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SIGNIFICANCE OF ALKYLATE-REPLACEMENT VALUES OF AVIATION FUEL COMPONENTS

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ADVANCE RESTRICTED REPORT

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SUMMARY

Object. - To discuss the significance of alkylate-replacement values and to illustrate methods of estimating these values.

Scope. - Equations expressing alkylate-replacement values in terms of the blending characteristics of fuel are given and methods of estimating alkylate-replacement values are described. The estimated effect on engine performance resulting from the replacement of alkylate is discussed and illustrated by test data obtained with F-3 and F-4 laboratory engines and data obtained with a Wright R-1820 G200 cylinder.

Conclusions. - Alkylate-replacement value depends not only upon the rating of the fuel component that is replacing the alkylate but also upon the ratings of the alkylate and the base fuel. The alkylate-replacement value of a fuel component is independent of the relative proportion of the component and of the knock limits of the blends provided that the knock limits follow the reciprocal blending equation. The alkylate-replacement value of a fuel component in the case where the knock limits of the blends do not follow the reciprocal blending equation depends upon the knock limits of the fuel blends.

INTRODUCTION

The alkylate-replacement value of a fuel component is defined as the ratio of the quantity of gasoline of a specified quality which can be made with the component to the quantity which can be made with an equal amount of alkylate when either is blended with another component. The other component is usually a low-octane base stock.

The alkylate-replacement value is useful in estimating the relative quantities of finished gasoline that can be produced from various high-octane components. Alkylate is used as the standard for comparison because it is the most commonly used high-antiknock component.

The concept of alkylate-replacement value is valid not only for blends with ratings lower than the rating of alkylate but also for blends with ratings exceeding the rating of alkylate.

This paper discusses the factors affecting alkylate-replacement values, illustrates convenient methods of estimating alkylate-replacement values, and shows how differences in engines and operating conditions alter alkylate-replacement values and engine performance. The effects of engine differences are illustrated by data obtained from F-3 and F-4 engines and from an R-1820 G200 cylinder. Blends of virgin base stock, alkylate, and catalytically cracked stock were tested.

The experimental data presented in this report are merely for illustration. The ratings of alkylate and catalytically cracked stock are below average and the numerical results are therefore not representative of these types of fuel; furthermore, no attention has been paid to volatility requirements, Reid vapor pressure, and other fuel characteristics.

The analysis and the tests covered in this report were conducted at the NACA Aircraft Engine Research Laboratory at Cleveland during July 1944.

ALKYLATE-REPLACEMENT VALUES

Equations for alkylate-replacement values. - The alkylate-replacement value of a fuel component can be estimated very easily if the relations between blend composition and knock ratings of the separate components are known. For blends of most paraffinic fuels, the following equation from reference 1 applies:

$$\frac{1}{P_b} = \frac{N_1}{P_1} + \frac{N_2}{P_2} + \frac{N_3}{P_3} + \ldots \qquad (1)$$

where

P_b knock-limited indicated mean effective pressure of blend

$P_1, P_2, P_3 \ldots$ knock-limited indicated mean effective pressures of components 1, 2, 3, . . .

N_1, N_2, N_3 . . . mass fractions of components 1, 2, 3, . . . in blend

Assume that component 1 is the fuel whose replacement value is desired, component 2 is the alkylate, and component 3 is the base stock.

The alkylate-replacement value is found by holding P_b constant and finding the variation of N_1 with N_2. The value of N_3 is $1 - (N_1 + N_2)$ and consequently

$$\text{replacement value} = -\frac{\Delta N_2}{\Delta N_1} = \frac{\frac{1}{P_3} - \frac{1}{P_1}}{\frac{1}{P_3} - \frac{1}{P_2}} \tag{2}$$

where

ΔN_2 change in concentration of alkylate

ΔN_1 change in concentration of replacement component

The alkylate-replacement value, as is shown by equation (2), depends not only upon the knock limits of the replacement component P_1 and the alkylate P_2 but also upon the knock limit of the base stock P_3. Equation (2) also shows that the replacement value is independent of the concentrations of the various components and of the knock limit P_b of the final blend.

Engine tests (reference 2) have shown that equation (1) does not apply to some blends of nonparaffinic fuels.

In such cases, the alkylate-replacement value depends not only upon the knock limits of the three components, as was the case in equation (2), but also upon the knock limit P_b of the final blend and the nature of the fuel components.

Graphical estimation of alkylate-replacement values. - A general method of estimating alkylate-replacement values that is applicable to blends of any fuels is as follows: Plot the knock limit of blends of alkylate with base stock and replacement component with base stock against blend composition, as is shown in figure 1. The choice of an ordinate scale is immaterial; indicated mean effective pressure on a linear scale, indicated mean effective pressure on a reciprocal scale, performance number, octane number, or lead rating is permissible. Read from the graph the percentages of alkylate (point A) and replacement component (point B) that are required in blends with the base stock to produce a gasoline of the desired grade. The alkylate-replacement value is the quotient of the percentages of alkylate and replacement component. In the case illustrated, the alkylate-replacement value is 60/35 = 1.71.

When the knock limits of the blends follow equation (1), graphical determination of the replacement value can be made on special graph paper with percentage composition for the abscissa and knock-limited indicated mean effective pressure plotted on an inverted reciprocal scale for the ordinate (fig. 2). Plot the knock limits of the base stock and the replacement component. Connect these two points with a straight line. Draw a horizontal line across the graph at the knock limit of alkylate. The percentage of replacement component that is required in a blend with the base stock to give the same knock limit as pure alkylate is represented by the intersection of the two lines. The reciprocal of this percentage is the alkylate-replacement value of the component being studied. In the case shown, a blend consisting of 71 percent replacement component in the base stock has the same knock limit as alkylate and the replacement value is therefore 1.4. For convenience, a reciprocal scale of alkylate-replacement values has been added at the top of figure 2 to permit direct reading of the replacement values.

