolerated. Clamping devices will be necessary to hold tubes in alignment to guarantee good in-place welds. If an acceptable arrangement is not developed, butt welding may be limited to bench assembly operations.

3.4.2.2 Flare-Bevel Butt Weld Joint: A flare-bevel butt joint (Figure 3-5b), wherein one tube end is flared to accept the beveled end of the adjoining tube, has been evaluated to determine its ability to withstand angular misalignment but it too is subject to imperfect joints unless carefully aligned.

3.4.2.3 Butt Weld with Insert: The butt weld with insert (Figure 3-5c), wherein the two tube ends are joined with a sleeve insert, serves to align the tube ends and provide filler material during the weld process which is made in one pass. It was selected for the Boeing SST prototype for use with titanium tubing.

3.4.2.4 Bellmouth Welded Joint: The Georgia Division of Lockheed has developed a bellmouth welded joint (Figure 3-5d), wherein one end of the tube is expanded sufficiently to accept the unexpanded end of the mating tube, which is being used with AM-350 tubing on the C-5A airplane.

3.4.2.5 Double Melt Through Welded Joint: The Georgia Division of Lockheed uses this joint (Figure 3-5e), with AM-350 tubing on the C-5A in locations wherein it is impossible to insert a tube into a bellmouth joint. This joint is also used on the Spartan missile hydraulic system.

3.4.2.6 Weatherhead Swaged Sleeve Weld Joint: This joint (Figure 3-5f) utilizes separate swaged-on supporting sleeves at the end of each tube which are joined together by a single butt weld. The sleeves are pre-swaged on the tubing, offering support for flexure as well as for burst pressure. This design is used to join 21Cr-6Ni-9Mn stainless steel tubing on the Boeing 747 airplane.

3.4.2.7 "T" Ring Weld: This is essentially a butt weld utilizing a "T" ring as filler metal during the welding process (Figure 3-5g). Lockheed-California Company uses this weld exclusively for 21-6-9 tubing on the L-1011.

3.4.3 Swaged Joints: Two swaged type permanent joints developed for aircraft use are worthy of note.

3.4.3.1 Boeing H Fitting: This fitting, as shown in Figure 3-6a, is composed of three basic parts: sleeve, slide, and back-off nut. It is designed to be either permanent or reconnectable. The sleeve is so designed to receive a tube assembly at each end that is inserted equidistance into the sleeve against a stop, the center portion of the outside diameter is threaded to accommodate the back-off nut. A series of sharp-edged circumferential grooves are machined inside of each end of the sleeve that bite into the tubing, creating the attachment and seal between tube and sleeve, when the two slides with tapered bores are forced over the sleeve ends. To disconnect the fittings, the back-off nut is turned against the slide, forcing it off its tapered bore. This permits removal of the tube from the sleeve. The fitting materials can be 7075-T6 aluminum, 303-1/4 hard or AM 355 stainless steel, and used on tubing materials, 6061 T-6 aluminum, 304-1/8 hard or AM-350 stainless steel.

The assembly tools for assembling the joint can be powered by either pneumatic or hydraulic actuators. Both the assembly tools and the fitting designs were developed by The Boeing Company. The Parker Aircraft Company has been granted a license to market the H fitting.

Although not yet installed on any production airplanes, approximately 40 H fittings of 3/8, 1/2 and 5/8 inch size have been flying on each of two United Airline's Boeing 720 airplanes without failure in the high pressure hydraulic system since approximately 1963.

In 1971, the fitting was redesigned as shown in Figure 3-6b, incorporating a wrenching hex on one of the slides and a nut which spans the coupling. This has met all of Boeing's requirements in the -4 through -10 (1/4 through 5/8 inch tube diameter) sizes and is approved as a repair fitting for high pressure line of both 304-1/8 hard and 21-6-9 material.

3.4.3.2 McDonnell-Douglas Permaswage Fitting: The McDonnell swaging method was developed to provide a permanent joint which was unencumbered by the cleanliness and quality control constraints of the other joining methods (Figure 3-6c). Swaging can permanently couple a wet or a dry line in-place and the power source is universally available. The split-type hand swaging tool may be powered from (1) a hydraulic hand pump or service cart, or (2) shop air hose, through a self-contained hydraulic booster. Verification of joint integrity is by visually checking the tube insertion marks and gaging the swaged union O.D. with a "GO" - "NO-GO" (tuning fork) tool.

Two styles of run-unions are used: (1) dual swaged unions and (2) brazed to swaged unions. The former is shown in Figure 3-6c. The union lengths and swage tool are identical for either style but the brazing cavity is shorter than the swaged cavity. The adjacent tube may bottom in the fitting bore or gap from 1/2 inch to 1-1/2 inch depending on the tube size. This installation adjustment feature, combined with slotted attachment brackets for line clamps, is provided to eliminate the piping fit and preload problems.

The swaged run-unions accommodate line sizes for 1/4 O.D. through 1-1/2 O.D. tubing. All unions are CRES 21-6-9 through the 1-1/4 O.D. size range. Dual-swaged alum-alloy unions are used on pump suction lines. Adjacent lines may touch or gap 1/4 in. when dual swaged unions are employed.

Swaging tools and unions may be obtained from Deutsch Metal Components Division[15]. The fitting designs are controlled by McDonnell design standard drawings.

3.4.3.3 Raychem [16] Cryofit Tube Fitting: The Cryofit tube fitting (Figure 3-6d) concept is based on a heat shrinkage Nickel-Titanium alloy. The material is expanded and stored at liquid nitrogen temperatures. After the fitting is installed and permitted to warm up through the transformation temperature, it recovers or contracts the tubing with high recovery force. The process is partially reversible to permit the removal of fitting from the tubing. Additional information may be obtained from The Raychem Corporation.

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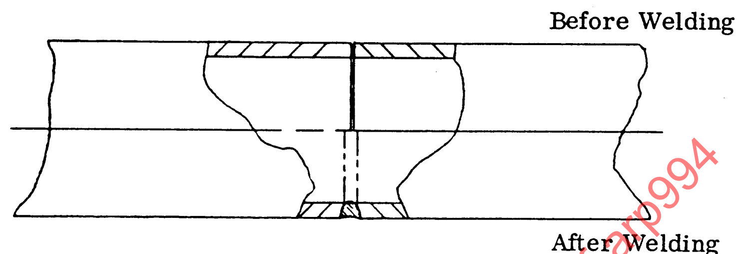
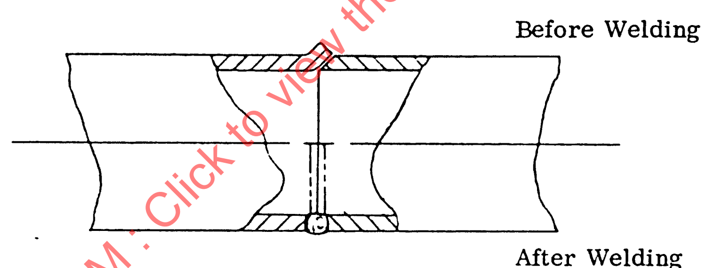
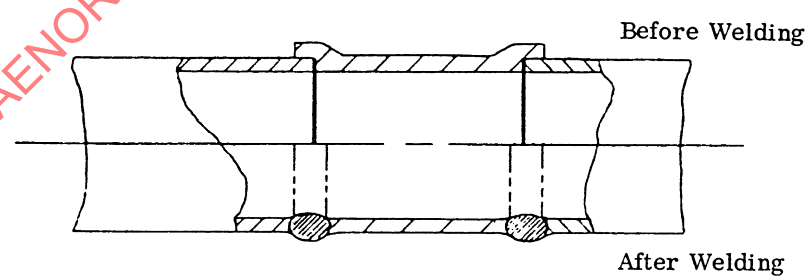
(15) Deutsch Metal Components Division, 14800 S. Figueroa St., Los Angeles, California 90061
(16) Raychem Corporation, 300 Constitution Drive, Menlo Park, California 94025



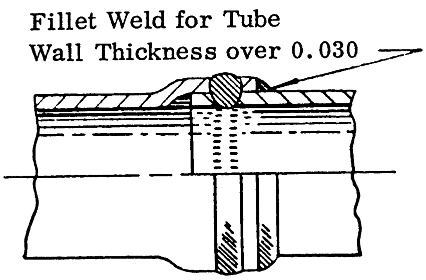
SQUARE-BUTT WELDED JOINT
FIGURE 3-5a



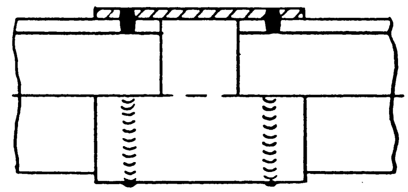
FLARE-BEVEL BUTT-WELD JOINT
FIGURE 3-5b



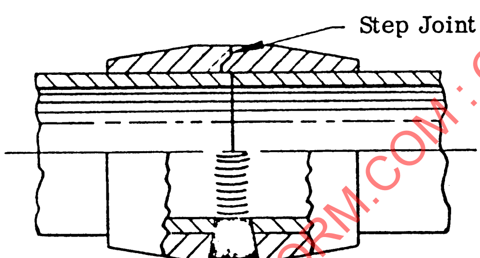
BUTT WELD WITH INSERT
FIGURE 3-5c



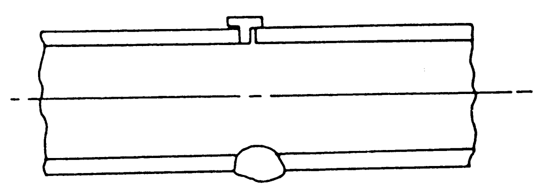
BELLMOUTH WELDED JOINT
FIGURE 3-5d



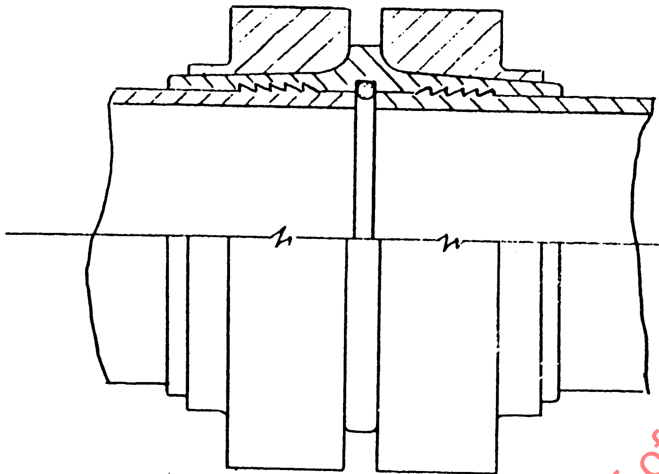
DOUBLE MELT THROUGH WELD JOINT
FIGURE 3-5e



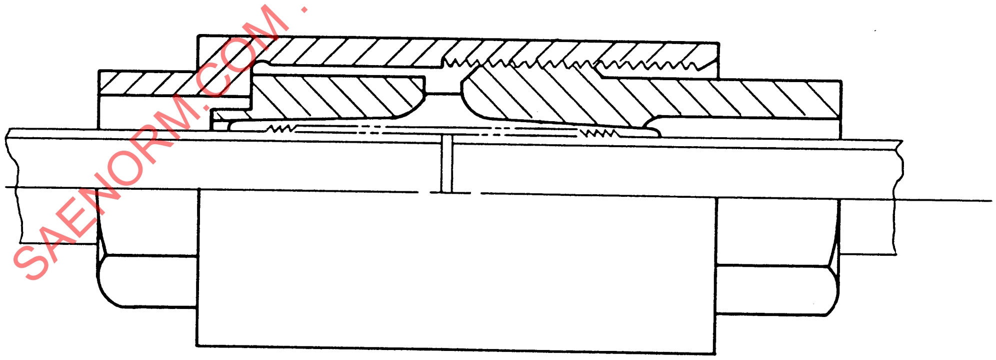
WEATHERHEAD SWAGED-SLEEVE
WELD JOINT
FIGURE 3-5f



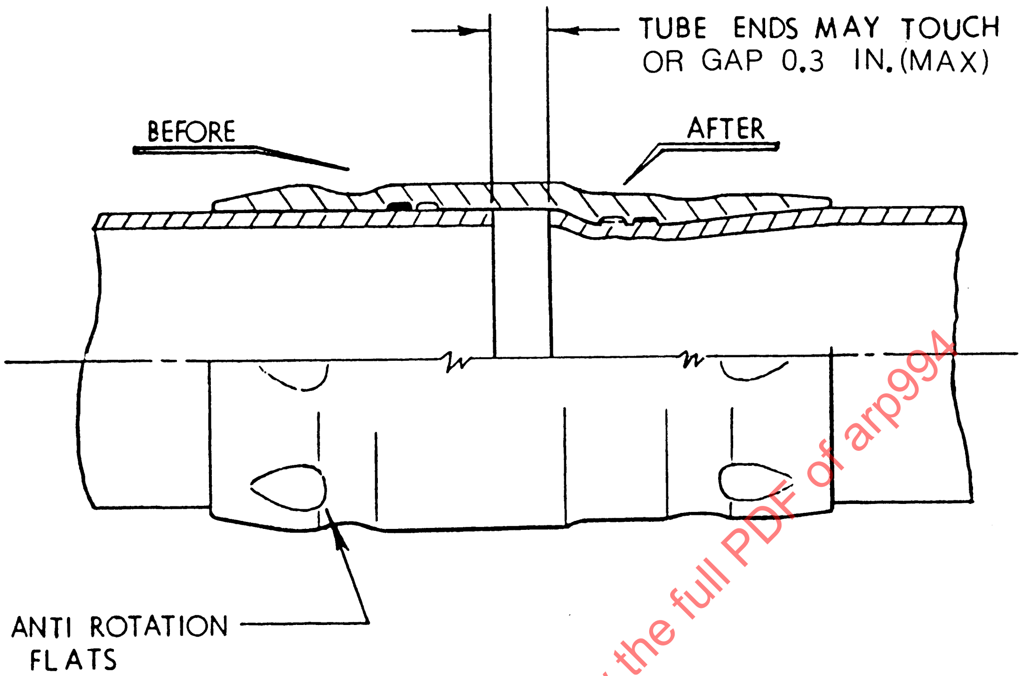
BUTT-WELD T-RING
FIGURE 3-5g



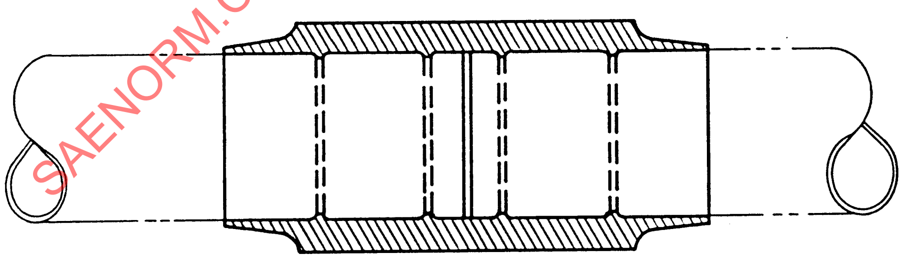
BOEING "H" FITTING
FIGURE 3-6a



REPAIR "H" FITTING
FIGURE 3-6b



McDONNELL-DOUGLAS PERMASWAGE FITTING
FIGURE 3-6c



RAYCHEM CRYOFIT FITTING
FIGURE 3-6d

3.5 <u>Self-Sealing Disconnect Coupling</u>: The self-sealing disconnect coupling applications include three classifications: ground support equipment, air vehicles and space vehicles. There are different types and they are referred to as:

a. Push-pull, which requires axial motion to connect and generally requires a rotational motion to lock or unlock.

b. Threaded, have either a fast lead (multiple) thread for fast connection and disconnection with minimum turns or, standard (straight) thread for connection and disconnection.

c. Rack and panel, consisting of one or more separate coupling halves installed on a rack or panel.

d. Remotely actuated, these are capable of connection and disconnection by other than direct manual means but also may include manual actuation provisions.

The prime function of the self-sealing coupling is to join or disconnect two fluid (rigid or flex) lines without the loss of fluid or the inclusion of air into the system. It also seals both disconnected lines so that system pressure may be applied.

MIL-C-25427, Coupling Assembly, Hydraulic, Self-Sealing Quick Disconnect, covers the detail requirements for the standard couplings, for use in Type I and Type II hydraulic systems. The design configurations are controlled by MS24333 Coupling Assembly, Flared Fitting to Internal Thread Boss, MS24334 Coupling Assembly, Flareless Fitting to Internal Thread Boss and MS24335 Flange, Bulkhead Mounting, Coupling. The couplings may be made from any material that is compatible with the tubing material and system requirement for the specific application.

Manufacturers of all qualified and approved standard quick-disconnect couplings are listed in QPL-25427, of the latest date. AIR 1047A is a good guide for the selection of quick-disconnect couplings.

When using self-sealing couplings, great care should be taken to ensure they are positively joined and will not inadvertently disconnect in service. This is especially true in return lines since a blocked return line can cause a hydraulic block in an actuation system which cannot be overcome by a redundant actuator. This has caused loss of aircraft and should be avoided wherever possible. If self-sealing couplings must be used in return lines, great care should be made, such as by the use of lockwire, to ensure that they will not uncouple in service.

3.6 <u>Housing Fluid Fitting Bosses</u>:

3.6.1 <u>Bosses per AND 10050</u>: Aircraft fluid power system components in both commercial airplanes and military aircraft and missiles have, for many years, used internal straight-thread bosses per AND10050, and said boss is still called out in many component specifications. It has been entirely satisfactory in components where pressures have not exceeded 2000 psi. However, in higher pressure systems where surge pressures approach or exceed 4000 psi, care must be taken in the installation of all O-ring gaskets and fittings in order to prevent fluid leakage.

It has been found that if an extrusion gap of any magnitude exceeding 0.002 develops between the underside of the wrenching hex on the fitting and the mating surface face of the boss, that O-ring extrusion will take place under pressure surges. Upon reduction of pressure, the extruded portion of the O-ring is trapped and cut between the faces of the joint. Repetition of this action eventually causes O-ring failure.

Three procedures which help to minimize this problem are:

a. Use of a slip-on protective thimble over the fitting threads as shown in Figure 3-7, when installing the gasket O-ring to protect it from being cut on the sharp edges.

b. Use of a torque wrench to ensure the fittings are installed to the full recommended torques as listed in Table 3-3. This will ensure that there will be no working of the fitting within the thread clearance.

c. Use of the O-ring gasket approved for the fluid used.

3.6.1 (Continued)

Another point of caution is to ensure the boss has sufficient strength to withstand deformation and failure due to pressure and deflection loads. Aluminum alloy bosses are susceptible to bell-mouthing and cracking under prolonged pressure impulsing, especially in the larger sizes. Careful stress analysis and testing under realistic pressure and temperature conditions is required to ensure a satisfactory design. One method of strengthening a fitting boss in a lightweight design is to leave a larger reinforcing ring of material around the opening in a raised boss as shown in Figure 3-8.

3.6.2 Bosses per MS33649: In an attempt to reduce the possibility of having a seal extrusion gap between the fitting and housing, this standard was released (1966) with closer control of the squareness of the threads to the spotface surface where the fitting seats on the housing. In addition, the new Standard specifies somewhat deeper threads and tap drill holes (as shown in Table 3-4). The purpose of this change was to prevent fittings from bottoming at the bottom of the hole rather than at the face of the housing (under the hex). Calculations show that, with adverse tolerances, a bulkhead fitting with an MS33657 end installed in an AND10050 boss per the instructions given in AND10064, will bottom in the hole and this was considered responsible for many of the leaks encountered.

While the change has overcome the foregoing problem, it has also imposed a new one for some components previously designed. The deeper threads and tap drill holes can result in inadequate wall thicknesses and/or break through into an adjacent fluid passage. Therefore, although the new Standard supersedes AND10049 and AND10050, care should be taken when making new parts to an existing design that it is not detrimentally weakened by the deeper holes. If it is found that such is the case, care must be taken to not only ensure that the old standard is called out on the drawings but to verify that the shop has not converted its tooling to the new Standard.

3.6.3 Bosses per SAE AS 757: This Standard was released (in 1963) to provide a boss which eliminates the possibility for interference fit and pinching of the O-ring in tightening. It is similar to MS16142 (Ships) except with higher quality threads (Class 3 rather than 2), better finish on the sealing surface, closer control of spotface squareness with the threads, larger spotface, and deeper threads. However, since interference and pinching have not been established as a service problem, neither the military nor the industry have seen fit to adopt this Standard and it has been cancelled due to this lack of usage. It remains available, however, and two companion Standards as well: AS 756 specifying end dimensions for universal fittings with an anti-O-ring extrusion washer, and AS 758 for installation instructions.

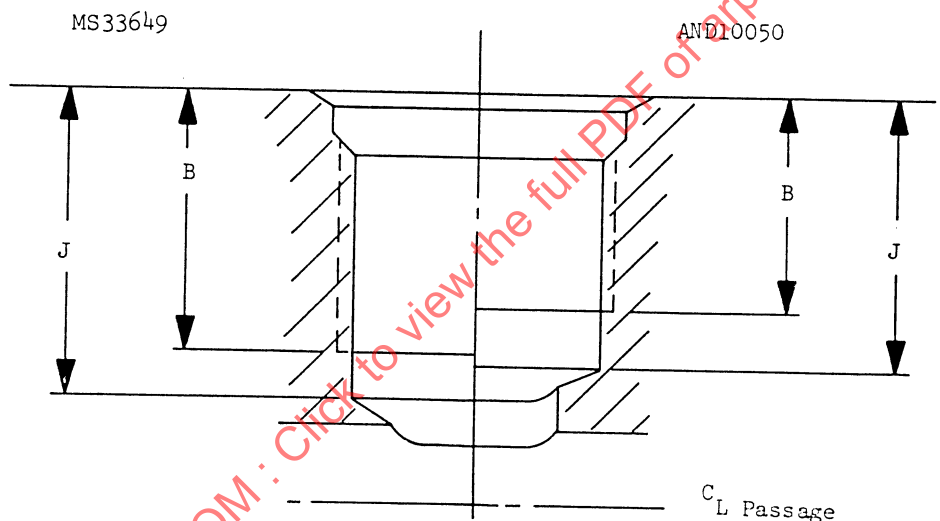
3.6.4 Boeing Recessed Boss: This design, for use with the diametral-sealed fitting shown in Figure 3-3g, was first developed in 1961 for use in hydraulic components on the X-20A (Dyna-Soar) manned re-entry space vehicle. It was later adopted by the Commercial Airplane Division for use on the 747 airplane. This is a true dual-seal configuration in that either the lower (diametral) O-ring or the upper (gasket) O-ring will function if the other has been damaged or has failed. Due to the deeper hole required (0.25 to 0.31 in most sizes) use of this design does introduce a weight penalty. However, for a large commercial airplane with fully powered flight controls with no manual reversion provisions, the reliability gain was deemed worth the weight penalty. Airline experience has shown the design to be an improvement over the AND10050 boss. Dimensions are controlled by a Boeing standard drawing.

