NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

May 1945 as
Restricted Bulletin E5E19

FUEL-VAPORIZATION LOSS AS DETERMINED BY THE CHANGE IN THE SPECIFIC GRAVITY OF THE FUEL IN AN AIRCRAFT FUEL TANK

By Charles S. Stone and Walter E. Kramer

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESTRICTED BULLETIN

FUEL-VAPORIZATION LOSS AS DETERMINED BY THE CHANGE IN THE SPECIFIC GRAVITY OF THE FUEL IN AN AIRCRAFT FUEL TANK

By Charles S. Stone and Walter E. Kramer

SUMMARY

An investigation was conducted to determine the feasibility of using the change in the specific gravity of fuels in aircraft fuel tanks to measure fuel-vaporization loss. The relation of specific gravity to fuel loss for each of the six fuels tested was determined by fuel-distillation tests and for three of the same fuels, by simulated-flight tests. The increase in specific gravity was found to be a linear function of fuel-vaporization loss up to the 40-percent fuel-loss point. An equation based on the specific gravity of the fuel was found to be accurate to within ±0.32-percent fuel loss. This method can be used for determining the fuel-vaporization loss from fuel tanks in combat and transport aircraft where other methods of measurement are not practicable.

INTRODUCTION

The density or specific gravity of a volatile fuel increases when the more volatile components are lost by vaporization. In long-range combat missions, the amount of fuel lost through vaporization during flight must be determined in addition to the amount of fuel actually consumed by the engine so that the quantity of fuel needed can be closely calculated and the maximum load capacity can be attained. The fuel-vaporization loss in flight must also be known to apply properly any preventative or fuel-recovery methods for reducing the fuel-vaporization loss.

At present, the measurement of fuel-vaporization loss from aircraft fuel tanks is rather difficult and lack of space, particularly in fighter airplanes, makes instrumentation for measurement of the loss a problem. As part of a program requested by the Army Air Forces, Materiel Command, a method for measuring fuel loss by the change in the specific gravity of the fuel was developed at the NACA laboratory in Cleveland, Ohio, that offers a simple and reasonable solution to this problem. Only a small sample of fuel need be withdrawn from the tank before and after the flight to determine the fuel-vaporization loss. Tests were conducted to show the relation of specific gravity to fuel-vaporization loss for six fuels of different initial specific gravities. The relation was studied by determining the variation in specific gravity with fuel loss produced by fuel-distillation and by simulated-flight methods. Additional data not included herein show a close correlation between the fuel-vaporization loss during simulated and actual flight.

Investigators studying the problem of gasoline-vaporization loss occurring during storage and transportation have found that a correlation exists between the changes in some of the physical properties of the gasoline and the vaporization loss. Wiggins reported in reference 1 that the density of stored crudes increases when gasoline is lost by vaporization and that improved storage methods reduced both the loss and the changes in density. Chenicek and Whitman (reference 2) and Barber and Ritchie (reference 3) determined fuel-vaporization loss by measuring changes in fuel-vapor pressure. Fuel losses as small as 0.05 percent were detected; the apparatus used, however, was very fragile and complicated and the method used was very time consuming. Chenicek and Whitman found that a relation existed between the specific gravity of fuel and fuel-vaporization loss, but presented little data on the variation of specific gravity with the loss.

APPARATUS AND TEST PROCEDURE

Three AN fuels (AN-F-29; AN-F-28, Amendment-2; AN-VV-F-756, Amendment-2) and three CFR-AFD fuels (V-7, V-9, V-10) were used in the tests. The characteristics of these fuels are outlined in table 1 and their A.S.T.M. distillation curves are shown in figure 1.

A standard A.S.T.M. gasoline-distillation apparatus was used to obtain a series of fuels with various percentages removed by distillation for each of the six fuels to evaluate the specific-gravity change. The amount of fuel lost through distillation was measured by weighing the fuel before and after distillation and the specific gravity of a sample of each residual fuel obtained by distillation was then determined.

Simulated-flight tests were conducted on the three AN fuels to produce fuel-vaporization loss. A diagrammatic sketch of the simulated-flight bench-test installation used in the tests is shown in figure 2. The simulated altitudes were produced by evacuating the cylindrical plastic fuel tank with three vacuum pumps, each with a capacity of 9 cubic feet per minute, to the desired altitude pressure. The altitude pressure was controlled by an air bleed valve in the line between the tank and the vacuum pumps. The fuel agitator was not used for these tests.

