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USAAVLABS TECHNICAL NOTE 7
EMULSIFIED FUEL VULNERABILITY STUDY

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By

Albert J. Erickson

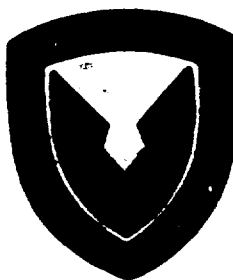
Larry D. Beth

November 1970

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USAAVLABS Technical Note 7
November 1970

EMULSIFIED FUEL VULNERABILITY STUDY

Final Report

By

**Albert J. Erickson
Larry D. Beth**

**U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA**

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SUMMARY

This report presents a study of the vulnerability of emulsified fuel and the tests developed to determine vulnerability criteria for liquid JP-4 and emulsified JP-4 fuels.

The following studies were conducted: vapor pressure, flow dispersion, weight loss, and fluid flow.

Test results showed that the emulsion was a significant improvement over the liquid fuel in all areas investigated. The most striking difference is the relative physical characteristics of the two fuels.

Though the physical-chemical properties studied showed that the emulsion significantly retarded the vapor pressure and rate of vaporization of the liquid fuel, the authors believe that both the liquid and the emulsified fuels will provide a flammable or explosive fuel-air ratio if given enough time and surface area available for vaporization.

However, if the liquid and the emulsified fuels are given identical conditions (puncture wound in fuel container below the level of the fuel from ballistic or shrapnel penetration, with no immediate fire upon puncture) for the range of orifice areas and emulsion yield stresses investigated, the following will result:

1. The flow rate from the puncture will be significantly lower for the emulsion. This significance is magnified if the wound is within 10 inches of the liquid surface. At such a level, the leakage of emulsion will be zero and the liquid flow will be infinitely greater.
2. Assuming a puncture located at a level more than 10 inches below the fuel surface, the surface area available for vaporization of the liquid from the wound will be virtually the surface area of the compartment into which the fuel flows. The surface area available for vaporization of the emulsified fuel will be considerably less since emulsions tend to form a glob and resist flow. This difference is extremely significant.

The combination of 1 and 2 above, together with the results of the weight loss study, gives an indication of the relative vulnerability of the liquid and the emulsion.

Similar studies should be conducted with various base liquid fuels and their emulsions. In addition, work should be conducted to determine the relative "misting" characteristics of the liquid and emulsified fuels.

FOREWORD

This report contains a study of the vulnerability of emulsified fuel and describes the tests conducted to determine vulnerability criteria for liquid and emulsified fuels.

This work was initiated in July 1969 and completed in May 1970. This program was conducted by the Safety and Survivability Division of the U. S. Army Aviation Materiel Laboratories under House Task 70-2, Task 1F162205A52904.

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INTRODUCTION

The purpose of this house task was to study those characteristics of fuels that are most commonly related to vulnerability and to compare an aqueous emulsified JP-4 fuel with its base liquid JP-4 fuel relative to the following characteristics: vapor pressure, weight loss due to vaporization, flow through various orifices, and flow dispersion.

For this study, a referee grade liquid JP-4 fuel and an aqueous JP-4 emulsion produced in a closed process with this referee grade liquid JP-4 fuel and designated EF4R-104H were selected. These same fuels are undergoing safety investigations and evaluations under the Army-wide modified fuels program. All quality assurance tests required for the safety investigations were used for this study.

Presented herein are the details of four studies: vapor pressure, flow dispersion, weight loss, and fluid flow.

The comparative analysis of the liquid and emulsified JP-4 fuels was based on the overall retardant effect of the microencapsulation of the liquid JP-4 fuel by the aqueous surfactants on the basic characteristics of the base JP-4 fuel.

VAPOR PRESSURE STUDY

INTRODUCTION

Vapor pressures of the liquid and the emulsified JP-4 fuels were studied over a range of temperatures (32° to 140°F) at designated time intervals. The Reid vapor pressure apparatus and an equivalent system were used to measure the vapor pressures. The equivalent system used the same vapor liquid ratio and pressure transducers as the Reid apparatus, and it was designed to increase the surface area for vaporization and heat transfer of the fuels.

DISCUSSION

With the Reid vapor pressure apparatus, the vapor pressure was determined using the ASTM 0 323 procedure (see Appendix I).

With the equivalent system, a 500 ± 0.1 -milliliter-volume tin container was substituted for the gasoline and vapor chambers of the Reid vapor pressure apparatus. The container was mated with the specially prepared cap and gasket assembly. The sample and containers were prepared by the method prescribed for the Reid vapor pressure apparatus with minor modification to ensure even distribution of emulsion on the heat transfer surface.

Comparison tests were run at 100°F with the Reid vapor pressure apparatus and the equivalent system. The results using the two different systems were identical.

With both systems, the vapor pressure was measured by direct connection of the vapor chamber to Statham Laboratories pressure transducers, Model PL 96 TCD-5-350. A data graph was used to record the transducer output.

The conditions under which the fuels were investigated are shown in Table I. The procedure for determining the yield stress is given in Appendix II.

The vapor pressure was recorded continuously for the first 60 seconds after the vapor chamber was connected to the pressure transducer. During this 60-second period, the containers were not agitated in any way; therefore, the conditions were kept as static as possible. After the first 60 seconds, the containers were agitated and the liquid samples were brought to equilibrium to verify the condition of the fuel.

TABLE I. VAPOR PRESSURE STUDY TEST CONDITIONS	
Ambient Temperature, °F	70-78
Relative Humidity, %	28-33
Barometric Pressure, mm Hg	758-765
Initial Fuel Temperature, °F	28-32
Yield Stress, dynes/cm ²	1300-1350

RESULTS

Results of this test are shown in vapor pressure versus temperature/time curves. Figures 1 and 2 are composites of the liquid JP-4 fuel and the

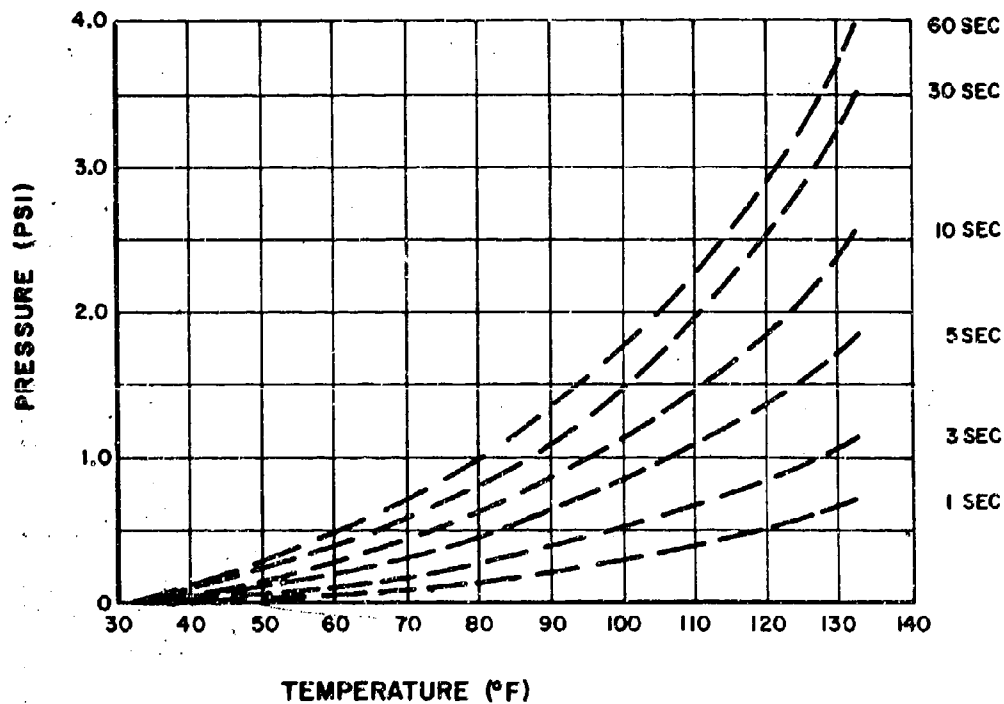


Figure 1. Vapor Pressure Versus Temperature/Time Curves for Liquid JP-4.

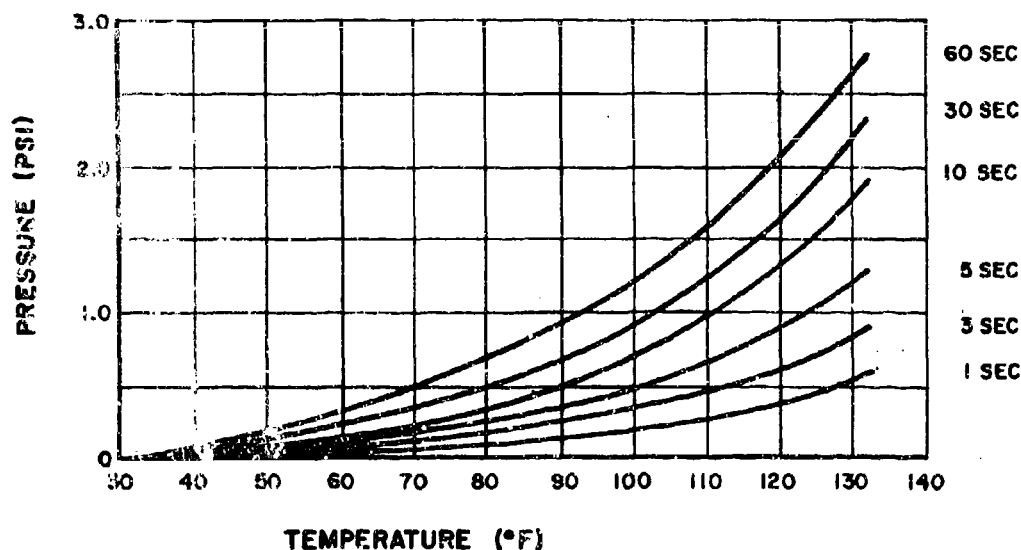


Figure 2. Vapor Pressure Versus Temperature/Time Curves for Emulsified Fuel.

emulsified fuel time curves respectively. Figures 3 through 8 are comparisons of the liquid JP-4 and the emulsified fuel at time intervals of 1, 3, 5, 10, 30, and 60 seconds respectively. The initial fuel temperature was 32°F.

The equilibrium vapor pressures for the test fuels are shown in Table II. The emulsion was broken with denatured ethyl alcohol. The alcohol phase was removed by repeated washings with distilled water. The procedure for breaking the emulsion is given in Appendix III.

TABLE II. EQUILIBRIUM VAPOR PRESSURE OF TEST FUELS		
Fuel	Equilibrium Vapor Pressure	Time To Reach Equilibrium
Referee Grade JP-4	2.70-2.80 psi	15-20 min
Broken Emulsion	2.55-2.65 psi	15-20 min
Emulsified Fuel	2.55-2.65 psi	36-48 hr

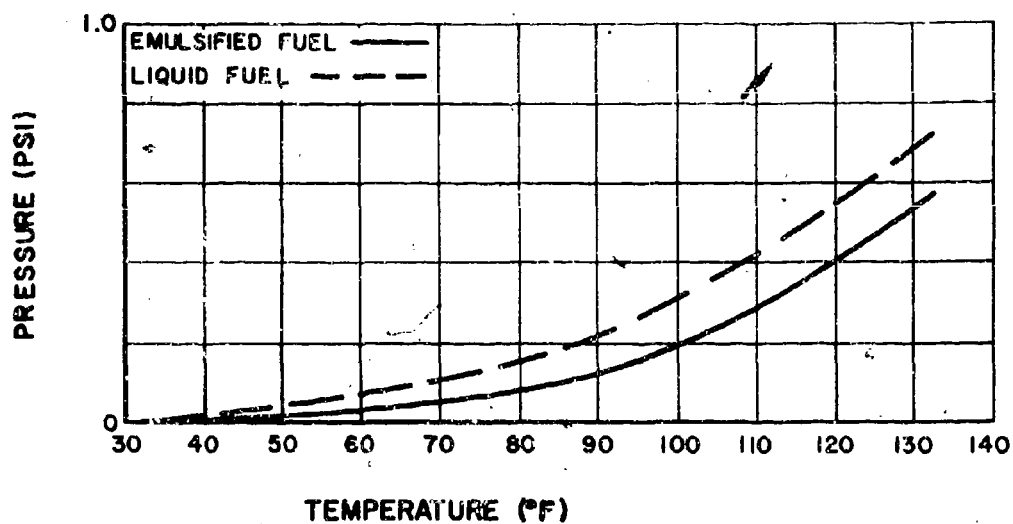


Figure 3. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 1 Second.

