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RESEARCH MEMORANDUM

CARBON DEPOSITION OF SEVERAL SPECIAL

TURBOJET-ENGINE FUELS

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RESEARCH MEMORANDUM

CARBON DEPOSITION OF SEVERAL SPECIAL TURBOJET-ENGINE FUELS

By Jerrold D. Wear and James W. Useller

SUMMARY

Investigations were conducted to determine the carbon-forming characteristics of MIL-F-5624 and MIL-F-5161 type fuels in a single combustor from a J33 turbojet engine and of a MIL-F-5161 fuel in a J35 full-scale engine. Single-combustor simulated engine conditions were 20,000-foot altitude, 90-percent rated engine speed, and zero ram. Full-scale engine operation was at sea-level, zero-ram conditions.

The carbon deposition of MIL-F-5624 and MIL-F-5161 fuels obtained in the single combustor could be estimated from a previously established empirical correlation with volumetric average boiling temperature and hydrogen-carbon ratio. The carbon deposition in the full-scale engine using MIL-F-5161 fuel was greater than the deposition normally obtained with MIL-F-5624 fuels. This trend, also noted in other types of turbojet engine, was concluded to be the result of fuel characteristics rather than combustion-chamber configuration. The results obtained in these investigations, together with other available full-scale-engine operational information, indicate that MIL-F-5161 fuels form more carbon than most MIL-F-5624 fuels, as predicted by the correlation, and may result in marginal operation in several turbojet engines.

INTRODUCTION

One important consideration in the selection of a satisfactory fuel for turbojet engine operation is its tendency to form carbon deposits in combustion-chamber liners. The present turbine-engine fuel specification MIL-F-5624 was formulated to permit maximum variations in fuel properties that would result in satisfactory turbojet-engine operation and performance. To supply a MIL-F-5624 type fuel for engine development purposes, fuel specification MIL-F-5161 has been issued, which provides for a "minimum quality" fuel with more rigid control of the fuel properties influencing engine performance. Recently, operation with MIL-F-5161 fuel, together with particular

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batches of MIL-F-5624 fuel, has been reported to result in excessive carbon deposition, accompanied by warping and cracking of liners, in both annular and tubular combustion chambers of full-scale turbojet engines.

Investigations are being conducted at the NACA Lewis laboratory to evaluate means of accurately predicting the carbon-deposition characteristics of turbojet-engine fuels from their chemical and physical properties. An investigation reported in reference 1 determined the carbon-deposition characteristics of 19 fuels in a small-scale annular combustor, and correlated these characteristics with a function of the hydrogen-carbon ratio and the volumetric average boiling temperature of the fuel. This correlation was also effective in predicting the carbon-deposition characteristics of several MIL-F-5624 specification fuels (formerly designated AN-F-58 fuels) in a single tubular combustor (reference 2).

The investigation reported herein was conducted to determine whether the correlation developed in reference 1 would adequately predict the carbon-deposition characteristics of several fuels, meeting specification MIL-F-5624 and MIL-F-5161 in most respects, that have been reported to be marginal or unsatisfactory in full-scale turbojet engine operation. This investigation was conducted in a single tubular J33 combustor. One MIL-F-5161 fuel was also used in a full-scale J35 turbojet engine to determine whether the unsatisfactory carbon-forming tendency of the fuel was peculiar to particular combustion-chamber configurations or the result of the fuel composition. The data obtained from these investigations, together with published and other available information on full-scale engine operation, are used to indicate the applicability of the carbon-deposition correlation to full-scale engine results.

The single tubular combustor was operated for a 4-hour period, at simulated inlet conditions of 20,000-foot altitude, 90-percent rated engine speed, and zero ram. The full-scale J35 engine was operated in regular cycles for a total of 25 hours at sea-level, zero-ram conditions.

FUELS

The fuels used for the investigations reported herein are identified as follows:

A. NACA 49-162; MIL-F-5624 type with high aromatic content. Marginal performance with reference to carbon deposition indicated in full-scale turbojet engines.

B. NACA 50-264 and 50-39; MIL-F-5161 type fuels. Marginal performance with reference to carbon deposition indicated in full-scale turbojet engines.

