



AEROSPACE RECOMMENDED PRACTICE

ARP994™

REV. C

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Superseding ARP994B

Design of Tubing Installations for Aerospace Hydraulic Systems

RATIONALE

Revision C updates references and corrects the data in Figures 3A and 3B.

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1. SCOPE

This document provides recommended practices for the design and selection of tube, hose, and fitting systems that are used to transmit hydraulic fluid on aircraft.

NOTE: Guidance for the sizing of hydraulic tubing is contained in Appendix A.

2. APPLICABLE DOCUMENTS

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 +1 724-776-4970 (outside USA), www.sae.org.

AMS2700	Passivation of Corrosion Resistant Steels
AMS4083	Aluminum Alloy Tubing, Hydraulic, Seamless, Drawn, Round, 1.0Mg - 0.60Si - 0.28Cu - 0.20Cr (6061-T6), Solution and Precipitation Heat Treated
AMS5557	Steel, Corrosion- and Heat-Resistant, Seamless or Welded Hydraulic Tubing 18.5Cr – 10.5Ni – 0.40Ti (SAE30321) Solution Heat Treated
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-T-6845	Tubing, Steel, Corrosion-Resistant (S30400), Aerospace Vehicle Hydraulic System 1/8 Hard Condition
AIR310	Fittings, Catalog of Flared, Flareless, Pipe Threaded, Port, Hose, and Other Type Tube Standard Connectors
AIR797	Hose Characteristics and Selection Chart
AIR1047	A Guide for the Selection of Quick-Disconnect Couplings for Aerospace Fluid Systems
AIR1388	Service Damage Limits for Aircraft Hydraulic Tubing
AIR1564	Cross Reference for Materials for Fluid Systems Components, Including Military and Federal Specifications and Their International Equivalents
AIR1569	Handling and Installation Practice for Aerospace Hose Assemblies
AIR1593	Clamp Loads and Bending Stresses in Aircraft Tubing Installations
AIR1657	Handbook of Hydraulic Metric Calculations
AIR1698	Hose Assembly Identification Practices
AIR1922	Aerospace - System Integration Factors That Affect Hydraulic Pump Life

AIR4918	Industry Practices and Guidelines for the Selection of Coiled Tubes, Flexible Hoses, Swivels, and Extension Fittings for Aircraft Fluid Systems
AIR5005	Aerospace - Commercial Aircraft Hydraulic Systems
AIR5378	Aircraft Tube Bending Methods, Techniques and Tooling
AIR5386	Hose and Hose Assembly Selection, Installation, Inspection and Maintenance Guidelines, Listing of
AIR5426	Fitting and Fitting Assembly Selection, Installation, Inspection and Maintenance of
AIR5693	Compatibility of PTFE Hose Assemblies With Typical Fluids Found in Aerospace Applications
AIR6185	Aerospace - Lightning Effects on Hydraulic Transport Elements on Aircraft
ARP24	Determination of Hydraulic Pressure Drop
ARP584	Coiled Tubing - Corrosion Resistant Steel, Hydraulic Applications, Aerospace
ARP899	Tube Fittings, Fluid Systems, Permanent Type, General Requirements for
ARP1185	Flexure Testing of Hydraulic Tubing Joints and Fittings
ARP1258	Qualification of Hydraulic Tube Joints to Specified Flexure Fatigue Requirements
ARP1658	Hose Assemblies, Installed, Visual Inspection Guide For
ARP1709	Coupling Assembly, Hydraulic Self Sealing, Quick Disconnect
ARP1785	Standard Codes for Outer Sleeving on Hose Assemblies
ARP1835	Preparation for Delivery, General Requirements for Hose Assemblies
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
ARP5891	Achieving Cleanliness Standards for Aircraft Hydraulic Systems During Manufacture
AS130	Tube Bending Radius
AS150	Hose Assembly, Type Classifications of, Basic Performance and Fire Resistance
AS603	Impulse Testing of Hydraulic Hose, Tubing, and Fitting Assemblies
AS611	Hose Assembly and Tubing, Polytetrafluoroethylene, Cleaning Methods for
AS683	Installation Procedures and Torques for Fluid Connections

