SAE INTERNATIONAL

AEROSPACE RECOMMENDED PRACTICE

ARP492™ REV. C

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Reaffirmed 2021-03

Superseding ARP492B

Aircraft Engine Fuel Pump Cavitation Endurance Test

RATIONALE

ARP492C has been reaffirmed to comply with the SAE five-year review policy.

1. SCOPE:

1.1 This SAE Aerospace Recommended Practice (ARP) defines procedures for testing aircraft engine fuel pumps for the purpose of determining their resistance to deterioration, during steady state endurance test, while receiving MIL-T-5624 Grade JP-4 fuel as a homogenous mixture of gas and liquid expressed as a ratio of vapor volume to liquid volume (V/L).

If any of the above conditions do not apply, refer to Section 2.

1.2 The procedure recommended herein is based on experience gathered by a number of laboratories conducting component qualification tests to MIL-E-5009, currently MIL-E-5007. It is intended to produce a uniform reproducible steady state test condition for fuel pump cavitation testing as required by various military engine specifications.

1.3 This test is NOT intended to establish altitude, climb rate, starting, or other transient performance of the article tested.

1.4 PURPOSE:

1.4.1 This procedure is intended to apply to all pumps downstream of engine inlet.

1.4.2 The procedure will be defined in terms of recommended test setups and recommended testing methods.

1.4.3 Two methods of determining V/L are provided.

CAUTION: Operation at low line velocities may result in nonhomogeneous flows and cause erratic or incorrect readings.

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https://www.sae.org/standards/content/ARP492C

1.4.3.1 Method I - V/L Meter: When using this method, the vapor-to-liquid ratio is sensed in a measuring section installed in inlet line upstream of the pump as shown in Figure 1. The vapor-to-liquid ratio is assumed to be the indicated volume flow rate vapor-to-liquid ratio and is read out as V/L on a meter dial.

1.4.3.2 Method II - V/L Calculation: This method assumes that an equilibrium mass flow rate of dissolved air evolves from the flowing air saturated liquid fuel in accordance with Henry's Law for solution of gases in liquids. The volume flow rate vapor-to-liquid ratio is then calculated from the mass flows in accordance with Dalton's Law of Partial Pressures, the Perfect Gas Law and the liquid fuel thermal expansion behavior. The necessary calculations are described in Appendix A.

CAUTION: At low pump inlet pressures and/or high fuel temperatures, special care must be taken to obtain accurate readings of the test data that enter the V/L calculation. As can be seen from the V/L equation in Appendix A, a primary factor in the V/L calculation is the ratio of two pressure differentials measured during the test. If these pressure differential are small, as is the case when the tank pressure.P_1 (and, therefore, the pump inlet pressure P_2) is close to the absolute true vapor pressure of the fuel, P_{TVP}, even small errors in the measurements will cause large errors in the calculated value of V/L. A good practice in this connection would be the inclusion of note(s) on the test sheet calling attention to data points taken at low values of (P_1-P_{TVP}) together with the attendant estimated possible error in the calculated V/L resulting from measurement errors.

1.4.3.3 Recommended V/L Meters: Recommended V/L meters are listed in Appendix B.

1.5 Within this document the term "pump inlet" shall define the fuel inlet port of the complete system to be tested. If lines or other components are placed upstream of the inlet of the actual pumping component by specific test requirement, such as to provide an engine inlet, they shall be part of the complete system to be tested.

