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RESEARCH MEMORANDUM

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CARBON-DEPOSITION CHARACTERISTICS OF MIL-F-5624A FUELS CONTAINING HIGH-BOILING AROMATIC HYDROCARBONS

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

An investigation was conducted in a single J33 combustor to determine the effect of additions of typical high-boiling single-ring and dicyclic aromatic hydrocarbons on the combustor carbon-deposition characteristics of MIL-F-5624A fuels. Triisopropylbenzene and monomethylnaphthalene were used to increase the high-boiling aromatic contents of grade JP-3 and JP-4 fuels. The quantities of carbon deposited after 4-hour combustor operation were compared with those predicted from carbon-deposition correlations previously developed.

The results showed that additions of the high-boiling aromatic components to JP-3 and JP-4 fuels increased carbon deposition. The effects of these fuel components on carbon deposition were satisfactorily predicted by the NACA K factor (function of hydrogen-carbon ratio and volumetric average boiling temperature of the fuel) and the smoking tendency correlations previously developed.

INTRODUCTION

Numerous investigations have been conducted at the NACA Lewis laboratory and other laboratories to determine the effects of fuel properties on carbon deposition in turbojet-engine combustors. A survey of various empirical methods for predicting the carbon-forming propensity of turbojet fuels from results of simple laboratory tests of the fuels is presented in reference 1. The results of this survey indicated that two methods most accurately predicted combustor carbon deposition. The first of these methods made use of the NACA K factor (a function of hydrogen-carbon ratio and volumetric average boiling temperature of the fuel) described in detail in reference 2. The second method, based on the smoking tendency of a fuel, is described in reference 3. The application of these methods to carbon-deposition data obtained in both fuel-atomizing and fuel-vaporizing combustors is further discussed in reference 4.

Recent engine operating experience with fuels containing small concentrations of high-boiling aromatic hydrocarbons has indicated the importance of these components in determining the quantity of carbon that will be deposited in the combustion chamber. Although the NACA K factor will predict increased carbon deposition with fuels containing increased concentrations of high-boiling and low-hydrogen-carbon-ratio components, it was considered desirable to conduct more specific experiments. The effects of high-boiling single-ring and dicyclic aromatic hydrocarbons on carbon deposition were determined in a single turbojet combustor. The results of these experiments are described herein.

The "base" fuels used for the investigation were: (1) MIL-F-5624A, grade JP-3 fuel, and (2) MIL-F-5624A, grade JP-4 fuel. The effect of an addition of 10 percent of a mixture of α- and β-monomethylnaphthalene (hereinafter designated monomethylnaphthalene) on the carbon-deposition characteristics of each of these fuels was determined. The grade JP-3 fuel was also used as a base fuel for additions of 10 and 40 percent triisopropylbenzene (boiling temperature similar to monomethylnaphthalene). Comparisons of the carbon-deposition results obtained with these fuel blends are presented to indicate the relative effects on carbon formation of single-ring and of dicyclic aromatic hydrocarbons for blends of constant aromatic concentration and for blends of constant hydrogen-carbon ratio. Comparisons of these results with the NACA K factor and smoking tendency correlations are also presented to demonstrate further the validity of the correlations.

The single J33 combustor conditions chosen for this investigation were the same as those used in reference 1, simulating full-scale engine operation at 90 percent of normal-rated engine rotational speed, Mach number of zero, and altitude of 20,000 feet for a 4-hour period.

FUELS

The following fuel blends were used in this investigation:

NACA fuel	Description
50-264	MIL-F-5624A, grade JP-3; a "minimum quality" JP-3 base fuel.
51-353	90 weight percent 50-264 plus 10 weight percent triisopropylbenzene; a high-boiling single-ring aromatic blend.
52-50	90 weight percent 50-264 plus 10 weight percent of a mixture of α- and β-monomethylnaphthalene; a high-boiling dicyclic aromatic blend.
52-32	60 weight percent 50-264 plus 40 weight percent triisopropylbenzene; a high-boiling, single-ring aromatic blend having a hydrogen-carbon ratio very similar to NACA fuel 52-50.
52-53	MIL-F-5624A, grade JP-4; a "high quality" JP-4 base fuel.
52-105	90 weight percent 52-53 plus 10 weight percent of a mixture of α- and β-monomethylnaphthalene; a high-boiling dicyclic aromatic blend.

