AEROSPACE RECOMMENDED PRACTICE

ARP4945 REV. A

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Superseding ARP4945

Aerospace-Solenoid Valve, Hydraulic, Three Way, Two Position, Direct Acting

RATIONALE

ARP4945A has been reaffirmed to comply with the SAE five-year review policy.

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) is intended as a guide to aid in the specifying and testing of direct acting three way, two position, single and multiple coil, normally open and normally closed solenoid valves used for the pilot actuation of hydraulic control systems and the control of hydraulic components.

The information presented should be useful in standardizing terminology, in specifying requirements and performance parameters, and in defining test methods.

The recommendations do not restrict or attempt to define the internal design features of solenoid valves. Standard mechanical, electrical and fluid porting interfaces are recommended to provide commonalty, interchangeability, design flexibility and to be more affordable.

In general, this recommended practice is directed toward solenoid valves for use in military and commercial flight control and hydraulic actuation systems.

For military aircraft applications, this recommended practice covers solenoid valves for use in hydraulic actuation systems of the following types as defined in AS5440 with rated operating pressures to 8000 psi (55,160 kPa) and flow rates typically less than 1 gpm (3.785 L/min).

Type I -65 to +160 °F fluid temperature
(-54 to +71 °C)
Type II -65 to +275 °F fluid temperature
(-54 to + 135 °C)

For commercial aircraft applications, the information and guidelines of ARP4752 are considered. References are made to several documents that address phosphate ester hydraulic fluids. Detail Specification requirements, however, may need to be modified for a specific application.

When recommended by a paragraph, the word “should” is used. The word “shall” is used to designate a firm requirement of a paragraph.

2. REFERENCES:

This section includes a broad list of references that may be used in the preparation of a solenoid valve Detail Specification. It is recommended that only those references that are applicable and necessary in defining the requirements of the product be included.

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The effective date of references shall be as specified in the purchase order or contract. If not specified, the effective date 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.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS-QQ-P-35	Passivation Treatments for Corrosion - Resistant Steel
AMS-QQ-C-320	Chromium Plating (Electrodeposited)
AMS-STD-2175	Classification and Inspection of Castings
AMS-H-6088	Heat Treatment of Aluminum Alloys
AMS-H-6875	Heat Treatment of Steel Raw Materials
AMS-F-7190	Forging, Steel, for Aircraft/Aerospace Equipment and Special Ordnance Applications
AMS-A-8625	Anodic Coatings, for Aluminum and Aluminum Alloys
AMS-DTL-23053	Insulation Sleeving, Electrical Heat Shrinkable, Specification for
AMS-P-83461	Packing, Preformed, Petroleum Based Hydraulic Fluid Resistant, Improved Performance at 275°F (135°C)
ARP598	The Determination of Particulate Contamination in Liquids by the Particle Count Method
AS1241	Fire Resistant Phosphate Ester, Hydraulic Fluid for Aircraft
ARP1383	Impulse Testing of Aerospace Hydraulic Actuators, Valves, Pressure Containers and Similar Fluid System Components
AS4059	Aerospace - Cleanliness Classification for Hydraulic Fluids
ARP4386	Terminology and Definitions for Aerospace Fluid Power, Actuation, and Control Technologies
AS4716	Gland Design, O-ring and Other Elastomeric Seals
ARP4752	Aerospace Fluid Power - Design and Installation of Commercial Transport Aircraft Hydraulic Systems
AS5440	Hydraulic Systems, Aircraft, Design, Installation, Requirements for
AS8775	Hydraulic System Components, Aircraft and Missiles, General Specification for
AS8791/1	Retainer, Packing, Hydraulic, and Pneumatic Polytetrafluoroethylene, Single Turn
AS8879	Screw Threads - UNJ Profile, inch
AS22759	Wire, Electrical, Fluoropolymer-Insulated, Copper or Copper Alloy
AS28775	Packing, Preformed, Hydraulic, +275 °F (O-Ring)
AS40401	Solenoid Electrical, General Specification for

2.1.2 ISO Publications: Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ISO 261	General Purpose Metric Screw Threads - General Plan
ISO 10012-1	Quality Assurance Requirements for Measuring Equipment - Metrological confirmation system for measuring equipment

2.1.3 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-HDBK-5400	Electronic Equipment, Airborne General Guidelines For
MIL-PRF-8516	Sealing Compound, Synthetic Rubber Electrical Connectors and Electric Systems, Chemically Cured

2.1.3 (Continued):

MIL-DTL-16878	Wiring, Electrical, Insulated, General Specification for
MIL-I-16923	Insulating Compound, Electrical, Embedding
MIL-W-22759	Wire Electrical, Fluoropolymer-Insulated, Crosslinked Modified ETFE, Normal Weight, Nickel-Coated, High Strength Copper Alloy, 200°C, 600 Volt
MIL-PRF-23586	Sealing Compound with Accelerator, Electrical, Silicone Rubber
MIL-PRF-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base Metric Nato Code H-537
MIL-PRF-87257	Hydraulic Fluid, Fire Resistant; Low Temperature, Synthetic Hydrocarbon Base, Aircraft and Missile
MIL-STD 130	Identification Marking of U.S. Military Property
MIL-STD-202	Test Methods for Electronic and Electrical Component Parts
MIL-STD 461	Requirements for the Control of Electromagnetic Interference
MIL-STD-464	Electromagnetic Environmental Effects Requirement for Systems
MIL-STD-681	Identification Coding and Application of Hook-up and Lead Wire
MIL-STD-704	Aircraft Electrical Power, Characteristics
MIL-STD-810	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-889	Dissimilar Metals
MIL-STD-1472	Human Engineering Department of Defense Design Criteria Standard
MIL-STD-7179	Finishes, Coatings and Sealants for the Protection of Aerospace Weapons Systems
MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
MIL-HDBK-310	Department of Defense Handbook - Global Climatic Data for Developing Military Products

U.S. Government Publications: Available from ASC/ENSI, Building 125, 2335 Seventh St., Ste 6, Wright Patterson AFB, OH 45433-7809.

AFSC DH 1-3	Personnel Subsystem Design Three Handbook
AFSC DH 1-4	Electromagnetic Compatibility

2.1.4 RTCA Publications: Available from Radio Technical Commission for Aeronautical Secretariat, One McPherson Square, Suite 500, 1425 K Street, NW., Washington DC 20005.

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

2.1.5 NAS Standards: Available from Aerospace Industries Association, 1250 Eye Street NW, Washington, DC 20005.

NAS 1613 Seal Element Packing, Preformed, Ethylene Propylene Rubber

2.1.6 ANSI Publications: Available from ANSI, 11 West 42nd Street, New York, NY 10036-8002.

ANSI Z540.1 Laboratories, Calibration, and Measuring and Test Equipment

3. REQUIREMENTS:

3.1 Introduction:

This section is intended to be a guide for the preparation of a specification for a three-way, two position solenoid valve. The valve may be either a normally open or normally closed type. It is recommended that for standardization of document, the specification paragraphs be organized as follows:

1. SCOPE
2. REFERENCES
3. REQUIREMENTS
3.1 Design Requirements
3.1.1 Mechanical
3.1.2 Hydraulic
3.1.3 Electrical
3.2 Performance Requirements
3.3 Environmental Requirements
4. QUALITY ASSURANCE PROVISIONS
5. PREPARATION FOR DELIVERY
6. NOTES

Applicable documents should be listed under 2. REFERENCES.

The mechanical interfaces included in this specification show examples of plug-in and face mounted installation options, with and without interface connectors. The interface dimensional details and hydraulic definition apply to single or multiple coil designs. This information represents typical 3000 psi (21,000 kPa) aerospace solenoid valve designs that have proven to be reliable and cost effective.

The recommended Detail Specification limits stated in 3.2 and 4.2 are consistent with the requirements of most aerospace hydraulic actuation systems and can be met with reliable solenoid valve designs of proven producibility. Reducing the limits recommended will generally make the product more difficult to produce and increase its cost. Changes to the recommended limits should be carefully considered before closer control is arbitrarily imposed.

3.1.1 Terminology and Definitions: Unless otherwise stated, terminology and definitions shall be defined by or consistent with ARP4386.

3.1.1.1 Solenoid Valve: An electrically energized flow control valve that is capable of directing flow from a pressurized source to a control port when electrically energized (normally closed). When de-energized, the control port will be vented to the system return pressure. Alternately, a normally open design directs flow from a pressurized source to a control port when de-energized and vents the control port to return when energized.

3.1.1.2 Three Way, Two Position: A valve having three hydraulic ports arranged so that the valve action in one direction opens supply pressure to the control port and the reverse valve action vents the control port to return pressure.

3.1.1.3 Port Designation: A fluid connection to or from the solenoid valve. Fluid ports are labeled P, (Supply) C, (Control) and R, (Return).

3.1.1.4 Direct Acting: The solenoid alone causes the valve to operate -- that is, there is no amplification by internal hydraulic pilot.

3.1.1.5 Purchaser: The Purchaser is the organization that has the responsibility for the design and development of the hydraulic system that includes the solenoid valve. Typically, the Purchaser is an aircraft manufacturer or a modification center. The Purchaser is responsible for compiling the Procurement Specification.

3.1.1.6 Supplier: The Supplier is the manufacturer of the solenoid valve who is responsible for its design, production and qualification.

3.2 Detail Specification Considerations:

3.2.1 Scope: The introductory paragraph of the solenoid valve Detail Specification shall identify specifically the type of component. It is preferred to have a brief description of the application included in the introductory paragraph, together with any additional information, which describes broadly the solenoid valve requirements. Any unusual design or performance requirements may be cited to indicate the general nature of the hardware to be produced by the specification (i.e., high temperature, low leakage, high response, etc.)