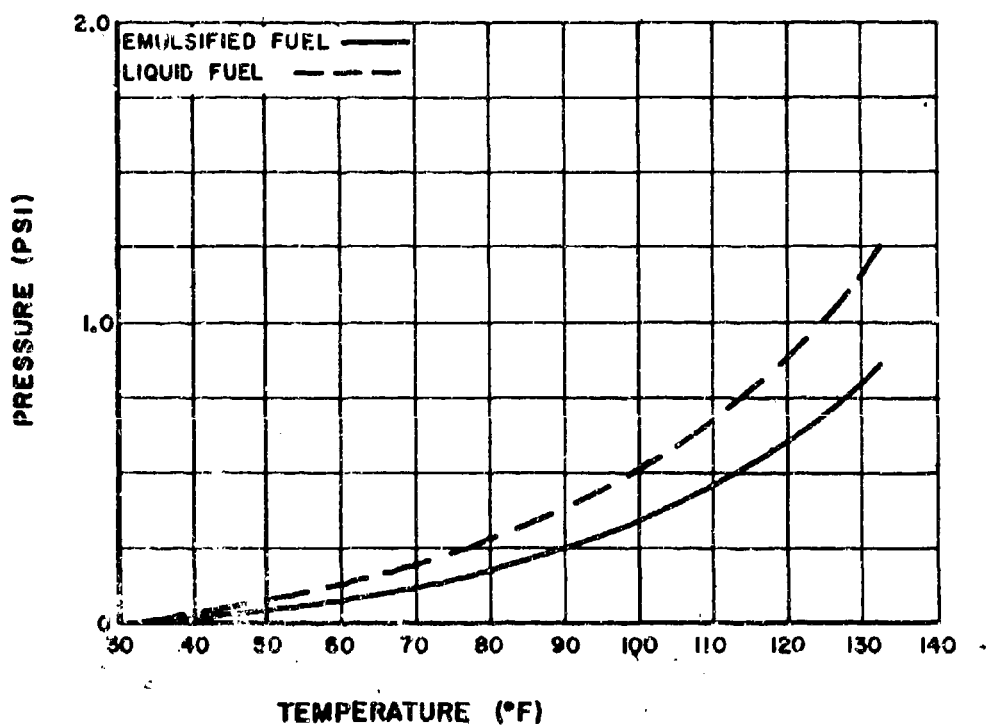


Figure 4. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 3 Seconds.

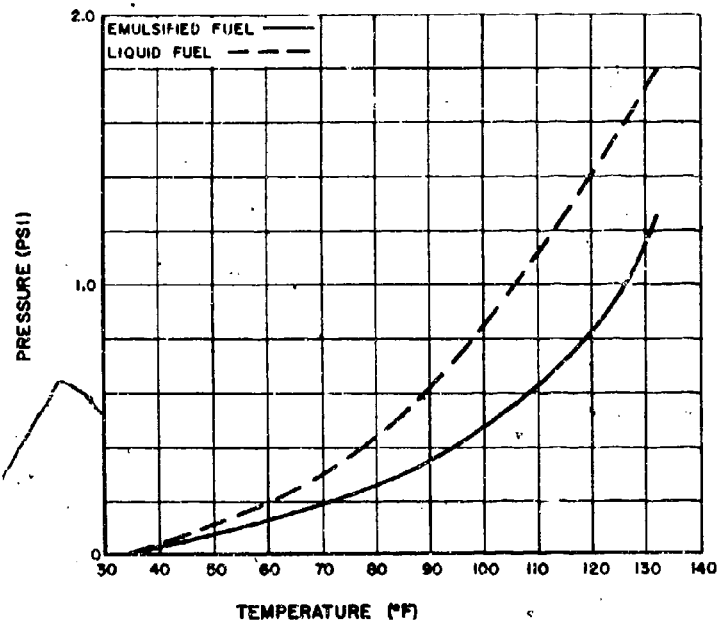


Figure 5. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 5 Seconds.

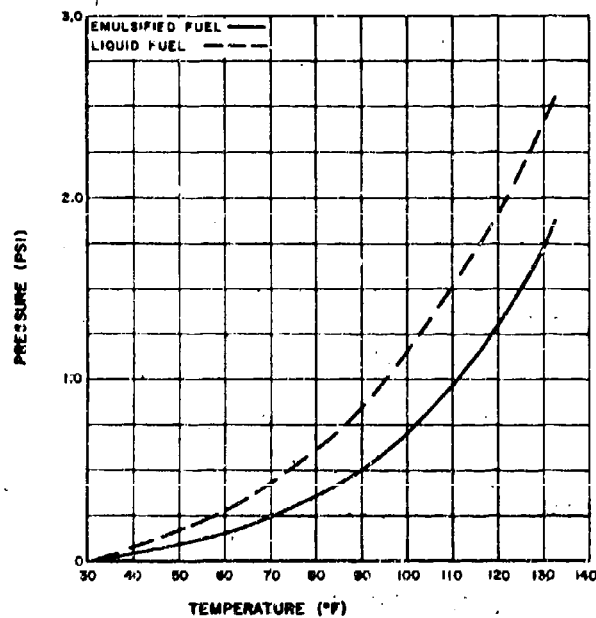


Figure 6. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 10 Seconds.

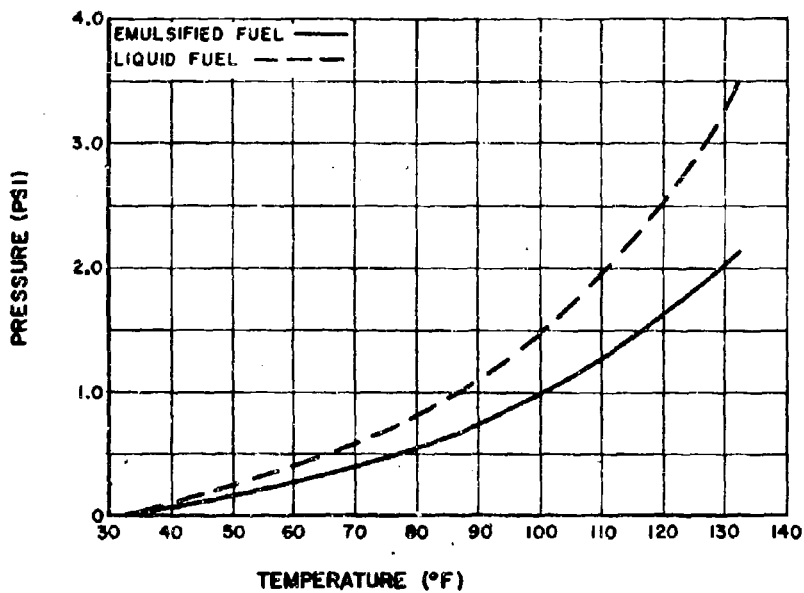


Figure 7. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 30 Seconds.

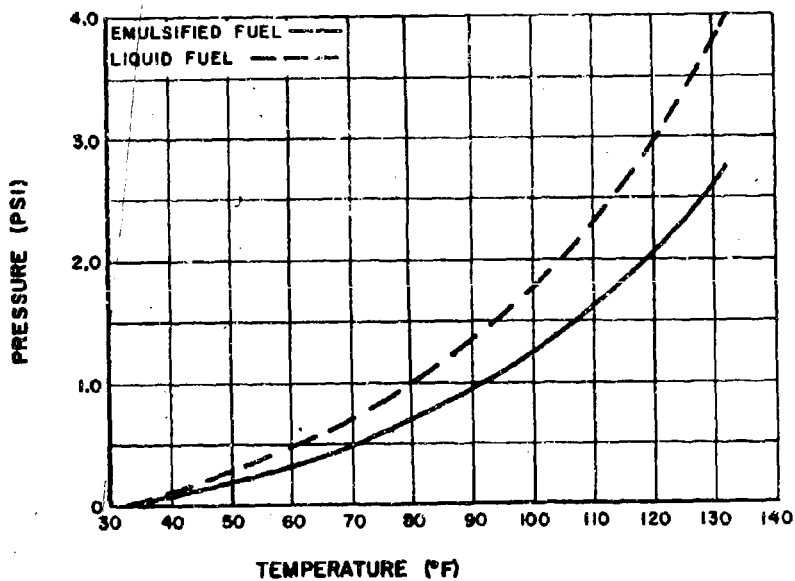


Figure 8. Comparison of Vapor Pressure of Liquid JP-4 and Emulsified Fuel at 60 Seconds.

The highest temperature tested was 132°F. At this temperature, the emulsion showed definite signs of breakage. It was estimated that the breakage approached 5 percent.

In every case, the equilibrium vapor pressures of the liquid and the emulsified JP-4 fuels were approximately equal; however, the time required to reach equilibrium was vastly different for the two fuels. The emulsion required 36 to 48 hours to reach equilibrium, and the liquid required 15 to 20 minutes.

FLOW DISPERSION STUDY

INTRODUCTION

The flow dispersion study was designed to study the flow rates and the subsequent surface areas of the liquid and emulsified JP-4 fuels on smooth and gridded aluminum surfaces at slopes of 0 degrees, 2 degrees, and 5 degrees.

The experimental setup used in this phase of the program is shown in Figure 9. A high-speed camera was mounted above the cylindrical container to measure the rate of dispersion. The polyethylene-lined, cylindrical, metal container was placed with the open end flush with the aluminum honeycomb panel flooring material. The container was lifted by means of a pulley system fastened to the ceiling.

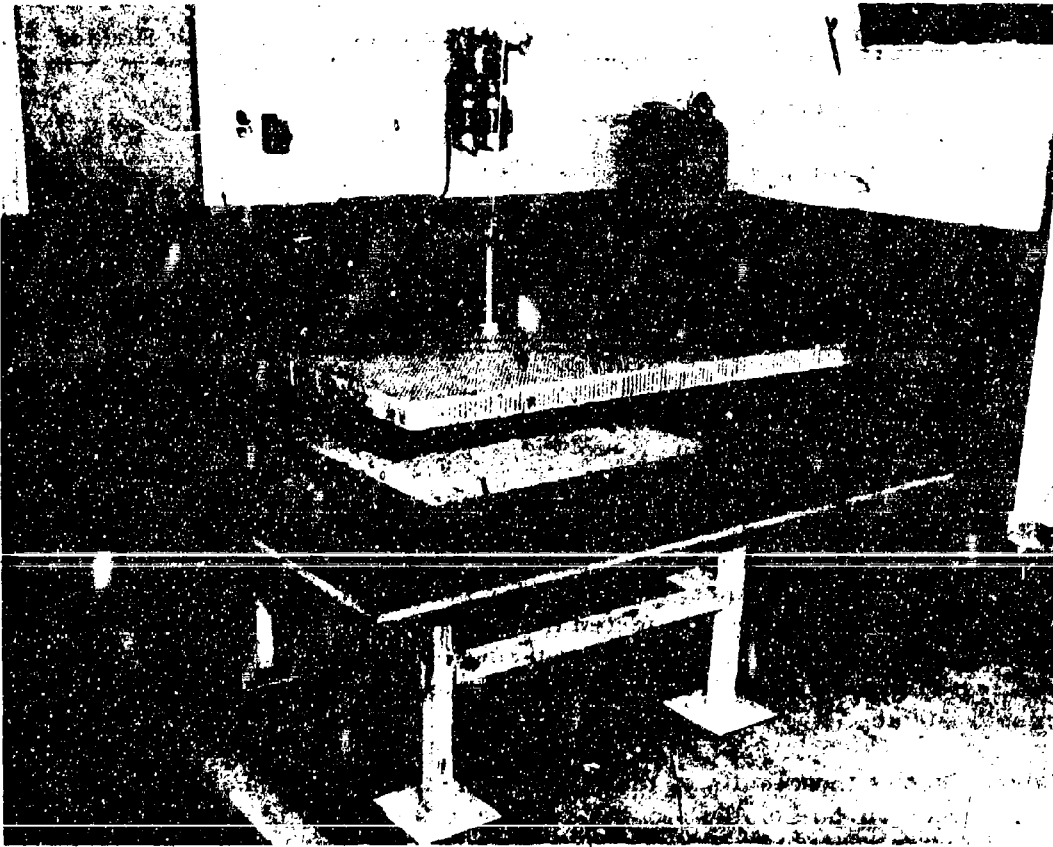


Figure 9. Experimental Setup Used for Flow Dispersion Study.

