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RESEARCH MEMORANDUM

CARBON DEPOSITION OBTAINED WITH MIL-F-5624A FUELS IN A SINGLE COMBUSTOR AND IN THREE FULL-SCALE ENGINES

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NATIONAL ADVISORY COMMITTEE
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WASHINGTON

June 10, 1954

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CARBON DEPOSITION OBTAINED WITH MIL-F-5624A FUELS IN A SINGLE COMBUSTOR AND IN THREE FULL-SCALE ENGINES

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SUMMARY

Investigations were conducted in a full-scale single turbojet combustor and in three different type full-scale engines to (1) provide data relating single-combustor carbon deposition to full-scale-engine carbon deposition, and (2) allow estimates to be made of the tolerances of full-scale engines for carbon deposition. Five MIL-F-5624A grades JP-3 and JP-4 fuels were tested in the single combustor at simulated low-altitude operating conditions. Some of these fuels were also tested in the full-scale engines at static sea-level conditions.

Data obtained in the full-scale single combustor and in the corresponding full-scale engine with comparable fuels indicated that fuels causing an increase in carbon deposition in the single combustor also caused an increase in carbon deposition in the full-scale engine. Similar trends were observed, qualitatively, from comparison of the single-combustor test results with results from the two other full-scale engines. Fuels producing deposits in excess of 7 to 9 grams during a 4-hour test in the single combustor (1) operated satisfactorily with respect to combustor deposits in the corresponding full-scale engine, (2) caused marginal operation in one of the two additional full-scale engines, and (3) caused excessive exhaust smoke in both the additional full-scale engines. Fuels producing deposits in excess of 7 to 9 grams in the single combustor have NACA K values of at least 315, smoking tendencies greater than 15, and Smoke Volatility Index values less than 54.

INTRODUCTION

Combustion-chamber carbon deposition is an important factor that influences the choice of fuels for the turbojet engine. Many investigations have been conducted to determine the effects of fuel composition and fuel volatility on deposition in an effort to establish a means of predicting the carbon-forming propensity of a fuel. As a result, a number of laboratory methods have been proposed as fuel quality control tests (ref. 1). However, these methods have been based primarily on data obtained in small-scale or in single-tube full-scale combustors. The selection of a quality control method that can be used in fuel procurement specifications will require full-scale engine data to establish the reliability of the method. In addition, full-scale engine data will be necessary to establish the maximum permissible value of the particular control test.

The results of a number of carbon deposition tests conducted at the NACA Lewis laboratory in a single-tube combustor and in full-scale engines are presented herein. These tests were conducted to provide some information concerning the relation between single combustor and full-scale-engine carbon deposition. These data together with limited flight operational data provide some indication of the tolerable limits of deposition and of the necessary control test limits that would ensure adequate fuel quality.

Full-scale single combustor tests were conducted at conditions simulating full-scale engine operation at an altitude of 20,000 feet and an engine speed of 90 percent normal rated speed. Full-scale tests were conducted in three engines at sea-level zero-ram conditions under cyclic operation. Since the full-scale engines were operated primarily to obtain data other than carbon-deposition data, the operating conditions varied with the engine. MIL-F-5624A grades JP-3 and JP-4 fuels were investigated. In some tests fuel from the same batch was used in both the single combustor and a full-scale engine; in other tests similar fuels were used.

APPARATUS AND PROCEDURE

The turbojet engines and the various engine conditions used in the carbon-deposition investigations are described.

J33 full-scale single combustor. - A complete description of the J33 combustor test apparatus and instrumentation is presented in reference 2. The inlet conditions simulated full-scale engine conditions at 20,000 feet altitude, 90-percent normal rated engine speed, and zero Mach number for a 4-hour run time. The combustor liner and dome, which were welded together for these tests, were weighed before and after each test and the increase in weight was considered as the weight of carbon deposited. Wire brushes were used to clean the liners prior to each test.

J33-9 full-scale engine (I). - The combustor numbers, spark plug location, and direction of compressor rotation are shown schematically in figure 1(a). The J33-9 turbojet engine was operated at sea level, zero ram on a cyclic operating schedule. The operating cycle consisted of approximately 5 minutes at idle engine speed (4000 rpm) followed by 15 minutes at take-off engine speed (11,500 rpm). The idle time included the time for acceleration and deceleration. Each hour of operation consisted of 45 minutes at take-off rpm and 15 minutes at idle rpm. There was no regularly scheduled shutdown period. The performance of the engine at 6000 rpm was checked each day before a test run to ascertain constancy of engine performance. The total run time for each of four tests was 49 hours and 20 minutes, 49 hours and 20 minutes, 50 hours and 30 minutes, and 37 hours and 54 minutes. Both new and used combustor liners and used domes were cleaned, if necessary, but not weighed before any one test. After the completion of the test, the liners and domes were weighed, then cleaned with wire brushes and reweighed. The difference in weight was considered as the weight of carbon deposited.

<u>J35-A-15 full-scale engine (II) (ref. 3)</u>. - The combustor numbers, spark plug location, and direction of compressor rotation are shown in figure 1(b). The J35-A-15 turbojet engine was operated at sea-level, zero-ram conditions for a total time of 25 hours. This time was divided into seven 3-hour periods followed by a 4-hour period. At the beginning and end of each period, the engine was operated for 5 minutes at rated conditions (7600 rpm). During the rest of each period the engine was operated at 90-percent rated speed. Following each period of operation, the engine was shut down for approximately 2 hours. The new combustor liners used for the investigation were weighed before and after completion of the 25-hour test, and the increase in weight was considered as the weight of the carbon deposited.

<u>J47-GE-25 full-scale engine (III)</u>. - The combustor numbers, spark plug location, and direction of rotation of the compressor are shown in figure 1(c). The J47-GE-25 turbojet engine was operated at sea-level zero-ram conditions for a total time of 37 hours and 47 minutes. The maximum running time for any one day was about $1\frac{1}{2}$ hours, which included running at engine speeds from 3000 rpm to 7950 rpm. About 75 percent of the total operating time was at 7950 (rated) rpm and the other 25 percent, at engine speeds varying between 3000 and 7950 rpm. The complete test covered a time period of about $1\frac{1}{2}$ months. Combustor liners, which had been previously used, were cleaned with wire brushes and then weighed before and after the complete test. The increase in weight was considered as the weight of the carbon deposited.