3.2.2 Requirements: The Requirements section of the document defines specification requirements for the solenoid valve including all operating, non-operating, and storage conditions. The paragraphs below provide a comprehensive summary of requirements frequently specified. The specification should include only those requirements that are necessary to ensure that system performance requirements are met.

The solenoid valve must be designed to meet performance and all other requirements of the Detail Specification while installed in the hydraulic control system, during both ground and airborne operations, at the end of a life equivalent to that defined in the specification provided the environment is no more stringent than that specified. The lack of a design verification test shall not relieve the solenoid valve Supplier of the responsibility for full compliance with the requirement of the specification.

If applicable for a multiple coil design, it must be stated that during normal operation, each coil of a multiple coil design shall be supplied with current from an independent power source. It shall be stated whether the requirement applies to one or more coils operational.

3.2.3 Design Requirements: The solenoid valve shall be a completely self-contained package which meets the requirements for the total operation specified. It shall be designed in accordance with AS40401 and AS8775 except as specified. Any deviations from the requirements of the Detail Specification must be specifically noted by the Supplier and shall require written approval from the Purchaser prior to acceptance.

3.2.4 Mechanical: This paragraph briefly states the type of solenoid valve being specified, the number of coils and the fluid flow path when energized.

3.2.4.1 Workmanship: Workmanship shall be defined by process standards such that each solenoid valve complies with all requirements including proper operation and personnel safety.

3.2.4.2 Physical Description: The physical description of the solenoid valve shall include the following:

a. Envelope dimensions
b. Mounting definition
c. Electrical connection and polarity
d. Coil pin connections or lead wire color coding as applicable
e. Dry weight

If the installation is face mounted, the solenoid valve hydraulic ports shall be defined and legibly marked. Suitable locating means shall be provided to prevent incorrect connection with the manifold. The port identification shall be as follows:

a. Supply port - P
b. Return port - R
c. Control port - C

3.2.4.2 (Continued):

All assemblies having the same part number shall be functionally interchangeable.

The envelope shall represent the installation space available for the solenoid valve. It shall indicate maximum dimensions and specify the location and dimensions of electrical connectors or other critical areas as applicable.

Examples of three specific types of 3000 psi (21,000 kPa) low flow (less than 1 gpm or 3.78 L/min) solenoid valve installations are included for information and guidance. These are:

Figure 1 - Installation Data, End Face Mounted Solenoid Valve, Two Coil, Normally Closed
Figure 2 - Installation Data, Side Face Mounted Solenoid Valve, Four Coil, Normally Closed
Figure 3 - Installation Data, Plug in Solenoid Valve, Two Coil, Normally Closed.

Both electrical lead wire and connector interfaces are shown as well as single and multiple coil variations of the above types. Depending on the number of coils required, the coil envelope length may be changed from that shown in the figures. Consideration shall be given to specifying the mounting and porting configurations and methods of dimensioning given in Figures 1 through 3 for design standardization. The dimensional parameters shown represent proven producible and cost effective designs for single and multiple coil solenoid valves.

3.2.4.3 Identification: The solenoid valve shall be marked for identification in accordance with MIL-STD-130. Identification may be by nameplate or other permanent marking method as specified. Name plates shall be permanently attached with an approved adhesive. Decals shall not be used. Part marking shall be located as shown on the Source Control Drawing. Part marking typically includes the following:

a. Equipment nomenclature
b. Purchaser Cage Code
c. Supplier Code Identification, Part Number (including dash number and revision number) and Serial Number
d. Date of manufacture
e. Country

The following additional information may be included:

a. Purchaser part number
b. Rated pressure
c. Rated current
d. Rated voltage
e. Fluid

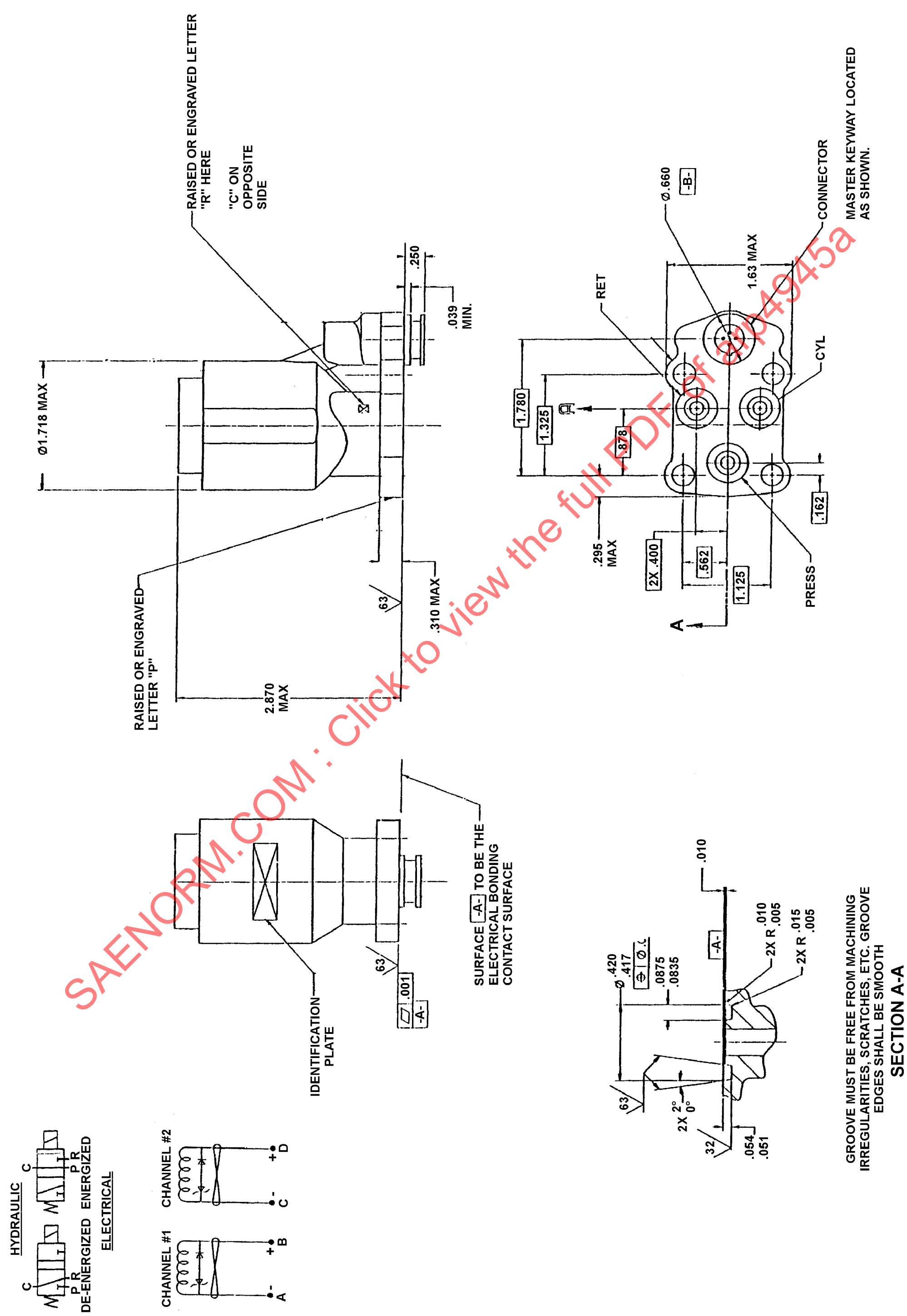

FIGURE 1 - Installation Data, End Face Mounted Solenoid Valve, Two Coil, Normally Closed