AS1055	Fire Testing of Flexible Hose, Tube Assemblies, Coils, Fittings, and Similar System Components
AS1709	Coupling Assembly, Hydraulic Self Sealing, Quick Disconnect
AS2094	Test Methods for Tube-Fitting Assemblies
AS4459	Fittings, Tube, Fluid System, 3000 psig (21 000 kPa) Rated Pressure, Externally Swaged, Specification For
AS4467	Standardization, Hydraulic Tube Walls
AS5148	Assembly, Installation, and Torque for Flareless and Straight Thread Fluid Fittings and Tube Assemblies
AS5440	Hydraulic Systems, Military Aircraft, Design and Installation, Requirements For
AS5586	General Requirements for Hydraulic System Reservoirs
AS5620	Titanium Hydraulic Tubing, Ti-3Al-2.5V Cold Worked and Stress Relieved, Up to 35000 kPa (5080 psi), Requirements for Qualification Testing and Control
AS5902	Installation of Externally Swaged Fittings
AS5958	Fittings, Axially Swaged Tube with Flareless Separable, Fluid System for Operating Pressures up to and Including 5080 psi (35000 kPa), Specification for
AS5959	Axially Swaged Fittings, Installation and Inspection Procedure
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
AS33611	Tube Bend Radii
AS85421	Fittings, Tube, Fluid Systems, Separable, Beam Seal, 3000/4000 psi, General Specification For
AS85720	Fittings, Tube, Fluid Systems, Separable, High Pressure Beam Seal, 5000/8000 psi, General Specification For
MA2094	Test Methods for Tube-Fitting Assemblies, Metric (ISO 10583)

Trikha, A. K. (1998). *Reduction of hydraulic system pressure spikes through limiting of servovalve current change rate* (Report No. 985561). SAE International and AIAA. <https://doi.org/10.4271/985561>.

2.2 EASA Publications

Available from European Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany (for visitors and for mail over 1 kg) and Postfach 10 12 53, D-50452 Cologne, Germany (for mail 1 kg or less); Tel: +49 221 8999 000, www.easa.europa.eu.

AMC 25.734	Protection Against Wheel and Tyre Failures
AMC 20-128	Design Considerations for Minimizing Hazards caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure
CS-23	Certification Specifications for Normal Category Aeroplanes (CS-23) and Acceptable Means of Compliance and Guidance Material to the Certification Specifications for Normal-Category Aeroplanes (AMC & GM to CS-23)

- CS-25 Certification Specifications and Acceptable Means of Compliance for Large Aeroplanes
- CS-29 Certification Specifications, Acceptable Means of Compliance and Guidance Material for Large Rotorcraft (CS-29)

2.3 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

- 14 CFR Part 23 Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
- 14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes
- 14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft
- AC 20-128 Design Considerations for Minimizing Hazards caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure
- TSO C-140 Aerospace Fuel, Engine Oil, and Hydraulic Fluid Hose Assemblies

2.4 ISO Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

Or if using the Switzerland address:

Available from International Organization for Standardization, ISO Central Secretariat, 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, Tel: +41 22 749 01 11, www.iso.org.

- ISO 16682 Aerospace Series – Terminology for Clamping Devices
- ISO 8575 Aerospace – Fluid Systems – Hydraulic System Tubing

2.5 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

- DO-160 Environmental Conditions and Test Procedures for Airborne Equipment

2.6 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

- MIL-DTL-5513 Swivel Joint, Hydraulic
- MIL-DTL-5541 Chemical Conversion Coatings on Aluminum and Aluminum Alloys
- MIL-PRF-87257 Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile
- MIL-PRF-81309 Corrosion Preventive Compounds, Water Displacing, Ultra-Thin Film

3. TUBING AND FITTINGS

3.1 Selection of Tube and Fitting Combinations

The selection of tubing and fitting combinations for military aircraft should take into account the operating, proof, and burst pressure requirements per AS5440.

The selection of tubing and fitting combinations for commercial transport aircraft should take into account the design operating, proof, and ultimate pressures as described in ARP4752.

The selection of tubing and fitting combinations for commercial transport helicopter hydraulic systems should take into account design operating and proof pressures as described in ARP4925.

NOTE: For commercial transport helicopters, there is no specific regulatory requirement for burst or ultimate pressure substantiation. ARP4925 contains an additional discussion on the voluntary application of burst or ultimate pressure requirements.

