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RESEARCH MEMORANDUM

EFFECT OF FUEL PROPERTIES ON LINER TEMPERATURES IN A SINGLE TUBULAR TURBOJET COMBUSTOR

By Helmut F. Butze

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EFFECT OF FUEL PROPERTIES ON LINER TEMPERATURES IN A SINGLE TUBULAR TURBOJET COMBUSTOR

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SUMMARY

The effect of fuel properties on combustor-liner temperatures was investigated in a single tubular combustor at combustor-inlet conditions representative of those encountered in turbojet-powered high-flight-speed aircraft. Tests were conducted with three liquid jet-type fuels varying in volatility and aromatic content, and with hydrogen. Two liners, one uncoated and the other coated on its inner surface with a corrosion-resisting ceramic (NBS A418), were used in the investigation.

Variations in fuel properties produced only moderate and not always consistent changes in average liner temperatures. A fuel high in aromatic content produced higher average liner temperatures than did a similar fuel containing no aromatics; however, differences did not exceed 160° F. Liner temperatures obtained with hydrogen were not significantly different from those obtained with the liquid fuels. Average liner temperatures obtained with the corrosion-resistant ceramic-coated liner were greater, in all cases, than those obtained with the uncoated liner.

INTRODUCTION

The high combustion-chamber pressures and temperatures encountered in turbojet-powered aircraft flying at supersonic speeds impose severe cooling and, hence, durability problems on the combustor liner (ref. 1). In addition, the use of fuels burning with highly luminous flames may greatly increase the radiant heat-transfer rate from flame to liner and thus aggravate the cooling problem. A brief investigation of the effect of varying the fuel composition and, hence, the flame radiation characteristics on liner temperature in a turbojet combustor was conducted at the NACA Lewis laboratory and is reported herein.

In a turbojet combustor heat is transferred from flame to liner by convection and by radiation. Heat transfer by radiation is primarily a function of the temperatures and emissivities of the flame and the liner and, according to reference 2, may constitute more than half the total heat transfer from flame to liner. Flame temperature depends primarily on operating conditions; flame emissivity varies directly with combustor pressure (ref. 3). In addition, experiments conducted with a laboratory-scale research burner (ref. 4) indicate that the emissivities of flames from aromatic fuels are somewhat higher than those of paraffinic fuels.

The primary purpose of the present investigation was to determine 4447
whether fuel composition, varying within the range normally encountered in jet fuels, has a significant effect on liner wall temperatures in a production-model combustor. In addition, since there is considerable interest in the use of ceramic coatings for corrosion protection and radiation suppression, combustor-liner temperatures were determined both with a plain liner and with a liner whose inner surface was coated with a well-adhering ceramic coating (NBS-A418). Three hydrocarbon jet-type fuels of varying volatility and aromatic content were employed in the investigation. In addition to these fuels, hydrogen was used because of its low flame emissivity. Tests were conducted at combustor-inlet pressures and temperatures representative of (1) a subsonic cruise condition and (2) supersonic (Mach 2) flight of an engine with a compressor pressure ratio of 5 at an altitude of 35,000 feet. In addition to liner temperatures, combustion-efficiency data were recorded.

APPARATUS

Combustor Installation

The combustor installation is shown schematically in figure 1. A production-model J33 inner liner and dome were installed in a high-pressure combustor housing similar in shape to that of a J33 engine, except that circular inlet and exhaust transition sections were used. This combustor assembly was connected to the laboratory 450-pound-per-square-inch air-supply system and to an atmospheric-exhaust muffler.

Flow rates and pressures of the combustion air were regulated by remotely controlled valves upstream and downstream of the combustor. The combustion air was heated to the desired temperature by means of a heat exchanger consisting of a series of coiled Inconel tubes, connected in parallel, through which the high-pressure air flowed. The tubes were heated externally, in crossflow, by combustion gases from an auxiliary turbojet combustor.

Separate fuel systems were used for the liquid fuels and for hydrogen. The liquid fuels were pumped from a tank of 1000-gallon capacity; flow rate was controlled by means of a needle valve located downstream of a high-pressure pump. Hydrogen was supplied from a bank of high-pressure cylinders connected in parallel; its flow rate was controlled by a pressure regulator and by a needle valve. A pressure-atomizing nozzle having a nominal flow capacity of 40 gallons per hour (at a pressure drop of 100 lb/sq in.) and a 70° spray angle was used for the liquid-fuel tests. For the hydrogen tests the swirler was removed from a 3.5-gallon-per-hour nozzle, and six 0.136-inch-diameter holes were drilled at equal circumferential distances in the nozzle tip at an angle of 45° from the axis.

Four water-spray nozzles, located downstream of the exhaust-gas thermocouples and supplied by a high-pressure high-capacity pump, were used to cool the exhaust gases prior to their passage through the exhaust-control valve.

Instrumentation

Airflow rates were measured by a square-edged orifice plate installed according to ASME specifications. Liquid-fuel flow was measured by a calibrated rotameter located upstream of the high-pressure pump, while hydrogen flow rate was determined by means of a suitably sized square-edged ASME orifice. Inlet-air and exhaust-gas temperatures were measured by two enclosed single-junction Chromel-Alumel thermocouples (plane B-B, fig. 1), and by eight two-junction platinum - platinum-rhodium (13 percent) thermocouple rakes (plane C-C, fig. 1), respectively. By means of a suitable switching arrangement, either individual temperatures or an average of all exhaust-gas thermocouples could be obtained. Inlet-air and exhaust-gas total pressures were each measured by four three-point total-pressure probes located at planes A-A and D-D (fig. 1), respectively, and connected to strain-gage pressure pickups. All combustor pressures and temperatures were indicated on automatic balancing potentiometers.

The wall temperatures of the combustor inner liner were determined by means of Chromel-Alumel thermocouples welded, at selected locations, to the outer surface of the liner; the junctions were covered with an insulating ceramic cement in order to minimize heat transfer by convection. A developed view of the liner, showing thermocouple locations and designations, is presented in figure 2(a); a photograph of the liner and dome showing the method of thermocouple installation is presented in figure 2(b).