DISCUSSION

A measured quantity of fuel was poured into the cylindrical container. The container was lifted, permitting the fuel to flow, and the rate of dispersion was measured photographically. The camera was set at a speed of 20 frames per second. The tests were performed on both smooth and gridded aluminum flooring material at slopes of 0 degrees, 2 degrees, and 5 degrees. Tests were conducted with both 30 and 60 milliliters of fuel at the 0-degree slope for both surfaces. With the surface sloped at 2 degrees and 5 degrees, only 30 milliliters of fuel was used.

The conditions under which the flow dispersion study was conducted are shown in Table III.

TABLE III. DISPERSION STUDY TEST CONDITIONS		
Condition	Gridded Surface	Smooth Surface
Ambient Temperature, °F	70-75	75-80
Relative Humidity, %	70	31
Barometric Pressure, mm Hg	761	762
Yield Stress, dynes/cm ²	1300-1350	1300-1350

RESULTS

Table IV shows the results of the dispersion test on the gridded UH-1 simulated floor surface. The liquid JP-4 dispersed very rapidly during the first few tenths of a second, while the emulsion failed to disperse. Even after several minutes, the emulsion failed to disperse. The slope of the surface only slightly affected the liquid fuel, and it had no effect on the emulsified fuel. The surface area covered by the liquid was slightly smaller during the first 0.3 second on the sloped surface than on the smooth surface.

Table V shows the results of the dispersion test on the smooth surface. The dispersion rate on the smooth surface was similar to the rate obtained on the gridded surface. The results for the emulsion were identical on both surfaces.

TABLE IV. FLOW DISPERSION STUDY RESULTS, GRIDDED
UH-1 SIMULATED FLOOR SURFACE

Time (sec)	0-Deg Slope 60 ml		0-Deg Slope 30 ml		2-Deg Slope 30 ml		5-Deg Slope 30 ml	
	Area (cm ²)		Area (cm ²)		Area (cm ²)		Area (cm ²)	
	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4
0.05	111	62	85	31	69	31	69	31
0.10	262	62	248	31	164	31	164	31
0.15	466	62	340	31	220	31	220	31
0.20	647	62	383	31	374	31	383	31
0.25	791	62	419	31	410	31	428	31
0.30	869	62	438	31	447	31	466	31
0.35	909	62	457	31	476	31	506	31
0.40	937	62	466	31	486	31	527	31
0.50	993	62	486	31	506	31	548	31
0.75	1080	62	527	31	558	31	602	31
1.00	1140	62	558	31	613	31	658	31
1.50	1201	62	602	31	670	31	754	31
3.00	1362	62	705	31	766	31	896	31
4.00	1447	62	741	31	830	31	979	31
5.00	1534	62	791	31	-	31	-	31

TABLE V. FLOW DISPERSION STUDY RESULTS, SMOOTH ALUMINUM SURFACE

Time (sec)	0-Deg Slope 60 ml		0-Deg Slope 30 ml		2-Deg Slope 30 ml		5-Deg Slope 30 ml	
	Area (cm ²)		Area (cm ²)		Area (cm ²)		Area (cm ²)	
	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4	Liquid JP-4	Emul JP-4
0.05	69	62	65	31	45	31	48	31
0.10	214	62	182	31	111	31	116	31
0.15	457	62	349	31	255	31	277	31
0.20	741	62	527	31	476	31	476	31
0.25	1065	62	602	31	613	31	591	31
0.30	1264	62	658	31	670	31	658	31
0.35	1447	62	693	31	693	31	693	31
0.40	1569	62	705	31	705	31	705	31
0.50	1641	62	729	31	729	31	741	31
0.75	1696	62	741	31	791	31	830	31
1.00	1715	62	754	31	830	31	882	31
1.50	1771	62	779	31	856	31	937	31
3.00	1829	62	856	31	937	31	1021	31
4.00	1848	62	882	31	993	31	1109	31
5.00	1867	62	909	31	-	31	-	31

The flow dispersion pattern for the 0-degree slope was circular. The gridded surface slightly retarded the wetting of the surface area by the liquid fuel. At the 2-degree and 5-degree slopes, the dispersion pattern was elliptical, with the long axis increasing with the slope.

The liquid seeks its own level and will wet available surface area commensurate with the quantity released. The emulsion tends to remain in the location released with a shape that approximates a right conical configuration with a 90-degree vortex.

The surface area available for vaporization for a liquid leakage in a confined area (ullage of the fuel compartment or cargo compartment of a rotary-wing aircraft) is approximately equal to the surface area available within the confined area. The surface area available for vaporization for an emulsion leakage is approximately equal to the surface area of a right cone with a 90-degree vortex.

WEIGHT LOSS STUDY

INTRODUCTION

The weight loss study was designed to study the rate of vaporization for the liquid and emulsified JP-4 fuels over a range of temperatures from 68° to 140°F at designated time intervals. Several trials were run at each of the temperatures studied.

DISCUSSION

The following procedure was used with both the liquid and the emulsified fuels.

Approximately 180 grams of fuel was placed in a circular container. The top of the container was sealed and placed in an isothermal oven. The temperature in the oven was controlled to within $\pm 2^\circ\text{F}$. After the sample reached the test temperature, the weight of the sample and container was recorded. Then the top was removed from the container, and timing was initiated. The weight was recorded at 1-minute intervals for the first 5 minutes and at 5-minute intervals for the remainder of the tests.

Different-sized containers were used in this study. For each test, the surface area of the fuel was calculated. In the calculation of the surface area, the creep of the liquid fuel up the sides of the container was taken into consideration.

The tests in this study were conducted under the conditions in Table I. The liquid fuel used in this study had a Reid vapor pressure of 2.7 to 2.8 psi, and the emulsion had a Reid vapor pressure of 2.55 to 2.65 psi. The weight loss was calculated in milligrams per square centimeter, and the temperature readings were taken in degrees Fahrenheit.

RESULTS

Results of this study are shown in weight loss versus temperature/time curves. Figures 10 and 11 are composites of the emulsified fuel and the liquid fuel time curves respectively. Figures 12 through 15 are comparisons of the liquid and emulsified fuels at 1, 10, 30, and 60 minutes respectively.

The sharp upward deflection of the emulsion curves at the higher temperatures and greater time intervals was due to breakage of the emulsion.

It was estimated that the emulsion was approximately 50 percent broken at the end of 1 hour at the highest temperature. In those tests where the breakage of the emulsion resulted in creep, this was included in the calculated surface area.

There is a significant difference in the rates of vaporization of the liquid and the emulsified fuels. At all times and temperatures investigated, the weight loss per unit area for the liquid fuel was greater than the weight loss for the emulsified fuel. However, due to the breakage of the emulsified fuel, its rate of vaporization approached that of the liquid fuel at the higher temperatures investigated.

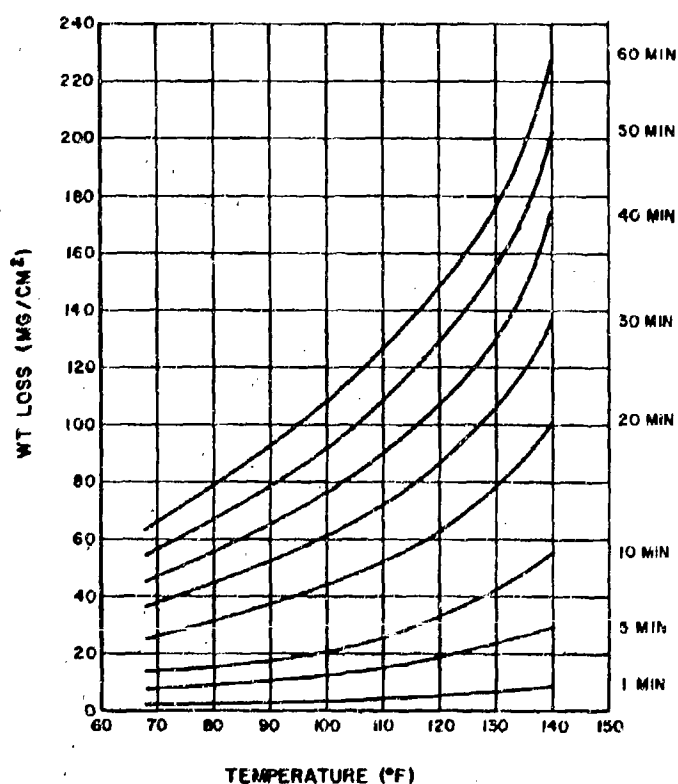


Figure 10. Weight Loss Versus Temperature/Time Curves for Emulsified Fuel.

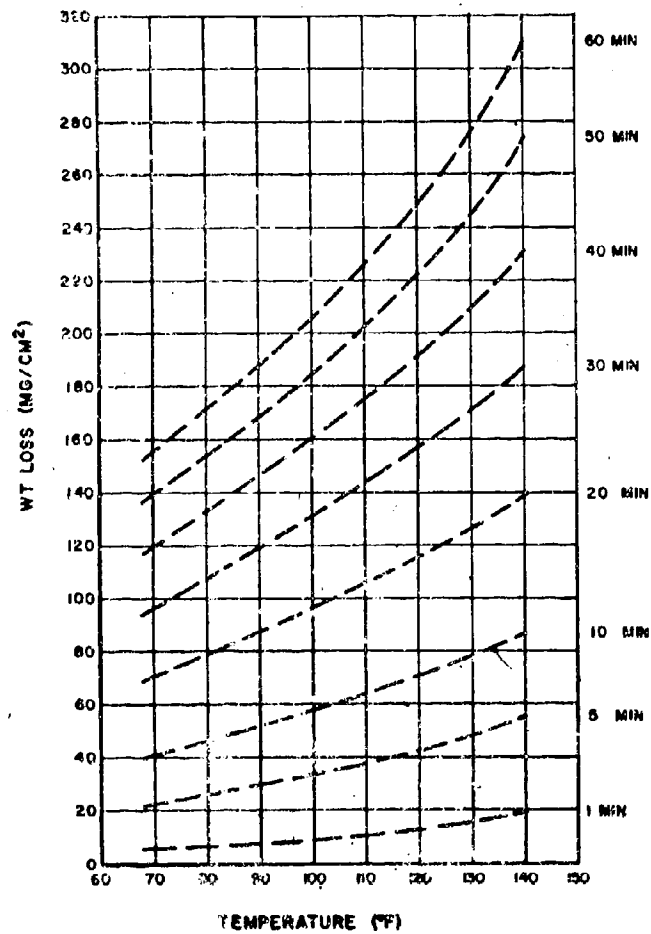


Figure 11. Weight Loss Versus Temperature/Time Curves for Liquid Referee Grade JP-4 Fuel.

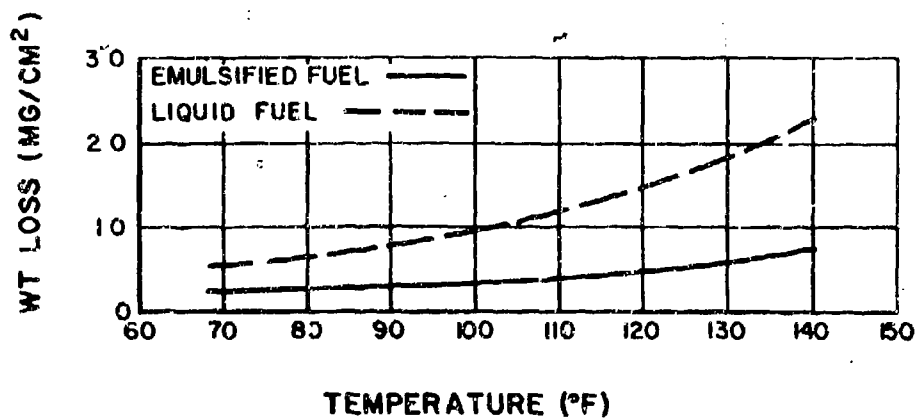


Figure 12. Comparison of Weight Loss of Liquid JP-4 and Emulsified Fuel at 1 Minute.

