REPORT No. 904

ESTIMATION OF F-3 AND F-4 KNOCK-LIMITED PERFORMANCE RATINGS FOR TERNARY AND QUATERNARY BLENDS CONTAINING TRIPETANE OR OTHER HIGH-ANTIKNOCK AVIATION-FUEL BLENDING AGENTS

By Henry C. Barnett

SUMMARY

Charts are presented that permit the estimation of F-3 and F-4 knock-limited performance ratings for certain ternary and quaternary fuel blends. Ratings for various ternary and quaternary blends estimated from these charts compare favorably with experimental F-3 and F-4 ratings. Because of the unusual behavior of some of the aromatic blends in the F-3 engine, the charts for aromatic-paraffinic blends are probably less accurate than the charts for purely paraffinic blends.

INTRODUCTION

An investigation of the knock-limited performance of tripetane and other high-antiknock components of aviation fuels was conducted at the NACA Cleveland laboratory in the F-3 and the F-4 rating engines (reference 1). The data of reference 1 are presented herein in the form of charts, which can be used to estimate the F-3 and the F-4 antiknock ratings for multicomponent blends of the various fuels investigated.

The F-4 data appearing in these charts are based on the following blending equation suggested in reference 2 for supercharged-engine data:

\[
\frac{1}{\text{imep}} = \frac{N_1}{(\text{imep})_1} + \frac{N_2}{(\text{imep})_2} + \frac{N_3}{(\text{imep})_3} + \cdots
\]

where

\(\text{imep}\) = knock-limited indicated mean effective pressure of fuel blend

\((\text{imep})_1, (\text{imep})_2, (\text{imep})_3, \cdots\) = knock-limited indicated mean effective pressure of components 1, 2, 3, \ldots

\(N_1, N_2, N_3, \cdots\) = mass fractions of components 1, 2, 3, \ldots in fuel blend

Equation (1) has been satisfactory for blends in which all components are paraffinic and have equal concentrations of tetraethyl lead. The equation applies most generally when the experimental data are taken at high fuel-air ratios. With the exception of data for one fuel in the present analysis, all the F-4 knock-limited performance data are considered at a fuel-air ratio of 0.11.

The analysis of F-3 data presented herein is strictly empirical but has been found to agree satisfactorily in most cases with the experimental data. The accuracy of the performance charts presented was checked by testing prepared blends under F-3 and F-4 conditions and comparing the observed ratings with those predicted from the charts.

EXPERIMENTAL DATA

The experimental results upon which this analysis is based are presented in table I (reproduced from reference 1). No performance numbers in this table greater than 161 were used in this analysis, as will be indicated later. The performance numbers for the F-4 tests were estimated from a reference-fuel framework (reference 1) consisting of knock-limited performance curves for 90-percent S-3 reference fuel plus 10-percent M-4 reference fuel and for S-3 reference fuel clear and with 0.5, 1.25, 2, 4, and 6 ml TEL per gallon.

The use of this method of rating instead of the usual procedure of direct matching was necessary because of the extensive nature of the program; complete mixture-response curves for 132 blends were obtained. For this reason, the accuracy of the performance numbers shown in table I for F-4 ratings is largely dependent on the day-to-day reproducibility of the engine. The brief analysis of the results given in reference 1 indicates that this reproducibility is good at high fuel-air ratios. Inasmuch as the analysis herein is concerned only with data at a fuel-air ratio of 0.11, it is believed that the performance-number ratings at this fuel-air ratio are reasonably accurate.

All blends investigated were prepared on a volume basis.

PREPARATION OF PERFORMANCE CHARTS

In order to make the final charts useful for the prediction of blends giving F-4 performance numbers greater than 161 at a fuel-air ratio of 0.11, it was considered desirable to extrapolate the performance curve to at least a performance number of 200. This extrapolation was made by plotting the performance numbers against knock-limited indicated mean effective pressure from the reference-fuel framework in reference 1. (See fig. 1.) Although there is a definite break in this curve at a performance number of 130, the curve appears to be linear between 130 and 161. On the assumption that this linear relation is true, a straight line was drawn through the points at 130 and 161 and extended to a performance number of 200. The extrapolation between
In reference 1, a different method of extrapolation was used for performance numbers greater than 161 (fig. 1); consequently, the performance-number values above 161 in table I for F-4 ratings are not the same as those used in preparing the performance charts in the present report.