C. NACA 50-249 and 50-250; MIL-F-5624 type fuels with low Reid vapor-pressure values. These fuels are typical of low-volatility MIL-F-5624 fuels that could be produced for turbojet engines.

D. NACA 49-65; a high-aromatic, high-olefin type fuel not meeting either fuel specification. Severe carbon deposition has been obtained during operation with this fuel in full-scale turbojet engines.

The specifications for MIL-F-5624 and MIL-F-5161 fuels and analyses of the fuels used in this investigation are given in table I.

APPARATUS AND PROCEDURE

Single Combustor

The single-combustor carbon-deposition studies were conducted in a J33 combustor, which is described in reference 2. The carbon-deposition characteristics were determined by making test runs of 4-hour duration at conditions simulating engine operation at 20,000-foot altitude, 90-percent rated engine speed, and zero ram (combustor inlet-air temperature, 271° F; inlet-air pressure, 53.9 in. Hg abs.; inlet-air flow rate, 2.87 lb/sec; fuel-air ratio, 0.012; combustor temperature rise, 820° to 840° F). The weight of carbon reported herein represents the combined total of liner, dome, ignition-plug and nozzle deposits, determined by weighing the combustor assembly before and after each test run (the combustor components were cleaned prior to each run).

Full-Scale Engine

The carbon-deposition study of a MIL-F-5161 fuel (NACA 50-264) was conducted on a J35-A-15 turbojet engine operating at sea-level, zero-ram conditions. Prior to the beginning of the tests, new combustion chambers and liners were installed in the engine and the fuel nozzles were cleaned. The engine was operated for a total of 25 hours, which 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 and 1200° F turbine-outlet temperature established by use of a variable-area exhaust nozzle). During the rest of each period, the engine was operated at 90-percent rated speed and the corresponding decreased turbine-outlet temperature resulting from the fixed nozzle position that was maintained throughout the period. Following each period of operation, the engine was inoperative for approximately 2 hours during which the lubrication supply was replenished and a perfunctory inspection was made of the engine installation. The combustion chambers were not disturbed during this inspection in order to preserve any carbon deposits.

RESULTS AND DISCUSSION

Single Combustor

The quantities of carbon deposited by the various fuels during 4-hour runs in the single combustor at simulated engine conditions of 20,000-foot altitude, 90-percent rated engine speed, and zero ram are presented in the following table:

NACA fuel	Carbon deposited, grams	
	Individual runs	Average
49-162	15.0, 13.5, 13.9, 13.8	14.1
49-65	16.8, 14.0	15.4
50-264	9.5, 10.1	9.8
50-39	[a]6.0 [a]9.2 [a]7.4	7.5
50-249	8.4, 8.6	8.5
50-250	5.4, 6.0	5.7

[a]Values obtained from 2-hour run multiplied by 2. (See fig. 4, reference 2)

The average values of carbon deposition given in this table are plotted in figure 1 against a function of the volumetric average boiling temperature (arithmetic average of the 10-, 30-, 50-, 70-, and 90-percent A.S.T.M. evaporated temperatures) and hydrogen-carbon weight ratio. The correlation function K was developed in reference 1 and is related to the two fuel properties, volumetric average boiling temperature t, and hydrogen-carbon weight ratio H/C by means of the empirical equation

$$K = (t + 600)(0.7)^{\frac{(H/C) - 0.207}{(H/C) - 0.259}}$$

Numerical values of K for the fuels investigated herein are also given in table I.

The solid curve in the "carbon deposited" side of figure 1 was obtained from figure 6, reference 2, with 4-hour run-time data. The agreement between the data reported herein and the curve of figure 6, reference 2, is satisfactory. Fuels 49-162 and 49-65 (PPF 47-3), which have been reported to be marginal or unsatisfactory with respect to carbon deposition in turbojet engines, have the highest K values and gave the most carbon deposition. The two MIL-F-5161 fuels, 50-264 and 50-39, also rated marginal in regard to carbon deposition have the next highest K values. The two "low-volatility" turbine-engine fuels 50-249 and 50-250 have the lowest K values of the fuels investigated, and fuel 50-250 gave the lowest carbon-deposition values.

In general, the carbon-deposition tendencies of MIL-F-5624 and MIL-F-5161 type fuels in single combustors of turbojet engines can be estimated from the correlation of reference 1. The carbon deposition increased as the K values increased. It is apparent that full-scale-engine experience is required to establish the value of K that would separate fuels tending to give innocuous carbon deposits from fuels tending to give deleterious carbon deposits.