FUELS

Inspection data of the MIL-F-5624A fuels used in the investigations reported herein are presented in table I.

52-9. - Fuel 52-9 was a production JP-3 fuel as obtained from refinery A.

52-20. - Fuel 52-20 was a production JP-3 fuel as obtained from refinery B.

During one of the tests with engine I (run time of 49 hr and 20 min), fuel 52-9 was used during the first 30 hours, a 78-22 volume percent blend of fuels 52-9 and 52-20, respectively, was used during the next 12 hours, and fuel 52-20 was used during the final time of 7 hours and 20 minutes. The total amount of fuel required for the complete test consisted of approximately 80 percent by volume of fuel 52-9 and 20 percent by volume of fuel 52-20.

52-30. - Fuel 52-30 was an approximate 80-20 volume percent blend of fuels 52-9 and 52-20, respectively, used in the single combustor to simulate the blend previously described that was run in engine I.

Fuel 52-28. - Fuel 52-28 was a production JP-4 fuel obtained from refinery C. This fuel was tested in the single combustor and in engine I.

Fuel 50-264. - Fuel 50-264 was a JP-3 fuel considered as "minimum quality" because the aromatic content was approximately the maximum permitted by JP-3 specification. This fuel was tested in the single combustor and in engine II.

Fuel 52-76. - Fuel 52-76 was a JP-4 fuel considered as "minimum quality" because the aromatic content was nearly at the maximum limit permitted by the specification. This fuel was investigated in the single combustor and in engines I and III.

Fuel 53-49. - Fuel 53-49 was a JP-4 fuel supplied to NAAS El Centro for flight use (ref. 4) and was marginal in quality. This fuel was tested in the single combustor.

Production fuels. - Many additional batches of production fuels had been run in engines I, II, and III prior to the present investigation. Full inspection data are not available for these many batches, but their quality is believed to be much the same as that of fuels 52-9, 52-20, and 52-28 listed previously.

RESULTS

The results of carbon deposition investigations conducted in a full-scale single combustor and in three full-scale turbojet engines with several MIL-F-5624A fuels are described in the following section.

<u>Full-scale single combustor</u>. - The carbon deposition values obtained with five test fuels are presented in table II. Each value presented is an average of two or more tests. It is noted that the largest deposits occurred with a "minimum quality" JP-3 fuel, 50-264; the smallest, with a production JP-4 fuel, 52-28. The "grey white" or "grey" deposits noted for some fuels in table II indicate the presence of a metallic contaminant, probably lead. As observed in reference 5, the presence of a metallic constituent such as lead may reduce carbon deposition by a catalytic action.

<u>Full-scale engine I</u>. - The carbon deposition values obtained with three test fuels are presented in table III. The values represent results of a single test with any one fuel. Generally, the carbon appeared to be heaviest on the sides of the liners and domes that were facing opposite to the direction of compressor rotation (see fig. 1(a)). No relation between the relative quantities of carbon and the circumferential position of the combustor was evident in this engine. Emission spectra of powder deposits obtained from the downstream end of liners after the test with a JP-4 fuel, 52-28, indicated that these deposits contained a large amount of lead. Similar deposits were noted with this fuel in the full-scale single-combustor tests.

Fuel-nozzle filter plugging during the first test with a JP-4 fuel, 52-76, limited the fuel flow to the engine to such an extent that the desired engine speed could not be maintained; the test was terminated after 37 hours and 54 minutes. This run is not included in analysis of data but is shown in table III only to indicate, approximately, the effect of time and reproducibility of the amount of carbon obtained from a single fuel. In a second test with fuel 52-76 the desired number of running hours was obtained, although some filter plugging did occur. There was a considerable amount of carbon on the ignition plugs after fuel 52-76 was used.

<u>Full-scale engine II</u>. - The carbon deposition values obtained with a minimum quality JP-3 fuel, 50-264, are presented in table IV. The values represent results of a single test. Carbon deposits formed in the dome end of the combustor and on the fuel nozzle. Some warping of the liners occurred that had not been previously encountered, and a much larger amount of soot was found in the exhaust muffler than had been obtained from previous tests with a production JP-3 fuel during this length of run. There was some evidence of greater deposition in combustion chambers located at the bottom of the engine.

Full-scale engine III. - The carbon deposition values obtained with a minimum quality JP-4 fuel, 52-76, are presented in table V. The values represent results of a single test. The large carbon deposit weight obtained in combustor 7 (fig. 1(c)) was caused by a large deposit on one of the spark plugs, as shown in figure 2. Abnormally large deposits in combustors using the type of spark plug shown in figure 2 have been obtained previously. Several of the liners were severely warped after the test and required replacement.

During the test with this fuel, the exhaust cooling water draining from the exhaust muffler was black. Also, inspection of the inside of the muffler showed large quantities of soot; one total-pressure instrumentation rake was plugged with soot. This amount of exhaust soot was considered to be much greater than that normally encountered with production JP-4 fuel.