The same procedure can be applied when the ratings of the fuels are expressed in terms of matching blends of reference fuels provided that the knock limits of the reference-fuel blends agree with the reciprocal blending equation. A graph is drawn with percentage composition for the abscissa and knock ratings plotted on a linear scale for the ordinate. The method is illustrated in figure 3.

Relation between alkylate-replacement values and ratings expressed in terms of leaded blends of S and M. - When ratings of the base fuel, the alkylate, and the test fuel are expressed in terms of matching blends of S and M reference fuels each containing the same lead concentrations, the relation between ratings and alkylate-replacement value can be found from the single graph shown in figure 4. It has been found experimentally that the knock-limited indicated mean effective pressure of blends of alkylate with a paraffinic base and S with M reference fuel vary with blend composition according to the reciprocal blending equation. A straight line in figure 4 will therefore represent the relation between ratings and the concentrations of alkylate with base.

For the specific case illustrated in figure 4, a fuel with a rating of 90 is equivalent to a blend of 80 percent alkylate with 20 percent base, or 100 barrels of the fuel will replace 80 barrels of alkylate. The alkylate-replacement value is consequently 0.8.

The alkylate-replacement value of a fuel is, in reality, a statement of the fuel rating in terms of a blend of alkylate with base stock. Precise ratings depend upon careful standardization of reference fuels and, because the ratings of alkylate and base stocks vary widely, the alkylate-replacement value should not be used in place of the usual rating of a fuel.

EFFECT OF ENGINE CONDITIONS ON ALKYLATE-REPLACEMENT VALUES AND PERFORMANCE

The alkylate-replacement value is not the same for all engines and engine conditions. As a corollary to this statement, when alkylate is replaced by another component and either the F-3 or the F-4 rating is held constant, the resulting blend will not give the same knock-limited performance under all conditions as the original alkylate blend. It is desirable that some method of estimating the performance of the blends in other engines and at other conditions be developed. Such a method is explained in the succeeding paragraphs. In the specific examples given, it is assumed that the F-4 ratings are held constant but the same analysis applied to constant F-3 ratings.

Trilinear graph. - The knock-limited performance of all blends of a base stock, alkylate, and a replacement component can be represented by a trilinear graph (fig. 5). It was shown in reference 2 that a line representing blends of equal knock ratings is a straight line on this graph. Figure 5 was constructed from knock-test data obtained for blends of a virgin base stock, alkylate, and catalytically cracked stock. The solid lines in the figure represent the

F-4 rich performance numbers and the dashed lines represent the F-3 performance numbers. The F-3 performance numbers were found by converting F-3 octane numbers according to the official Army-Navy conversion table. With the aid of figure 5, it is possible to select a fuel blend having any desired F-4 or F-3 rating within the limits imposed by the pure components. The alkylate-replacement values of catalytically cracked stock in virgin base stock as determined by tests with F-3 and F-4 methods are 0.23 and 0.67, respectively.

Figure 6 is similar to figure 5 except that the lines were drawn from data obtained on a Wright R-1820 G200 cylinder at rich and lean mixtures under the following engine conditions:

Compression ratio	7.3
Spark advance (both plugs), degrees B.T.C.	25
Engine speed, rpm	2000
Inlet-air temperature, °F	200
Cylinder-head temperature, °F	550

The cylinder-head temperature was controlled by a thermocouple located near the exhaust-end zone and the control temperature was approximately equivalent to a rear spark-plug-boss temperature of 450° F. Manifold injection was used.

The alkylate-replacement value of catalytically cracked stock in virgin base stock may be estimated directly from figure 6. At rich mixtures, the figure shows that a blend of 88 percent alkylate and 12 percent virgin base stock has the same knock limit as catalytically cracked stock and consequently the alkylate-replacement value of the catalytically cracked stock is 0.88. A similar calculation can be made for the alkylate-replacement value at lean mixtures but in this case the catalytically cracked stock has a lower rating than the virgin base stock and additions of catalytically cracked stock require additions of alkylate instead of replacement of alkylate. The alkylate-replacement value is therefore negative. Figure 6 shows that a blend of 85 percent catalytically cracked stock and 15 percent alkylate has the same knock limit as the base stock and the alkylate-replacement value of catalytically cracked stock is therefore

$$\text{replacement value} = -\frac{\Delta N_2}{\Delta N_1} = -\frac{0.15}{0.85} = -0.18$$

The lines of constant F-4 rich knock ratings in figure 5 are parallel because the knock limits of all components agree with the reciprocal blending equation. Similarly, the lines of constant knock ratings at any one of the engine conditions given in figures 5 or 6 are parallel.

Effect of alkylate replacement on F-3 ratings at constant F-4 rating. - The estimated variations of F-3 performance of blends when catalytically cracked stock replaces alkylate and when F-4 rich ratings are held at performance numbers of 130 and 120 are shown in figure 7. These values are cross-plotted from data of figure 5. The curves illustrate the degree to which the replacement of alkylate with catalytically cracked stock reduces the F-3 ratings of the blends when the F-4 rich ratings are held constant.

The end points of the curves in figure 7 at 35 and 69 percent of catalytically cracked stock represent limiting conditions of a two-component blend containing only alkylate and catalytically cracked stock.

