AEROSPACE INFORMATION REPORT

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Superseding AIR1326

Aircraft Fuel System Vapor-Liquid Ratio Parameter

RATIONALE

AIR1326A has been reaffirmed to comply with the SAE five-year review policy.

FOREWORD

Changes in this revision are format/editorial only.

1. SCOPE:

The AIR is limited to a presentation of the historical background, the technical rationale which generated the V/L fuel condition interface requirement in specifications between the aircraft fuel delivery system and the aircraft engine fuel system, and limitations in the usage of the V/L concept.

1.1 Purpose:

Since the introduction, in July 1951, of the vapor-liquid (V/L) ratio fuel condition parameter as an airframe/engine interface design requirement for military applications, many questions have arisen concerning interpretation of the requirement (1, 2).[1] The more important questions concern; (a) applicability of the concept to transient as well as steady state endurance demonstrations of engine fuel pump capability and, (b) limitations of the formula employed to calculate V/L ratio with respect to accuracy and range of conditions covered.

Therefore, the primary purpose of this Aerospace Information Report (AIR) is to present the background which led to the introduction of the vapor-liquid (V/L) ratio parameter defining the condition of the fuel at the airframe/engine interface and to interpret its application to specification requirements. A secondary purpose is to promote a better understanding of the subject among airframe and engine fuel system designers and users by providing a bibliography of the many, but not all, of the documents and papers published on the subject.

2. REFERENCES:

See Appendix A.

1. Numbers in parentheses refer to the Bibliography in Appendix A.

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3. HISTORICAL BACKGROUND:

3.1 Early History:

Early reciprocating engine aircraft, prior to WW II, which used wide boiling range high vapor pressure hydrocarbon fuels (aviation gasoline) were found to be altitude limited due to deficiencies in the airframe/engine fuel supply system. This situation was caused by the lack of definitive design requirements in early aircraft specifications. The resolution of this problem was largely accomplished by the actual physical testing of the design changes installed in the aircraft itself.

The advent of the turbojet engine brought about the need for new fuel requirements (3). The first fuel developed, AN-F-32, JP1, a low vapor pressure fuel, did result in a short-lived period of successful operation, but still incomplete requirements for airframe/engine fuel system design prevailed. In 1947, the requirement for a wide boiling range jet fuel, AN-F-58, JP3, was issued. The requirement for this fuel was largely dictated by the desire to establish a military fuel of maximum availability anticipating that a national emergency might produce fuel shortages. This fuel permitted the conversion of a greater percentage of the crude oil to aviation fuel. Approximately only 10% of a barrel of crude oil is utilized to produce kerosene, whereas approximately 50% of the barrel can be utilized for JP-3 fuel. Considerable opposition, however, developed against the high volatility of JP-3 fuel (RVP of 5-7 psia). After engine performance studies and testing, it was determined that a fuel having a Reid vapor pressure of 2.0 - 3.0 psia would be satisfactory and would represent a compromise between engine performance and fuel availability. The new fuel became known as JP-4 and was included in MIL-F-5624A issued in May, 1951. JP-4 is now accepted as the prime military fuel.

The development of the turbojet engine during the 1950 decade, when operation at higher altitudes, higher mach numbers, higher tank fuel temperatures and increased fuel flows were required, created the need for more definitive design parameters at the airframe/engine interface. The evolution of these requirements are described further in this report.

3.2 Design Parameter Evolution:

During the initial years of WW II, it had been recognized that Net Positive Suction Head (NPSH), commonly used in the commercial pumping industry for single boiling point fluids, was not adequate to define the possible two-phase condition that could be generated in aircraft fuel systems using wide boiling range hydrocarbon fuels. Hence, the Coordinating Research Council (CRC) was asked to advise on this matter and subsequently provided a section to the CRC Handbook on Vapor Lock (January 1946 edition) which presented the means for predicting Vapor-Liquid Ratios in dynamic fuel systems using hydrocarbon fuels (4).

The military then published requirements for turbojet powered aircraft that limited aircraft fuel delivery systems to 3 and then subsequently 4 inches of mercury line drop (tank to engine inlet) at a specified flight altitude, usually 6000 feet, and at the specified engine power setting identified in the engine model specification (5, 6, 7, 8). The objective of this requirement was to create a worst case situation, i.e., “No Assistance From Airplane Boost Pump”, at a nominal to high power setting. Attempts to apply this aircraft system “worst-case” requirement to the engine fuel system by simulated test techniques were not entirely satisfactory due mainly to variables possible in the test set-ups which produced inconsistent results. These factors then led the military to conclude that the Vapor-Liquid Ratio (V/L) parameter should be used as the design criterion for the condition of fuel at the aircraft/engine interface. This design and test requirement was then subsequently incorporated into engine military specifications (1, 2, 9, 10). Some years later new Military Aircraft Fuel System Specifications also incorporated V/L as the design parameter.