DISCUSSION OF RESULTS

Relation of Full-Scale-Engine Deposits to Full-Scale-Single-Combustor Deposits and to Fuel Properties

A summary of some fuel properties from table I and results of carbon deposition investigations are shown in the following table:

Fuel number and fuel	Fuel properties			Carbon deposition (g/combustor)			
	NACA K	Smoking tendency	Smoke Volatility Index	Single combustor	Engine		
					I	II	III
52-9, JP-3	286	11.0	62	---	80% } 22.4	---	----
52-20, JP-3	252	8.5	73	---	20% }	---	----
52-28, JP-4	252	8.0	78	2.5	14.9	---	----
52-30, JP-3	277	9.9	66	3.7	----	---	----
52-76, JP-4	316	19.4	51	7.4	26.0	---	10.3
53-49, JP-4	321	15.2	43	6.9	----	---	----
50-264, JP-3	331	18.6	45	9.8	----	9.1	----

A comparison of data obtained in the single combustor with those obtained in engine I (similar combustion chamber) is shown in figure 3. Two fuels, 52-28 and 52-76, were tested in both units and can be compared directly. A third comparison can be made between a combination of fuels 52-9 and 52-20 used in the full-scale engine and a blend of these two fuels (52-30), made up of approximately the same proportions as used in the full-scale engine, used in the single combustor. The order of the carbon deposition among the fuels was the same for both test units; however, percentage changes of the deposit values between fuels were not the same.

Carbon deposition data obtained for five fuels in the single combustor and for three fuels in engine I are plotted in figure 4 against NACA K (ref. 6), a function of the volumetric average boiling temperature and the hydrogen-carbon ratio of the fuel. For both test units, the carbon deposit weight increased with an increase in K. It is seen that the data of figure 4 for the single combustor approach a straight-line correlation with K somewhat better than do the full-scale data. The effective K for the two fuels, 52-9 and 52-20, that were used in different proportions during one test in the full-scale engine was assumed to be the same as the K of fuel 52-30, which is a blend of known proportions of these two fuels.

Figure 5 presents carbon deposition data for the same fuels from the single-combustor and engine I plotted against the smoking tendencies of the fuels. Smoking tendency is defined as 320/h, where h is the smoke point in millimeters (ref. 7). Increase in the smoking tendency of a fuel did not in all cases indicate an increase in carbon deposition for the data taken for the single combustor. The smoking tendency of one fuel, 50-264, was determined about two years previous to the time the values for the other fuels were obtained. The testing techniques had not been finalized before the earlier test, so this value may be in error. The full-scale engine data did show a general increase in carbon weight with increase in smoking tendency of the fuels.

A fuel-quality control designated Smoke Volatility Index (SVI) is currently used in MIL-F-5624B fuel specification to exclude fuels that might cause severe carbon deposition in full-scale engines. It is defined as follows:

$$\text{SVI} = \text{smoke point} + \frac{\text{volume percent evaporated at } 400^{\circ}\text{ F}}{2.4}$$

where smoke point is the maximum height in millimeters of a smoke-free flame, of the whole fuel, determined by the I.P.T. lamp; volume percent evaporated at 400° F is from ASTM distillation D-86; and 2.4 is a constant. The use of the SVI as a fuel quality control is described more fully in references 8 and 9. The MIL-F-5624B specification requires fuels to have SVI values of 54 or greater.

SVI values of the fuels investigated herein are given in table I. The smoke points of all fuels except 53-49 were determined by the modified Davis factor lamp (ref. 7). The values obtained by this method are 1 or $1\frac{1}{2}$ millimeters less for the fuels investigated than values obtained by the I.P.T. lamp. The SVI values of those fuels investigated in the single combustor and in engine I are plotted in figure 6 against the carbon deposit values obtained. The results are similar to those of figure 5 (smoking tendency) in that a decrease in SVI did not in all cases indicate an increase in carbon deposits for the single-combustor data. The same qualification that applied to the smoking tendency of fuel 50-264 applies also to the SVI value of fuel 50-264. The full-scale-engine data did show increased deposit weight with decrease in SVI. As with K and smoking tendency, the effective SVI value for the combination of two fuels, 52-9 and 52-20, used during one test in the full-scale engine was assumed to be the same as the SVI of fuel 52-30.

From the data obtained in the full-scale single combustor and full-scale engine I on three fuels, it appears that the severity of carbon deposition in this full-scale engine can be estimated equally well by single-combustor data, by NACA K, by smoking tendency of the fuel, or by Smoke Volatility Index.

Although less quantitative in nature, the results obtained in full-scale engines II and III indicate similar trends. For example, data obtained in engine II indicated more liner warping and much more soot in the exhaust muffler with fuel 50-264 (which had values of K, smoking tendency, and SVI of 331, 18.6, and 45, respectively) than had previously been obtained with many batches of production JP-3. These batches had values of K, smoking tendency, and SVI similar to those of fuel 52-30, which are 277, 9.9, and 66, respectively. Fuel 50-264 gave 9.8 grams of carbon in the single combustor, while 3.7 grams were obtained with fuel 52-30. Similarly, data obtained in full-scale engine III indicated more severe liner warping, much more soot in the exhaust muffler, and the greater possibility of spark plug fouling when using fuel 52-76 rather than a production JP-4 such as 52-28. The K, smoking tendency, and SVI values of fuel 52-76 are 316, 19.4, and 51, respectively; for fuel 52-28 the values are 252, 8.0, and 78, respectively. The weight of carbon deposit obtained in the single combustor was 7.4 grams with fuel 52-76 and 2.5 grams with fuel 52-28.

Tolerable Limits of Carbon Deposition in Full-Scale Engines

Information from single-combustor investigations and from limited flight experience can be used only to obtain an approximate carbon deposition limit for full-scale engines. The tolerable limit among engines varies as does the amount of deposit from any one fuel.

