REPORT No. 811

PREIGNITION-LIMITED PERFORMANCE OF SEVERAL FUELS

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SUMMARY

Preignition-limited performance data were obtained on a supercharged CFR engine at two sets of operating conditions over a wide range of fuel-air ratios to determine the preignition characteristics for the following five fuels: S-3 reference fuel, S-3 plus 4 ml TEL per gallon, AFD-33 (140-P), benzene, and diisobutylene. Maximum thermal-plug temperatures at constant intake-air pressures were also determined to correlate the preignition characteristics of each fuel with its ability to increase general engine-temperature levels. Additional runs were made to compare the preignition-limited performance of triptane, triptane plus 4 ml TEL per gallon, and AN-F-28R fuel.

The results indicated that in the fuel-air-ratio range from 0.070 to 0.085, the relative order of the fuels according to increasing preignition-limited indicated mean effective pressures was diisobutylene, benzene, S-3, AFD-33, and S-3 plus 4 ml TEL per gallon. The relative order of the fuels for the two sets of operating conditions was not the same for all fuel-air ratios. The addition of tetraethyl lead to either S-3 reference fuel or triptane raised the preignition-limited performance. The plot of fuel flow against air flow at the preignition limit for each fuel shows that the data approximately follow two straight lines: one for the rich-mixture region and one for the lean-mixture region. The respective slopes of these lines changed only slightly in the various preignition-limited runs.

INTRODUCTION

Preignition and knock are two distinct types of fuel failure; the occurrence of either preignition or knock may lead to excessive engine temperatures or stresses with concurrent destruction of engine components. Each may also alter engine combustion and engine temperature in such a way as to increase the probability that the other may occur.

Extensive investigations have been completed and are still being conducted to determine the knock-limited performance of aviation-fuel components. Possibly because the preignition-limited performance of an engine can be radically affected by changes in design, relatively little work has been done toward giving aircraft fuels a preignition rating.

Several investigations have been conducted (references 1, 2, and 3) to determine the fundamental relations that govern the preignition of fuels in an internal-combustion engine. The results of these experiments have indicated that the hot-spot threshold temperature required to produce preignition is relatively insensitive to the fuel composition. The ability of a fuel to heat engine hot spots to the required preignition temperature either by normal combustion or by surface combustion depends, however, upon the fuel composition, the engine operating conditions, and the geometry of the engine and the hot spot.

In order to study the effects of fuel composition on the preignition-limited performance of an engine, it is advisable to use an engine-heated hot spot; the integrated heat-transfer processes as affected by the engine and the hot-spot geometry, the engine variables, and the fuel composition can then be considered in the same manner as that when they contribute to the preignition temperature of hot spots occurring in aircraft engines in service (such as exhaust valves and spark plugs). Heron, Felt, and Vaughn of the Ethyl Corporation have obtained, in unpublished tests, pre-ignition-limited data for several fuels using engine-heated hot spots.

The preignition-limited data presented herein were obtained at two sets of operating conditions over a wide range of fuel-air ratios for the following five fuels: S-3 reference fuel, S-3 plus 4 ml TEL per gallon, AFD-33 (140-P), benzene, and diisobutylene. Maximum thermal-plug temperatures at constant intake-air pressures were also determined to correlate the preignition characteristics of the fuel with its capacity to increase general engine-temperature levels. Additional runs were made to compare the preignition-limited performance of triptane, triptane plus 4 ml TEL per gallon, and AN-F-28R fuel. The investigation was conducted at the NACA Cleveland laboratory from April to July 1944.

Until more full-scale-engine data concerning the preignition characteristics of aircraft fuels become available, the results of this and similar investigations must be considered only as preliminary indications of the preignition characteristics of aviation fuels in the service engine.