3.3 Development of V/L Measurement Instrument:

Fuel Pump Panels in the Aircraft Industries Association (AIA) and the Society of Automotive Engineers (SAE Panel A-1), circa 1952, began the joint task of exploring the feasibility of and initiating the design of a measuring device or meter to physically measure the Vapor-Liquid ratio of the flowing fluid at the inlet of a fuel pump during test (11). Several companies subsequently became interested in the design and development of a V/L meter. Three meters; one based on a light beam and photo-electric sensitive plate, one based on a capacitance bridge comparison between a flowing and a non-flowing test section and a later design, currently in use, based on sensing the average dielectric constant of the flowing fluid, were designed and tested (12). The use of the V/L meter is covered later in paragraph 9.

3.4 V/L Calculation Method (SAE ARP492A):

The CRC method of calculating the V/L from known or set test conditions was initially used (4). Since the V/L calculation method depends on air solubility and vapor equilibrium conditions in the initial and final states, which is not easily attained or determined, and since the test set-up and test procedure has a marked effect on the release of dissolved air from fuel, SAE Committee A-16 and later AE-5 took up the task of standardizing the test set-up and procedure.

SAE ARP492A, “Aircraft Fuel Pump Cavitation Endurance Test”, was then prepared and issued after a long period of coordination with the Military and Industry (13). It was issued as an Industry Recommended Practice in 1957. The ARP defines the procedure for testing an aircraft engine fuel pump for the sole purpose of determining its resistance to deterioration during endurance testing under Military Specification (emergency) V/L conditions at the pump inlet. The test was structured for the use of MIL-F-5624, grade JP-4 fuel, as it is the prime military fuel.

WADC Technical Report 55-422, “Physical Properties of JP-4 Fuels and Development of Equations for Predicting Fuel System Performance Under Two-Phase Flow Conditions”, and the work of other authored documents and papers referenced in the Technical Report were used extensively in preparing ARP492A (14).

3.5 Establishment of V/L Value:

The emergency “No Assistance From Aircraft Boost Pump” interface fuel condition in military specification MIL-E-5007A was established at 0.45 V/L. This value was established on the basis of the calculated V/L for a single engine fighter using high vapor pressure Aviation Gasoline (AN-F-48) at 6000 feet fuel tank altitude, 110 °F fuel temperature and 4 inches of Hg line loss (tank to engine inlet), at a specified engine power level (fuel flow rate) plus a safety margin (10). Turbo-propeller powered aircraft specifications, usually cargo type, specified a V/L requirement of 0.30 because of the difference in performance needs.

In later years the use of lower vapor pressure fuels (primarily JP-4) did ease the need for high V/L capabilities at the airframe/engine fuel system interface; however, retention of the 0.45 and 0.30 V/L values by the military is considered justifiable for safety and return flight margins after battle damage with aircraft power and support sub-systems inoperative.

3.6 Design Intent:

The design intent of current airframe and engine specifications related to the V/L requirement at the engine fuel inlet is to insure the continued operation of the engine within a defined flight envelope upon the unexpected loss of tank booster pumps. It is an emergency capability and pumps to date have been accordingly designed for limited life when operated at the maximum V/L condition. The life test in the specifications is also of limited duration compared to the normal operational test.

4. AIRCRAFT FUEL SUPPLY CONDITIONS:

4.1 Two-Phase Fuel Flow In Aircraft Fuel Supply Systems (15, 16):

Two-phase fuel flow in relation to an aircraft feed system is defined as a condition where liquid fuel in combination with a gaseous product, evolved from the fuel, are flowing together in a line from the fuel tank to the engine inlet.