In each simulated flight, 15 pounds of fuel heated to an initial temperature of 110° F were used. Flight conditions were simulated by controlling the pressure in the tank to the pressure that would be encountered during the desired flight path. Fuel samples were withdrawn from the tank at suitable time intervals during the test and at the start and the end of each test. The specific gravity of these fuel samples was determined.

Because the tank was mounted on a scale, the amount of fuel lost by vaporization was determined directly from the scale readings. These losses were corrected for the fuel samples withdrawn during the test.

An analytical-type Westphal balance was used to measure the specific gravity of the fuels. The balance used was accurate to within ±0.0004 of a specific-gravity unit. The specific-gravity measurements were standardized by immersing the vessels containing the fuel samples in a constant-temperature bath at 20° ±0.06° C (68° ±0.1° F). The samples were kept in the bath for at least 1 hour in order to attain the desired temperature before each measurement was made.

ACCURACY OF MEASUREMENTS

The conditions of the tests were such that two sources of errors were possible: (1) an error that was common to both the distillation and the simulated-flight procedures and (2) an error that may have occurred only in the simulated-flight tests. The source of error common to both procedures may have occurred in the determination of the specific gravity of the fuel samples and involved the removal of the samples from the constant-temperature bath and the manipulation of the Westphal balance. The error introduced in this procedure was considered to be very small because the readings of the Westphal balance were reproducible to within ±0.0004 of a specific-gravity unit. The reproducibility and accuracy were determined by making successive determinations of different samples of the same fuel and by frequently measuring the specific gravity of gas-free distilled water under the same conditions.

The chief source of error may have occurred in the sampling process during the simulated-flight tests. The short length of copper tubing leading from the fuel tank to the sample bottle contained about 10 percent of the fuel sample that was withdrawn. Because this portion of the fuel was stagnant and was removed from the main body of the fuel, it may not have suffered the same vaporization losses as the fuel in the tank and may have caused some error in the results.

The possible magnitude of this error can be calculated by assuming the worst condition possible: that no change has taken place in the trapped portion of the fuel between successive samples. From the largest test-sample interval that occurred (between a fuel loss of 8.12 and 11.32 percent on AN-F-29 fuel), the following data are obtained:

Percentage fuel loss	Measured specific gravity
8.12	0.7428
11.32	.7465

Assuming that 10 percent of the fuel is trapped in the sampling tube and that it has not been affected during the interval between samples, the theoretically true specific gravity of the fuel in the tank at the fuel loss of 11.32 percent can be obtained from the equation

$$0.1\ (0.7428) + 0.9\ (A) = 0.7465$$

where

A theoretically true specific gravity of the fuel in the fuel tank

Solving

$$A = 0.7469$$

If a fuel-vaporization loss of 3.2 percent can cause a change in specific gravity of 0.0041, then the maximum possible error caused by using the actual reading in place of the true reading is

$$3.2 \times \frac{0.0004}{0.0041} = 0.31\text{-percent fuel loss}$$

The possible error thus calculated is the maximum possible individual error that can occur between any of the test points. It is not a cumulative error because the sampling tube is completely flushed during sample removal and individual specific-gravity determinations are made.

RESULTS AND DISCUSSION

The variation of specific gravity with fuel loss as obtained by distillation for each of the six fuels is shown in figure 3. The curves for the AN-F-29 and the AN-VV-F-756, Amendment-2 fuels change slope at about the 46-percent point and the 44-percent point, respectively. This change in slope indicates some change in the characteristics of the fuel at these points. The curve for the AN-F-28, Amendment-2 fuel is linear up to the 65-percent fuel-loss point and from this point it follows a nonlinear curve. The data for the three CFR fuels were taken up to only the 40-percent point for the V-7 and V-10 fuels and up to only the 44-percent point for the V-9 fuel. The specific gravity for all six fuels varies linearly up to the 40-percent fuel-loss point and, because fuel losses greater than 40 percent will seldom occur, only that portion of each curve up to the 40-percent fuel-loss point need be considered. This fuel loss of 40 percent causes a change in specific gravity of 2.8 percent for AN-VV-F-756, Amendment-2 fuel, 4.6 percent for AN-F-28, Amendment-2 fuel, and 5.5 percent for AN-F-29 fuel.

The data of figure 3 are replotted in figure 4 and show the increase in specific gravity as a function of the fuel-distillation loss produced by the distillation method. The curves show that the change in specific gravity with fuel-distillation loss for each type of fuel is different, but that the functions are linear for all six fuels.