The chemical and physical properties of these fuels are presented in table I.

APPARATUS AND PROCEDURE

Carbon-deposition data were obtained in a single-tube J33 combustor. Photographs of the combustor inner liner and dome assembly are presented in figure 1. The combustor was installed in the laboratory air-supply and exhaust facilities as shown schematically in figure 2. A complete description of the test apparatus and instrumentation is presented in reference 5.

The combustor was operated at the following conditions for a 4-hour period:

Inlet-air pressure, in. Hg abs	53.9
Inlet-air temperature, $^{\circ}F$	271
Air-flow rate, lb/sec	2.87
Fuel-air ratio	0.0123

The quantity of carbon deposited was determined by weighing the combustor inner line assembly before and after each test run. The liner was cleaned prior to each run with mechanical rotating wire brushes.

RESULTS AND DISCUSSION

The results of the carbon-deposition tests in the single J33 combustor are presented in table II. It is noted that the average percentage variation of individual runs from the average value varies from 1 to 11 percent. This reproducibility compares favorably with that reported in reference 4 (from less than 1 percent to 14 percent).

The quantities of carbon deposited by the six fuel blends are plotted in figure 3 against the NACA K factor. The smallest carbon deposition was obtained with grade JP-4 fuel (NACA fuel 52-53), the largest, with the "minimum quality" grade JP-3 fuel plus 40 percent triisopropylbenzene (NACA fuel 52-32). A 10-percent addition of monomethylnaphthalene to grade JP-4 (NACA fuel 52-105) resulted in an increase in carbon deposition of almost 200 percent, while a similar addition to the JP-3 fuel resulted in an increase of only 28 percent. The grade JP-4 fuel plus 10 percent monomethylnaphthalene produced considerably less carbon than did the minimum quality JP-3 base fuel (NACA fuel 50-264). NACA fuels 52-32 and 52-50 have almost identical hydrogen-carbon ratios; however, because of its increased concentration of high-boiling material, fuel 52-32 has a somewhat higher K factor and resulted in increased carbon deposition.

The correlation curve shown in figure 3 was obtained from previous tests with a large number of fuels (reference 1) and indicates very satisfactory agreement with the present data. The average and maximum deviations of the carbon-deposition data from the predicted correlation curve were 12 and 43 percent, respectively. The corresponding values reported in reference 1 for a much larger number of fuels were 16 and 85 percent, respectively.

The quantities of carbon deposited by the fuels are plotted against smoking tendency in figure 4. In this case, also, the correlation curve was obtained from reference 1. The average deviation of the data from the curve was 18 percent and the maximum deviation, 59 percent. These values compare favorably with corresponding values of 16 and 65 percent reported in reference 1.

The results obtained in this investigation indicated that the addition of high-boiling aromatic components to jet-engine fuels increased the carbon-forming propensity of the fuels. Both the NACA K factor and the smoking tendency correlations satisfactorily predicted the increased carbon deposition resulting from additions of monomethylnaphthalene and triisopropylbenzene. However, for similar concentrations of either component, these correlations predicted somewhat greater carbon deposition with monomethylnaphthalene blends than with triisopropylbenzene blends, while the actual deposition obtained was similar.

The addition of 10 percent monomethylnaphthalene increased the carbon-deposition characteristics of the JP-4 fuel by a much greater amount than in the case of the minimum quality JP-3 fuel. This trend is also predicted by the K factor. Jet fuels having a high K factor (for example, fuel 50-264) have, in general, relatively low hydrogen-carbon ratios, and those having a low K factor (for example, fuel 52-53), high hydrogen-carbon ratios. Thus, for fuels of similar boiling temperature, the addition of very low hydrogen-carbon ratio components such as the aromatic hydrocarbons will have a much greater effect on the K factor for fuels having a low K factor than for fuels having a high K factor.