![Figure 1](image1.png)

**Figure 1.** Relation between performance numbers and knock-limited indicated mean effective pressure as determined in F-4 rating engines.

**TERNARY BLENDS**

As an example of the preparation of a performance chart, first it is desired to know the F-3 and the F-4 performance numbers of all possible ternary blends of hot-acid octane, an aviation alkylate, and a virgin base stock. These three fuels were chosen because their blending relations follow equation (1). A plot of composition against the reciprocal of the knock-limited indicated mean effective pressure for binary blends of any two of these fuels will result in a straight line. The three binary combinations of these materials are shown in figure 2. The ordinate scale of this figure is a reciprocal scale used for convenience in order that the indicated mean effective pressures can be plotted directly.

![Figure 2](image2.png)

**Figure 2.** Knock-limited performance determined by F-4 rating method for binary blends of hot-acid octane, aviation alkylate, and virgin base stock. All blends contain 4 ml TEL per gallon.

Experimental data for figure 2 were taken from table I.

In the next operation, lines of constant performance number are drawn on the plot (shown as dotted lines, fig. 2). These lines are established by reading values of indicated mean effective pressure at equal increments of performance number in figure 1. The data as shown in figure 2 are the basic information needed to establish F-4 rating lines on the final chart for multicomponent blends.

For convenience in relating composition and knock-limited performance of ternary fuel blends, all performance charts are prepared on triangular coordinate paper. A brief description of the use of triangular coordinate paper is given in the appendix. A more detailed description of triangular plots is given in reference 3.

The performance chart for the system of hot-acid octane, aviation alkylate, and virgin base stock is shown in figure 3. Lines of constant performance number in this figure were determined by noting the intersections of the constant performance lines (fig. 2) with the blending lines. For example, the 150-performance-number line in figure 2 intersects the blending line of hot-acid octane and aviation alkylate at a composition of 32-percent hot-acid octane and 68-percent alkylate and intersects the blending line of hot-acid octane and virgin base stock at a composition of 07-percent hot-acid octane and 33-percent virgin base stock. These two compositions were plotted on figure 3 and joined by a straight line. Any point on this line represents a blend of hot-acid octane, alkylate, and virgin base stock that will give a performance number of 150 in the F-4 engine at a fuel-air ratio of 0.11. All performance lines in figure 3 were established in this manner.

The lines in figure 3 are parallel, which is to be expected when the curves shown in figure 2 are linear. On the basis of data in this report and in references 4 and 5, it appears that most paraffinic fuels blend linearly at high fuel-air ratios. Even though certain constituents such as the aromatics or ethers did not blend linearly with paraffinic base...
fuels, the procedure just outlined for the preparation of performance-number charts is not altered. A nonlinear relation in a plot of the type shown in figure 2 results in a variation of slope with performance number on the final triangular plot.

The procedure used for determining the lines of constant F–3 performance for blends of the same fuels used in preparing figure 3 differs from that used for F–4 performance in that performance numbers are plotted directly against composition on linear coordinate paper and an estimated “best” curve is drawn through the data points to determine the binary blending relations shown in figure 4. There is nothing to justify the use of this empirical method for dealing with F–3 ratings except that the end result agrees reasonably well with the experimental results. One or two exceptions to this method will be pointed out later.

The compositions at the intersections of a given constant performance line with the blending lines (fig. 4) were plotted on triangular coordinate paper and joined by straight lines. The resulting F–3 performance lines are shown in figure 5. The final chart (fig. 6) was obtained by superimposing figure 5 on figure 3. Performance charts for the following fuel constituents blended with aviation alkylate and virgin base stock (all blends leaded to 4 ml TEL/gal) were prepared in the same manner and are presented in figure 7: triptane, diisopropyl, neohexane, isopentane, benzene, cumene, mixed xylenes, toluene, and methyl tert-butyl ether. Charts for hot-acid octane, triptane, diisopropyl, neohexane, isopentane, benzene, mixed xylenes, toluene, and methyl tert-butyl ether blended with aviation alkylate and one-pass catalytic stock are presented in figure 8.
Figure 5.—Knock-limited performance determined by F-3 rating method for ternary blends containing hot-acid octane, aviation alkylate, and virgin base stock.