3.6.5 SAE AS 685 Boss: This is a bolted-flange piloted-seal boss prepared by SAE Committee E-21 for use on propulsion system components. See AS 686 for mating parts.

TABLE 3-3

INSTALLATION TORQUE FOR BOSS FITTINGS

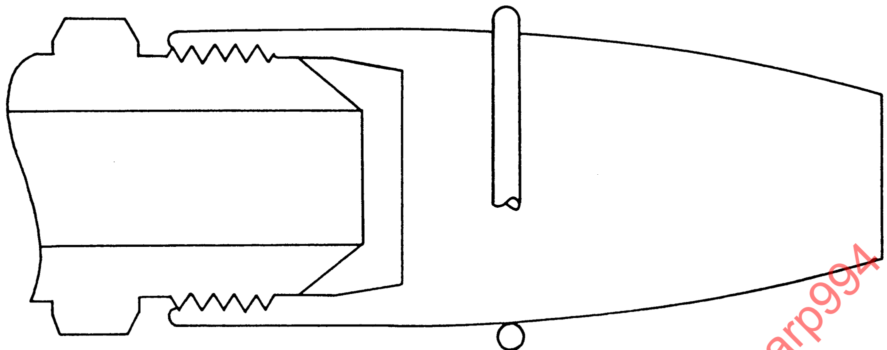
TUBING O.D. INCH	FITTING SIZE DASH NO.	WRENCH TORQUE: FOR STEEL OR TITANIUM	IN-LB ± 5% FOR ALUMINUM FITTINGS
1/4	-4	140	110
5/16	-5	190	140
3/8	-6	270	170
1/2	-8	500	280
5/8	-10	700	360
3/4	-12	900	450
1.0	-16	1200	750
1-1/4	-20	1600	900
1-1/2	-24	2000	900



A change from AND10050 to MS33649 in old components could result in inadequate wall thickness or breakthrough into the passage.

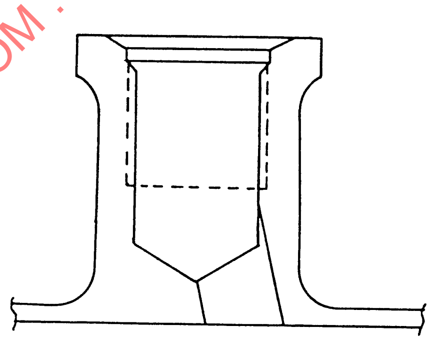
TABLE 3-4
COMPARISON OF AND10050 and MS33649
FITTING BOSS DEPTHS

	MS33649		AND10050	
	B min	J min	B min	J min
-3	0.538	0.583	0.406	0.500
-4	0.568	0.656	0.438	0.594
-5	0.568	0.656	0.438	0.594
-6	0.598	0.709	0.469	0.594
-8	0.714	0.834	0.562	0.718
-10	0.802	0.930	0.625	0.781
-12	0.877	1.064	0.688	0.906
-16	0.877	1.064	0.688	0.938
-20	0.877	1.116	0.688	0.984



USE OF PROTECTIVE THIMBLE TO PROTECT O-RING WHEN INSTALLING OVER FITTING THREADS.

Figure 3-7



REINFORCED RAISED BOSS

Figure 3-8

4. LINE SIZING

The choice of system line sizes is usually based on trade studies which balance energy loss against cost and weight. Large diameter tubing will conduct the fluid with lower pressure loss than smaller sizes, but will weigh more, be harder to bend, flare, swage, weld, or braze and will cost more.

CONTENTS

4.1 Basic Requirements and Rules of Thumb:

4.1.1 Fluid Velocity Limitation: A historical rule of thumb is to size the tubing for an average flow velocity of 15 feet per second. Table 4-1 indicates the average rate of flow for tube size between 1/4 in. and 1-1/2 in. OD, based on a maximum wall thickness of standard aluminum-alloy tube conforming to Standard AND10106, for laminar flow. It is lifted directly from MIL-H-5440 where it has been included in the original issue and all subsequent revisions through Revision D which included the following statement:

"3.5.7 Fluid velocity limitations. It is desired that tube sizes be such that the average velocity of oil in pressure and return lines leading to the directional control valves shall not be in excess of approximately 15 feet per second, except where system analysis shows that proper functioning can be achieved even though the rate be higher. The velocity of flow in the suction lines shall be governed by the pressure requirements for suction lines, as specified herein."

TABLE 4-1

Maximum Laminar Flow for Nominal Tube Sizes

MIL-H-5606B or Phosphate Ester at 100 F

Tube Dash No.	Tube O.D.	Flow - GPM
-4	1/4	1.2
-5	5/16	2.3
-6	3/8	3.5
-8	1/2	6.0
-10	5/8	10.5
-12	3/4	16.0
-16	1	29.0
-20	1-1/4	45.0
-24	1-1/2	70.0

However, it should be noted that in MIL-H-5440E such reference to the 15 fps velocity and the table have both been deleted in favor of the following:

"3.5.7 Fluid velocity limitations - Tubing size and maximum fluid velocity for each system shall be determined considering, but not limited to, the following:

(a) Allowable pressure drop at minimum required operating temperatures.
(b) Pressure surges caused by high fluid velocity and fast response valves.
(c) Back pressure in return lines, as it may affect brakes and pump case drain lines.
(d) Pump inlet pressure, as affected by long suction lines, and a high response rate variable volume pump. Consideration should be given to both pressure surges and cavitation."

The following subparagraph from MIL-H-5440E is also pertinent to the line sizing analysis:

"3.5.7.1 Fluid flow effects - The systems shall be so designed that malfunctioning of any unit or subsystem shall not occur because of reduced flow, such as created by single-pump operation of a multi-pump system, or reduced engine speed of a single-pump system. The system shall also be so designed that increased flow will not adversely affect the proper functioning of any unit or subsystems, such as increased flow rate caused by accumulator operation, or units affected by air load operation."

It is a matter of record that a number of high-flow systems in recent aircraft have been designed with lines resulting in fluid velocities of 25 - 30 fps and even higher in order to avoid excessive weight penalties.

4.1.2 Pressure Drop Balance: A second rule of thumb that has been commonly used for initial sizing of hydraulic system lines is to allow 1/3 of the available working pressure (1000 psi in a 3000 psi system) for tubing pressure drop at the minimum full-performance design temperature, and size actuators (and valves) to meet the maximum-rate force requirements with the remaining 2/3 pressure available.

In a complex system with a number of load combinations, many of which peak at different portions of the flight regime and thus at different minimum fluid temperatures, the task of choosing line sizes is often tedious and time consuming. Selecting tube diameters that will produce a desired pressure differential available for given loads is relatively simple; but, selecting line sizes that produce the lightest system (while still satisfying the pressure requirements at the loads) requires a high degree of experience. As the number of lines in a system increases, the problem of minimizing the system weight becomes quite formidable.

In order to simplify the work, computer programs have been devised and used to give a greater degree of optimization than is feasible to obtain by hand calculations. It is even possible to let the pressure differential across the actuators be a variable in the solution and obtain a truly minimum-weight system for lines and actuators. This approach can produce a worthwhile weight reduction in a high-flow system with long lines where an increase in allowable tubing pressure drop can provide more weight saving than needs to be added for the slightly larger actuator sizes.

4.1.3 Pressure Surge Limits: Pressure surges result from either the rapid release of stored energy into a line or actuating cylinder or from the abrupt closure of a valve from a high-flow condition. In the latter case, the magnitude of the pressure rise is a direct function of the original fluid velocity, i.e. for rigid pipes:

Pressure rise $\Delta P = V \sqrt{B \times \frac{w}{g}}$ psi

where V = original fluid velocity in./sec

B = fluid bulk modulus psi

w = fluid density lb/in.^{3}

g = 386 in./sec^2

For MIL-H-5606 fluid at 100F, with the following physical characteristics:

B = 270,000 psi with all entrained gas removed
= 200,000 psi in a typical system

w = 0.845 specific gravity = 0.0305 lb/in.^{3}

ΔP = 4.0V psi pressure rise

For military aircraft, MIL-H-5440 specifies that "peak pressure (ripple or surge) resulting from any phase of the system operation shall not exceed 135 percent of the main system, subsystem, or return system operating pressure when measured with electronic equipment, or equivalent." In a 3000 psi system, the surge peak should not exceed 4050 psi.

Therefore, for flow velocities above 262 in./sec (22 ft/sec), valve closing times must be limited to values greater than $2\ell/C$ seconds where ℓ = length of pressure line from pump to valve and C = the speed (of sound) at which the fluid pressure wave will travel along the oil filled tube.

$$C = \sqrt{\frac{B}{w/g}}$$

4.1.3 (Continued)

For MIL-H-5606 at 100 F and 3000 psi

$$C = \sqrt{\frac{200,000}{.0305/386}} = 50,000 \text{ in./sec}$$

For a 20 ft pressure line, valve closing time must be greater than 0.0096 seconds.

For high flow velocity conditions, the required valve closure time, T, can be calculated from the following equation:

$$T = \frac{\Delta P}{\Delta P_a} \times Tr$$

where ΔP = the rise in pressure due to instantaneous valve closure

ΔP_a = allowable pressure rise

Tr = time for a return trip of the pressure wave from the pump

$= \ell/C$

For commercial transport airplanes, an even more stringent surge pressure limit is imposed. FAR 25, Volume III, Transmittal 1, Amendment 25-23, Effective 5-8-70, specifies that transient pressures will not exceed 125 percent of the design operating pressure.

4.2 Minimum Full-Performance Design Temperatures: As indicated previously, one of the primary considerations in designing tubing is in meeting the allowable pressure drop at minimum operating temperature. The latter is often specified directly in the airplane performance specification or indirectly in terms of a specified time in which a military aircraft must be ready for takeoff following an alert during cold soak at a specified low ambient temperature. In the latter case, various means of warming up the system fluid can be considered in determining the fluid temperature at the flight condition where full performance must be met. Trade studies of all possible methods are required to arrive at the optimum combination of warm-up equipment and tube sizes which result in the minimum (or acceptable) weight and cost penalties. The applicable requirements specified for military aircraft systems, and typical practices for commercial aircraft are as follows:

4.2.1 Minimum Operating Temperature for Sizing Lines for Military Aircraft:

4.2.1.1 Pump Suction Lines: The following requirements for suction lines are quoted directly from MIL-H-5440:

"3.10.29.9 Suction line. -

3.10.29.9.1 Suction line flow. - The suction line from the reservoir to the power pump or pumps shall be so designed as to provide adequate flow and pressure at the pump inlets, with the power pump or pumps operating at the maximum fluid volume output required at the service ceiling of the aircraft, and with the hydraulic fluid at the expected stabilized temperature, but this stabilized fluid temperature shall be not warmer than -20 F, unless provisions are incorporated to control the fluid temperature. Due regard may be given to selecting an altitude less than service ceiling for any system in which the pump does not operate during "in flight" conditions, but this altitude shall be not less than 10,000 feet above sea level. Test data and analysis shall be furnished for the approval of the procuring activity, showing that satisfactory service life of the pump or pumps will be indicated under all operating conditions of the aircraft. This information shall be included in the system design report (see 3.4.1.10).

4.2.1.1 (Continued)

3.10.29.9.2 Suction line, cold starting. - Unless otherwise specified by the procuring activity, during cold starting on the ground at all ambient air temperatures down to -65 F, the above conditions of suction-line pressure drop shall not apply until stabilized fluid operating temperatures have been obtained.

3.10.29.9.3 Suction-line filters. - Filters shall not be installed in the suction line to power-driven pumps, unless such a location for the filter is specifically approved by the procuring activity. If a suction-line filter is contemplated, complete test data shall be submitted showing that the pressure drop through the filter will not interfere with the operation of the hydraulic system, particularly at high altitudes. Suitable relief valves shall be provided in the filter.

4.2.1.2 Landing Gear Retraction Systems (Air Force): The following requirement is taken from the AFSC Design Handbook 2-1 Airframe, Design Note 4A6:

SUB-NOTE 1(1) Landing Gear Performance Requirements

RULE	IF The Landing Gear System is	AND The Temperature is	THEN The maximum allowable time to extend and lock the gear is 1	AND The maximum allowable time to retract and lock the gear is 2	AND
1	Power Operated	Above $-20^{o}F$ ($-29^{o}C$)	15 sec	10 sec	The gear must be retracted and locked before the aircraft reaches 75% of the gear placard speed at the maximum rate of acceleration.
2		$-65^{o}F$($-54^{o}C$) to $-20^{o}F$($-29^{o}C$)	30 sec 3	10 sec 3	

NOTES:

1. If the landing gear is used as a speed reducing device, the time to extend and lock the gear must be determined by the desired performance.

2. For zero-launch aircraft, the landing gear retraction sequence must be completed one second prior to reaching the gear placard speed.

3. The system must meet these requirements when stabilized at the temperature extremes without allowing warmup time.

4. For multiengine aircraft, the system must meet these requirements during an engine-out condition.

It should be noted that this requirement is more severe than that previously specified in AFSCM 80-1 (HIAD) which allowed the time of operation (for both retraction and extension) between -65 and -20 F to be up to "twice the fastest time obtained at normal temperatures (approximately +70 F)."

4.2.1.3 Flight Control Systems (Air Force): AFSC DH2-1 specifies the following:

Ensure that, after the initial breakaway, the increase in force required to operate the control subsystem at -65 F, does not exceed 150 percent of the force required at +70 F (+21 C). Design control subsystems to meet the anticipated temperatures encountered during flight.

4.2.1.4 Flap Actuation Systems (Air Force): AFSC DH2-1 specifies that, between -65 and -20 F, the time of operation must be not more than 50% greater than the normal speed selected with all components of the flap actuating mechanism stabilized at the specified extreme temperature, and without assuming time for warmup of the components.

4.2.2 Minimum Operating Temperatures for Sizing Lines for Commercial Transport Airplanes: The Federal Aviation Regulations do not specify any low temperature requirements for hydraulic systems in transport category airplanes. However, the following minimum operating temperature capabilities are typical for large commercial jet transport airplanes:

Ambient temperature range in flight: -110 to +130 F
Minimum cold start capability (ambient and fluid): -65 F
Minimum fluid temperature for rated pump suction flow: -20 F
Minimum fluid temperature for full system performance: +50 F

5. ROUTING

CONTENTS

CONTENTS (Cont'd)

5. ROUTING

5.1 Line Location:

5.1.1 Fluid-Carrying Lines: Well planned line location will reduce system complexity and weight, and minimize damage and hydraulic fluid leakage. The hydraulic line installation design objective should be to obtain a service life equivalent to the airframe structure while retaining capability for ease of line replacement and repair. A minimum number of reconnectable fittings for component servicing should be used. Minimize the use of bends and branches, and exploit the most direct routing consistent with other requirements.

Certain basic design criteria should be recognized in the interest of adequate strength, long service life, safety, and reliability.

(a) Avoid straight tube runs between rigid end points.
(b) Provide flexible mountings to relieve strain.
(c) Use semi-loops in steel and titanium lines to facilitate installation alignment or relieve stresses.
(d) Do not use straight or looped aluminum alloy tubing between end points permitting relative motion.
(e) Provide for installation adjustment with slotted attach brackets and oversized cutouts, where maximum use of slot and tolerance buildup will not result in tube interference or chafing.
(f) Avoid running lines within pressurized compartments or personnel stations: or near exhaust stacks, hot manifolds, or electrical, electronic and oxygen lines and insulating material.
(g) Use permanent joints wherever practical.
(h) Use stainless steel or titanium alloy tubing for all system pressure lines and for system return lines in designated fire zones and for all sizes 3/8 in. and smaller regardless of location.
(i) Limit the use of aluminum alloy lines to area outside of designated fire zones, to system return and pump suction lines, and to sizes 1/2 in. and larger. If there is vital need to reduce weight, 3/8 in. aluminum lines can be considered but only in areas not normally accessible to damage by service or other personnel.
(j) Avoid long lines in open areas unless recommended support spacing is possible.
(k) Limit minimum tube wall thickness to 0.020 in. in any material.

5.1.2 Drain & Vent Lines: Extend drain lines below exterior surfaces of the aircraft so that exhausted hydraulic fluid or its vapor will not be blown back into the aircraft, or against stacks, hot manifolds or other ignition sources, or collect in pools in structure. Do not permit discharge into wing leading edges, inspection doors, wheel wells, exhaust outlets, air intakes, or other ignition source. Seal drain line opening through outer surface, to prevent return of vapor or liquid into a compartment. Also, add a scarf end to drain lines so that the airstream will create negative pressure. In addition:

(a) Loss of fluid through a reservoir vent must not occur during flight or ground maneuvers.
(b) No valves of any description should be used in discharge lines downstream of relieving devices.
(c) Consider routing vent lines to a collection tank for dumping during a ground turnaround rather than during flight.

5.1.3 Mockups: A full-scale tubing installation mockup is a highly desirable engineering tool for establishing optimum routing and locating bends, joints and supports. Provide accurate simulation of surrounding structure and adjacent equipment in order to verify adequate tool clearances, tolerances, accessibility, and alignment. See section 14 for more detail.

5.1.4 Tube Jigging: High-strength tubing of relatively thin wall tends to make tube jigging a requirement rather than just good practice. Design for precise fit-up and alignment to preclude the need for manual deflection into position. Permanent in-place joining, either by brazing or welding, requires fit-up accuracies at least as stringent as reconnectable fittings. While the utilization of templates and three-dimensional tube jigs is not usual on preproduction vehicles, the use of the necessary tools and fixtures for accurate fabrication of tube assemblies for production aircraft is justified.

5.1.5 Temperature Considerations: Most military aircraft hydraulic systems are classified by type according to operating temperature range.

Type I: -65 F to +160 F temperature range
Type II: -65 F to +275 F temperature range
Type III: -65 F to +450 F temperature range

All hydraulic systems are required to cold start and operate after cold soak and stabilization on the ground at -65 F but need not deliver maximum performance at that temperature. Systems which are started on the ground and operated continuously during flight are not required to start at temperatures below -65 F, but those started in flight may be required to do so depending on the operational requirements and location in the aircraft.

If bypass flow is necessary for cold starts, it is desirable to route the flow to the reservoir rather than directly back to the pump, to prevent a short fluid circuit in which the fluid may overheat locally and damage a pump rather than circulate more widely and warm up the system.

Requirements for commercial aircraft hydraulic systems are similar. They are typically designed to operate throughout an ambient temperature range from -110 F to +130 F and cold start on the ground at -65 F. The maximum system design temperature for commercial aircraft is limited by the hydraulic fluid. The phosphate ester based fluids in general use are controlled by SAE Standard AS 1241 which lists four types according to the amount of moisture allowed. Maximum recommended operating temperature for Types I and II is 225 F and for Types III and IV, 250 F.

Routing lines through areas where excessive heat may be added from electrical equipment, hot ducts, and other heat sources should be avoided wherever possible. If routing near local heat sources exceeding maximum rated system temperature is unavoidable, insulation, local cooling or other protection must be provided. Upper temperature limits of commonly used hydraulic system materials are given in Table 5-1. Long-term temperature limits are given; many of the materials listed can be operated at higher temperatures for short time periods without serious degradation.

TABLE 5-1

Maximum Long Term Operating Temperatures - Hydraulic System Materials

Temperature - ^{o}F

175	200	225	250	275	350	400	500
Nylon	Alum Alloy 70-Series	AS 1241 Fluids Type I and II	AS 1241 Fluids Type III, IV		Viton Cad Plate	Teflon	
			Alum Alloy 20 Series				

5.1.6 Fire Prevention Considerations:

5.1.6.1 For Military Aircraft: The pertinent paragraphs in MIL-H-5440F are quoted below:

"3.6.2 Fire hazards - The hydraulic system shall be integrated with other systems that will eliminate or isolate the system(s) from fire hazards caused by proximity of combustible gases, heat sources, bleed air ducts, or electrical equipment, etc. If feasible, all hydraulic equipment shall be isolated from the engines and other hot areas by the use of firewalls, shrouds, or equivalent means. Sources of hydraulic fluid leakage from removable joints in lines and equipment located in the vicinity of material or condtions that will permit spontaneous ignition of the hydraulic fluid shall be protected by devices that will inhibit fluid ignition. A single failure in the hydraulic system or any other system such as fuel, environmental control or electrical, shall not cause a hydraulic fire."

"3.6.11 Pump supply shutoff valves - Pump supply (suction) shutoff valves shall be provided if the fire protection requirements of the particular model aircraft specify the need for such equipment in other systems, such as fuel or lubricating oil systems, or both. These valves, when required, shall not be located on the engine side of firewalls or flame-tight diaphragms, but shall be located as close as practicable to these members. However, the valves shall be so removed from the engine that the loss of the engine from the attaching structure will not impair the operation of the valve. These valves shall be operable from the cockpit, to both the "closed" and "open" positions."

"3.11.28.6 Tubing in fire hazard areas - Within powerplant compartments and at other locations where fires are likely to occur, all hydraulic tubing shall be corrosion resistant steel, unless the tubing is separated from the engine or potential fire area by a flame-tight barrier. Where separable tube fittings are required, they shall be corrosion resistant or carbon steel."

"3.11.28.9 Location of hydraulic tubing - Hydraulic lines shall not be installed in the cockpit or cabin and shall be remote from personnel stations. In addition, hydraulic lines shall be located remotely from exhaust stacks and manifolds; electrical, radio, oxygen and equipment lines; and insulating materials. In all cases, the hydraulic lines should be below the aforementioned, to prevent fire from line leakage. Hydraulic lines shall not be grouped with lines carrying other flammable fluids in order to prevent inadvertent cross connection of different systems. Hydraulic drain and vent lines shall exhaust in areas where the fluid will not be blown into the aircraft, collect in pools in the structure, or be blown onto or near exhaust stacks, manifolds, or other sources of heat. Tubing shall be located so that damage will not occur due to being stepped on, used as handholds, or by manipulation of tools during maintenance. Components and lines shall be so located that easy accessibility for inspection, adjustment, and repair is possible. Hydraulic tubing shall not be used to provide support of other aircraft installations, such as wiring, other aircraft tubing, or similar installations. Attachment of so-called marriage clamps for spacing of such installations is likewise prohibited."