APPARATUS AND PROCEDURE

The investigations were made on a high-speed supercharged CFR engine coupled to a 25-horsepower alternating-current dynamometer. The engine was equipped with an aluminum piston, a sodium-cooled exhaust valve, and a cylinder head with four 18-millimeter spark-plug holes. Unpublished data have shown that the use of a shrouded intake valve will decrease the sensitivity of thermal-plug temperatures to knock. A 180° shrouded intake valve (position of shroud shown in fig. 1) was therefore installed to aid in isolating the effects of preignition from the effects of knock. A magnetostriction pickup unit installed in the top spark-plug hole was used in conjunction with a cathode-ray oscilloscope to follow the changing pressure diagram during advancing preignition and to detect knock. The fuel-metering and the air-metering arrangements were essentially the same as those described in reference 4. All operating temperatures were measured with iron-constantan thermocouples and a self-balancing potentiometer.

The following engine operating conditions were maintained constant for the runs:

Compression ratio	7.0
Coolant temperature, °F	250
Engine speed, rpm	1800
Oil temperature, °F	140

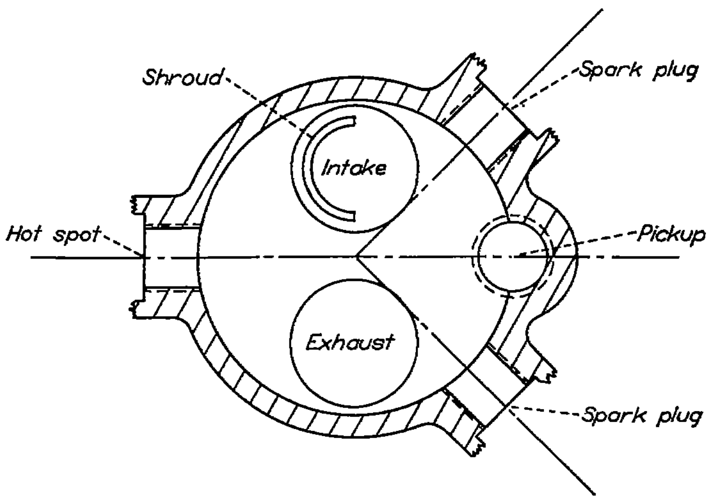

FIGURE 1.—Schematic diagram of CFR cylinder showing position of spark plugs, hot spot, pickup, and shrouded intake valve.

Two different types of hot spot were used to cause preignition. The first was a finned hot spot (fig. 2). A valve-controlled air blast was provided to permit sudden cooling during runaway or unstable preignition. For the runs with this hot spot, a constant intake-air temperature of 100° F and a fixed spark advance of 32° B. T. C. were maintained.

The second hot spot (open tube) consisted of a short piece of Inconel tubing silver-soldered to the center electrode of a spark plug (fig. 3). This hot spot was not used as a spark plug. The outside diameter of the tube was 0.10 inch and the wall thickness was 0.010 inch. For the runs with this hot spot, a constant intake-air temperature of 225° F and a fixed spark advance of 20° B. T. C. were maintained.

For each series of runs, the hot spots were installed in the same cylinder hole. (See fig. 1.) For determining the maximum thermal-plug temperatures, the preignition hot spot was replaced with a thermal plug.

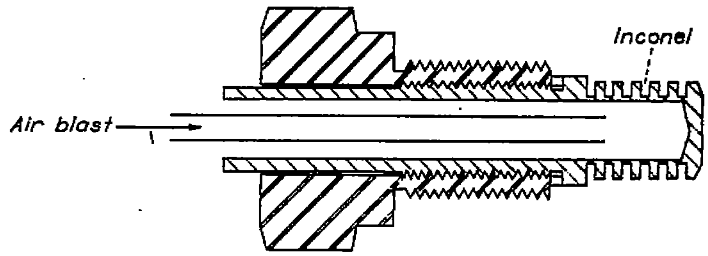

FIGURE 2.—Sketch of finned hot spot used in investigation.