Although no detailed analysis was made of combustor performance, it was observed that combustion efficiency values in excess of 98 percent were obtained with all fuels, and no effect of the carbon deposition on combustion efficiency was indicated.

Full-Scale Engine

The combustion-chamber carbon deposition accumulated during the 25-hour operation of the J35 turbojet engine using 50-264 fuel is presented in the following table:

Combustion chamber	Carbon (grams)
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

The carbon deposits formed at the entrance section of the combustion-chamber liner near the fuel nozzle and extended about one-fourth of the length of the combustion-chamber, as is shown in the photographs of four different liners in figure 2. Although some warping of the combustion-chamber liners occurred, it was not believed to be excessive for this engine considering the duration of operation. No cracks were observed in the combustion-chamber liners.

The carbon deposits included both soot-type deposits and very hard, globule formations. Small conical carbon deposits had begun to form on the engine fuel nozzles, as may be seen in figure 3. A large amount of soot was found in the test-cell sound-muffling chamber and in the area of the muffling-chamber exhaust discharge, which indicates that much of the carbon formed was blown out of the engine in the form of soot. The soot in the exhaust discharge area was considerably in excess of the quantity normally experienced with extended operation of the engine using MIL-F-5624 fuels with relatively low aromatic content (K values of 260 to 280). Determination of whether the engine exhaust gases contained smoke was impossible because of a steam cloud caused by water sprays used to cool the exhaust gases.

Replacement of the filter elements in the engine fuel system after 3 hours of operation was necessary because of the collection of large quantities of fine iron scale and other impurities. The impurities encountered in the fuel were probably from containers and plumbing, inasmuch as only a short time was allowed for such impurities to settle out.

It should be recognized that sea-level, zero-ram conditions present a severe type of operation with regard to carbon deposition, because maximum ambient pressures and fuel flows are encountered at these conditions. Previous investigations (references 1 and 2) demonstrated that fuels deposit less carbon with altitude flight operation than with sea-level operation, and this tendency can be validly assumed for the 50-264 fuel.

Combustion-chamber configuration. - An analysis was not made of the effect of the carbon deposition from fuel 50-264 on engine performance; however, it is believed that operation for an extended duration, perhaps 150 hours, would cause sufficient deposition to present serious combustion problems, such as increased blocking of the primary combustion-air passages and the engine fuel nozzles. Carbon deposition has never been appreciable with the combustion-chamber configuration used in this investigation operating with MIL-F-5624 fuels with K values of 260 to 280. Because severe carbon deposition has been reported in other full-scale engines with different-type combustion-chamber configurations using fuels similar to 50-264 (MIL-F-5161), it is concluded that the increase in the severity of the carbon-deposition problem was caused primarily by changes in fuel characteristics and not by combustion-chamber configuration.

Application of "K" factor correlation. - Several fuels were investigated in a full-scale turbojet engine for their carbon-deposition tendencies and were reported in reference 3. One of the fuels, PPF 47-3 (similar to 49-65), gave sufficient carbon deposits to be detrimental to engine performance. From the analysis of fuel 49-65 given in table I, a "K" value of 345 is obtained. This K value is somewhat greater than the values for MIL-F-5161 fuels that have been reported to give carbon-deposition problems in other full-scale engines.

Fuels 49-162, 49-65, 50-264, and 50-39, all of which have been observed to be marginal or unsatisfactory with respect to carbon deposition in turbojet engines, have K values of 345, 345, 331, and 327, respectively. Fuels with K values of 260 to 305 have operated satisfactorily in full-scale engines with reference to carbon deposition. From the foregoing observations it is suggested that fuels with K values of 310 or less will not give carbon deposition problems in current turbojet engines that have been designed for use with MIL-F-5624 type fuels.

SUMMARY OF RESULTS

The following results were obtained from single-combustor and full-scale-engine studies of carbon-deposition characteristics of MIL-F-5624 and MIL-F-5161 type fuels, and from comparisons of these results with other available full-scale engine operational information:

1. Carbon deposition obtained in the single combustor with MIL-F-5624 and MIL-F-5161 type fuels was correlated by an empirical correlation previously established.