From the data and from the general equation of a straight line, an equation can be derived relating the percentage of fuel loss to the change in specific gravity. The equation is

$$L = K\,(A - A_o)$$

where

L percentage fuel loss

A final specific gravity of fuel at 20° C (68° F)

A_o initial specific gravity of fuel at 20° C (68° F)

K constant, characteristic of each fuel

The value of the constant K experimentally determined for each of the fuels used is given below in increasing order:

Fuel	K
AN-F-29	980
CFR-AFD-V-7	997
CFR-AFD-V-10	1053
AN-F-28, Amendment-2	1153
CFR-AFD-V-9	1738
AN-VV-F-756, Amendment-2	1951

Figure 5 compares the data obtained in the simulated-flight tests with the curves obtained from the derived equation. No loss greater than 18 percent was obtained during simulated flight because of the time required to produce large losses

The maximum deviation of the simulated-flight data from the values calculated by the derived equation is 0.87-percent fuel loss and the average deviation is ±0.32-percent fuel loss.

The constant K is plotted in figure 6 as a function of the initial specific gravity of the fuels. The figure shows a relation between these functions for fuels of widely differing specific gravities. The constants for fuels of intermediate specific gravities may possibly be obtained by interpolation.

CONCLUSIONS

The following conclusions are based on measurements of fuel-vaporization losses produced by fuel-distillation and simulated-flight tests. Fuel losses occurring from actual spillage of fuel through the vent due to airplane maneuvers, to temperature expansion of the fuel, and to excessive boiling and surging of the fuel cannot, of course, be determined by this method.

1. The change in the specific gravity of the fuel can be used as a rapid and accurate method for determining fuel-vaporization loss within ±0.32-percent fuel loss.

2. The loss can be determined by the equation

$$L = K\ (A - A_o)$$

for the fuel loss not exceeding 40 percent, where

L percentage fuel loss

A final specific gravity of fuel at 20° C (68° F)

A_o initial specific gravity of fuel at 20° C (68° F)

K constant, characteristic of each fuel

3. Fuel sampling during flight with subsequent specific-gravity determination on the ground is a readily applicable method for the determination of fuel-vaporization losses from airplanes where instrumentation for other methods is difficult.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Wiggins, John H.: Loss of Gasoline by Evaporation from Crude Is $250,000,000 for 1922. Nat. Petroleum News, vol. XIV, no. 47, Nov. 22, 1922, pp. 30, 32.

2. Chenicek, George W., and Whitman, Walter G.: Determination of Evaporation Losses. Refiner and Natural Gas Mfr., vol. 9, no. 11, Nov. 1930, pp. 115-126, 146.

3. Barber, Everett M., and Ritchie, A. V.: A Variable Vapor-Volume Barometric Type of Vapor Pressure Apparatus. Ind. and Eng. Chem. (Anal. ed.), vol. 8, no. 6, Nov. 15, 1936, pp. 472-476.

TABLE 1

CHARACTERISTICS OF SIX AVIATION FUELS USED IN SPECIFIC-GRAVITY TESTS

Fuel	Hydrogen-carbon ratio	TEL content (ml/gal)	Reid vapor pressure (lb/sq in.)	Heat of combustion (Btu/lb)	Specific gravity at 20° C (68° F)
AN-F-29	0.162	4.20	6.3	18,260	0.7348
AN-F-28, Amendment-2	.168	4.50	6.3	18,800	.7190
AN-VV-F-756, Amendment-2	.186	0	7.0 (max.)	18,700	.6957
CFR-AFD-V-7	----------	4.17	6.9	----------	0.7322
CFR-AFD-V-9	----------	4.06	6.4	----------	.7031
CFR-AFD-V-10	----------	4.29	6.7	----------	.7253