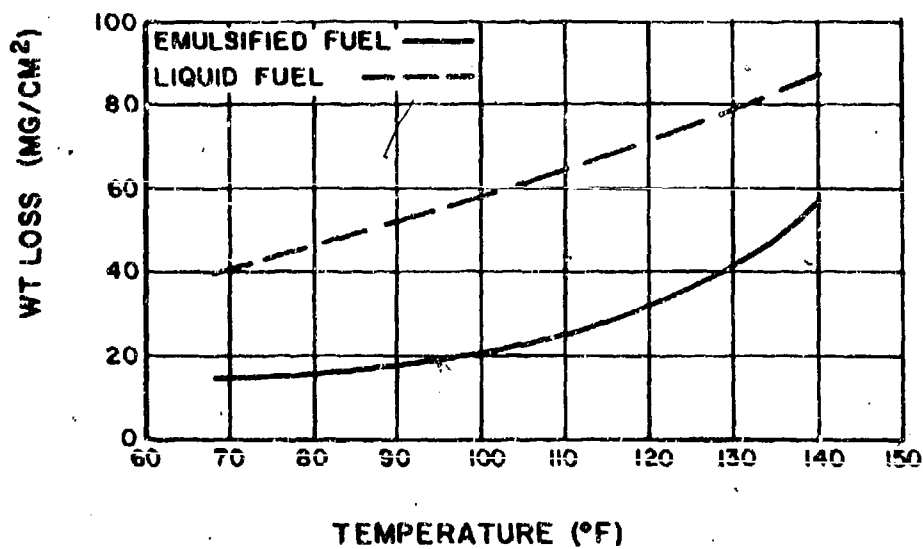


Figure 13. Comparison of Weight Loss of Liquid JP-4 and Emulsified Fuel at 10 Minutes.

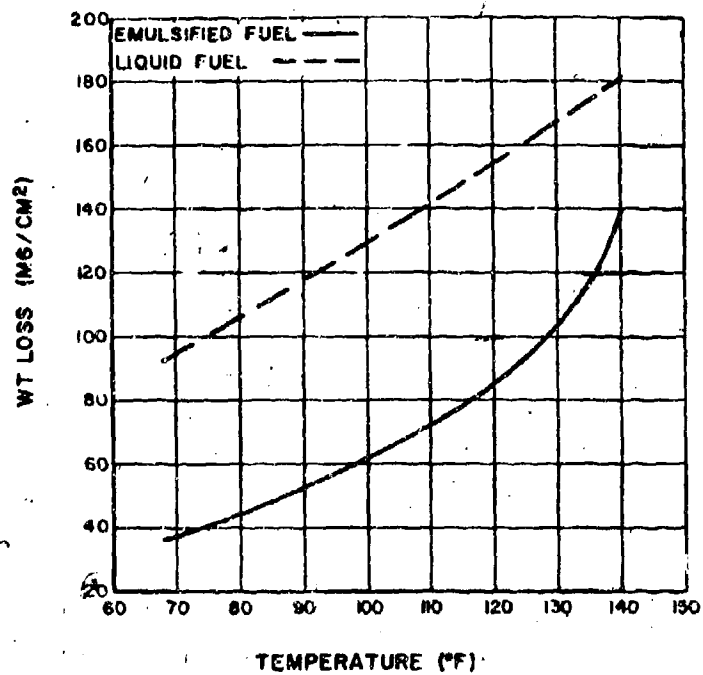


Figure 14. Comparison of Weight Loss of Liquid JP-4 and Emulsified Fuel at 30 Minutes.

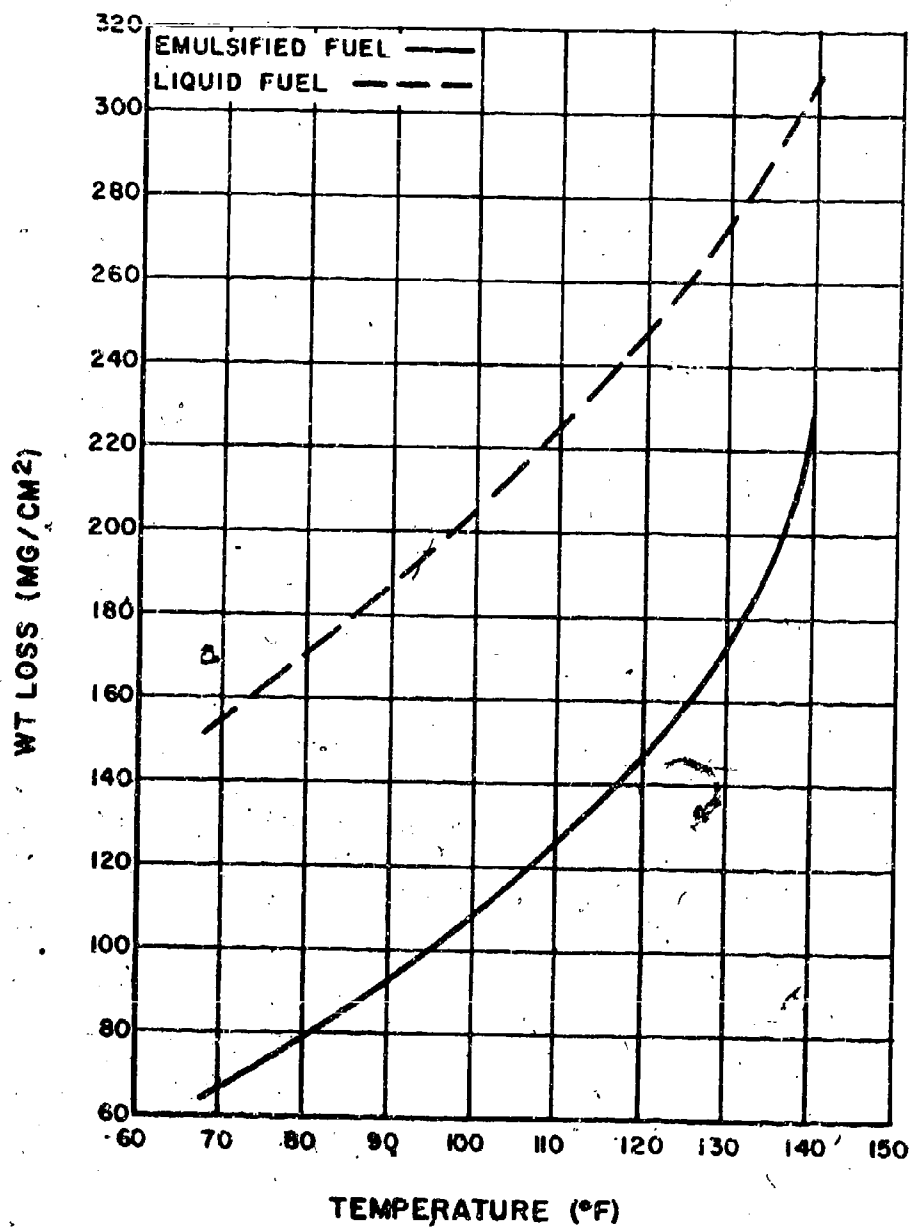


Figure 15. Comparison of Weight Loss of Liquid JP-4 and Emulsified Fuel at 60 Minutes.

FLUID FLOW STUDY

INTRODUCTION

The fluid flow study was designed to study the flow rates of the liquid and emulsified JP-4 fuels through various-sized sharp-edged orifices at various pressure heads. The pressure heads were limited to 50 inches and below. The experimental setup used in this phase of the program is shown in Figure 16.

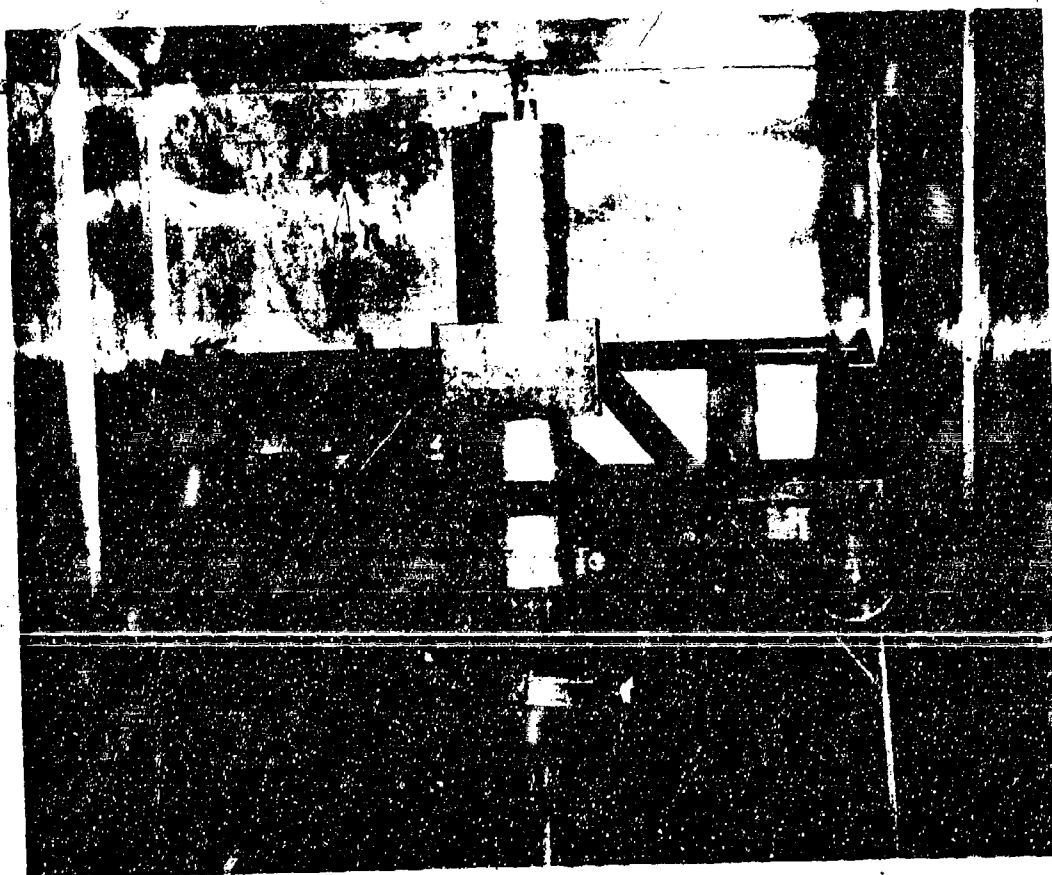


Figure 16. Experimental Setup Used for Fluid Flow Study.

DISCUSSION

The fluid flow study was conducted as follows. The flow tank, which is 47.5 inches high with an inner diameter of 12 inches, was filled with test fuel. A 28-volt power source was used to open and close the pneumatic valve located in back of the orifice. While the valve was open, the fuel was collected and weighed. The time interval required to collect the fuel was measured by a stopwatch. The pressure head was measured before and after each test.

The coefficient of discharge (C_d) for the sharp-edged orifices was determined by measuring the flow rate of water through the orifice. Then, using the flow rate, the coefficient of discharge was calculated by the following equation:

$$C_d = \frac{Q}{A_O \sqrt{2gh}} \quad (1)$$

where C_d = coefficient of discharge

Q = flow rate, in.³/sec

A_O = orifice area, in.²

g = acceleration of gravity, in./sec²

h = head, in.

The coefficient of discharge for the orifices was determined to be 0.695. Solving equation (1) for Q yields the following equation:

$$Q = A_O C_d \sqrt{2gh} \quad (2)$$

Using equation (2), the flow rate for the liquid fuel was calculated.

The tank was then filled with emulsified fuel, and the flow rate was measured. The emulsified fuel used in this test had a yield stress of 1600 dynes per square centimeter. This yield stress was measured after the fuel had been pumped into the flow tank and run through an orifice. The same fuel was used in the other tests, and it had a yield stress of 1300-1350 dynes per square centimeter before it was pumped into the flow tank.

All tests were conducted using both the side and bottom orifices under both static and simulated in-flight conditions. A small electric motor was used to vibrate the tank to simulate in-flight conditions.