Liners

Two J33 liners were used: (1) a plain liner and (2) a liner whose inner surface was coated with NBS A418 ceramic coating to a thickness of 1 to 1.5 mils. This ceramic, which is a high-barium enamel with a 30 percent chromium oxide addition, was developed primarily for corrosion resistance.

FUELS

The following fuels were used in the investigation:

(1) A JP-4 fuel containing approximately 10 percent aromatics (NACA fuel 52-288)

(2) A JP-5 fuel containing less than 1 percent aromatics (NACA fuel 56-16)

(3) A JP-5 fuel containing approximately 25 percent aromatics (NACA fuel 56-70)

(4) Hydrogen (approx. 99 mole percent pure)

Chemical and physical properties of the liquid fuels are presented in table I. The JP-4 fuel is representative of current production jet fuel. The JP-5 fuels represent low-volatility jet-type fuels having extreme variations (within current military specifications) in aromatic content. NACA fuel 56-70 was prepared by adding approximately 15 percent α,β-monomethylnaphthalene to a production JP-5 fuel to bring the aromatic content up to 25 percent. Hydrogen was included in the test program for its considerably lower visible flame radiation characteristics.

PROCEDURE

Liner-temperature and combustion-efficiency data were recorded at the nominal combustor-inlet conditions shown in the following table:

Test condition	Inlet-air total pressure, lb/sq in. abs	Inlet-air temperature, °F	Inlet-air reference velocity[a], ft/sec	Combustor temperature rise, °F
1	30	350	111	600
2	30	350	111	1200
3	85	640	150	600
4	85	640	150	1200

[a]Based on max. cross-sectional area of combustor housing (0.267 sq ft) and inlet-air static pressure and temperature.

These conditions simulate approximately the operation of a turbojet engine with a compressor pressure ratio of 5 at an altitude of 35,000 feet at flight Mach numbers of 0.9 (conditions 1 and 2) and 2.0 (conditions 3 and 4).

Combustion efficiency, which is defined as the ratio of the actual enthalpy rise across the combustor to the total enthalpy supplied by the fuel, was computed by the method of reference 5. Enthalpy values for hydrogen were obtained from reference 6. Temperatures were taken as
4447 total temperatures, and no corrections were made for conduction and radiation errors.

RESULTS

Liner temperatures and other combustor data obtained during this investigation are presented in table II. Large differences in temperature existed on the various parts of the liner. The observed temperatures show a random variation in both axial and circumferential directions. A typical distribution (run 19, table II) is presented in figure 3, where liner temperatures are shown on a developed view of the combustor liner. Wall temperatures, in this example, varied from 1600° to 885° F. The highest temperatures were observed in the upstream half of the liner. Figure 3 also indicates that the cooling-air louvers were effective only for a short distance axially; thus, the liner temperature immediately downstream of the louver had decreased from 1600° to 885° F, while only a few inches downstream from that point a liner temperature of 1195° F was observed.

Because of the mild operating conditions, combustion-efficiency values (table II) were generally near 100 percent and did not reflect any differences among the fuels tested. The fact that combustion-efficiency values slightly above 100 percent were obtained in many cases is believed to be due principally to errors in average exhaust-gas temperature measurements caused by an insufficient number of thermocouples. However, thermocouple errors and lack of mass weighting of temperatures also could contribute to the error.

Thermocouples in Line with Louvers

Temperatures of the plain and ceramic-coated liners are shown in figures 4 and 5, respectively, as a function of axial distance from the fuel nozzle for thermocouple locations in line with cooling-air louvers (thermocouples 1, 2, 4, 5, 6, and 7, fig. 2(a)) and for the four different fuels. The temperatures immediately downstream of the second louver (thermocouple 3, fig. 2(a)) are not included in this plot, because this particular thermocouple, unlike the others, is effectively cooled by an air-entry louver. The data show no consistent trend among the fuels. The order of the fuels was different not only at the different operating conditions, but also at the different positions along the length of the liner. However, at all but one operating condition the temperatures obtained with the high-aromatic JP-5 fuel (56-70) tended to be somewhat higher than those obtained with the other fuels.

Thermocouples between Circular Air-Entry Holes

The effect of fuel type on liner temperatures for thermocouple lo- 4447
cations between the circular air-entry holes (thermocouples 8, 9, 10, and 11, fig. 2(a)) is shown in figures 6 and 7 for the uncoated and ceramic-coated liners, respectively. No consistent trends can be observed among the different fuels, although again the high-aromatic JP-5 fuel (56-70) tended to produce somewhat higher liner temperatures than the other liquid fuels. Liner temperatures obtained with hydrogen were even more inconsistent than those obtained with the liquid fuels. For any given fuel, liner temperatures between air-entry holes generally showed greater variation with axial distance than the temperatures in line with louvers.

Dome Temperatures

Dome temperatures (thermocouple 16, fig. 2(a)) obtained with the four different fuels at the various operating conditions are shown in figure 8 for both the uncoated and the ceramic-coated liners. For the liquid fuels, fuel type seemed to have no significant effect on dome temperatures. The lowest temperatures were observed at the high-temperature-rise conditions. The largest effect of fuel properties was noted for the 1200° F temperature rise, where dome temperatures observed with hydrogen were appreciably higher than those obtained with the liquid fuels; this effect was especially pronounced with the ceramic-coated liner.

DISCUSSION

Effect of Fuel Properties

Because of the large variations in trends observed, it is almost impossible to rate the fuels on the basis of the individual liner temperature patterns presented in figures 4 to 7. In addition, individual temperatures generally could not be reproduced very accurately. Although no reproducibility tests as such were conducted, it was observed that individual temperatures varied with time even after burning had been stabilized and that, on repeat runs, variations as great as ±100° F were encountered. Therefore, an over-all comparison was attempted by simply averaging all measured temperatures for each test run. These average liner temperatures are presented in figure 9. The degree of reproducibility was such that differences in average temperatures less than 50° F are not considered significant.