National Advisory Committee
for Aeronautics

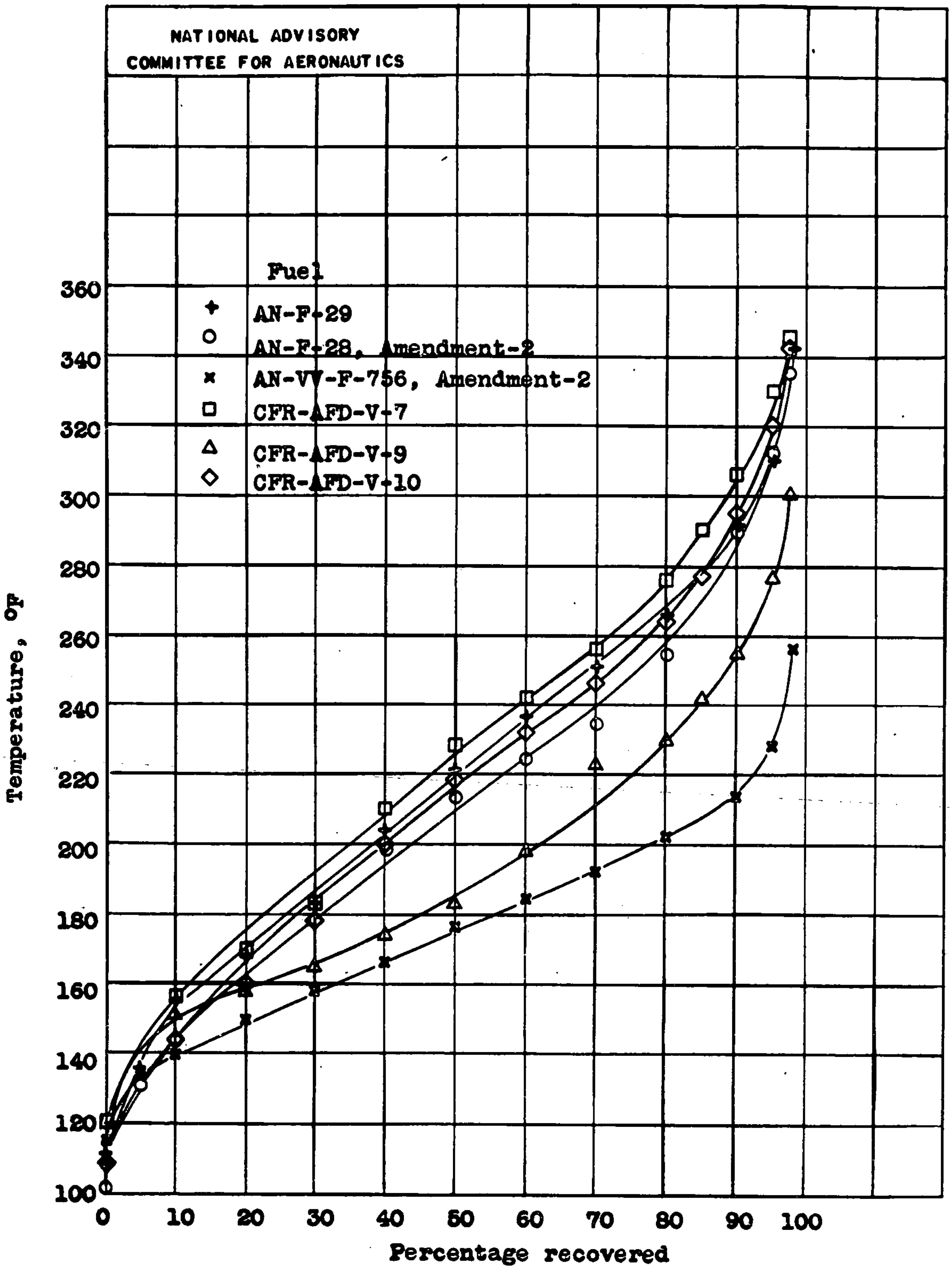
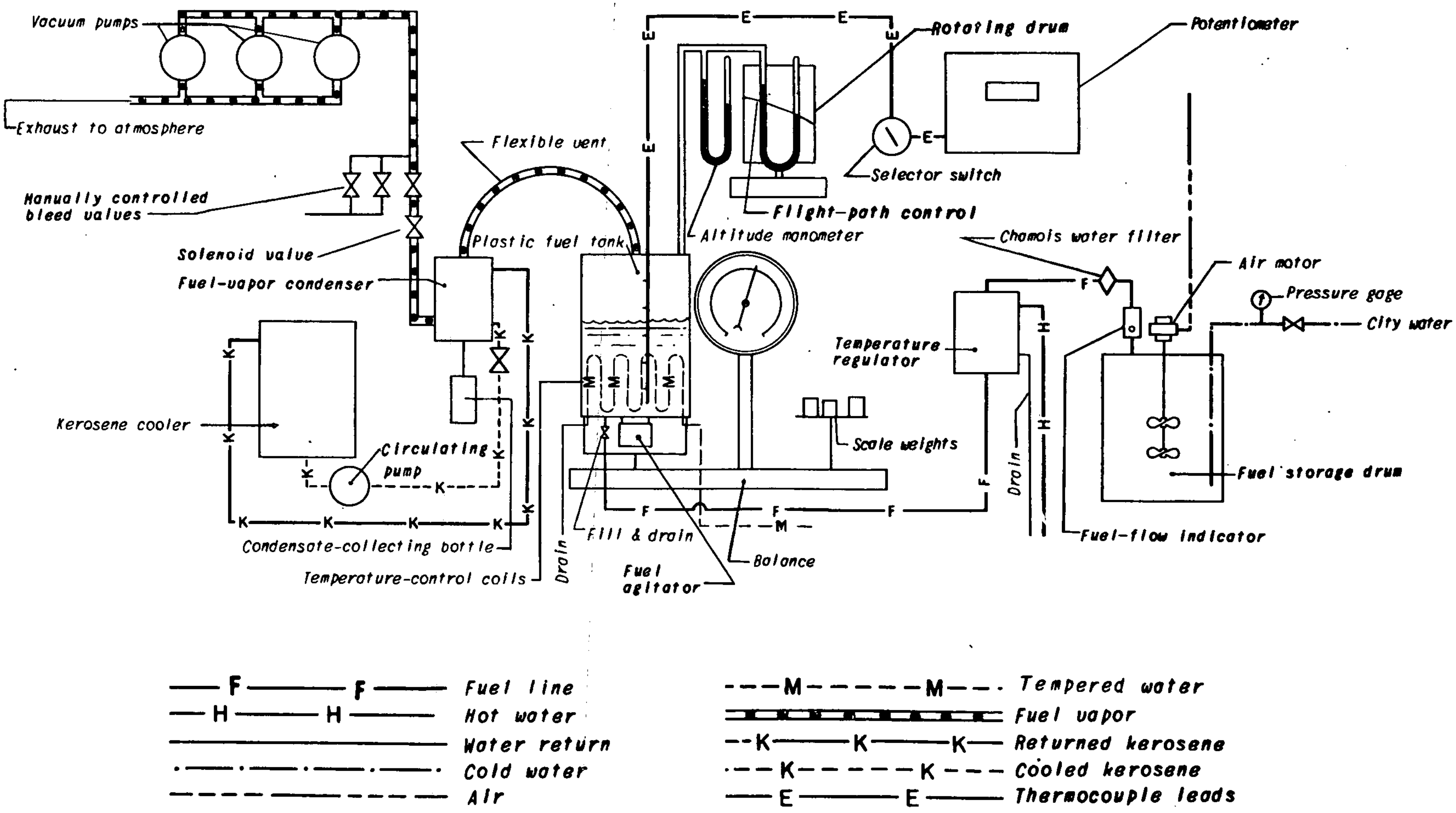