2. The carbon deposition in the full-scale engine when using MIL-F-5161 fuel was greater than the deposition normally obtained with MIL-F-5624 fuels. This trend, also noted in other types of turbojet engine, was concluded to be the result of fuel characteristics rather than combustion-chamber configuration.

3. Both single-combustor and full-scale-engine results indicate that MIL-F-5161 fuels form more carbon than most MIL-F-5624 fuels, as predicted by correlation, and may result in marginal operation in several turbojet engines.

4. Fuels with values of K (from a previously established empirical correlation) of 310 or less will not be carbon-deposition offenders in current turbojet engines that have been designed for use with MIL-F-5624 type fuels.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, February 21, 1951.

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TABLE I - FUEL SPECIFICATIONS AND ANALYSES

	Specifications		Analysis					
			NACA fuel					
	MIL-F-5624	MIL-F-5161	49-162	49-65	50-264	50-39	50-249	50-250
A.S.T.M. distillation D 86-46, (°F)								
Initial boiling point	----------------	95 to 131	109	142	100	102	155	154
Percentage evaporated								
5	----------------	----------------	135	195	120	126	218	217
10	----------------	149 to 203	158	221	152	165	242	247
20	----------------	----------------	210	243	224	221	279	285
30	----------------	----------------	270	258	268	266	303	304
40	----------------	----------------	323	273	301	296	319	319
50	----------------	302 to 356	358	288	330	328	331	333
60	----------------	----------------	398	303	368	368	344	344
70	----------------	----------------	432	318	413	403	359	356
80	----------------	----------------	462	334	444	434	373	373
90	400 (min.)	455 to 545	500	353	477	470	398	403
Final boiling point	600 (max.)	500 to 599	584	401	512	520	486	492
Residue, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.2	1.0	1.2	1.5
Loss, (percent)	1.5 (max.)	1.5 (max.)	1.0	0.5	1.8	1.5	0.5	0.5
Freezing point, (°F)	-76 (max.)	-76 (max.)	< -76	-----	< -76	< -76	-------	-------
Aromatics								
A.S.T.M. D-875-46T (percent by volume)	25 (max.)	20 to 25	25	33	22	23	15	9
Silica gel[a] (percent by volume)	----------------	----------------	31	37	26	29	20	13
Olefins,								
A.S.T.M. D-875-46T (percent by weight)	----------------	----------------	------	39	7	10	13	13
Reid vapor pressure, (lb/sq in.)	5.0 to 7.0	6.0 to 7.0	4.5	-----	6.0	5.9	2.0	2.0
Hydrogen-carbon ratio	----------------	----------------	0.150	0.142	0.153	0.154	0.159	0.164
Heat of combustion, (Btu/lb)	18,400 (min.)	18,400 to 18,600	18,500	18,150[b]	18,460[b]	18,515	18,530[b]	18,620[b]
Specific gravity	0.7275 to 0.8017	0.7275 to 0.8017	0.801	0.800	0.791	0.794	0.787	0.777
Accelerated gum, (mg/100 ml)	20.0 (max.)	20.0 (max.)	16	337	12	55	59	268
Air-jet residue, (mg/100 ml)	10.0 (max.)	10.0 (max.)	8	5	9	22	4	3
Sulfur, (percent by weight)	0.50 (max.)	0.3 to 0.5	------	-----	0.38	------	-------	-------
Aniline point, (°F)	----------------	----------------	------	50.9	108.0	------	117.5	129.6
Bromine number	30.0 (max.)	5.0 to 30.0	12	67	8	11	15	15
NACA K factor[c]	----------------	----------------	345	345	331	327	311	294

[a]Determined by method of reference 4.
[b]Determined by method of reference 5.
[c]Calculated from equation given in reference 1.