Noticeable differences in average temperatures existed among the fuels (fig. 9); however, no one fuel consistently rated higher or lower than the others. The comparisons are complicated by the fact that the fuels differed not only in composition but also in volatility. Changes
4447 in volatility can affect markedly the fuel-spray patterns, the penetration of the fuel, and wall wetting (ref. 7). Probably the most accurate comparison would be between the two JP-5 fuels (56-16 and 56-70), which differed only in aromatic content. The high-aromatic fuel (56-70) consistently produced higher average liner temperatures than fuel 56-16; differences in temperature as much as 160° F were observed. This trend is in agreement with the concept that aromatic fuels burn with greater luminosity and, hence, should have higher flame emissivities with resultant higher liner temperatures.

A comparison of the hydrogen and liquid-fuel data shows no significant differences in average liner temperatures between the two classes of fuels. Hydrogen was used in this study because of the low emissivity of the hydrogen flame, but its radiation may not be completely negligible. The emissivity of the hot water vapor from the hydrogen-air flame at the highest pressure and temperature-rise conditions is estimated to be about 0.10 as compared with an emissivity of 0.15 for the products from a nonluminous hydrocarbon-air flame (ref. 7). Exact calculations are impossible because of the varying temperature and composition throughout the combustor. At the conditions used in this study, all the hydrocarbon flames were probably luminous, and emissivities of the order of 0.5 to 1.0 might be expected. Therefore, the radiant heat transfer from the jet-type fuels should be considerably greater than that from hydrogen. The fact that there was little difference in average liner temperatures between the two classes of fuels might be attributed to increased convective heat transfer with hydrogen, since the hydrogen flame, because of its greater reactivity, might be expected to extend closer to the combustor walls than the liquid fuel flame.

Despite the fact that no consistent differences were found between the over-all average liner temperatures for the liquid and the gaseous fuels, dome temperatures obtained with hydrogen (fig. 8) at the high temperature-rise conditions were considerably higher than those obtained with the liquid fuels. The higher dome temperatures observed with hydrogen may be the result of changes in flame seating or the lack of fuel-cooling of the dome. The wider flammability limits of hydrogen fuel would be expected to result in more intense combustion in the very rich fuel-air mixtures in the extreme upstream end of the combustor. Also, with liquid fuels, the considerable amount of fuel spray that impinges on the walls in the upstream end of the combustor (ref. 8) would cool these walls. Further evidence of the effect of fuel-cooling can be found in the fact that, for the liquid fuels, the lowest dome temperatures were obtained at the high-temperature-rise or high-fuel-flow conditions.

Effect of Ceramic Coating

The effect of the ceramic coating can best be observed in figure 9, where the average liner temperatures of the plain and the ceramic-coated liners are compared. In all cases the average temperatures of the ceramic-coated liner were higher than those of the uncoated liner, with differences in average temperature ranging from 10° F to approximately 300° F. The particular ceramic coating used is primarily a corrosion-resistant coating and according to reference 9 has a total emissivity between 0.85 and 0.95, which is somewhat greater than the emissivity of the uncoated Inconel (between 0.6 and 0.85). Thus, somewhat higher liner temperatures might be expected in a liner coated with this particular ceramic. However, since the same trend was also observed with hydrogen where the effect of radiant heat transfer should be considerably smaller, it is possible that changes in convective heat transfer, resulting from slight changes in the shape or surface condition of the liners, might have contributed to the higher temperatures observed with the ceramic-coated liner.

Additional evidence of the higher liner temperatures obtained with the ceramic-coated liner was found in the condition of the two liners at the end of the test program. The uncoated liner was in good condition and showed very little distortion, whereas the ceramic-coated liner had warped appreciably and was considered unfit for further tests at the end of the test program. However, the coating itself was still in good condition and showed little evidence of spalling.

Effect of Operating Conditions

The data presented in figure 9 show that average liner temperatures generally increased with increasing fuel-air ratio and with increasing combustor-inlet pressure, temperature, and velocity. The trends were similar for both the plain and the ceramic-coated liner and are essentially consistent with previous experience (ref. 1).

SUMMARY OF RESULTS

From an investigation of the effect of fuel properties on combustor-liner temperatures in a single J33 combustor, the following results were obtained:

1. Variations in fuel properties produced only moderate and not always consistent changes in average liner temperatures.

2. A fuel high in aromatic content (JP-5, 56-70) produced higher average liner temperatures than did a similar fuel containing no aromatics (JP-5, 56-16); however, differences in temperature did not exceed 160° F.

3. Liner temperatures observed with hydrogen were not significantly different from those observed with the liquid fuels.

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4. Average temperatures obtained with a liner coated with a corrosion-resistant coating (NBS A418) were higher, under all conditions, than those obtained with an uncoated liner.

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National Advisory Committee for Aeronautics
Cleveland, Ohio, March 6, 1957

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TABLE I. - PHYSICAL PROPERTIES OF LIQUID FUELS

Fuel properties	JP-4 (NACA fuel 52-288)	Low-aromatic JP-5 (NACA fuel 56-16)	High-aromatic JP-5 (NACA fuel 56-70)
ASTM distillation, D86-46, °F:			
Initial boiling point	144	376	356
Percent evaporated			
5	198	394	380
10	243	400	391
20	287	410	403
30	308	416	413
40	322	422	423
50	334	428	431
60	347	434	440
70	361	440	446
80	379	447	453
90	411	458	467
Final boiling point	484	486	500
Residue, percent	1.0	0.5	1.0
Loss, percent	1.0	0	0.5
Aromatics, percent by volume (silica gel)	10.8	0.9	25.6
Specific gravity	0.778	0.793	0.841
Hydrogen-carbon ratio	0.167	0.165	0.155
Net heat of combustion, Btu/lb	18,675	18,800	18,450
Smoke volatility index	65.2	43.7	22.1
Smoke point, mm	28.8	39.5	15.0