The preignition-limited data were obtained in the following manner: For the lean-mixture region, the fuel flow was set at a constant value and the intake-air pressure was decreased by decrements of ½ inch of mercury until runaway preignition was encountered. Time was allowed for equilibrium to be established at each pressure except the pressure at which preignition occurred. Preignition was stopped by cutting off the fuel flow or by applying the air blast to the finned hot spot; and the data were recorded at the penultimate intake-air pressure, that is, ½ inch of mercury higher than the point at which preignition occurred. For the rich-mixture region, the same procedure was used except that the intake-air pressure was increased by increments of ½ inch of mercury instead of being decreased and the data were recorded at ½ inch of mercury lower than the pressure required to produce preignition.

In order to obtain the maximum thermal-plug temperatures, the intake-air pressure was held at a constant value and the fuel flow was varied until the maximum thermal-plug temperature was established. Temperatures were determined for the five fuels at intake-air pressures of 20, 30, and 40 inches of mercury absolute. The spark advance was 14° B. T. C.

RESULTS AND DISCUSSION

The values of the preignition-limited indicated mean effective pressure and intake-air pressure and the indicated specific fuel consumption obtained for the five fuels at the two sets of operating conditions are shown as functions of fuel-air ratio in figures 4 and 5. The general shape of the curves of preignition-limited indicated mean effective pressure is the same for both sets of data and for all five fuels. A minimum point occurred at a fuel-air ratio somewhat richer than stoichiometric. The displacement of the benzene

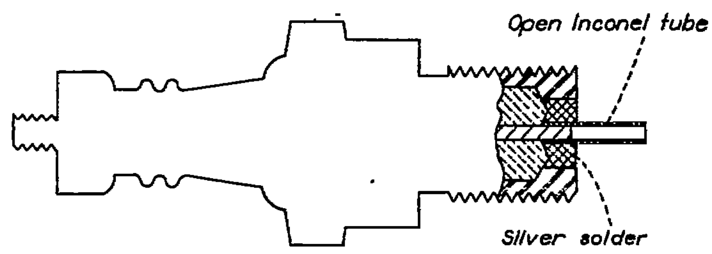

FIGURE 3.—Sketch of open-tube hot spot used in investigation.