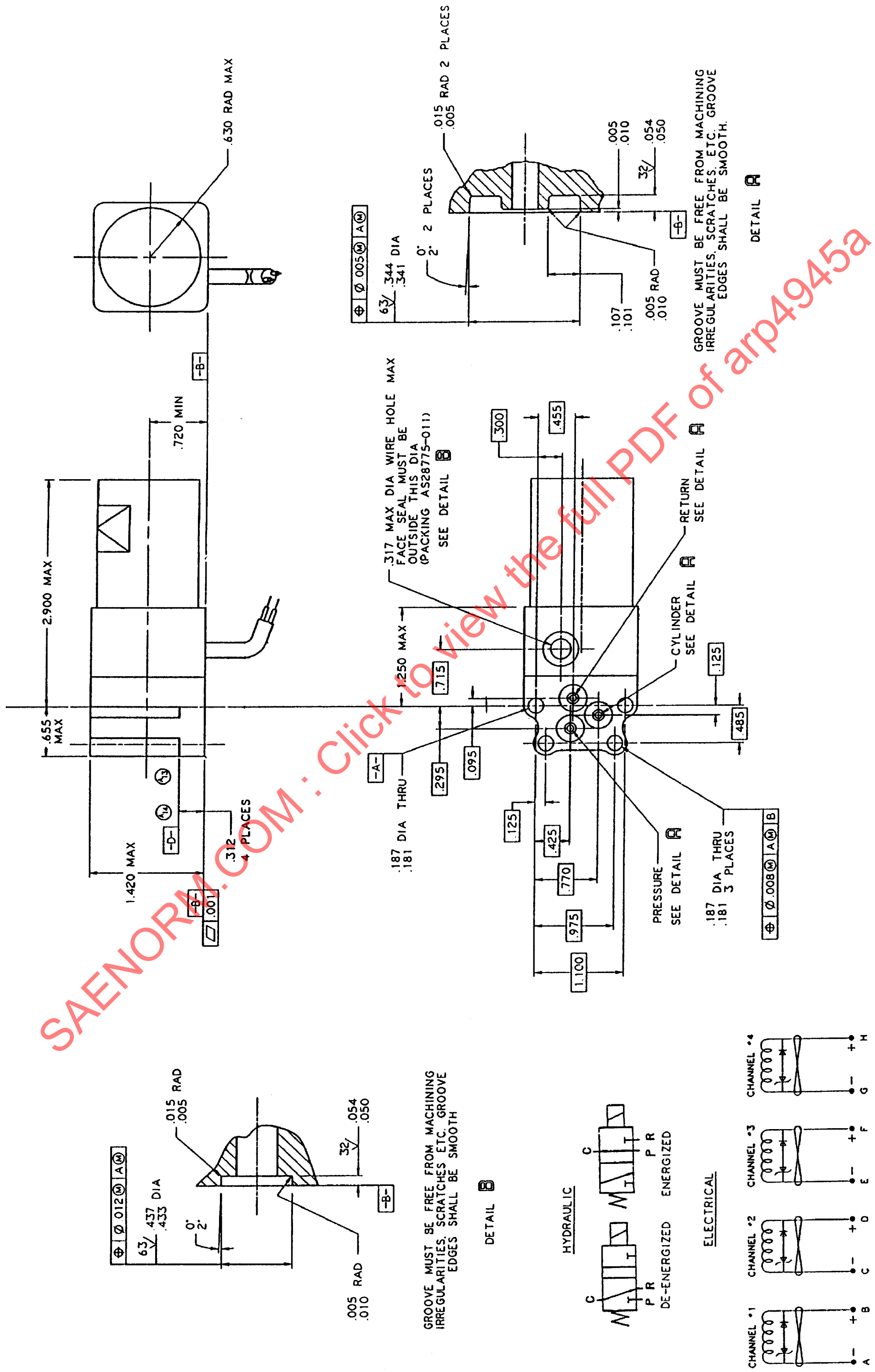

FIGURE 2 - Installation Data, Side Face Mounted Solenoid Valve, Four Coil, Normally Closed

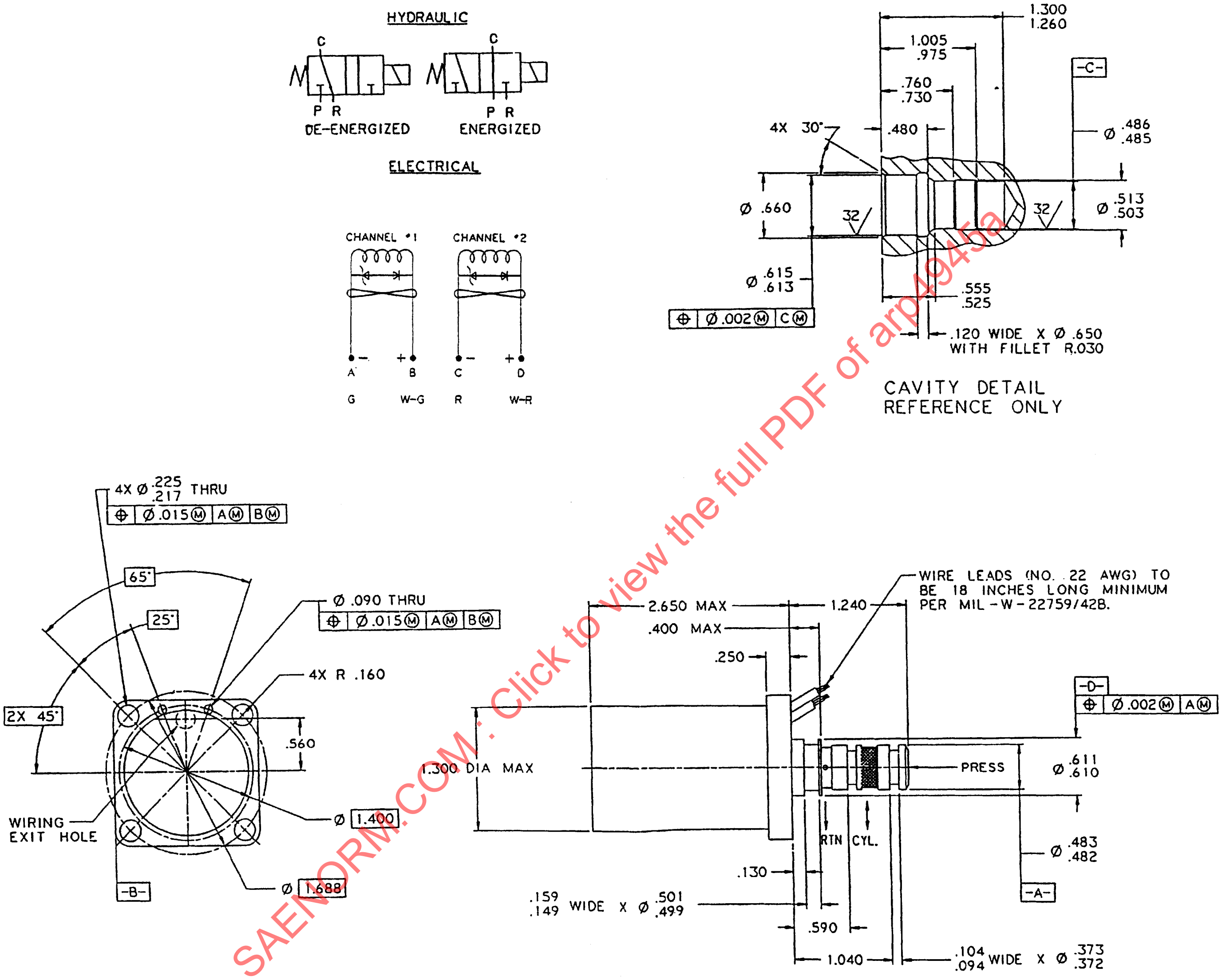

FIGURE 3 - Installation Data, Plug-in Solenoid Valve, Two Coil, Normally Closed

3.2.4.3 (Continued):

Serial numbers shall be assigned in consecutive sequence with no gaps in numbering. Records shall be maintained of all serialized units delivered to Purchaser.

3.2.4.4 Weight: The maximum allowable dry weight of the solenoid valve shall be specified. The Supplier may be requested to conduct a weight control program consistent with the requirements of the specification where weight is critical.

3.2.4.5 Installation and Adjustments: The design shall contain a provision that prevents the solenoid valve from being installed incorrectly. The solenoid valve shall not require adjustment when installed. Internal adjustments shall have suitable locking means to indicate when unauthorized adjustments have been made. Mounting bolt torque requirements shall be specified.

3.2.4.6 Attitude: The solenoid valve shall be designed to conform to all requirements of the specification while mounted in all positions, unless otherwise specified.

3.2.4.7 Materials: Materials used shall conform to AS8775 and to all applicable specifications and specified environments. All metals used shall be corrosion resistant or suitably protected against the specified environment and fluid.

Fluid or environmental conditions often require special precautions to be taken regarding the selection of compatible materials to minimize the effects of chemical or electrical reaction, fungus growth, etc. Where applicable, these conditions shall be specified.

3.2.4.8 Moisture Resistance: The design configuration shall be such that moisture cannot collect in depressions, indentations, or other irregular surfaces to the extent of causing malfunction from corrosion, freezing, insulation resistance or dielectric failures or other injurious effects.

3.2.4.9 Metals: Metallic components shall be designed to withstand all pressure, temperature, dynamic and life requirements without exceeding stress levels specified in MIL-HDBK-5. All metal parts, shall be corrosion resistant metal, or shall be sufficiently protected in accordance with MIL-STD-7179 to resist corrosion. Heat treatment of steel and aluminum shall conform to AMS-H-6875 or AMS-H-6088 as applicable. Stainless steel parts shall be passivated per AMS-QQ-P-35. Chrome plating if used shall be per AMS-QQ-C-320 unless otherwise specified in the detail specification. Anodizing of aluminum alloys shall be per AMS-A-8625. Dissimilar metals, as referenced in MIL-STD-889, which have active electrolytic corrosion shall not be used in intimate contact except where such electrolytic contact is required for proper operation of the unit. However, metal plating or metal spraying of dissimilar base metals to provide similar or suitable mating surfaces is permitted. Any such plating or spray used shall offer a low impedance path to radio frequency current. Cadmium plating shall not be used on any surface that will be in contact with hydraulic fluids.

It is recommended that the material of the mating surface in contact with the solenoid valve be specified.

3.2.4.10 Non-Metallic Materials: Environmentally exposed non-metals, including plastics, fabrics, and protective finishes, shall be moisture and flame resistant and self extinguishing. Such materials shall not be capable of supporting fungus growth, and shall not be adversely affected by weathering and specified aircraft fluids at temperatures between -65 and +160 °F (-54 and +71 °C) for Type I systems and between -65 and +275 °F (-54 and +135 °C) for Type II systems. Materials shall be selected that are suitable for operation in an ozone environment at 70,000 ft (21,300 m) altitude (as applicable). Also, external materials shall not be adversely affected by normal cleaning solvents such as Methyl Ethyl Ketone, Alcohol and Chlorothane at normal room temperatures. All plastic materials shall be subject to approval for each specific application.

3.2.4.11 Castings and Forgings: Castings exposed to pressurized fluid shall be of high quality, clean, sound and free from porosity. Castings shall be in accordance with AMS-STD-2175, Class II, Grade B and steel forgings shall be in accordance with AMS-F-7190, Grade A. Those castings not conforming to Class II, Grade B or better shall be identified for deviation to this requirement.

