SAE Aerospace
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AEROSPACE RECOMMENDED PRACTICE

ARP994 REV. A

Issued 1976-04
Revised 2012-08

Superseding ARP994

(R) Recommended Practice for the Design of Tubing Installations for Aerospace Fluid Power Systems

RATIONALE

The original version of ARP994 was published in 1976 and, prior to this revision, had not undergone any major revision. In order to update this document to reflect current aerospace design and manufacturing processes, it was decided to break this task into two stages as ARP994 is a large, complex and multi-disciplinary document. The two stages are:

a. A basic update of the document to delete obsolete/redundant information and to update references, etc.

b. A comprehensive technical update of the document

Revision A is the first stage of this update of ARP994.

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1. SCOPE

This document provides recommended practices for the design of tubing systems that are used for the transmission of liquid and gasses in fluid power systems for aerospace vehicles such as aircraft, missiles and boosters. The 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.

The sections regarding tubing materials and fitting types are 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.

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.

2. REFERENCES

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

AMS2430 Shot Peening, Automatic

AMS4943 Titanium Alloy Hydraulic SeamlessTubing, 3.0Al - 2.5V, Annealed

AMS4944 Titanium Alloy Tubing, Seamless, Hydraulic, 3.0Al - 2.5V, Cold Worked, Stress Relieved

AMS5554 Steel, Corrosion and Heat-Resistant, Seamless Tubing 16.5Cr - 4.5Ni - 2.9Mo - 0.10N Annealed

AMS5561 Steel, Corrosion and Heat-Resistant, Welded and Drawn or Seamless and Drawn Tubing 9.0Mn – 20Cr – 6.5Ni – 0.28N High-Pressure Hydraulic

AMS-S-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks, and Fuel Cell Cavities, High-Adhesion

AMS-T-6845 Tubing, Steel, Corrosion-Resistant (S30400), Aerospace Vehicle Hydraulic System 1/8 Hard Condition

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

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

AIR737 Aerospace Hydraulic and Pneumatic Specifications, Standards, Recommended Practices, and Information Reports

AIR797 Hose Characteristics and Selection Chart

AIR1047 A Guide for the Selection of Quick-Disconnect Couplings for Aerospace Fluid Systems

AIR1569 Handling and Installation Practice for Aerospace Hose Assemblies

AIR4918 Industry Practices and Guidelines for the Selection of Coiled Tubes, Flexible Hoses, Swivels, and Extension Fittings for Aircraft Fluid Systems

AIR5386 Hose and Hose Assembly Selection, Installation, Inspection and Maintenance Guidelines, Listing of

ARP573 Silver, Copper and Nickel Alloy Brazed Joints for Aerospace Propulsion Systems

ARP584 Coiled Tubing, Corrosion Resistant Steel, Hydraulic Applications, Aerospace

ARP600 Torque Determination, Method of, for Tube or Hose End Fitting Connections, Flared, Flareless, or Miscellaneous Screw Thread Style

ARP1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

ARP1897 Clamp Selection and Installation Guide

ARP4146 Coiled Tubing – Titanium Alloy Hydraulic Applications, Aerospace

ARP4698 Guide for Choosing a Minimum Wall Thickness of Tubing for Use With Weld Fittings Coded for a Range of Wall Sizes

ARP4752 Aerospace – Design and Installation of Commercial Transport Aircraft Hydraulic Systems

ARP4784 Definitions and Limits, Metal Material Defects and Surface and Edge Features, Fluid Couplings, Fittings and Hose Ends

ARP4925 Aerospace Design and Installation of Commercial Transport Helicopter Hydraulic Systems

ARP5412 Aircraft Lightning Environment and Related Test Waveforms

ARP5414 Aircraft Lightning Zoning

ARP5415 User's Manual for Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning

ARP5891 Achieving Cleanliness Standards for Aircraft Hydraulic Systems During Manufacture

AS478 Identification Marking Methods

AS568 Aerospace Size Standard for O-Rings

AS611 Hose Assembly and Tubing, Polytetrafluoroethylene, Cleaning Methods for

AS683 Installation Procedures and Torques for Fluid Connections

AS685 Piloted Ring Seal Fluid Connection Bosses

AS686 Piloted Ring Seal Tube Swivel Connection Assembly

AS756 Fitting End Assembly, Universal, Design Standard

AS758 Fittings - Installation in Straight Threaded Boss

AS1038 Fitting, Elbow, 90°, Standard and Reducer, Bulkhead, Flared

AS1040 Fitting, Elbow, 45°, Standard and Reducer, Bulkhead, Flared

AS1055 Fire Testing of Flexible Hose, Tube Assemblies, Coils, Fittings, and Similar System Components

AS1241 Fire Resistant Phosphate Ester Hydraulic Fluid for Aircraft

AS1424 Hose Assemblies, Metal, Medium Pressure, High Temperature

AS1709 Coupling Assembly, Hydraulic Self Sealing, Quick Disconnect

AS1731 Coupling, Rigid, Fixed Cavity, Threaded Ferrule Type Tube Ends, Envelope Dimensions Design Standard

AS1732 Body, Coupling, Rigid, Fixed Cavity, Threaded, Ferrule Type Tube Ends, Type I

AS1734 Nut, Coupling, Rigid, Fixed Cavity, Threaded, Ferrule Type Tube Ends, Type I

AS1792 Nut, Fitting, Lightweight, Flareless

AS1958 Port - Fluid Connection, Ring Locked Insert, Standards Dimensions for

AS1985 Fitting Assembly, Adapter Ring Locked Port Connection to Flared Tube End

AS1986 Fitting Assembly, Adapter, Ring Locked Port Connection to Beam Seal 4000 PSI and 5000 PSI /9/

AS4099 Adapter, Assembly, Port Connection, Ring Locked to Flareless Tube End

AS4383 Fitting Assembly, Reducer Ring Locked Port Connection to Beam Seal 5000 psi

AS4330 Tubing, Flared, Standard Dimensions for, Design Standard

AS4375 Fitting End, Flareless, Design Standard

AS4395 Fitting End, Flared, Tube Connection, Design Standard

AS4396 Fitting End, Bulkhead, Flared Tube Connection, Design Standard

AS4459 Fittings, Tube, Fluid System (3000/4000 psig Rated Pressure), Externally Swaged, Specification for

AS4467 Standardization, Hydraulic Tube Walls

AS4941 Aerospace - General Requirements for Commercial Aircraft Hydraulic Components

AS5202 Port or Fitting End, Internal Straight Thread, Design Standard

AS5203 Tube End, Double Flare, Design Standard

AS5440 Hydraulic Systems, Military, Aircraft Design and Installation Requirements for

AS5529 Sleeve, Flareless Tube Fitting, Internally Swaged

AS5530 Union, Flareless Tube Fitting, Internally Swaged

AS5863 Fitting End, 24° Cone, Flareless, Fluid Connection, Design Standard

AS5959 Axially Swaged Fittings, Installation and Inspection Procedure

AS5986 Fitting Assembly, Adapter Ring Locked Port Connection to Beam Seal 4000 PSI and 5000 PSI /9/

AS18280	Fittings, 24° Cone Flareless, Fluid Connection, 3000 psi
AS21902	Union, Flareless Tube
AS21921	Nut, Sleeve Coupling, Flareless
AS21922	Sleeve, Coupling, Flareless
AS24333	Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect, Flared Fitting to Internal Thread Boss
AS24334	Coupling Assembly, Hydraulic, Self-Sealing, Flareless Fitting to Internal Thread Boss
AS24335	Flange, Bulkhead Mounting, Hydraulic Self-Sealing Coupling
AS25427	Coupling Assembly, Hydraulic, Self-Sealing, Quick Disconnect
AS33514	Fitting End, Standard Dimensions for Flareless Tube Connection and Gasket Seal
AS33611	Tube End Radii

2.2 ASTM Specifications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B338 Standard Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensors and Heat Exchangers

2.3 ISO Publications

Available from:

- American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.
- International Organization for Standardization, 1, rue de Varembe, Case postale 56, CH-1211Geneva 20, Switzerland, Tel: +41-22-749-01-11, www.iso.org.

ISO12 Aerospace; Pipelines; Identification

2.4 NASA Specifications

Available from NASA, Documentation, Marshall Space Flight Center, AL 35812, www.nas.nasa.gov.

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

2.5 National Aircraft Standards Committee Standards

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

NAS1095	Flareless Fitting Connections, Fabrication and Assembly
NAS1760	Fitting End, Flareless Acorn, Standard Dimensions For

2.6 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

AND10050 Bosses, Standard Dimensions for Gasket Seal Straight Thread

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

MIL-DTL-5513 Joints, Hydraulic Swivel

MIL-T-8504 Tubing, Steel, Corrosion-Resistant (304), Aerospace Vehicle, Hydraulic Systems, Annealed, Seamless and Welded (Not for New Design)

MIL-T-8808 Tubing, Steel, Corrosion-Resistant (18-8 Stabilized) Aircraft Hydraulic Quality (Not for New Design)

MIL-STD-1247 Markings, Functions and Hazard Designations of Hose, Pipe, and Tube Lines for Aircraft Missile, and Space Systems

MIL-DTL-5541 Chemical Conversion Coatings on Aluminum and Aluminum Alloys

MIL-PRF-5606 Hydraulic Fluid, Petroleum Base, Aircraft, Missile and Ordnance (Not for New Design)

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

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

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.

3.1 Tubing

Stainless steel, titanium, and aluminum tubing are generally used for aircraft high and low pressure fluid lines. The primary alloys in use are listed below, as well as other materials and alloys selected for the special applications indicated. Their major physical properties are noted in Table 1.

TABLE 1 - MAJOR PHYSICAL PROPERTIES OF AEROSPACE FLUID POWER SYSTEM TUBING

		F_{TU} ULTIMATE TENSILE STRENGTH (PSI)		F_{TY} YIELD TENSILE STRENGTH AT 0.2% OFFSET (PSI)					
TUBE MATERIAL	CONDITION	ROOM TEMP	450 °F	ROOM TEMP	450 °F	DENSITY (LB/IN^3)	F_{TU} AT ROOM TEMP DENSITY	F_{TU} AT 450 °F DENSITY	ELONGATION IN 2 INCHES MINIMUM %
Ti 6Al-4V	Annealed	130 000	104 000	120 000	86 500	0.160	812 000	650 000	10
Ti 3Al-2.5V	Annealed	85 000	70 000	75 000	56 000	0.162	518 000	432 000	15
Ti 3Al-2.5V	Cold worked	125 000	101 000	105 000	87 000	0.162	773 000	623 000	10
Ti Cml. Pure	Grade 2	50 000	26 000	40 000	16 800	0.163	306 500	159 500	20
304 CRES	1/8 Hard	105 000	84 000	75 000	61 000	0.290	362 000	290 000	20
304 CRES	Annealed	75 000	57 000	30 000	22 000	0.290	259 000	183 000	35
21-6-9 CRES	Cold Worked	142 000	116 000	125 000	83 000	0.290	490 000	400 000	20
AM 350 CRES	Cold Reduced & Tempered	185 000	165 000	140 000	119 000	0.282	656 000	550 000	18 25
6061-T6 AL	Heat Treat & Aged	42 000	10 920	35 000	8390	0.098	428 000	111 000	8
5052-0 AL	Annealed	26 000	13 800	10 000	7000	0.097	268 000	142 000	--

		F_{TU} ULTIMATE TENSILE STRENGTH (MPa)		F_{TY} YIELD TENSILE STRENGTH AT 0.2% OFFSET (MPa)					
TUBE MATERIAL	CONDITION	ROOM TEMP	232 °C	ROOM TEMP	232 °C	DENSITY (g/cm^3)	F_{TU} AT ROOM TEMP DENSITY	F_{TU} AT 232 °C DENSITY	ELONGATION IN 5.1 CM MINIMUM %
Ti 6Al-4V	Annealed	896.3	717.1	827.4	596.4	4.43	5599	4482	10
Ti 3Al-2.5V	Annealed	586.1	482.6	517.1	386.1	4.48	3571	3185	15
Ti 3Al-2.5V	Cold worked	861.8	696.4	723.9	599.8	4.48	5330	4295	10
Ti Cml. Pure	Grade 2	344.7	179.3	275.8	115.8	4.51	2113	1100	20
304 CRES	1/8 Hard	723.9	579.2	517.1	420.6	8.03	2500	1999	20
304 CRES	Annealed	517.1	393.0	206.8	151.7	8.03	1786	1262	35
21-6-9 CRES	Cold Worked	979.1	799.8	861.8	572.3	8.03	3378	2758	20
AM 350 CRES	Cold Reduced & Tempered	1275.5	1137.6	965.3	771.5	7.81	4523	3792	18 25
6061-T6 AL	Heat Treat & Aged	289.6	75.9	241.3	57.8	2.71	2951	765	8
5052-0 AL	Annealed	179.3	95.1	68.9	48.3	2.68	1848	979	--

AIR1564 provides a cross reference between several material specifications.

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

AMS-T-6845 is used on some commercial airplanes, military aircraft and missiles.

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 AMS-T-8506.

3.1.1.3 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.

3.1.1.4 AISI 321 Cold Worked 1/8-Hard Tubing

MIL-T-8808 has been used in systems with permanent welded or brazed connections. Because of its stabilized condition, it retains its corrosion resistance after heating to fusion temperature much better than the AISI 304 alloys.