5.1.6.2 For Commercial Aircraft: The pertinent requirements specified in F.A.R. 25 are included in a number of different paragraphs, the applicable portions of which are quoted below:

"25.1435 Hydraulic systems.
(c) Fire protection. Each hydraulic fluid must meet the applicable requirements of 25.863, 25.1183, 25.1185, and 25.1189."

The phosphate ester fluids currently in use (1972) are fire resistant but not nonflammable and therefore the following requirements must be met:

5.1.6.2 (Continued)

"25.863 Flammable fluid fire protection.

(a) In any area where flammable fluids or vapors might be liberated by the leakage of fluids systems, there must be means to prevent the ignition of those fluids or vapors, and means to minimize the hazards in the event ignition does occur.

(b) Compliance with paragraph (a) of this section must be shown by analysis or tests, and the following factors must be considered:

(1) Possible sources and paths of fluid leakage, and means of detecting leakage.

(2) Flammability characteristics of fluids, including effects of any combustible or absorbing materials.

(3) Possible ignition sources, including electrical faults, overheating of equipment, and malfunctioning of protective devices.

(4) Means available for controlling or extinguishing a fire, such as stopping flow of fluids, shutting down equipment, fireproof containment, or use of extinguishing agents.

(5) Ability of airplane components that are critical to safety of flight to withstand fire and heat.

(c) If action by the flight crew is required to prevent or counteract a fluid fire (e.g. equipment shutdown or actuation of a fire extinguisher) quick acting means must be provided to alert the crew."

"25.1183 Lines, fittings, and components.

(a) Except as provided in paragraph (b) of this section, each line, fitting, and other component carrying flammable fluids in any area subject to engine fire conditions, and each fuel line, fitting, and other flammable fluid system component in a designated fire zone, must meet the following requirement:

(1) Each line, fitting, and component must be at least fire resistant.

(2) Each flexible hose assembly (hose and end fitting) must be approved.

(b) Paragraph (a) of this section does not apply to -

(1) Lines and fittings already approved as part of a type certificated engine under Part 33 of this chapter; and

(2) Vent and drain lines, and their fittings, whose failure will not result in or add to, a fire hazard."

"25.1185 Flammable fluids.

(a) Except for the integral oil sumps specified in 25.1013(a), no tank or reservoir that is a part of a system containing flammable fluids or gases may be in a designated fire zone unless the fluid contained, the design of the system, the materials used in the tank, the shut-off means, and all connections, lines, and control provide a degree of safety equal to that which would exist if the tank or reservoir were outside such a zone.

(b) There must be at least one-half inch of clear airspace between each tank or reservoir and each firewall or shroud isolating a designated fire zone.

(c) Absorbent materials close to flammable fluid system components that might leak must be covered or treated to prevent the absorption of hazardous quantities of fluids."

5.1.6.2 (Continued)

"25.1189 Shutoff means.

(a) Each engine and each fire zone specified in 25.1181 (a) (4) and (5) must have a means to shut off or otherwise prevent hazardous quantities of fuel, oil, deicer, and other flammable fluids, from flowing into, within, or through any designated fire zone, except that shutoff means are not required for -

(1) Lines forming an integral part of an engine; and

(2) Oil systems for turbine engine installations in which all external components of the oil system, including the oil tanks, are fireproof.

(b) The closing of any fuel shutoff valve for any engine may not make fuel unavailable to the remaining engines.

(c) Operation of any shutoff may not interfere with the later emergency operation of other equipment, such as the means for feathering the propeller.

(d) Each flammable fluid shutoff means and control must be fireproof or must be located and protected so that any fire in a fire zone will not affect its operation.

(e) No hazardous quantity of flammable fluid may drain into any designated fire zone after shutoff.

(f) There must be means to guard against inadvertent operation of the shutoff means and to make it possible for the crew to reopen the shutoff means in flight after it has been closed.

(g) Each tank-to-engine shutoff valve must be located so that the operation of the valve will not be affected by powerplant or engine mount structural failure.

(h) Each shutoff valve must have a means to relieve excessive pressure accumulation unless a means for pressure relief is otherwise provided in the system."

In addition, the following pertinent requirements are specified:

"25.855 Cargo and baggage compartments.

(a) Each cargo and baggage compartment (including tie-down equipment) must be constructed of materials that at least meet the requirements set forth in 25.853.

(b) No compartment may contain any controls, wiring, lines, equipment, or accessories whose damage or failure would affect safe operation, unless those items are protected so that -

(1) They cannot be damaged by the movement of cargo in the compartment; and

(2) Their breakage or failure will not create a fire hazard."

5.1.6.2 (Continued)

"25.865 Fire protection of flight controls, engine mounts, and other flight structure.

Essential flight controls, engine mounts, and other flight structures located in designated fire zones or in adjacent areas which would be subjected to the effects of fire in the fire zone must be constructed of fireproof material or shielded so that they are capable of withstanding the effects of fire."

"25.1187 Drainage and ventilation of fire zones.

(a) There must be complete drainage of each part of each designated fire zone to minimize the hazards resulting from failure or malfunctioning of any component containing flammable fluids. The drainage means must be -

(1) Effective under conditions expected to prevail when drainage is needed; and

(2) Arranged so that no discharged fluid will cause an additional fire hazard.

(b) Each designated fire zone must be ventilated to prevent the accumulation of flammable vapors.

(c) No ventilation opening may be where it would allow the entry of flammable fluids, vapors, or flame from other zones.

(d) Each ventilation means must be arranged so that no discharged vapors will cause an additional fire hazard.

(e) Unless the extinguishing agent capacity and rate of discharge are based on maximum air flow through a zone, there must be means to allow the crew to shut off sources of forced ventilation to any fire zone except the engine power section of the nacelle and the combustion heater ventilating air ducts."

5.1.7 Combat Damage Considerations: The pertinent paragraph in MIL-H-5440F is quoted below:

"3.11.29.4 System protection from combat damage - Redundant systems shall be separated a minimum of 18 inches, preferably in a plane perpendicular to ground fire, or protected to a degree specified by the procuring authority."

5.1.8 Maintainability Considerations: Assuming that tubing or joints may fail at any point in the system, and leakage constitutes failure, first line maintenance repairs should be possible at any point. Provisions should be made for tubing and joint repairs which do not require removal of adjacent components.

5.1.8.1 Fitting location: All reconnectable fittings should be located to be readily accessible for service disconnection, reconnection, and inspection, wearing gloves in cold weather.

5.1.8.2 Component Lines: Where two or more lines are attached to a hydraulic component and incorrect connection of lines to the component is possible, the two lines should be sufficiently different to prevent such an occurrence.

5.1.8.3 Drain lines: Drain or vent lines coming from the pump, reservoir, or other hydraulic components should not be connected to any other line or any other fluid system in the aircraft in such manner as to permit mixture of the fluids at any of the components being drained or vented.

5.1.8.4 Mounting lightweight components: Lightweight components that do not have mounting provisions may be supported by the tube installation provided that the component is rigidly installed and does not result in destructive vibration or cause other adverse conditions in the tubing installation. Clamps or similar devices may be used to support such units to structure, provided that nameplates, flow-direction arrows or markings, or other data are not obscured and that the supporting member does not affect the operation of the unit.

5.1.8.5 Removal of entrapped air: Suitable means, such as bleeder valves, shall be provided for removal of entrapped air where it interferes with the proper functioning of the hydraulic system. Disconnection of lines or loosening of tubing nuts does not constitute "suitable means". Equipment and system configuration shall, insofar as practicable, be designed to automatically scavenge free air to a reservoir or other collection points where operation will not be affected and where release can be conveniently accomplished. Where air removal bleed valves are provided, they should be operable without disconnection or removal of lines or components. Such installation shall permit attachment of a flexible hose so that fluid bleed off may be directed into a container.

5.1.8.6 Ground test provisions: The following requirements are specified in MIL-H-5440F for military aircraft and are applicable to most commercial aircraft:

"Each hydraulic system shall include a set of self-sealing couplings for attachment of ground test equipment. System ground test provisions shall be so designed that pressurization of any hydraulic system in the aircraft is not necessary in order to test another hydraulic system. In particular, use of only one hydraulic test stand shall be necessary to test the system, without use of "Y" connections between the test stand and the aircraft or use of a second ground test stand connected to another hydraulic system in the aircraft."

MIL-H-5440 also specifies the following ground test connections for use with exisitng ground carts:

"Ground test connections. A set of self-sealing couplings consisting of bulkhead halves, and protective caps shall be provided at a convenient location in the aircraft easily accessible from the ground, for attachment of ground test equipment. The ground connections shall be compatible with those connections supplied on ground test units in use by the procuring activity. Connections on ground test units are as follows:

Pressure connections on ground test units

- Aeroquip T150S1-80 coupling half (15051-8D)
- Aeroquip E155-25-8D nut
- Aeroquip 155S9-8D dust plug
- Aeroquip T150S1-12D coupling half
- Aeroquip E155-25-12D nut
- Aeroquip 155S9-12D dust plug
- Aeroquip E155-25-16D nut (Air Force only)
- Aeroquip T150S1-16D coupling half (Air Force only)
- Aeroquip 155S9-16D dust plug (Air Force only)

Suction connections on ground test units

- Aeroquip T150S1-16D coupling half
- Aeroquip E155-25-16D nut
- Aeroquip 155S9-16D dust plug
- Aeroquip B140S1-20D coupling half
- Aeroquip E145-25-20D nut
- Aeroquip 145S9-20D dust plug
- Aeroquip B140S1-24D coupling half (Air Force only)
- Aeroquip E145-25-24D nut (Air Force only)
- Aeroquip 145S9-24D dust plug (Air Force only)
- Aeroquip T150S1-12D coupling half
- Aeroquip E155-25-12D nut
- Aeroquip 155S9-12D dust plug

Electric-motor-driven pumps used in emergency or auxiliary system shall not be used for ground test purposes unless the motor is designed for continuous operation."

5.1.8.6 (Continued)

The following additional precautions should also be observed:

(a) The suction lines to the ground cart should be of adequate size for their length to prevent excessive back pressure on the aircraft return lines.
(b) The pressure line ground test connection on the aircraft should lead directly to the system pressure filter to prevent contamination of the aircraft system by the ground cart fluid.

5.2 Clearances: The clearances and spacings noted below are the absolute minimums recommended and should not be decreased.

5.2.1 Multiple Line Spacing: Minimum recommended clearances between tubes within the same system are dependent upon the spacing required to accomodate wrenches and other tools required for connecting mating tubes. As much space as is practical should be allowed between tubes and they should not be spaced closer than noted below (depending on the type of connecting fittings used). See 5.5.5 for recommended spacing between systems.

5.2.1.1 Tightening Wrench: The center-to-center line spacing shown in Fig. 5.2.1 is the absolute minimum which should be allowed but only where space is extremely limited and with the recognition that there is insufficient space for effecting tube repairs without disconnecting adjacent lines.

Minimum center-to-center line spacing, shown in Fig. 5.2.2, provides wrench clearance when alternate lines are equipped with fittings in the same plane, or adjacent lines are equipped with fittings in different planes.

Minimum center-to-center line spacing, shown in Fig. 5.2.3, provides wrench clearance at bulkheads or where adjacent lines are equipped with fittings in the same plane.

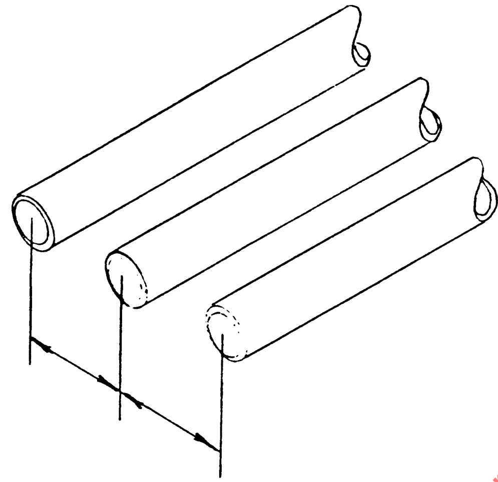
5.2.1.2 Weld Tool: Minimum center-to-center line spacing for adjacent CRES lines is given in Fig. 5.2.4. Welding tool clearances are given in Fig. 5.2.5. Note that these spacings are based on the Astro-Arc[17] TIG welding head and are greater than those required for the Navan [18] and Ry-Tek[19] heads.

5.2.1.3 Braze Tool: Minimum line spacings for clearance of the Aeroquip Space-Craft brazing tool, with brazed joints on adjacent tubes in the same plane, are given in Fig. 5.2.6. Minimum line spacing for tubes with brazed joints in different planes are given in Fig. 5.2.7.

5.2.1.4 Swage Tool: Minimum line spacings to structure and adjacent lines for the Deutsch swage tool for installing McDonnell-Douglas Permaswage fittings are given in Fig. 5.2.8. Minimum line spacings with adjacent tiered lines are given in Fig. 5.2.9.

5.2.1.5 Cryofit Assembly Tool: Tool head clearance distance and the tool numbers for installing Cryofit unions, tees, ells and crosses are given in Fig. 5.2.10. The clearance distance, C, is measured as the tangent point to tangent point distance from the outer diameter of the tube upon which the fitting is installed to the closest solid obstruction (e.g., the closest tube, fitting, or bulkhead). It should be noted from the figure that sufficient open space must be provided on one "side" of the fitting installation area to permit access of the tool head. The envelope depicted extends along the tubes one fitting length in each direction from the tube ends to be joined.

(17) Astro-Arc Inc., 11144 Penrose St., Sun Valley, California 91352.
(18) Navan Products Inc., 1320 East Imperial Highway, El Segundo, California 90245.
(19) Ry-Tek Inc., Santa Fe Springs, California.

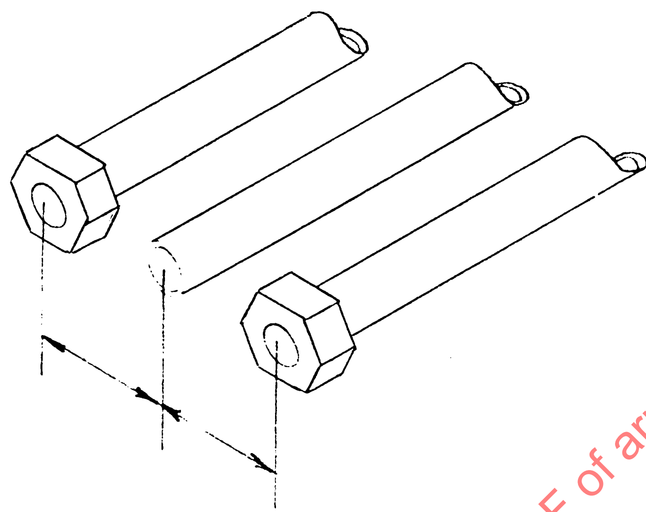


MINIMUM LINE SPACING (NO FITTINGS)											
TUBE OD.	3/16	1/4	5/16	3/8	1/2	5/8	3/4	1	1-1/4	1-1/2	2
3/16	.43	.47	.50	.53	.59	.66	.72	.84	.97	1.09	1.34
1/4		.50	.53	.56	.62	.69	.75	.88	1.00	1.12	1.38
5/16			.56	.59	.66	.72	.78	.91	1.03	1.16	1.41
3/8				.62	.69	.75	.81	.94	1.06	1.19	1.44
1/2					.75	.81	.88	1.00	1.12	1.25	1.50
5/8						.88	.94	1.06	1.19	1.31	1.56
3/4							1.00	1.12	1.25	1.38	1.62
1								1.25	1.38	1.50	1.75
1-1/4									1.50	1.62	1.88
1-1/2										1.75	2.00
2											2.25

MINIMUM LINE SPACING

NOT REQUIRING WRENCH CLEARANCE

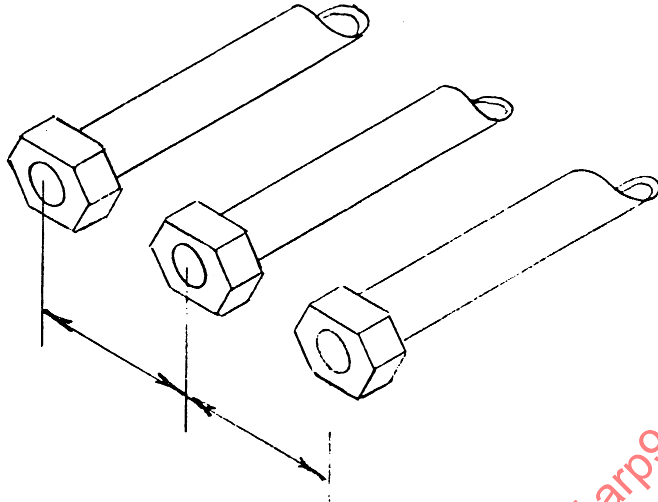
FIGURE 5.2.1



MINIMUM LINE SPACING (STAGGERED FITTINGS)												
TUBE OD	3/16	1/4	5/16	3/8	1/2	5/8	3/4	1	1-1/4	1-1/2	1-3/4	2
3/16	.85	.85	.90	.95	1.10	1.15	1.35	1.60	1.80	2.05	2.45	2.65
1/4		.90	.95	1.00	1.10	1.20	1.40	1.65	1.85	2.05	2.45	2.70
5/16			.95	1.00	1.15	1.20	1.45	1.65	1.85	2.10	2.50	2.70
3/8				1.05	1.20	1.25	1.45	1.70	1.90	2.15	2.55	2.75
1/2					1.25	1.30	1.55	1.75	1.95	2.20	2.60	2.80
5/8						1.35	1.60	1.80	2.00	2.25	2.65	2.85
3/4							1.65	1.90	2.10	2.30	2.70	2.95
1								2.00	2.20	2.45	2.85	3.05
1-1/4									2.35	2.55	3.00	3.20
1-1/2										2.70	3.10	3.30
1-3/4											3.25	3.45
2												3.55

WRENCH CLEARANCE FOR STAGGERED FITTINGS

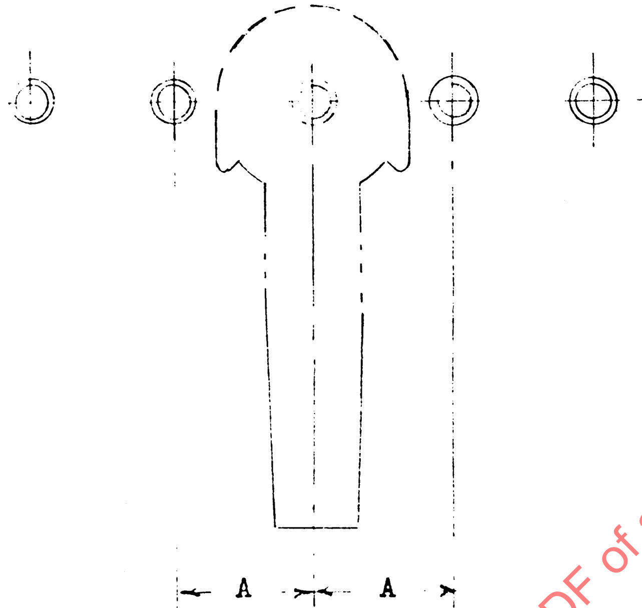
FIGURE 5.2.2



MINIMUM LINE SPACING (ADJACENT FITTINGS)										
TUBE OD	3/16	1/4	5/16	3/8	1/2	5/8	3/4	1	1-1/4	1-1/2
3/16	.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
1/4	.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
5/16	.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
3/8	.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
1/2	1.00	1.05	1.10	1.15	1.25	1.35	1.50	1.60	1.90	2.20
5/8	1.05	1.15	1.20	1.25	1.35	1.40	1.55	1.70	2.00	2.30
3/4	1.25	1.35	1.40	1.45	1.55	1.60	1.75	1.90	2.20	2.45
1	1.40	1.45	1.50	1.55	1.65	1.70	1.85	2.00	2.30	2.60
1-1/4	1.75	1.80	1.85	1.90	2.00	2.05	2.20	2.35	2.65	2.95
1-1/2	1.90	2.00	2.05	2.05	2.20	2.25	2.35	2.55	2.85	3.10

WRENCH CLEARANCE FOR ADJACENT FITTINGS

FIGURE 5.2.3



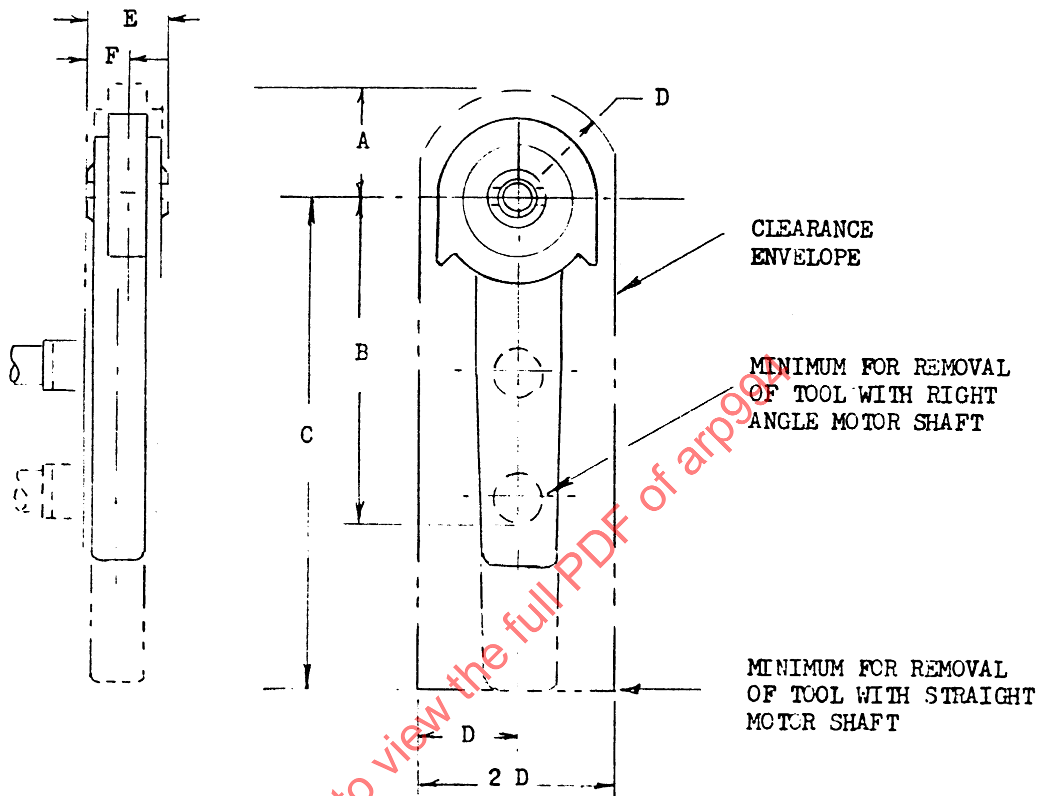
SEE FIGURE 5.2.5 FOR WELDING TOOL CLEARANCES