In designing castings, the applied loads shall be multiplied by a casting factor of 1.50. Minimum edge margins for fasteners, pin plugs or similar devices in cast parts shall be 2.0 times the diameter or be capable of accepting the next size, pin plug or thread insert for repair purposes, whichever is greater.

3.2.4.12 Protective Treatment: Materials subject to deterioration when exposed to the climatic and other environmental conditions specified shall be protected. The method of protection shall not prevent compliance with other requirements. The use of any protective coating that will crack, chip, scale or erode during the required life or as a result of climatic or other environmental conditions shall be avoided. Assembly requiring the contact of dissimilar metals shall be adequately protected against galvanic interaction in service by the use of an appropriate finish system. The solenoid finish and markings shall be compatible with the specified fluids. Any protective coating for the case, and mounting surfaces shall not interfere with the electrical continuity if required by the purchaser.

3.2.4.13 Encapsulation and Potting: Materials used to support and protect electrical junctions, terminations and components from mechanical damage, while providing electrical insulation shall conform to MIL-I-16923. Materials used to provide electrical insulation and to specifically prevent intrusion from moisture, salt spray, hydraulic fluid and other environments shall conform to MIL-PRF-8516 or MIL-PRF-23586. The Supplier may specify other potting compounds if specifically approved by the Purchaser. Resistance to intrusion of water into internal cavities shall be a major design goal. Particular attention shall be given to protection of moisture or fluid from "wicking" on lead wire conductors or sleeving during altitude/humidity exposure.

3.2.4.14 Structural Strength: All component parts of the solenoid valve shall have sufficient strength to withstand all loads or combination of loads resulting from hydraulic pressure, pressure impulse cycling, temperature, actuation, vibration, shock etc. that may be imposed during installation, transportation and operation under rated conditions. The ultimate stress allowables for metals shall be either as specified in MIL-HDBK-5 or 1.5 times the yield stress as described in MIL-HDBK-5, whichever is lower.

3.2.4.15 Threaded Parts and Retaining Methods: It shall be a design objective to minimize the use of threaded joints. The solenoid attachment bolts selected for the application shall be included during all qualification testing of 4.2. The thread form on all threaded parts subject to fatigue loading shall be in accordance with AS8879. A suitable root radius may also be specified as applicable. Threads conforming to ISO 261 may be acceptable providing their adequacy in fatigue is substantiated. All threaded parts shall be securely locked or safetied by safety wire, self locking nuts, or other devices approved by the Purchaser.

Segmented or swaged shear rings, and similar devices are preferred to threads. Staking, swaging, peening or any other means of permanent deformation and the use of lockwashers shall be specifically approved by the Purchaser. The use of snap or spring rings shall be prohibited except where failure of the ring will not affect the safety of the unit or the fluid system. No snap ring or spring ring used to fasten adjoining parts shall be loaded.

3.2.4.16 Orifice Protection: Filter screens shall be specified for protection of fixed orifices smaller than 0.070 in (1.78 mm) diameter in accordance with ARP4752 if required by the purchaser.

3.2.4.17 Seals: Seals, gaskets, and packings shall be of a material and installation as to satisfy the requirements of all applicable specifications and specified tests. If a specific seal compound is desired for fluid or environmental compatibility (such as AMS-P-83461 or NAS 1613), the specification for the compound shall be included. The cure date of elastomeric seals within the solenoid valve shall be clearly marked on the exterior of the valve housing, if required by the Purchaser.

Gland designs shall be per AS4716 unless specified by the purchaser. Packings with a cross-sectional diameter of less than 0.070 in (1.78 mm) are prohibited. Back-up rings in accordance with AS8791/1 shall be used on all radial static O-ring installations exposed to pressures greater than 1500 psi (10 MPa). Face seal configurations shall be approved by the Purchaser.

3.2.5 Hydraulic: The type of hydraulic system that the solenoid valve shall be designed to operate in along with any exceptions (such as fluid temperature for performance testing) is specified in this paragraph. As a design guide, AS5440 or ARP4752 is referenced.

3.2.5.1 Hydraulic Fluid: The test fluid (for example, MIL-PRF-83282, MIL-PRF-87257, or AS1241) and filtration level are specified in this paragraph. Exposure to other fluids, such as preservation oil or alternate test fluids shall also be specified.

3.2.5.2 Fluid Contamination: The solenoid valve shall meet all requirements of the Detail Specification when operating in the hydraulic fluid having contamination and cleanliness classification of Class 8 as determined by AS4059. A maximum in-service cleanliness classification may also be specified.

3.2.5.3 Operating Pressure: The nominal system supply and return pressures are specified in this paragraph.

3.2.5.4 Proof Pressure: The solenoid valve shall withstand, without evidence of external leakage or permanent performance degradation, the following proof pressures unless otherwise specified by the purchaser: 1.5 times supply pressure applied for 3 min to the pressure and control ports simultaneously with return open followed by supply pressure applied simultaneously to all ports for 3 min. Normally, proof pressure tests are applied at room temperature for production acceptance tests and at a maximum temperature for qualification tests. Proof pressure shall be applied at a maximum rise rate of 25,000 psi/min (172,000 kPa/min). Each condition shall be maintained for a minimum of 3 min unless otherwise specified by the purchaser without evidence of external leakage, loosening of parts, permanent set, degradation of performance or evidence of instability.

3.2.5.5 Burst Pressure: The solenoid valve shall not rupture with burst pressures of 2.5 times supply pressure applied to the pressure and control ports simultaneously with the return port open followed by 1.5 times the supply pressure applied simultaneously to all ports for a minimum of 3 min unless otherwise specified by the purchaser. Pressure shall be applied at a maximum rise rate of 25,000 psi/min (172,000 kPa/min.). Permanent deformation is allowed and the solenoid valve is not required to perform following this pressure application.

3.2.5.6 Pressure Variations: Often supply and return pressure variations or spikes are specified, depending on application requirements. The solenoid valve shall exhibit no instability as a result of changes in pressure and shall operate satisfactorily over the variation range specified.

3.2.5.7 Impulse Pressure: Pressure impulse requirements for solenoid valves are specified as necessary to satisfy system requirements. When specified, the solenoid valve shall be designed to withstand, without damage or performance degradation, the number of specified supply and return pressure impulse cycles wherein the pressure is cycled from 0 to the specified pressure to 0 psi. Part of the cycles should be specified in the energized mode and part in the de-energized mode. Impulse cycling is usually done at room temperature. The impulse testing parameters for testing in accordance with ARP1383 shall be specified.

Impulse pressure testing of a solenoid valve will impose severe fatigue cycles that permanently reduce useful solenoid valve life. As such, a solenoid valve that has successfully completed pressure impulse testing shall not be used for subsequent structural test evaluation, or for normal field operation.

3.2.5.8 High Pressure Design Considerations: Designs of solenoid valves to be used in high pressure applications up to 8000 psi (55,160 kPa) require special attention to material stress levels, magnetic properties of highly stressed materials, increased sensitivity to contamination and sealing. In general, as the design pressure increases, the overall solenoid valve package size is reduced.

In the design of high pressure actuation systems, it is usually the intent to scale down the size of the system elements in proportion to the increase in operating pressure. As pressure increases, for example, the effective area of the actuator driven by the solenoid valve fluid is proportionately reduced, assuming that the actuator force requirement does not change. The flow rate requirement of the solenoid valve, then, is also reduced by the same proportion. The end result is that the metering orifice size of the solenoid valve is significantly smaller with higher pressures.

Reduction in flow rate:

$$Q_2 = Q_1(P_1 / P_2) \qquad \text{(Eq. 1)}$$

where:

Q = flow rate
P = pressure at actuator

Reduction in orifice area:

$$A_2 = A_1(Q_2 / Q_1)(P_1 / P_2)^{1/2} \qquad \text{(Eq. 2)}$$

where:

A = orifice area

With a substantially reduced orifice size, orifice contamination becomes a greater concern. To overcome this, a finer filtration screen is usually specified.

Structural issues related to high pressure include valve rejection forces which tend to separate the valve from its manifold and pressure containment within the solenoid. As pressure is increased, the rejection force on the valve assembly usually increases, assuming that the design is such that supply pressure is exposed to the end of the valve tending to reject it from its housing. Offsetting this increased rejection force is the probability that the valve diameters will be somewhat smaller, as good structural design practice and manufacturing considerations permit.

3.2.5.8 (Continued):

If the actuation system requires that return pressure cavities and passages must withstand supply operating pressure as return proof pressure, then the internal solenoid plunger pressure vessel will have to withstand substantially greater loads. The solenoid plunger pressure vessel may be integral with the coil bobbin and usually is required to carry magnetic flux to the plunger. This area of the solenoid design must be carefully engineered to meet performance requirements while with-standing the specified cyclic pressure loads. Refer to 3.2.5.7 Impulse Pressure.

Sealing is another design consideration to contend with. For very high pressure non-metallic sealing, extrusion gap reduction may be required and seal back-up rings are used. These are usually specified by the Purchaser.

Careful design analysis and development testing is required to ensure that the final design dimensions and performance parameters will provide a robust, producible and cost effective design.

3.2.5.9 External Leakage: There shall be no allowable external leakage throughout all operational and environmental ranges and over the life of the solenoid valve unless otherwise specified by the purchaser.