Data presented herein qualitatively indicate the amounts of carbon deposition that can be tolerated by the engines investigated. In engine I no difficulties attributable to carbon deposits were encountered with the test fuel depositing the largest quantity of carbon. This fuel, a minimum quality JP-4 fuel (52-76), produced 7.4 grams of carbon in the single combustor. In engine III the same fuel caused no difficulties definitely attributable to carbon deposition, although liner warping did occur. In engine II, operation with a minimum quality JP-3 fuel (50-264), giving 9.8 grams of carbon in the single combustor, was considered marginal. In engines II and III there was evidence of very severe exhaust smoke with the minimum quality JP-3 (50-264) and JP-4 fuels (52-76), respectively. On the basis of these data a marginal fuel in some engines may be considered to deposit 7 to 10 grams of carbon in the single combustor during a 4-hour test. It is of interest to note that, in terms of possible fuel-quality control methods, such a fuel would have an NACA K of about 320 and a smoking tendency of about 18 (figs. 4 and 5). The SVI value for this marginal fuel would be about 44 (fig. 6), which is below the minimum specification value of 54. The SVI value of 54 would also rule out fuel 52-76, which gave the most carbon in engine I and marginal performance in engine III. Fuel 50-264 (SVI of 45), which was considered marginal in engine II, would also be eliminated by the SVI specification. Data obtained from flight operations at Patuxent Naval Air Test Center (ref. 1) indicated a limiting value of K equal to 310, which would represent a smoking tendency of about 13 (from correlations of ref. 1). Reference 4 provides another source of flight operational data. Fuel 53-49 caused excessive carbon deposition in a number of aircraft engines used for flight operations at NAAS El Centro. This fuel produced 6.9 grams of carbon in the single combustor, with some evidence of lead contaminants, and has a K of 321, a smoking tendency of 15.2, and a SVI value of 43 (table I). Additional information as to the effect of carbon deposition on flight operations is presented in reference 8.

CONCLUDING REMARKS

Limited investigations conducted in a full-scale single turbojet combustor and in three full-scale engines designated I, II, and III indicated a qualitative relation between carbon deposition in a single combustor and in full-scale engines. The relative quantities of carbon deposited followed trends observed in the single combustor. Engines I and III were not adversely affected by a "minimum quality" JP-4 fuel that produced 7.4 grams of carbon in the single combustor, although excessive exhaust smoke was obtained in engine III. A fuel producing carbon deposits in excess of 9 grams in the single combustor caused "marginal operation" and excessive exhaust smoke in full-scale engine II. From these data, and from qualitative flight operational data, marginal jet fuels appear to (1) cause deposits in excess of 7 to 9 grams in the full-scale single combustor, (2) have NACA K values greater than 315, and (3) have smoking tendencies greater than 15 to 19. The results of these three quality control methods are in general agreement with the currently used Smoke Volatility Index. It is pointed out that full-scale engine tolerance of carbon deposits will vary considerably with engine design.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, April 12, 1954

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TABLE I. - FUEL INSPECTIONS

NACA fuel number	50-264	52-9	52-20	52-28	52-30	52-76	[a]53-49
Gravity	47.4	52.2	55.4	55.8	52.1	48.2	43.0
°API	0.791	0.770	0.757	0.756	0.771	0.787	------
Specific, 60/60° F							
A.S.T.M. distillation D86-46, °F							
Initial boiling point	100	119	118	137	119	142	130
Percentage evaporated							
5	120	175	148	178	167	201	205
10	152	207	174	194	199	220	247
20	224	243	215	217	244	244	310
30	268	274	249	236	272	263	348
40	301	300	275	256	295	283	376
50	330	321	299	275	316	304	395
60	368	341	325	299	337	324	418
70	413	367	347	317	362	348	435
80	444	409	376	347	401	381	452
90	477	464	421	400	460	438	474
Final boiling point	512	521	494	486	517	494	510
Residue, percent	1.2	1.2	1.2	1.2	1.4	1.2	------
Loss, percent	1.8	0.8	0.8	0.6	1.1	0.8	------
Freezing point, °F	-76	------	------	------	------	-76	-76
Aromatics (silica gel), total percent by volume	26	------	------	10	------	24	14
Aromatics in fraction boiling above 400° F (silica gel), volume percent of total	------	------	------	------	------	5.5	10.9
Reid vapor pressure, lb/sq in.	6.0	4.9	6.0	2.8	5.4	2.3	2.3
Hydrogen-carbon ratio[b]	0.153	0.166	0.172	0.171	0.168	0.156	[c]0.161
Heat of combustion[d], Btu/lb	18,460	18,700	18,725	18,725	18,675	18,475	------
Gum, mg/100 ml							
Air-jet residue	9	------	------	------	------	1	3
Accelerated	12	------	------	------	------	3	12
Aniline point, °F	108.0	137.7	135.7	133.7	133.3	106.5	129
Bromine number	8	------	------	------	------	------	2.0
NACA "K" factor[e]	331	286	252	252	277	316	321
Smoking tendency[f]	18.6	11.0	8.5	8.0	9.9	19.4	[g]15.2
Smoke Volatility Index[h]	45	62	73	78	66	51	43

[a]Inspections of JP-4 fuel from several Naval Air Stations and one Marine Air Station. California Research Corp. (Richmond, Calif.), Cal Research J No. 348.
[b]Determined by combustion furnace.
[c]Method not listed.
[d]Determined by aniline-gravity constant.
[e]Reference 6.
[f]Reference 7; 320/h, where h is smoke point in mm determined by modified Davis Factor lamp.
[g]Smoke point h determined by I.P.T. lamp.
[h]References 8 and 9.

TABLE II. - CARBON DEPOSITION OBTAINED WITH FIVE FUELS

IN FULL-SCALE SINGLE COMBUSTOR

[Run time, 4 hr]

Fuel	Carbon, g	Remarks
50-264	9.8 (ref. 3)	
52-28	2.5	Grey-white powder in down-stream end of liner
52-30	3.7	
52-76	7.4	
53-49	6.9	Grey deposits