Figure 6.—Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing hot-acid octane, aviation alkylate, and virgin base stock. F-4 ratings at fuel-air ratio of 0.11.
Figure 7.— Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-anti-knock blending agents, aviation alkylate, and virgin base stock.
FIGURE 7.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylation, and virgin base stock.

(c) Neohexane blends; F-4 ratings at fuel-air ratio of 0.11.
(d) Isopentane blends; F-4 ratings at fuel-air ratio of 0.11.
(e) Benzene blends; F-4 ratings at fuel-air ratio of 0.11.
(f) Cumene blends; F-4 ratings at fuel-air ratio for peak power.

Figure 7—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.
(g) Mixed xylene blends; F-4 ratings at fuel-air ratio of 0.11.
(h) Toluene blends; F-4 ratings at fuel-air ratio of 0.11.

**FIGURE 7—Continued.** Knock-limited performance determined by F-4 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.
(1) Methyl tert-butyl ether blend; F-4 ratings at fuel-air ratio of 0.11.

Figure 7.—Concluded. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and virgin base stock.

(a) Hot-oxid octane blend; F-4 ratings at fuel-air ratio of 0.11.

Figure 8.—Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.
Figure 8.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylates, and one-pass catalytic stock.
F-4 performance number

F-3 performance number

(d) Neohexane blends; F-4 ratings at fuel-air ratio of 0.11.
(e) Isopentane blends; F-4 ratings at fuel-air ratio of 0.11.

Figure 8—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-octane knocking blending agents, aviation alkylate, and one-pass catalytic stock.
Benzene +4 ml TEL/gal

F-4 performance number
------
F-3 performance number

Mixed xylenes +4 ml TEL/gal

F-4 performance number

Figure 8.—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-antiknock blending agents, aviation alkylate, and one-pass catalytic stock.

(f) Benzene blend; F-4 ratings at fuel-air ratio of 0.11.

(g) Mixed xylenes blend; F-4 ratings at fuel-air ratio of 0.11.
Estimation of knock-limited performance ratings of ternary and quaternary blends

Toluene + 4 ml TEL/gal

F-4 performance number
F-3 performance number

Methyl tert-butyl ether + 4 ml TEL/gal

F-4 performance number
F-3 performance number

One-pass catalytic stock + 4 ml TEL/gal

Alkylate + 4 ml TEL/gal

F-3 performance number

F-4 performance number

Form 8.—Concluded. Knock-limited performance determined by F-3 and F-4 rating methods for ternary blends containing high-sulfur blending agents, aviation alkylate, and one-pass catalytic stock.
In Figure 7 (f) the lines showing F-4 performance numbers for cumene blends were determined by plotting peak knock-limited power values rather than power values at a fuel-air ratio of 0.11. This deviation from the procedure used for all other plots in Figures 6, 7, and 8 was necessary because most of the mixture-response curves for the cumene blends investigated (reference 1) intersected at fuel-air ratios between 0.10 and 0.11. (See Figure 9.) The fuel-air ratio for peak knock-limited power varied between 0.115 and 0.132 for the cumene blends used in preparing Figure 7 (f).

No plot was prepared for blends of cumene, aviation alkylate, and one-pass catalytic stock because rich-mixture peaks were not obtained for a sufficient number of the binary blends of cumene and one-pass catalytic stock reported in reference 1.

Lines of F-3 performance for xylenes blends were not plotted in Figures 7 (g) and 8 (g) because the curve of composition against F-3 ratings for binary blends of xylenes and aviation alkylate passed through a minimum. (See Figure 10.)

In general, data obtained on the F-3 engine for the aromatic blends could not be handled with complete satisfaction by the empirical procedure previously explained. For this reason, the accuracy of the lines of constant F-3 performance shown for the aromatic-paraffinic systems in Figures 7 and 8 is questionable.