3.2.5.10 Internal Leakage: Internal leakage shall be specified as the maximum allowable flow from pressure (P) to return (R) in either the energized condition (with the pressure port open to the control port for a normally closed design) or de-energized condition (with the control port open to return) and when subjected to operating supply pressure and over a specified temperature range. For military applications, the specified temperature range shall be -40 to +160 °F (-54 to +71 °C) for Type I systems and to 275 °F (135 °C) for Type II systems. The leakage shall be measured after a 2-min wait unless otherwise specified by the purchaser to allow time to drain the line and cavities down stream of the valve elements. An allowable leakage of 0.25 in^3/min (4 ml/min) is typically specified for an easily produced hard seat valve with a low end allowable leakage of 2 drops/min or less for a leakage critical application (20 drops = 1 ml).

3.2.5.11 Interflow: Interflow, the momentary internal leakage that occurs as the valve shuttles to vent control pressure to return, may be specified if the application requires. Typically, interflow is measured at the return port, with the cylinder port blocked, at operating pressure and with rated voltage applied. An allowable interflow maximum of 0.076 in^3 (1.25 ml) is typical. Interflow shall be collected for 10 cycles of actuation to improve accuracy of measurement.

3.2.5.12 Rated Flow: Rated flow is specified in both the energized and de-energized positions. Rated flow from pressure to control and from control to return are specified as gpm (L/min) minimum values or as a flow window for a specified pressure drop. Rated flow is normally measured at a reduced pressure differential consistent with the application. This typically ranges from 150 to 1000 psid (1000 to 7000 kPa). Rated flow requirements shall be specified at normal fluid and ambient temperatures. A suggested test set-up for this measurement is shown in Figure 4.

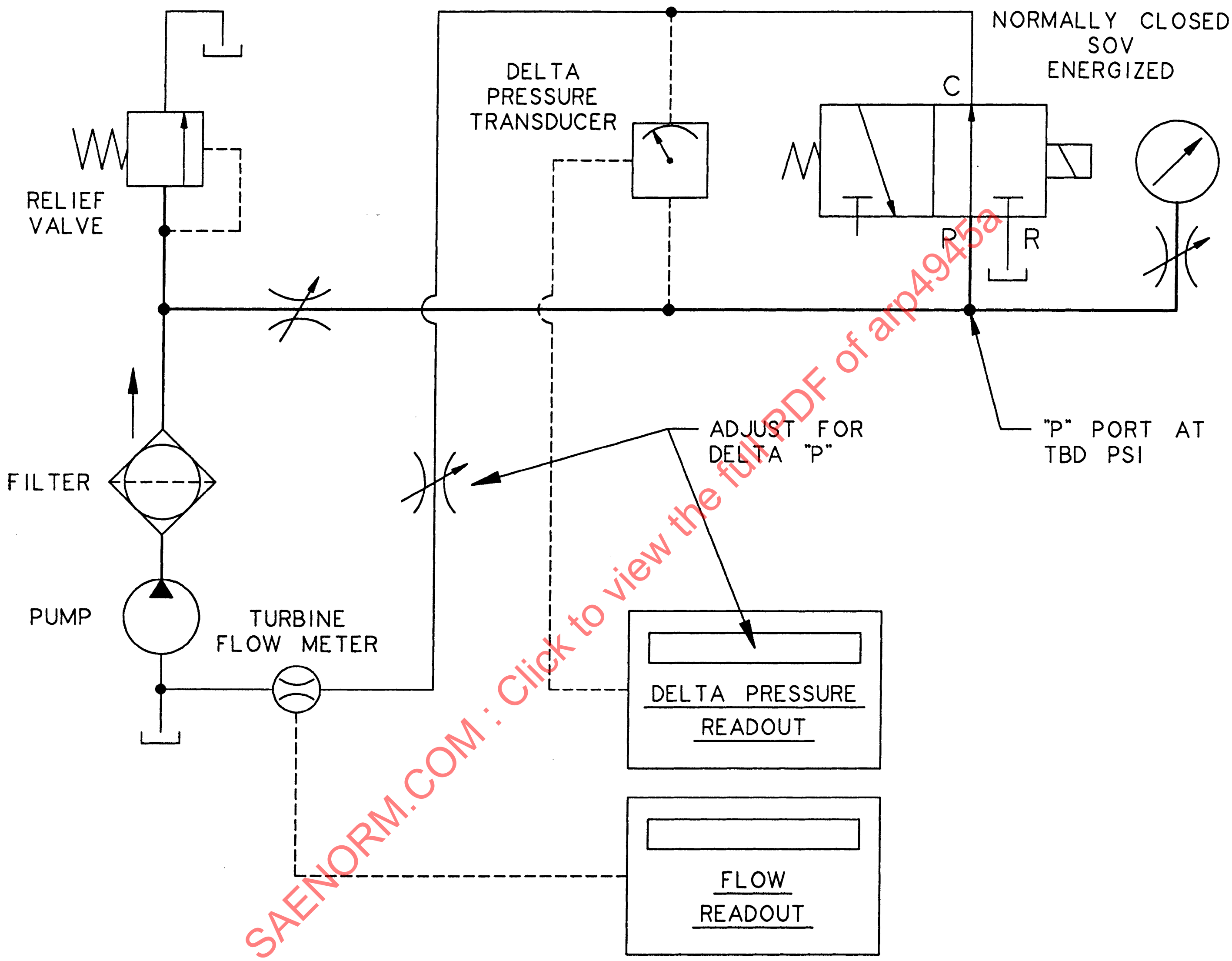

FIGURE 4A - Test Set-up for Rated Flow Measurement Pressure to Cylinder Ports

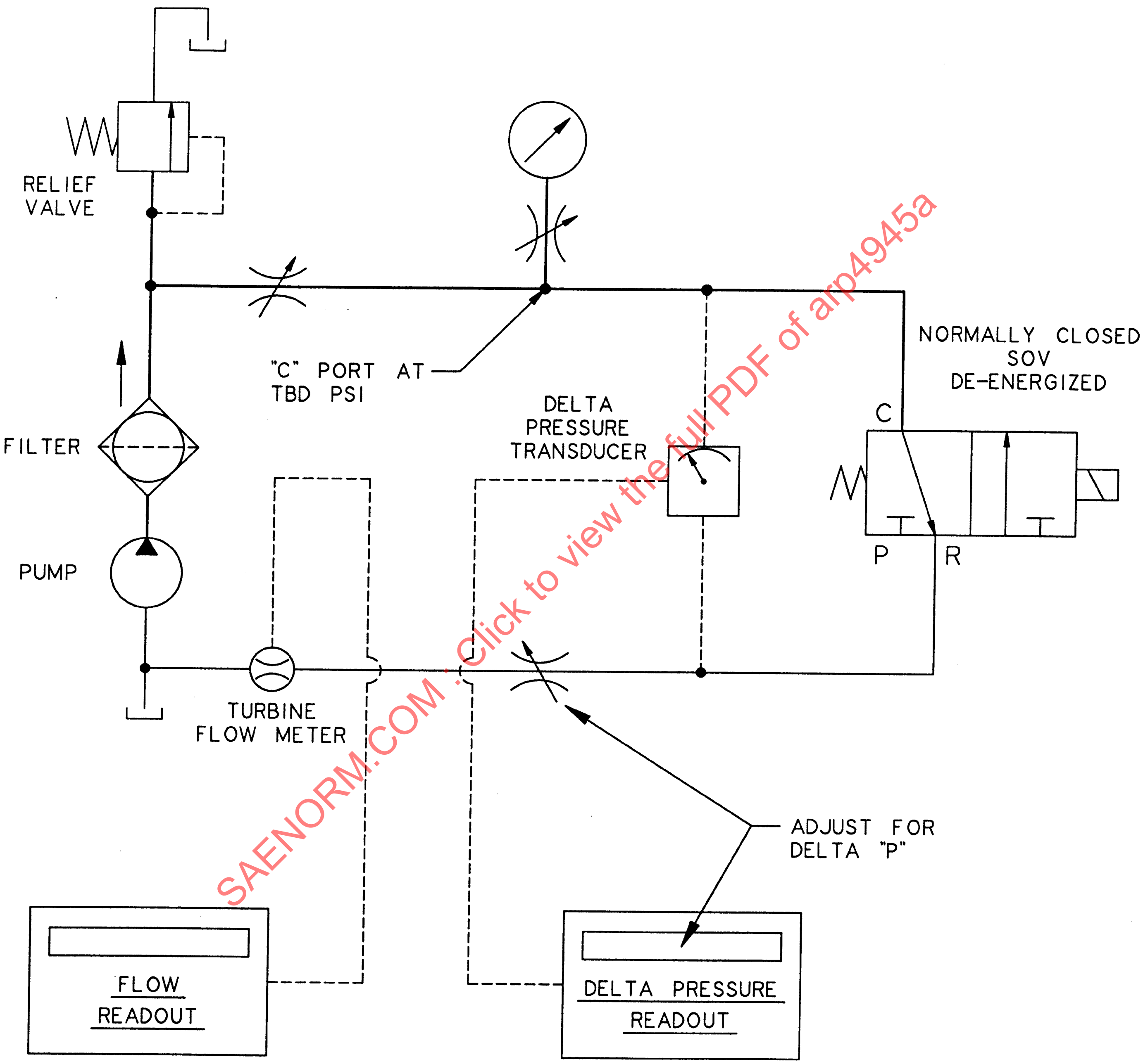

FIGURE 4B - Test Set-up for Rated Flow Measurement Cylinder to Return Ports

3.2.6 Electrical: The solenoid valve shall be designed to conform to the electronic equipment requirements of the specification. MIL-HDBK-5400 can be used for general guidelines.