TABLE II. - COMBUSTOR PERFORMANCE AND LINER TEMPERATURE DATA

Run	Fuel	Combustor-inlet total pressure, lb/sq in. abs	Combustor-inlet temperature, °F	Air flow, lb/sec	Combustor-inlet reference velocity, ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Mean combustor-outlet temperature, °F	Combustion efficiency, percent	Differential pressure across combustor, lb/sq in.	Liner temperature, °F, at thermocouple (fig. 2(a)) -															
											1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Plain liner																										
1	52-288	29.9	354	3.05	115	88	0.0080	960	105.1	1.6	780	705	480	660	670	730	775	835	895	650	595	700	765	660	730	550
2		29.9	343	3.08	114	182	.0164	1555	108.4	1.8	500	615	450	635	750	850	955	575	885	730	710	770	685	625	835	450
3		84.7	648	8.51	156	264	.0085	1245	101.9	6.2	1275	1280	870	1185	1210	1110	1150	1380	1310	915	980	1105	1175	----	1210	895
4		84.7	649	8.51	158	538	.0174	1845	105.6	7.0	1415	1490	950	1420	1215	1530	----	1395	1305	1010	1165	1255	920	----	1430	745
5	58-70	30.0	358	3.14	119	89	0.0079	950	105.5	1.7	835	835	585	740	770	750	800	935	940	1030	700	805	860	725	860	525
6		30.0	348	3.15	117	186	.0165	1560	109.2	1.8	495	640	500	650	855	925	1075	565	715	1085	805	815	650	620	925	405
7		84.8	644	8.57	155	274	.0088	1248	99.6	6.4	1375	1375	955	1210	1215	1090	1055	1475	1700	1300	915	1165	1180	1025	----	1055
8		84.8	645	8.57	156	555	.0180	1850	104.0	7.2	1440	1620	1040	1585	----	1280	1540	----	----	1310	----	1405	----	1160	----	755
9	56-16	29.8	345	3.10	116	91	0.0082	950	102.2	1.6	685	720	455	620	750	----	690	780	580	595	505	695	770	545	650	430
10		29.8	350	3.14	118	185	.0162	1650	107.8	1.9	570	765	470	720	945	----	945	820	800	980	690	670	860	660	795	440
11		84.6	655	8.58	157	262	.0085	1240	98.6	6.3	1140	1145	815	1000	1130	----	1045	1260	1015	1010	865	1180	1185	970	1220	900
12		84.6	650	8.49	154	547	.0179	1870	104.1	7.1	1250	1360	880	1220	1430	----	1120	1580	1165	1280	1015	1090	1420	1200	1410	725
13	H_2	29.9	360	3.16	118	52.4	0.00287	965	107.7	1.7	820	850	500	725	770	700	695	755	860	415	535	690	410	515	785	580
14		29.9	350	3.15	117	68.7	.00610	1555	108.2	2.0	1085	1120	610	940	1015	1020	985	1240	925	460	720	905	510	590	920	590
15		84.7	640	8.65	158	98.9	.00311	1245	103.0	6.4	1060	1170	770	1065	1110	990	1015	1035	1000	680	800	970	790	775	1020	965
16		84.3	643	8.62	158	201.4	.00649	1845	104.7	7.4	1200	1550	1090	1305	1595	1285	1445	1490	1245	770	905	1250	735	810	1385	960
Ceramic-coated liner																										
17	52-288	29.9	351	3.07	116	86	0.0078	950	108.7	1.8	915	880	480	650	705	825	835	855	890	665	870	825	665	740	935	560
18		29.9	354	3.11	117	185	.0164	1560	107.3	2.1	920	1155	550	845	990	905	995	700	1000	1000	945	945	950	1050	1120	475
19		84.7	642	8.58	154	257	.0083	1240	104.1	6.8	1520	1600	885	1195	1215	1085	1050	1175	1185	1180	1140	1315	1150	1365	1310	925
20		84.7	645	8.57	155	530	.0172	1850	107.5	7.7	1450	1670	910	1360	1440	1325	1570	1265	1310	1395	1365	1420	1310	1500	1410	795
21	58-70	30.0	359	3.12	118	89	0.0079	950	104.7	1.8	1280	1170	585	840	685	770	765	850	865	810	800	880	935	1000	675	485
22		30.0	351	3.12	117	186	.0168	1560	107.2	2.1	1020	1385	640	1025	1135	1015	1120	1015	1190	1110	1070	965	1065	1270	1240	450
23		84.8	638	8.82	155	288	.0086	1230	101.4	7.1	1500	1640	920	1300	1240	1080	1085	1140	1135	1085	1010	1560	1160	1380	1430	1040
24		84.8	659	8.56	157	551	.0179	1850	103.5	7.8	1690	1780	975	1510	1510	1265	1325	1510	1465	1460	1535	1590	1370	1620	1630	880
25	58-16	30.1	365	3.10	118	86	0.0077	960	106.8	1.8	1060	990	530	745	805	700	735	----	865	755	755	780	785	860	700	600
26		30.1	355	3.09	116	180	.0162	1550	107.7	2.0	1080	1295	605	955	1080	940	1050	----	1140	1010	965	880	970	1130	760	490
27		85.3	645	8.60	154	262	.0085	1240	101.6	7.0	1510	1430	865	1200	1205	1095	1090	----	1160	1056	1100	1310	1140	1300	1390	1065
28		84.9	642	8.80	155	544	.0176	1850	104.7	7.8	1250	1520	865	1360	1430	1340	1435	----	1325	1400	1320	1355	1280	1445	1440	785
29	H_2	29.9	365	3.14	120	31.7	0.00280	955	106.1	1.8	925	910	450	560	580	----	550	590	740	785	845	670	485	----	1300	585
30		29.9	360	3.14	118	70.0	.00619	1555	104.8	2.2	1240	1285	590	820	865	----	1065	1025	1200	1195	1280	1085	725	----	1460	1195
31		84.7	640	8.61	155	97.0	.00513	1240	101.5	6.7	1270	1575	750	900	915	----	905	890	1070	1160	1180	1040	815	----	1505	970
32		84.7	636	8.62	155	207.2	.00668	1840	102.0	8.0	1635	1785	845	1110	1120	----	1170	1175	1510	1510	1590	1360	910	----	1720	1390