**QUATERNARY BLENDS**

The performance charts presented in Figures 6, 7, and 8 are of interest primarily from considerations of maximum knock-limited performance attainable with various combinations of fuel blending agents and current base stocks. The producers of aviation fuel, however, are interested in the maximum knock-free power attainable with a finished blend that meets physical-property specifications for aviation fuels. In the present analysis, an attempt has been made to show how performance charts can be prepared for ternary blends in which each of the components has been isopentanized to a Reid vapor pressure of 7 pounds per square inch.
The addition of isopentane to adjust the vapor pressure of the components in a system such as that shown in figure 7 (a) will necessarily affect the maximum knock-free power attainable because of the performance rating of isopentane relative to the ratings of the other components in the system. (See table II.) In figure 7 (a), for example, a blend of 58.5-percent triptane, 30.5-percent alkylate, and 11-percent virgin base stock has a lean-rich performance-number rating of 135/200 and a Reid vapor pressure of approximately 3.5 pounds per square inch (estimated from table II). In order to obtain the same performance (135/200) with a blend of triptane, alkylate, and virgin base stock that has been isopentanized to a Reid vapor pressure of 7 pounds per square inch (maximum from specification), a blend of 55-percent triptane, 17-percent alkylate, 7-percent virgin base stock, and 21-percent isopentane could be used. The addition of isopentane has thus effectively decreased the quantity of triptane needed to obtain the 135/200 performance rating, which is attributed to the fact that isopentane has better performance characteristics than the alkylate or the virgin base stock used as well as a higher Reid vapor pressure than the other three constituents in the blend. (See table II.)

It must be emphasized that the preceding example is merely given as a sample consideration of a fuel characteristic other than knock that must be considered for a finished fuel blend. This example is not intended to imply that the preparation of fuel blends as presented herein with Reid vapor pressures adjusted to meet specifications will necessarily produce blends that will meet all pertinent specifications.

Several performance charts for quaternary blends containing isopentane were prepared for comparison with the charts previously described for ternary blends. In each of the quaternary systems, the vapor pressure was adjusted to 7 pounds per square inch. Three assumptions were made in the preparation of these charts:

1. The relation between composition (volume basis) and Reid vapor pressure for binary blends of isopentane with another paraffinic fuel is linear.
2. The relation between composition and the reciprocal of F-4 (rich) knock-limited indicated mean effective pressure for binary blends of isopentane with another paraffinic fuel is linear.
3. The relation between composition and F-3 performance number for binary blends of isopentane with another paraffinic fuel is linear.

On the basis of the available data, assumption (3) appears to be valid for only a few cases. For this reason the F-3 performance lines on the charts for quaternary blends may be in error.

As an example of the preparation of the performance chart for a quaternary system, it is assumed desirable to isopentanize the blends represented by figure 7 (a). The first step in this problem is to determine the amount of isopentane to be added to each of the pure components (fig. 7 (a)) to obtain a Reid vapor pressure of 7 pounds per square inch and to determine the resultant F-3 and F-4 performance-number ratings for these blends. This information was obtained from the foregoing assumptions and the data in table II and is presented in the following table:
Figure 11.—Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends containing triptane, aviation alkylate, virgin base stock, and isopentane. F-4 ratings at fuel-air ratio of 0.11.
The triangular chart shown in figure 11 (a) was obtained by treating these three blends (all of which have Reid vapor pressures of 7 lb/sq in.) as separate components by the procedure used in preparing figure 7 (a). Any point on figure 11 (a) represents the F–3 and F–4 performance number of a quaternary blend. The actual quantity of each component in the blend, however, cannot be readily determined from the chart because the percentages given on the altitudes of the triangle show only the amounts of the binary blends at the vertices. For this reason, the grid of the chart was so adjusted, as shown in figure 11 (b), that the quantity of any one of the four components in the blend could be determined from the chart.

As an example of the method of determining the composition of fuel in figure 11 (b), it is assumed that a blend of triptane, aviation alkylate, virgin base stock, and isopentane having a lean-rich rating of 130/180 is desired. The concentrations of triptane, alkylate, and virgin base stock in the blend having the desired rating can be read directly from the altitudes of the triangle in the manner used in previous charts. These concentrations are 48, 19, and 13 percent, respectively. The concentration of isopentane can be determined by subtracting the sum of the percentages of the other components from 100.