This occurs as follows: When hydrocarbon fuel is placed in a vented container, it releases or dissolves air until the sum of the partial pressures of vapor and air within the container equals the ambient atmospheric pressure. Accordingly, for a given fuel there is an ultimate decrease in the amount of dissolved air with each increase in fuel vapor pressure or with a decrease in ambient air pressure. Since a reduction in air pressure above the fuel results in a decrease in the amount of dissolved air within the fuel, it follows that air is evolved from the fuel throughout all parts of the system, wherein a drop in absolute pressures occurs during climb of an airplane to altitude. At system absolute pressure levels which are high relative to the vapor pressure of fuel, the gaseous product is mainly air which had been previously dissolved in the fuel. As the pressure level is reduced, the vapor space contains an increasing fraction of fuel vapor until at absolute pressure levels which approach the vapor pressure of the fuel, the gaseous mixture is mainly the volatile components of the fuel. It is for the latter reason that the CRC method of calculating the two-phase flow (V/L ratio) as used in SAE ARP492A has questionable accuracy at high fuel temperatures and high V/L ratios. (See paragraph 8.)

Some of the more important factors in the formation of two-phase fuel flow in a feed line are:

a. The type or batch of fuel
b. Fuel temperature and changes in temperature
c. Initial absolute pressure of the fuel subsequent to delivery in the feed line
d. The line pressure loss and the degree to which equilibrium conditions are again established in the fuel in the feed line

4.2 Aircraft Operation-”With Assistance From Tank Boost Pump”:

Operation of the aircraft fuel supply system “With Assistance From Tank Boost Pump” is generally not a problem because the tank mounted fuel booster pumps can operate with some liquid boiling or cavitation taking place within the impeller - which must then separate the vapor or depend upon reabsorbtion by the fuel. The minimum pressure specified at the engine fuel pump inlet or connection is usually well above the true vapor pressure of the fuel (5 psi in MIL-E-5007) and at a condition of zero V/L.

4.3 Aircraft Operation-"Without Assistance From Tank Boost Pump":

Operation of the aircraft fuel supply system "Without Assistance From Tank Boost Pump" is the condition where two-phase flow is encountered. The specification generally requires the aircraft system to supply and the engine pump(s) to accept, at the specific fuel inlet temperature and V/L ratio, the fuel required to meet engine performance guarantees within a defined flight envelope. This condition is an emergency requirement and unless otherwise spelled out in the aircraft and engine specification applies to steady state operation only.

5. DEFINITION OF VAPOR-LIQUID RATIO (V/L):

Definition: V/L = the equilibrium ratio of vapor volume (actually air and fuel vapor) to volume of liquid, both at the same temperature.

Relationship: In terms of one volume of Vapor and Liquid, often referred to as Percent Quality:

$V + L = 1$
$V = 1 - L$

V = Vol. of vapor
L = Vol. of liquid both in same units

$$\text{Parameter } \frac{V}{L} = \frac{1-L}{L}$$

Example: Using 0.45 V/L as an example and substituting:

$$0.45 = \frac{1-L}{L} \text{ or } 0.45L = 1 - L$$

Solving for L, L + 0.45L = 1 or 1.45L = 1

$$L = \frac{1}{1.45} \text{ or 0.69 or 69\% liquid}$$

V = 1 - L = 1 - 0.69 = .31 or 31% vapor

6. EFFECT OF V/L ON PUMP DELIVERY (11):

The term “Vapor Lock” has come to be defined as the change in normal engine performance as the result of the formation of fuel vapor-air mixtures in the fuel feed system. As such, performance loss can result (a) from inability of the fuel pump to meet the required volume demand for fuel, and (b) from disturbances (such as flow and pressure instability) in the fuel metering and/or injection system. Limiting the subject to the usual case of vapor lock in which the fuel pump is unable to supply the engine fuel demand, the effect is explained as follows:

6.1 Pump Delivery (Zero V/L):

Since the majority of the turbojet and turbofan aircraft engines manufactured in the United States use positive displacement rotary type high-pressure fuel pumps in the main fuel system, this section deals specifically with this type rather than the piston or plunger reciprocating pump. Piston pump delivery, however, is degraded by the V/L condition of fuel in the same general manner as for rotary pumps.

The volumetric delivery of a rotary pump at steady state conditions (namely rpm, inlet and discharge pressure, fluid temperature and composition), and when operated at an rpm and inlet pressure which assures that the tooth spaces are ideally filled (operation above the so-called knee point), can be defined in a simplified manner as follows:

$Q = Q_t - Q_B - Q_S$
Q_D = Delivery of pump in fraction of geometric tooth-space in volume units/revolution
Q_T = Geometric tooth-space volume delivered to discharge side per pump revolution (assume unity)
Q_B = Back-delivery volume returned to inlet side per pump revolution in fraction of displacement
Q_S = Slip volume, a function of pump tooth clearance in the housing, pressure difference, speed and viscosity in fraction of displacement
OR $Q_D = (1.00 - Q_B - Q_S)$

This behavior refers to an incompressible liquid medium which is completely air, gas and vapor free down to the vaporization pressure and is properly boosted to overcome inlet filling losses (operation above knee of curve).