TUBE OD	NOTE	A (ADJACENT CRES TUBING)							
		1/4	5/16	3/8	1/2	5/8	3/4	1	1-1/4
1/4		1.19	1.22	1.25	1.85	1.85	1.85	2.38	2.38
5/16	(1)		1.22	1.25	1.88	1.88	1.88	2.41	2.41
3/8				1.25	1.94	1.94	1.94	2.44	2.44
1/2					2.00	2.06	2.12	2.50	2.50
5/8	(2)					2.06	2.12	2.56	2.56
3/4							2.12	2.63	2.63
1	(3)							2.75	2.88
1-1/4									2.88

NOTES: (1) ASTRO-ARC MODEL K-375
(2) K-875
(3) K-1500

CLEARANCE DIMENSIONS WELDED STEEL LINES

FIGURE 5.2.4

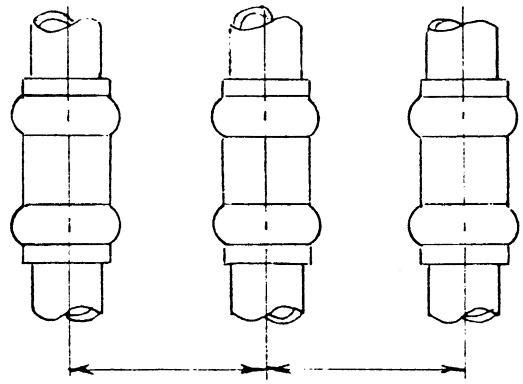


ASTRO-ARC MODEL NO.	DIMENSIONS (1)											
	A		B		C (2)		D		E		F	
	Min	Rec	Min	Rec	Min	Rec	Min	Rec	Min	Rec	Min	Rec
K- 375	1.31	1.56	3.12	3.38	8.38	9.00	1.00	1.25	1.32	1.57	.78	1.03
K- 875	2.31	2.69	6.88	7.25	13.12	14.00	1.75	2.12	1.88	2.13	.96	1.21
K- 1500	2.62	3.12	8.00	8.50	14.30	15.00	2.25	2.75	1.88	2.18	.96	1.21

NOTES: (1) SPACE REQUIREMENT FOR TOOL INSTALLATION AND REMOVAL
(2) INCLUDES ALLOWANCE FOR MOTOR SHAFT BEND RADIUS

MINIMUM AND RECOMMENDED WELDING TOOL CLEARANCES

FIGURE 5.2.5

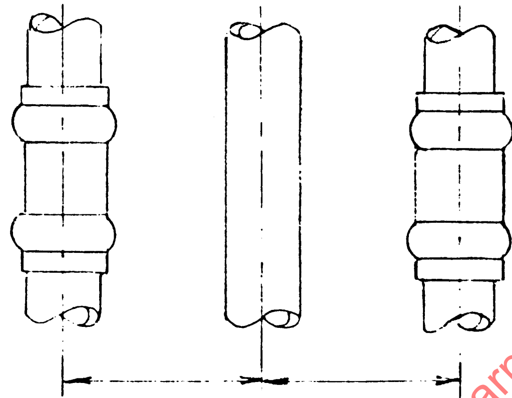


TUBE OD	MINIMUM LINE SPACING (ADJACENT FITTINGS)							
	3/16	1/4	5/16	3/8	1/2	5/8	3/4	1
3/16	.91	.94	.98	1.02	1.10	1.16	1.23	1.38
1/4	.94	.97	1.01	1.05	1.13	1.19	1.26	1.41
5/16	.98	1.01	1.05	1.09	1.17	1.23	1.30	1.45
3/8	1.04	1.07	1.11	1.15	1.23	1.29	1.36	1.51
1/2	1.20	1.24	1.28	1.32	1.39	1.45	1.53	1.67
5/8	1.42	1.46	1.50	1.54	1.61	1.67	1.75	1.89
3/4	1.57	1.60	1.64	1.68	1.76	1.82	1.89	2.04
1	1.97	2.01	2.05	2.09	2.16	2.22	2.30	2.44

LINE SPACING

ADJACENT AEROQUIP SPACECRAFT FITTINGS

FIGURE 5.2.6

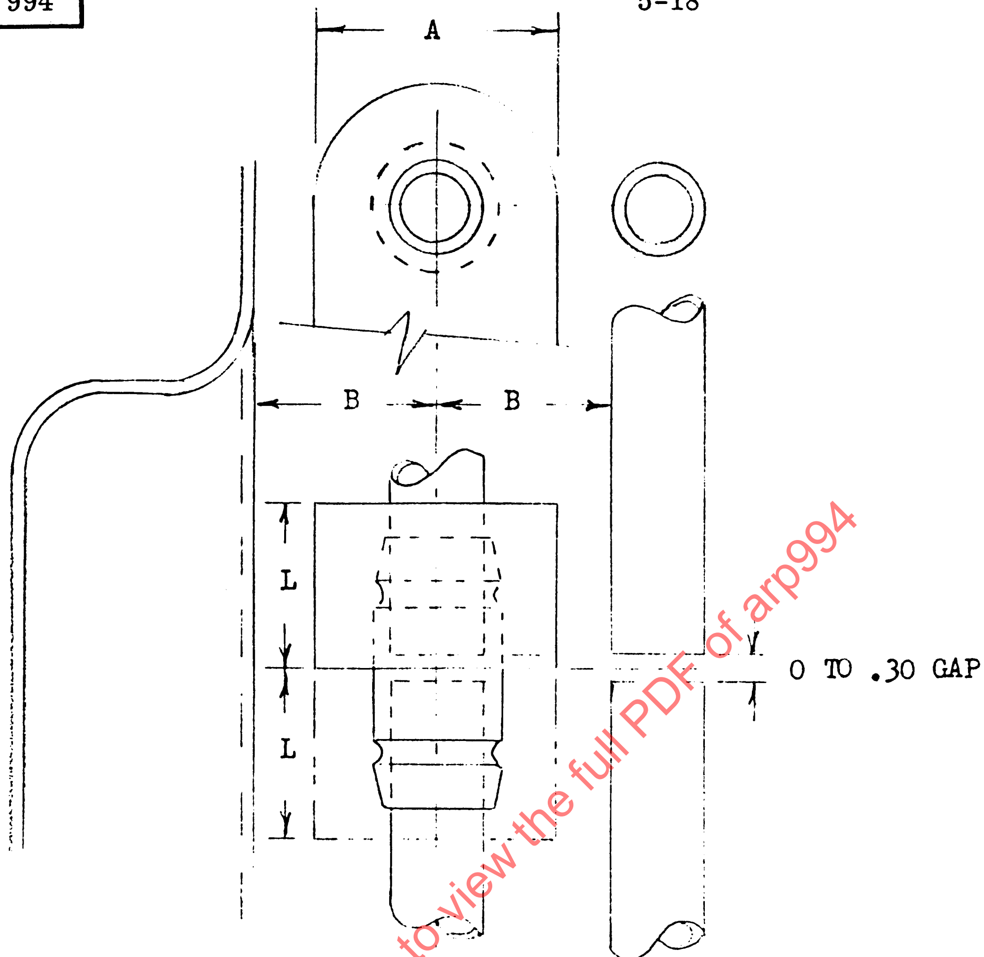


TUBE OD	MINIMUM LINE SPACING (STAGGERED FITTINGS)							
	3/16	1/4	5/16	3/8	1/2	5/8	3/4	1
3/16	.84	.87	.90	.93	.99	1.06	1.12	1.24
1/4	.87	.90	.93	.96	1.02	1.09	1.15	1.27
5/16	.91	.94	.97	1.00	1.06	1.13	1.19	1.31
3/8	.97	1.00	1.03	1.06	1.12	1.19	1.25	1.37
1/2	1.13	1.16	1.19	1.23	1.29	1.35	1.41	1.54
5/8	1.35	1.38	1.41	1.45	1.51	1.57	1.63	1.76
3/4	1.50	1.53	1.56	1.59	1.65	1.72	1.78	1.90
1	1.90	1.93	1.96	2.00	2.06	2.12	2.18	2.31

LINE SPACING

STAGGERED AEROQUIP SPACECRAFT FITTINGS

FIGURE 5.2.7

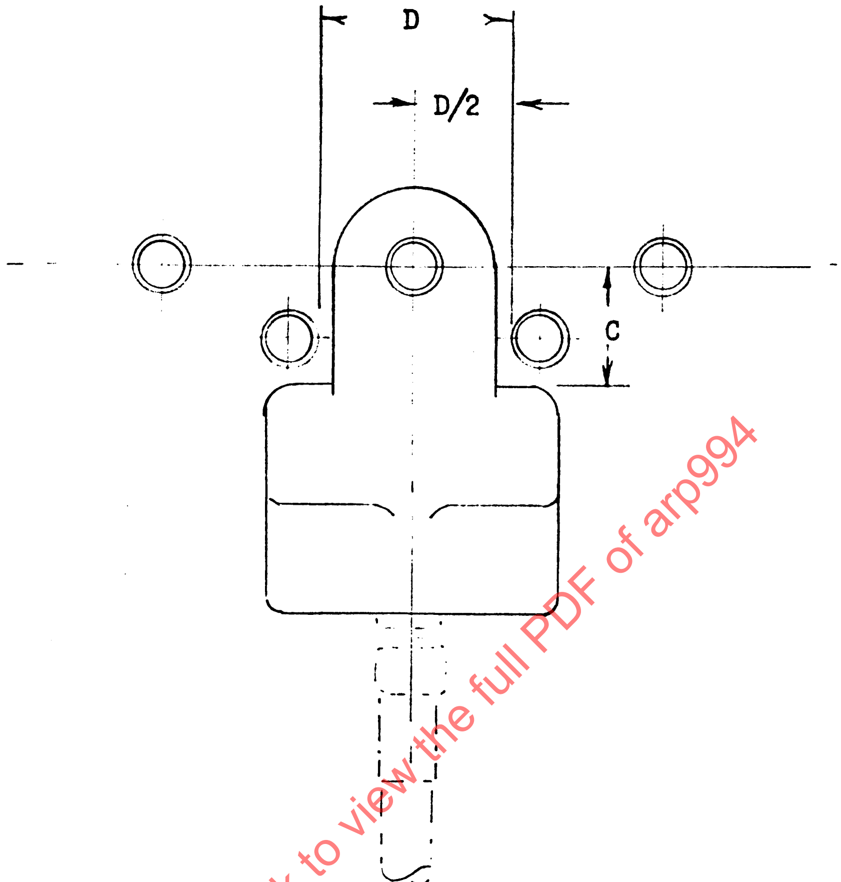


TUBE OD	TOOL A	TOOL CLEAR. B	UNOBSTRUCTED L
3/16 thru 3/8	1-11/16	7/8	1-1/4
1/2 thru 3/4	2-1/4	1-3/16	1-5/8
1 thru 1-1/2	3-1/2	1-13/16	2

SINGLE TIER CLEARANCE DIMENSIONS

PERMASWAGE FITTINGS

FIGURE 5.2.8



POWER SWAGE TOOL

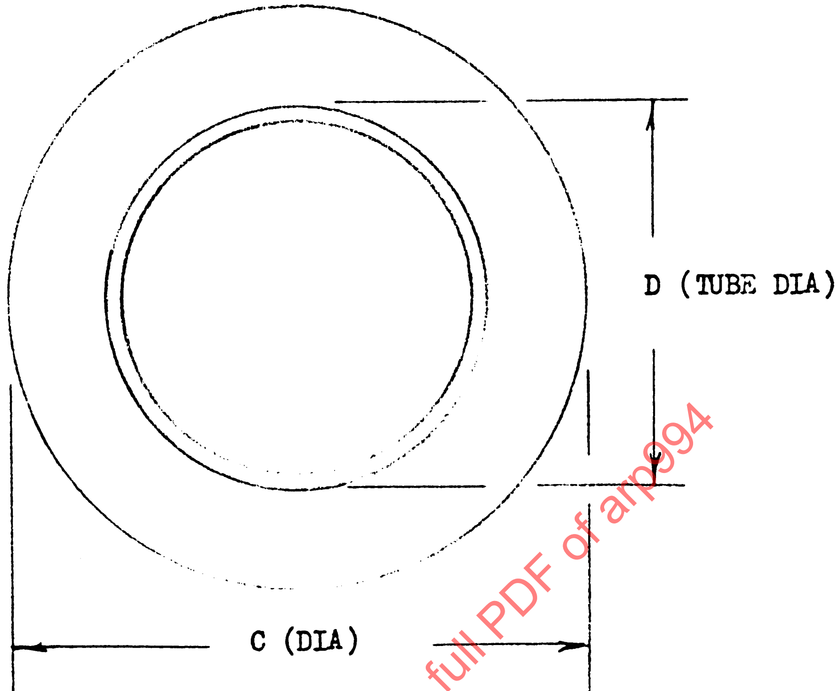
HORSESHOE TYPE DIE HEAD

TUBE OD	C	D
3/16 thru 3/8	1	1-3/4
1/2 thru 3/4	1-1/4	2-3/8
1 thru 1-1/2	2	3-5/8

TIERED CLEARANCE DIMENSIONS

PERMASWAGE FITTINGS

FIGURE 5.2.9

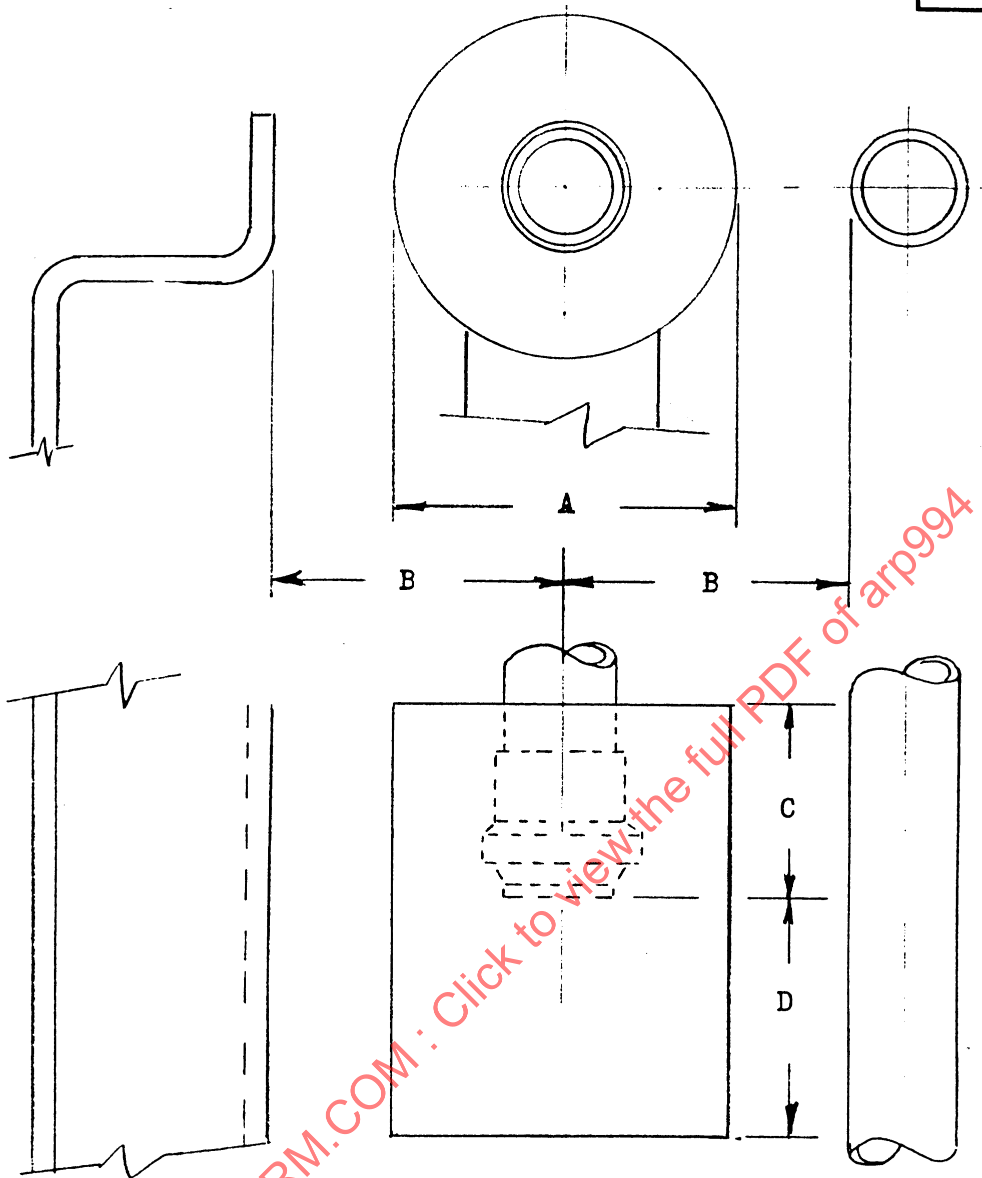


TUBE DIAMETER D	CLEARANCE DIAMETER C	TOOL NUMBERS	
		UNION	TEE, ELL, AND CROSS
3/16	.28	T3P00902 - SIZE	T3P00802 - SIZE
1/4	.30		
3/8	.32		
1/2	.34		
5/8	.36		
3/4	.40		
1	.50		

CLEARANCE DATA AND TOOL NUMBERS

CRYOFIT CONNECTORS

FIGURE 5.2.10

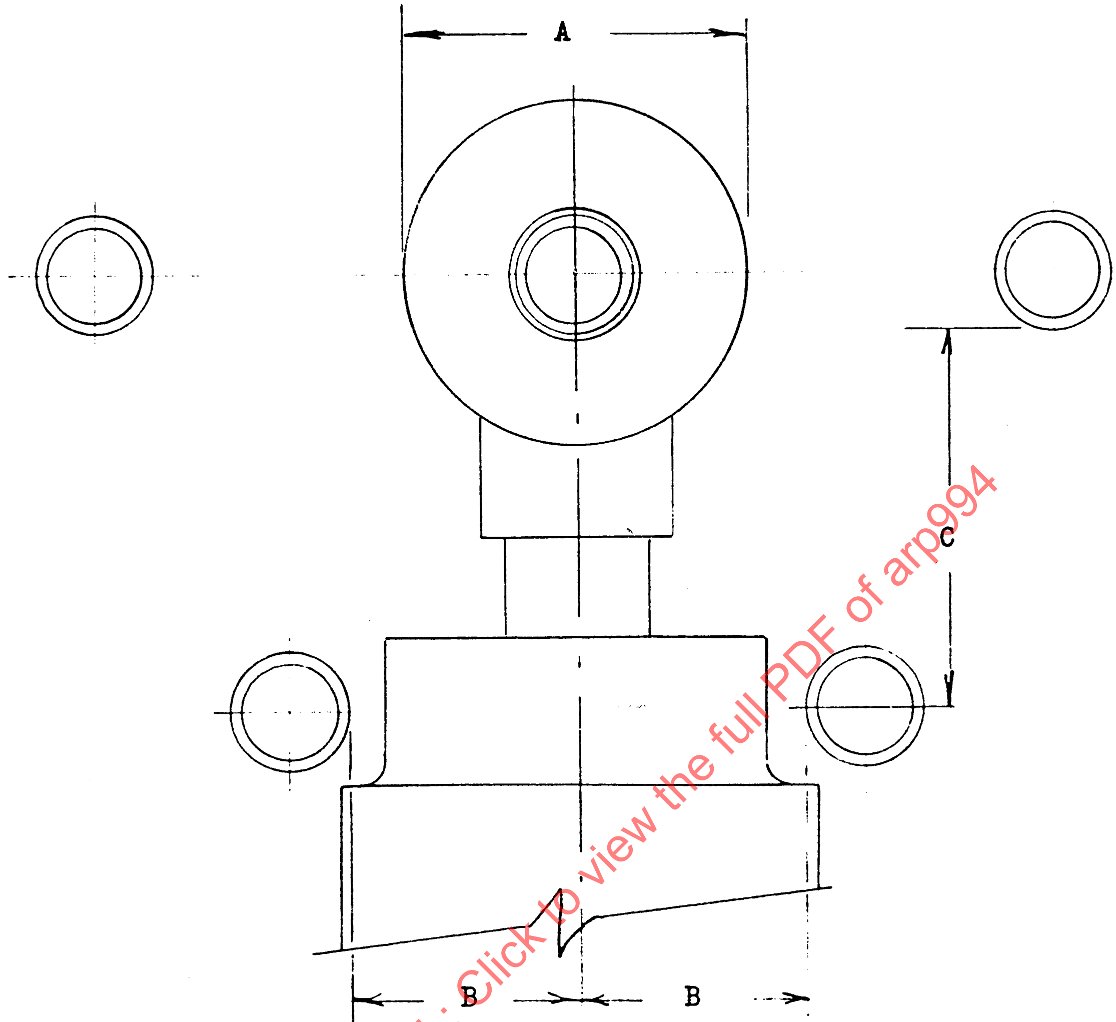


TUBE OD	TOOL A	TOOL CLEARANCE B	UNOBSTRUCTED LENGTH C	TOOL ASSY SPACE D
1/4 thru 1/2	2-9/32	1-1/4	3-1/4	3-3/4
5/8 thru 1	3-1/2	1-7/8	3-3/4	3-5/8
1-1/4 thru 1-1/2	3-31/32	2-1/8	4	4

SINGLE TIER CLEARANCE

SWAGED FLARELESS FITTINGS

FIGURE 5.2.11



TUBE OD	TOOL A	TOOL CLEAR. B	MAXIMUM C
1/4 thru 1/2	2-9/32	1-1/4	5-1/2
5/8 thru 1	3-1/2	1-7/8	6-1/4
1-1/4 thru 1-1/2	3-31/32	2-1/8	6-1/4

DOUBLE TIER CLEARANCE

SWAGED FLARELESS FITTINGS

FIGURE 5.2.12

5.2.1.6 In-place Swaging Tool for Swaged Flareless Sleeve [20]: Minimum line spacing to structure and adjacent lines for the Boeing and Lockheed swaged flareless sleeve is given in Fig. 5.2.11. Minimum line spacing with adjacent tiered lines is given in Fig. 5.2.12. In each case, inplace repair with MS couplings requires a tube deflection in the amount of dimension A.