3.1.1.5 Annealed (16.5Cr - 4.5Ni - 2.9Mo - 0.10N)

This material is a higher strength stainless steel alloy with good strength at elevated temperatures up to 800 °F (427 °C). 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. 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 available in seamless form per AMS5554. Glass bead peening is done per AMS2430.

3.1.1.6 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 has been used on some 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 AMS5561.

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 0.5 in (12.7 mm) because of its susceptibility to damage.

3.1.2.1 6061-T6 (Solution Heat-Treated and Artificially Aged) Tubing

Tubing per AMS-T-7081 is used on commercial and military airplanes.

3.1.3 Titanium Tubing

Because of its very high strength-to-weight ratio, alloyed titanium tubing is used in aircraft hydraulic systems in low and medium temperature environments.

3.1.3.1 Commercially Pure Titanium Tubing

Tubing per ASTM B338, Grade 2 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 (110 316 MPa)) that has led to its 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. This material is controlled by AMS4943.

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. This material is controlled by AMS4944.

3.1.3.4 Annealed 6AL-4V Titanium Alloy Tubing

This material has the highest strength of all titanium tubing alloys for aircraft use.

3.1.4 Tubing Wall Gages

Standard wall gages can be calculated utilizing the method shown in AS4467. Although AS4467 is used for titanium, the method can also be utilized for other materials and coordinated with the tube supplier. ARP4698 provides an initial sizing for steel and titanium. As a minimum, pressure impulse tests, flexure fatigue tests, and burst tests of bent tube specimens are recommended.

3.2 Standard Reconnectable Fittings

Only those fittings which have become government or industry standards for aircraft use are listed here. Installation and torquing information is listed in ARP600 and AS683.

3.2.1 Standard Flared Fittings

There are 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.

3.2.1.1 AS/MS Flared Fitting

The three-piece 37 degree flare-angle assembly, consisting of fitting body, sleeve, and nut is shown in Figure 1. Drawings of AS/MS flared fitting shapes are listed in AIR737. Male and female fitting end designs can also be found in AIR737.

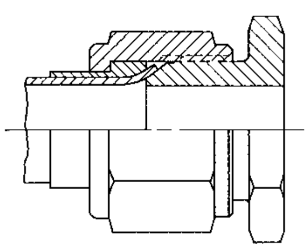


FIGURE 1 - AS/MS FLARED FITTING

3.2.1.2 NASA Marshall Center Flared Fittings

This is a closer tolerance three-piece 37 degree flare-angle assembly of the same design configuration as the AS flared fitting. It is controlled by MSFC-SPEC-143.

3.2.1.3 Standard Ferrule, Braze Flared Fitting

This fitting assembly consists of a ferrule, nut, and body fitting as shown in Figure 2. 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 AS/MS flare assembly. However, no flaring of the tube end is required. The brazing is performed in accordance with ARP573.

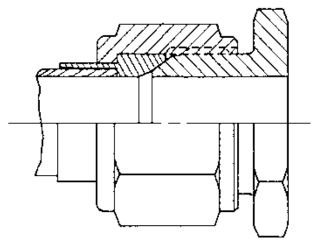


FIGURE 2 - STANDARD FERRULE, BRAZED FLARED FITTING

3.2.1.4 Universal Fittings - Cluster Installation

The Universal Fittings part numbers can be found in AIR737 and 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 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 (20.6 MPa) pressure and temperatures of -65 to 160 °F (-54 to 71 °C).

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 flare less fitting assembly, consisting of fitting body, sleeve, and nut shown in Figure 3, has been in standard use on most commercial jet transport airplanes and on some military aircraft. It is controlled by specification AS18280 and the fitting ends by AS4375/AS5863.

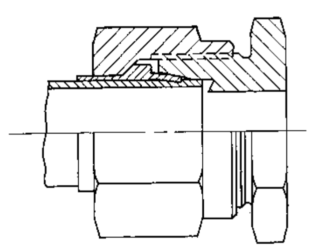


FIGURE 3 - AS FLARELESS FITTING

Drawings of AS/MS flareless fitting shapes are listed in AIR737. Male and female fitting end designs can also be found in AIR737. 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.

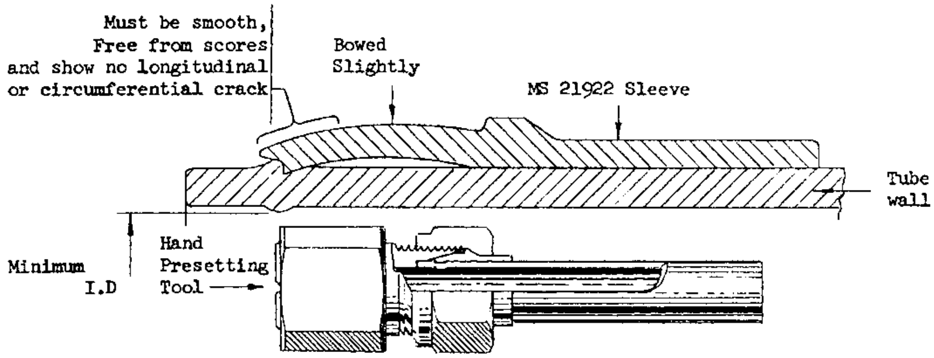
b. Carbon steel alloys: C-1137 or C1141 bar stock and forging, and AISI 4130 and 4140 bar stock and forging with a chromate cadmium finish. It should be noted that cadmium plated fittings should not be used for new applications

c. Stainless steels: AISI304, 316, and 347 bar stock and forgings given a passivation treatment.

d. In addition, individual companies have standardized flareless fittings made of the 6AL-4V alloy of titanium. They are controlled by 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. A 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 0.016 in (0.41 mm). 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 2.

TABLE 2 - SWAGED FLARELESS SLEEVES WITH LIGHTWEIGHT UNION AND NUT



Size	Tube OD Size Nom, (inch)	Wall thickness (inch)	ALUMINUM 6061-T6 AMS-T-7081Min. ID After Presetting	Working Pressure (psi)	Wall thickness (inch)	CRES 1/8-1/4 HARD AMS-T-6845 Min. ID After Presetting	Working Pressure (psi)	Wall thickness (inch)	CRES ANNEALED MIL-T-8504 Min. ID After Presetting	Working Pressure (psi)
2	0.125	0.020	0.060	3000	0.016	0.070	3000	0.020	0.060	3000
3	0.188	0.028	0.095	3000	0.018	0.110	3000	0.020	0.115	3000
4	0.250	0.035	0.150	3000	0.020	0.165	3000	0.028	0.155	3000
5	0.313	0.049	0.180	3000	0.022	0.225	3000	0.028	0.225	3000
6	0.375	0.049	0.240	3000	0.025	0.290	3000	0.035	0.270	3000
8	0.500	0.065	0.330	3000	0.028	0.400	3000	0.049	0.380	3000
10	0.625	0.083	0.420	3000	0.035	0.485	3000	0.058	0.475	3000
12	0.75	0.095	0.530	3000	0.042	0.610	3000	0.065	0.590	3000
16	1.00	0.065	0.830	1500	0.065	0.840	1500	0.083	0.800	1500
20	1.25	0.083	1.050	1500	0.065	1.080	1500	0.065	1.080	1500
24	1.50	0.095	1.280	1500	0.065	1.330	1500	0.065	1.330	1500
32	2.00	0.156	1.650	1500	0.065	1.830	1500	0.095	1.780	1500

Size	Tube OD Size Nom, (mm)	Wall thickness (mm)	ALUMINUM 6061-T6 AMS-T-7081 Min. ID After Presetting	Working Pressure (MPa)	Wall thickness (mm)	CRES 1/8-1/4 HARD AMS-T-6845 Min. ID After Presetting	Working Pressure (MPa)	Wall thickness (mm)	CRES ANNEALED MIL-T-8504 Min. ID After Presetting	Working Pressure (MPa)
2	3.2	0.51	1.52	20.7	0.41	1.78	20.7	0.51	1.52	20.7
3	4.8	0.71	2.41	20.7	0.46	2.79	20.7	0.51	2.92	20.7
4	6.4	0.89	3.81	20.7	0.51	4.19	20.7	0.71	3.94	20.7
5	8.0	1.24	4.57	20.7	0.59	5.72	20.7	0.71	5.72	20.7
6	9.5	1.24	6.10	20.7	0.64	7.37	20.7	0.89	6.86	20.7
8	12.7	1.65	8.38	20.7	0.71	10.16	20.7	1.24	9.65	20.7
10	15.9	2.11	10.67	20.7	0.89	12.32	20.7	1.47	12.07	20.7
12	19.1	2.41	13.46	20.7	1.07	15.49	20.7	1.65	14.99	20.7
16	25.4	1.24	21.08	10.3	1.65	21.34	10.3	2.11	20.32	10.3
20	31.8	2.11	26.67	10.3	1.65	27.43	10.3	1.65	27.43	10.3
24	38.1	2.41	32.51	10.3	1.65	33.78	10.3	1.65	33.78	10.3

32	50.8	3.96	41.01	10.3	1.65	46.48	10.3	1.65	45.21	10.3

NAS1095 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.

3.2.2.1 Swivel Elbow Fitting

This design was developed for commercial jet transport airplanes and has replaced nearly all the bulkhead elbows and banjo fittings formerly used. As shown in Figure 4, 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 AS18280 standard drawings which specify a choice of carbon steel, stainless steels, aluminum, and 6Al-4V titanium: 90 degree elbow reducer; 45 degree elbow reducer; Tee reducer with swivel on run; Tee reducer with swivel on side; and cross reducers.

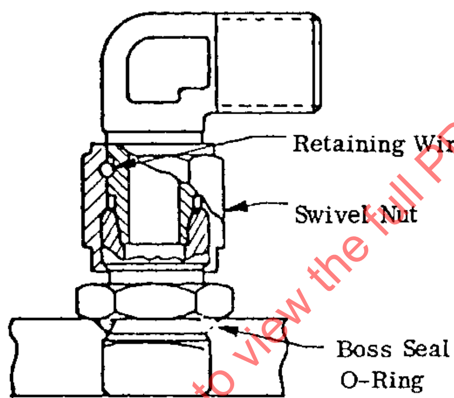


FIGURE 4 - SWIVEL ELBOW FITTING CONNECTED TO STANDARD UNION IN AS5202 BOSS

3.2.2.2 Ring Locked Fluid Port Adapters

AS1985/AS1986/AS4099/AS4383/AS5986 Ring Locked Fluid Port Adapters are threaded into bosses according to AS1958 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 Figure 5. Sealing is metal-to-metal backed up by a standard AS568 Class I O-ring.

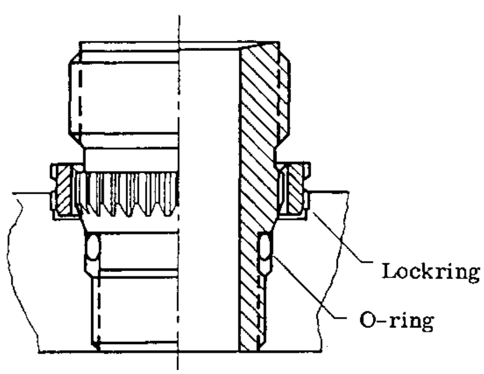


FIGURE 5 - RING LOCKED FLUID ADAPTER

3.2.3 Beamseal Fitting

The fitting assembly is made up of a shoulder (sleeve) and nut which threads onto a male threaded shoulder (connector) as shown in Figure 6.

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 over tightening 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.

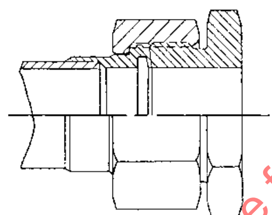


FIGURE 6 - BEAMSEAL FITTING

3.2.4 Threaded Swaged Ferrule Fittings

This is an adaptation of a fuel system line connector to low pressure hydraulic applications. The design shown in Figure 7 illustrates an AS1734 half connector connected to a male adapter. The connection consists of a machined ferrule swaged to the tube, an a-ring and two metal washers on the ferrule, a spacer ring, and coupling nut which is torqued hand tight to the adapter. This can utilize either the standard AS1732 swage or specialty fitting shown in Figure 17.

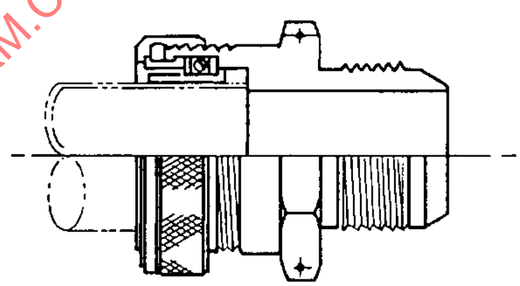


FIGURE 7 - AS1731 STYLE SUCTION LINE FITTING

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

They deviate from the standard in the following major respects:

a. Fitting cone and finish

Proprietary finish: 32 µin (0.81 µm) RHR (same as AS4395 and AS4396); AS finish: 100 µin (2.54 µm) RHR max.

b. Hex sealing face side

Proprietary finish in area of seal: 32 µin RHR, remaining surfaces

100 µin (2.54 µm) RHR (same as AS4395 and AS4396); AS4395: total surface 100 µin (2.54 µm) RHR

c. Perpendicularity of hex sealing face to thread axis

AS4395: 0.005 in (0.127 mm) TIR up to -10 size, 0.008 in (0.203 mm) TIR for -12 to -48 sizes

3.3.1.2 Flared Conical Seal

Voi-Shan flared conical seal is used with the three-piece 37 degree flare angle assembly as shown in Figure 8, installed between the inside diameter of the flared tube and the conical face of either male fitting AS4395 or AS4396. 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, the installation of this seal is used to stop the leakage and prevent replacement of the fitting or tube assembly.