TABLE III. - CARBON DEPOSITION OBTAINED WITH THREE FUELS IN FULL-SCALE ENGINE I

Combustor	JP-3 fuel (80 percent, 52-9; 20 percent, 52-20)		JP-4 fuel, 52-28		JP-4 fuel, 52-76			
			Run time, 49 hr, 20 min		Run time			
	Run time, 49 hr, 20 min		Carbon, g		37 hr, 54 min		50 hr, 30 min	
	Carbon, g				Carbon, g		Carbon, g	
	Liner	Dome	Liner[a]	Dome	Liner	Dome	Liner[a]	Dome
1	4.2	22.7	4.8	13.3	8.9	19.3	7.9	19.2
2	6.2	16.1	4.6	7.8	7.7	12.7	.6	1.5
3	7.7	10.0	5.9	7.9	4.9	11.2	9.8	19.1
4	7.4	12.9	4.8	5.1	.7	1.8	5.8	13.4
5	7.3	20.5	7.2	14.1	8.6	13.0	7.8	15.3
6	7.0	13.7	3.4	8.2	14.1	15.3	18.0	22.3
7	8.0	17.8	4.8	13.1	7.4	17.6	7.7	12.4
8	3.7	25.3	6.0	6.3	8.4	21.0	9.1	11.9
9	6.3	15.4	4.4	11.9	7.2	10.5	10.1	15.2
10	5.7	25.0	5.6	7.7	8.0	11.9	7.3	12.3
11	3.9	10.4	4.0	9.4	7.3	16.2	11.5	15.6
12	4.4	13.1	5.0	6.8	6.3	15.1	14.0	24.3
13	5.4	17.1	5.7	7.5	9.3	16.0	10.2	11.0
14	5.8	11.4	7.0	16.5	9.0	21.7	12.4	14.0
Total	83.0	231.4	73.2	135.6	107.8	203.3	132.2	207.5
Average per liner or dome	5.9	16.5	5.2	9.7	[b]8.2	[b]15.5	[c]10.1	[c]15.9
Average per combustor	22.4		14.9		[b]23.7		[c]26.0	

[a]New liners.
[b]Values of combustor 4 not used in averages. Partly plugged fuel nozzle filter resulted in a lean mixture and consequently a decrease of carbon deposits.
[c]Values of combustor 2 not used in averages.

TABLE IV. - CARBON DEPOSITION OBTAINED WITH FUEL

50-264 IN FULL-SCALE ENGINE II[a]

[Run time, 25 hr]

Combustor	Carbon, g
1	9.4
2	7.9
3	8.5
4	12.6
5	10.7
6	9.1
7	5.0
8	9.2
Total	72.4
Average	9.1

[a]Data from reference 3.

TABLE V. - CARBON DEPOSITION OBTAINED WITH FUEL

52-76 IN FULL-SCALE ENGINE III

[Run time, 37 hr and 47 min]

Combustor	Carbon, g
1	5.2
2	5.7
3	10.0
4	8.6
5	4.6
6	3.8
7	42.1
8	2.2
Total	82.2
Average	10.3

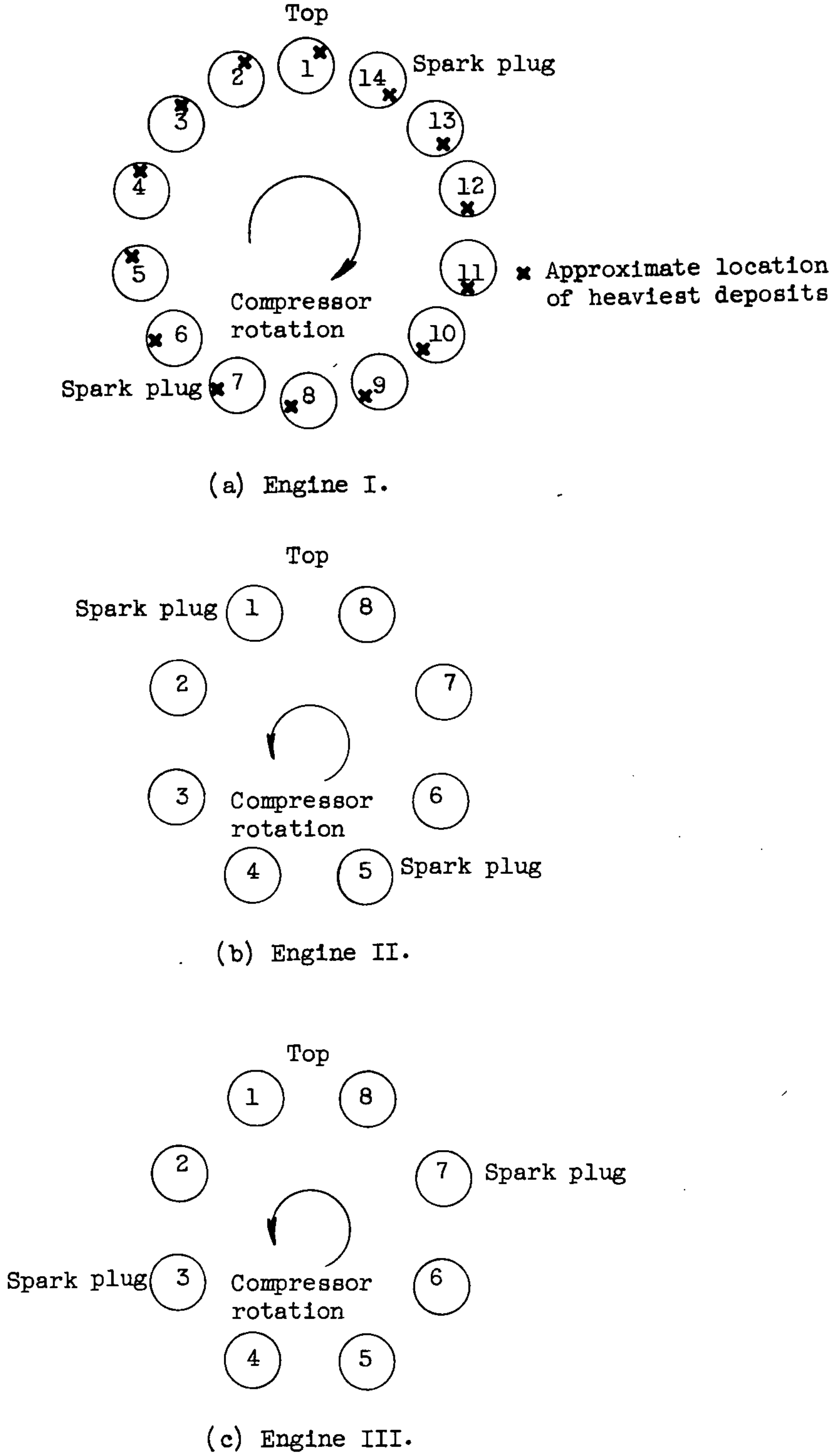

Figure 1. - Diagrammatic sketch showing relative location of combustors in full-scale engines. Downstream view.