5.2.2 Adjacent Structure: Take into consideration: vibration, wear, structural deflection, manufacturing tolerances, and tube movement due to temperature changes or pressure surges. In some locations, clearances will be dictated by maintenance and service requirements; in other locations, by assessment of deflections or other motions in service. To the maximum extent feasible, it should be demonstrable that every tube can be replaced or repaired without disturbing adjacent lines, structure, or components.

5.2.2.1 Supported Locations: Where tubing is clamped to structure or other rigid member, allow a minimum clearance of 0.25 in. in the vicinity of clamps, and 0.13 in. at the clamping point. Where relative motion may exist between adjoining members, allow a minimum clearance of 0.25 in. in excess of the expected movement.

5.2.2.2 Unsupported Locations: Clearance must be sufficient to prevent contact during deflection or movement in service against any projection, nut, bolt, bracket, or structural edge. Provide 0.25 in. clearance in excess of the expected movement. Minimize strain between supports and position clamps to prevent distortion of clamp pads. Clear adjacent structure and equipment between line clamps by 0.5 inch. Where a tube passes through a grommet, it must not deflect the grommet sufficiently to contact structure or to cut the grommet.

5.2.3 Other Lines and Cables: Clear all control cables and linkages by a minimum of 1.0 inch. A minimum of 0.5 in. clearance is acceptable adjacent to cable pulleys and 2.0 in. clearance is preferable at cable mid-span. Allow 2.0 in. minimum between parallel oxygen lines and hydraulic lines, and locate all fittings and joints at least two inches away from a point of crossing. Provide a minimum of two inches between hydraulic and electrical lines and route fluid lines below electrical systems lines. Clamp crossing hydraulic tubes to maintain a minimum clearance of 0.25 inch.

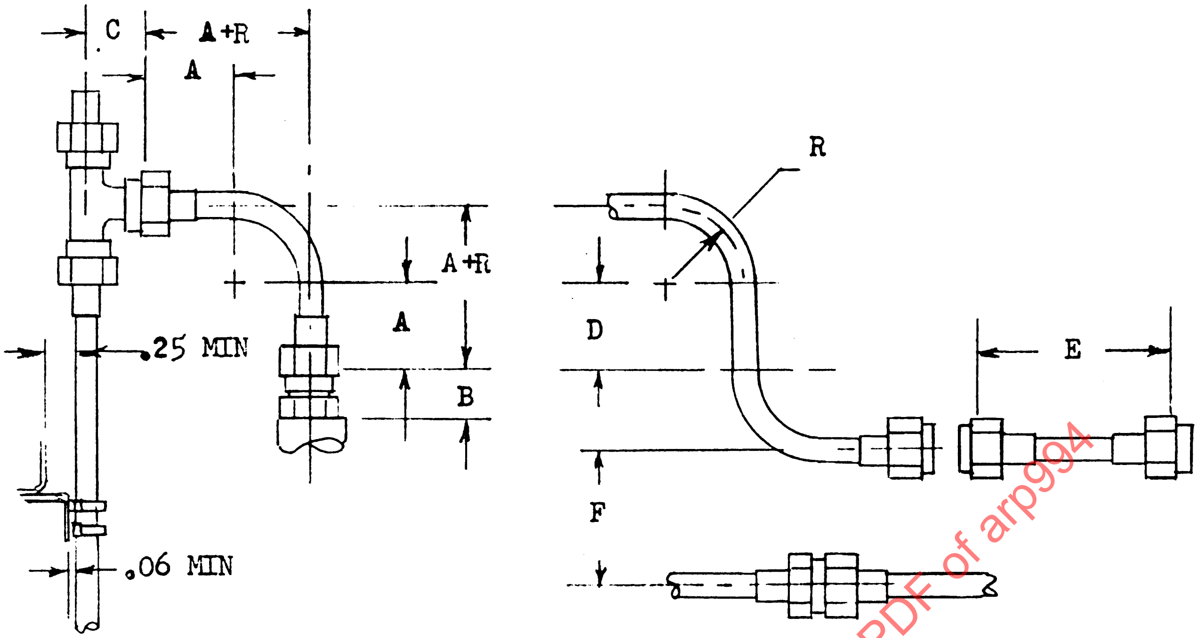
5.3 Bends:

5.3.1 Bend Radii: Provide as large a bend radius as space and clamp location will allow. Preferred and minimum bend radii for commonly used hydraulic tubing materials are given in MS33611; Table I for conventional and cold drawn stainless steel and aluminum alloy; Table 2 for cold worked 21-6-9 CRES; Table 3 for AM-350 CRT; and Table 4 for cold worked and stress relieved 3.0Al - 2.5V titanium alloy.

5.3.2 Bend Location: Minimum allowable spacing for a bend from a fitting or permanent joint depends on the clearance required by the assembly tools and are given below:

Figure 5.3.1 Reconnectable Fittings
Figure 5.3.2 Welded Joints
Figure 5.3.3 Aeroquip Spacecraft Brazed Joints
Figure 5.3.4 Linair Production - Brazed Joints
Figure 5.3.4 McDonnell Douglas Permaswage Joints
Figure 5.3.5 Raychem Cryofit Joints

(20) Haskel Engineering & Supply Co., 100 East Graham Place, Burbank, California 91502.

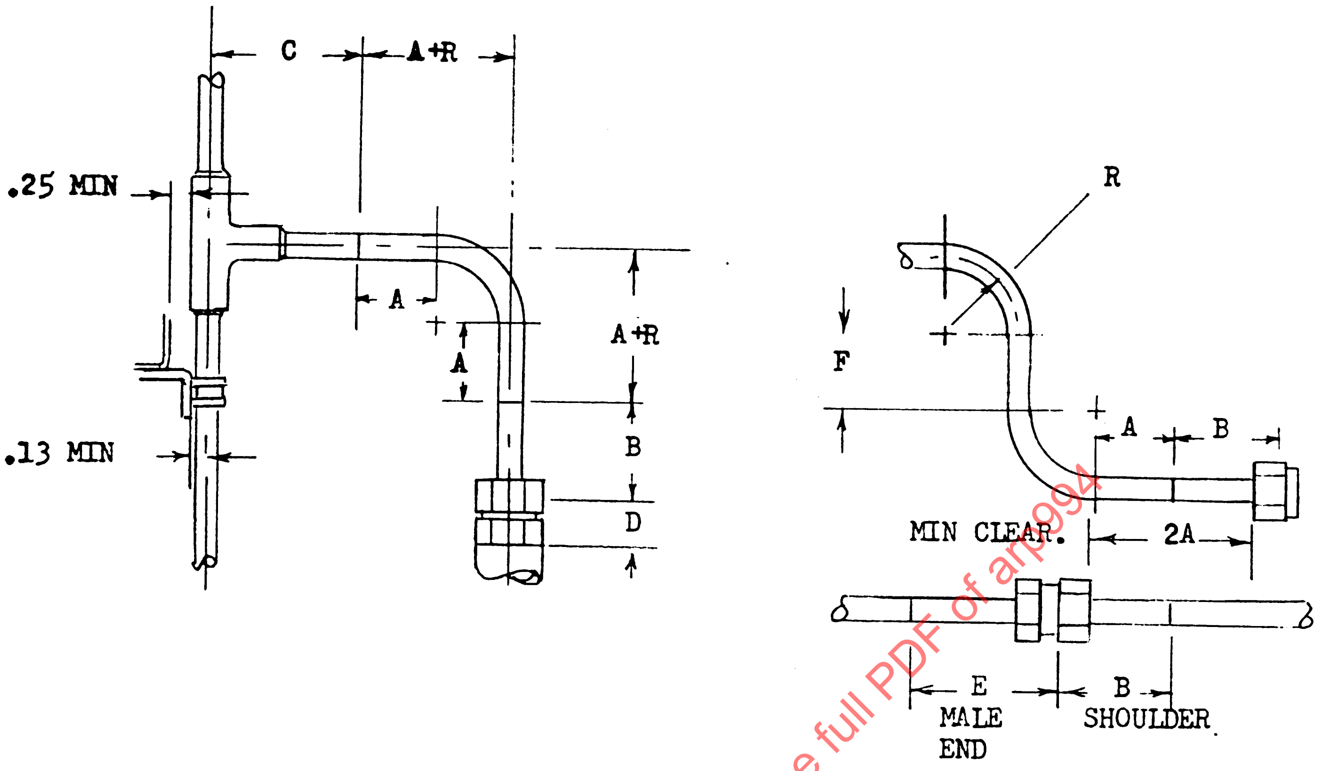


TUBE OD	R (2)	DIMENSIONS (1)						
		A		B	C	D Min	E Min	F
		Min	Rec					
1/4	.75	.95	1.30	.48	.62	1.00	1.50	1.25
5/16	.94	.95	1.35	.51	.66	1.00	1.50	1.25
3/8	1.12	.95	1.40	.54	.71	1.00	1.50	1.25
1/2	1.50	1.05	1.45	.60	.83	1.00	1.64	1.50
5/8	1.88	1.05	1.50	.68	.96	1.30	1.66	1.75
3/4	2.25	1.05	1.60	.79	1.06	1.50	1.66	2.00
1	3.00	1.55	2.30	.85	1.25	3.00	2.68	2.50
1-1/4	3.75	1.55	2.30	.90	1.39	3.80	2.68	3.00

NOTES: (1) TYPICAL FOR SWAGED DYNATUBE FITTINGS
(2) BEND RADII THREE TIMES TUBE SIZE

MINIMUM BEND SPACING
RECONNECTABLE FITTINGS

FIGURE 5.3.1



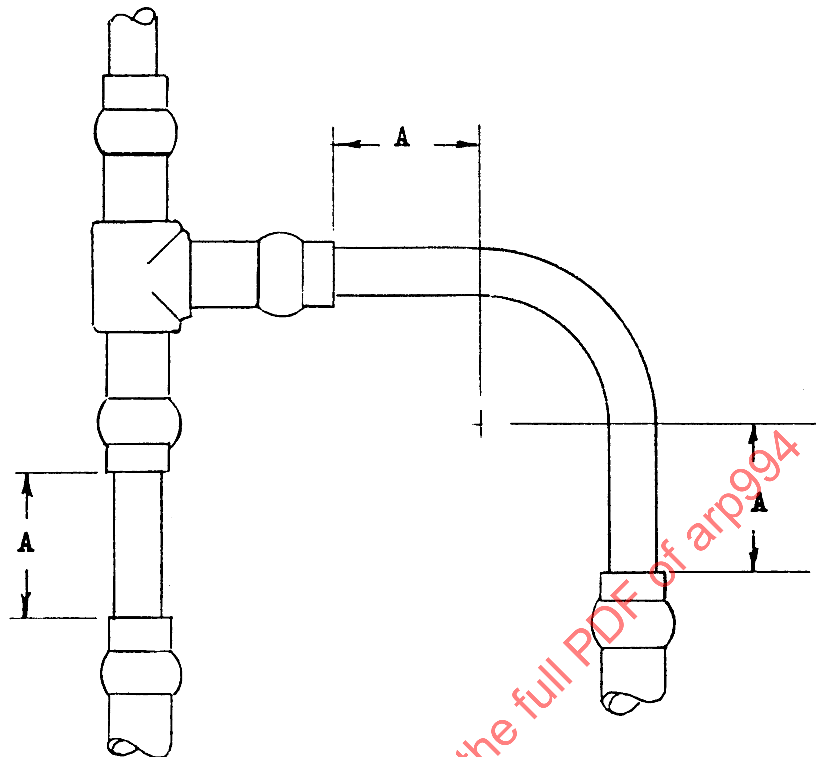
TUBE OD	R (1)	DIMENSIONS						
		A		B	C	D	E	F
		Min	Rec					Min
1/4	.75	1.44	2.00	1.34	1.31	.48	1.56	1.00
5/16	.94	1.44	2.00	1.34	1.34	.51	1.59	1.00
3/8	1.12	1.44	2.00	1.38	1.38	.54	1.62	1.00
1/2	1.50	1.44	2.00	1.38	1.43	.60	1.68	1.00
5/8	1.88	1.44	2.00	1.38	1.50	.67	1.76	1.30
3/4	2.25	1.44	2.00	1.39	1.56	.72	1.79	1.50
1	3.00	1.44	2.00	1.44	1.69	.84	1.85	3.00
1-1/4	3.75	1.44	2.00	1.44	1.81	.87	1.91	3.80

NOTE: BEND RADII EQUAL TO 3 TIMES TUBE SIZE

MINIMUM BEND SPACING

WELDED FITTINGS

FIGURE 5.3.2



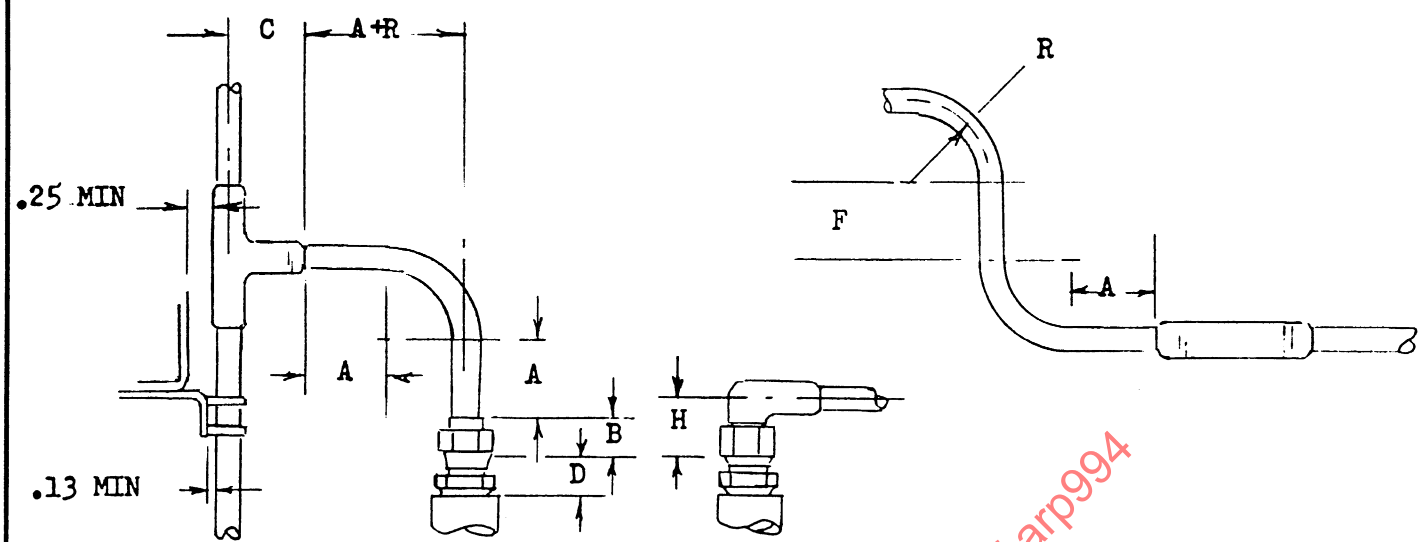
TUBE OD	A
1/4 thru 3/4	.74
1	1.45
1-1/4 thru 1-1/2	1.84 (1)

NOTE: (1) LOW PRESSURE ONLY

MINIMUM BEND SPACING

AEROQUIP SPACECRAFT FITTING

FIGURE 5.3.3

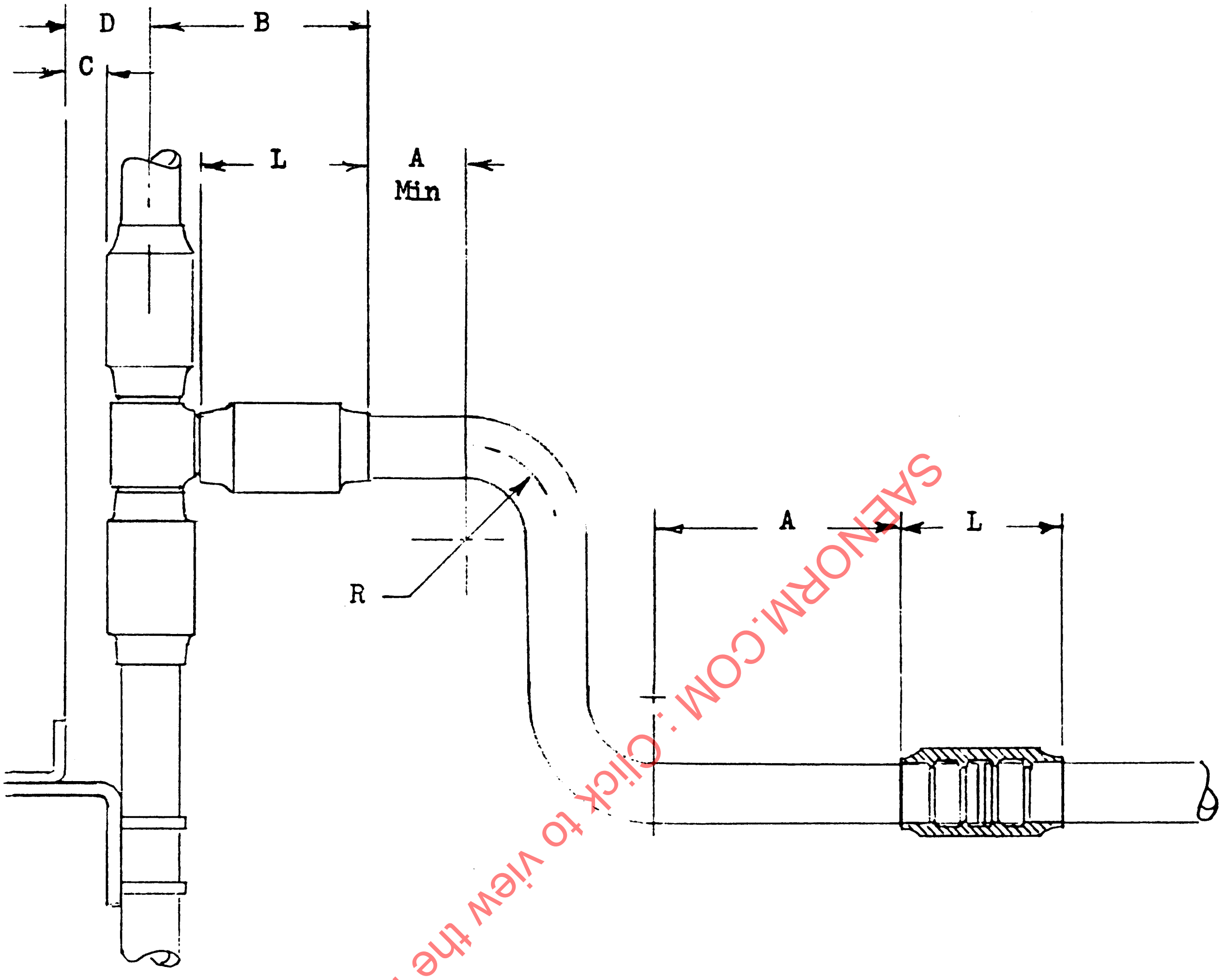


TUBE OD	R	A		B	C	D	F	H
		Min	Rec					
3/16	1	1	1-1/2	.42	.74	.61	1.00	.75
1/4	1	1	1-1/2	.42	.83	.68	1.00	.78
5/16	1-1/4	1	1-1/2	.42	.90	.68	1.00	.87
3/8	1-1/2	1	1-1/2	.42	1.00	.69	1.00	.99
1/2	2	1-1/8	1-1/2	.46	1.27	.75	1.00	1.19
5/8	2-1/2	1-1/8	1-1/2	.52	1.38	.87	1.30	1.38
3/4	3	1-1/8	1-1/2	.54	1.53	.99	1.50	1.49
1	3	1-1/2	2	.61	1.74	1.00	3.00	1.69
1-1/4	3-3/4	1-1/2	2	.61	1.74	1.00	3.00	1.93

MINIMUM BEND SPACING

LINAIR PRODUCTION BRAZE AND PERMASWAGE

FIGURE 5.3.4



TUBE OD	A		B	C	D	L
	Min	Rec				
1/4	.54	1.95	1.33	.19	.39	.97
3/8	.67	2.47	1.60	.21	.46	1.24
1/2	.74	2.71	1.81	.22	.55	1.36
5/8	.88	3.30	2.22	.23	.63	1.65
3/4	1.02	3.84	2.52	.24	.72	1.92
1	1.34	5.10	3.34	.25	.89	2.55

MINIMUM BEND SPACING

CRYOFIT 3P02101 - SIZE FITTINGS

FIGURE 5.3.5

5.4 Tube Connections:

5.4.1 Reconnectable Fittings: Locate all reconnectable fittings for easy installation and service access in accordance with the following guidelines:

a) Minimize use of reconnectable fittings to only those locations where planned disconnection for servicing is required.

b) Position fittings to permit removal of components without unclamping tubing or removing sections of line.

c) Use longest possible lines between fitting locations to reduce weight and leakage points.

d) Support tube-to-tube unions, elbows and tees within 6.0 in. on one side or the other.

e) Do not use universal fittings in bosses.

f) Provide adequate clearances to assure no contact with mechanisms control cables or structure during operational excursions.

5.4.2 Permanent Joints: Use permanent joints, welded, brazed or swaged, in all possible locations where planned disconnection for servicing is not required. Even so, reduce the number of permanent joints to a minimum.

5.5 Damage Protection: Hydraulic systems must be protected from damage which may occur due to conditions arising inside the aircraft, such as stresses imposed in service, on-board hazards, and corrosion. They must also be protected from external hazards such as obstacles and debris during takeoff and landing and gunfire.

5.5.1 Stresses in Service: Hydraulic system tube fractures and joint failures are almost always caused by bending fatigue. Failures due to pressure impulse seldom occur and failures in hoop tension almost never. There are two principal modes of bending failure (Refer to Section 9 for further discussion on stress considerations):

(1) Low Frequency - large amplitude flexure caused by movement of supporting structure occurring most often at rigid connection points such as bulkheads or components.

(2) High Frequency - low amplitude vibration causing a portion of a tube run to fail in fatigue due to localized induced high bending stresses occurring most often at tube supports or near unsupported midspan joints.

In order to prevent bending failures, the following guidelines are suggested:

(a) Design tube installation to requirements similar to those imposed on the attaching structure.

(b) Subject tube routing to a stress analysis based on anticipated fatigue life, accounting for differential motion of end points, vibration, thermal expansion, and sliding through supports.

(c) Permit relative motion between ends of steel tube runs only if the combined calculated stress resulting from Bourdon effect, torsion, tension and compression is less than 10% of the tube ultimate stress.

(d) Do not permit relative motion between ends of aluminum alloy tube runs.