RESULTS

Results of the fluid flow study are shown in Figures 17 through 31. Figures 17 and 24 are composites of the flow rates for the liquid fuel. The flow rate versus the head is plotted in Figure 17, and the flow rate versus the orifice area is plotted in Figure 24.

The results of the flow study for the emulsified fuel are shown in Figures 18 and 25. Figures 19 through 23 and 26 through 31 show comparisons of the liquid JP-4 and the emulsified fuel flow rates.

The results from the tests using a side orifice in the tank were identical to the results using the bottom orifice for both the liquid and the emulsified fuels.

Vibrating the tank did not affect the flow rate of the liquid fuel. The flow rate of the emulsified fuel was not affected at the higher heads; however, at the lower heads (below 20 inches), the flow rate was increased by the vibration.

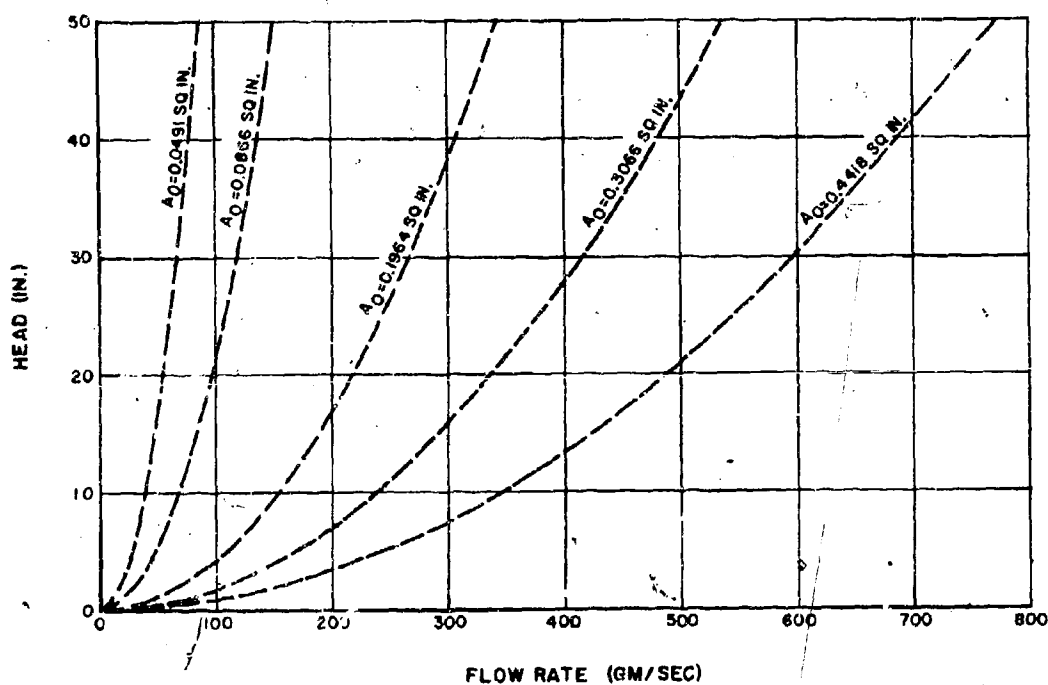


Figure 17. Results of Flow Test Using Liquid JP-4.

Both circular and slotted orifices were used in this study. The slotted orifices consisted of two semicircles and a rectangle. The shape of the orifice did not change the flow rate; the flow rate through the circular orifice was identical to the flow rate through the slotted orifice of the same orifice area.

Under every condition tested, the flow rate for the liquid fuel was greater than the flow rate for the emulsified fuel. The flow rate of the emulsified fuel approached the flow rate of the liquid fuel at the greater pressure heads, but as the height of the head increased, the difference in the flow rates of the two fuels increased.

For the emulsified fuel, there was essentially no flow through a circular orifice with a diameter of 1.5 inches under a static pressure head of 10 inches.

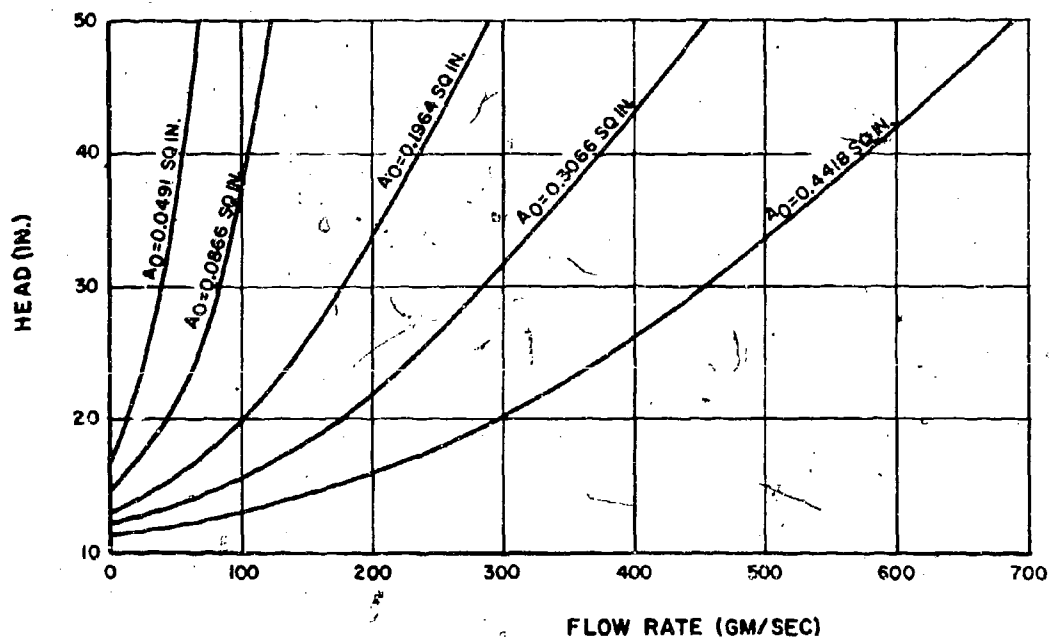


Figure 18. Results of Flow Test Using Emulsified Fuel.

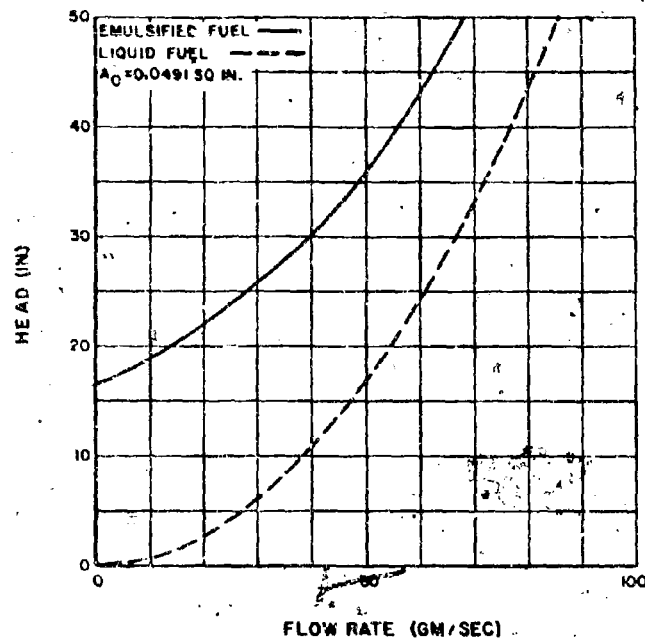


Figure 19. Comparison of Liquid and Emulsified Fuel Flow Rates.

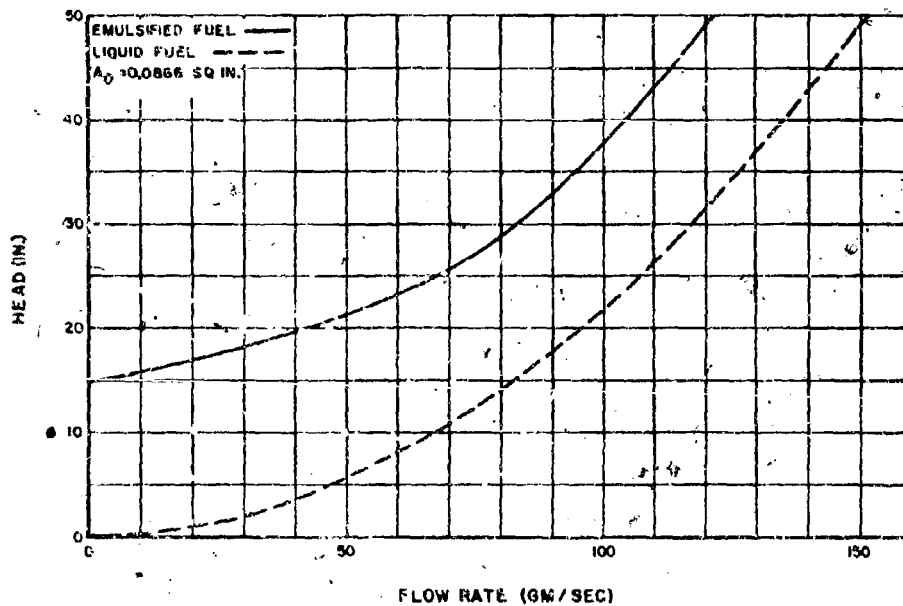


Figure 20. Comparison of Liquid and Emulsified Fuel Flow Rates.

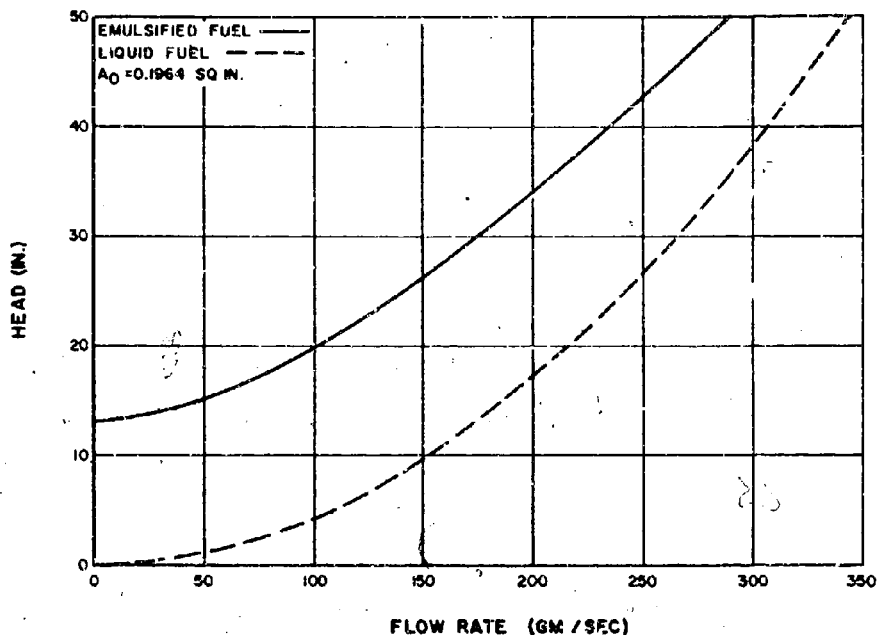


Figure 21. Comparison of Liquid and Emulsified Fuel Flow Rates.

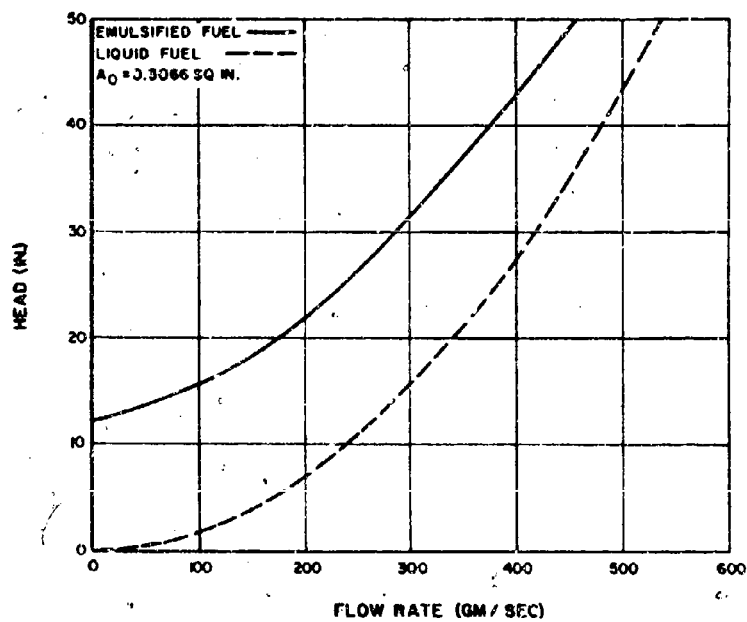


Figure 22. Comparison of Liquid and Emulsified Fuel Flow Rates.