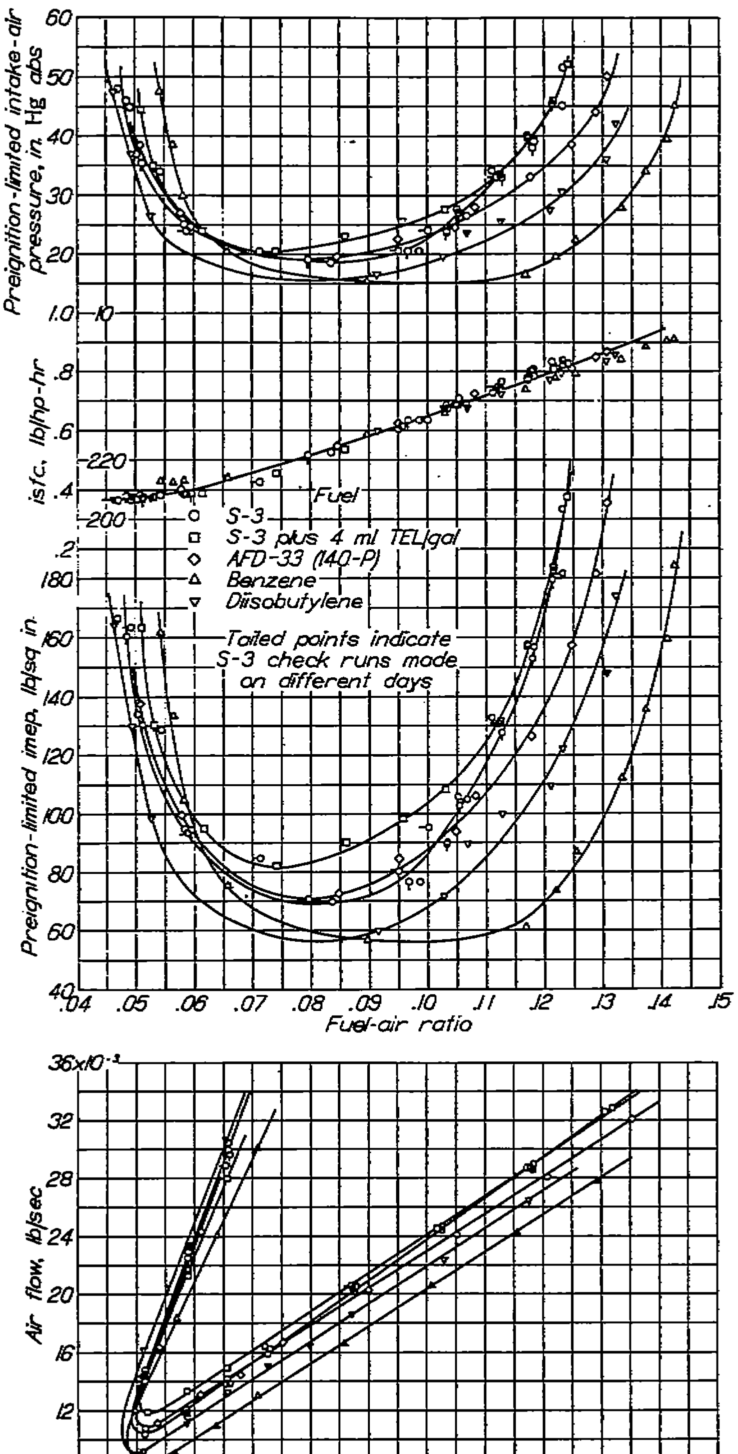

FIGURE 4.—Preignition-limited performance of five fuels using a finned hot spot. Supercharged CFR engine; compression ratio, 7.0; intake-air temperature, 100° F; coolant temperature, 250° F; spark advance, 32° B. T. C.; engine speed, 1800 rpm.

curve toward the richest mixtures in each case was probably due to the fact that its stoichiometric-mixture ratio is appreciably larger than that of the other fuels.

In the range of fuel-air ratios from 0.070 to 0.085, the relative order of the fuels for both types of hot spot according to increasing preignition-limited indicated mean effective pressure was diisobutylene, benzene, S–3, AFD–33, and S–3