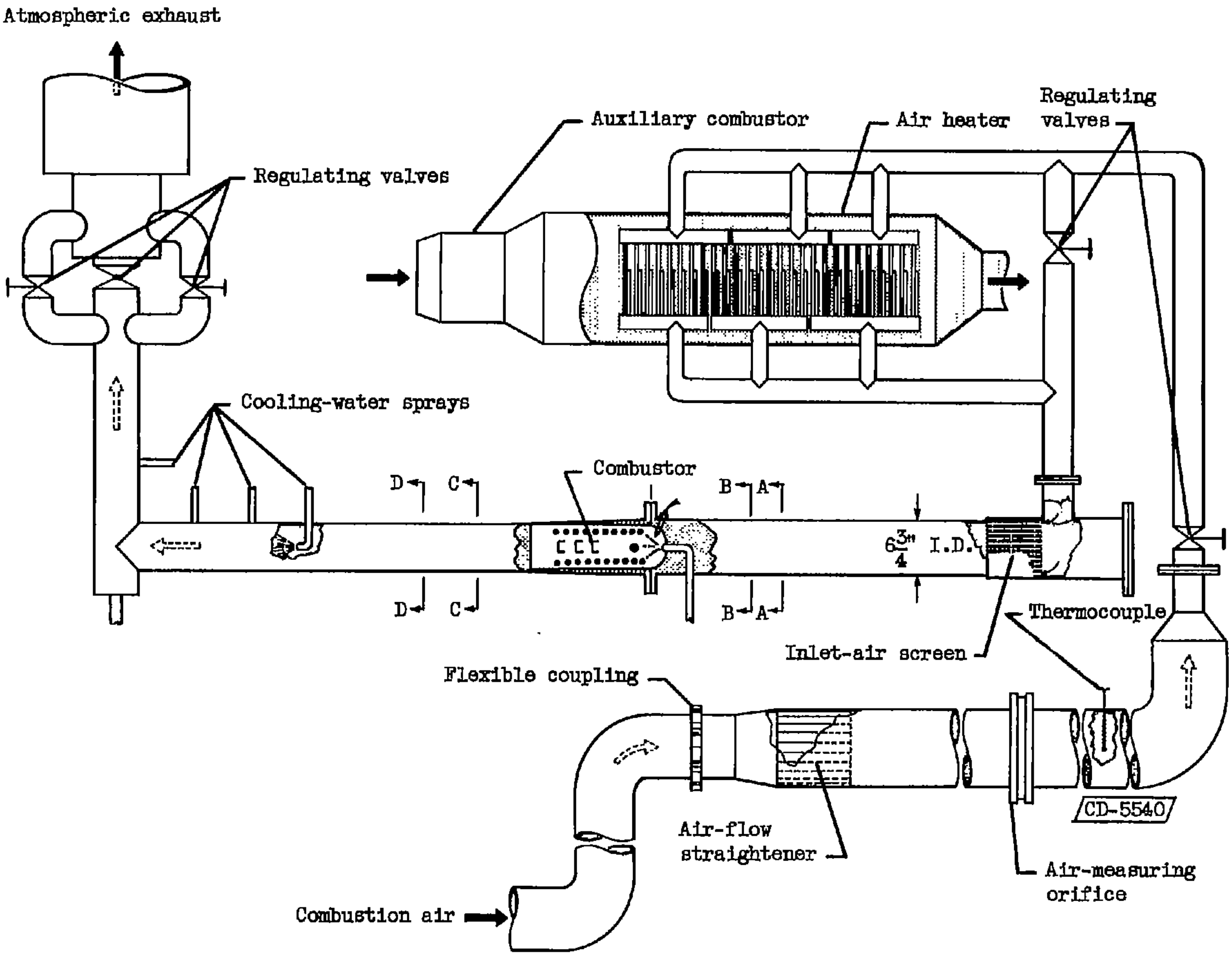
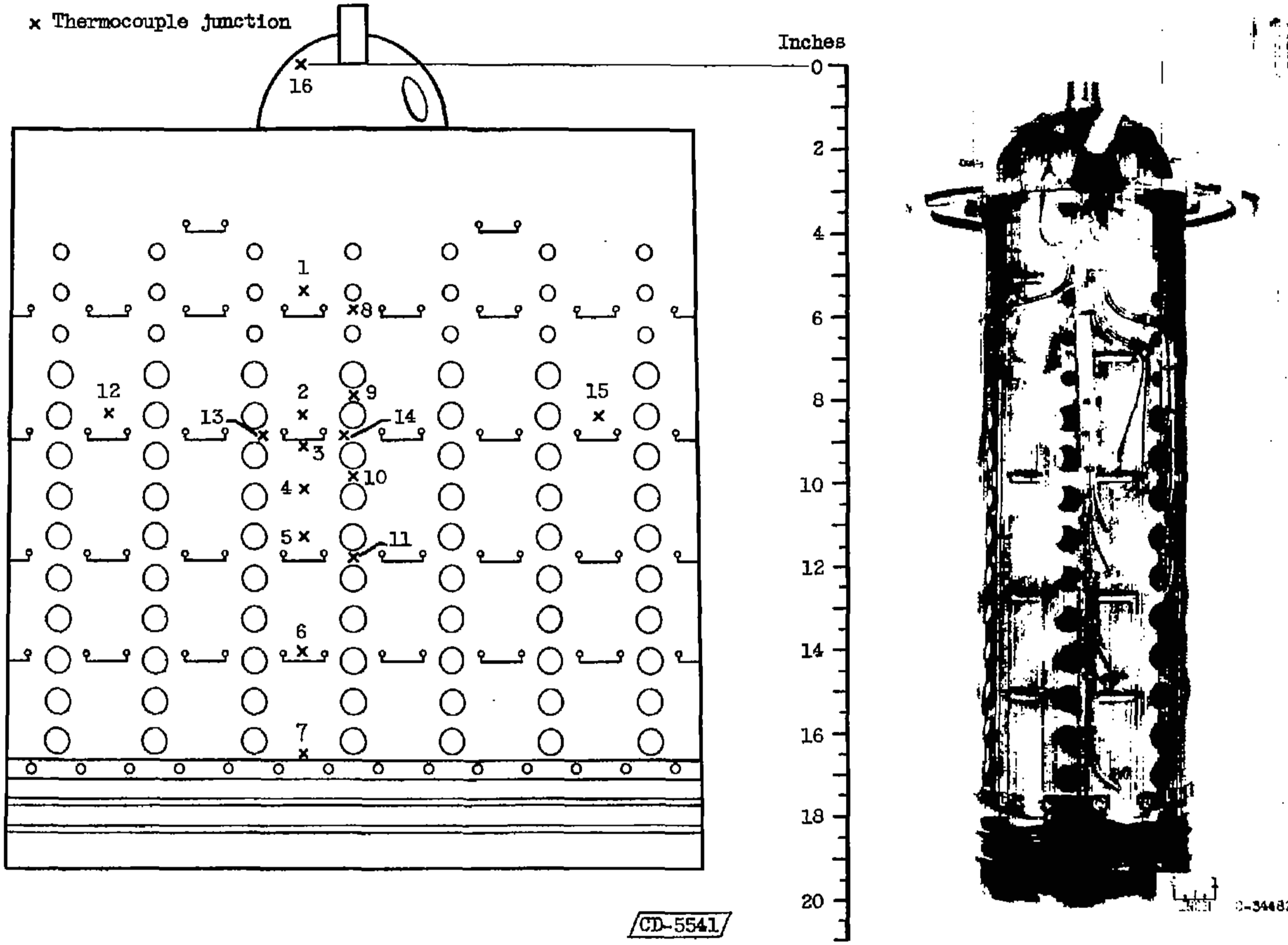