6.2 Pump Delivery (With V/L):

Pump delivery is degraded by the fact that inlet tooth space is filled with air-gas vapor (value depending on V/L ratio) instead of the solid fuel required for complete tooth filling to meet engine flow requirements. Pump mechanical damage can also occur from the filling cavitation and implosion effects from compressibility at pump discharge.

The delivery equation is now defined as:

$$Q_D = (1.00 - Q_B - Q_S) - (A_t)$$

The first parenthesis is the normal full liquid delivery of the pump, no air present. The second factor (A_t) is the volumetric effect of air and represents the fraction of pump displacement lost when air and vapor are entrained with the liquid.

Tests on a typical spur gear-type pump with oil showed losses in mass delivery rates (on the flat part of the curve) almost 40% greater than the % entrained air at pump inlet due principally to inlet filling losses and the further evolution of soluble air in the oil. Operation with aviation fuel would be comparable because it too releases soluble air when pressure is reduced.

The above points up the need to provide some form of pump inlet boost for positive displacement pumps to assure proper engine fuel system operation during aircraft suction feed operation.

7. DEVELOPMENT AND DERIVATION OF V/L EQUATION:

WADC Technical Bulletin 55-422, Part 2, is the definitive document which draws together the labors of various individuals and research agencies who contributed to the development of the equation for predicting vapor/liquid formation in hydrocarbon fuel systems (14).

The following provides an explanation of the basis and use of the various elements that make up the V/L equation. Also, a generalization of the equation is provided to allow its use for a broader range of hydrocarbon fuels than specified in ARP492A (13). This generalization and clarification is for the purpose of condensing the great volume of information into a more readily available package for the fuel system design engineer.

7.1 Definitions Applicable to the V/L Equation of ARP492A:

7.1.1 V/L, Vapor Liquid Ratio: The equilibrium ratio of volume of vapor (actually air and fuel vapor) to volume of liquid, both at the same temperature.

7.1.2 V/L, Calculation: Involves determining the amount of air that will come out of solution between two partial pressures (P initial - P_{TVP}) and (P final - P_{TVP}) while flowing in a closed system.

7.1.3 S, Solubility: The air solubility in volume percent, measured at 32 °F and one atmosphere pressure, which will dissolve in a petroleum liquid when the air in equilibrium with the liquid is at a partial pressure of 760 mm of Hg. In the basic V/L formula, "S is expressed in units of volume of air, measured at 32 °F and one atmosphere pressure, dissolved in 100 volumes of fuel at 60 °F.

Note that the computations are based on solubility values obtained at 60 °F fuel temperature. Appropriate subscripts for "S are used for different stations in the system.

7.1.4 k, Solubility Coefficient: The solubility of non-reactive gases in liquids generally follow Henry's Law which states that the mass of gas dissolved in a liquid at equilibrium is proportional to the partial pressure of the gas in the vapor phase with which the solution is in equilibrium. Stated mathematically, $S = k P_a$.

Where: S = volume % of air dissolved; the volume (ml) of air, measured at 32 °F at one atmosphere pressure, dissolved in 100 ml of fuel at 60 °F (17).

P_a = partial pressure of air in the vapor phase with which the solution is in equilibrium.

k = gas solubility coefficient. Determined with the partial pressure of the air in equilibrium with the fuel at 760 mm of Hg.

By definition: $k = \dfrac{S\ (\%)}{760\ \text{mm of Hg}}$

The pressure is measured in mm of mercury so that "k" units are gas volume %/mm of Hg partial pressure. "k" varies with temperature and fuel composition. "S" in corrected volume units is proportional to the mass of gas dissolved in the liquid.

7.1.5 S_1, Volume of Air Dissolved: Volume of air initially dissolved in the fuel, measured at 32 °F and one atmosphere pressure in the vapor phase, per 100 volumes of the fuel at 60 °F.

7.1.6 S_f, Volume of Air Dissolved: Volume of air measured at 32 °F and one atmosphere pressure that the fuel will dissolve under the lower or final partial pressure of air in the vapor phase, per 100 volumes of the fuel at 60 °F.