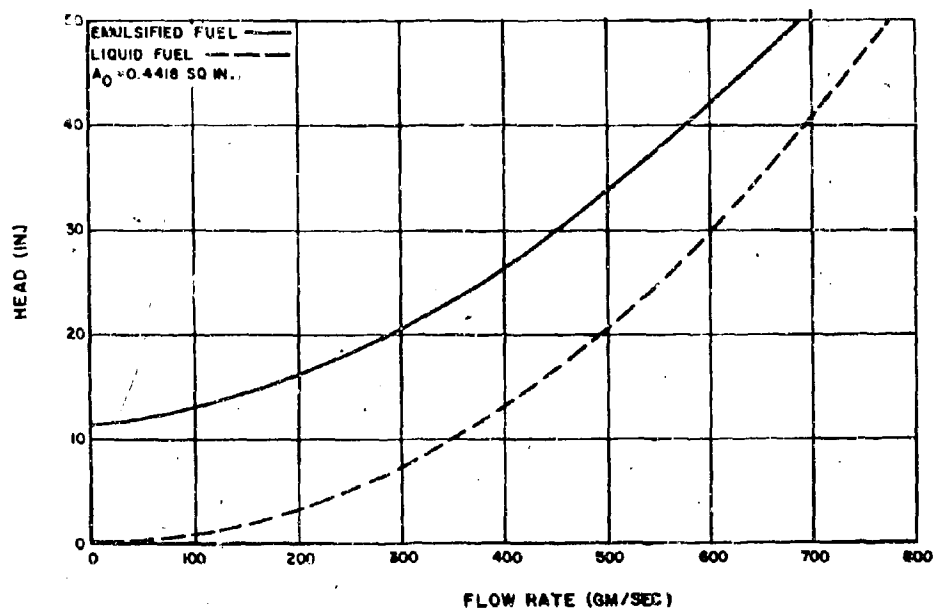


Figure 23. Comparison of Liquid and Emulsified Fuel Flow Rates.

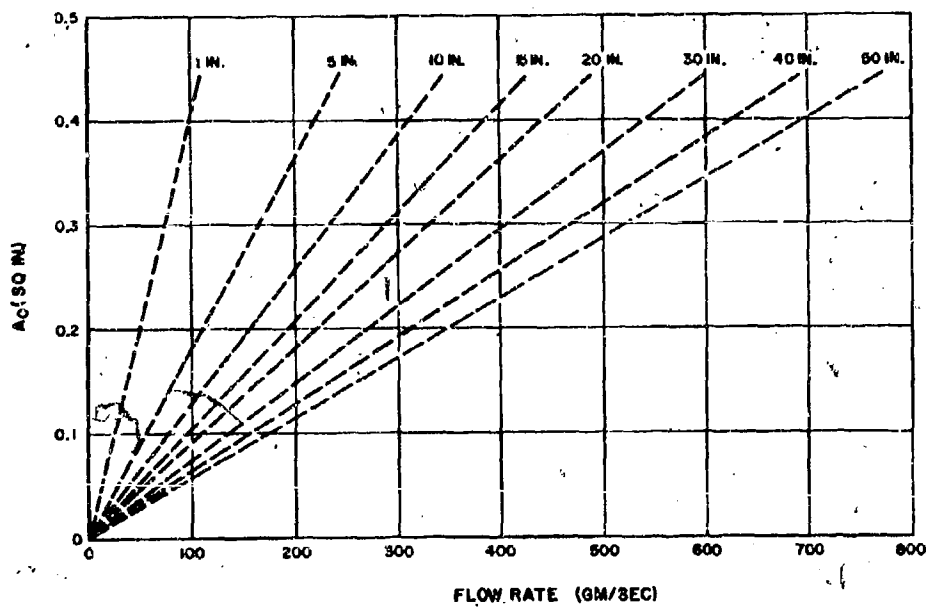


Figure 24. Results of Flow Test Using Liquid JP-4.

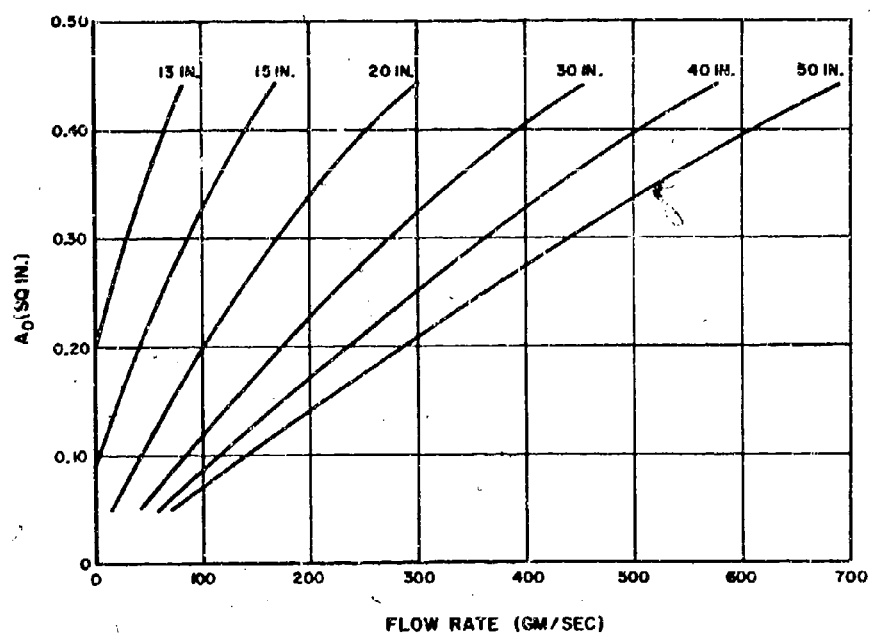


Figure 25. Results of Flow Test Using Emulsified Fuel.

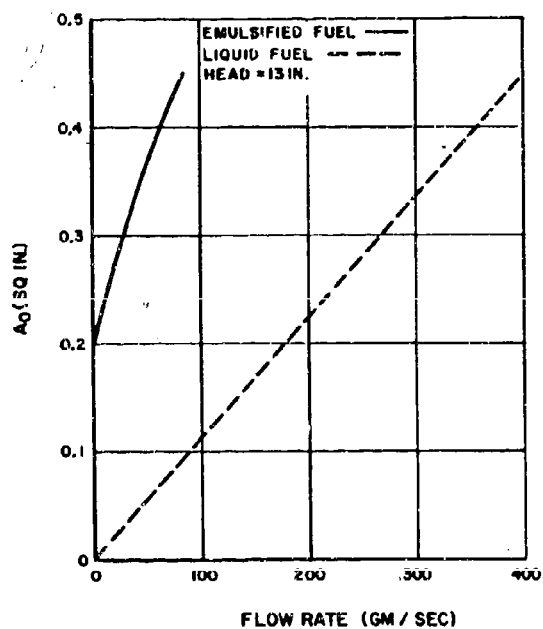


Figure 26. Comparison of Liquid and Emulsified Fuel Flow Rates.

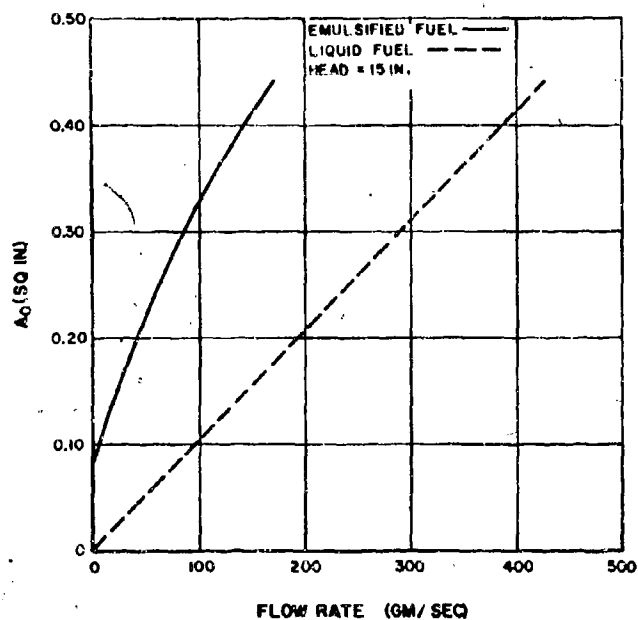


Figure 27. Comparison of Liquid and Emulsified Fuel Flow Rates.

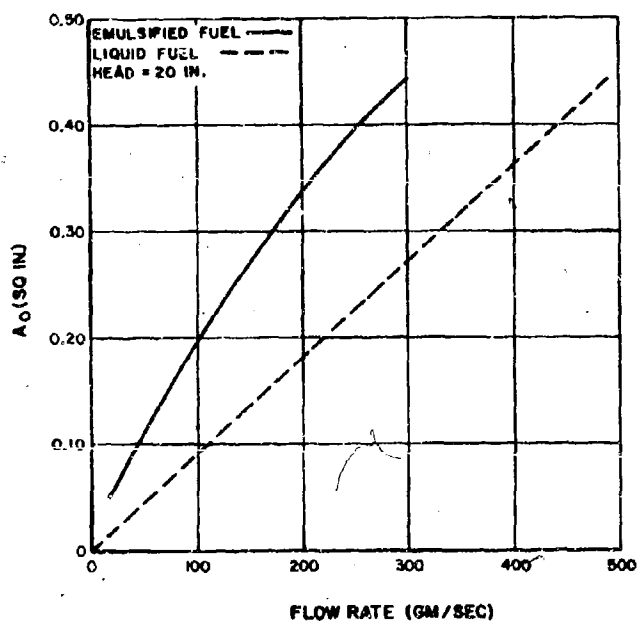


Figure 28. Comparison of Liquid and Emulsified Fuel Flow Rates.

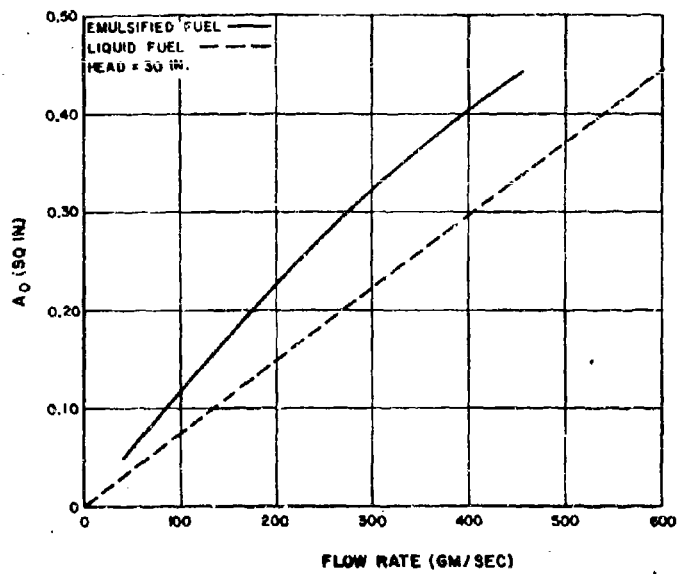


Figure 29. Comparison of Liquid and Emulsified Fuel Flow Rates.