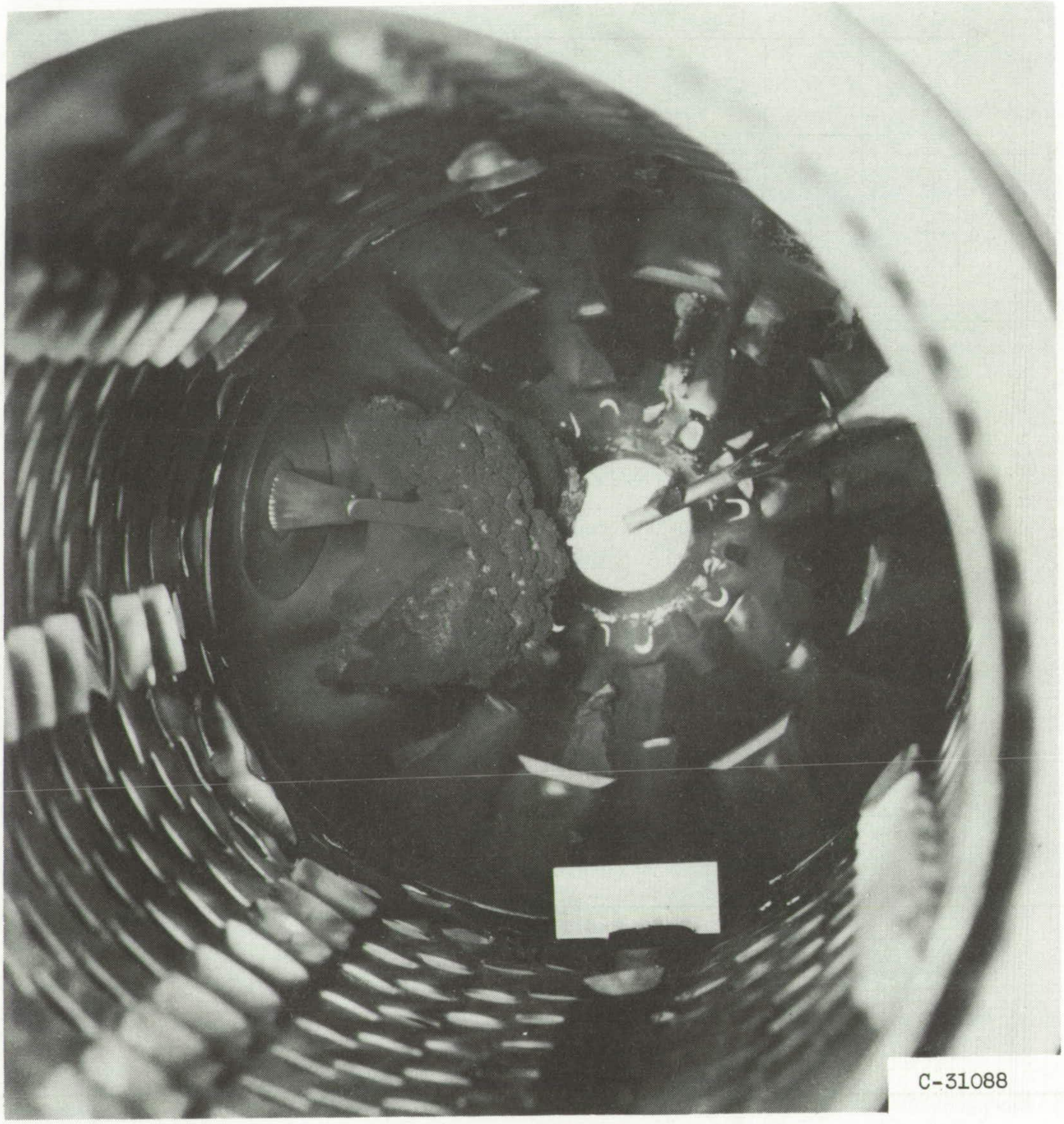

Figure 2. - Carbon deposits obtained in combustor of full-scale engine III. Fuel, a minimum quality JP-4, 52-76.