5.5.1 (Continued)

(e) Use steel or titanium tubing in all sizes below 0.5 in. O.D. regardless of system pressure requirements.

5.5.2 On-board Hazards: Route hydraulic lines with due consideration for on-board hazards created by identified heat zones, powerplant compartments and other hostile fluid carrying or electrical systems. Avoid locations where tubing becomes a convenient hand grip or step subject to damage during installation or servicing.

Protect against spillage of battery acid.
Protect line lagging from fluid soak damage.
Use steel or titanium tubing and fittings regardless of pressure requirements in powerplant compartments, through fuel tanks or in other designated fire protection areas.
Route hydraulic lines as far away as possible from all lines conducting flammable fluids.

5.5.3 Corrosion: Protect aluminum alloy lines against corrosion in exposed areas such as wheel wells and weapon bays. Use corrosion resistant tubing on shock struts, main and nose landing gear trunnions, and nacelles. Care must be used in selecting dissimilar mating metals and dry-film lubricants in fittings so that deterioration due to galvanic action or material-fluid incompatibility cannot occur. See section 12, Protective Coatings.

5.5.4 External Hazards: Route hydraulic lines with the design objective of minimizing damage which might occur due to wheel-thrown debris and tire tread, and in military aircraft, due to gunfire, engine rotor burst and other component failure. Take advantage of protection offered by primary structure and armor plate. Protect all exposed lines on landing gear struts and in wheel wells from possible tire blowout and separated tread.

5.5.5 System Separation: Where more than one system is installed to provide improved safety, separate the hydraulic lines of each system with respect to the other by routing on opposite sides of structural elements or by use of protective shrouding.

When dual lines are provided for emergency operation, separate the normal and emergency lines as far as possible from each other, so that events causing total loss of one system will not affect the other. In military aircraft, system separation requires special consideration.

6. PROVISIONS FOR FLEXURE

This section applies to flexible lines and fittings used to convey liquids or gasses from one point to another under conditions wherein the points of attachment may be in relative motion and subject to vibration.

CONTENTS

6.1 Hose: Hose configurations employing various liners and construction details conforming to industrial and Government specifications may be selected for compatible applications.

6.1.1 Synthetic Rubber: Synthetic rubber hose intended for use with airborne equipment is marked for ready identification to prevent issue and installation of over-age or improper type hose on aircraft or aircraft accessories. Material compatibility with fluid and ambient operating conditions must be considered. Refer to ARP 610 for aircraft hose applicable to pneumatic systems.

6.1.2 Teflon: Teflon hose conforming to ARP 604 and MIL-H-38360 is applicable to aerospace fluid power systems employing 3,000 psi pressure at temperatures to 400 F. ARP 614 is applicable to 4,000 psi, 400 F usage.

6.1.3 Flexible Metal: Medium pressure, high temperature flexible metal hoses conforming to ARP 602 may be employed in fluid power applications where very high temperatures or fluid compatibility problems are encountered.

6.1.4 Installation: Hose is commonly used where flexure is required, but rigid tubing is preferred and should be utilized as a tubing loop, etc., (see 6.2), whenever it is suitable for the application. When hose is used, it should be installed in conformance with the following considerations (6.1.4.1 through 6.1.4.9), and as described in Fig. 6-1. While straight fittings are preferable, 45 deg or 90 deg elbows may allow a superior installation.

6.1.4.1 Slack or Bend: High pressure hose assemblies should not be installed in a manner that will cause a mechanical load on the hose. Hoses will change length from +2 to -4% when pressurized. Provide adequate slack or bend in accordance with A to compensate for change in length and expected length tolerances.

6.1.4.2 Shielding: Hoses exposed to extreme heat sources such as hot piping or manifold must be protected by means of a fireproof boot or a metal baffle as shown by B.

6.1.4.3 Flex Allowance: When hose assemblies are subjected to considerable flexing (C) or vibration, sufficient slack should be left between rigid fittings and caution should be exercised in the installation so that the point of flexure does not occur at the end fitting.

6.1.4.4 Twisting: Hoses should be installed without twisting (D) to avoid possible rupture of the line or loosening of the attaching nuts. Marking the casing exterior or sleeve with one or more longitudinal lines will assist inspection for installation and operational twist. Swivel connectors at one or both ends will relieve twist stresses.

6.1.4.5 Bend Radii: Avoid sharp bends (E). The bend radius should be five or more times the outside diameter of the hose. Military Standard MS33790 may be used for guidance in establishing appropriate bend radii.

6.1.4.6 Arrangement: Use applicable elbows and fittings (F) to make neat installations facilitating inspection and maintenance while providing larger bends without excessive slack. Fitting type and size should be such as to prevent cross connection of similar size lines.

6.1.4.7 Clearance: Hose shall clear all other lines, equipment, and adjacent structure under every operating condition to prevent structural damage, abrasion, or excessive wear due to vibration and flexural motion or aerodynamic buffeting where appropriate.

6.1.4.8 Restraint: When hose is used at pressures in excess of 500 psi, greater protection is required against the effect of vibration and shock waves. The ideal method is to contain the hose by means of a structural system separated from the hose and in no way interfering with normal flexibility of the hose.

6.1.4.9 Support: Hose shall be supported in a manner that will not introduce deflection of rigid lines due to any possible relative motion that may occur. Hose between two rigid connections may be restrained as necessary, but it shall not be rigidly supported by tight, rigid clamps about its exterior (OD). If hose between rigid connections must move longitudinally, any restraining devices used should be of a type such as a sliding nylon block clamp which will not cause wear on the casing.

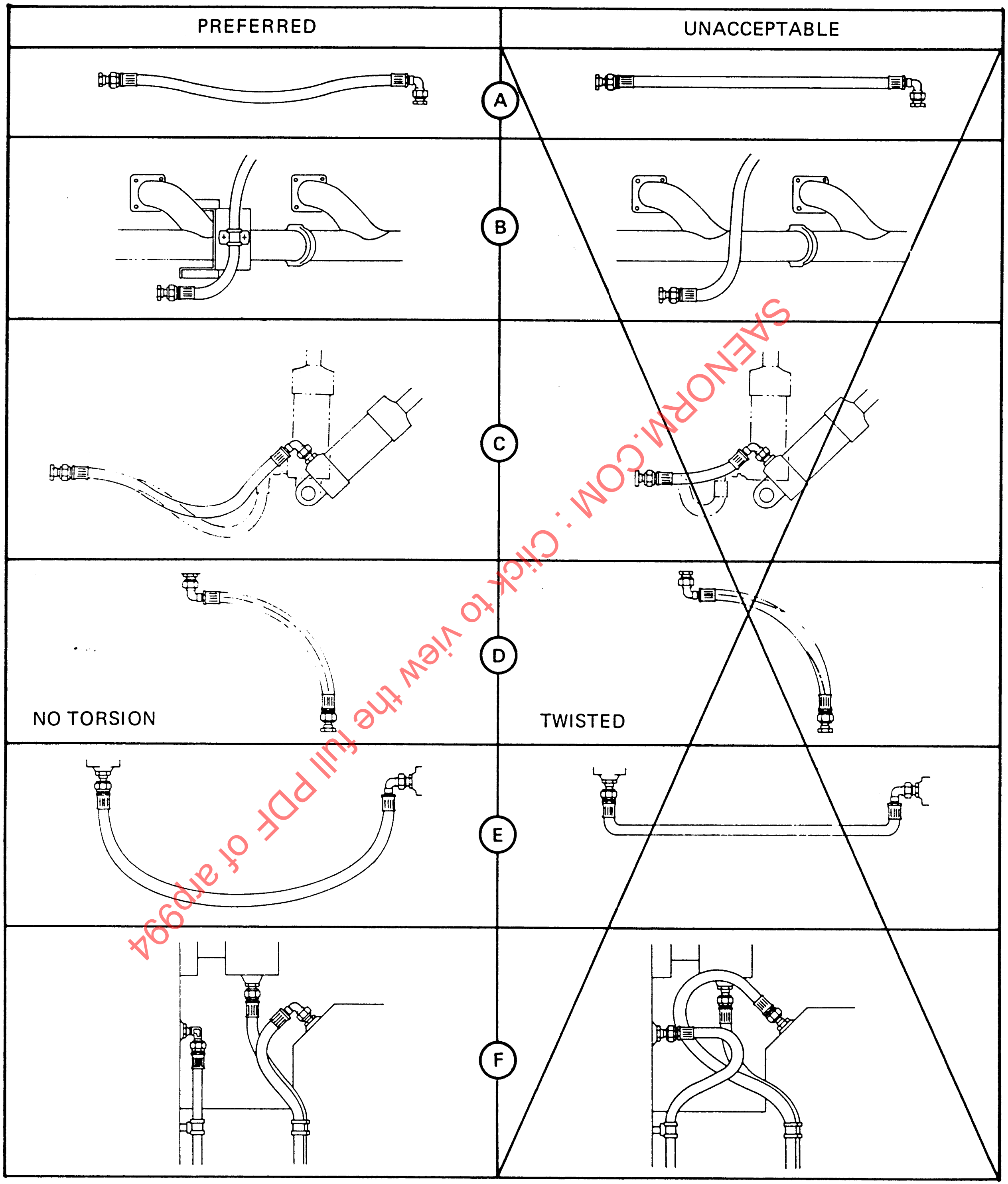


FIGURE 6-1. HOSE INSTALLATION CRITERIA

6.2 Flexible Tubing: Basic tubing configurations conforming to Styles A and B of ARP 584 should be used for guidance in the design of tubing applications requiring large relative motion of contiguous connections in fluid power lines. CRES (21-6-9) tubing may be utilized in lieu of CRES (18-8) tubing within the tolerance limits described by ARP 584. Careful design consideration must be given to the basic mechanical and physical properties of the tubing and also the effects of manufacturing (i.e. work hardening, ovality, wall thinning) which can affect the fatigue life. See References 16.11 and 16.12.

For convenience, configuration Styles A and B are reproduced from ARP 584 in Fig. 6-2 and 6-3 respectively. (Note that for other materials and flexible line configurations, other dimensional limits can be used.)

6.2.1 Installation: A space layout and geometry study will indicate which configuration style can be used most advantageously. The design should accommodate installation and replacement of the flexible tubing without overstressing it. Structural stops may be incorporated to limit the potential travel of the flexural member within prescribed limits under all conditions of service and maintenance.

6.2.1.1 Style A Configuration: Since the helical configuration has better fatigue life when deflected in the wind-up direction, the design should favor this type of action when possible; however, the recommended deflection (± 13 deg max) may be appropriately divided about the free position.

The centerline of the helix should be located parallel with, and as close as possible to, the major axis to minimize the effects of misalignment, and its travel during actuation should not vary from the limits shown in Section A-A of Fig. 6-4.

The actuator's misalignment, α , should not exceed 1.5 deg, and torsional rotation, θ , about its central axis should be limited to 1 deg by mechanical means when the actuator is mounted on self-aligning bearings.

A symmetrical arrangement of left and right hand helices about the actuator's centerline results in the advantage of balanced rotational forces during actuation.

6.2.1.2 Style B Configuration: The total deflection (13 deg) of the torsion tube may be displaced in either direction, but no combination of deflections should exceed 13 degrees.

The axis of the torsion tube shall coincide with the actuator's pivot centerline within the limits shown in Fig. 6-5.

Misalignment of the actuator, α , is limited to ± 3 deg when combined with offset "b" max, an axial rotation, θ , of ± 1 deg and the principal deflection Ø established as follows:

System Type	Temperature Range	Ø Max. Deflection, Deg
Type I	-65 to +160 F	13.0
Type II	-65 to +275 F	12.3
Type III	-65 to +450 F	11.3

A larger angle of misalignment can be tolerated if the clamp at the structure can flex in the plane of the tubing, thereby reducing bending of the tube.

Reduction of the axial rotation of the actuator can be obtained by use of symmetrically arranged coiled tubing and appropriate mechanical restraint.

6.2.1.3 Fittings: During tubing flexure, loads are imposed on the fittings to which the ends of the tubing are attached. Consequently, the fittings to be installed adjacent to the structure should be supported; particularly with respect to bending loads. In addition, the installation tolerances noted in Fig. 6-3 and 6-4 necessitate the provision of a universal adjustment for at least one, and preferably both, fitting support brackets.

6.2.1.3 Continued:

Before flexible tubing is installed, the associated actuating mechanism must be placed in the position required to assemble the parts with the tube in a free unstressed condition. The least accessible fitting should be firmly tightened, then the adjustments should be made at the support brackets to align the uncoupled fitting with its point of attachment. At this time, the mismatch at the uncoupled fitting should be determined. The offset measured perpendicular to the tube should not exceed 0.062 in. in any direction. The axial gap or interference should not exceed 0.032 in. and the misalignment of tube and fitting centerlines should not exceed 1.5 degrees.

6.3 Tight Spiral Coiled Tubing: Tight spiral pre-shaped tube assemblies have also been used. They project the use of flexible tubes to additional applications which might otherwise require a hose or an extension unit.

Typical applications in a wheel brake line installation are shown in Fig. 6-6. Pre-shaping the assembly so that it is unstressed in the mid-position, as shown in Fig. 6-7, will minimize maximum stresses in the extreme positions.

Such assemblies have been used in AISI 304 stainless steel, both annealed and 1/8-hard, and in 21-6-9 alloy, in sizes up to 1/2-inch diameter. With the latter, some springback must be accounted for in fabrication which is accomplished in two phases:

a) Initially, the tube is shaped in a continuous series of tight spirals formed along a helical path about a straight centerline axis. The bending radius is approximately one pipe diameter and the diametrical envelope is nearly the same as an equivalent size hose. In this condition, the spiral tube assembly appears functionally similar to hose assembly drawings.

b) The straight sections of the assembly are then shaped with a template as with a rigid tube.

The concept is patented by the McDonnell Douglas Corporation and assemblies may be obtained from Linair Engineering [14]. In addition to single-tube assemblies, dual tube assemblies, such as shown in Fig. 6-8, can also be made and may be useful for actuator supply lines.

6.4 Swivel Joints: Swivel joints are generally used where large angular motions occur, and special consideration should be given to their limitations, such as increased weight and size and the need for elastomer seals and their increase in torque during their service life.

A swivel joint should be designed to be hydraulically balanced whenever possible to minimize friction in the joint and eliminate end loading. If it is not possible to hydraulically balance the joint, rolling element bearings may be required.

Flared and flareless tube fittings are generally employed, but other types of available connectors may be applied with success. Permanent attachments are not recommended.

For reference see MIL-J-5513.

6.4.1 Installation: Swivel joints should be installed with particular attention to alignment and freedom of action throughout the actuation. Wracking and stressing of fittings will contribute to early failure of the unit, and undue flexing will cause loss of fluid at the seals. The swivel joint should be rigidly mounted to avoid unfavorable effects of vibration.

6.5 Bellows: Various types of formed and welded bellows are available for application in fluid systems. In most cases, restraint of the bellows is recommended for all, except very low pressure systems.

Bellows for high pressure systems are usually contained in a cylindrical type of container which maintains alignment and limits the amount of axial travel to safe parameters. The bellows should incorporate a high degree of hydraulic balance. Generally, the design requirements of bellows for fluid power systems are so specific that most units are custom designed.

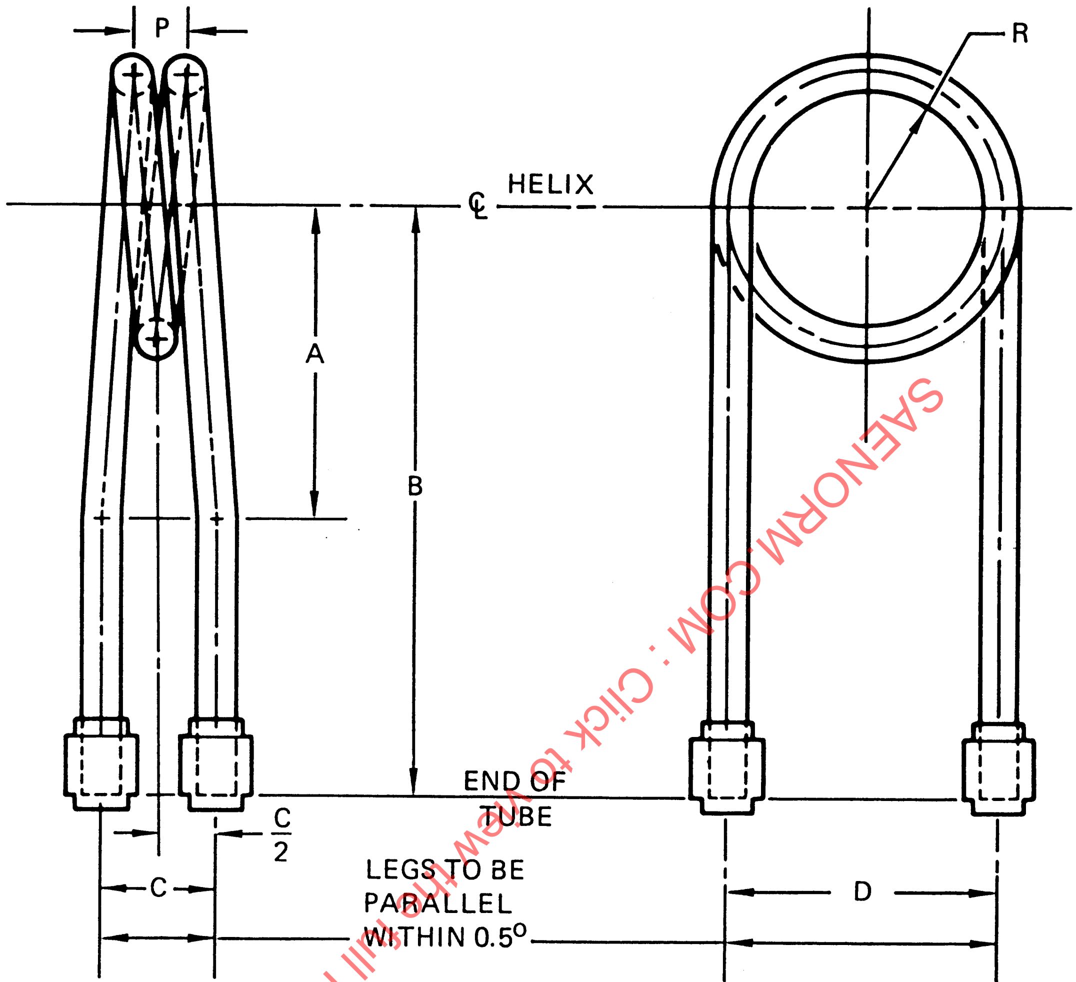
6.5 (Continued)

Weight and cost are important factors in the selection of bellows to accommodate line movement. Reliability is considered to be good; therefore, many applications have been incorporated in space vehicles.

6.5.1 Installation: Bellows are usually installed by permanent means, such as brazing or welding. Alignment is very vital to the performance of the unit, and care should be taken to ensure against lateral motion by means of structural support of the line beyond each end of the bellows. These provisions must not interfere with the axial movement of the line.

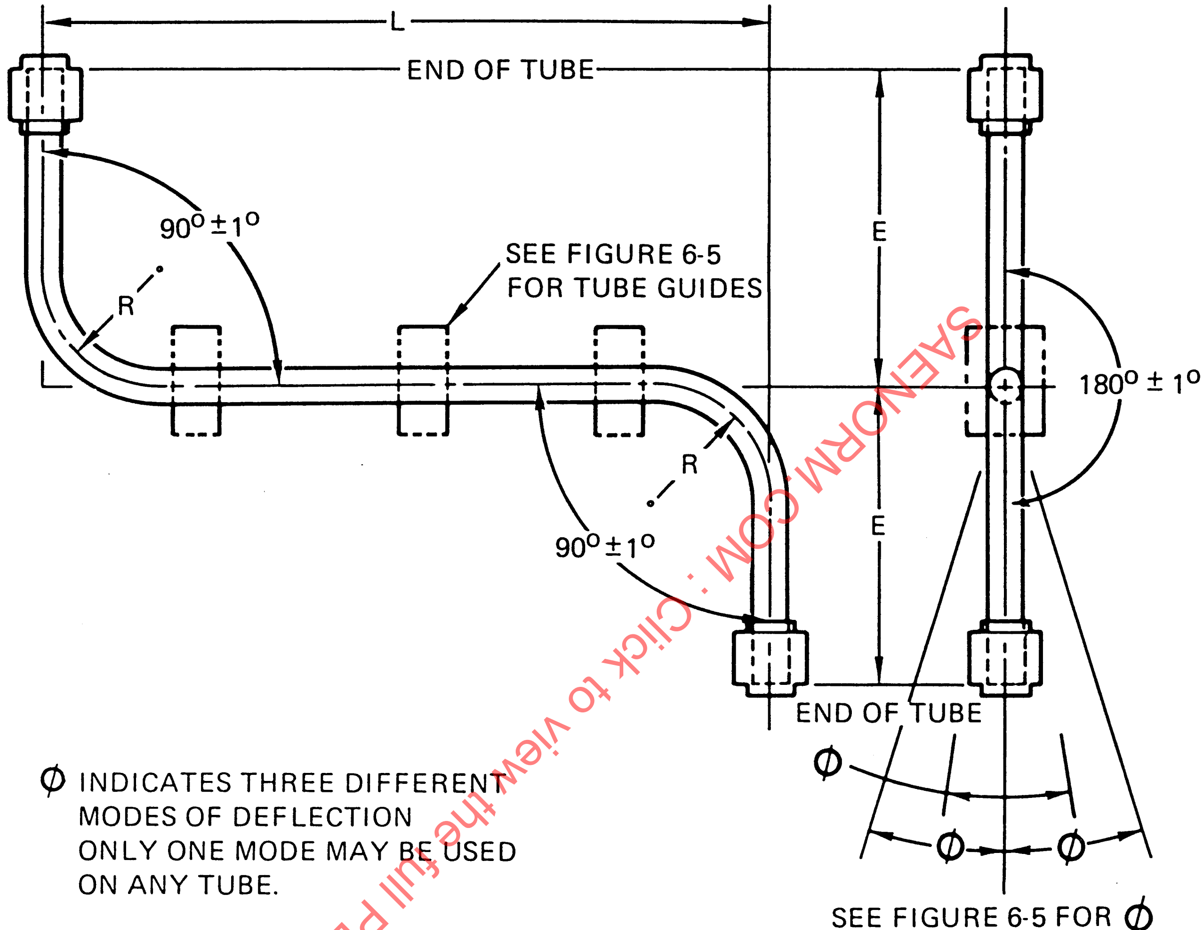
6.6 Extension Units: Extension units are intended as a replacement for flexible hose in applications where a hose installation is impracticable or would result in excessive weight. Extension units combined with swivels can simulate any motion and stroke desired. Extension units should be hydraulically balanced to eliminate end loading. Like swivel joints, they have the disadvantage of requiring elastomer seals. See Fig. 6-9 for an illustration of a hydraulic extension unit.