7.1.7 S_g, Volume of Air Evolved: Equals S_1-S_f; Volume of air evolved, measured at 32 °F and one atmosphere pressure in the vapor phase per 100 volumes of the fuel at 60 °F.

7.1.8 P_{TVP}, True Hydrocarbon Vapor Pressure: Physical data in psia obtained from TVP versus Temperature Curves for various air free hydrocarbon fuel blends at a vapor-liquid ratio of zero.

7.1.9 t, Fuel Temperature: Final equilibrium test temperature in °F of the liquid and vapor phase.

7.1.10 P, Absolute Pressure: Absolute static pressure in psia of the liquid and vapor phase. Using subscripts to designate the system stations, P_1 is the initial static absolute pressure; P_f is the final static absolute pressure.

7.1.11 P_a, Partial Pressure of Air: The partial pressure of the air in equilibrium with the liquid. The absolute static pressure of the liquid and vapor phase in psia minus true vapor pressure of fuel at t °F. $P_a = P - P_{TVP}$.

7.2 V/L Formula:

The basic V/L formula is (for V/L ratios less than 1.0):

$$V/L = \frac{S_g}{95.8 + 0.07_t} \times \frac{t + 460}{492} \times \frac{14.7}{P_a}$$

Substituting for S_g and P_a

$$V/L = \frac{S_1 - S_f}{95.8 + 0.07_t} \times \frac{t + 460}{492} \times \frac{14.7}{P_f - P_{TVP}}$$

Introducing the solubility relationship of $S = k\,P_a$ or $k(P - P_{TVP})$ and changing the “k” units from gas volume %/mm of Hg to gas volume %/psi we obtain:

$$S_1 = \frac{760}{14.7} k\,(P_1 - P_{TVP})$$

$$\text{and } S_f = \frac{760}{14.7} k\,(P_f - P_{TVP})$$

$$S_g = S_1 - S_f = 51.7\,k\,(P_1 - P_f)$$

$$\text{and } V/L = 51.7\,k \frac{(P_1 - P_f)}{95.8 + 0.07_t} \times \frac{t + 460}{492} \times \frac{14.7}{P_f - P_{TVP}}$$

Reducing the formula further to the form presented in ARP492A, “Appendix I: Calculation of V/L Ratio” (gathering together the numerical constants)

$$V/L = 1.54\,k \frac{(P_1 - P_f)}{(P_f - P_{TVP})} \times \frac{t + 460}{95.8 + 0.07_t}$$

7.2 (Continued):

"k" Values. The solubility coefficient "k" for fuels can be calculated by the formula in ARP492A, Appendix I, A.4.1. Additional research however, has shown that the formula is not accurate for kerosene type fuels (17).

"k" can also be calculated from measured air solubility (S) values for the particular fuel or obtained from research literature. Some published typical values are (14) (17):

TABLE 1

FUEL (TYPE)	S, % (Solubility Adjusted To +32 °F)	(Vol. %k mm Hg Partial Press.)
Aviation Gasoline	20-25	.026 -.033
JP-4	14-18	.0185-.024
Kerosene	12-15	.016 -.020

An alternate method of determining "s" can be obtained from the "Data Book For Designers" (reference Appendix A) (18). Obtain the Ostwald Coefficient for AIR from the Gas Solubility versus Temperature Curve at 60 °F (Figure AF-1). Correct the Coefficient for fuel density, as required. Next calculate the Bunsen Absorption Coefficient which reduces the volume of dissolved gas to 32 °F and one atmosphere.

$$A = \frac{O_c \times 492}{T}$$

$$S = 100 \times A$$

A = Bunsen Coefficient
O_c = Ostwald Coefficient
T = Fuel Temp., °Rankine

7.3 Explanation of Formula:

To calculate the equilibrium V/L ratio, several correction factors must be applied to the basic parameter S_g to correct for test conditions other than air measurements at 32 °F, one atmosphere pressure, and 100 volumes of liquid at 60 °F. These corrections are:

TABLE 2

FACTOR	PURPOSE
$95.8 + 0.07_t$	Corrects for variation of volume of liquid with change in test temperature. When t = 60 °F this factor will be 100. The experimental sample of 100 volumes of fuel is the volume occupied at a temperature of 60 °F.
$\frac{t + 460}{492}$	Corrects for change in volume of the air-vapor mixture with change in test temperature at constant pressure. The volume of air that will dissolve in 100 volumes of fuel at 60 °F is determined at 32 °F and one atmosphere pressure. The ideal gas law is then used to calculate the volume that this gaseous mixture will occupy at (t) test temperature.
$\frac{14.7}{P_a}$	Corrects for change of initial air volume with change in stream pressure, at constant temperature, by a pressure ratio calculation. When P_a is very small (P absolute static pressure is close to P_{TVP}) fuel boiling is a potential possibility.