Figure 1. - Single-combustor installation and auxiliary equipment.



(a) Developed view of liner.

(b) Liner and dome.

Figure 2. - Views of combustor liner showing thermocouple locations, designations, and method of installation.

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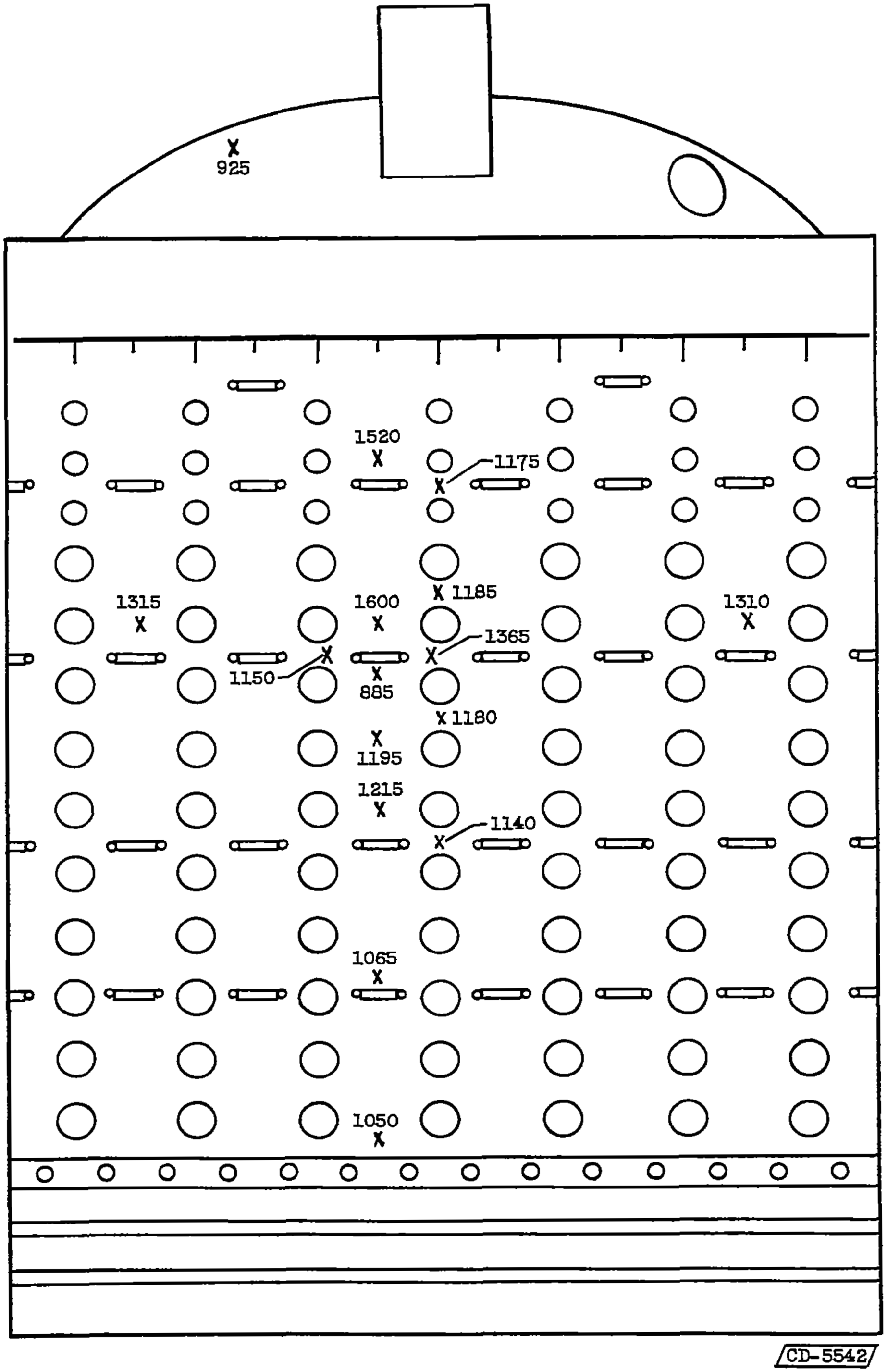

Figure 3. - Typical distribution of liner temperatures on ceramic-coated liner. Combustor-inlet total pressure, 85 pounds per square inch absolute; temperature, 640° F; reference velocity, 150 feet per second; temperature rise, 600° F. Fuel, NACA 52-288.