2. APPLICABLE DOCUMENTS:

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

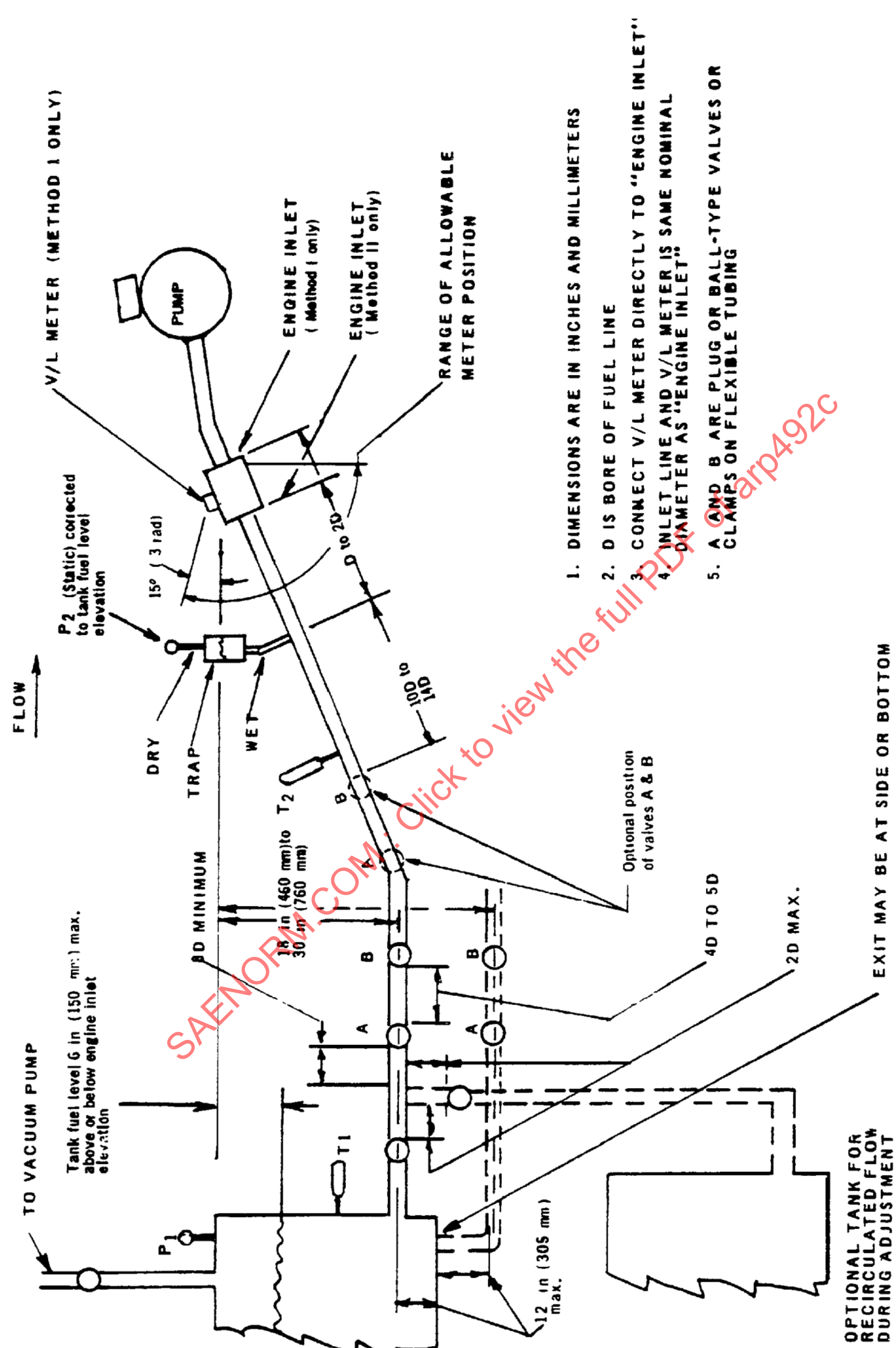

FIGURE 1 - Test System

2.1 SAE Publications:

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

AIR1326 Aircraft Fuel System Vapor-Liquid Ratio Parameter
ARP4024 Aircraft Engine Fuel Pump Net Positive Suction Pressure Performance Test (For low inlet pressure conditions which maintain the fuel in liquid form rather than a mixture of gas and liquid
ARP4026 (DRAFT) Aircraft Engine Fuel Pump Special Fuels Cavitation Endurance and Net Positive Suction Pressure Performance Tests (For fuels other than MIL-T-5624 GRADE JP-4 fuel)
ARP4028 Aircraft Engine Fuel Pump Two Phase (Slugging Flow) Inlet Performance Test (For when the gas and liquid mixture is NOT a homogenous solution)

3. GENERAL REQUIREMENTS:

3.1 Fuel:

MIL-T-5624, Grade JP-4

3.1.1 Fuel Temperature:

a. T_1 in supply tank: ±1 °F (0.5 °C) of T_2 at the pump inlet
b. T_2 at pump inlet: In accordance with the specific test requirement

3.1.2 Fuel Pressure:

a. P_1 at fuel surface in supply tank: In accordance with the specific test requirement
b. P_2 at pump inlet: Depressed below P_1 as required to produce the required V/L
c. P_3 at pump discharge: In accordance with the specific test requirement, which typically will be the engine fuel system pressure required for the specified metered flow

3.1.3 Fuel Flow: System discharge and pump bypass flows shall be in accordance with the specified test requirements.

3.2 Inlet V/L Condition:

In accordance with the specific test requirements.