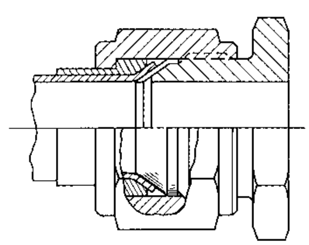


FIGURE 8 - FLARED CONICAL SEAL

3.3.2 Nonstandard Flareless Fittings

3.3.2.1 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. Figure 9 shows the relative size of the standard and miniaturized configurations. The fittings are made from titanium. Either the AS21922 flareless steel sleeve or a standard sleeve may be used with the miniaturized fittings.

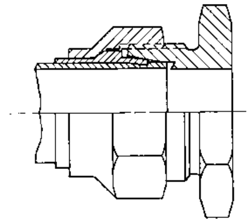


FIGURE 9 - MINIATURIZED FLARELESS FITTING

3.3.2.2 Brazed-on Flareless Sleeves

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.

This design is similar to the standard MS flareless connection and couples to the AS33514 male fitting end standard. See Figure 10.

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.

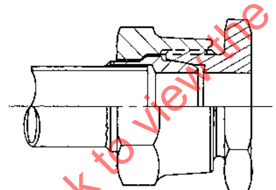


FIGURE 10 - BRAZED-ON SLEEVE FLARELESS FITTING

3.3.3 Mil-Flo Miniflare Fitting

This fitting is shown in Figure 11. 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.

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.

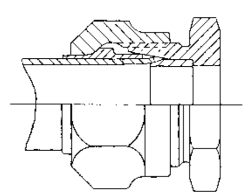


FIGURE 11 - MIL-FLO MINIATURE FITTING

3.3.4 Lo-Torque Fitting

This reconnectable tube assembly consists of three pieces: adapter, sleeve, and nut shown in Figure 12. 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 AS21902 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.

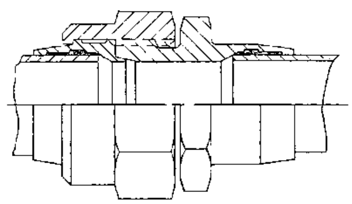


FIGURE 12 - LO-TORQUE FITTING

3.3.5 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 13, this fitting has a smaller drop dimension, and permits closer boss spacing since it eliminates the swing clearance required for the AS1038 and AS1040 elbows. They are manufactured in both stainless steel and aluminum in sizes -8 through -24, for operating pressures to 3000 psi (20.7 MPa) and temperature of -65 to +450 °F (-54 to 232 °C) depending on boss seal design and material.

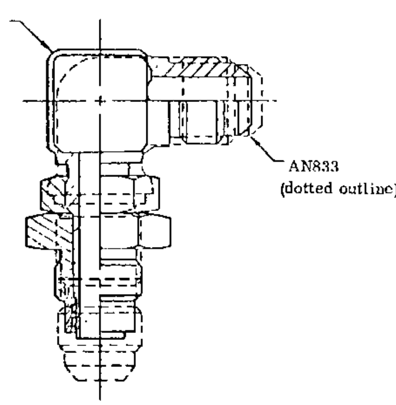


FIGURE 13 - UNIVERSAL BOSS FITTING AND AN FITTING COMPARISON

3.3.6 Metal-Seal Tube-to-Component Fittings

This fitting as shown in Figure 14, consists of a union or reducer with a standard flared end per AS4395 or a standard flareless end per AS33514 on one end and a simple straight-threaded end on the other but with a metal lip seal machined under the torquing hex. Titanium fittings are used with steel and aluminum bosses and all steel hydraulic lines except oxygen. All bosses are per AS5202.

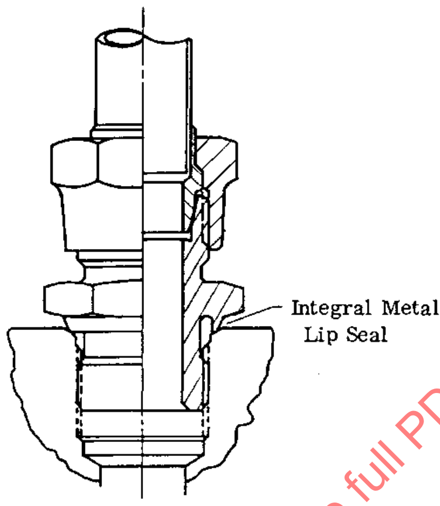


FIGURE 14 - METAL SEAL TUBE-TO-COMPONENT FITTING

3.3.7 Recessed Boss Seal Fittings

The boss end has a groove for a standard diametral-seal a-ring and backup ring, and a boss seal a-ring is used under the hex to keep moisture out of the threads.

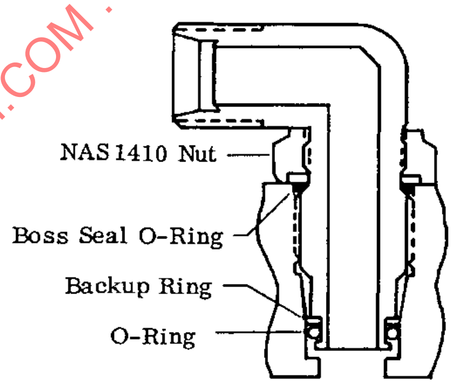


FIGURE 15 - 90 DEGREE ADAPTER FITTING INSTALLED IN RECESSED SEAL BOSS

3.3.8 Miniature End Fitting

(See Figure 16). It is a flareless style tube end connector used to terminate hydraulic lines. The sleeve is installed over a tube by swaging with a special tool which creates a metal to metal seal (no elastomer). It is interchangeable with AS21922 and NAS1760 fittings. It may be used with AS21921 or AS1792 nuts. The sleeve is compatible with all types of aerospace tubing (aluminum, stainless steel, titanium). Swaging can permanently couple a wet or a dry line in-place and the power source is universally available.

The swaging tool may be powered from:

1. a hydraulic hand pump or service cart;

2 shop air hose, through a self-contained hydraulic booster;

3. battery operated hydraulic pump;

4. electrically operated hydraulic pump.

Verification of joint integrity is by visually checking the fitting outside diameter and tube stick out dimension with a comprehensive "GO" - "NO-GO" inspection gage.

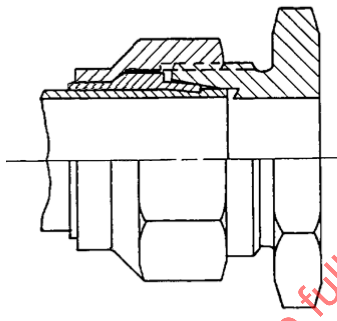


FIGURE 16 - MINIATURE END FITTING

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. A 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 except at removable components and structural production breakpoints. Four major types have been seriously considered which are 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 Induction Brazed Joint

The 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 17. 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 union is made from stainless steel AM-355 bar stock and passivated.

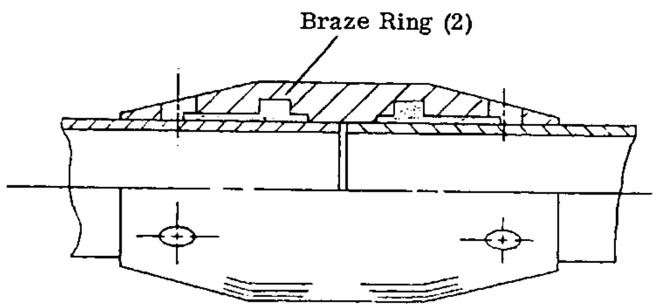


FIGURE 17 - INDUCTION BRAZED JOINT

3.4.1.2 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 19 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 alloys 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.

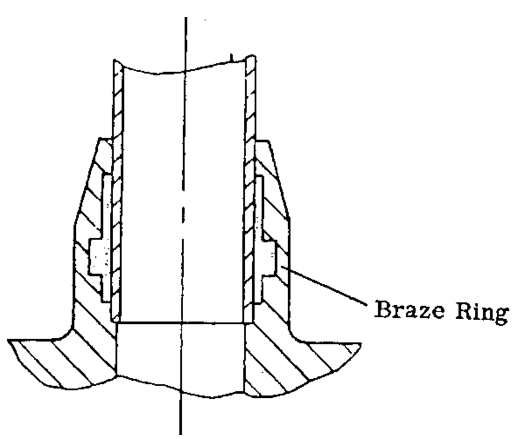


FIGURE 18 - FURNACE-BRAZED JOINT

3.4.1.3 Space-Craft Brazed Joint

The induction brazed joint consists of a close tolerance tubular union (sleeve) with two formed ring cavities, containing the preformed braze alloy rings, see Figure 19. 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 AS/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.

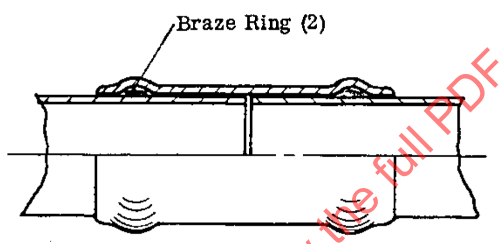


FIGURE 19 - SPACECRAFT BRAZED JOINT

3.4.1.4 Brazed Tube Fittings

These brazed fittings were designed 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 20.

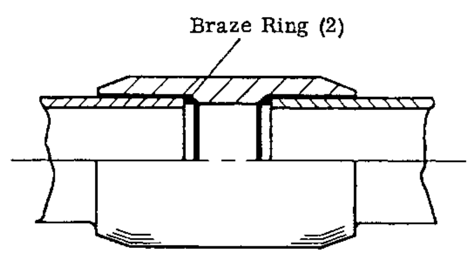


FIGURE 20 - BRAZED TUBE FITTING

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 0.188 in (4.8 mm) OD through 1.25 in (31.8 mm) OD. 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 (20.68 MPa) pressure lines range through the 1.00 in (25.4 mm) OD size, and return lines range through the 1.25 in (31.8 mm) OD sizes.

Fitting types can be provided which directly replace detachable flared or flareless connections and meet all the applicable requirements of AS18280.

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 are shown in Figures 21 thru Figure 27.

3.4.2.1 Square Butt Weld Joint

The square butt weld (Figure 21), 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 fit-up, 100% weld penetration is more certain 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.

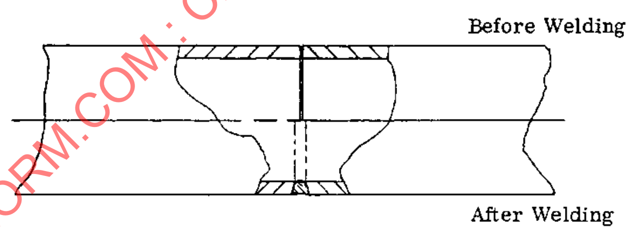


FIGURE 21 - SQUARE-BUTT WELDED JOINT

3.4.2.2 Flare-Bevel Butt Weld Joint

A flare-bevel butt joint (Figure 22), 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.

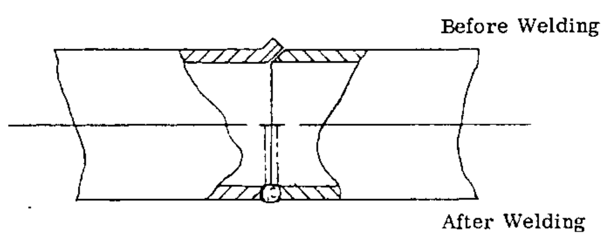


FIGURE 22 - FLARE-BEVEL BUTT-WELD JOINT

3.4.2.3 Butt Weld with Insert

The butt weld with insert (Figure 23), 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.

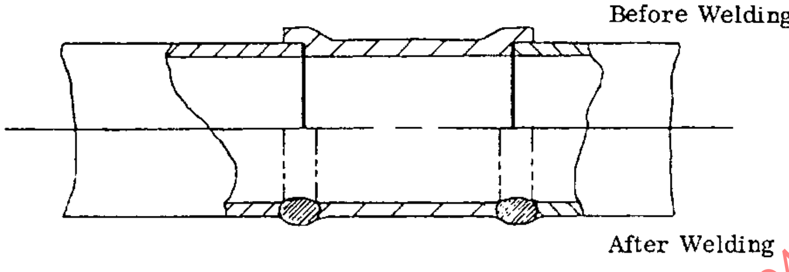


FIGURE 23 - BUTT WELD WITH INSERT

3.4.2.4 Bellmouth Welded Joint

This is a bellmouth welded joint (Figure 24), wherein one end of the tube is expanded sufficiently to accept the unexpanded end of the mating tube, which can be used with AM-350 tubing..

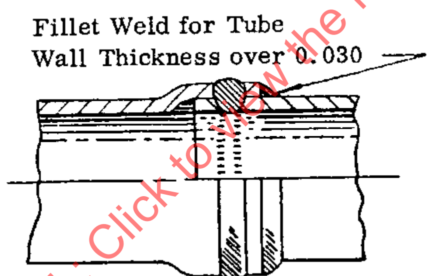


FIGURE 24 - BELLMOUTH WELDED JOINT

3.4.2.5 Double Melt Through Welded Joint

This joint (Figure 25), is used in locations wherein it is impossible to insert a tube into a bellmouth joint.