Figure 1. - A.S.T.M. distillation curves of six aviation fuels used in specific-gravity tests.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 2. - Diagrammatic sketch of simulated-flight bench-test installation.

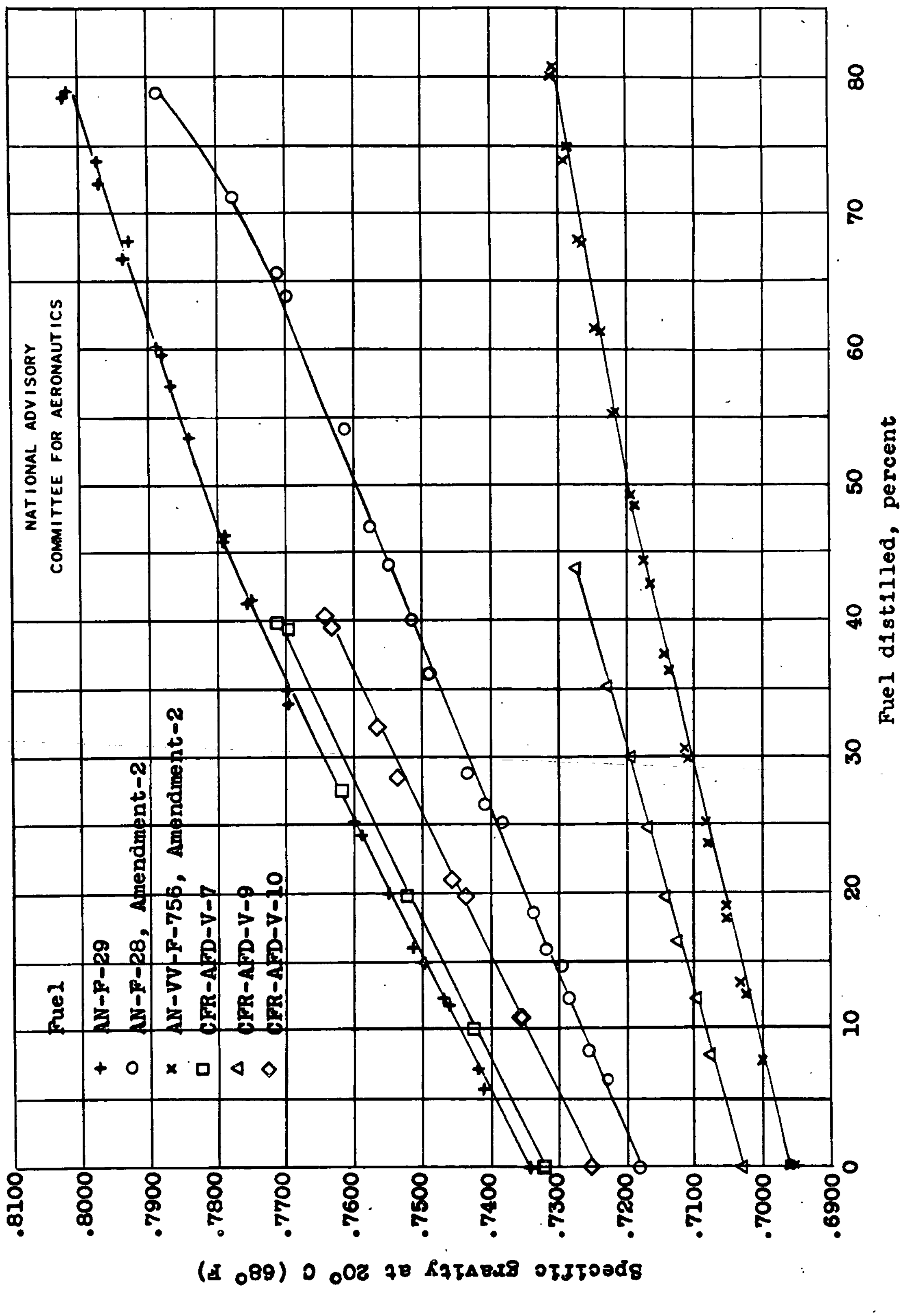


Figure 3. - Variation of specific gravity with fuel distilled.