CONCLUDING REMARKS

From an investigation of the effects of additions of typical high-boiling single-ring and dicyclic aromatics on the carbon forming propensity of MIL-F-5624A fuels it was found that these fuel components increased carbon deposition in a single combustor. From comparisons of these data with correlation curves previously obtained, it is concluded that both the NACA K factor (function of hydrogen-carbon ratio and volumetric average boiling temperature of the fuel) and the smoking tendency of the fuel satisfactorily predicted the results obtained.

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4. Wear, Jerrold D., and Cook, William P.: Effect of Fuel Properties on Carbon Deposition in Atomizing and Prevaporizing Turbojet Combustors. NACA RM E52C24, 1952.

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TABLE I - FUEL ANALYSES

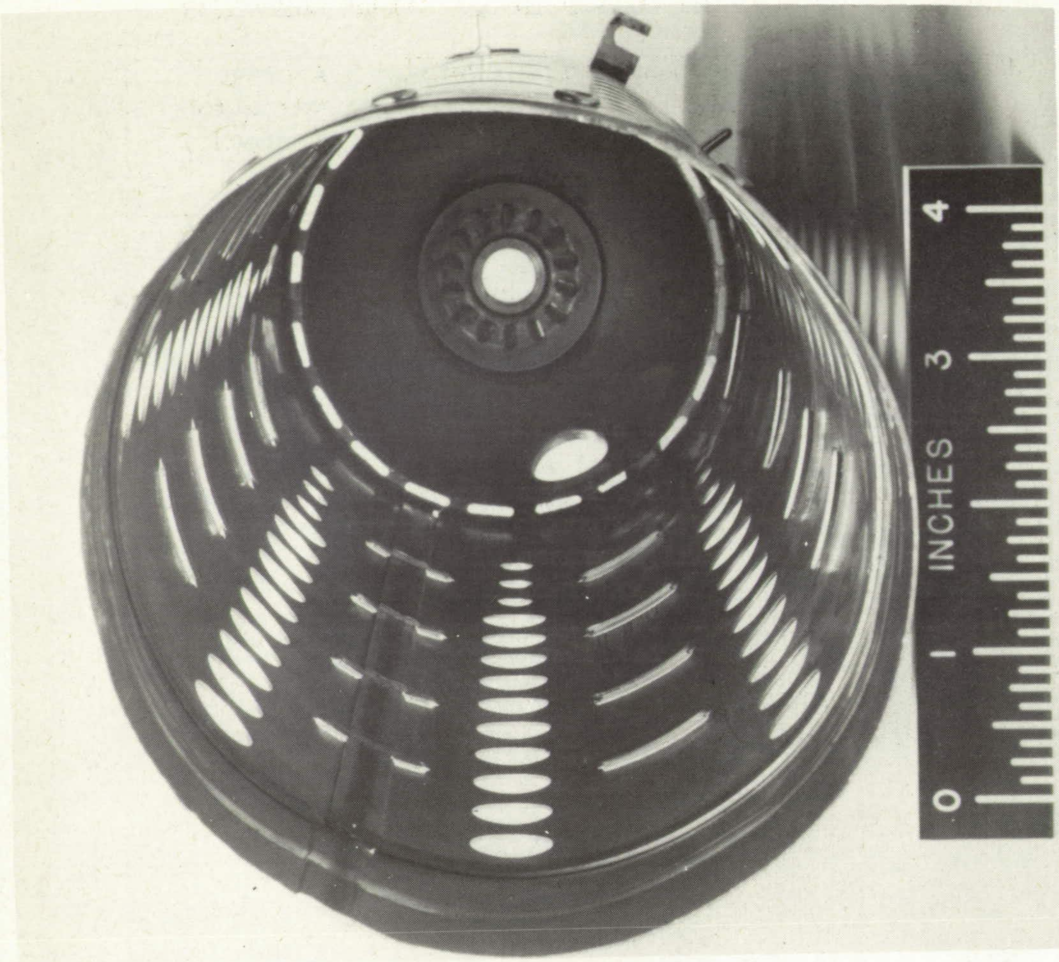
NACA fuel	A.S.T.M. distillation percent evaporated, (°F)					Volumetric average boiling temperature (°F)	Gravity (°A.P.I.)	Aromatics (percent by volume) (a)	Aromatics (percent by volume) (b)	Smoking tendency 320/h (c)	Hydrogen-carbon ratio	NACA K factor (d)
	10	30	50	70	90							
50-264	152	268	330	413	477	328	47.3	22	26	18.6	0.153	331
51-353	205	295	358	428	469	351	44.5	---	---	23.0	.152	341
52-50	205	293	356	425	474	351	41.8	---	---	26.9	.148	353
52-32	234	350	422	442	458	381	40.6	---	---	29.1	.149	363
52-53	200	244	278	321	400	289	55.4	8.5	10.7	9.3	.170	258
52-105	204	253	291	343	431	304	50.2	---	---	13.3	.160	300