Effect of alkylate replacement on ratings in full-scale cylinder. - The effect of alkylate replacement on the ratings of blends in a Wright R-1820 G200 cylinder can be estimated from figure 6. The lines representing blends having F-4 rich ratings of 130 and 120 performance numbers were transferred from figure 5 to figure 6 and the corresponding ratings of the blends in the full-scale cylinder were read from the graph and plotted in figure 8. Figure 8 shows, therefore, the variation of rich- and lean-mixture ratings in a full-scale cylinder of blends having F-4 rich ratings of 130 and 120 performance numbers. The replacement of alkylate with catalytically cracked stock increased the rich-mixture ratings and decreased the lean-mixture ratings.

CONCLUSIONS

1. Alkylate-replacement value depends not only upon the rating of the fuel component that is replacing the alkylate but also upon the ratings of the alkylate and the base stock.

2. The alkylate-replacement value of a fuel component is independent of the knock limit of the blends and of the relative proportions of the components provided that the knock limits of the blends follow the reciprocal blending equation.

3. The alkylate-replacement value of a fuel in the case where the knock limits of the blends do not follow the reciprocal blending equation depends upon the knock limit of the fuel blend.

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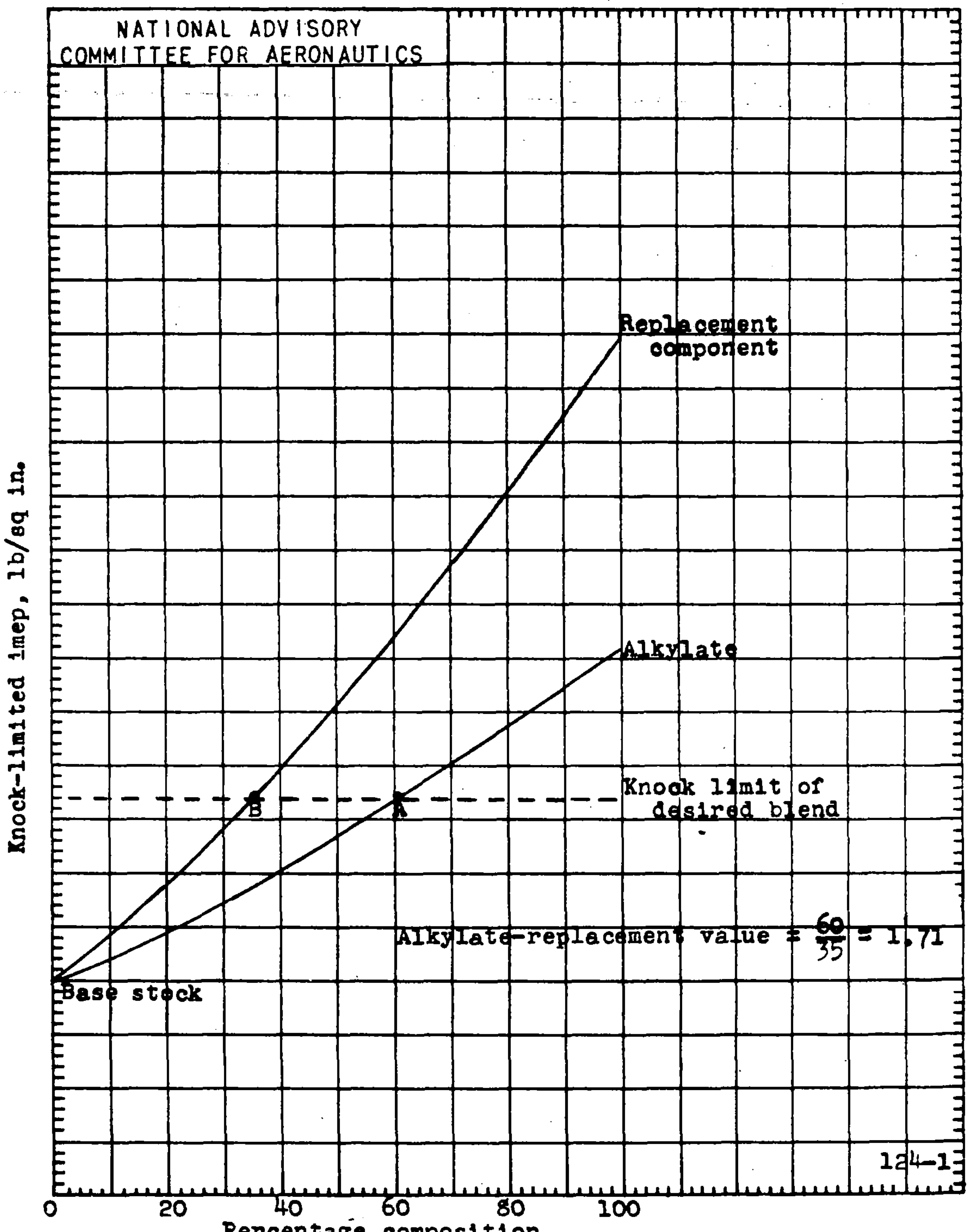

Figure 1. - General method for estimating alkylate-replacement values.