3.2.6.1 Excitation: The excitation voltage requirement is specified in this paragraph along with the number of coils that shall be excited when performance is to be measured. Typically, the excitation voltage is 28 V DC nominal. Performance requirements are typically specified to apply over a range from 18 to 32 V DC. Power supplied shall be per MIL-STD-704.

3.2.6.2 Electrical Wiring: Electrical wiring requirements are typically defined in the specification and on the source control drawing. The electrical wiring references are MIL-DTL-16878, AS22759, and AMS-DTL-23053. If the design is to be supplied with lead wires rather than a connector, a pull test shall be specified to ensure adequate strain relief and prevent damage during attachment. It is recommended that internal wiring other than coil magnet wire be AWG 24 or larger. Lead wire shall be twisted in same coil pairs. In a multiple coil design, wiring from each coil within the solenoid valve shall be physically separated to preclude loss of more than one channel due to electrical arcing, excessive current, wire chafing, crack propagation, or other damage to the extent possible. Coils shall be suitable taped, impregnated, potted and secured to the frame as required to prevent damage from humidity, salt fog, vibration, and other environmental conditions in accordance with AS40401. Prevention of moisture intrusion during long term humidity exposure and during altitude cycling is critical. If applicable, connector requirements, including receptacle and plug part numbers are typically specified on the source control drawing.

3.2.6.3 Coil Connections: The external wiring configuration for the solenoid coils shall be as shown in Figure 5 and specified on the Source Control Drawing or in the specification, along with the connector pin identification or lead wire color coding per MIL-STD-681 as applicable. Coil connections for single and multiple coil designs shall be as shown in Figure 5.

3.2.6.4 Performance: This paragraph states the duty cycle conditions for the solenoid valve when installed in the system. In the use of multiple coil designs, or even single coil designs, it is important to know how the valve is to be used, i.e., continuously energized, intermittently energized, all coils energized simultaneously, etc. Often, a "holding" current or voltage significantly less than pull-in is specified. The solenoid valve must be designed for the specific temperature rise that will result. As an example of the problem this presents in multiple coil designs, a valve with all coils energized at full voltage and at maximum temperature, even though designed for subsequent stabilized temperature rise, when de-energized and then re-energized may not function with fewer than all coils active. In the extreme, it is conceivable that it may not function with all coils active.

Also included in this paragraph are the rated supply and return pressures and the rated fluid and ambient test conditions under which the performance requirements apply.

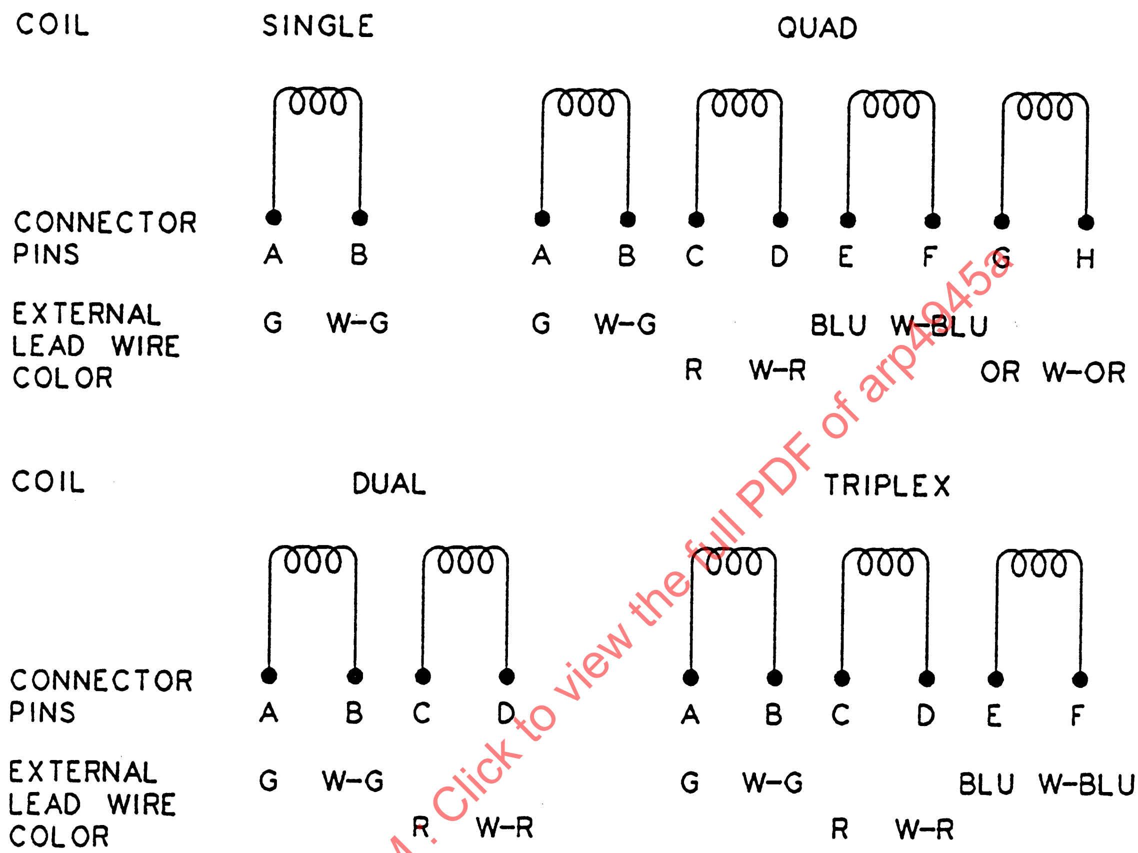

FIGURE 5 - Connector Pin Identification and Wire Color Coding

3.2.6.5 Rated Current: Rated current at 68 °F (20 °C) shall be stated as amps/coil. Specifying rated current and resistance combinations less than those recommended by the Seller may require the solenoid valve to be designed with less than optimum electrical power. In general, a very low value for rated current requires the use of extremely fine magnet wire, resulting in greater manufacturing losses and reduction in reliability.

3.2.6.6 Coil Resistance: The DC resistance of the solenoid coil or coils shall be left unspecified or specified as a minimum. If a nominal value is required by the application, a ±10% tolerance for individual coil resistance shall be specified at a temperature of 68 °F (20 °C).

3.2.6.7 Insulation Resistance: Insulation resistance is specified between solenoid coil lead wires (or connector pins) and the valve body/ground and between the individual coils for multiple coil designs. The applicable test reference is Method 302 of MIL-STD-202. The resistance value shall not be less than 100 MΩ at a test voltage of 500 V DC, applied for 2 min under room temperature and humidity conditions unless otherwise specified by the purchaser.

3.2.6.8 Dielectric Strength: Dielectric withstanding voltage is specified between mutually insulated circuits and between insulated circuits and ground. The applicable test reference is Method 301 of MIL-STD-202. The solenoid valve shall be capable of withstanding without damage or breakdown, a minimum of 25 applications of 1050 V AC, 60 Hz for 1 min at an ambient pressure equal to 70,000 ft (21,000 m) altitude (as applicable). Any arc-over (air discharge), flashover (surface discharge or breakdown (puncture discharge) at the specified test voltage shall constitute a failure. Failure may be evidenced by fluctuations in the leakage current, a steady increase in the leakage current, or more than twice the normal leakage at the specified test voltage as established by a sample lot. Repeated applications of high voltage to the solenoid valve may eventually break down the coil insulation, so a maximum number of tests shall be specified or a reduced rate for subsequent tests.

3.2.6.9 Transient Suppression: Negative voltage transients during switching are suppressed by incorporating diodes across the wires of each coil. This may be accomplished within the unit if required. Negative voltage transients shall be specified as a not to exceed voltage or as not exceeding the limitations specified under the Electromagnetic Interference and Compatibility requirement of 3.2.6.10. The diodes incorporated within the solenoid valve shall be specified as being capable of withstanding a 600 V peak inverse voltage.

3.2.6.10 Electromagnetic Interference and Compatibility (EMIC): EMIC requirements are usually demonstrated during the "actuation system level" testing of the applicable actuation system. The Seller is usually not expected to be involved with this effort other than to incorporate appropriate EMIC design features to aid in meeting the specified limits.

If required by the Buyer, EMIC requirements may be specified. The extent of the requirements should be carefully considered before specifying due to the unique test equipment/facility that may be required to verify performance. If EMI requirements are specified, the solenoid valve is typically designed (using the guidelines of AFSC DH 1-4) to comply with MIL-STD-461.

No degradation of performance shall occur when the input leads are bundled together through their entire length with a wire carrying a 600 V minimum peak-to-peak relay switching transient. The magnetic effect of each solenoid coil shall be equal, or less than that specified in AS40401 when measured at a distance of two inches and greater from the solenoid case.

3.2.6.11 Electrical Bonding: If required by the application, electrical bonding shall be specified such that a sufficiently low resistance path from the connector bulkhead to the solenoid valve mounting surface designated on the source control drawing is maintained. Reference MIL-STD-464.

3.2.6.12 Pull-in Voltage: This paragraph specifies the maximum voltage per coil that is required of the solenoid valve at a specified temperature and pressure to shuttle the valve. Typically this is 18 V DC at a temperature corresponding to continuous operation at 28 V DC applied to all coils in a specified ambient environment and with a specified fluid temperature. For military applications, the specified ambient environment shall be 140 °F (60 °C) with the fluid temperature at 160 °F (71 °C) for a Type I system or 160 °F (71 °C) ambient and with the fluid temperature at 275 °F (135 °C) for a Type II System. Pressure should be specified at the extreme of the operating pressure range that results in the highest minimum operating voltage.