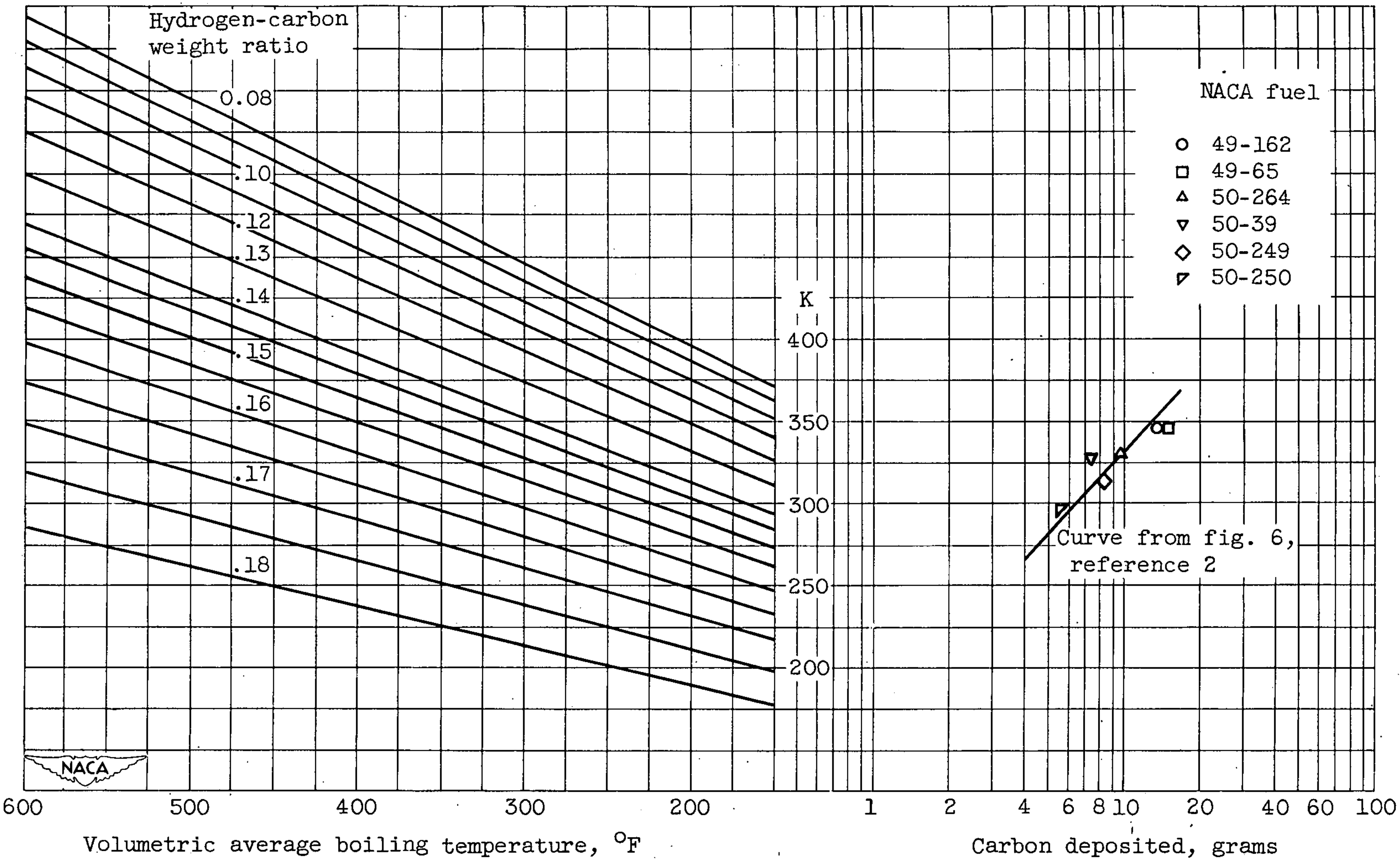

Figure 1. - Carbon deposition of six fuels correlated with volumetric average boiling temperature and hydrogen-carbon weight ratio in a single tubular combustor. Simulated engine conditions: altitude, 20,000 feet; engine speed, 90-percent rated; ram, zero; run time, 4 hours.