3.3 Duration of Endurance Test:

In accordance with the specific test requirements.

3.4 Pump Speed:

In accordance with the specific test requirement and, in general, will be an intermediate rated speed for the pump application.

4. DETAIL REQUIREMENTS:

4.1 Test Setup:

The equipment should be in accordance with Figure 1 subject to the limitations provided herein.

4.1.1 Fuel Tanks:

4.1.1.1 Shape of the tank is optional.

4.1.1.2 Insulation of the tank is optional. During cavitation test, the temperature difference between T_1 and T_2 should not exceed 1 °F (0.5 °C).

4.1.1.3 The minimum quantity of fuel shall be a volume equivalent to the system discharge flow for 2 min plus 15 gal (57 L). The maximum quantity of fuel shall be a volume equivalent to the system discharge flow for 5 min plus 15 gal (57 L). The system discharge flow shall be as defined by 3.1.3. The tank volume shall be at least 1.1 times the fuel volume.

4.1.2 Inherent Pressure Loss: The pressure loss from P_1 to P_2 should not exceed 2 in (50 mm) Hg at the test flow rate with the inlet line throttle valve(s) fully open.

4.1.3 Downstream Test Equipment:

4.1.3.1 A pump bypass line and valving may be provided as necessary to control system discharge flow in a manner consistent with the pump/control installation for the applicable engine.

4.1.3.2 Any other elements of the engine fuel system downstream of the pump which have an effect on the pump inlet conditions should be simulated.

4.1.3.3 Care should be taken to assure that the tank return flow is returned below the fuel surface and does not interfere with the tank to inlet line flow. The tank return point should be as isolated as possible from the tank to inlet connection and under no condition closer than 6.0 inch (150 mm) to the tank to inlet connection.

4.1.4 Additional Test Equipment: All necessary devices for testing, other than already described, may be placed in the test system as required other than in the inlet line.

4.2 General Procedure for Testing:

4.2.1 Test setup should conform to 4.1.

4.2.2 Preparation for Test:

4.2.2.1 Prior to cavitation endurance testing, check the leakage of the fuel system from the supply tank to the test system as follows: Without operating the test pump, depress tank pressure to estimated pump inlet pressure required for the cavitation test or lower, then close the vacuum supply line and observe tank pressure. A recommended rate of pressure increase is 0.4 in (10 mm) Hg/h to 0.6 in (15 mm) Hg/h maximum. Repair leaks as required. This check may be made with a slave pump in place of the test pump providing the pump inlet connection that must be disconnected for installing the test unit provides a positive seal and that steps are taken to as sure that the test pump or components do not introduce new fuel system leaks.

4.2.2.2 The pump or component to be tested shall have fluid passed through it at flows and contamination level and time period as required by the specific test requirements prior to setting of any cavitation test conditions. This precontamination may be performed on a test setup separate from the V/L test setup.

4.2.2.3 In the heating cycle, the test pump may be used for circulating fuel. The rate of heat addition to the fuel mass in the tank should not exceed 4 °F (2 °C) per minute. A record of fuel temperature during the heating cycle should be maintained and included with the test data. At no time during the heating cycle should the tank fuel temperature exceed 5 °F (2.5 °C) above test temperature. Gradually, over a 10 min period, reduce the tank pressure above the fuel surface to the specified value.

4.2.2.4 With the inlet line throttle valve(s) open wide, with the fuel temperature maintained, establish the speed, flow and discharge pressure conditions for the test.

4.2.2.5 Adjust the inlet throttle valve(s) to obtain the desired V/L ratio. When using the two valve inlet throttling configuration, adjust valves A and B uniformly to maintain approximately the same valve opening. Any further adjustments to maintain the desired inlet pressure should be made with the upstream valve, A. Obtain an initial fuel sample for RVP determination.