[a]A.S.T.M. D875-46T method.
[b]Silica gel method.
[c]Reference 3.
[d]Reference 2.

TABLE II - CARBON DEPOSITION IN J33 SINGLE COMBUSTOR

NACA fuel	Carbon deposition (g) Run				Average	Average variation (percent) (a)
	1	2	3	4		
50-264	9.2	12.8	11.6	10.4	11.0	11
51-353	13.5	15.4	14.3	----	14.4	5
52-50	14.4	13.9	14.0	----	14.1	1
52-32	16.1	17.9	17.5	----	17.2	4
52-53	2.2	2.4	----	----	2.3	4
52-105	6.4	6.8	----	----	6.6	3

[a]Arithmetical average percent variation of individual carbon-deposition values from arithmetical average deposition value.



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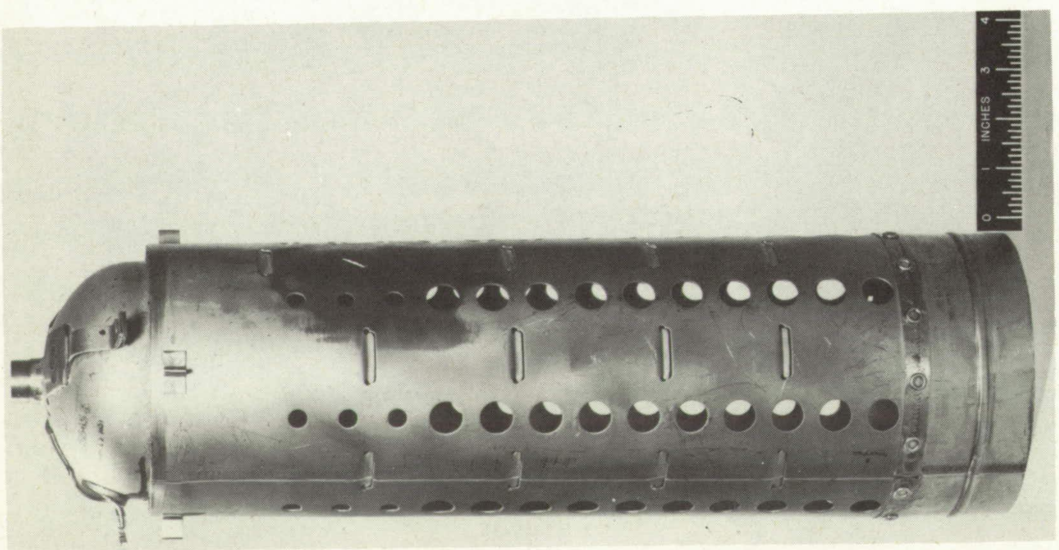

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Figure 1. - Inner liner and dome of J33 single tube combustor used in carbon-deposition investigation.