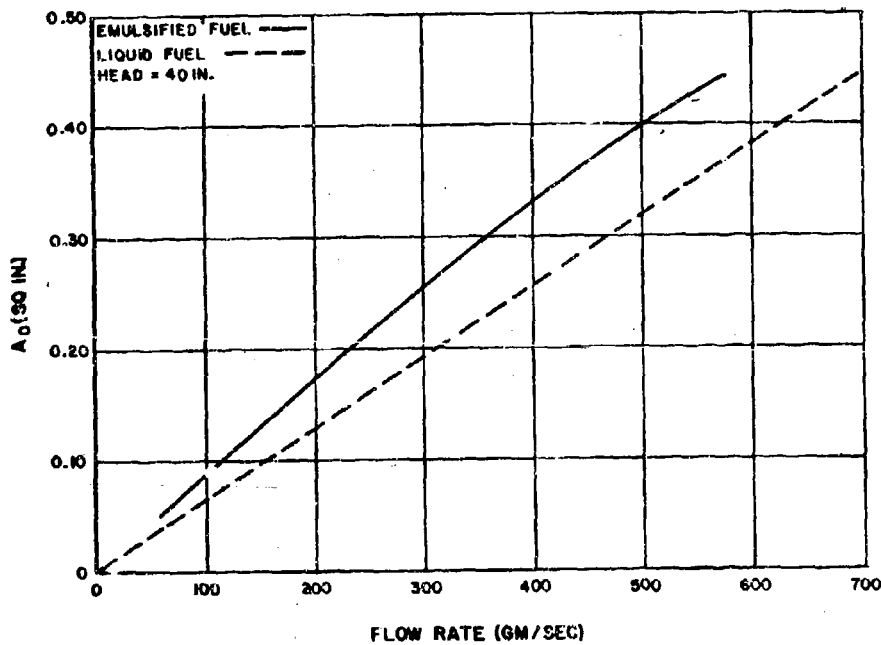


Figure 30. Comparison of Liquid and Emulsified Fuel Flow Rates.

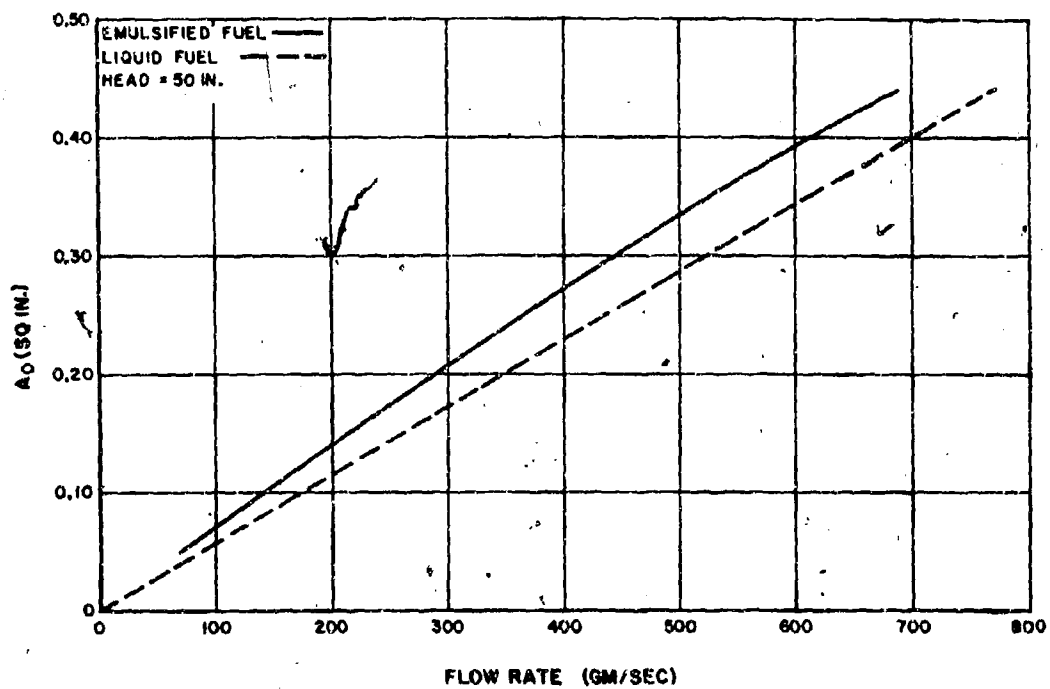


Figure 31. Comparison of Liquid and Emulsified Fuel Flow Rates.

CONCLUSIONS

It is concluded that:

1. The surface area available for vaporization of emulsified fuels is significantly less than that available for liquid fuels under identical circumstances.
2. Liquid fuel will flow from a ruptured tank at a significantly higher rate than emulsified fuel, causing a significantly greater fire hazard.
3. The significant advantage gained by emulsification of liquid aviation fuels is mainly due to its physical characteristics.

RECOMMENDATIONS

It is recommended that:

1. Similar vulnerability studies be conducted with various base fuels and their emulsions.
2. Developmental efforts to increase the thermal stability of emulsified fuels be continued.
3. A house task be established to study the "misting" characteristics of liquid and emulsified fuels.

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APPENDIX I
TEST FOR REID VAPOR PRESSURE OF PETROLEUM PRODUCTS

SCOPE

This method of test covers the determination of the absolute vapor pressure of volatile crude oil and volatile petroleum products, except liquified petroleum gases.

SUMMARY OF METHOD

The gasoline chamber of the vapor pressure apparatus is filled with a chilled sample and connected to the air chamber at 100°F. The apparatus is immersed in a constant-temperature bath ($100^{\circ} \pm 0.2^{\circ}\text{F}$) and is shaken periodically until equilibrium is reached.

APPARATUS

The Reid vapor pressure bomb, consisting of an air chamber and a gasoline chamber, shall conform to the following requirements.

The upper section, or air chamber, shall be a cylindrical vessel $2 \pm 1/8$ inches in diameter and $10 \pm 1/8$ inches in length (inside dimensions), with the inner surfaces of the ends slightly sloped to provide complete drainage from either end when held in a vertical position. On one end of the air chamber, a suitable gage coupling with an internal diameter of not less than $3/16$ inch shall be provided to receive the $1/4$ -inch gage connection. In the other end of the air chamber, an opening approximately $1/2$ inch in diameter shall be provided for coupling with the gasoline chamber.

The lower section, or gasoline chamber, shall be a cylindrical vessel of the same inside diameter as the air chamber and of such volume that the ratio of the volume of the air chamber to the volume of the gasoline chamber shall be between the limits of 3.8 and 4.2. In one end of the gasoline chamber, an opening approximately $1/2$ inch in diameter shall be provided for coupling with the air chamber. The inner surface of the end containing the coupling member shall be sloped to provide complete drainage when inverted. The other end of the gasoline chamber shall be completely closed.

HANDLING OF SAMPLES

The extreme sensitivity of vapor pressure measurements to losses through evaporation and to slight changes in composition requires the utmost precaution in the handling of samples.

The size of the sample container from which the vapor pressure sample is taken shall be not less than 1 quart nor more than 2 gallons.

In all cases, the sample container and its contents shall be cooled to 32° to 40°F before the container is opened. Samples in leaky containers shall not be considered for tests, but shall be discarded.

PREPARATION FOR TEST

Completely immerse the open gasoline chamber and the sample transfer connection in the water cooling bath for a sufficient time to allow the chamber and connection to reach bath temperature.

After purging and rinsing the air chamber and pressure gage, connect the gage to the air chamber. Immerse the air chamber to at least 1 inch above its top in the water bath, maintained at $100^{\circ} \pm 0.2^{\circ}\text{F}$, for not less than 10 minutes just before coupling it to the gasoline chamber. Do not remove the air chamber from the bath until the gasoline chamber has been filled.

PROCEDURE

With everything in readiness, empty the chilled fuel chamber and inject the chilled fuel into the gasoline chamber.

Without delay, attach the air chamber to the gasoline chamber. Not more than 20 seconds shall be consumed in completing the assembly of the apparatus after filling the gasoline chamber.

Turn the assembled vapor pressure apparatus upside down to allow the sample in the gasoline chamber to run into the air chamber, and shake vigorously in a direction parallel to the length of the apparatus. Immerse the assembled apparatus in the bath, maintained at $100^{\circ} \pm 0.2^{\circ}\text{F}$, in an inclined position so that the connection of the gasoline and air chambers is below the water level. If no leaks are observed, immerse the apparatus to at least 1 inch above the top of the air chamber.

After the assembled vapor pressure apparatus has been immersed in the bath for 5 minutes, tap the pressure gage lightly and observe the reading. Withdraw the apparatus from the bath, invert it, shake it vigorously, and replace it in the bath in the shortest possible time to avoid cooling the apparatus. At intervals of not less than 2 minutes, repeat this agitation and gage observation at least five times, until the last two consecutive gage readings are constant, to ensure equilibrium. Read the final gage pressure to the nearest 0.50 pound for gages with intermediate graduations of 0.1 psi. Record this value as the Reid vapor pressure.

APPENDIX II
METHOD FOR DETERMINING THE YIELD STRESS OF EMULSIFIED
FUELS BY CONE PENETRATION

SCOPE

This method uses the ASTM D-217 cone penetrometer to obtain a value representing the yield stress.

SUMMARY OF METHOD

A sample cup is filled with emulsified fuel and stabilized at the test temperature. The surface is levelled and smoothed, and the cone assembly of the penetrometer is released for 5 seconds. The resulting depth of penetration, shown on the dial indicator of the penetrometer, is converted to a yield stress value.

APPARATUS

Penetrometer - A penetrometer shall be used to measure the penetration of the cone in the emulsified fuel. The cone assembly, or the table of the penetrometer, shall be adjustable to enable accurate placement of the tip of the cone on the level surface of the fuel while maintaining a "zero" reading on the indicator. The cone should fall, when released, without appreciable friction for at least 4 cm, and the tip of the cone should not hit the bottom of the sample container. The instrument shall be provided with levelling screws and a spirit level to maintain the cone shaft in a vertical position.

Cone and Rod Assembly - A cone, manufactured of plastic but having an aluminum tip and stem, and conforming to the dimensions shown in Figure 32, shall be used. A rod, manufactured of aluminum and weighing 15.00 ± 0.05 gm, shall be used to support the cone. The combined weight of the cone and rod assembly shall be 30.0 ± 0.1 gm.

Sample Container - Aluminum petrolatum container having an inside diameter of 3-13/16 inches and a height of 2-1/2 inches, with cover and a ring conforming with requirements of Figure 33.

Constant-Temperature Bath - Suitable air bath to bring the temperature of the sample to $76^{\circ} \pm 4^{\circ}\text{F}$. A temperature-controlled room may be used.

Spatula - Corrosion resistant, 1/2 inch wide.

GENERAL PROCEDURE FOR OPERATING CONE PENETROMETER

Place the sample in the container in such a manner as to remove large air pockets that may be entrained. Smooth the surface of the sample and level it with the lip of the container by scraping with a spatula. Level the penetrometer with the aid of the levelling screws and the spirit level. Clean the cone carefully before each test, making sure that it is in the raised position. Set the mechanism to hold the cone in the "zero" position. Place the sample container on the penetrometer table and lower the assembly so that the tip of the cone just touches the surface at the center of the sample. Watching the shadow of the cone tip is an aid to accurate setting. Release the cone shaft rapidly, and allow it to drop for 5.0 ± 0.1 seconds. The release mechanism should not drag on the shaft. Gently depress the indicator shaft until it is stopped by the cone shaft, and read the penetration from the indicator dial. Make three tests, and report the average value, to the nearest unit, as the penetration of the sample. (Where applicable, for the additional measurements, it is preferable to use fresh samples of the same material.)

CONVERSION TO YIELD STRESS

Use the relation between the penetration and yield stress, as shown in Figure 34, to determine the yield stress of the emulsified fuel.

Note: For determination of yield stress above 5000 or below 600, use the following formulas.