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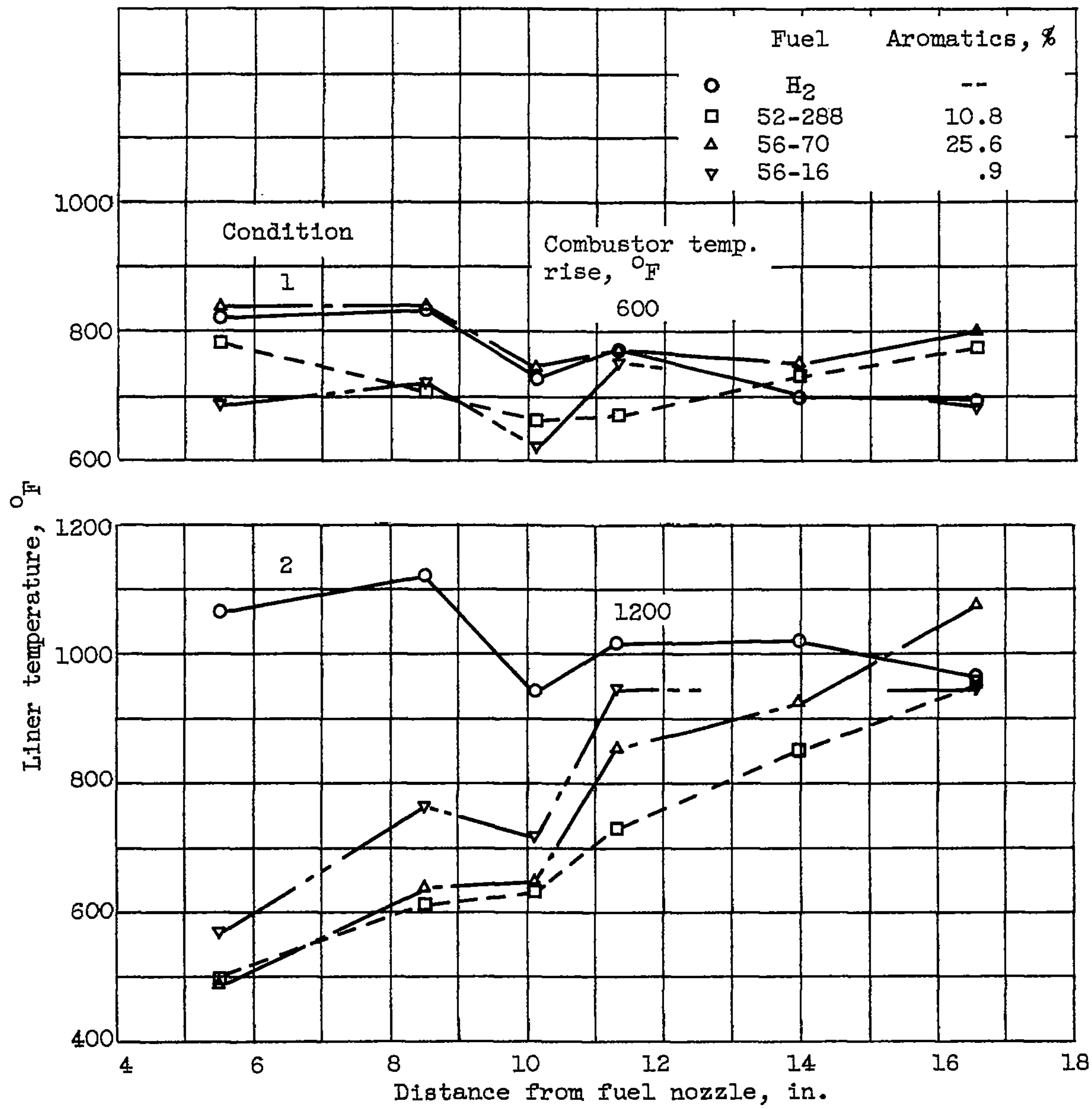

(a) Inlet-air total pressure, 30 pounds per square inch absolute; inlet-air temperature, 350° F; inlet-air reference velocity, 111 feet per second.

Figure 4. - Effect of fuel characteristics on temperatures of uncoated liner in single tubular turbojet combustor. Thermocouples in line with louvers.

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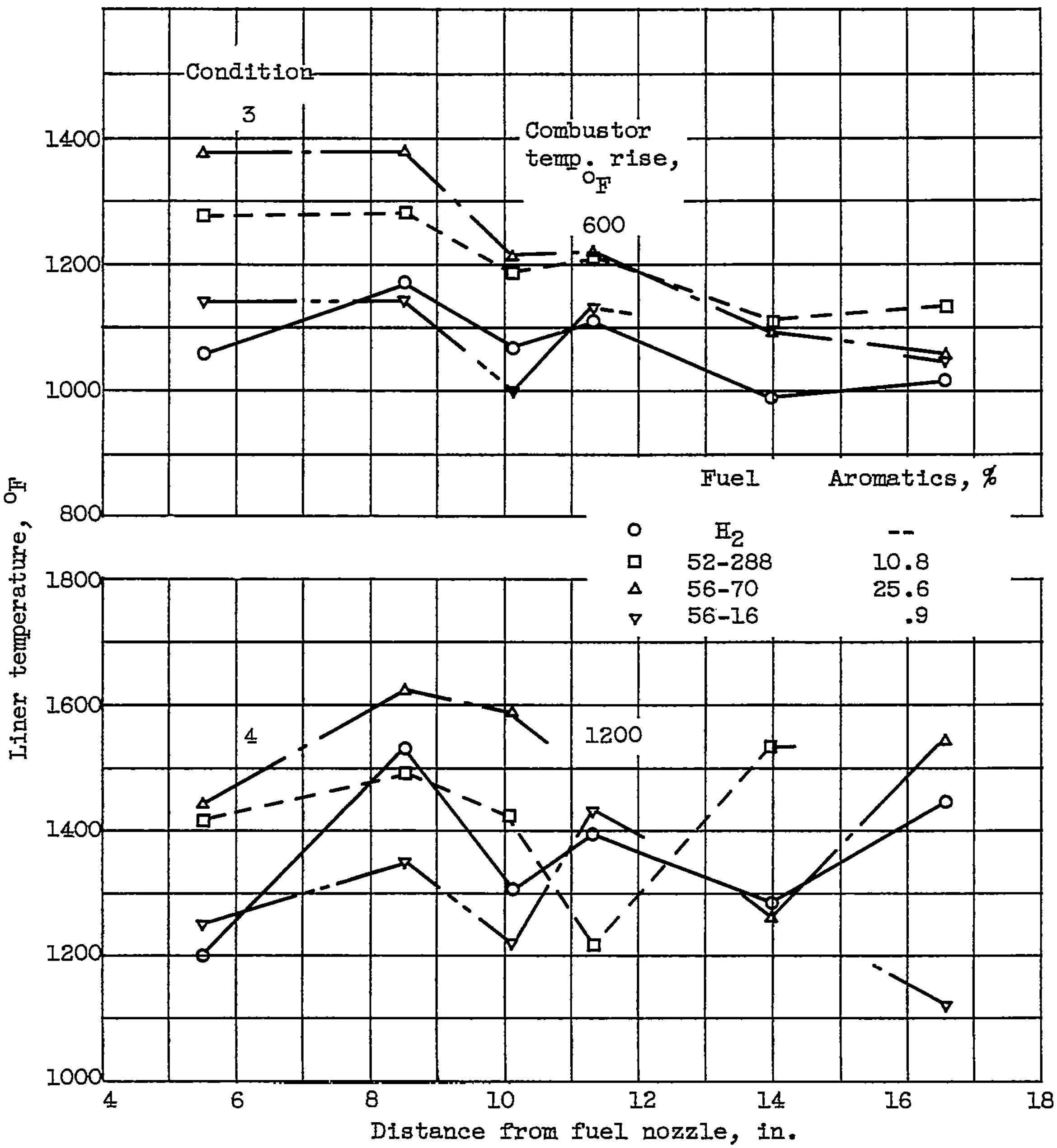
CF-3