8. LIMITATIONS ON USE OF CALCULATION METHOD - ARP492A:

The calculation method is applicable and accurate only within the bounds of certain assumptions and constraints. The major ones are (for complete details refer to ARP492A):

8.1 Assumptions:

That equilibrium conditions prevail. That is:

1. The fuel is 100% saturated with air as it leaves the fuel tank and again 100% saturated under the new conditions at the pump inlet. It is known that the evolution and solution of air in fuel is time related and subject to various system geometry variables (14 and 15).

2. That the air solubility coefficient (k) of the particular fuel under test is known and accurate. The coefficient is known to vary with fuel surface tension and for various petroleum fuels (14 and 17).

8.2 Constraints:

1. The formula used to calculate the V/L ratio is only applicable for conditions below the initial boiling point of the fuel. It does not account for the evolution of liquid fuel into the vapor phase as would occur during boiling. Equilibrium hydrocarbon vapor phase must prevail. No minimum limit, however, such as a minimum ΔP over fuel TVP has been established. Use of the formula for fuel temperatures above 120 °F and below one atmosphere pressure (altitude testing) using MIL-T-5624, grade JP-4, fuel is of questionable accuracy because of the risk of boiling off significant volumes of the more volatile fractions.

2. When used to set the inlet condition for a fuel pump cavitation test, the system set up in ARP492A must be strictly followed if industry-wide uniform results are an objective. The method of throttling the supply line to obtain the desired pressure drops and the size and configuration of the approach to the pump are important. The form of the two-phase flow, which usually varies from bubble through stratified flow, has different effects on pump operation.

9. USE AND ADVANTAGES OF V/L METER:

The development of a meter to accurately measure the vapor/liquid ratio of the fuel at the engine pump inlet has been an objective since V/L formation was recognized as an important aircraft fuel system parameter.

A number of meters based on various physical concepts have been designed and tested with varying success. The latest and most successful, using industry usage as the criterion, is a full flow continuous measuring instrument which determines the vapor-liquid ratio of a two-phase non-homogenous flow by the capacitance principle. The portable instrument is composed of two major elements. A test section (Sensor) for installation in the flow pipe and a Capacitance to Voltage Converter and readout package which can be remotely located. The Sensor, whose sensing elements are located in a helical pattern as a liner on the inside diameter of the tube, senses the average dielectric constant of the flowing fluid and the instrument converts this into an output voltage proportional to the percent liquid in the sensor. The scale is calibrated at V/L = ∞ (AIR) at zero voltage and V/L = O (liquid) at full scale (100% voltage).

ARP492A permits the use of a V/L meter (Method 1) or the calculation procedure (Method 2) without indicating a preference.

Test experience and reasoning indicates that the meter has the advantage in accuracy and range of test conditions over the calculation method assuming it is properly installed and calibrated. All things considered, the meter senses both the air/gases and hydrocarbon vapor evolved, whereas, the calculation method accounts for only the air evolved and assumes equilibrium conditions for the hydrocarbon vapor phase. It is generally agreed, based upon testing done to date, that reasonable correlation between the meter and the calculation procedure under ARP492A test conditions has been obtained. At the higher test altitudes of 20 and 30K feet tank pressure, the meter, as might be expected because of possible hydrocarbon vapor evolution, reads higher than calculated.

MIL-E-5007C issued in 1965 requires engine design and performance capability “with no assistance from airplane boost pump” using MIL-T-5624, grade JP-4, fuel at 135 °F from S.I. to 30K feet altitude and from zero to 0.45 V/L (19). The companion test specification, MIL-E-5009D, requires completion of a cavitation endurance test at 20 inch Hg absolute (approximately 10K) and 0.45 V/L. (20) Since certain blends of MIL-T-5624, grade JP-4 fuel have an ASTM distillation IBP (initial boiling point) near or below 135 °F this poses weathering problems during climb to tank test altitude (loss of RVP). Also, Flash Vaporization of the fuel due to sudden reduction of pressure can occur at simulated altitudes as low as 23K feet thus creating test difficulties and measurement inaccuracies during a design and performance test.