Performance charts for the following quaternary systems have been prepared and are presented in figure 12:

Triptane, hot-acid octane, aviation alkylate, and isopentane
Triptane, diisopropyl, aviation alkylate, and isopentane
Triptane, diisopropyl, hot-acid octane, and isopentane
Diisopropyl, hot-acid octane, aviation alkylate, and isopentane

The vapor pressure determined for the diisopropyl used in figure 12 was 7.4 pounds per square inch. (See table II.) In the preparation of figure 12, however, a vapor pressure of 7 pounds per square inch was assumed for diisopropyl.

ACCURACY OF PERFORMANCE CHARTS

The accuracy of the charts was determined by selecting ternary or quaternary blends from the various charts and investigating these blends by the standard F–3 and F–4 procedures. Inasmuch as the F–4 ratings shown on the charts were estimated at a fuel-air ratio of 0.11, the check ratings were determined at this same fuel-air ratio.

The check blends investigated and their ratings are shown in table III. These blends are also shown on the various charts by the symbols. The fuel numbers shown adjacent to each of the symbols on the charts correspond to the fuel numbers given in this table. All the data in table III are presented in figure 13 to show the relation between estimated and observed performance numbers. For the 25 blends shown in figure 13, the average deviation from the match line was 3.1 performance numbers for the F–3 ratings and 1.5 for the F–4 ratings.

![Performance chart for quaternary blends](image-url)
Percentage isopentane can be determined by subtracting sum of percentages of other components from 100.

Reid vapor pressure, approximately 7 lb/sq in.

(b) Blends of triptane, disisopropyl, aviation alkylate, and isopentane; F-4 ratings at fuel-air ratio of 0.11.

(c) Blends of triptane, disisopropyl, hot-acid octane, and isopentane; F-4 ratings at fuel-air ratio of 0.11.

Figure 12—Continued. Knock-limited performance determined by F-3 and F-4 rating methods for quaternary blends.
DISCUSSION OF PERFORMANCE CHARTS

The data in figures 7 and 8 can be used for certain general comparisons of paraffins, aromatics, and ethers. In figure 7 (a), for example, at the point representing a blend of 81-percent aviation alkylate, 19-percent virgin base stock, and 4 ml TEL per gallon, the lean-rich rating is 110/123. Moving on a straight line from this point toward the triptane vertex until 20-percent triptane has been added results in a blend having a rating of 118/145. The addition of 20-percent triptane to the base blend has thus increased the lean rating of the base blend by 8 performance numbers and the rich rating by 22.

On the other hand, if in figure 7 (e) 20-percent benzene is added to the same base blend used in the foregoing example, then the rating changes from 110/123 to 106/146. The addition of 20-percent benzene has decreased the lean rating by 4 performance numbers, whereas the rich rating has been increased by 23.

From this comparison, it follows that in the illustrative example the aromatic (benzene) and the paraffin (triptane) are equally effective for increasing the F-4 (rich) performance.
but that triptane is more effective than benzene for improving lean performance.

When any two of the charts in figure 7 or 8 are compared, the nearer a given constant performance line is to the base of the triangle, the better the performance of the fuel represented by the top vertex of the triangle. For example, in figure 7 (a) the line representing an F-4 performance number of 200 is much nearer the base of the triangle than the same line in figure 7 (b). Triptane plus 4 ml TEL per gallon has therefore a higher rating than diisopropyl plus 4 ml TEL per gallon.

Observations similar to those made in the foregoing discussion can be made for the charts in figures 11 and 12. In the case of these figures, however, the effect of a single component cannot be isolated from the other components because the concentration of isopentane varies with that of any other component in the system.

SUMMARY OF RESULTS

Charts are presented that permit the estimation of F-3 and F-4 knock-limited performance ratings for certain ternary and quaternary fuel blends. Ratings for various ternary and quaternary blends estimated from these charts compare favorably with experimental F-3 and F-4 ratings. Because of the unusual behavior of some of the aromatic blends in the F-3 engine, the charts for aromatic-paraffinic blends are probably less accurate than the charts for purely paraffinic blends.

AIRCRAFT ENGINE RESEARCH LABORATORY,
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS,
CLEVELAND, OHIO, January 20, 1946.
APPENDIX

USE OF TRIANGULAR COORDINATE PAPER

The use of triangular coordinate paper to represent composition for a three-component system will be greatly simplified if it is remembered that for any point in an equilateral triangle the sum of the perpendiculars from that point to each of the sides is equal to the altitude of the triangle. For example, in the following diagram $OP + OM + ON = Bb$.