6.6.1 Installation: Experience on the A-7 aircraft shows several areas that require special consideration. Extension units should work through most of the stroke occasionally to lubricate the packings and piston rod. Swivel units should be used on both ends where misalignment could be appreciable. When extension units are used in high vibration areas, they should work through most of their stroke all the time. Shock mounting may be required to prevent vibration feedback into the hydraulic system.



TUBE OD	WALL THICKNESS NOM	R ±0.047	P PITCH	A ± 0.032	B ± 0.032	C ± 0.032	D ± 0.032
0.250	.028	1.000	0.375	3.000	6.000	0.906	2.000
0.313	.035	1.125	0.438	3.000	6.000	1.032	2.250
0.375	.042	1.375	0.500	3.250	6.000	1.125	2.750
0.500	.058	1.750	0.625	4.000	7.000	1.375	3.500
0.625	.078	2.250	0.750	5.000	9.500	1.656	4.500
0.750	.083	2.625	0.875	6.000	12.000	1.938	5.250
1.000	.120	3.500	1.125	7.000	14.000	1.406	7.000

FIGURE 6-2. STYLE A "HELICAL CONFIGURATION"



Ø INDICATES THREE DIFFERENT
MODES OF DEFLECTION
ONLY ONE MODE MAY BE USED
ON ANY TUBE.

TUBE OD	WALL THICKNESS NOM	R RAD	L ± 0.032	E ± 0.032
0.250	.028	1.000	11.125	4.000
0.313	.035	1.125	14.000	5.000
0.375	.042	1.375	16.750	6.000
0.500	.058	1.750	22.250	8.000
0.625	.078	2.250	27.875	10.000
0.750	.083	2.625	33.375	12.000
1.000	.120	3.500	44.500	16.000

FIGURE 6-3. STYLE B "TORSION TUBE"

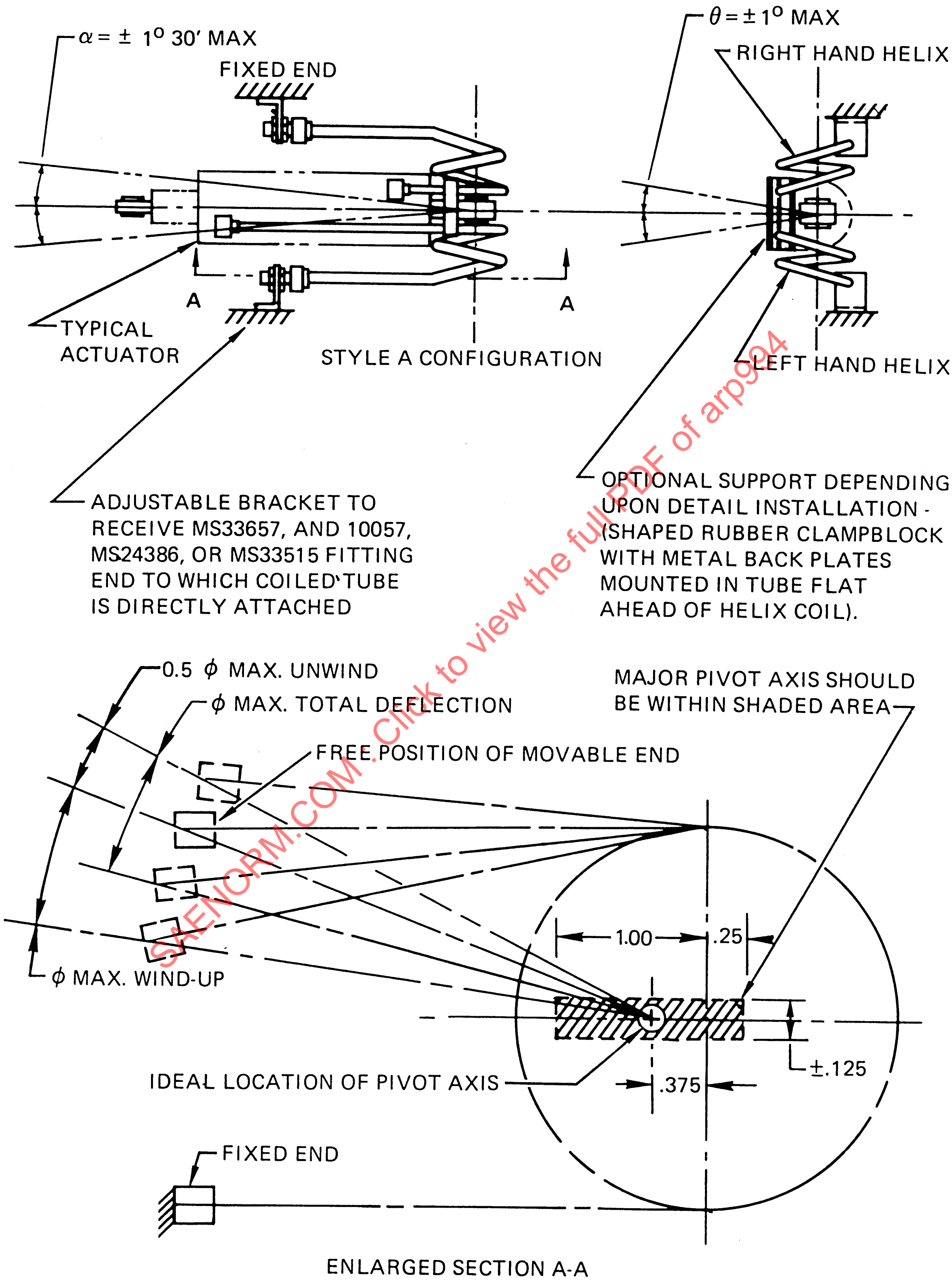


FIGURE 6-4. INSTALLATION OF STYLE A

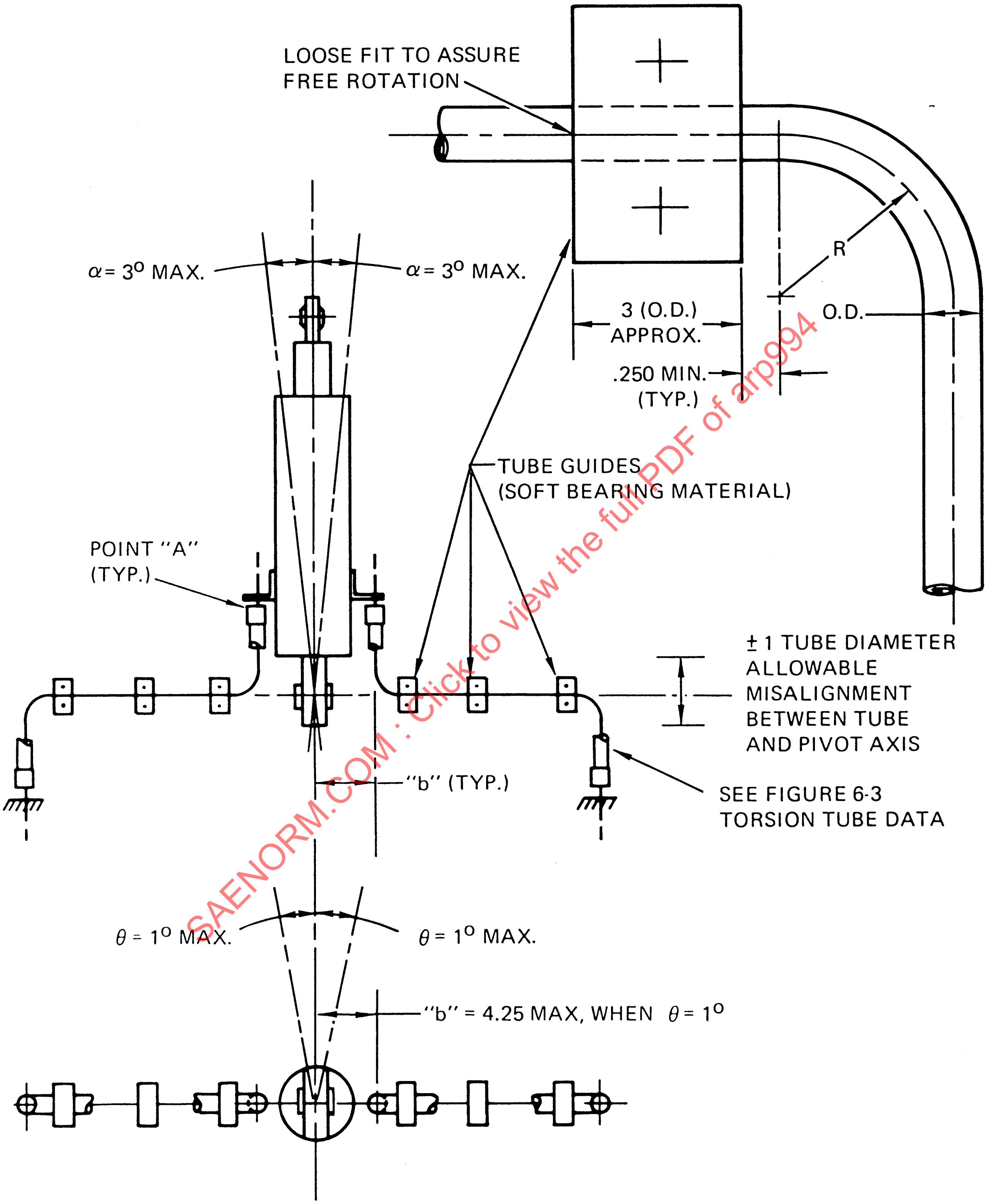


FIGURE 6-5. INSTALLATION OF STYLE "B" TORSION TUBE

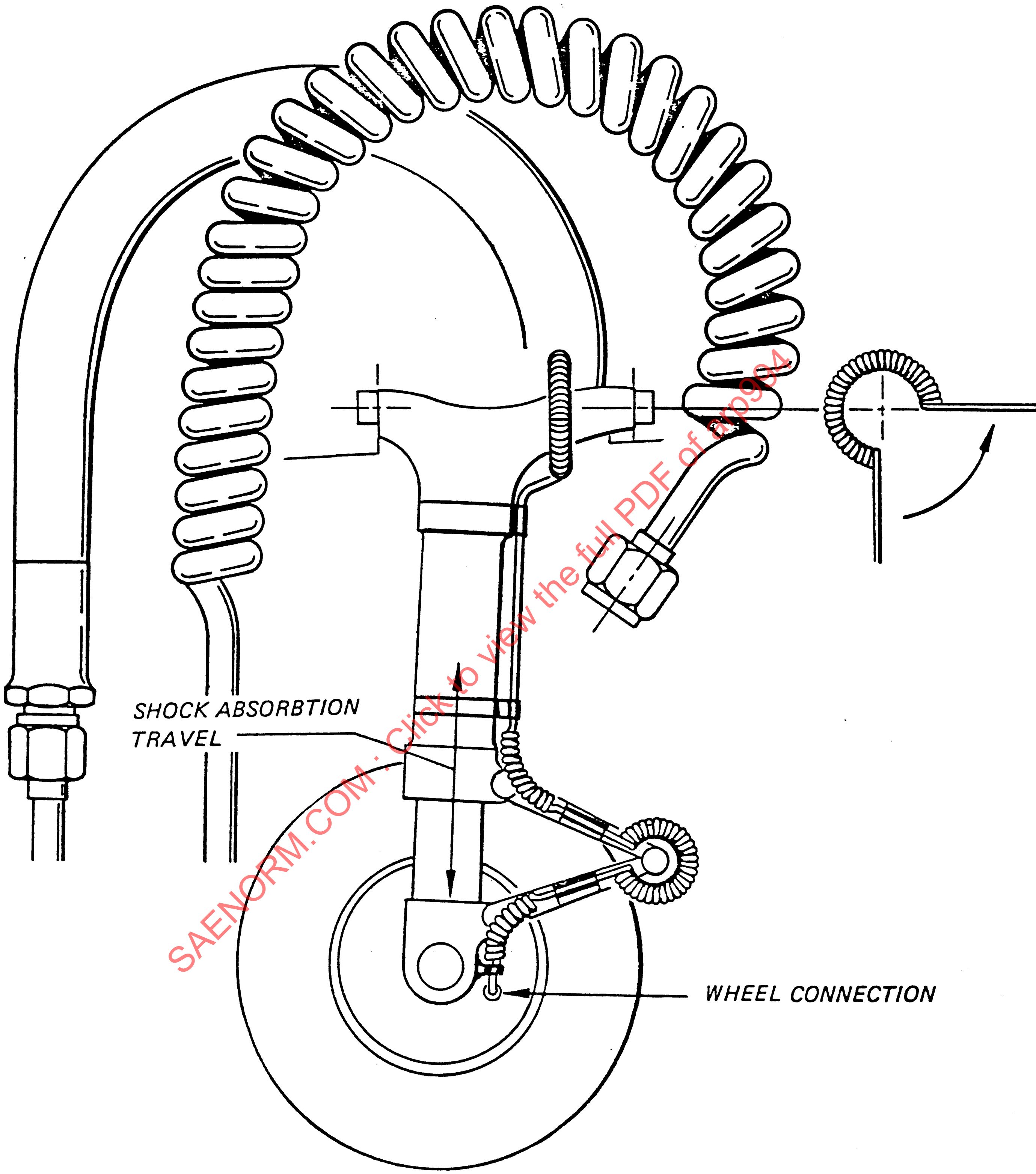


FIGURE 6-6. TIGHT SPIRAL BRAKE LINE INSTALLATION

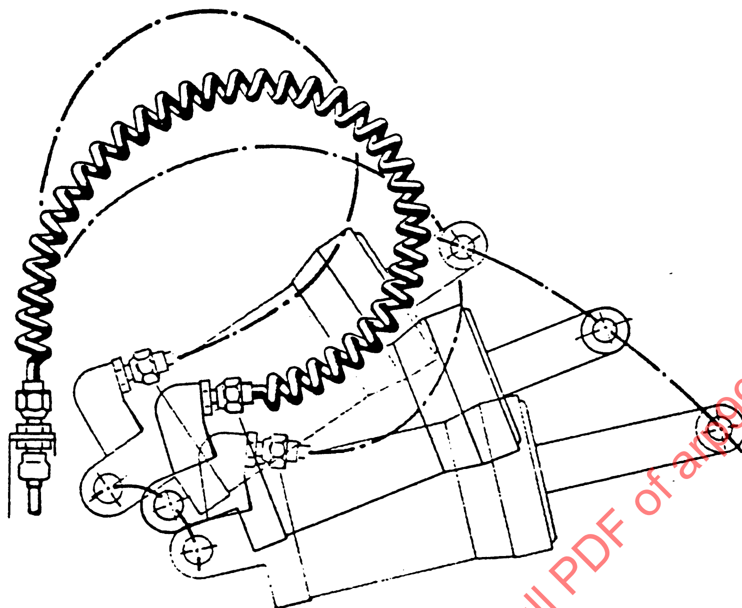


FIGURE 6-7. SPIRAL TUBE PRESHAPED TO PROVIDE NONSTRESSED CONDITION IN NOMINAL POSITION

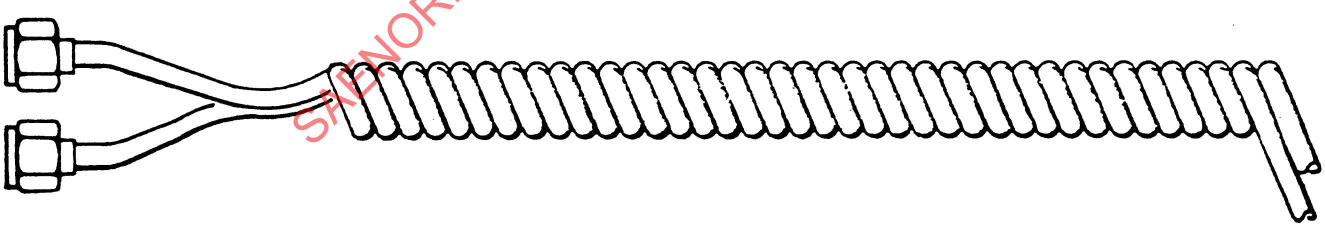


FIGURE 6-8. DUAL SPIRAL TUBE

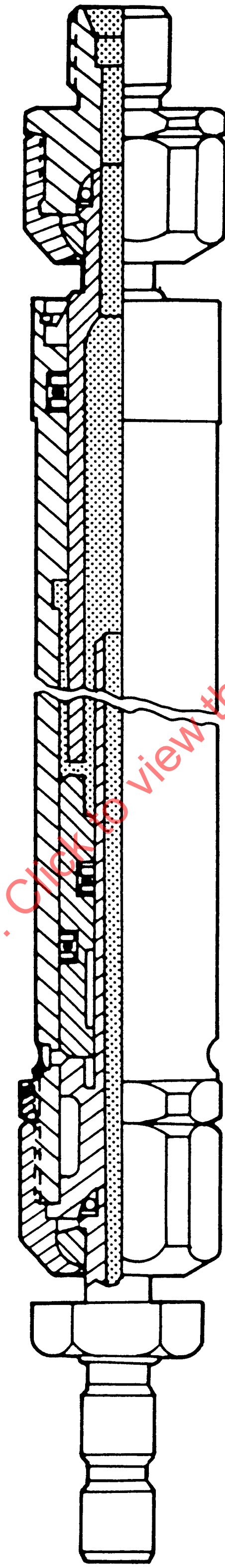


FIGURE 6-9. HYDRAULIC EXTENSION UNIT

7. SUPPORT, CLAMPING, AND BONDING

CONTENTS

7.1 General Considerations: The basic functions of tube supports are as follows:

a) To maintain static clearance between the tubes and equipment, wire bundles, structure, or other tubes.

b) To prevent motion and vibration which may result in tube abrasion from adjacent equipment, operating mechanisms, structure, other tubes, or the tube support itself.

c) To prevent damage to the tube resulting from support structure deflection.

These functions must be accomplished while allowing some axial tube motion relative to the clamping device to accommodate thermal expansion of the tubes.

In general, it is desirable to provide as much clearance as practicable between tubes and surrounding equipment or structure. It is recommended that a minimum clearance of 1/8 in. be maintained between tubing and structure or other rigid members from which the tubing is supported. A minimum clearance of 1/4 in. should be maintained between tubing and other adjacent structure or units. In areas where relative motion between the tubing and adjoining components exists, a minimum clearance of 1/4 in. should be maintained under the most adverse conditions anticipated. Clearance between tubes and wire bundles should be at least 1/2 inch. These recommendations are in agreement with the requirements specified in MIL-H-5440, MIL-H-8891, and MIL-P-5518.

7.2 Types of Supports and Applications:

7.2.1 Blocks: Support blocks may be used to clamp several tubes which are parallel and in close proximity at the clamping point. The support block configuration is a function of the specific application, however, the general design features are as shown in Fig. 7-1. Blocks require accurately formed tube assemblies installed with little or no preload if adequate service life is to be attained.

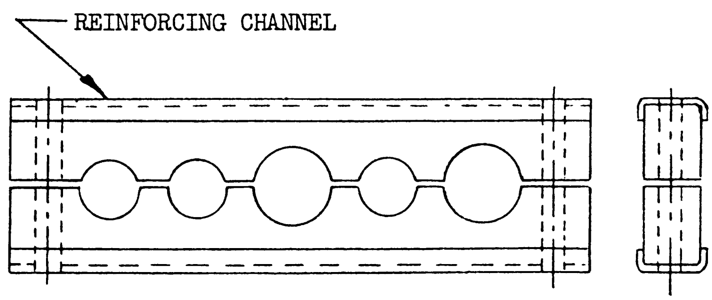


FIGURE 7-1. SUPPORT BLOCK CONFIGURATION

In some designs utilizing rigid block material, the reinforcing channels have been deleted. Another variation is the addition of a thin aluminum bonding strap to make contact with the tubes. However, this method of bonding is no longer acceptable from the standpoint of MIL-B-5087. Several block materials are available. These include cork-neoprene, silicate rubber, neoprene, buna "N", ethylene propylene rubber, nylon, and laminated phenolic. Selection of block material is a function of the environment and fluids to which the block is subjected.

When using laminated phenolic block material it is important that the design be such as to provide essentially equal clamping pressures for all tubes. This can be accomplished in most cases by judicious placement of attach screws. When using relatively rigid block materials best results are obtained if the attach screws are separated by no more than two tubes. Figure 7-2 illustrates two possible screw placement approaches:

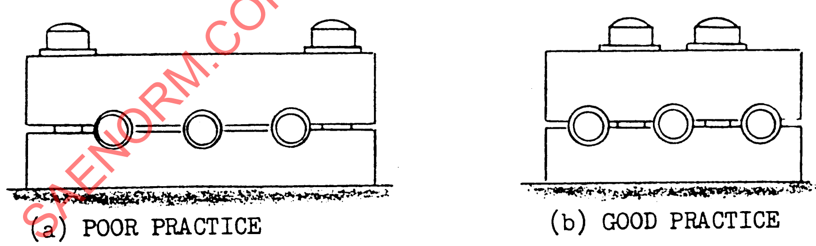


FIGURE 7-2. SUPPORT BLOCK ATTACH SCREW PLACEMENT

If the screws are located as in Fig. 7-2(a), progressive tightening beyond a certain point tends to lessen the clamping pressure on the center tube. The clamping pressure is more evenly distributed by locating the screws as in Fig. 7-2(b). Adequate, but not excessive, clamping pressure is ensured by use of screws requiring installation by screwdriver rather than a wrench. In designs making use of laminated phenolic block material without the reinforcing channel the orientation of the laminations is an important consideration.

For maximum strength, the plane of the laminations should be normal to the tube centerline except when flat-head screws are used to attach the block to structure. In this case, the laminations of the countersunk (top) portion of the block must be situated normal to the centerlines of the screws to prevent lamination separation when the screws are tightened.

7.2.1 (Continued)

A variation of the block support which has been used successfully in high temperature applications is a spring-loaded design. The spring-loading feature enables relatively close control of clamping pressure on the tubes so that, with a controlled friction coating (such as teflon) on the block, large thermal expansions can be accommodated without subjecting the tubes to adverse loading.