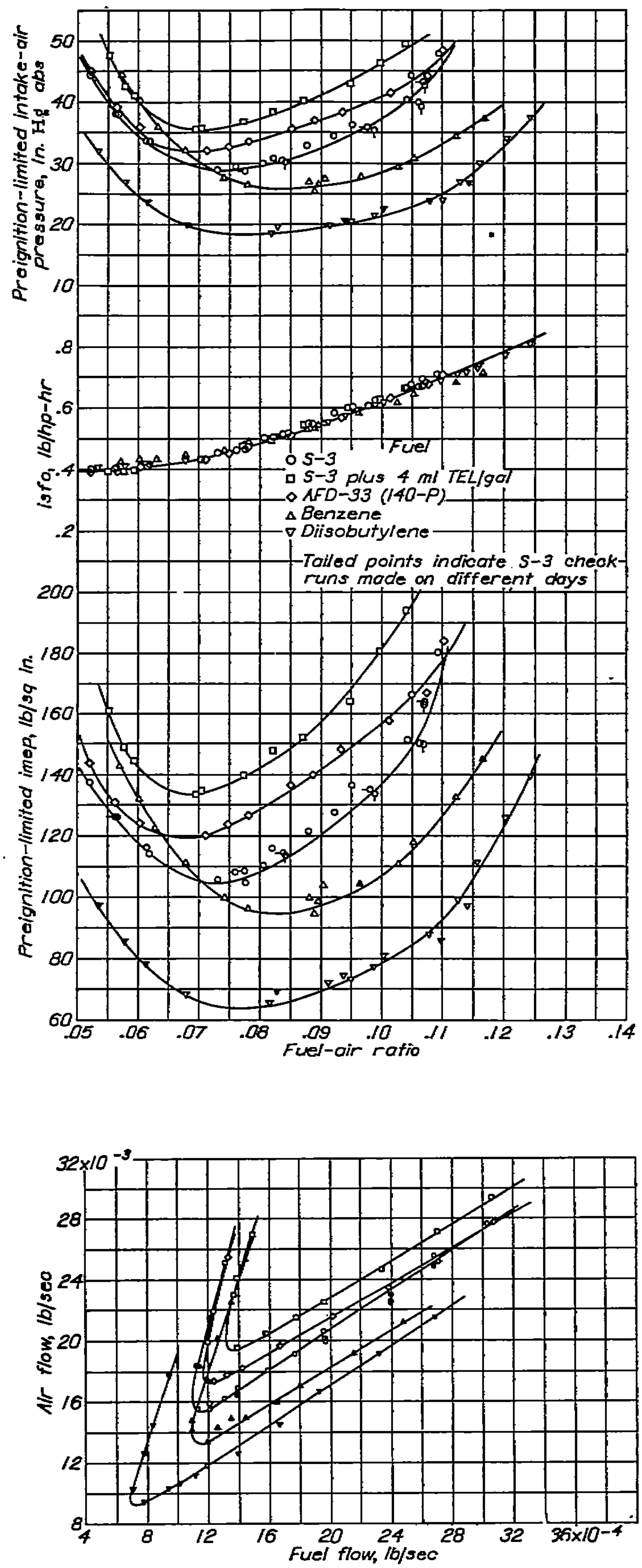

FIGURE 5.—Preignition-limited performance of five fuels using an open-tube hot spot. Supercharged CFR engine; compression ratio, 7.0; intake-air temperature, 225° F; coolant temperature, 250° F; spark advance, 20° B. T. C.; engine speed, 1800 rpm.

plus 4 ml TEL per gallon. The spread in the curves of preignition-limited indicated mean effective pressure of the fuels was greater for the runs plotted in figure 5 than for those plotted in figure 4 and an interchange in the order of preignition ratings at rich fuel-air mixtures for benzene and diisobutylene occurred.

The reproducibility of the preignition-limited data is shown by the three sets of data points for the S-3 reference curve, which were obtained on different days. (See figs. 4 and 5.) The deviations of the individual data points from the mean curve are no greater than are normally experienced in similar knock-limited-performance checks.

Plots of air flow against fuel flow for the two sets of data are also presented in figures 4 and 5. The curves approximately follow two straight lines, one for the rich region and one for the lean region. The respective slopes of these curves are nearly alike for all five fuels and for both sets of data. The plots of air flow against fuel flow in conjunction with the data for indicated specific fuel consumption have been quite useful for checking the fairing of the curves of preignition-limited indicated mean effective pressure plotted against fuel-air ratio.

Because the capacity of a fuel to increase general engine temperatures may influence its preignition characteristics, the maximum thermal-plug temperatures at constant intake-air pressures were determined. The temperatures are listed in the following table together with the rich preignition-limited fuel-air ratios of figure 4 observed at the same intake-air pressure. The engine conditions for the thermal-plug temperatures are the same as for the data in figure 4 except the spark advance, which was 14° B. T. C. More retarded spark timing was used to minimize knock for the thermal-plug temperatures at the higher intake-air pressures. Similar data taken at 33° B. T. C. indicate that according to thermal-plug temperatures, the fuels are in the same order as indicated by the data at 14° B. T. C.

Fuel	Intake-air pressure (in. Hg absolute)					
	20		30		40	
	Thermal-plug temperature (° F) (a)	Preignition-limited fuel-air ratio (b)	Thermal-plug temperature (° F) (a)	Preignition-limited fuel-air ratio (b)	Thermal-plug temperature (° F) (a)	Preignition-limited fuel-air ratio (b)
Benzene	561	0.123	669	0.135	761	0.141
Diisobutylene	541	.106	649	.123	735	.133
S-3 reference fuel	529	.093	631	.110	715	.118
AFD-33 (140-P)	537	.089	641	.114	728	.125
S-3 reference fuel+ 4 ml TEL per gallon	520	------	631	.108	715	.118

(a) Observed at a fuel-air ratio for maximum thermal-plug temperature.
(b) Data taken from fig. 4.