3.2.6.13 Drop-out Voltage: This paragraph specifies the minimum voltage per coil that may be sustained by the solenoid valve at a specified temperature and pressure before valve deactivation occurs. For military applications, this typically is 2.0 V DC at a temperature corresponding to continuous operation at 28 V DC applied to all coils in an ambient environment of -65 °F (-54 °C) and with the fluid temperature at 20 °F (-7 °C) for either a Type I or Type II system. Pressure should be specified at the extreme of the operating pressure range that results in the lowest maximum operating voltage.

3.2.6.14 Pull-in Response Time: This paragraph specifies the time required of the solenoid valve from the application of excitation voltage to the point where control pressure has increased to 80% of the supply level (normally closed design), at the specified supply pressure and temperature and with a specified number of active coils. Refer to Figure 6. Usually this is specified for a blocked control port but may be specified for a specific downstream impedance if the application performance requires. This will also avoid potentially damaging pressure spikes that may be realized with a blocked control port. A typical pull-in response time is 40 ms maximum. A suggested test set-up for this measurement is shown in Figure 7.

3.2.6.15 Drop-out Response Time: This paragraph specifies the time required of the solenoid valve from removal of excitation voltage to the point where control pressure has dropped to 20% of the supply level (normally closed valve), at the specified supply pressure and temperature and with a specified number of active coils. Usually this is specified for a blocked control port but may be specified for a specific downstream impedance if performance requires. A typical drop-out time is 30 ms maximum. A suggested test set-up for this measurement is shown in Figure 7.

3.2.7 Environmental Requirements: These paragraphs specify the environmental requirements for the solenoid valve. The solenoid valve shall not suffer damage, deterioration, or degradation of structural integrity, dynamic or functional performance, longevity or reliability beyond the limits of the specification when subjected to any environment or natural combination of environments specified and in MIL-HDBK-310 and tested in accordance with applicable procedures of MIL-STD-810 or RTCA-DO-160.

To avoid duplication of requirements, test description references are made to MIL-STD-810 only.

The solenoid valve shall be designed to have a shelf life of 10 years, with the supplier identifying those items requiring replacement within the time interval specified.

3.2.7.1 Temperature: The normal room temperature ambient and fluid temperatures for test purposes shall be:

a. Ambient:

60 to 100 °F
(15 to 38 °C)

b. Fluid:

80 to 120 °F
(27 to 49 °C)

The solenoid valve shall be capable of meeting the requirements of the specification during and after exposure to the following temperatures as shown in Table 1.

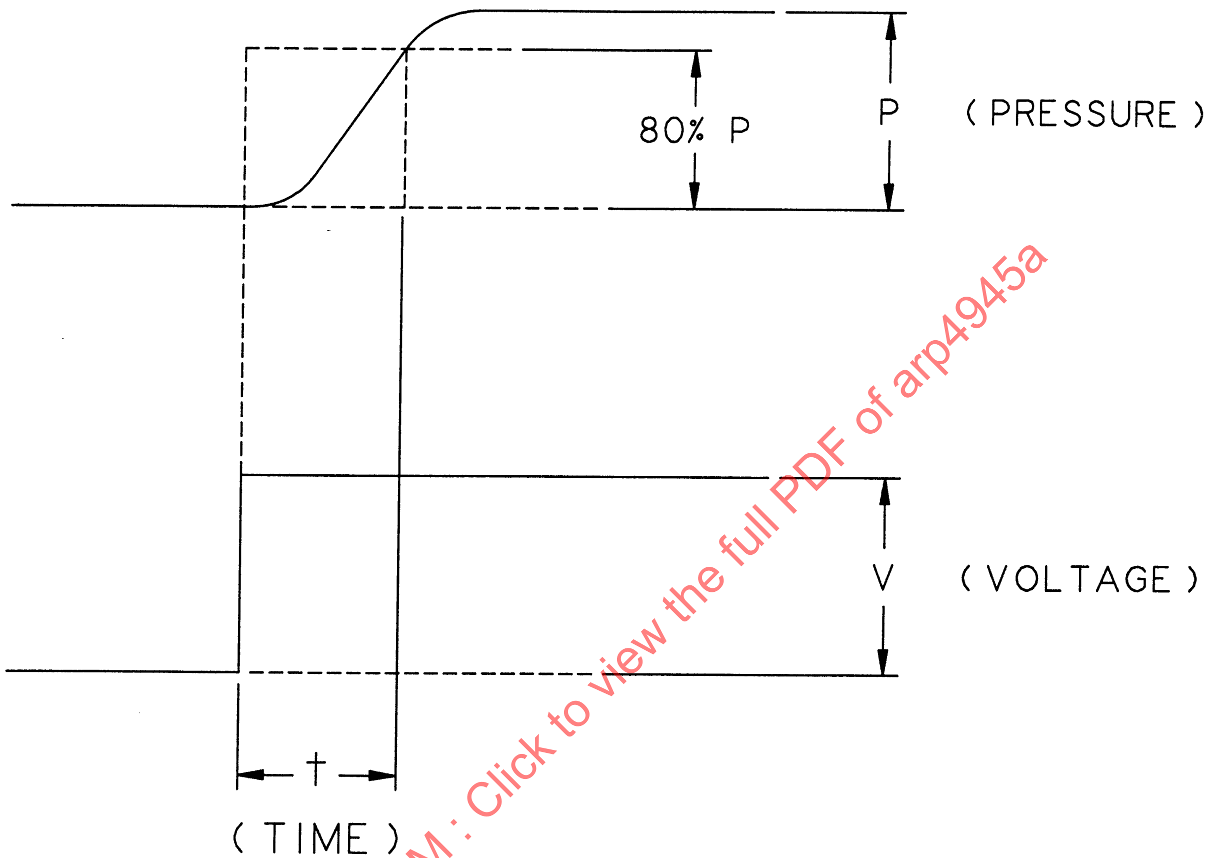

FIGURE 6 - Response Time Trace Measurement

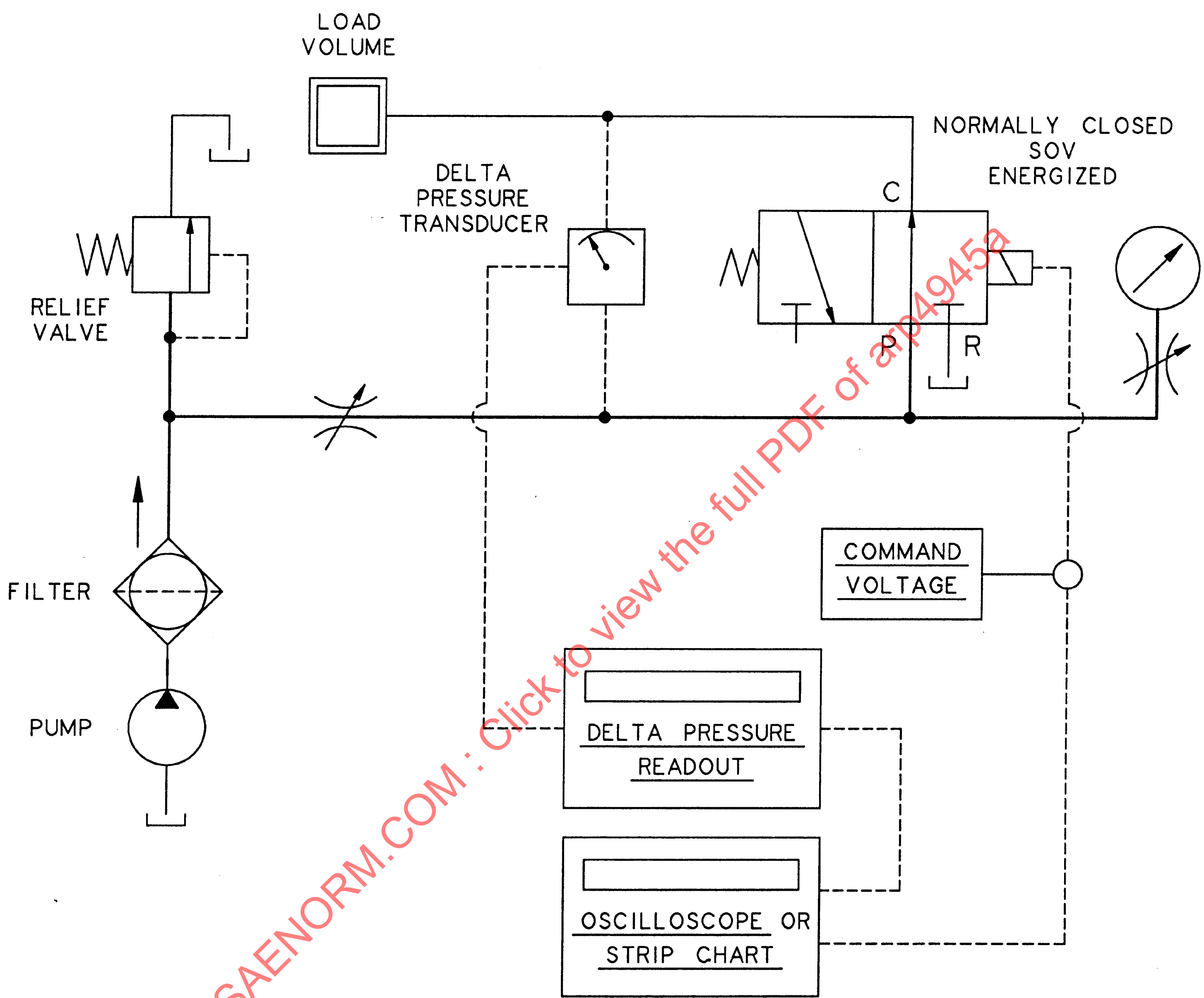

FIGURE 7 - Test Set-up for Response Time

TABLE 1

	Military Type I System	Military Type II System	Commercial System	Condition
Environmental Ambient:				
	-65 to +140 °F (-54 to +60 °C)	-65 to +160 °F (-54 to +71 °C)	-65 to +160 °F (-54 to +71 °C)	Continuous
	160 °F (71 °C)	275 °F (135 °C)		for 10 min
	225 °F (107 °C)	365 °F (185 °C)		for 1 min
Fluid:				
	20 to 160 °F (-7 to +71 °C)	20 to 275 °F (-7 to +135 °C)	-20 to +175 °F (-29 to 79 °C)	Continuous
	-40 to +20 °F (-40 to -7 °C)	-40 to +20 °F (-40 to -7 °C)		Continuous with degradation of performance allowed
Temperature Shock:				
	-40 to +140 °F (-40 to +60 °C)	-40 to +160 °F (-40 to +71 °C)		in 200 s
Storage:				
	-80 to +140 °F (-62 to +60 °C)	-80 to +160 °F (-62 to +71 °C)		

3.2.7.2 Altitude: The solenoid valve shall be capable of meeting the requirements of the specification during and after exposure to pressures encountered from sea level to 70,000 ft (21,000 m) altitude with a maximum rate of change of 60,000 ft (18,000 m) per minute.