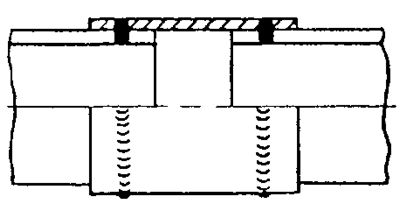


FIGURE 25 - DOUBLE MELT THROUGH WELD JOINT

3.4.2.6 Swaged Sleeve Weld Joint

This joint (Figure 26) 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.

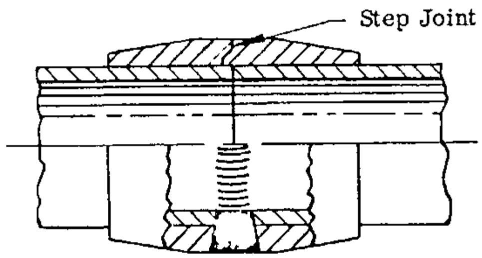


FIGURE 26 - SWAGED-SLEEVE WELD JOINT

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 27).

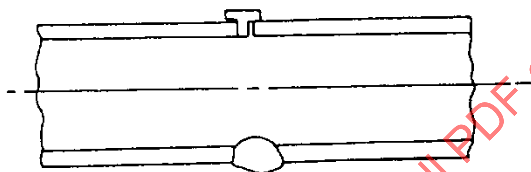


FIGURE 27 - BUTT-WELD T-RING

3.4.3 Swaged Joints

Four swaged type permanent joints developed for aircraft use are worthy of note.

3.4.3.1 Externally Swaged Fitting

The AS4459 external radial swaging method provides a permanent joint which is unencumbered by the cleanliness and quality control constraints of the other joining methods (Figure 30). 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, or (3) battery operated hydraulic pump, or (4) electrically operated hydraulic pump. Verification of joint integrity is by visually checking the tube insertion marks and gauging the swaged union OD with a "GO" - "NO-GO" inspection gage.

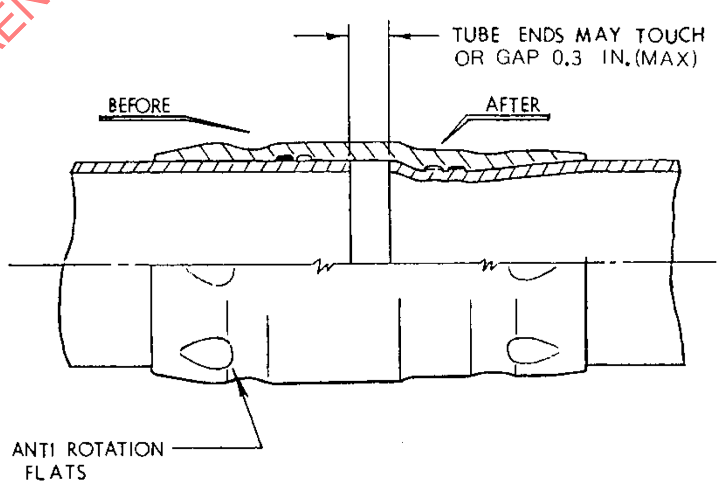


FIGURE 30 - AS4459 EXTERNAL SWAGE FITTING

Two styles of run-unions are used:

a. dual swaged unions;

b. brazed to swaged unions.

The former is shown in Figure 32. 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 to 1-1/2 in (12.7 to 38.1 mm) 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. A multitude of additional Permaswage swaged configurations are also available ranging from elbows, tees, bulkhead connectors, separable connectors (flared, flareless, beam-seal) in both inch and metric sizes.

The swaged run-unions accommodate line sizes for 0.188 in OD through 1.50 in OD (4.8 mm OD through 38.1 mm OD) tubing. Unions are CRES 21-6-9, CRES 316L, Commercially Pure Titanium, or Aluminum 6061-T6. Tube float tolerance allows adjacent lines to touch or gap up to 0.300 in (7.6 mm) when swaged fittings are employed.

3.4.3.2 Heat Shrinkable Fluid Couplings

This fitting (Figure 31) 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.

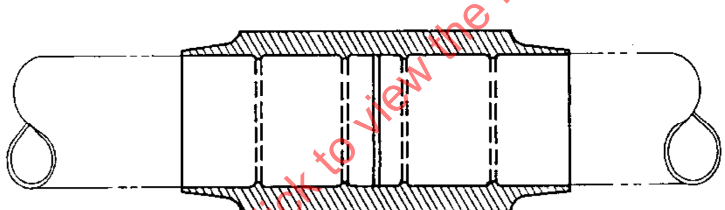


FIGURE 31 - HEAT SHRINKABLE FLUID COUPLING

3.4.3.3 Axially Swage Fitting

The AS5959 fitting (Figure 32) is an axially swage permanent fitting that is installed utilizing a tool that facilitates the axial movement of the swage ring to provide the swage force needed to compress the fitting and tube. This system can be installed with only 180 degree access during swaging, which allows for tight tube clusters and reduced installation time when compared to other swaging processes. Swaging can permanently couple a wet or a dry line in-place and the power source is universally available. The axial 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, (3) battery operated hydraulic pump, or (4) electrically operated hydraulic pump. Verification of joint integrity is by visually checking the tube insertion marks and gauging the swaged union OD with a "GO" - "NO-GO" inspection gage.

Axial swaging imparts the least amount of tube growth and tube preload. Tube float tolerance allows adjacent lines to touch or gap up to 0.300 in (7.6 mm) when swaged fittings are employed.

Fittings are available in aluminum, stainless steel, and titanium from sizes -03 through -24 for pressures up to 5080 psi (35.0 MPa).

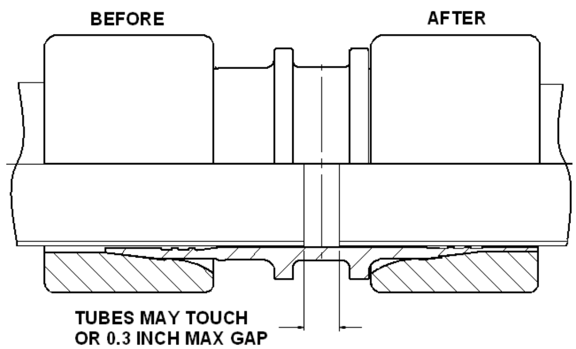


FIGURE 32 - AXIALLY SWAGE FITTING

3.4.3.4 Internally Swaged Flareless Sleeve and Lightweight Fittings:

This swaged-on sleeve and a swaged-on lightweight union and nut are shown in Figure 33. These are controlled by specifications AS5529 and AS5530.

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 AS 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 AS sleeve, greatly reducing the tendency for rotation, loosening, or failure due to over-torquing.

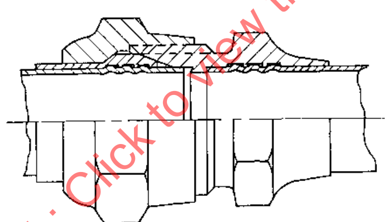


FIGURE 33 - INTERNALLY SWAGED FLARELESS SLEEVE WITH LIGHTWEIGHT UNION AND NUT

3.5 Self-Sealing Disconnect Coupling

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. AS1709 or AS25427 covers the detail requirements for the standard couplings, for use in Type I and Type II hydraulic systems. The design configurations are controlled by AS24333, AS24334 and AS24335. The couplings may be made from any material that is compatible with the tubing material and system requirement for the specific application.

AIR1047 is a 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 Housing Fluid Fitting Bosses

3.6.1 Bosses per AS5202

Bosses per AS5202 have been successfully used for many years in conjunction with screw in adaptors per AS21902.

Care should be taken when using this application at pressures greater than 3000 psi (20.6 MPa) due to potential problems occurring with the extrusion of the seal between the adaptor and the boss.

Table 3 provides recommended torques when installing adaptors into the bosses

TABLE 3 - INSTALLATION TORQUE FOR BOSS FITTINGS

FITTING SIZE DASH NO.	TUBING OD INCH	TUBING OD mm	WRENCH TORQUE: FOR STEEL OR TITANIUM (LB-IN)	FOR ALUMINUM FITTINGS (IN-LB ±5%)	WRENCH TORQUE: FOR STEEL OR TITANIUM (Nm)	FOR ALUMINUM FITTINGS (Nm ±5%)
-4	0.250	6.4	140	110	15.8	12.4
-5	0.313	8.0	190	140	21.5	15.8
-6	0.375	9.5	270	170	30.5	19.2
-8	0.500	12.7	500	280	56.5	31.6
-10	0.625	15.9	700	360	79.1	40.7
-12	0.750	19.1	900	450	101.7	50.8
-16	1.00	25.4	1200	750	135.6	84.7
-20	1.25	31.8	1600	900	180.8	101.7
-24	1.50	38.1	2000	900	226.0	101.7

3.6.2 Recessed Boss

This design, for use with the diametral-sealed fitting is shown in Figure 15. 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 [6.4 to 7.9 mm] 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.

3.6.3 SAE AS685 Boss

This is a bolted-flange piloted-seal boss for use on propulsion system components. See AS686 for mating parts.

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.

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 ft/s (4.6 m/s). Table 5 indicates the average rate of flow for tube size between 0.25 in (6.4 mm) and 1.50 in (38.1 mm) OD, based on a maximum wall thickness of standard aluminum-alloy tube, for laminar flow.

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 ft/s (4.6 m/s), 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 - MAXIMUM LAMINAR FLOW FOR NOMINAL TUBE SIZES

Tube Dash No.	Tube OD (INCHES)	Flow – Gallons per Minute	Tube OD (mm)	Flow Liters per Minute
-3	0.188	0.5	4.8	1.9
-4	0.250	1.2	6.4	4.5
-5	0.313	2.3	8.0	8.7
-6	0.375	3.5	9.5	13.2
-8	0.500	6.0	12.7	22.7
-10	0.625	10.5	15.9	39.4
-12	0.750	16.0	19.1	60.6
-16	1.000	29.0	25.4	109.8
-20	1.250	45.0	31.8	170.3
-24	1.500	70.0	38.1	265.0

4.1.1.1 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.

4.1.1.2 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."

A number of high-flow systems have been designed with lines resulting in fluid velocities of 25 to 30 ft/s (7.6 to 9.1 m/s) 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 [6.9 MPa in a 20.7 MPa] 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:

$$\text{Pressure rise } \Delta P = V\sqrt{B \, x \, \frac{w}{g}} \text{ psi} \qquad \text{(Eq. 1)}$$

where:

V = Original fluid velocity inch/sec (mm/s)

B = Fluid bulk modulus psi (MPa)

w = Fluid density lb/in^3 (g/cm^3)

g = 386 in/s^2 (9.81 m/s^2)

For MIL-PRF-5606 fluid at 100 °F (38 °C), with the following physical characteristics:

B = 270 000 psi (1861.6 MPa) with all entrained gas removed

= 200 000 psi (1388.0 MPa) in a typical system

w = 0.845 specific gravity = 0.0305 lb/in^3 (844.2 kg/m^3)

Δ P = 4.0V psi pressure rise

Therefore, for flow velocities above 262 in/s (6.54 m/s), valve closing times must be limited to values greater than 2l/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.

For MIL-PRF-5606 at 100 °F (37.8 °C) and 3000 psi (20.7 MPa)

$$C = \sqrt{\frac{200\,000}{.0305/386}} = 50\,000 \text{ in/s} \quad \text{(Eq. 2)}$$

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

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

$$T = \frac{\Delta P}{\Delta P_a} \times Tr \quad \text{(Eq. 3)}$$

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

= ℓ/C

4.2 Minimum Full-Performance Design Temperatures

One of the primary considerations in designing tubing is 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

4.2.1.1 Pump Suction Lines

4.2.1.1.1 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 (-29 °C), 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 ft (3048 m) 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.

4.2.1.1.2 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 (-54 °C), the above conditions of suction-line pressure drop shall not apply until stabilized fluid operating temperatures have been obtained.

4.2.1.2 Landing Gear Retraction System

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	AND	THEN	AND	AND
	The Landing Gear System is	The Temperature is	The maximum allowable time to extend and lock the gear is [1]	The maximum allowable time to retract and lock gear is [2]	
1	Power Operated	Above -20 °F (-29 °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 °F (-54 °C) to -20 °F (-29 °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 1 s 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 (-54 and -29 °C) to be up to "twice the fastest time obtained at normal temperatures (approximately +70 °F [+ 21 °C])."

4.2.1.3 Flight Control Systems

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 (-54 °C), does not exceed 150% 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

AFSC DH2-1 specifies that, between -65 and -20 °F (-54 to -29 °C), 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 warm-up of the components.

4.2.2 Minimum Operating Temperatures for Sizing Lines for Commercial Transport Airplanes

The commercial aircraft airworthiness 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:

a. Ambient temperature range in flight: -110 to +130 °F (-78 to 54 °C)

b. Minimum cold start capability (ambient and fluid): -65 °F (-54 °C)

c. Minimum fluid temperature for rated pump suction flow: -20 °F (-29 °C)

d. Minimum fluid temperature for full system performance: +50 °F (10 °C)

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 0.375 in (9.5 mm) 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 0.500 in (12.7 mm) and larger. If there is vital need to reduce weight, 0.375 in (9.5 mm) aluminum lines can be considered but only in areas not normally accessible to damage by service or other personnel.

j. Avoid long lines unless recommended support spacing is possible.

k. Limit minimum tube wall thickness to 0.020 in (0.51 mm) in any material.

l. Use CRES lines in areas exposed to flying debris, i.e., wheel wells.