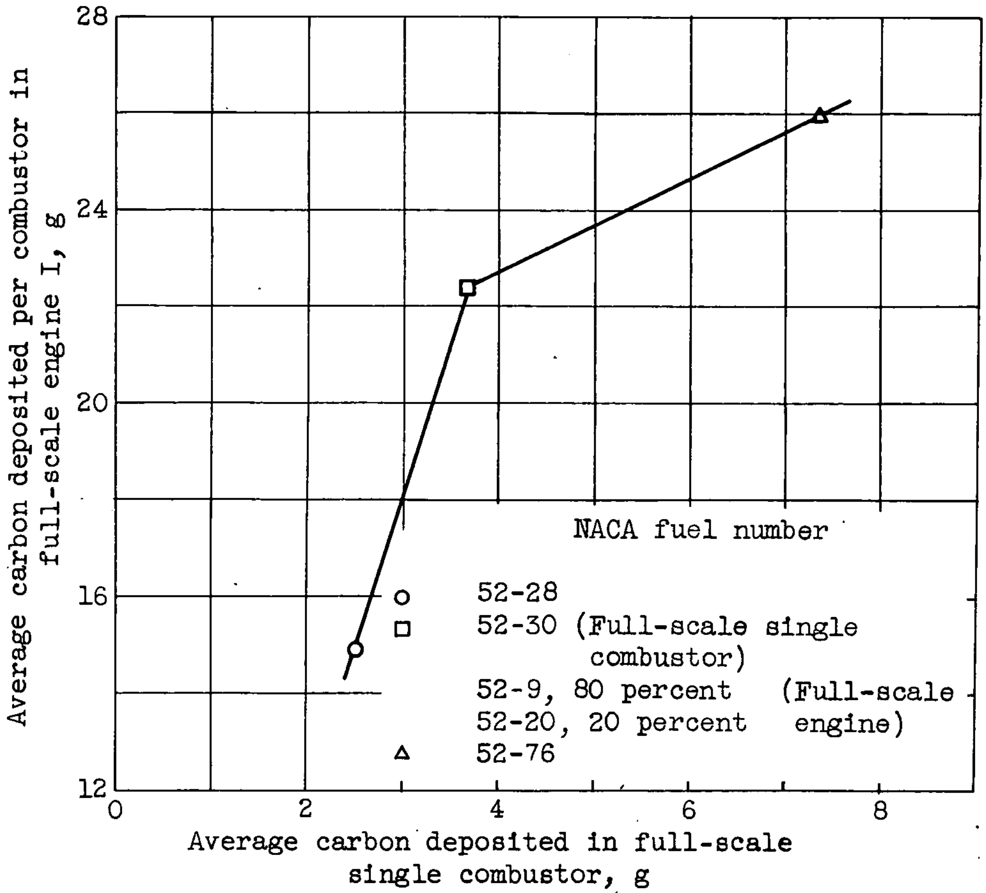

Figure 3. - Variation of carbon deposition obtained in full-scale single combustor during 4-hour run time and in full-scale engine I during approximately 50-hour run time. Fuels were common to both test units.

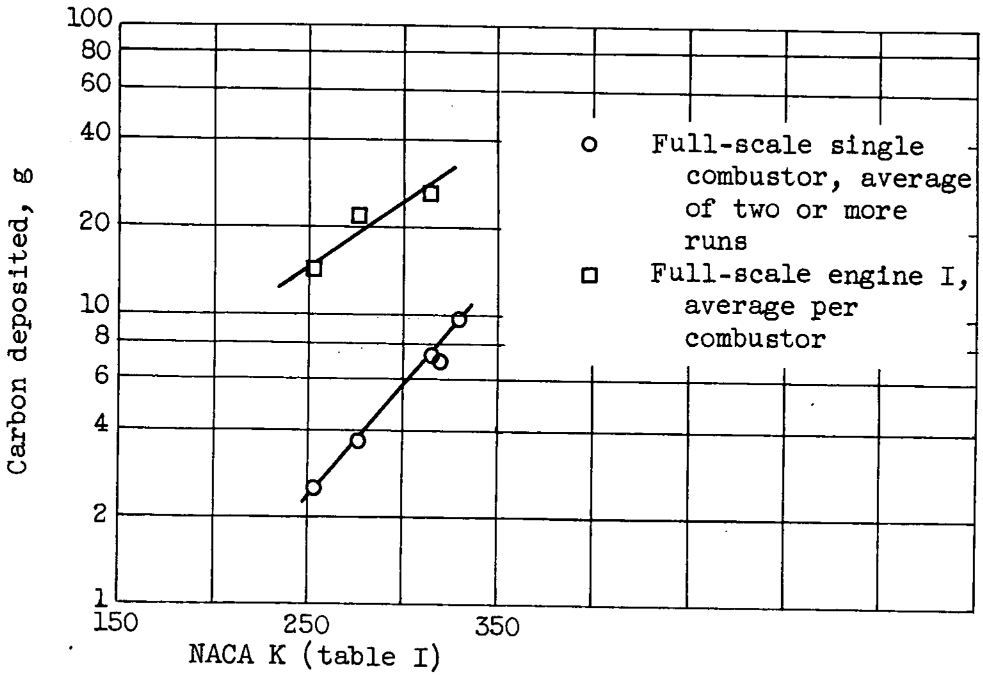

Figure 4. - Variation of carbon deposition obtained in full-scale single combustor and in full-scale engine I with NACA K values of several MIL-F-5624A fuels.