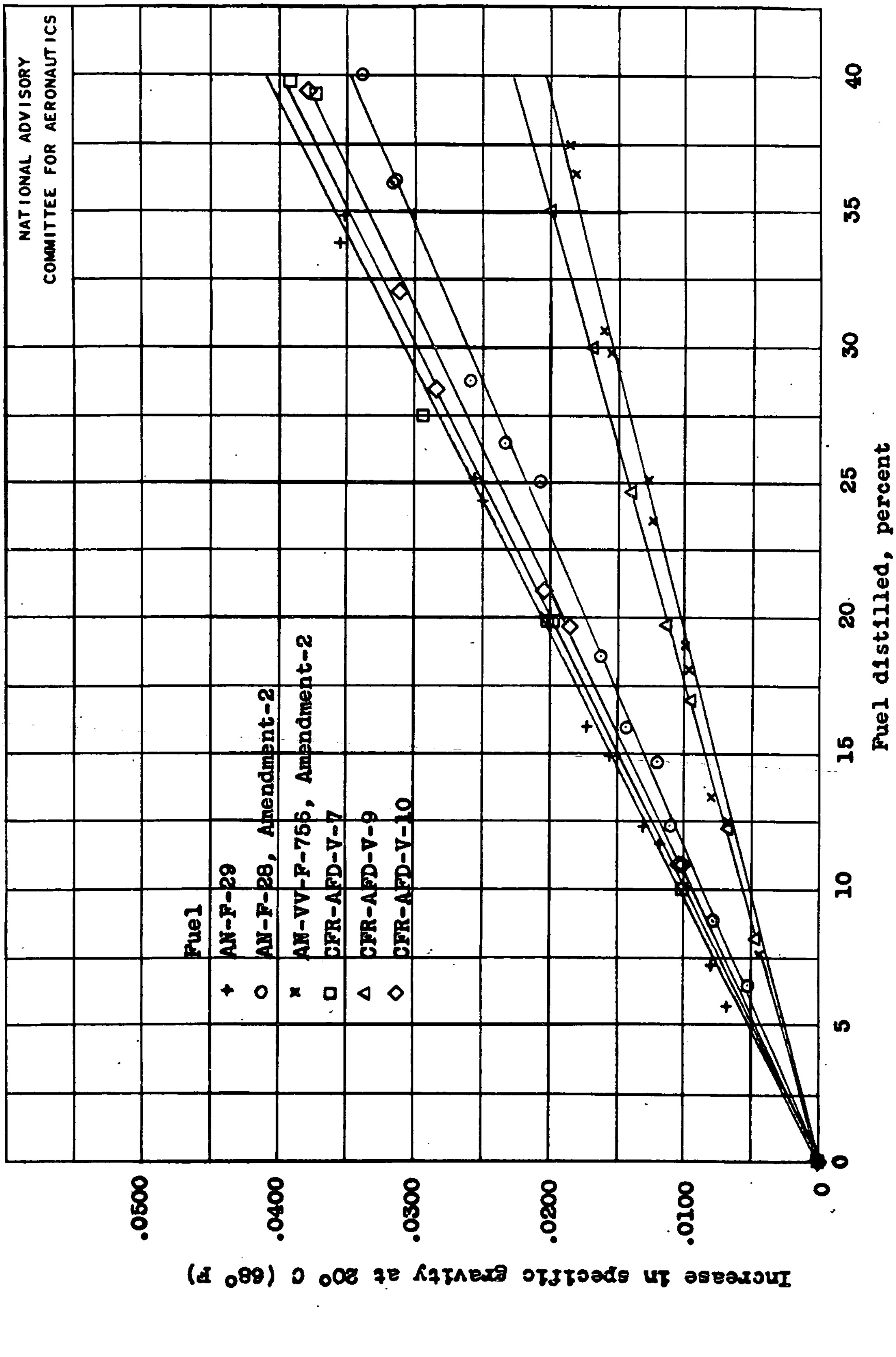


Figure 4. - Increase in specific gravity as a function of fuel distilled.

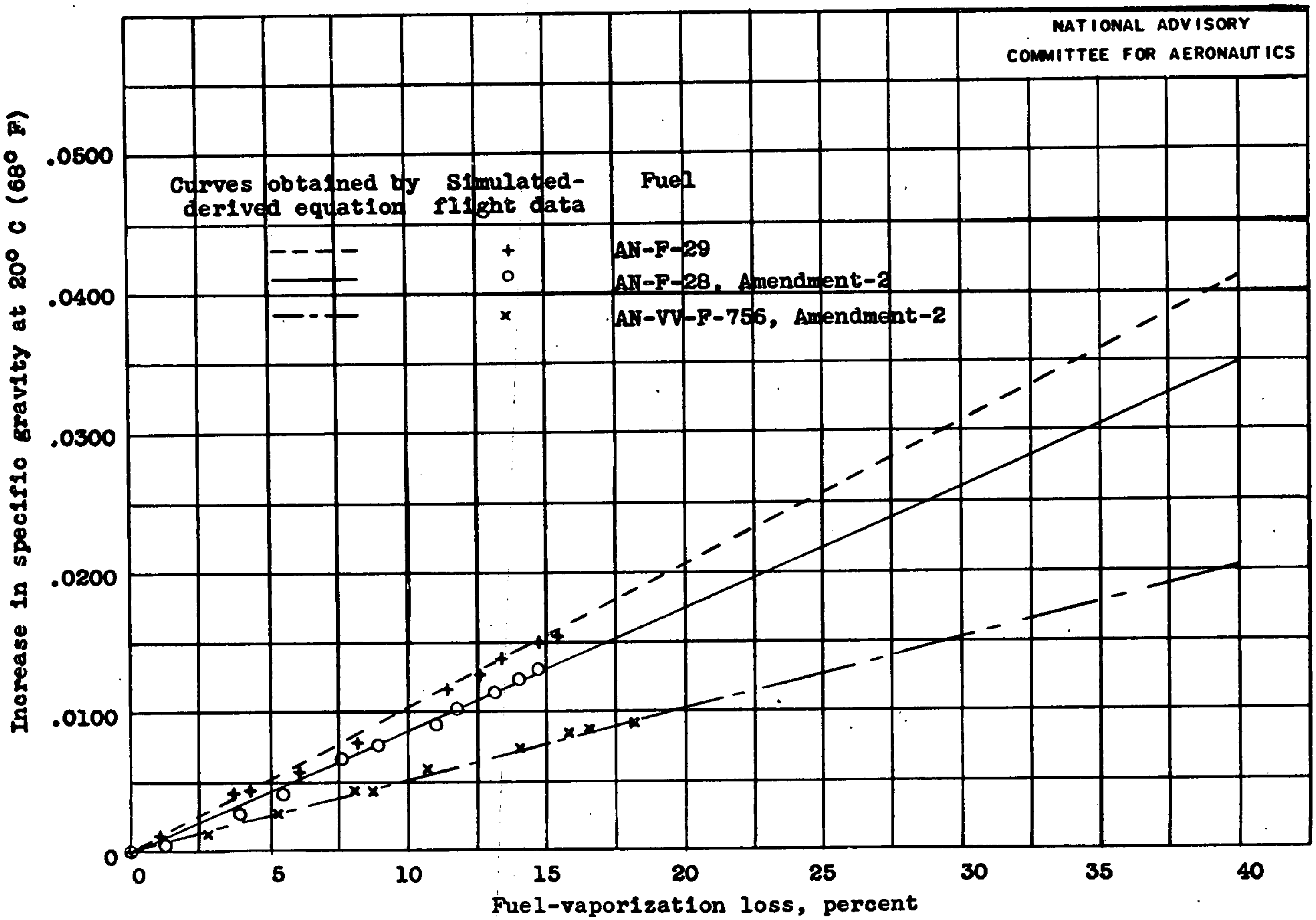


Figure 5. - Comparison of increase in specific gravity of fuel as a function of fuel-vaporization loss during simulated flight with increase predicted by derived equation.