5.1.2 Drain and 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. The use of three-dimensional mock-ups are permissible provided adequate structure is represented so as to facilitate proper runs. See AIR5992 and Section 14 for more detail.

5.1.4 Inspection Tools for Formed Tubes

High-strength tubing of relatively thin wall tends to make tube inspection for end to end fitting alignment and accuracy of clamping position a requirement rather than just good practice. Design for precise fit-up and alignment to preclude the need for rework to complete the installation. Permanent in-place joining, either by brazing or welding, requires fit-up accuracies at least as stringent as reconnectable fittings. The use of 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.

a. Type I: -65 to +160 °F (-54 to 71 °C) temperature range

b. Type II: -65 to +275 °F (-54 to 135 °C) temperature range

c. Type III: -65 to +450 °F (-54 to 232 °C) temperature range

All hydraulic systems are required to cold start and operate after cold soak and stabilization on the ground at -65 °F (-54 °C) 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 (-54 °C), 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 -65 to +130 °F (-54 to +54 °C) with -40 °F (-40 °C) the minimum temperature required for operational qualification. The maximum system design temperature for commercial aircraft is limited by the hydraulic fluid and seal material. The phosphate ester based fluids are controlled by AS1241. Maximum recommended operating temperature is 170 °F (77 °C) with excursions to 225 °F (107 °C). The +225 °F (107 °C) temperature is defined as the overheat warning temperature for the system.

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 6. 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 - MAXIMUM LONG TERM OPERATING TEMPERATURES - HYDRAULIC SYSTEM MATERIALS

Temperature							
175 °F (79 °C)	200 °F (93 °C)	225 °F (107 °C)	250 °F (121 °C)	275 °F (135 °C)	350 °F (177 °C)	400 °F (204 °C)	500 °F (260 °C)
Nylon	Alum Alloy 70-Series		AS1241 Type IV and Type V fluids		Viton	Teflon	
			Aluminum alloy 20 series				

5.1.6 Fire Prevention Considerations

See ARP4752 and ARP4925 for the commercial aircraft/helicopter fire resistance requirements

5.1.7 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.

5.1.7.1 Fitting Location

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

5.1.7.2 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.

5.1.7.3 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.

5.1.7.4 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.

5.1.7.5 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.

5.1.7.6 Ground Test Provisions

The following precautions should 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

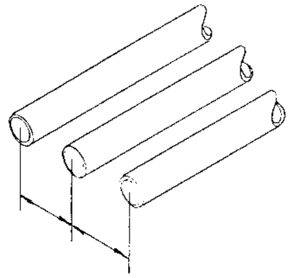
The clearances and spacings noted below are the absolute minimums recommended and should not be decreased.

5.2.1 Multiple Line Spacing

Minimum recommended clearances between tubes within the same system are dependent upon the spacing required to accommodate 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 Figure 34 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.

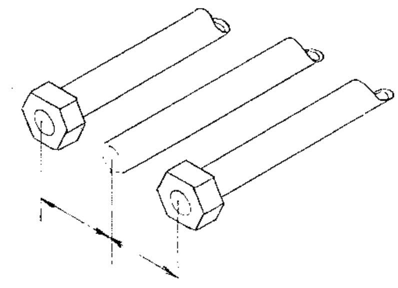


MINIMUM LINE SPACING (NO FITTINGS) (Inches)												
TUBE SIZE		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24	-32
	TUBE OD (Inch)	0.188	0.25	0.313	0.375	0.50	0.625	0.75	1.00	1.25	1.50	2.00
-3	0.188	0.43	0.47	0.50	0.53	0.59	0.66	0.72	0.84	0.97	1.09	1.34
-4	0.25		0.50	0.53	0.56	0.62	0.69	0.75	0.88	1.00	1.12	1.38
-5	0.313			0.56	0.59	0.66	0.72	0.78	0.91	1.03	1.16	1.41
-6	0.375				0.62	0.69	0.75	0.81	0.94	1.06	1.19	1.44
-8	0.50					0.75	0.81	0.88	1.00	1.12	1.25	1.50
-10	0.625						0.88	0.94	1.06	1.19	1.31	1.56
-12	0.75							1.00	1.12	1.25	1.38	1.62
-16	1.00								1.25	1.38	1.50	1.75
-20	1.25									1.50	1.62	1.88
-24	1.50										1.75	2.00
-32	2.00											2.25

MINIMUM LINE SPACING (NO FITTINGS) (mm)												
TUBE SIZE		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24	-32
	TUBE OD (mm)	4.8	6.4	8.0	9.5	12.7	15.9	19.1	25.4	31.8	38.1	50.8
-3	4.8	10.9	11.9	12.7	13.5	15.0	16.8	18.3	21.3	24.6	27.7	34.0
-4	6.4		12.7	13.5	14.2	15.8	17.5	19.1	22.4	25.4	28.5	35.1
-5	8.0			14.2	15.0	16.8	18.3	19.8	23.1	26.2	29.5	35.8
-6	9.5				15.8	17.5	19.1	20.6	23.9	26.9	30.2	36.6
-8	12.7					19.1	20.6	22.4	25.4	28.5	29.2	38.1
-10	15.9						22.4	23.9	26.9	30.2	33.3	39.6
-12	19.1							25.4	28.5	31.8	35.1	41.1
-16	25.4								31.8	35.1	38.1	44.5
-20	31.8									38.1	44.5	47.8
-24	38.1										44.5	50.8
-32	50.8											57.2

FIGURE 34 - MINIMUM LINE SPACING NOT REQUIRING WRENCH CLEARANCE

Minimum center-to-center line spacing, shown in Figure 35, provides wrench clearance when alternate lines are equipped with fittings in the same plane, or adjacent lines are equipped with fittings in different planes.

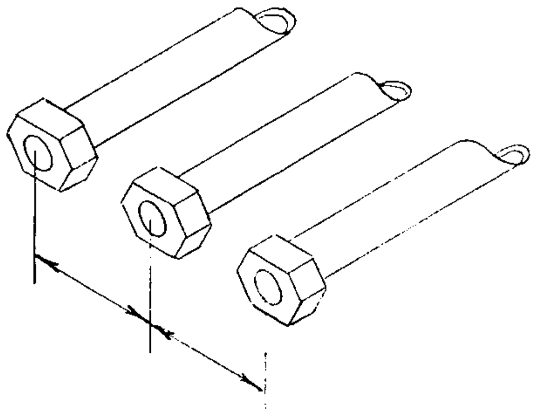


MINIMUM LINE SPACING (STAGGERED FITTINGS) (INCHES)													
TUBE SIZE		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24	-28	32
	TUBE OD (inch)	0.188	0.25	0.313	0.375	0.50	0.625	0.75	1.00	1.25	1.50	1.75	2.00
-3	0.188	0.85	0.85	0.90	0.95	1.10	1.15	1.35	1.60	1.80	2.05	2.45	2.65
-4	0.25		0.90	0.95	1.00	1.10	1.20	1.40	1.65	1.85	2.05	2.45	2.70
-5	0.313			0.95	1.00	1.15	1.20	1.45	1.65	1.85	2.10	2.50	2.70
-6	0.375				1.05	1.20	1.25	1.45	1.70	1.90	2.15	2.55	2.75
-8	0.50					1.25	1.30	1.55	1.75	1.95	2.20	2.60	2.80
-10	0.625						1.35	1.60	1.80	2.00	2.25	2.65	2.85
-12	0.75							1.65	1.90	2.10	2.30	2.70	2.95
-16	1.00								2.00	2.20	2.45	2.85	3.05
-20	1.25									2.35	2.55	3.00	3.20
-24	1.50										2.70	3.10	3.30
-28	1.75											3.25	3.45
-32	2.00												3.55

MINIMUM LINE SPACING (STAGGERED FITTINGS) (mm)													
TUBE SIZE		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24	-28	32
	TUBE OD (mm)	4.8	6.4	8.0	9.5	12.7	15.9	19.1	25.4	31.8	38.1	44.5	50.8
-3	4.8	21.6	21.6	22.9	24.1	27.9	29.2	34.3	40.6	45.7	52.1	62.2	67.3
-4	6.4		22.9	24.1	25.4	27.9	30.5	35.6	41.9	47.0	52.1	62.2	68.6
-5	8.0			24.1	25.4	29.2	30.5	36.8	41.9	47.0	53.3	63.3	68.6
-6	9.5				26.7	30.5	31.8	36.8	43.2	48.3	54.6	64.8	69.9
-8	12.7					31.8	33.0	39.4	44.5	49.5	55.9	66.0	71.1
-10	15.9						34.3	40.6	45.7	50.8	57.2	67.3	72.4
-12	19.1							41.9	48.3	53.3	62.2	68.6	74.9
-16	25.4								50.8	55.9	62.2	72.4	77.5
-20	31.8									59.7	64.8	76.2	81.3
-24	38.1										68.6	78.7	83.8
-28	44.5											82.6	87.6
-32	50.8												90.2

FIGURE 35 - WRENCH CLEARANCE FOR STAGGERED FITTINGS

Minimum center-to-center line spacing, shown in Figure 36, provides wrench clearance at bulkheads or where adjacent lines are equipped with fittings in the same plane.



MINIMUM LINE SPACING (ADJACENT FITTINGS) (INCHES)											
Tube size		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24
	TUBE OD (inch)	0.188	0.25	0.313	0.375	0.50	0.625	0.75	1.00	1.25	1.50
-3	0.188	0.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
-4	0.25	0.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
-5	0.313	0.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
-6	0.375	0.90	1.00	1.00	1.10	1.20	1.30	1.45	1.60	1.90	2.20
-8	0.50	1.00	1.05	1.10	1.15	1.25	1.35	1.50	1.60	1.90	2.20
-10	0.625	1.05	1.15	1.20	1.25	1.35	1.40	1.55	1.70	2.00	2.30
-12	0.75	1.25	1.35	1.40	1.45	1.55	1.60	1.75	1.90	2.20	2.45
-16	1.00	1.40	1.45	1.50	1.55	1.65	1.70	1.85	2.00	2.30	2.60
-20	1.25	1.75	1.80	1.85	1.90	2.00	2.05	2.20	2.35	2.65	2.95
24	1.50	1.90	2.00	2.05	2.05	2.20	2.25	2.35	2.55	2.85	3.10

MINIMUM LINE SPACING (ADJACENT FITTINGS) (mm)											
Tube size		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24
	TUBE OD (mm)	4.8	6.4	8.0	9.5	12.7	15.9	19.1	25.4	31.8	38.1
-3	4.8	22.9	25.4	25.4	27.9	30.5	33.0	36.8	40.6	48.3	55.9
-4	6.4	22.9	25.4	25.4	27.9	30.5	33.0	36.8	40.6	48.3	55.9
-5	8.0	22.9	25.4	25.4	27.9	30.5	33.0	36.8	40.6	48.3	55.9
-6	9.5	22.9	25.4	25.4	27.9	30.5	33.0	36.8	40.6	48.3	55.9
-8	12.7	25.4	26.7	27.9	29.2	31.8	34.3	39.4	40.6	48.3	55.9
-10	15.9	26.7	29.2	30.5	34.3	39.4	35.6	39.4	43.2	50.8	58.4
-12	19.1	31.8	34.3	35.6	36.8	39.4	40.6	44.5	48.3	55.9	62.2
-16	25.4	35.6	36.8	38.1	39.4	41.9	43.2	47.0	50.8	58.4	66.0
-20	31.8	44.5	45.7	47.0	48.3	50.8	52.1	55.9	59.7	67.3	74.9
-24	38.1	48.3	50.8	52.1	52.1	55.9	57.2	59.7	64.8	72.4	78.7

FIGURE 36 - WRENCH CLEARANCE FOR ADJACENT FITTINGS

5.2.1.2 Tool Clearances

When designing hydraulic system line installations, the fitting manufacturer should be consulted for the appropriate tool clearances for installation with respect to adjacent lines, fittings, or structure

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 (6.4 mm) in the vicinity of clamps, and 0.13 in (3.3 mm) at the clamping point. Where relative motion may exist between adjoining members, allow a minimum clearance of 0.25 in (6.4 mm) 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 (6.4 mm) 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 0.50 in (12.7 mm). 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 in (25.4 mm). A minimum of 0.5 in (12.7 mm) clearance is acceptable adjacent to cable pulleys and 2.0 in (50.8 mm) clearance is preferable at cable mid-span. Allow 2.0 in (50.8 mm) minimum between parallel oxygen lines and hydraulic lines, and locate all fittings and joints at least 2.0 in (50.8 mm) away from a point of crossing. Provide a minimum of 2.0 in (50.8 mm) 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 in (6.4 mm).