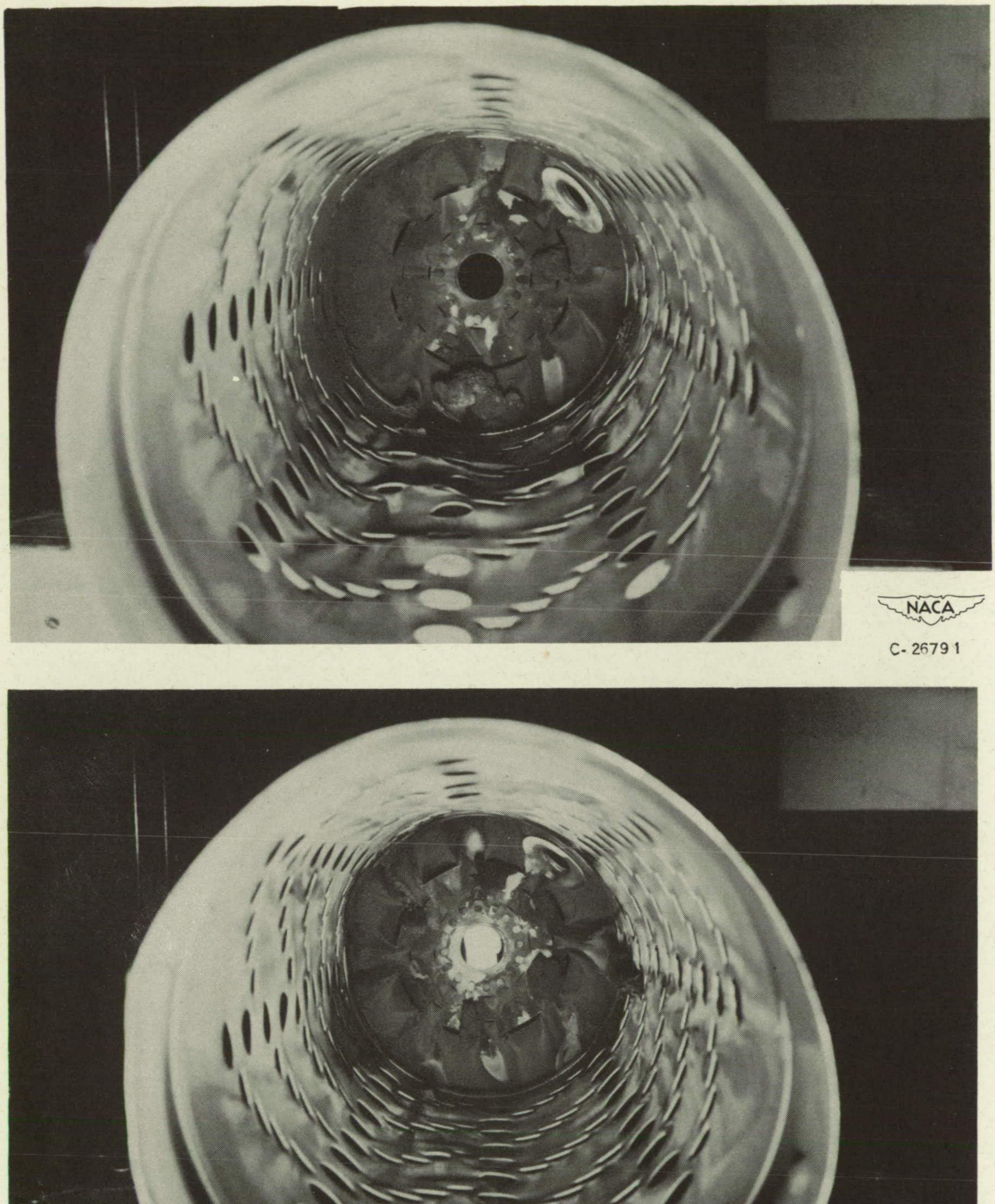

Figure 2. - Four J35 turbojet combustion-chamber liners with carbon deposits formed during operation for 25 hours with MIL-F-5161 fuel.