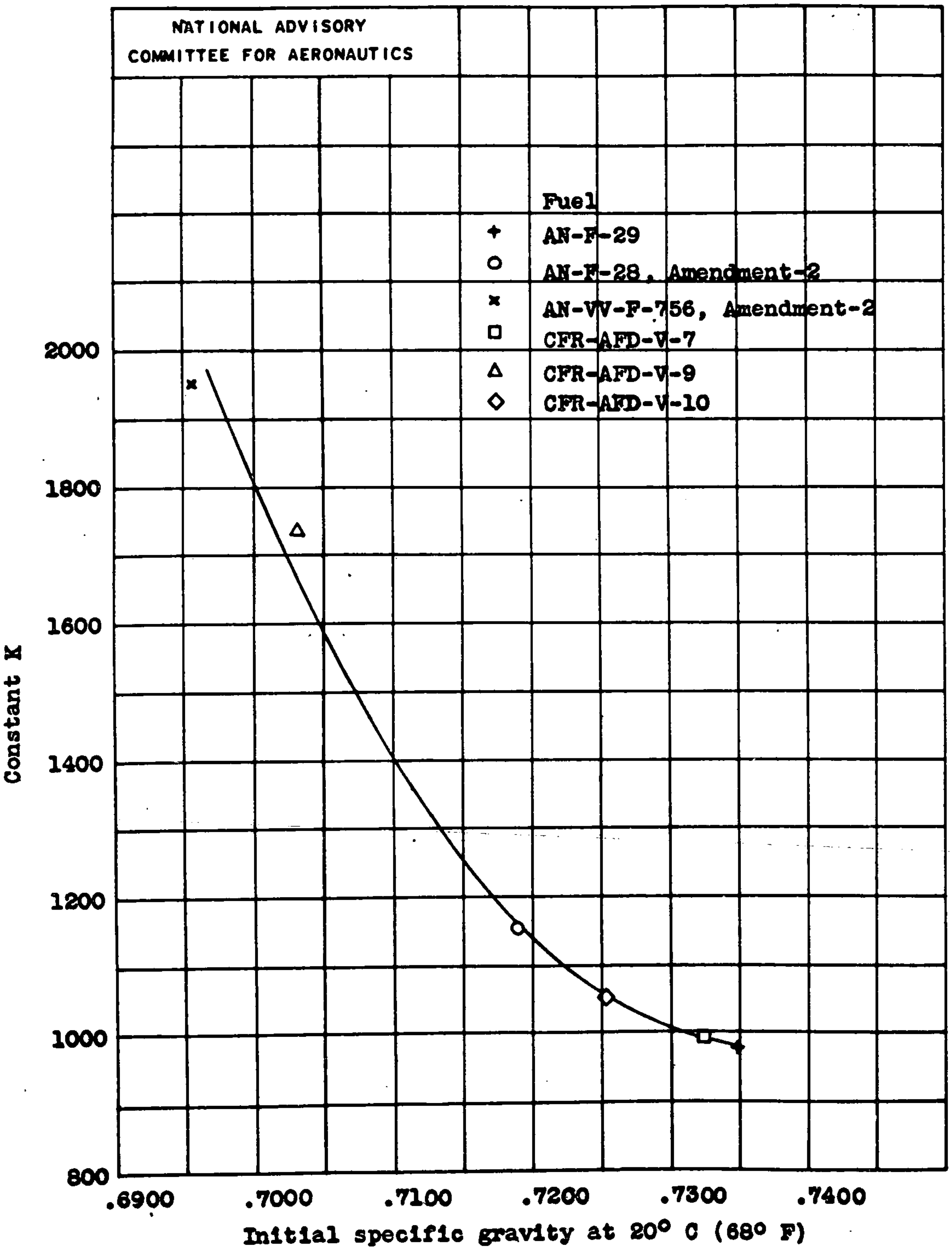


Figure 6. - Variation of constant K with the initial specific gravity of the fuel.