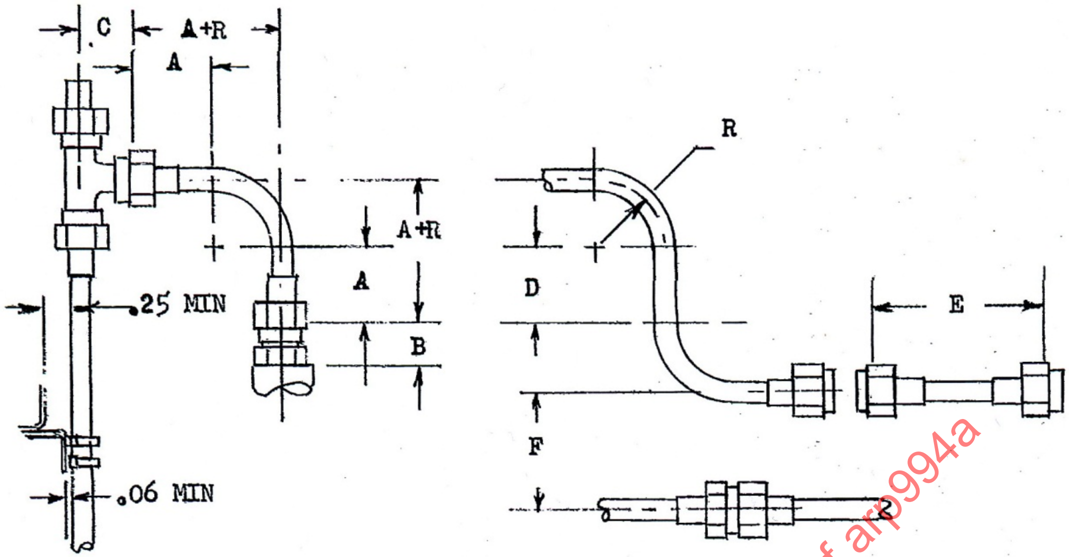
5.3 Bends

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 AS33611; new aircraft designs should use the minimum of 3D bends where possible.

5.3.2 Bend Location

The minimum allowable spacing for a bend from a fitting or permanent joint depends on the clearance required by the assembly tools and is provided in Figures 37 and 38:



TUBE SIZE	TUBE OD (INCH)	R[2]	DIMENSIONS [1] (INCHES)						
			A		B	C	D MIN	E MIN	F
			Minimum	Recommended					
-4	0.250	0.75	0.95	1.30	0.48	0.62	1.00	1.50	1.25
-5	0.313	0.94	0.95	1.35	0.51	0.66	1.00	1.50	1.25
-6	0.375	1.12	0.95	1.40	0.54	0.71	1.00	1.50	1.25
-8	0.500	1.50	1.05	1.45	0.60	0.83	1.00	1.64	1.50
-10	0.625	1.88	1.05	1.50	0.68	0.96	1.30	1.66	1.75
-12	0.750	2.25	1.05	1.60	0.79	1.06	1.50	1.66	2.00
-16	1.00	3.00	1.55	2.30	0.85	1.25	3.00	2.68	2.50
-20	1.25	3.75	1.55	2.30	0.90	1.39	3.80	2.68	3.00

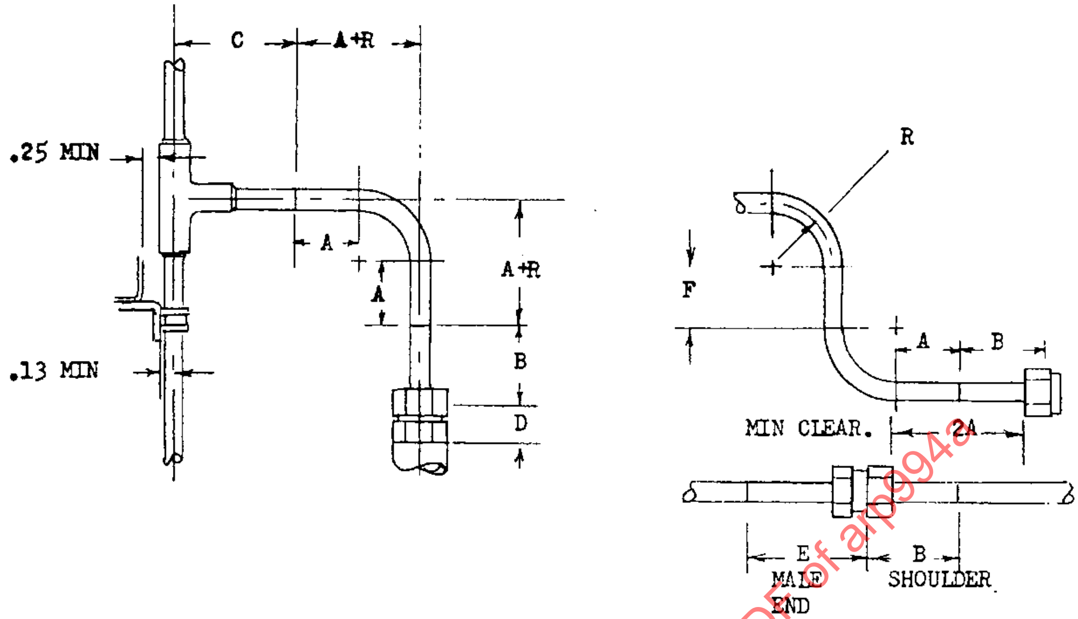
TUBE SIZE	TUBE OD (mm)	R[2]	DIMENSIONS [1] (mm)						
			A		B	C	D MIN	E MIN	F
			Minimum	Recommended					
-4	6.4	19.1	24.1	33.0	12.2	15.7	25.4	38.1	31.8
-5	8.0	23.9	24.1	34.3	13.0	16.8	25.4	38.1	31.8
-6	9.5	28.5	24.1	35.6	13.7	18.0	25.4	38.1	31.8
-8	12.7	38.1	26.7	36.8	15.2	21.1	25.4	41.7	38.1
-10	15.9	47.8	26.7	38.1	17.3	24.4	33.0	42.2	44.5
-12	19.1	57.2	26.7	40.6	20.1	26.9	38.1	42.2	50.8
-16	25.4	76.2	39.4	58.4	21.6	31.8	76.2	68.1	63.5
-20	31.8	95.3	39.4	58.4	22.9	35.3	96.5	68.1	76.2

NOTES:

1. Typical for swaged Beam Seal fittings

2. Bend radii three times tube size

FIGURE 37 - MINIMUM BEND SPACING – RECONNECTABLE FITTINGS



TUBE SIZE	TUBE OD (INCH)	R(1)	DIMENSIONS (INCHES)						
			A		B	C	D	E	F MIN
			Minimum	Recommended					
-4	0.250	0.75	1.44	2.00	1.34	1.31	0.48	1.56	1.00
-5	0.313	0.94	1.44	2.00	1.34	1.34	0.51	1.59	1.00
-6	0.375	1.12	1.44	2.00	1.38	1.38	0.54	1.62	1.00
-8	0.500	1.50	1.44	2.00	1.38	1.43	0.60	1.68	1.00
-10	0.625	1.88	1.44	2.00	1.38	1.50	0.67	1.76	1.30
-12	0.750	2.25	1.44	2.00	1.39	1.56	0.72	1.79	1.50
-16	1.00	3.00	1.44	2.00	1.44	1.69	0.84	1.85	3.00
-20	1.25	3.75	1.44	2.00	1.44	1.81	0.87	1.91	3.80

TUBE SIZE	TUBE OD (mm)	R(1)	DIMENSIONS (mm)						
			A		B	C	D	E	F MIN
			Minimum	Recommended					
-4	6.4	19.1	36.6	50.8	34.0	33.3	12.2	39.6	25.4
-5	8.0	23.9	36.6	50.8	34.0	34.0	13.0	40.4	25.4
-6	9.5	28.5	36.6	50.8	35.1	35.1	13.7	41.1	25.4
-8	12.7	38.1	36.6	50.8	35.1	36.3	15.2	42.7	25.4
-10	15.9	47.8	36.6	50.8	35.1	38.1	17.0	44.7	33.0
-12	19.1	57.2	36.6	50.8	35.3	39.6	18.3	45.5	38.1
-16	25.4	76.2	36.6	50.8	36.6	42.9	21.3	47.0	76.2
-20	31.8	95.3	36.6	50.8	36.6	46.0	22.1	48.5	96.5

FIGURE 38 - MINIMUM BEND SPACING – WELDED FITTINGS

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 (152.4 mm) 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

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

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

- 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.

e. Use steel or titanium tubing in all sizes below 0.5 in (12.7 mm) OD 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, power plant 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 fluids judged as 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.

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, 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. AIR4918 provides general guidelines for selection of hoses, flexible tubing and extension fittings.

6.1 Hose

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

Detailed information concerning topics highlighted in the following paragraphs may be found in AIR1569, AIR797, and AIR5386.

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.

6.1.2 Wire Reinforced PTFE Lined

PTFE hoses are available to aerospace fluid power systems employing up to 5080 psi (35 MPa) pressure at temperatures to 400 °F (204 °C).

Aramid Fiber Reinforced PTFE lined hoses are similar in construction to the wire reinforced PTFE lined hoses except that the wire reinforcement is changed to Aramid fiber. These hoses offer lighter weight and greater flexibility than wire reinforced hoses. The liners are similar in construction and as a result the fluid service for the Aramid fiber hose is similar to the wire reinforced hose. Aramid Fiber Reinforced PTFE Lined hoses are available to aerospace fluid power systems employing up to 8000 psi (55 MPa) pressure at temperatures to 275 °F (135 °C).

6.1.3 Flexible Metal

Medium pressure, high temperature flexible metal hoses conforming to AS1424 may be employed in fluid power applications where very high temperatures or fluid compatibility problems are encountered. They are most commonly used in brake lines and hot air bleed ducts.

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, and as described in Figure 39. While straight fittings are preferable, 45 or 90 degree 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” of Figure 39 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” of Figure 39. For special fire zones a fire sleeve may be required to extend the life of the hose if a fire breaks out. These sleeves are often made from high temperature materials such as silicone rubber, often reinforced with heat resistant fibers.

6.1.4.3 Flex Allowance

When hose assemblies are subjected to considerable flexing, “C“ Figure 39, 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 baffle as shown by “D“ Figure 39, 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. To insure installation without twist the hose end fitting body must be secured from turning while the swivel nut is tightened. Twists of 20 degrees and less significantly reduces the fatigue life of hoses.

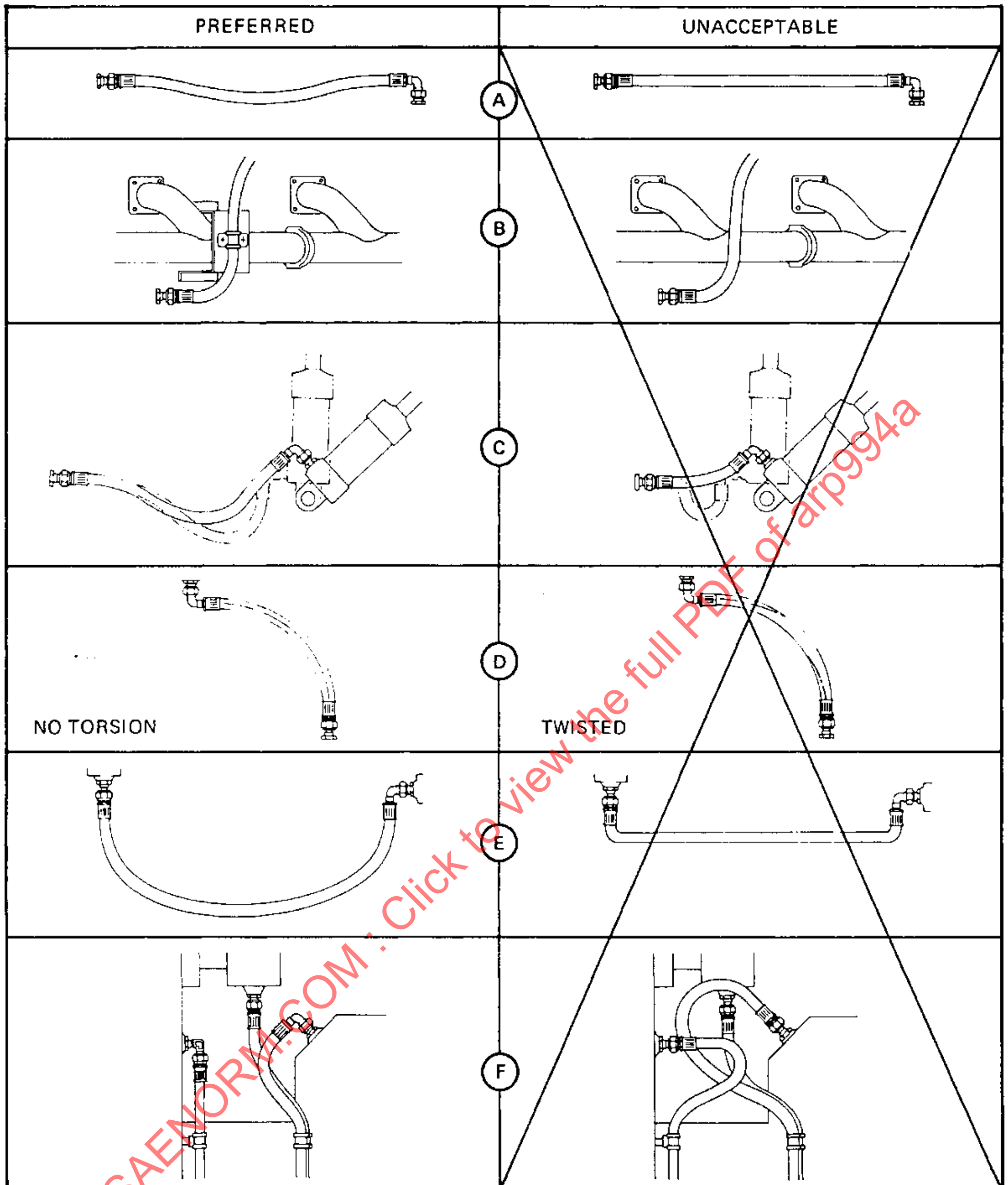


FIGURE 39 - HOSE INSTALLATION CRITERIA

6.1.4.5 Bend Radii

Avoid sharp bends as shown by "E" Figure 39. The bend radius should be five or more times the outside diameter of the hose. The complete range of motion for the hose ends must be considered when establishing minimum bend radius

6.1.4.6 Arrangement

Use applicable elbows and fittings as shown by “F“ Figure 39, 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. . Wire braid hoses chafing on structure have been known to "saw" large cuts in structure.