The selected tube and fitting joint should have qualification substantiation based on AS603, AS2094, ARP1185, and ARP1258.

Test methods for metric tube-fitting assemblies are described in MA2094.

3.2 Hydraulic Tubing

Recommended hydraulic tube materials and their basic properties are summarized in Table 1. AIR1564 provides a cross-reference between the listed AMS standard and similar international standards.

Hydraulic tube wall thickness is standardized per AS4467 and ISO 8575. When selecting tubing wall thickness for welding purposes, consult ARP4698.

Recommended materials for coiled tubing applications are described in ARP584 and ARP4146.

Table 1 - Recommended hydraulic tubing materials

Material	Specification	Type	Class	Minimum Tensile Properties		Density lb/in³ (g/cm³)
				Yield Strength at 0.2% Offset ksi (MPa)	Tensile Strength ksi (MPa)	
Titanium Alloy						
3Al-2.5V	AS5620	I	NA	105 (724)	125 (862)	0.162 (4.48)
		II	NA	95 (655)	100 (690)	
		III	NA	70 (483)	85 (586)	
Steel Alloy						
321 CRES	AMS5557	1	NA	30 (206)	75 (517)	0.290 (8.03)
21-6-9 CRES	AMS5561	1, 2	1	120 (827)	142 (979)	
304 1/8 Hard	AMS-T-6845	I	NA	75 (517)	105 (724)	
Aluminum Alloy						
6061-T6	AMS4083	NA	NA	35 (241)	42 (290)	0.098 (2.71)

NOTE: For AMS5561 tubing, Type 2 is recommended for locations subject to significant dynamic pressures such as pump discharge tubes.

3.3 Connection Methods

Guidance on fitting assembly selection, installation, inspection, and maintenance is provided in AIR5426. Fitting methods recommended for hydraulic applications are described in the following paragraphs. For military aircraft hydraulic systems, ARP899 should be consulted for permanent fittings.

Select mating metals and dry-film lubricants in fittings so that deterioration due to galvanic action or material-fluid incompatibility cannot occur.

3.3.1 Axially Swaged Fittings

The axial swage requirements for creating permanent joints and separable joints with the flareless interface are specified in AS5958 and the installation process for the swaging operation is specified in AS5959. The axial swage connection method is capable of withstanding operating pressures up to and including 5080 psig (35000 kPa) and an operating temperature range of -65 to +275 °F (-54 to +135 °C) ambient and fluid temperatures.

3.3.2 Externally Swaged Fittings

The external swage requirements for creating permanent and separable joints are specified in AS4459 and the installation process is specified in AS5902. Additional details are described in AIR5426.

3.3.3 Welded Joints

Specifications for welded joints are provided in AIR5426.

3.3.4 Fittings for Reconnectable Joints

For military aircraft, beam seal fittings according to AS85421 (Class 4000 or less) or AS85720 (greater than Class 4000) may be used for reconnectable joints according to AS5440.

Flareless fittings for reconnectable joints are recommended for commercial aircraft. Details for flareless fittings with bite-type sleeves and flareless fittings with machined acorn ends are described in AIR5426.

NOTE: Bite-type fittings should only be used with softer tube materials such as AMS-T-6845.

The installation of flareless fittings should be per AS5148.

3.3.5 Quick Disconnect Couplings

The selection of quick disconnect couplings should be based on AIR1047 and ARP1709. Recommended specifications for quick disconnect couplings include AS1709, AS24334, AS24335, and AS25427.

4. TUBE ROUTING

The hydraulic tube and fitting installation design should prevent incorrect connections between multiple hydraulic systems, prevent incorrect connections to other fluid systems, withstand expected pressure and installation stresses, and minimize hazards due to leakage.

4.1 Hydraulic Tube and Fitting Layout

Hydraulic tube and fitting installations should have the following characteristics:

- a. The installation design should not result in tubes being forced into alignment during installation.
- b. Hydraulic tubes should be installed with negligible preloading of clamps, tubing, and fittings.
- c. Avoid straight tube runs between rigid end points such as components and bulkhead fittings. This practice is intended to reduce assembly stresses and aid in installation and replacement.