4.2.3 Endurance Testing:

4.2.3.1 Operate the test system at the required conditions for the required time period. Maintain the test conditions within the following limits during the entire endurance period.

a. T_1: ±3 °F (1.5 °C)
b. T_1-T_2: ±1 °F (0.5 °C)

4.2.3.1 (Continued):

c. P_1: ±0.1 in (2.5 mm) Hg
d. P_2: As required to maintain the required V/L
e. V/L at Pump Inlet: Maintain at the required level or higher
f. Absolute Fuel RVP: 2 psi (13.8 kPa) minimum
g. System Discharge Flow: +10%, -0, or as specified
h. Bypass Flow: As required to maintain system discharge flow
I. Pump Discharge Pressure: +4%, -0, or as specified

4.2.3.2 Test fuel may be emptied and replaced as necessary to maintain test conditions.

4.2.3.3 The following data should be recorded at intervals not exceeding 1 h.

a. Inlet fuel temperature and pressure T_2 and P_2
b. Tank pressure above fuel (in (mm) Hg abs.) P_1 and fuel temperature T_1
c. Pump discharge temperature and pressures T_3 and P_3
d. System discharge flow
e. V/L ratio, if Method I is used
f. Time of day
g. Pump speed
h. Barometer
I. Bypass flow, plus any other flow(s) supplied by the pump which have an effect on the pump inlet conditions should be recorded

4.2.3.4 The following additional data shall be recorded initially and at least every 12 h when Method II is used for V/L determination. RVP checks shall also be made when Method I is used to assure that the fuel RVP does not fall below the required minimum.

a. RVP of fuel
b. Distillation test at 5% and 15% points
c. Specific gravity

4.2.3.5 For Method II testing, Calculation of vapor liquid ratio shall be according to Appendix A.

5. SUGGESTED TESTING TECHNIQUES:

5.1 Insulation of the tank and lines may be necessary to provide temperature stability.

5.2 Adjustments to inlet pressure may be made by very slight adjustments of flow instead of by readjusting the setting on the upstream throttle valves. System discharge flow must be maintained within specified limits.

5.3 The inlet side of the test system must be reasonably airtight to minimize fuel weathering as a result of vapor loss entrained in the air through flow to the vacuum system and to assure accurate test results.

5.4 A test tank with adjustable elevation will provide flexibility for meeting the requirements of test fuel volume and fuel level elevation.

5.5 A plastic gage line may be used to connect the P_2 pressure gage instead of the gage trap shown in Figure 1 to observe fuel level allowing for fluid head correction.

5.6 The fuel line must be arranged to avoid either separated or slugging type flow. Transparent piping may be used for viewing sections. The inlet line, including the inlet throttle valve(s), should be substantially the same size as the engine inlet. Any transition in line size should be gradual.

5.7 V/L determination by the Method II calculation assumes equilibrium conditions both in the tank and at the engine inlet and the change in equilibrium conditions accounts for the evolution of air/vapor. The application of line loss in the throttle valve(s) should be as gradual as possible to minimize local low pressure regions that could cause evolution of air/vapor that would not be either reabsorbed or accounted for at the engine inlet.

5.8 A cooling arrangement may be added to the vacuum system line to allow the condensation and return of vapor to the fuel tank.

5.9 It may be necessary to avoid a horizontal V/L meter sensing element installation where inside diameter differences between the sensing element and inlet line can allow vapor to be trapped within the sensing element. Tilting the V/L meter sensing element; e.g., 15°, from horizontal may be necessary to prevent erroneous readings due to retained vapor.

5.10 If using Method II to calculate V/L, the calculated value of the V/L must be up dated as the TVP degrades, i.e., the fuel "weathers", during the test.

5.11 It may be desirable to take RVP samples at intervals of 8 h or less in the initial portion of the endurance test to establish the change in RVP versus time to assure that the calculated V/L is maintained at the specified value.

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APPENDIX A
CALCULATION OF V/L RATIO

A.1 Introduction:

A.1.1 The V/L ratio (vapor volume to liquid volume ratio) at the inlet of the pump may be determined by calculation as outlined below. A uniform method of determining V/L ratio is needed to insure repeatable results for tests performed in various laboratories. Because of the possible differences in the assumptions and approximations that might be used in such calculations, the procedure for determining V/L ratio is completely outlined and each step must be strictly followed.

A.1.2 This method is based upon the assumption that the fuel is 100% saturated with air as it leaves the fuel tank and again 100% saturated at the new condition at the inlet of the pump. The calculation determines the amount of air released due to change of pressure on the fuel, in terms of a ratio.