Although the S-3 and the S-3 plus 4 ml TEL per gallon reference fuels have the same thermal-plug temperatures, they have different preignition characteristics (fig. 4) and therefore thermal-plug temperatures, in general, cannot be relied upon to establish a preignition rating. If the five fuels are divided into two classes, however, those containing tetraethyl lead (S-3 plus 4 ml TEL/gal and AFD-33) and those tested clear (S-3, benzene, and diisobutylene), the

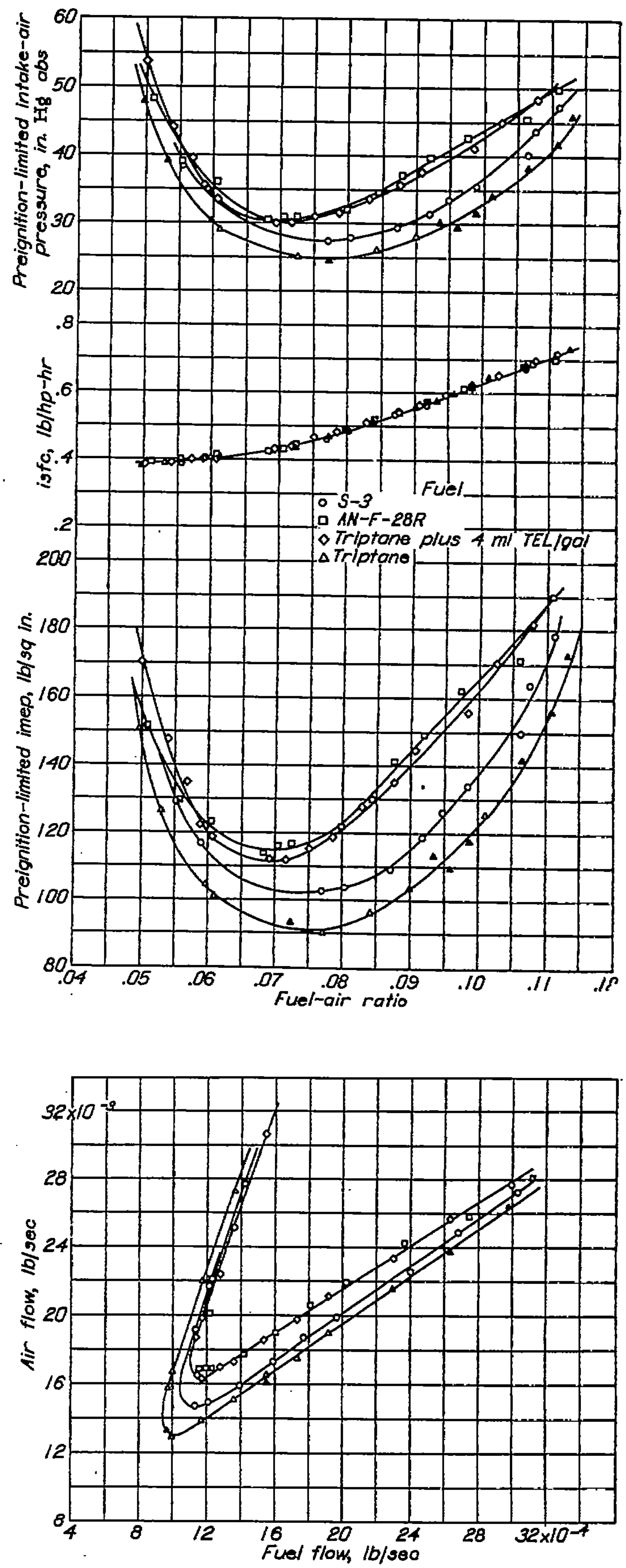

FIGURE 6.—Preignition-limited performance of triptane, triptane plus 4 ml TEL per gallon and AN-F-28R fuel. Open-tube hot spot; supercharged CFR engine; compression ratio, 7.0; intake-air temperature, 225° F; coolant temperature, 250° F; spark advance, 20° B. T. C.; engine speed, 1800 rpm.

rich-mixture fuel-air ratios required to prevent preignition at a given inlet-air pressure agree in their relative order with the thermal-plug temperatures. Thermal-plug temperatures were not determined at an inlet-air temperature of 250° F; therefore no comparison can be made with the data of figure 5.