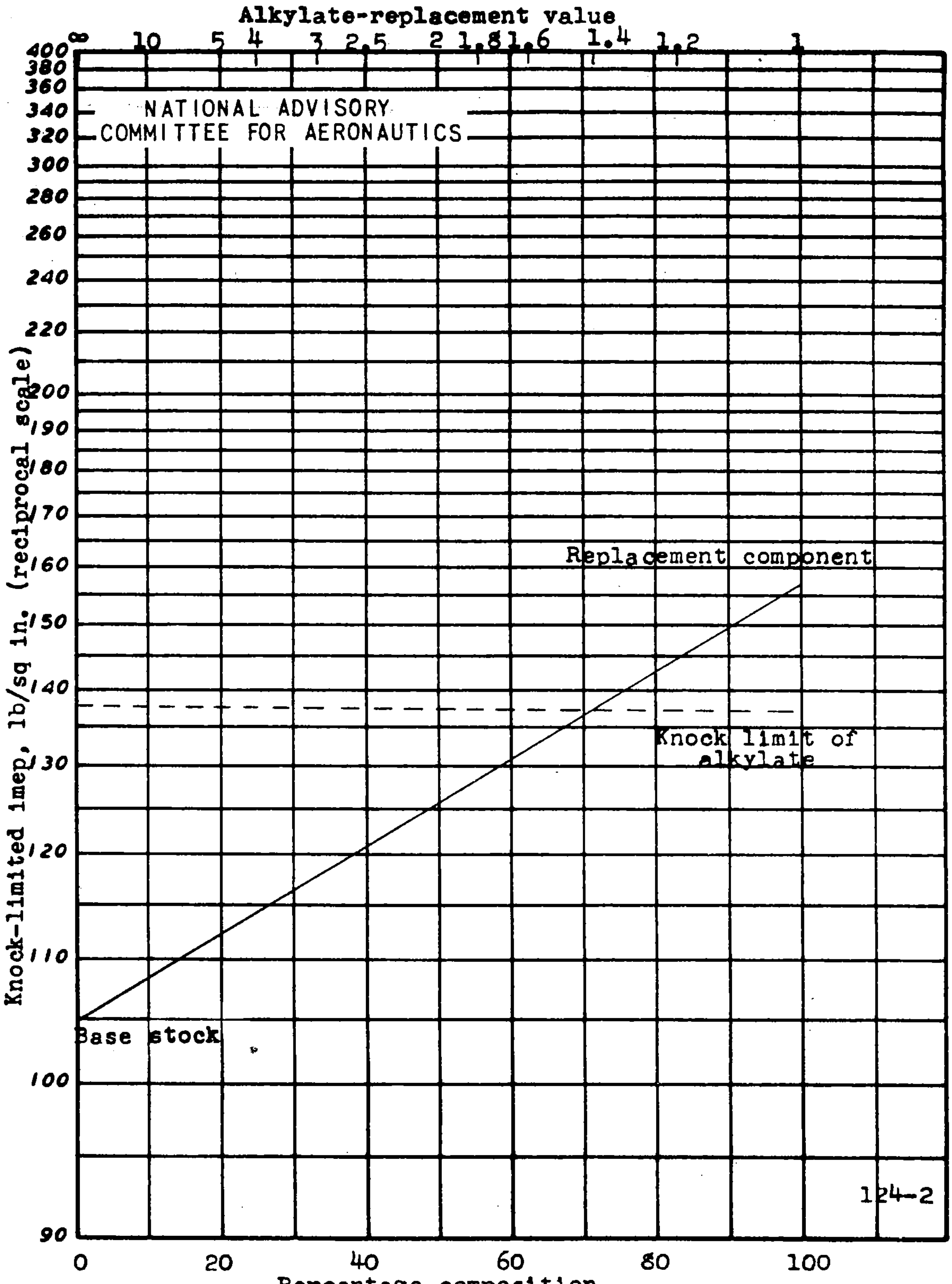

Figure 2. - Estimation of alkylate-replacement values for fuels whose blends follow the reciprocal blending equation.