6.1.4.8 Restraint

When a hose is used at pressures in excess of 500 psi (3.45 MPa), 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.

6.2 Flexible Tubing

Special formed flexible tubing is recommended where there is limited relative motion exists between hydraulic components and structure. Two documents provide details of the design and qualification of these tubes:

- For titanium alloy tubing - ARP4146
- For CRES 304 tubing - ARP584

CRES (21-6-9) tubing may be utilized in lieu of CRES (18-8) tubing within the tolerance limits described by ARP584.

For all materials, 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 Figures 40 and 41 for configurations defined in ARP4146 and ARP584.

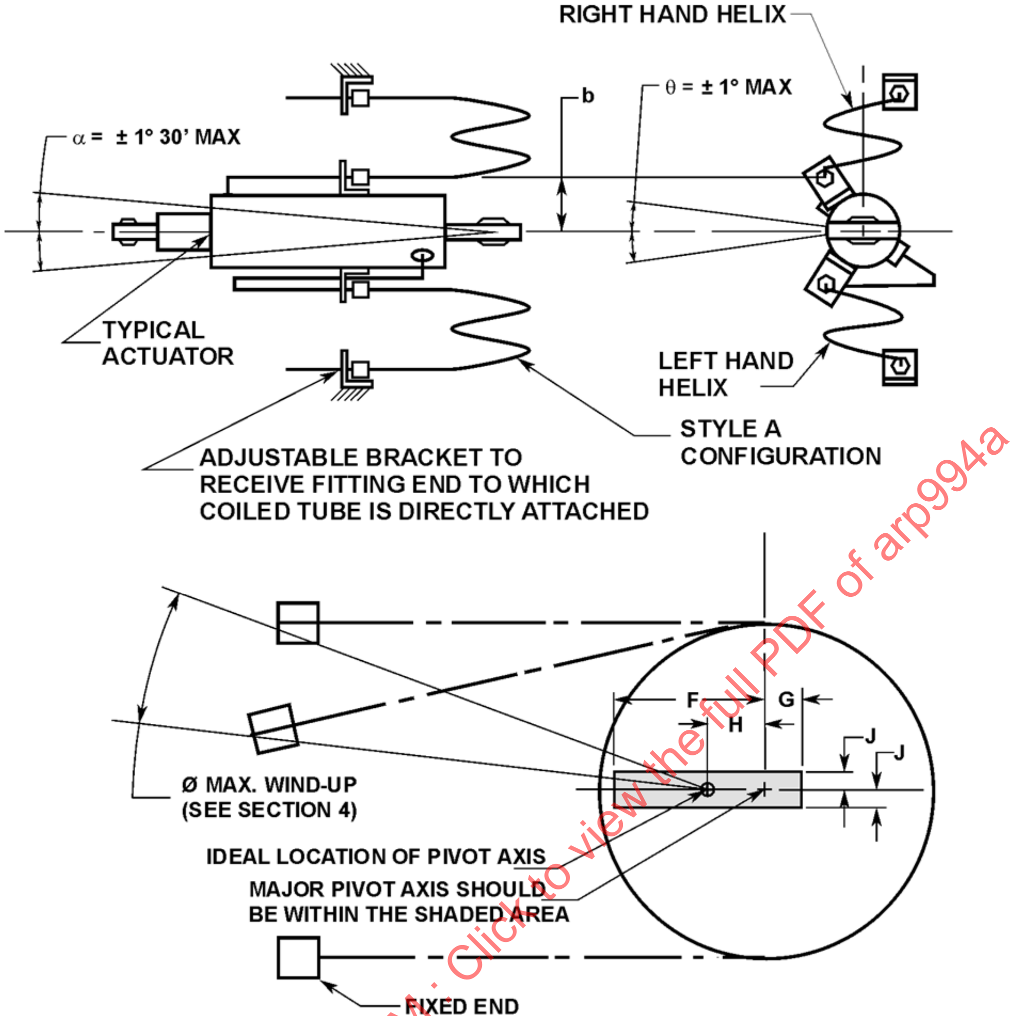
6.3 Swivel Joints

As an alternative, where space and motion requirements do not allow the use of flexible tubing or hoses, spherical and pin type swivels may be used. These 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. In general they are not as reliable as flexible tubes and hoses since they have mechanical moving elements and dynamic, elastomeric seals.

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.

Swivel joints should be qualified to MIL-DTL-5513 together with any specific application requirements.



F		G		H		J	
IN.	mm.	IN.	mm.	IN.	mm.	IN.	mm.
1.00	25.4	0.25	6.4	0.375	9.5	0 TO 0.125	0 TO 3.2

FIGURE 40 - SAMPLE INSTALLATION OF STYLE A FROM ARP584 OR ARP4146

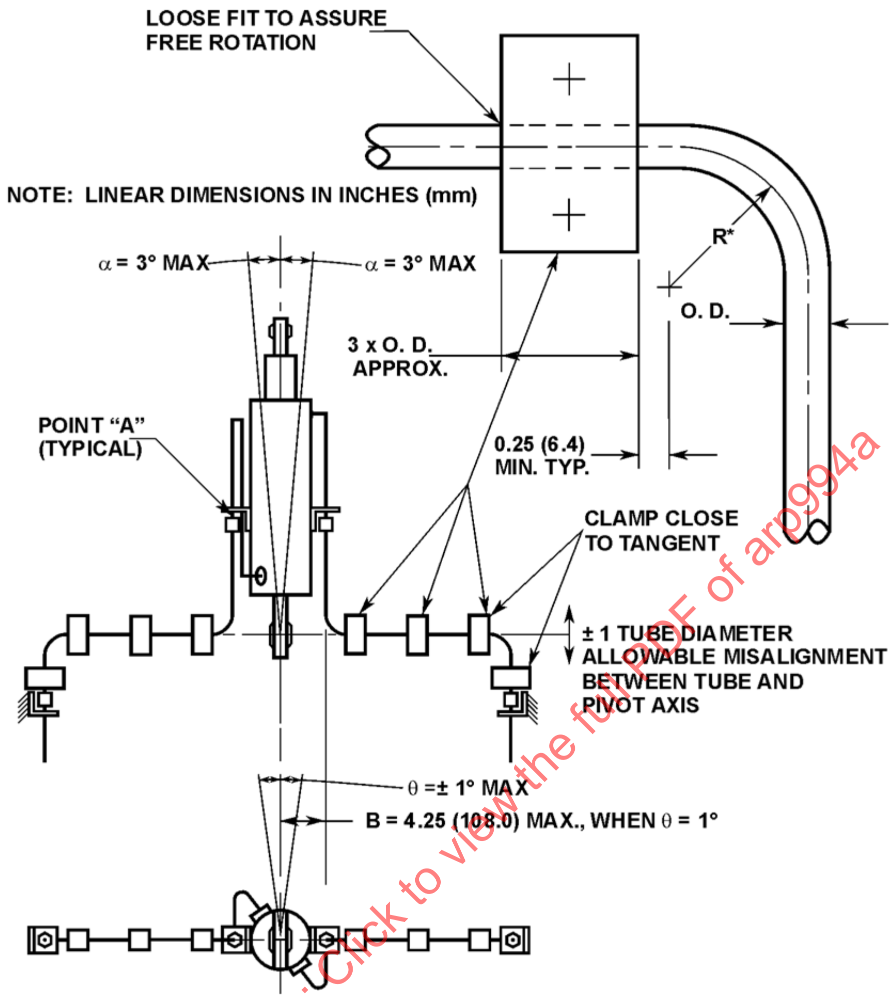


FIGURE 41 - SAMPLE INSTALLATION OF STYLE B FROM ARP584 OR ARP4146

6.3.1 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.

6.4 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.

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.

6.4.1 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.

6.5 Extension Units

Extension units are intended as a replacement for coiled tubing and flexible hoses in applications where space and motion are restrictive. 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 Figure 42 for an illustration of a hydraulic extension unit.

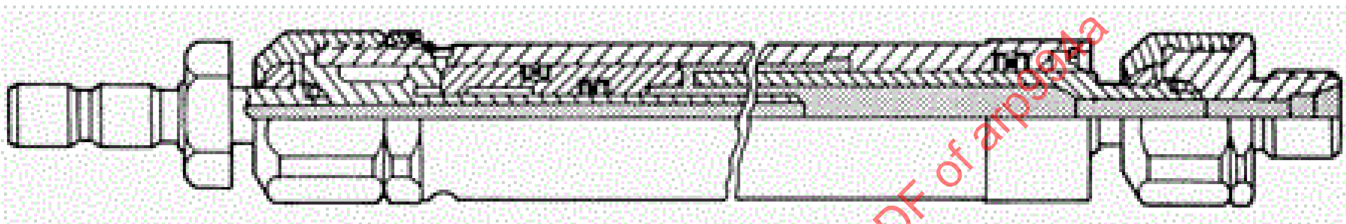


FIGURE 42 - HYDRAULIC EXTENSION UNIT

6.5.1 Installation

Experience gained on aircraft applications shows several areas that require special consideration. Extension units should work through most of the stroke occasionally to lubricate the seals and the 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.

7. SUPPORT, CLAMPING, AND BONDING

7.1 General Considerations Clamp Selection and Guidelines

Refer to ARP1897 for more information.

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 0.125 in (3.2 mm) be maintained between tubing and structure or other rigid members from which the tubing is supported. A minimum clearance of 0.25 in (6.4 mm) 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 0.25 in (6.4 mm) should be maintained under the most adverse conditions anticipated. Clearance between tubes and wire bundles should be at least 0.50 in (12.7 mm). These recommendations are in agreement with the requirements specified in ARP4752, ARP4925, and AS5440.

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 Figure 43. Blocks require accurately formed tube assemblies installed with little or no preload if adequate service life is to be attained.

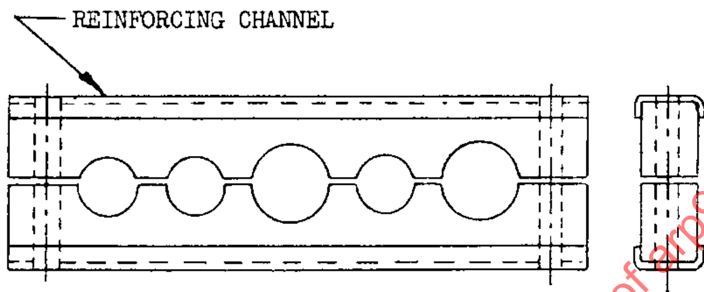


FIGURE 43 - SUPPORT BLOCK CONFIGURATION

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. 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 44 illustrates two possible screw placement approaches:

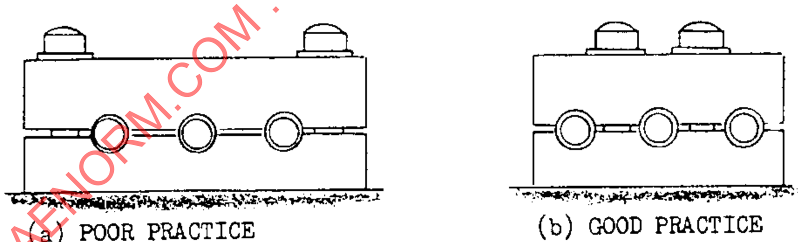


FIGURE 44 - SUPPORT BLOCK ATTACH SCREW PLACEMENT

If the screws are located as in Figure 44(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 Figure 44(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.

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 Figure 45:

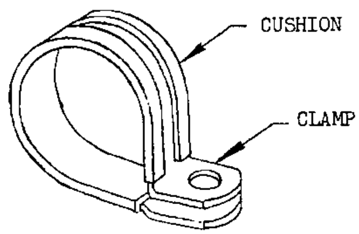


FIGURE 45 - TUBE CLAMP

This type of clamp is formed from aluminum, steel or stainless steel strap. Available cushion materials include fluorosilicon, nitrile butadiene, Teflon, 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.

In some moderate temperature applications nylon clamps (without cushions) similar in shape to that of Figure 45 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 0.375 in (9.5 mm) to 5.0 in (127 mm). 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 46. 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 47.

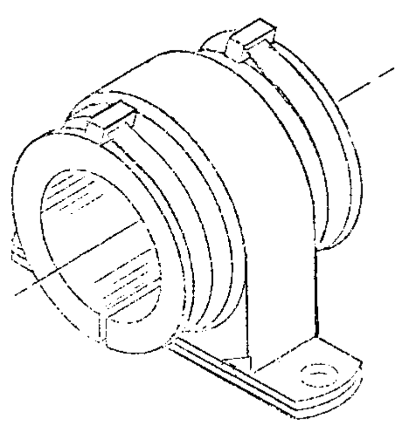


FIGURE 46 - SINGLE SIDE SADDLE CLAMP

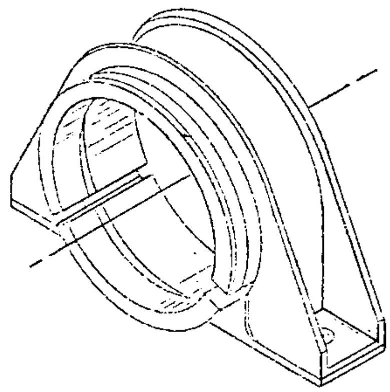


FIGURE 47 - DUAL SIDE SADDLE LAMP

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, MIL-PRF-7808 oil, sand and dust, fungus, and temperature exposures from -65 to +300 °F (-54 to 149 °C).