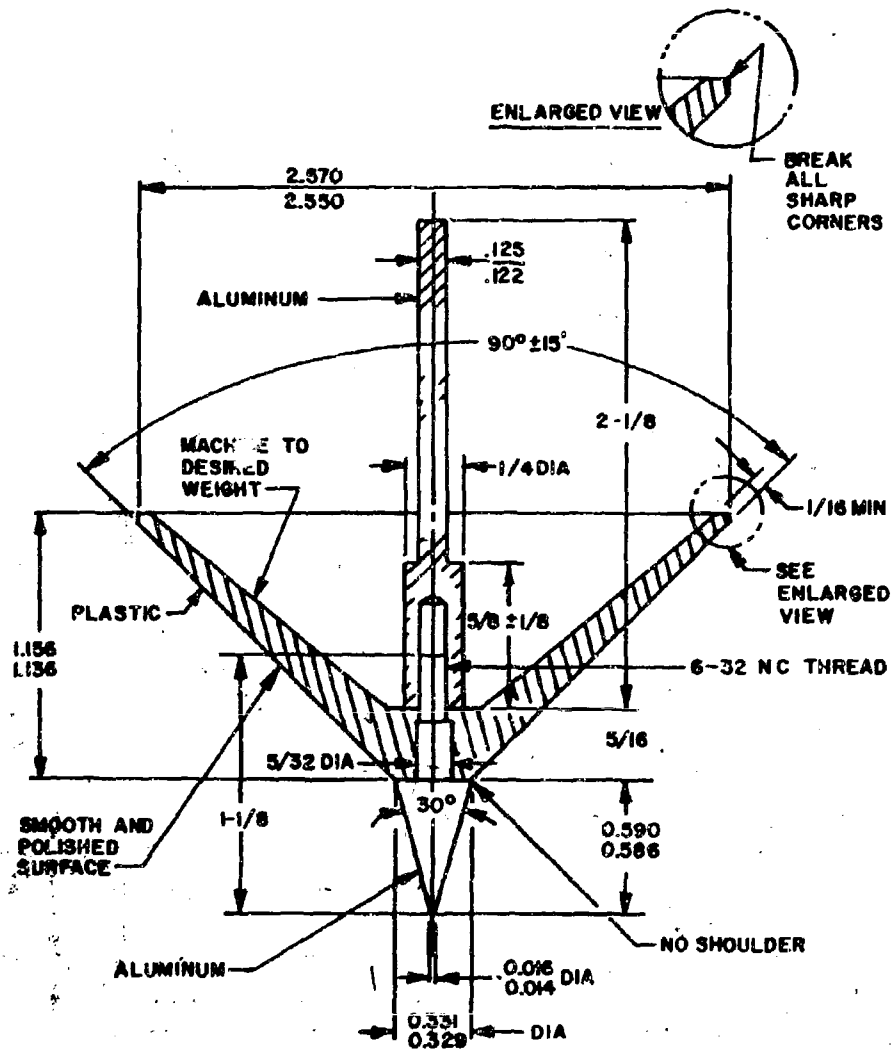
$$\begin{aligned} 200 &< \text{Y.S.} < 600 \\ 5000 &< \text{Y.S.} < 8000 \end{aligned}$$

$$\begin{aligned} \text{Y.S.} &= 8 \quad (430\text{-P}) \\ \text{Y.S.} &= 100 \quad (257\text{-P}) \end{aligned}$$

where P = penetration

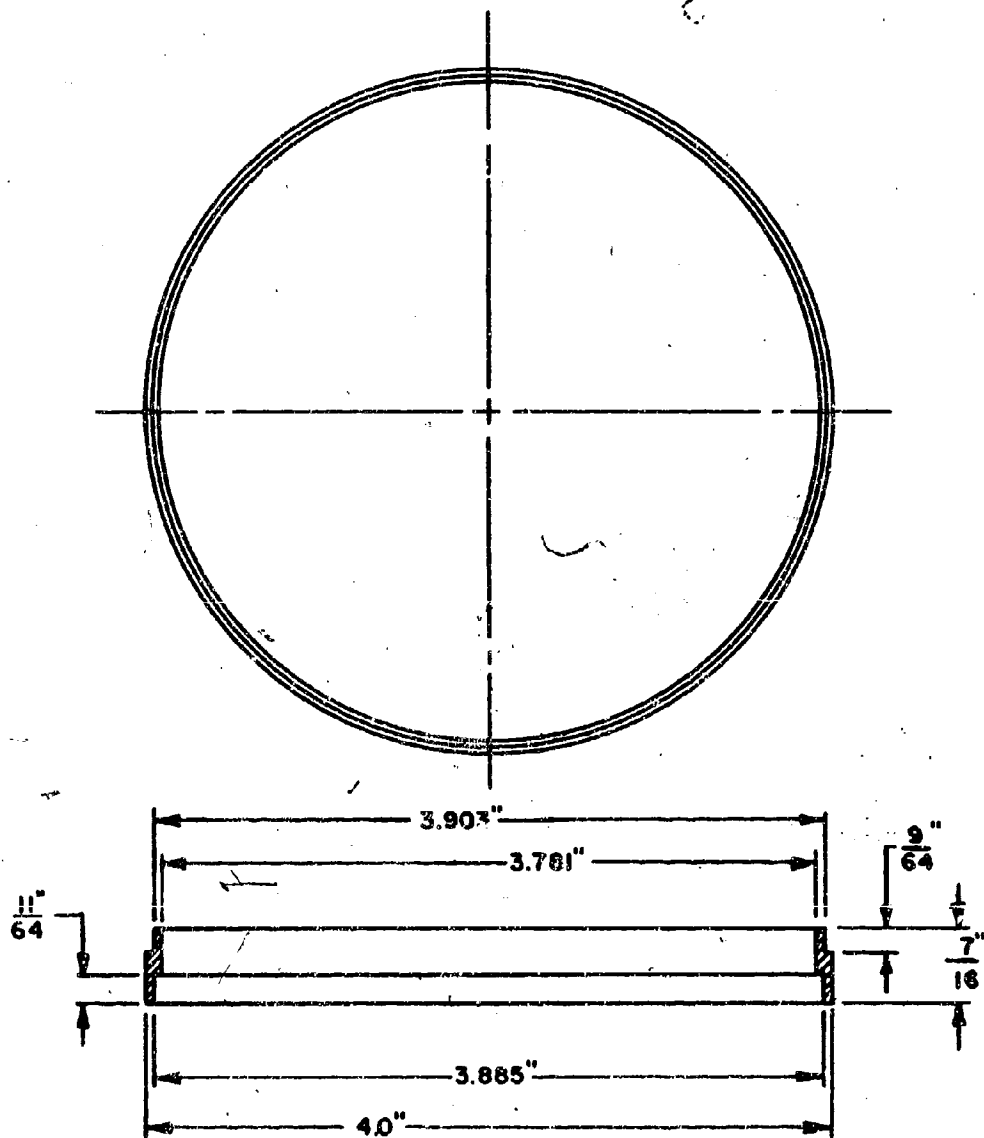
REPORTING

Room-Temperature Procedure - Convert the average penetration to yield stress, and report this value to the nearest 10 below 1000, to the nearest 50 between 1000 and 3000, and to the nearest 100 above 3000.



- NOTES:
1. TOLERANCES ON ALL FRACTIONAL DIMENSIONS TO BE 1/16 IN.
 2. THE TOTAL WEIGHT OF THE CONE SHALL BE 15.0 ± 0.05 GM AND THE TOTAL WEIGHT OF ITS MOVABLE ATTACHMENTS SHALL BE 15.0 ± 0.05 GM.
 3. UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES.

Figure 32. Penetrometer Cone.



DECIMAL TOLERANCE: ± 0.005 IN.
 FRACTIONAL TOLERANCE: $\pm 1/64$ IN.

Figure 33. Adapter Ring.

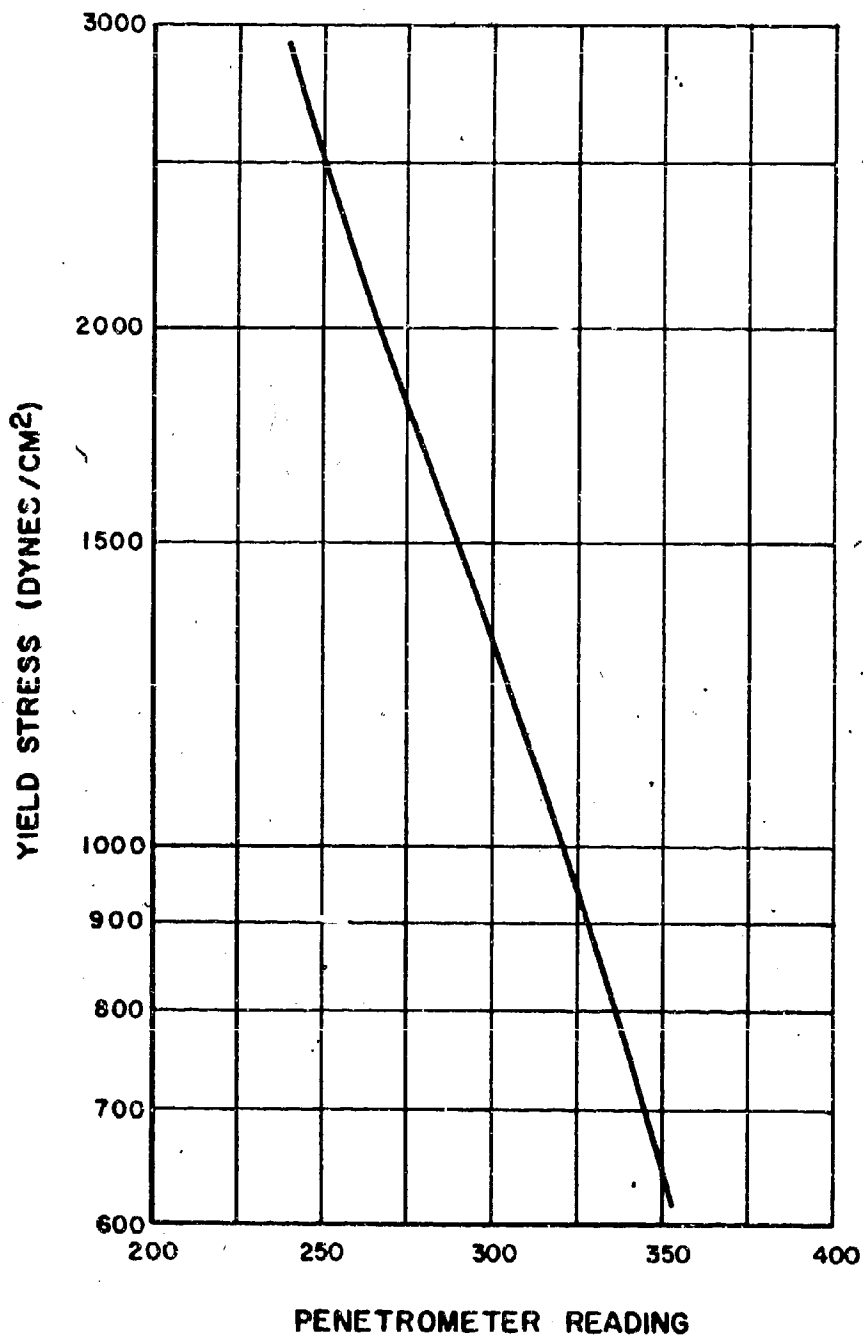


Figure 34. Yield Stress Versus Penetration.

APPENDIX III
PROCEDURE FOR BREAKING EMULSIFIED FUEL

1. Place a representative sample (900 ml or greater) of emulsified fuel in a glass container and immediately cap it vaportight.
2. Allow the fuel to stabilize at a temperature of 32° to 40°F for a minimum of 16 hours before opening the container.
3. Chill 400 ml or more of denatured ethyl alcohol to a temperature of 32° to 40°F.
4. Remove the cap from the chilled fuel sample container, add 400 ml of ethyl alcohol, and immediately replace the cap.
5. Shake the container until the emulsion is completely broken (usually 2 to 5 minutes).
6. Pour the broken fuel into a 1000-ml separatory funnel (chilled to 32° to 40°F), install the stopper, place in a bath or refrigerator at 32° to 40°F, and allow to settle until phase separation is essentially complete (15 to 20 minutes).
7. Drain out the emulsifier alcohol phase and sufficient fuel to leave a balance of 700 to 750 ml of fuel.
8. Remove the stopper, add 250 ml of distilled water (chilled to 32° to 40°F), and replace the stopper. Shake for a minimum of 1 minute, and allow to settle in a bath or refrigerator at 32° to 40°F.
9. Drain out the water phase and rewash per step 6.
10. Drain out the water phase and rewash again per step 6.
11. Drain out the water phase and use a 100-ml syringe or pipette to draw out the quantities of fuel required for the volatility determinations.

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This report presents a study of the vulnerability of emulsified fuel and the tests developed to determine vulnerability criteria for liquid JP-4 and emulsified JP-4 fuels. The following studies were conducted: vapor pressure, flow dispersion, weight loss, and fluid flow. Test results showed that the emulsion was a significant improvement over the liquid fuel in all areas investigated. The most striking difference is the relative physical characteristics of the two fuels. Similar studies should be conducted with various base liquid fuels and their emulsions. In addition, work should be conducted to determine the relative "misting" characteristics of the liquid and emulsified fuels.		

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