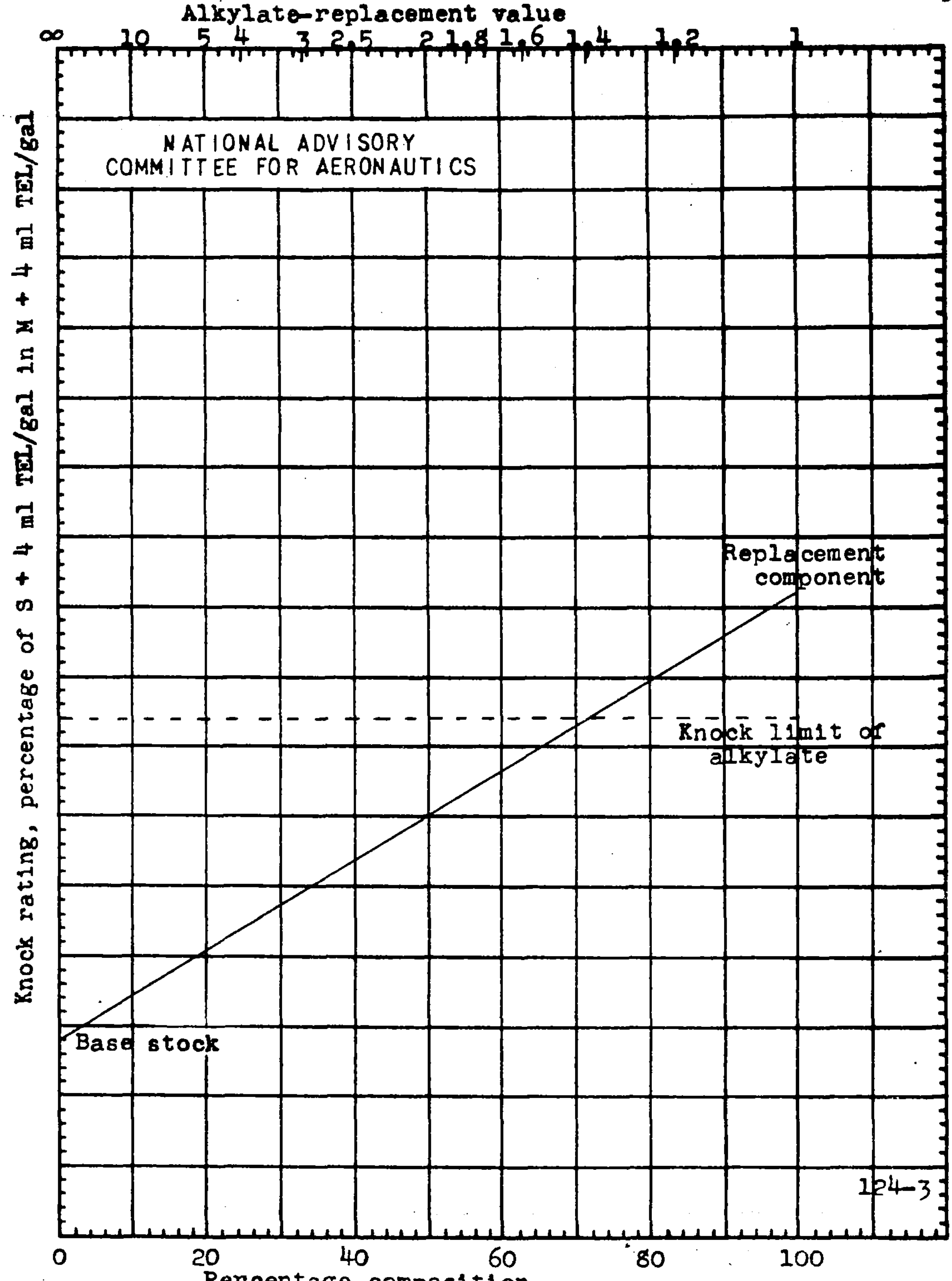

Figure 3. - Use of reference-fuel ratings for estimating alkylate-replacement values for fuels whose blends follow the reciprocal blending equation.

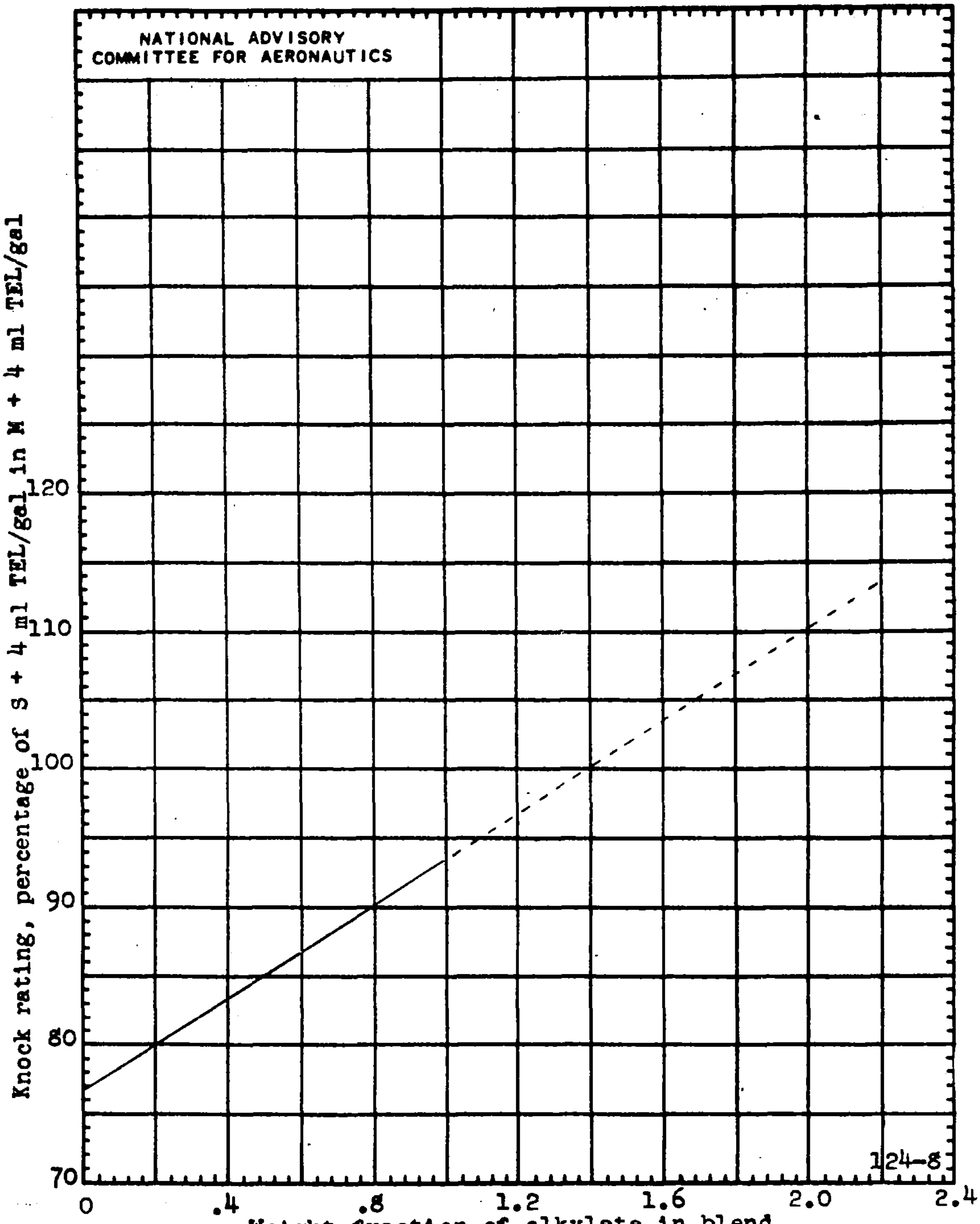

Figure 4. - Relation between knock ratings and percentage of alkylate in blends with virgin base stock. All fuels contain 4 ml TEL per gallon.