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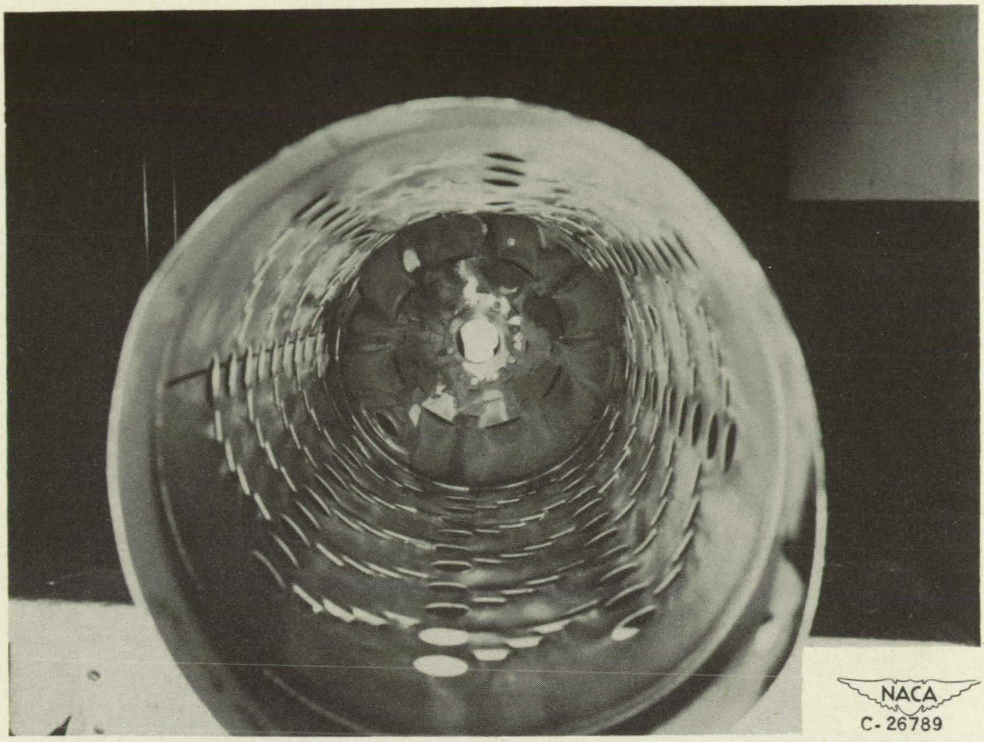

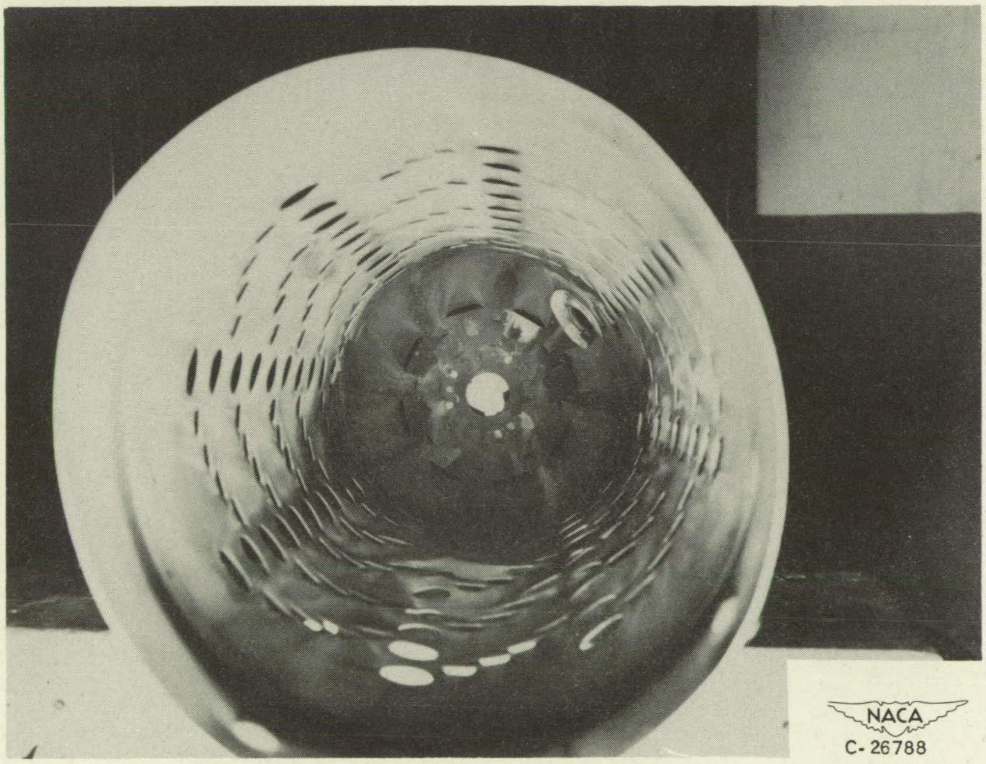

Figure 2. - Concluded. Four J35 turbojet combustion-chamber liners with carbon deposits formed during operation for 25 hours with MIL-F-5161 fuel.