The data presented in figures 4 and 5 for S-3 reference fuel indicate that the addition of tetraethyl lead to a fuel may raise its preignition-limited indicated mean effective pressure. (This effect has also been noted by other investigators.) Runs were therefore made on triptane and triptane plus 4 ml TEL per gallon to determine whether another fuel would be similarly affected. The data presented in figure 6 show that triptane was similarly affected by the addition of tetraethyl lead.

The preignition-limited performance of triptane plus 4 ml TEL per gallon was about the same as that of AN-F-28R. A curve for an S-3 run (slightly different from that presented in fig. 5) made during the course of the triptane and AN-F-28R runs is included in figure 6 for comparison. Under the conditions investigated, the preignition-limited performance of triptane was inferior to that of S-3 reference fuel; a comparison of figures 5 and 6 indicates that triptane plus 4 ml TEL per gallon was also inferior to S-3 plus 4 ml TEL per gallon.

SUMMARY OF RESULTS

The following results were obtained from preignition-limited performance investigations of several fuels:

1. In the range of fuel-air ratios from 0.070 to 0.085, the relative order of the fuels according to increasing preignition-limited indicated mean effective pressures was diisobutylene, benzene, S-3, AFD-33 (140-P), and S-3 plus 4 ml TEL per gallon. The relative order of the fuels for the two sets of operating conditions was not the same for all fuel-air ratios.

2. The addition of tetraethyl lead to both S-3 fuel and triptane raised the preignition-limited performances but had no effect on maximum thermal-plug temperatures.

3. The plot of fuel flow against air flow at the preignition limit for each fuel showed that the data approximately follow two straight lines: one for the rich-mixture region and one for the lean-mixture region. The respective slopes of these lines changed only slightly in the various preignition-limited runs.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, *October 1, 1944*.

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TITLE: Preignition-Limited Performance of Several Fuels	ATI- 33100
AUTHOR(S): Male, D. W.; Evvard, J. C.	REVISION (None)
ORIGINATING AGENCY: Aircraft Engine Research Laboratory, Cleveland, O.	ORIG. AGENCY NO. R-811
PUBLISHED BY: National Advisory Committee for Aeronautics, Washington, D. C.	PUBLISHING AGENCY NO. (None)

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
1945	Unclass.	U.S.	Eng.	7	table, graphs, drwg

ABSTRACT:

Tests were conducted on a supercharged CFR engine at two sets of operating conditions over a wide range of fuel/air ratios to determine the preignition characteristics of S-3 reference, S-3 plus 4 ml TEL/gal, AFD-33 (140-P), benzene, diisobutylene. The preignition-limited performance of triptane, triptane plus 4 ml TEL/gal and AN-F-28R fuel was also defined for comparison. It was found that in the fuel/air ratio range from 0.070 to 0.085, the relative order of the fuels according to increasing preignition-limited indicated mean effective pressures was diisobutylene, benzene, S-3, AFD-33 (140- and S-3 plus 4 ml TEL/gal. The relative order of the fuels for the two sets of operating conditions was not the same for all fuel/air ratios. The addition of TEL to both S-3 fuel and triptane was found to raise the preignition-limited performance,

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DIVISION: Fuels and Lubricants (12)	SUBJECT HEADINGS: Fuels, Liquid - Compression ignition characteristics (42671); Fuel-air mixtures - Combustion (42262.25); Fuels, Liquid - Performanc (42678)
SECTION: Liquid Fuels (2)	
ATI SHEET NO.: R-12-2-17	