7.2.2 Clamps: Several types of tube clamps are available as standard items. The clamp design which is perhaps most frequently used is shown in Fig. 7-3:

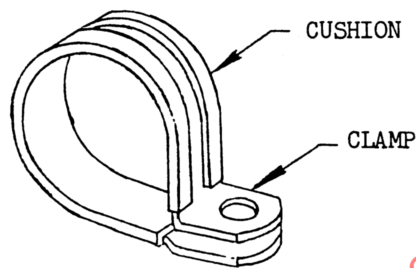


FIGURE 7-3. TUBE CLAMP

This type of clamp is formed from aluminum, steel or stainless steel strap. Available cushion materials include teflon, teflon impregnated asbestos, silicone impregnated fiberglass, neoprene, silicate rubber, EPR, vinyl and others. The particular clamp and cushion materials are selected on the basis of projected environmental conditions of the application and user preference. Reference 6-2 specifies use of clamps conforming to the dimensional requirements of MS21919 similar to the design shown in Fig. 7-3.

In some moderate temperature applications nylon clamps (without cushions) similar in shape to that of Fig. 7-3 are used. A single clamp may be used to support an individual tube or clusters of three or four small tubes by use of suitable "X" or "Y" spacers or separators.

Another type of single-tube clamp that is sometimes used is the saddle support, which, by means of two-point attachment, provides a more rigid attachment to structure than do the previously mentioned clamps. The saddle support also has its counterpart for high temperature applications. One version that has been used enables thermal expansion along the centerline of the tube by means of spring-loading to control clamping pressure. A second version provides this same benefit but is mounted on a slide track to enable lateral positioning of the clamp. Many special clamp configurations in addition to those included in manufacturer's catalogs have been used. The manufacturers should be contacted concerning special applications of this nature.

7.2.3 Elastomeric Vibration-Isolating Tube Mountings: A series of fluorosilicone tube mountings have been designed for tubing and piping sizes ranging from 3/8 in. to 5 inches. A design objective was to provide ease of installation in that the smaller size mounts are spread to slip over the tube, clamped to the tube with a commercially available heat-stabilized, self-locking nylon strap and bolted to the supporting structure as shown in Figure 7-4(a). The larger sizes are two-piece designs which are again clamped to the tube by the nylon strap method and bolted to the supporting structure as shown in Figure 7-4(b).

7.2.3 (Continued)

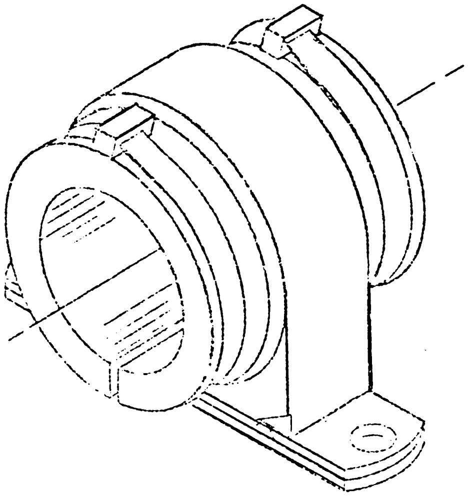


FIGURE 7-4a

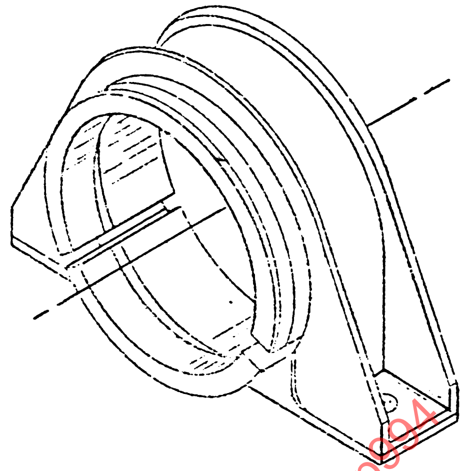


FIGURE 7-4b

There are many advantages in these mountings. The materials have been chosen to withstand the fuels, fluids, and ambient environments prevalent in the areas of the application. Among the environmental elements which these mounts will withstand are: gasoline, JP-4, JP--5, Chevron M2-V, MIL- L-7808 oil, sand and dust, fungus, and temperature exposures from -65 F to +300 F.

The stiffnesses of these elastomeric mounts have been designed to provide motion accommodation in both the lateral and longitudinal directions as well as any cocking motions imposed during the installed life of the mounting-pipe combination. The elastomeric mounts isolate the fluid lines from high frequency vibratory disturbances and protect them from shock loading. This extends the life of the mounted fluid lines by reducing the stress and strain levels imposed.

Besides the above advantages, these tube mounts are fail-safe in that the metal band through which the mount is bolted to the support structure is integrally bonded around the top of the mount. The presence of elastomer in the system also reduces sound transmission. Finally, the mounts have a low profile requiring little added space around the lines.

7.2.4 Other: Tube support may also be provided by bulkhead fittings, grommets or through bulkhead supports where tube runs pass through bulkheads or panels.

7.3 Support Spacing:

7.3.1 General: The tube supports are normally attached directly to structure or to structure-mounted brackets. Standard brackets for attaching clamps are available.

A complete understanding of the characteristics of the structure to which the supports are attached is required to ensure that the structure does not contribute detrimental loading to the tube. Aspects of the design which must be taken into consideration include the vibration characteristics of the structure and differences in flexibility of structural members to which adjacent supports are attached for a given tube run. Various methods have been used successfully to improve fatigue life of tube installations subjected to high vibration environments. In addition to reducing support spacing distances as discussed in 7.3.2, it has proved desirable to provide good bending support for clamps. This may be done by providing full support engagement of the clamp from bolt centerline to tube centerline as shown in Fig. 7-5. Rigid loop clamps, however, provide reliable support only in two directions and therefore should be avoided in highly mobile structural areas. When simple tubular spacer standoffs are used, loop clamps provide reliable support only in one direction.

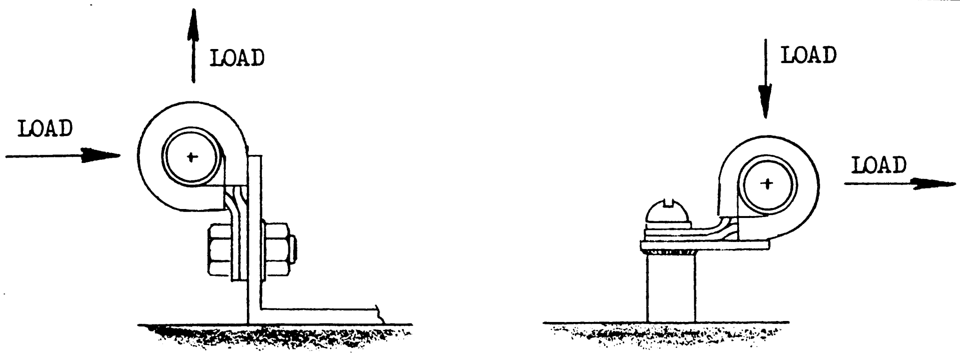


FIGURE 7-5. FULL SUPPORT ENGAGEMENT

7.3.1 (Continued)

Supports must be placed to accommodate some tube misalignment. If jig locating of components is not feasible, a greater misalignment must be tolerated. In this regard, it is beneficial to establish limits on the lateral force which can be applied at the end of the misaligned tube to bring it into proper mating position. These force limits will be a function of tube strength characteristics and the distance from the last support to the misaligned fitting. Where possible, tube supports should be placed such that they are readily accessible for inspection and maintenance.

Loop clamps will twist around their single mounting screw when the secured tube is forced to move in highly mobile areas of the airframe. This twisting results in a locking action that causes the clamp band to bite through the cushion and into the tube. Therefore, clamps secured to mobile structures should be mounted so as to prevent the twist-lock action, or an alternate type such as a saddle clamp or support block should be used.

7.3.2 Straight Tube Runs: Recommended maximum distances between supports for straight tube runs are shown in Table 7-1. These are the same as specified in References 7-2 and 7-3. Particular applications may require closer spacing than shown by these documents. Tube runs subjected to severe loading or vibration environments must be analyzed to determine proper support spacing.

TABLE 7-1 - HYDRAULIC LINES SUPPORT SPACINGS

Nominal Tube OD (inches)	Maximum Length Between Support Centers (measured along tube): Aluminum Alloy (inches)	Steel (inches)
1/8	9.5	11.5
3/16	12.0	14.0
1/4	13.5	16.0
5/16	15.0	18.0
3/8	16.5	20.0
1/2	19.0	23.0
5/8	22.0	25.5
3/4	24.0	27.5
1	26.5	30.0
1-1/4	28.5	31.5
1-1/2	29.5	32.5

7.3.3 Tube Bends: Supports should be placed as close to bends as practicable to minimize overhang; however, the support must not infringe upon the bend.

7.3.4 Tube Fittings: Tube support spacing should be reduced by approximately 20% when the span between supports includes fittings such as unions and tees.

7.3.5 Line-Mounted Components: Standard lightweight components, such as check valves, and nonstandard components of similar weight and usage, may be supported by the tubing, provided a tube clamp is used as close as practicable on each side of the component.

7.3.6 Tubes Passing Through Holes: In some cases, it may be necessary to use bulkhead fittings when a tube run passes through a bulkhead; however, tube fatigue has been a problem in such installations. Use of bulkhead fittings should be restricted only to those applications in which it is necessary to maintain a sealed compartment. Where practicable, it is advantageous to design the tube to pass through a hole in the bulkhead, using a clamp attached to the bulkhead for support between the tube and the hole. With this approach, adequate clearance is provided in the installed condition by virtue of the size of the hole necessary to allow the fitting to pass through. The use of grommets should be avoided because of their susceptibility to breakdown and subsequent tube damage on the edge of the hole.

7.4 Bonding: Electrical bonding of tubing to the aircraft structure is required to prevent an excessive accumulation of static charge as a result of flow of hydraulic fluid. According to MIL-B-5087, this bonding must be accomplished by use of certain hardware for applications in which this Military Specification is invoked.

A recent amendment to MIL-B-5087 requires a maximum spacing of 18 inches between bonding attachments for all tube runs. A more realistic approach which seems to have general acceptance among airframe manufacturers is based on maintaining a resistance to the nearest structure at each point in a tube run to a value less than some maximum limit. This enables the intent of the Military Specification to be met without the necessity to over-design for the sake of an arbitrary standard.

8. DIMENSIONAL ACCURACY

CONTENTS

8.1 Forming: Accuracy of forming tubing is very important since it affects the integrity of the entire fluid power system. Preloaded or deformed tubing can result in early failure with subsequent loss of fluid and system. Tape controlled bending machines ensure better repeatability than manually controlled machines, especially for materials such as 21-6-9 stainless steel and titanium where considerable springback must be accounted for.

8.1.1 Tube Bends: Before starting any forming be sure that the bending equipment is in good condition. Radius blocks, mandrels, indexing guides, etc., should be checked for smoothness and alignment.

8.1.1.1 Angular Mismatch: Good angular control facilitates interchangeability of piping, retains proper clearances to adjacent parts, and permits installation without excessive preload. In general, bends should follow the tooling or jig template within ± 1/16 in. in offset and location and within ± 2 deg in angular mismatch. Of course, there are always occasions where closer or looser tolerance may be advisable, however, these are the exceptions rather than the rule and should be treated as such. For tubes bent in more than one plane, a tool jig will ensure better accuracy than a master tube.

8.1.1.2 Flattening: When a tube is bent around a radius block, the tube fibers on the outside of the forming radius are stretched while the tube fibers on the inside are compressed. The resultant forces tend to make the tube cross section lose its round shape and assume an oval shape; called flattening, this condition is very detrimental to the fatigue life of the tube. High internal pressures tend to make the oval shape return to the circular shape. Hence, pressure pulsations or fluctations induce cyclic stresses that result in early fatigue failures in flattened tubing. The reduction in fatigue life is a function of the degree of flattening.

8.1.1.2 Continued:

Tube ovality for bends in commercial aircraft hydraulic steel and commercially pure titanium tubing should not exceed 5% where the % flatness = $100 \frac{\text{Min O.D.}}{\text{Max O.D.}}$. Tube ovality for bends in aircraft titanium alloy tubing should not exceed 3%. Tube ovality for bends in military aircraft hydraulic tubing shall be per MS33611 where the percent flatness = $\frac{\text{Max O.D. Min O.D.}}{\text{Nominal O.D.}} \times 100$. The MS33611 method adds the nominal O.D. as a factor, which makes it somewhat less precise.

Example:	Nominal	0.3750 tube
	Original dia.	0.378
	Max O.D. in bend	0.387
	Min O.D. in bend	0.369

Commercial % flatness = $100 - \frac{0.369}{0.387} = 4.65\%$

MS33611 % flatness = $\frac{0.387 - 0.369}{0.375} \times 100 = 4.80\%$

8.1.1.3 Marks and Kinks: Wrinkles or washboard appearance on tubes should not exceed 1% of the tube nominal diameter for working pressures 500 psi or greater, and 2% for working pressures less than 500 psi (See Fig. 8-1).

NOTE. Wrinkle depth used here is the distance from a line across the tops of the ridges to the bottom of the valley between.

Mandrel marks adjacent to the tube bend tangent lines should not exceed 2% of the tube O.D. for sizes up to 1/2 in. or 0.010 in. for larger sizes and should not be rough and have an abrupt change in direction (See Fig. 8-1).

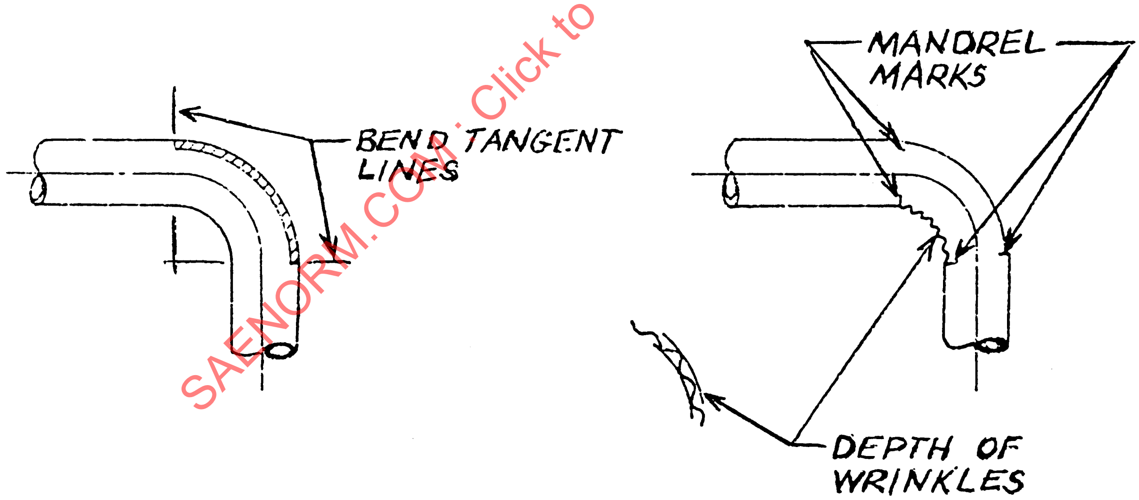


FIGURE 8-1 WRINKLES AND MANDREL MARKS

Nicks and scratches should not exceed:

5% of wall thickness for working pressure above 500 psi.

10% of wall thickness for working pressure below 500 psi.

8.1.2 Tube Ends: Tube assemblies may be readily checked for correct dimensional accuracy by performing the following inspection:

Place tubing in the proper installation position and loosely connect tubing fittings and clamps by hand. With clamps loose, it must be possible to run tube coupling nuts down by hand until the tube bottom on the fitting, without forcing the tubing into alignment. If the tube nuts cannot be run down by hand, check for alignment as follows:

Tighten the coupling nut at one end of the tube assembly lightly torquing with a wrench, and completely disconnect and shove back the nut on the other (free) end.

8.1.2.1 Angular Mismatch: The free tube end must be parallel with the fitting within 2 degrees. See Figure 8-2, Detail 1.

8.1.2.2 Lengthwise Mismatch: The free tube end must be in line with the fitting within 1/32 in. per 10 inches of tube length (radial match). See Figure 8-2, Detail 2.

8.1.2.3 Radial Mismatch: The free tube end must match the fitting cone lengthwise within 1/32 in. per 10 inches of tube length. See Figure 8-2, Details 3 and 4.

8.1.3 Overall Tube Length: Since many sections of tubing are assembled end to end to make up single tubing runs, the accumulated length tolerances can be appreciable. In order to minimize this effect, the overall length of each tube should be held to ± 1/32 inch.

8.2 Finishing of Ends: Various types of tubing end connections are utilized throughout the aerospace industry. The two types most commonly used are flared and flareless. Although these two connections have been standard for many years, each user has his own special techniques in fabrication and application. The following two paragraphs will deal with the acceptability of the finished product and not the interim processes.

8.2.1 Flared: Finished flares should meet the dimensional requirements of MS33584 for single flares and MS33583 for double flares. Flares should be concentric with the O.D. of the tube within 0.005 in. total indicator reading and shall be square with the tube centerline within 1/2 deg. The radius of the flare tangent point must be free from nicks, scratches or similar imperfections. The fabricated ends must not be cracked, creased, grooved or be heavily scored or marked by clamping dies or collets. Flares should retain 82% of the original tubing wall thickness.

8.2.2 Flareless: The sleeve sealing surface should be smooth and free from nicks, scoring and spiral or longitudinal tool marks. Bare plated areas or accumulated plating transfer from the swage die are not acceptable. Sleeves should be concentric and show no cracks or local die distortion. Rotation of the sleeve on the tube is acceptable, but there should be no perceptible longitudinal movement or rocking under normal hand loading.

For those users who never want the tube end to bottom in the fitting during installation, the "tube end projection beyond sleeve" should be 1/16 in. min to 3/32 in. max for all sizes.

For the users who want the tube end to bottom in the fitting during installation, the "tube end projection beyond sleeve" should be as noted in Table 8-1.

NOTE: Mismatches shown apply to Flareless Connections as well as Flared

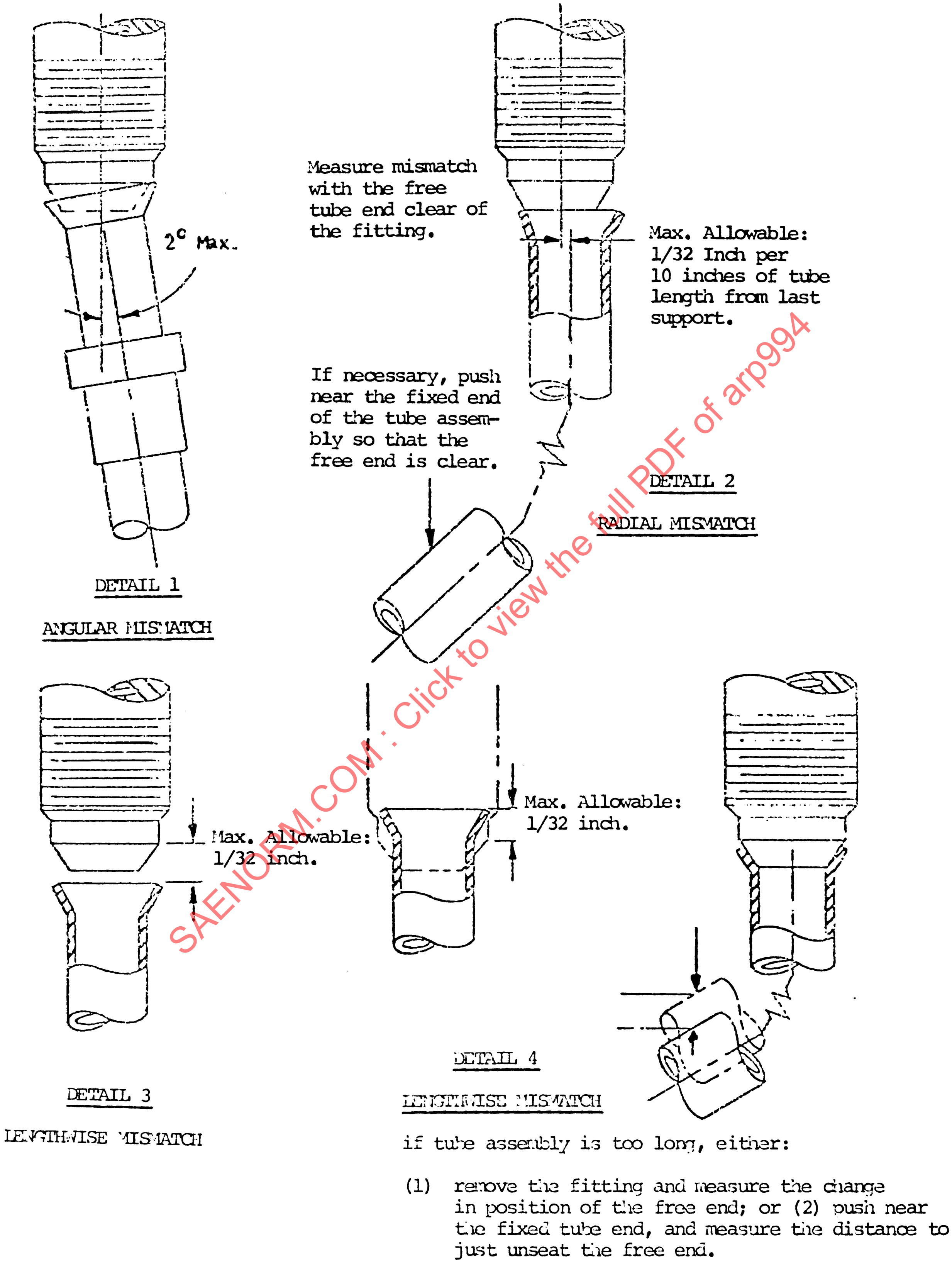


FIGURE 8-2. INSTALLATION MISMATCH

TABLE 8-1

TUBING O.D. x WALL	TUBE END PROJECTION BEYOND SLEEVE
3/16 x .018	.130-.150
3/16 x .020	.130-.160
1/4 x .016	.130-.160
1/4 x .020	.130-.160
1/4 x .028	.130-.160
5/16 x .020	.140-.180
5/16 x .028	.140-.180
5/16 x .049	.140-.180
3/8 x .020	.140-.180
3/8 x .028	.140-.180
3/8 x .035	.140-.180
3/8 x .065	.140-.180
1/2 x .028	.170-.210
1/2 x .035	.170-.210
1/2 x .049	.170-.210
1/2 x .083	.170-.210
5/8 x .028	.190-.240
5/8 x .035	.190-.240
5/8 x .042	.190-.240
3/4 x .020	.210-.240
3/4 x .032	.210-.240
3/4 x .035	.210-.240
3/4 x .049	.210-.240
3/4 x .053	.210-.240
1 x .035	.260-.280