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 Figure 48. 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.

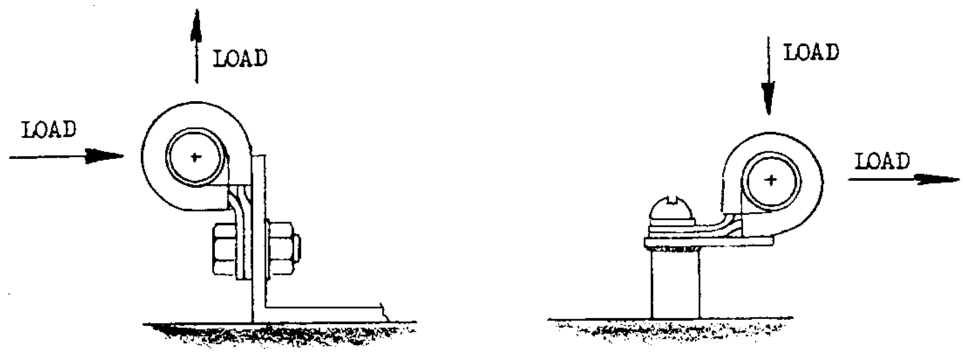


FIGURE 48 - FULL SUPPORT ENGAGEMENT

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 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 6. These are the same as specified in 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 6 - HYDRAULIC LINES SUPPORT SPACINGS

Nominal Tube OD			Maximum Length Between Support Centers (measured along tube)		Maximum Length Between Support Centers (measured along tube)	
			Aluminum Alloy (inches)	Steel and Titanium (inches)	Aluminum Alloy (mm)	Steel and Titanium (mm)
SIZE	OD (Inches)	OD (mm)				
-2	0.125	3.2	9.5	11.5	241.3	292.1
-3	0.188	4.8	12.0	14.0	304.8	355.6
-4	0.25	6.4	13.5	16.0	342.9	406.4
-5	0.313	8.0	15.0	18.0	381.0	457.2
-6	0.373	9.5	16.5	20.0	419.1	508.0
-8	0.50	12.7	19.0	23.0	482.6	584.2
-10	0.625	15.9	22.0	25.5	558.8	647.7
-12	0.75	19.1	24.0	27.5	609.6	698.5
-16	1.00	25.4	26.5	30.0	673.1	762.0
-20	1.25	31.8	28.5	31.5	723.9	800.1
-24	1.50	38.1	29.5	32.5	749.3	825.5

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 bulk head 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. ARP1870, ARP5412, ARP5414, and ARP5415 provide lightning strike zone criteria with analysis and protection criteria.

An bonding approach is 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 to be met without the necessity to over-design for the sake of an arbitrary standard.

8. DIMENSIONAL ACCURACY

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 ±0.0625 in (±1.6 mm) in offset and location and within ±2 degree 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 fluctuations 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.

Tube ovality for bends in commercial aircraft hydraulic steel and titanium tubing should not exceed 5% where the percentage flatness = $(1 - \frac{Min\ O.D.}{Max\ O.D.})$ x 100. 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 AS33611 where the percent flatness $= \frac{Max\ O.D.\ x\ Min\ O.D.}{Nominal\ O.D.})$ x 100.

The AS33611 method adds the nominal OD as a factor, which makes it somewhat less precise.

Example:

Nominal	0.3750 tube
Original diameter	0.378 in
Max OD in bend	0.387 in
Min OD in bend	0.369 in
Commercial	% flatness = $(1 - \frac{0.369}{0.387})$ x 100 = 4.65%
MS33611	% flatness = $100 - \frac{0.387 - 0.369}{0.375}$ x 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 (3.44 MPa) or greater, and 2% for working pressures less than 500 psi (3.44 MPa) (see Figure 49).

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 OD for sizes up to 0.50 in (12.7 mm) or 0.010 in (0.25 mm) for larger sizes and should not be rough and have an abrupt change in direction (see Figure 49).

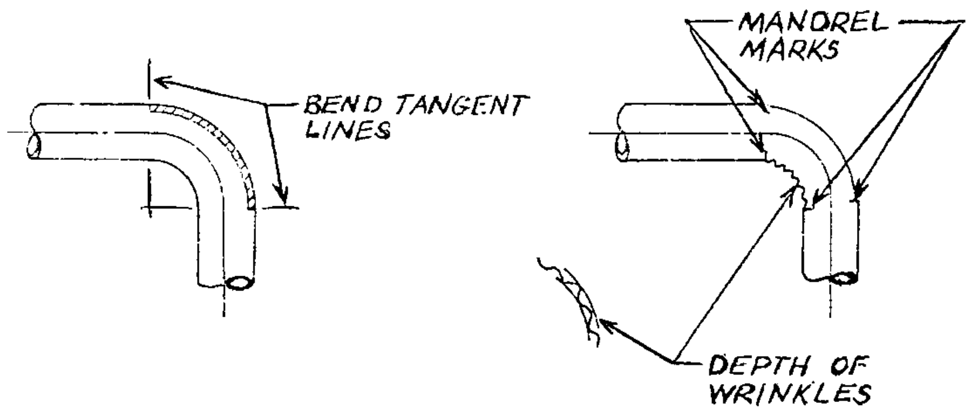


FIGURE 49 - WRINKLES AND MANDREL MARKS

Nicks and scratches should not exceed:

- 5% of wall thickness for working pressure above 500 psi (3.45 MPa).
- 10% of wall thickness for working pressure below 500 psi (3.45 MPa).

8.1.2 Tube Ends

See Figure 50.

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 by 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.

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

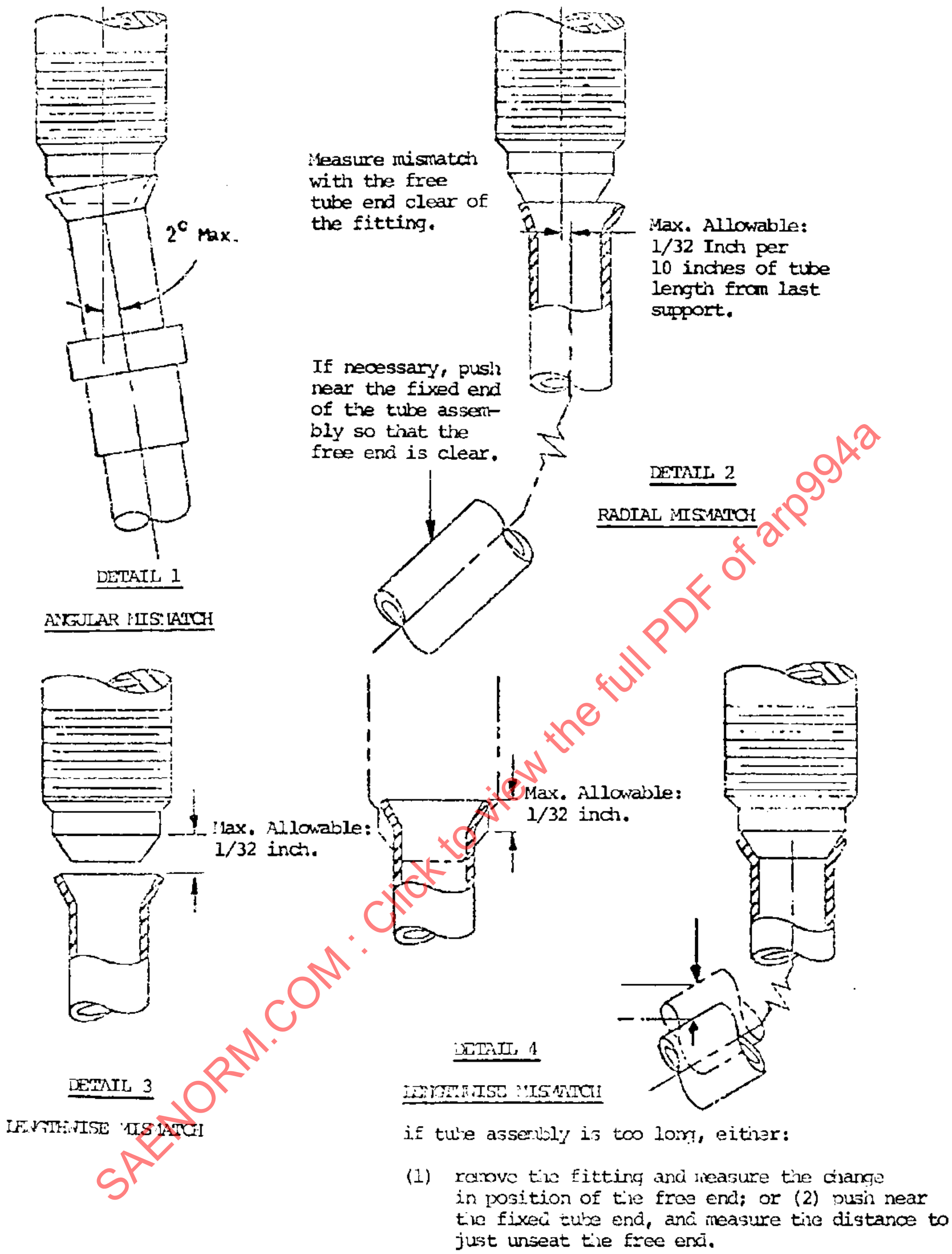


FIGURE 50 - INSTALLATION MISMATCH

8.1.2.1 Angular Mismatch

The free tube end must be parallel with the fitting within 2 degrees. See Figure 50, Detail 1.

8.1.2.2 Lengthwise Mismatch

The free tube end must be in line with the fitting within 0.0313 in (0.79 mm) per 10 in (254 mm) of tube length (radial match). See Figure 50, Detail 2.

8.1.2.3 Radial Mismatch

The free tube end must match the fitting cone lengthwise within 0.0313 in (0.79 mm) per 10 in (254 mm) of tube length. See Figure 50, 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 ±0.0313 in (±0.79 mm).

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 their 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 AS4330 for single flares and AS5203 for double flares. Flares should be concentric with the OD of the tube within 0.005 in (0.13 mm). Total indicator reading and shall be square with the tube centerline within 1/2 degree. 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 0.0625 in (1.6 mm) min to 0.0928 in (4.8 mm) 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 7.

TABLE 7 - INSTALLATION DIMENSION FOR TUBE END PROJECTION BEYOND SLEEVE

Size	TUBING OD x WALL (INCHES)	TUBE END PROJECTION BEYOND SLEEVE (INCHES)	TUBING OD x WALL (mm)	TUBE END PROJECTION BEYOND SLEEVE (mm)
-3	0.188 x 0.018	0.130 - 0.150	4.78 x 0.46	3.30 - 3.81
-3	0.188 x 0.020	0.130 - 0.160	4.78 x 0.51	3.30 - 4.06
-4	0.250 x 0.016	0.130 - 0.160	6.35 x 0.41	3.30 - 4.06
-4	0.250 x 0.020	0.130 - 0.160	6.35 x 0.51	3.30 - 4.06
-4	0.250 x 0.028	0.130 - 0.160	6.35 x 0.71	3.30 - 4.06
-5	0.313 x 0.020	0.140 - 0.160	7.95 x .0.51	3.56 - 4.06
-5	0.313 x 0.028	0.140 - 0.180	7.95 x 0.71	3.56 - 4.57
-5	0.313 x 0.049	0.140 - 0.180	7.95 x 1.24	3.56 - 4.57
-6	0.375 x 0.020	0.140 - 0.180	9.53 x 0.51	3.56 - 4.57
-6	0.375 x 0.028	0.140 - 0.180	9.53 x 0.71	3.56 - 4.57
-6	0.375 x 0.035	0.140 - 0.180	9.53 x 0.90	3.56 - 4.57
-6	0.375 x 0.065	0.140 - 0.180	9.53 x 1.65	3.56 - 4.57
-8	0.500 x 0.028	0.170 - 0.210	12.7 x 0.71	4.32 - 5.33
-8	0.500 x 0.035	0.170 - 0.210	12.7 x 0.90	4.32 - 5.33
-8	0.500 x 0.049	0.170 - 0.210	12.7 x 1.24	4.32 - 5.33
-8	0.500 x 0.083	0.170 - 0.210	12.7 x 2.11	4.32 - 5.33
-10	0.625 x 0.028	0.190 - 0.240	15.88 x 0.71	4.83 - 6.10
-10	0.625 x 0.035	0.190 - 0.240	15.88 x 0.90	4.83 - 6.10
-10	0.625 x 0.042	0.190 - 0.240	15.88 x 1.07	4.83 - 6.10
-12	0.750 x 0.020	0.210 - 0.240	19.05 x 0.51	5.33 - 6.10
-12	0.750 x 0.032	0.210 - 0.240	19.05 x 0.81	5.33 - 6.10
-12	0.750 x 0.035	0.210 - 0.240	19.05 x 0.90	5.33 - 6.10
-12	0.750 x 0.049	0.210 - 0.240	19.05 x 1.24	5.33 - 6.10
-12	0.750 x 0.053	0.210 - 0.240	19.05 x 1.35	5.33 - 6.10
-16	1.00 x 0.035	0.260 - 0.280	25.40 x 0.90	6.60 - 7.11