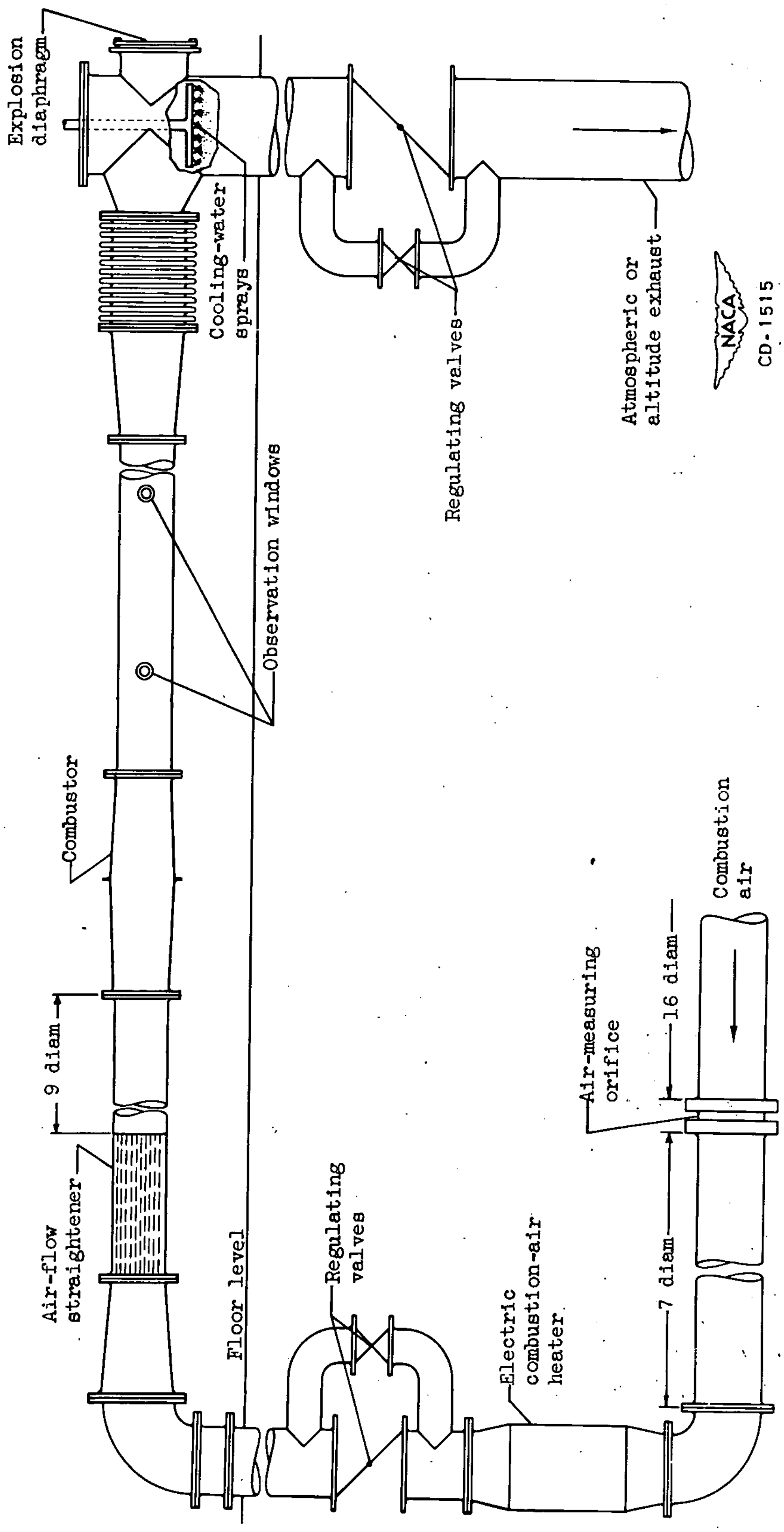

Figure 2. - Single-combustor installation and auxiliary equipment.