3.2.7.3 Explosive Atmosphere: The solenoid valve shall not cause ignition of an ambient-explosive-gaseous mixture with air when operated in such an atmosphere.

3.2.7.4 Temperature Shock: The solenoid valve shall be capable of meeting the requirements of the specification during and after exposure to the temperature shock test described in MIL-STD-810, Method 503.3, Variation I.

3.2.7.5 Humidity: The solenoid valve shall be designed to meet the requirements of the specification when subjected to the humidity effects described in MIL-STD-810, Method 507.3, Procedure III.

3.2.7.6 Fungus: The solenoid valve shall be designed to meet the requirements of the specification when subjected to the fungus test described in MIL-STD-810, Method 508.4.

3.2.7.7 Salt Fog: The solenoid valve shall be designed to meet the requirements of the specification when subjected to the salt fog test as described in MIL-STD-810, Method 509.3, Procedure I.

3.2.7.8 Sand and Dust: The solenoid valve shall be designed to meet the requirements of the specification when subjected to the sand and dust test as specified in MIL-STD-810, Method 510.3, Procedures I & II.

3.2.7.9 Immersion: The solenoid valve shall be capable of meeting the performance requirements of the specification after immersion in the hydraulic fluid at the specified temperature and time. For military applications, the specified temperature shall be 160 °F (71 °C) for a Type I System, or 275 °F (135 °C) for a Type II System for 72 h.

3.2.7.10 Vibration: When installed, the solenoid valve shall be capable of meeting the requirements of the specification during vibration of 60 min duration in each of three mutually perpendicular axes at the levels specified by the Purchaser. One axis shall be along the centerline of the solenoid plunger.

The solenoid valve shall also be capable of meeting the requirements of the specification after being subjected to one million cycles at each resonant frequency in each axis.

3.2.7.11 Shock: The solenoid valve shall meet the requirements of the specification after exposure to the functional shock spectrum specified in accordance with MIL-STD-810, Method 516.4.

3.2.7.12 Operational Service Life: The solenoid valve shall be designed for an operational service life of not less that 100,000 cycles. Operational service life is defined as the point where overhaul or repair cost exceeds 65% of the replacement cost.

3.2.7.13 Human Factors Engineering: The requirements for applying the principles and criteria for human factors engineering shall be in accordance with MIL-STD-1472 and AFSC DH 1-3.

4. QUALITY ASSURANCE PROVISIONS:

4.1 General:

The solenoid valve shall be subjected to verification to demonstrate compliance with the specification. Acceptance of items under the verification provisions specified herein shall not relieve the Supplier of responsibility to meet all other requirements of the specification.

4.1.1 Requirements Verification Methods: All requirements contained in Section 3 of the specification shall be verified by using one or more of the following methods:

a. Inspection: Visual verification that the item, as manufactured, conforms to the design documentation. This includes measurement of dimensions, surface finish, contamination, and similar physical characteristics.

b. Analysis: Verification that a requirement is met by technical evaluation of data, theoretical analysis or review of detail design specification.

c. Test: Verification that a requirement is met by a thorough exercise of the applicable item under appropriate conditions in accordance with approved test procedures.

Successful completion of these verifications shall not relieve the Seller of supplying units with the specified performance or level of reliability during subsequent testing or service use, nor can it be used as proof that the unit will perform as specified on the aircraft. Final verification shall be determined by unit operation as installed on the aircraft during service use.

NOTE: The requirements for conducting any of the tests to verify the requirements of Section 3 may be waived if the design can be verified by analysis or by similarity to an existing design which has been verified to meet the stated requirements.

4.1.2 Conformance Verification: A Quality Conformance Matrix is shown as Figure 8. This matrix provides accountability for each Section 3 requirement, the corresponding Section 4 verification requirement and the method of verification.

Para.	Section 3 Requirements	Verification Category			Verification Method			Verification Para.
		N/A	Qual	Accept	Anal	Insp	Test	
3.2.2	Requirements	X						
3.2.3	Design Requirements	X				X		4.2.2
3.2.4	Mechanical	X						
3.2.4.1	Workmanship		X			X		
3.2.4.2	Physical Description		X			X		4.2.2
3.2.4.3	Identification			X		X		
3.2.4.4	Weight		X				X	
3.2.4.5	Installation and Adjustments		X			X		
3.2.4.6	Attitude		X				X	4.2.4
3.2.4.7	Materials		X		X		X	4.2.4
3.2.4.8	Moisture Resistance		X			X	X	4.2.4
3.2.4.9	Metal		X		X		X	4.2.4
3.2.4.10	Non-Metallic Materials		X		X		X	4.2.4
3.2.4.11	Castings and Forgings		X			X	X	4.2.4
3.2.4.12	Protective Treatment		X			X	X	4.2.4
3.2.4.13	Encapsulation and Potting		X			X	X	4.2.4
3.2.4.14	Structural Strength		X		X		X	4.2.4
3.2.4.15	Threaded Parts and Retaining Methods		X			X	X	4.2.4
3.2.4.16	Orifice Protection		X			X		
3.2.4.17	Seals		X	X	X		X	4.2.4 & 4.5.5
3.2.5	Hydraulic	X						
3.2.5.1	Hydraulic Fluid	X						
3.2.5.2	Fluid Contamination	X						
3.2.5.3	Operating Pressure		X	X			X	4.2.4. & 4.5.5
3.2.5.4	Proof Pressure		X	X			X	4.2.4 & 4.5.5
3.2.5.5	Burst Pressure		X				X	4.2.4.12
3.2.5.6	Pressure Variations		X				X	4.2.4
3.2.5.7	Impulse Pressure		X				X	4.2.4.15
3.2.5.8	High Pressure Design Considerations	X						
3.2.5.9	External Leakage		X	X			X	4.2.4 & 4.5.5
3.2.5.10	Internal Leakage		X	X			X	4.5.5, 4.2.4 & 4.5.5
3.2.5.11	Interflow		X				X	4.2.4
3.2.5.12	Rated Flow		X	X			X	4.2.4 & 4.5.5
3.2.6	Electrical	X						
3.2.6.1	Excitation	X						
3.2.6.2	Electrical Wiring		X			X		

FIGURE 8 - Quality Conformance Matrix

Para.	Section 3 Requirements	Verification Category			Verification Method			Verification Para.
		N/A	Qual	Accept	Anal	Insp	Test	
3.2.6.3	Coil Connections			X			X	
3.2.6.4	Performance	X						
3.2.6.5	Rated Current		X	X			X	
3.2.6.6	Coil Resistance		X	X			X	
3.2.6.7	Insulation Resistance		X	X			X	4.2.4.17 & 4.5.5
3.2.6.8	Dielectric Strength		X	X			X	4.2.4.18 & 4.5.5
3.2.6.9	Transient Suppression		X				X	4.2.4.19
3.2.6.10	Electromagnetic Interference and Compatibility	X						
3.2.6.11	Electrical Bonding			X			X	4.5.5
3.2.6.12	Pull-in Voltage		X	X			X	4.2.4.20 & 4.5.5
3.2.6.13	Drop-out Voltage		X	X			X	4.2.4.21 & 4.5.5
3.2.6.14	Pull-in Response Time		X	X			X	4.5.5
3.2.6.15	Drop-out Response Time		X	X			X	4.5.5
3.2.7	Environmental Requirements	X						
3.2.7.1	Temperature		X				X	4.2.4
3.2.7.2	Altitude		X				X	4.2.4.4
3.2.7.3	Explosive Atmosphere		X				X	4.2.4.7
3.2.7.4	Temperature Shock		X				X	4.2.4.3
3.2.7.5	Humidity		X				X	4.2.4.11
3.2.7.6	Fungus		X				X	4.2.4.8
3.2.7.7	Salt Fog		X				X	4.2.4.5
3.2.7.8	Sand and Dust		X				X	4.2.4.6
3.2.7.9	Immersion		X				X	4.2.4
3.2.7.10	Vibration		X				X	4.2.4.10
3.2.7.11	Shock		X				X	4.2.4.9
3.2.7.12	Operational Service Life		X				X	4.2.4.13
3.2.7.13	Human Factors Engineering	X						

FIGURE 8 (Continued)