A.1.3 The physical properties of the fuel needed for the calculation are:

a. Distillation according to Federal Test Method Standard Number 791 (latest revision), at 5% and 15%

b. Reid vapor pressure according to Federal Test Method Standard Number 791 (latest revision)

c. Specific gravity according to Federal Test Method Standard Number 791 (latest revision)

A.2 Step One:

A.2.1 The first step is to determine the slope of the distillation-temperature curve at the 10% point.

$$\text{Slope} = \frac{T_{15} - T_5}{10} \qquad \text{(Eq.A1)}$$

where:

T_{15} = temperature °F (°C) at the 15% distillation point
T_5 = temperature °F (°C) at the 5% distillation point

A.3 Step Two:

A.3.1 The next step is to determine the true vapor pressure (TVP) at the pump inlet. This is based upon the Reid vapor pressure (RVP) of the test fuel and the measured fuel temperature at the pump inlet during the test. NACA Technical Note 3276 (TN 3276) shall be used to determine TVP. Figure A1 presents the equations from NACA TN 3276 and an iterative calculation method which can be programmed for a computer. For convenience, Figure A2 and Table A1 may be used to determine TVP when Step 1 results in a slope of 0 °F (0 °C)/% to 8 °F (4.4 °C)/%. The relationship for TVP versus temperature and RVP presented graphically in Figure A2 may also be calculated from the equation shown in the upper left hand portion of this figure. For slopes beyond 8 °F (4.4 °C)/%, or for more precise calculation, the procedure for determining TVP per NACA TN 3276 presented in Figure A1 is recommended.

A.4 Step Three:

A.4.1 The next step is the calculation of the air solubility coefficient. k = .2116(S.G.) [1-1.125 (S.G.)]. Where S.G. is the specific gravity of the fuel at 60 °F/60 °F (15 °C/15 °C).

A.5 Step Four:

A.5.1 The next step is the calculation of the V/L ratio.

a. English System:

$$V/L = 1.54k\left(\frac{P_1 - P_2}{P_2 - P_{TVP}}\right)\left(\frac{t + 460}{95.8 + .07t}\right) \qquad \text{(Eq.A2)}$$

where:

P_1 = absolute pressure at initial condition of fuel (tank), psi
P_2 = absolute pressure at new condition of fuel (pump inlet), psi
P_{TVP} = absolute TVP of fuel at test temperature, psi, step 2
t = fuel temperature at the pump inlet, °F
k = the solubility coefficient, step 3

EQUATION FOR CALCULATING TRUE VAPOR PRESSURE VS TEMPERATURE FROM REID VAPOR PRESSURE PER NACA TN 3276
(NOTE: THIS METHOD OF CALCULATION REQUIRES ONE REITERATIVE STEP TO SOLVE THESE EQUATIONS)

STEP (1) - CALCULATE TVP AT 100° AND 0 V/L - $TVP_{100\backslash 0}$

$$TVP_{100\backslash 0} = RVP + 0.0223*RVP + [(0.0119*RVP*S)/(1-0.0368*RVP)]$$

WHERE: RVP = REID VAPOR PRESSURE (PSI)
S = DISTILLATION SLOPE AT 10% (%/°F)

STEP (2) - CALCULATE A FUNCTION AT 100°F AND 0 V/L - $A_{100\backslash 0}$

$$A_{100\backslash 0} = \frac{1 - \left\{\left[(TVP_{100\backslash 0})/(10.)^{(1.167199)}\right]^{(1/5.2533)}\right\}}{0.00687917}$$

STEP (3) - CALCULATE b FUNCTION (BY REITERATION)

$$b = 0.056 + \{\ 262.\ /[(A_{100\backslash 0})/(b_i) + 560.]\} - [0.04*(S)^{0.5}]$$

(a) Assume initially b_i = 1. and calculate value of b

(b) If calculated value of $b - b_i \geq 10^{(-10)}$ then set b_i = b and recalculate value of b

(c) Repeat (a) and (b) until $b - b_i \leq 10^{(-10)}$

STEP (4) - CALCULATE A FUNCTION AT TEST TEMPERATURE - A_t

$$A_t = A_{100\backslash 0} + b*(100 - t)$$

WHERE: t = TEMPERATURE AT TEST TEMPERATURE

STEP (5) - CALCULATE THE TVP AT THE TEST TEMPERATURE - TVP_t

$$TVP_t = 10.^{(x)}$$

WHERE: $x = 1.167199 + 5.2553*[\log(1-0.00687917*A_t)]$

FIGURE A1 - Calculation of V/L Ratio (Equation for Calculating True Vapor Pressure Versus Temperature from Reid Vapor Pressure Per NACA TN 3276