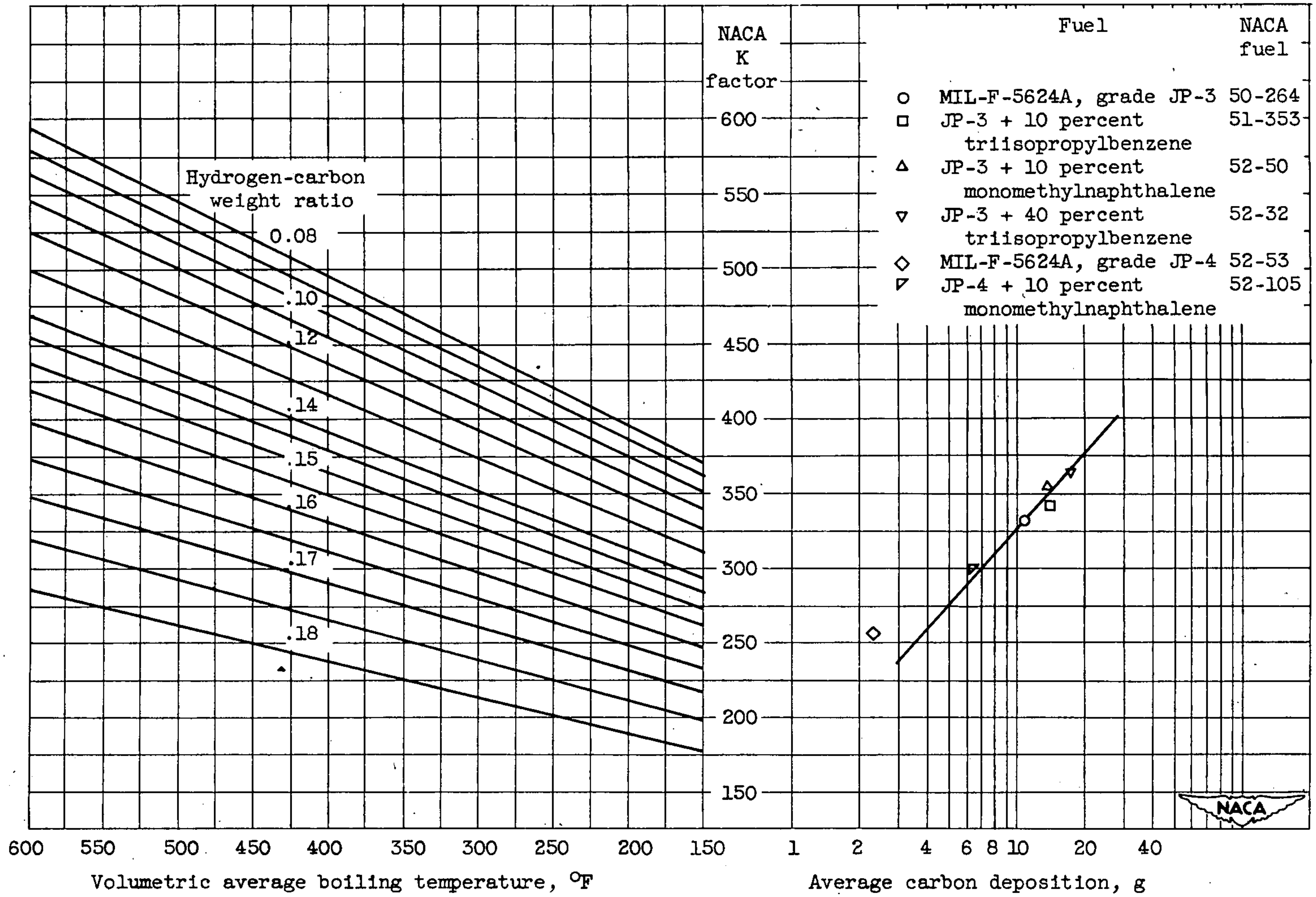

Figure 3. - Effects of additions of triisopropylbenzene and monomethylnaphthalene to MIL-F-5624A fuels on correlation of single-combustor carbon-deposition data with function of hydrogen-carbon ratio and volumetric average boiling temperature. Correlation curve from figure 3(a) of reference 1.