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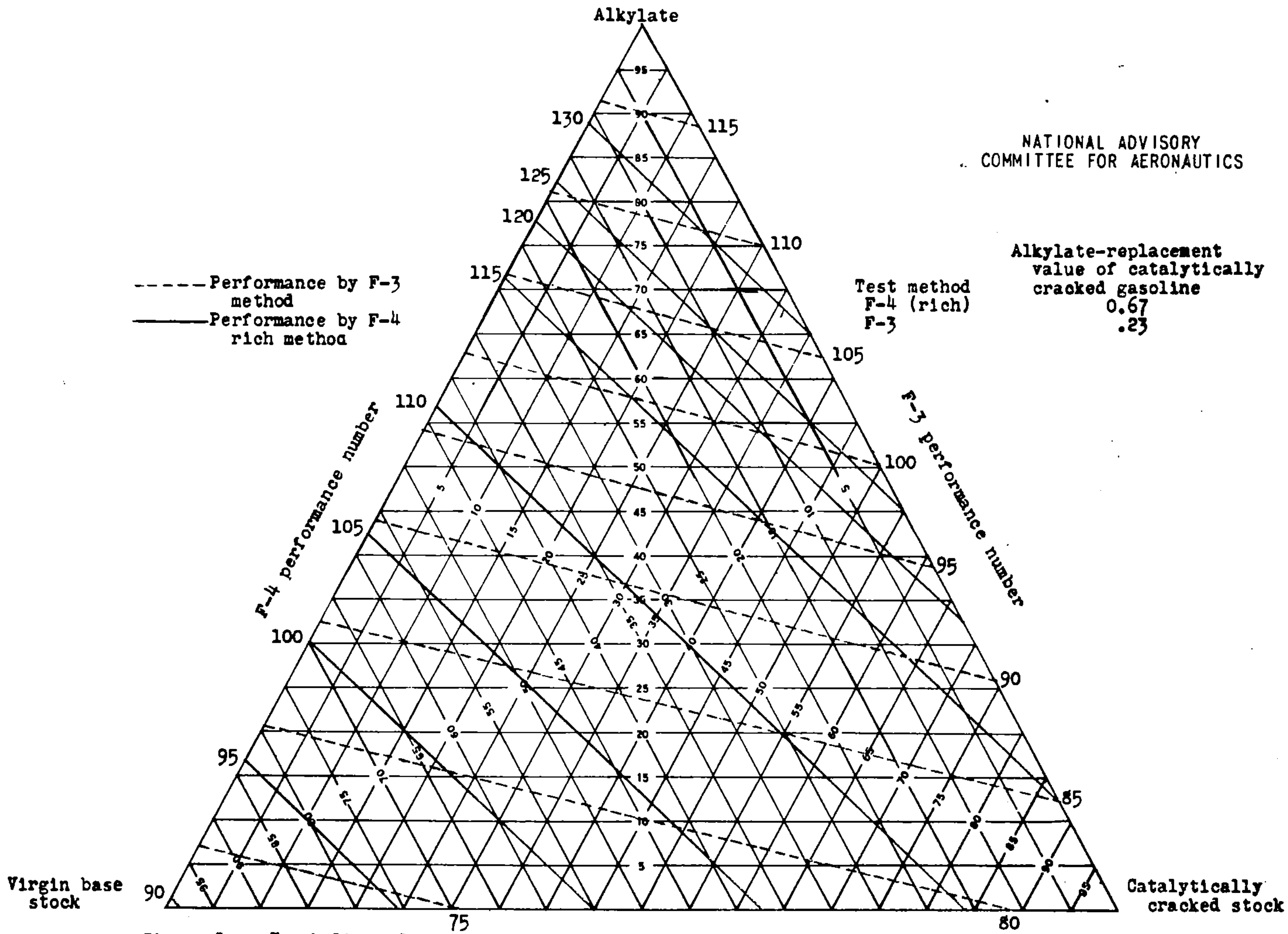

Figure 5. - Knock-limited performance of ternary blends of alkylate, virgin base stock, and catalytically cracked stock. All fuels contain 4 ml TEL per gallon; tests by F-3 and F-4 methods.