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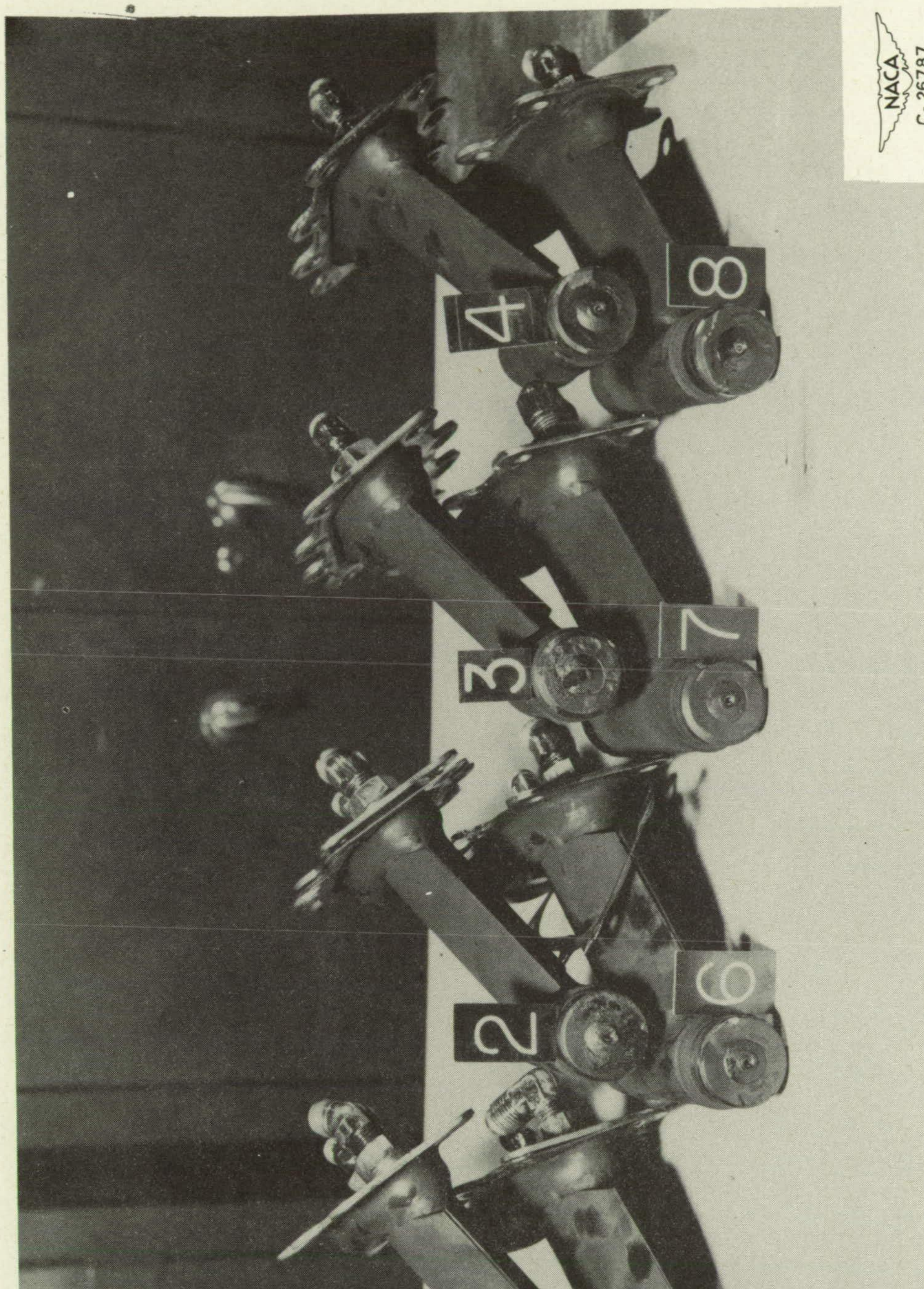

Figure 3. - J35 turbojet-engine fuel nozzles with carbon deposits formed during operation for 25 hours with MIL-F-5161 fuel.