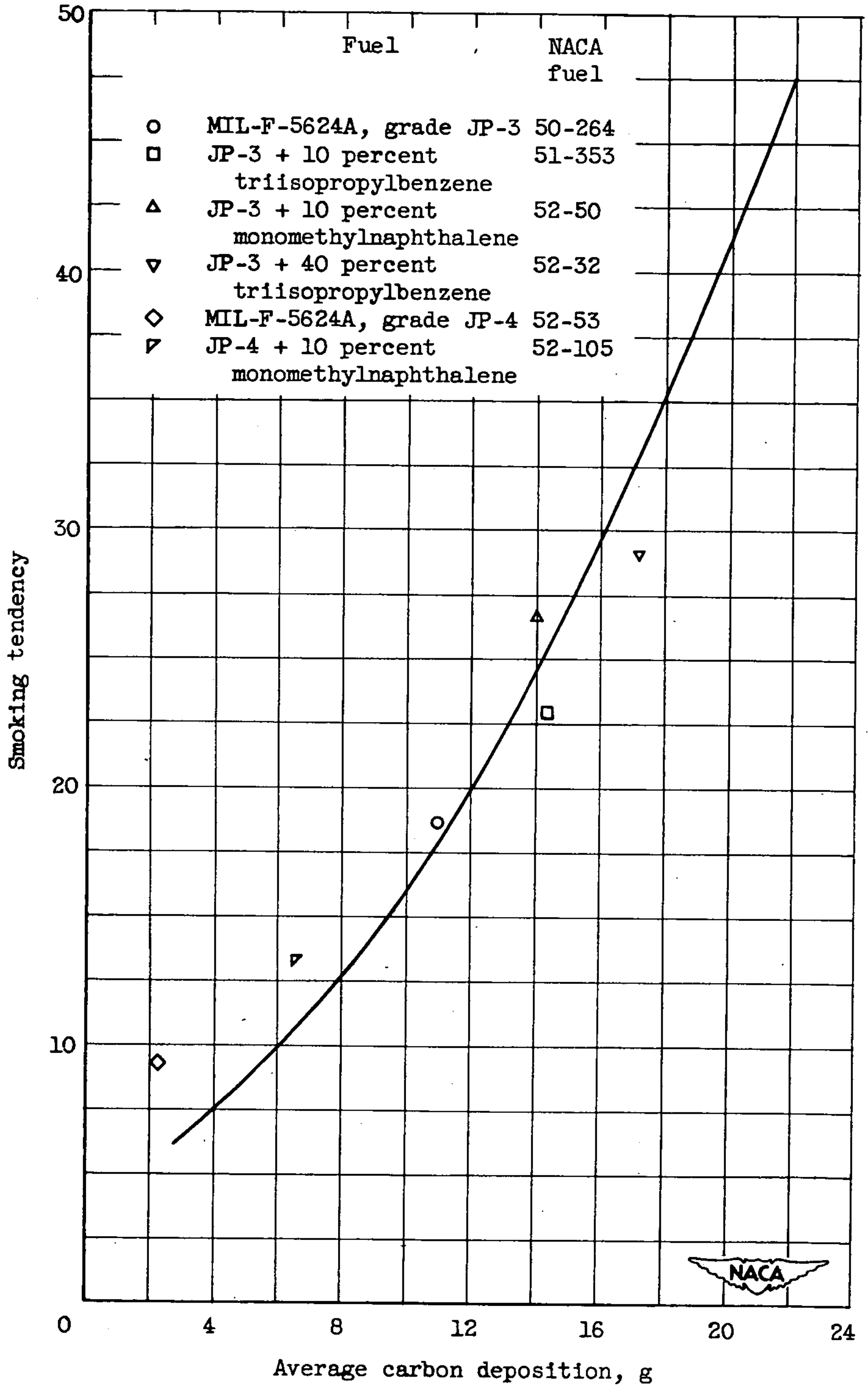

Figure 4. - Effects of additions of triisopropylbenzene and monomethylnaphthalene to MIL-F-5624A fuels on correlation of single-combustor carbon-deposition data with smoking tendency. Correlation curve obtained from figure 9(a) of reference 1.

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