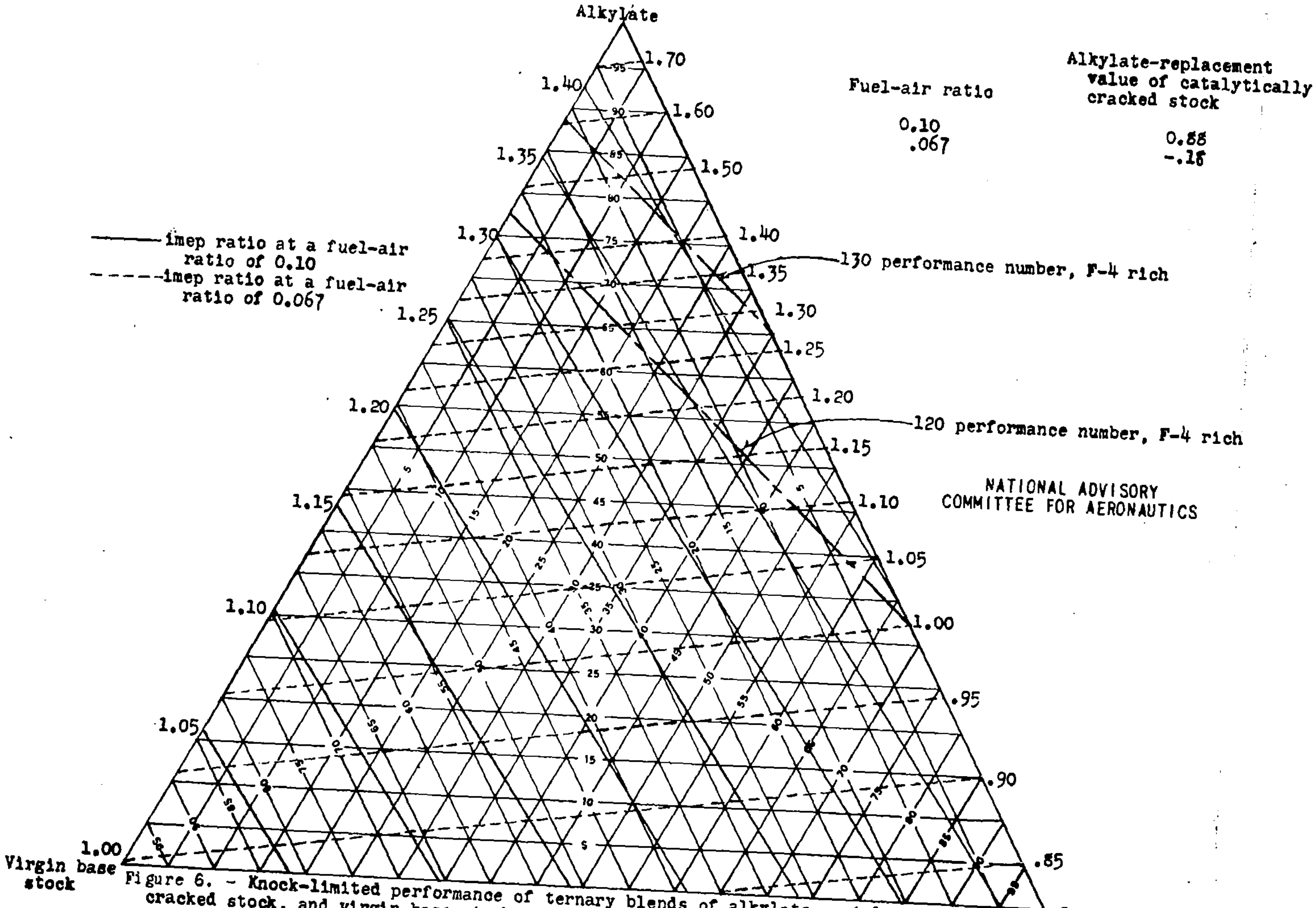

Figure 6. - Knock-limited performance of ternary blends of alkylate, catalytically cracked stock, and virgin base stock in a Wright R-1820 G200 cylinder. Ratios relative to S fuel. Fuels contain 4 ml TEL per gallon; compression ratio, 7.3; spark advance, 25° B.T.C.; engine speed, 2000 rpm; inlet-air temperature, 200° F; cylinder-head temperature at control thermocouple, 550° F.