If each of the vertexes of the triangle represent 100 percent of one of the three constituents, then the percentage of component $A$ in blend $O$ is $OM$, the percentage of the component $B$ is $OP$, and the percentage of component $C$ is $ON$.

The equation of a straight line on triangular coordinate paper is of the form

$$a = bN_1 + cN_2 + N_3$$

where $a, b, c$ constants

$N_1, N_2, N_3$ concentration of components 1, 2, and 3 in ternary blend

Any equation relating knock-limited performance and blend composition that can be reduced to this form can be represented by a straight line of constant performance on triangular coordinate paper. Equation (1) presented in the text of this report can be reduced to this form by multiplying through by any one of the performance values $(imep)_1, (imep)_2, or (imep)_3$.

REFERENCES


245
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Fuel composition (by volume)</th>
<th>F-3 ratings</th>
<th>Fuel-air ratio</th>
<th>F-4 ratings</th>
<th>Fuel composition (by volume)</th>
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<td>VBS</td>
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<td>A-118</td>
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<td>A-271</td>
<td>Tripropylene</td>
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<td>0.10</td>
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* Each fuel contains approximately 4 mol TRL/gal.
* Based on fixed-reference fuel framework (reference 1).
* Knock-limited performance of engine with one-pass catalytic stock was low on day fuels were investigated.
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<th>Fuel composition (by volume)</th>
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<tr>
<td>60% n-octane + 40% one-pass stock</td>
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<td>60% n-octane + 40% one-pass stock</td>
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<td>0.102</td>
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TABLE I—PERFORMANCE RATINGS OBTAINED IN F-3 AND F-4 ENGINES—Concluded
### TABLE II—F-3 AND F-4 PERFORMANCE RATINGS AND REID VAPOR PRESSURES FOR VARIOUS AVIATION-FUEL COMPONENTS

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<td>F-4</td>
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</table>

* Performance numbers are for pure blending agent containing 4 ml TEL/gal.

### TABLE III—F-3 AND F-4 PERFORMANCE RATINGS OF TERNARY AND QUATERNARY FUEL BLENDS

* The following abbreviations are used throughout the table: VBS for virgin base stock; alkylate for aviation alkylate; one-pass stock for one-pass catalytic stock; and MTB ether for methyl tert-butyl ether.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Fuel composition (by volume)</th>
<th>Performance numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>A-477 48% tetra-23% VBS+19% alkylate</td>
<td>113 110 160 149</td>
</tr>
<tr>
<td>8</td>
<td>A-487 11% tetra-62% VBS+41% alkylate</td>
<td>98 90 120 111</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-839 99% tria-16% VBS+3% alkylate</td>
<td>91 120 130 121</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-841 99% tria-13% VBS+27% alkylate</td>
<td>114 113 110 160</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-855 48% tria-28% VBS+29% alkylate</td>
<td>119 116 120 158</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-881 12% tria-14% VBS+74% alkylate</td>
<td>118 117 140 142</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-888 13% tria-61% VBS+38% alkylate</td>
<td>95 90 110 112</td>
</tr>
<tr>
<td>7 (b)</td>
<td>A-478 36% diisopropyl-12% VBS+48% alkylate</td>
<td>129 122 180 150</td>
</tr>
<tr>
<td>7 (b)</td>
<td>A-484 36% diisopropyl-52% VBS+14% alkylate</td>
<td>109 103 120 121</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-852 15% naphtha+14% VBS+80% alkylate</td>
<td>130 124 140 140</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-853 19% naphtha+61% VBS+20% alkylate</td>
<td>100 103 110 111</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-858 23% benzene+9% VBS+41% alkylate</td>
<td>97 100 140 139</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-862 47% benzene+41% VBS+12% alkylate</td>
<td>87 77 160 154</td>
</tr>
<tr>
<td>7 (a)</td>
<td>A-884 18% toluene+60% VBS+22% alkylate</td>
<td>92 97 130 130</td>
</tr>
</tbody>
</table>

* Each fuel contains approximately 4 ml TEL/gal.

* F-4 ratings made at fuel-air ratio of 0.11.