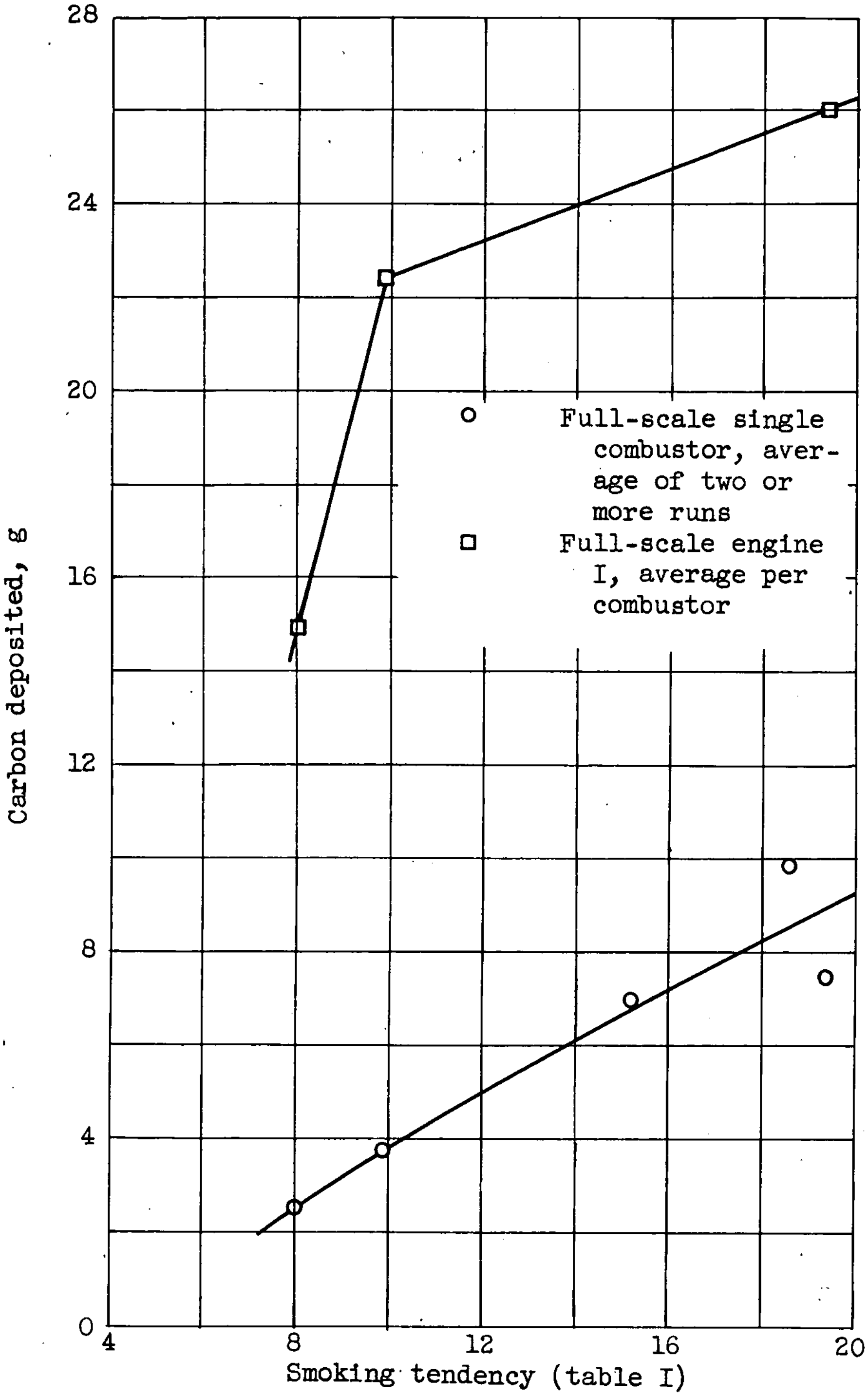

Figure 5. - Variation of carbon deposition obtained in full-scale single combustor and in full-scale engine I with smoking tendencies of several fuels.

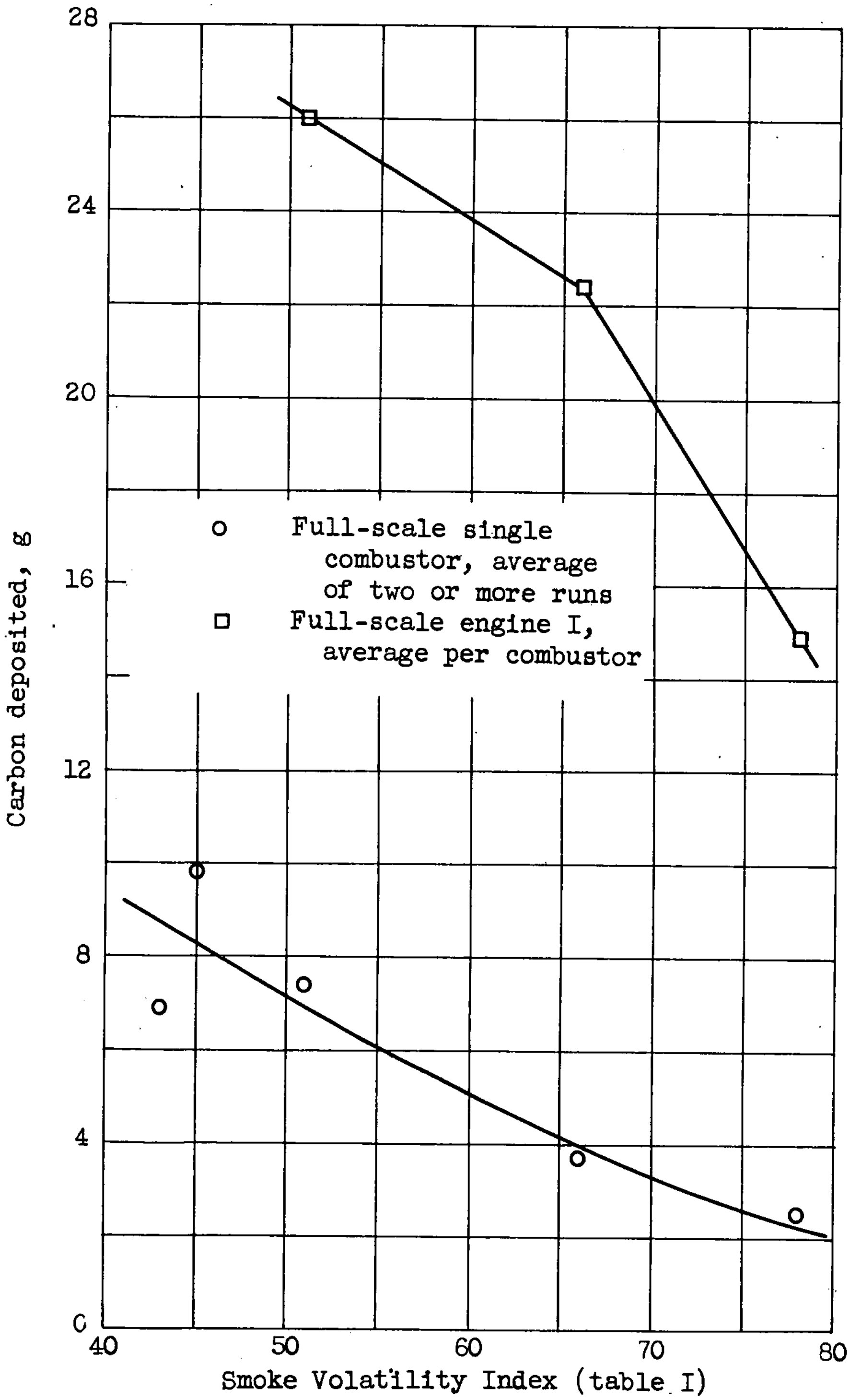

Figure 6. - Variation of carbon deposition obtained in full-scale single combustor and in full-scale engine I with Smoke Volatility Index of several fuels.