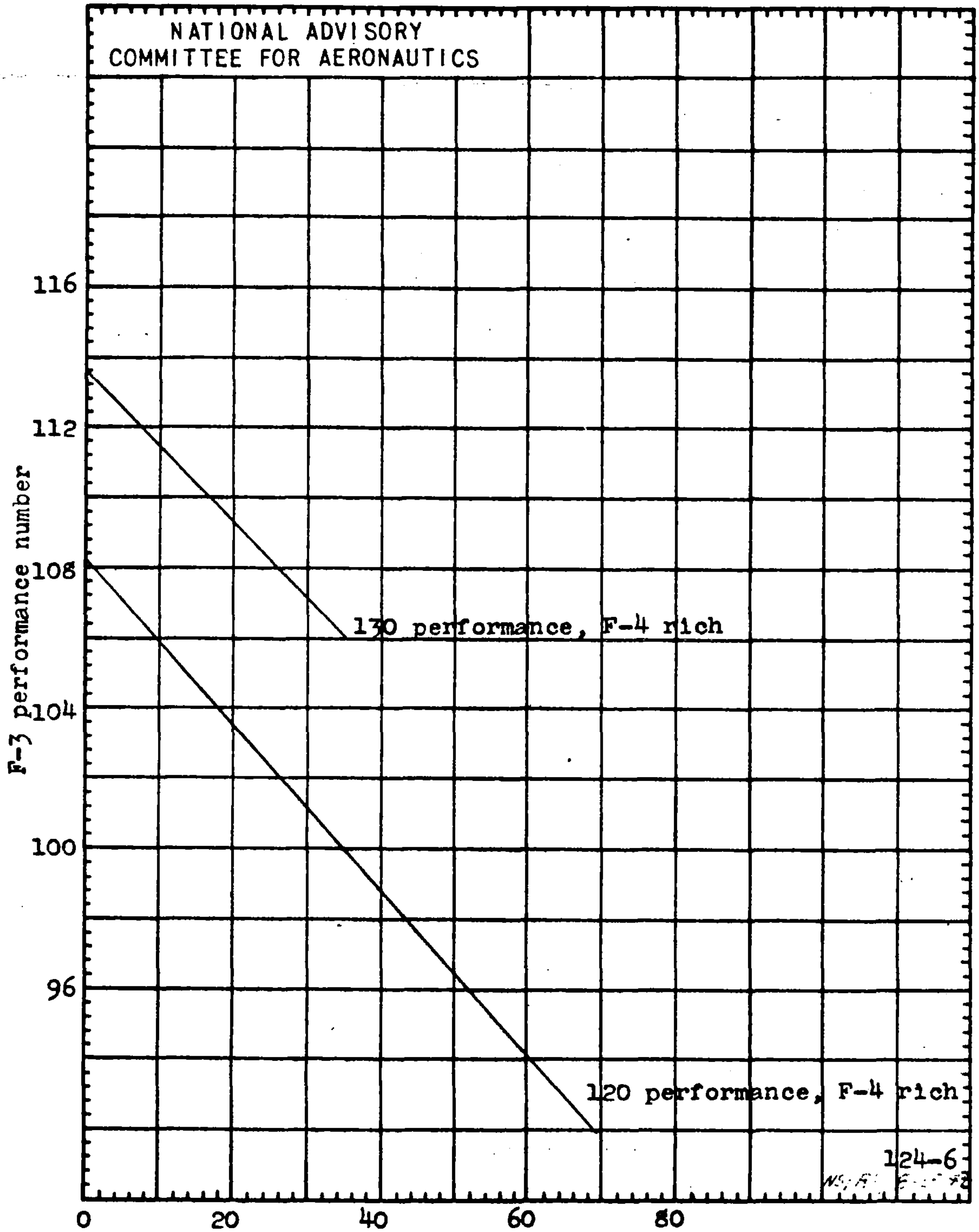

Figure 7. - Variation of F-3 performance number of fuel blends resulting from replacement of alkylate with catalytically cracked stock in virgin base stock and maintaining constant F-4 rich ratings.

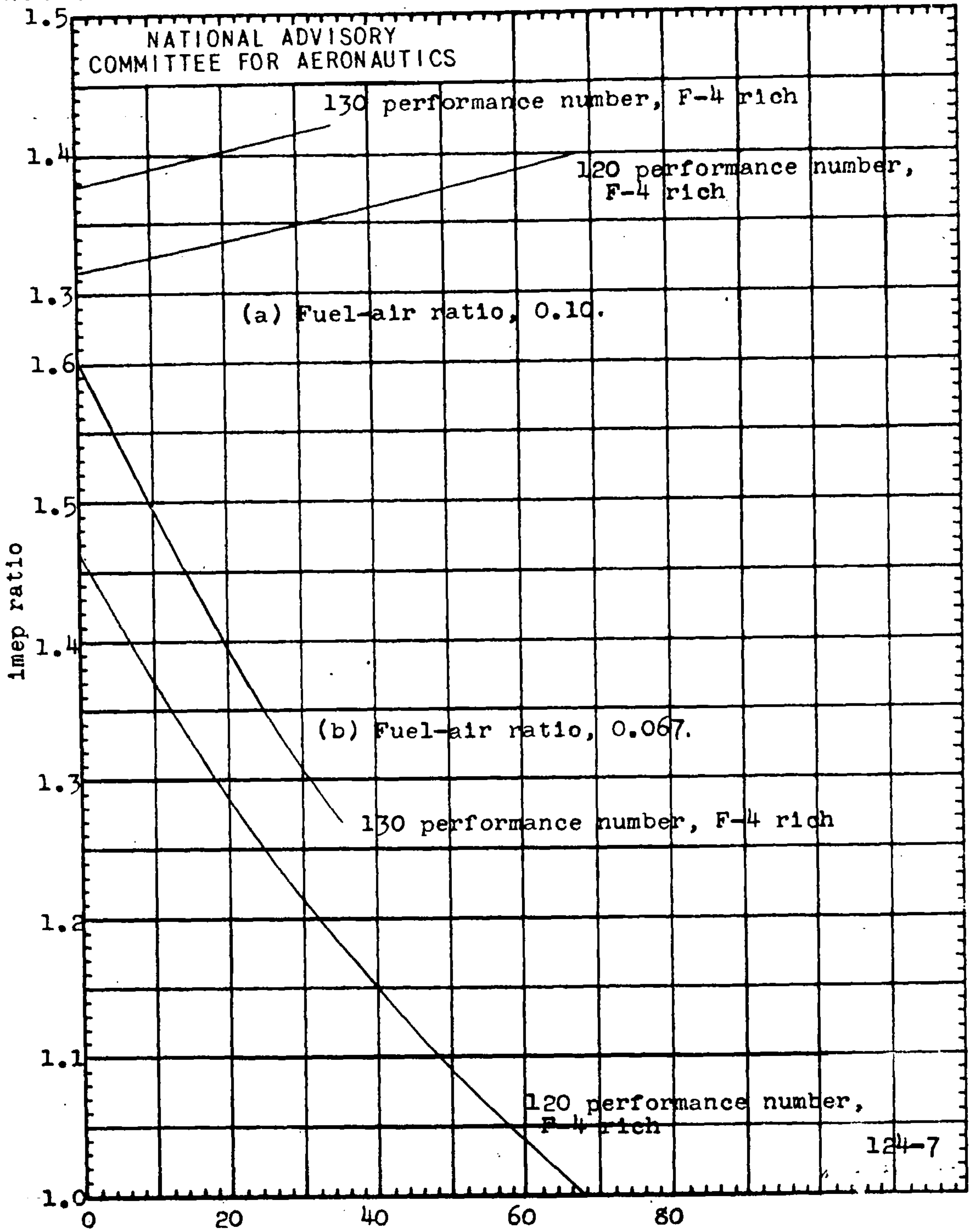

Figure 8. - Variation of power of fuel blends in R-1820 G200 cylinder caused by replacement of alkylate with catalytically cracked stock. Ratios relative to S fuel. Compression ratio, 7.3; spark advance, 25° B.T.C.; engine speed, 2000 rpm; inlet-air temperature, 200° F; head temperature at control thermocouple, 550° F.