(b) Inlet-air total pressure, 85 pounds per square inch absolute; inlet-air temperature, 640° F; inlet-air reference velocity, 150 feet per second.

Figure 4. - Concluded. Effect of fuel characteristics on temperatures of uncoated liner in single tubular turbojet combustor. Thermocouples in line with louvers.

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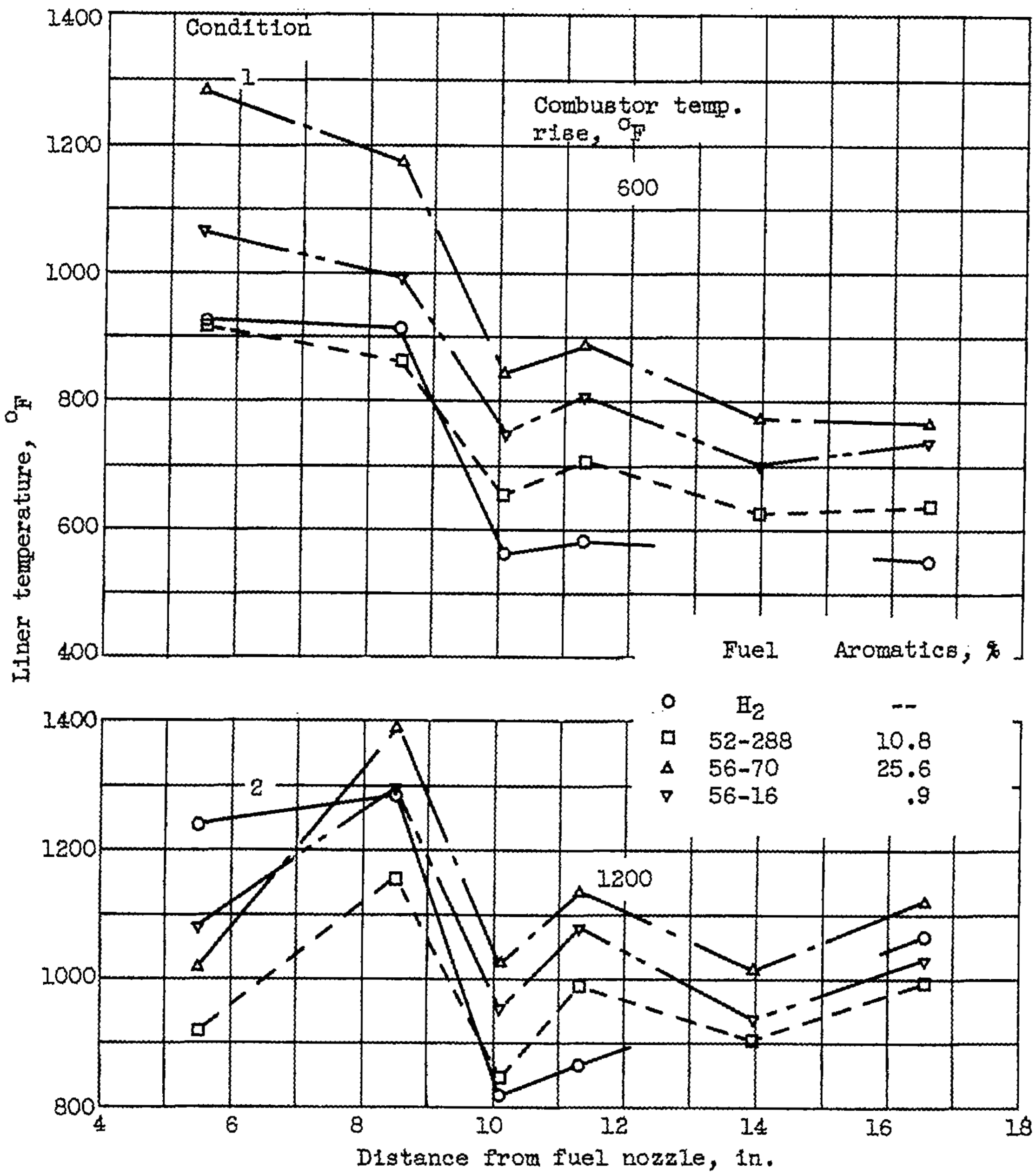

(a) Inlet-air total pressure, 30 pounds per square inch absolute; inlet-air temperature, 350° F; inlet-air reference velocity, 111 feet per second.

Figure 5. - Effect of fuel characteristics on temperatures of ceramic-coated liner in single tubular turbojet combustor. Thermocouples in line with louvers.

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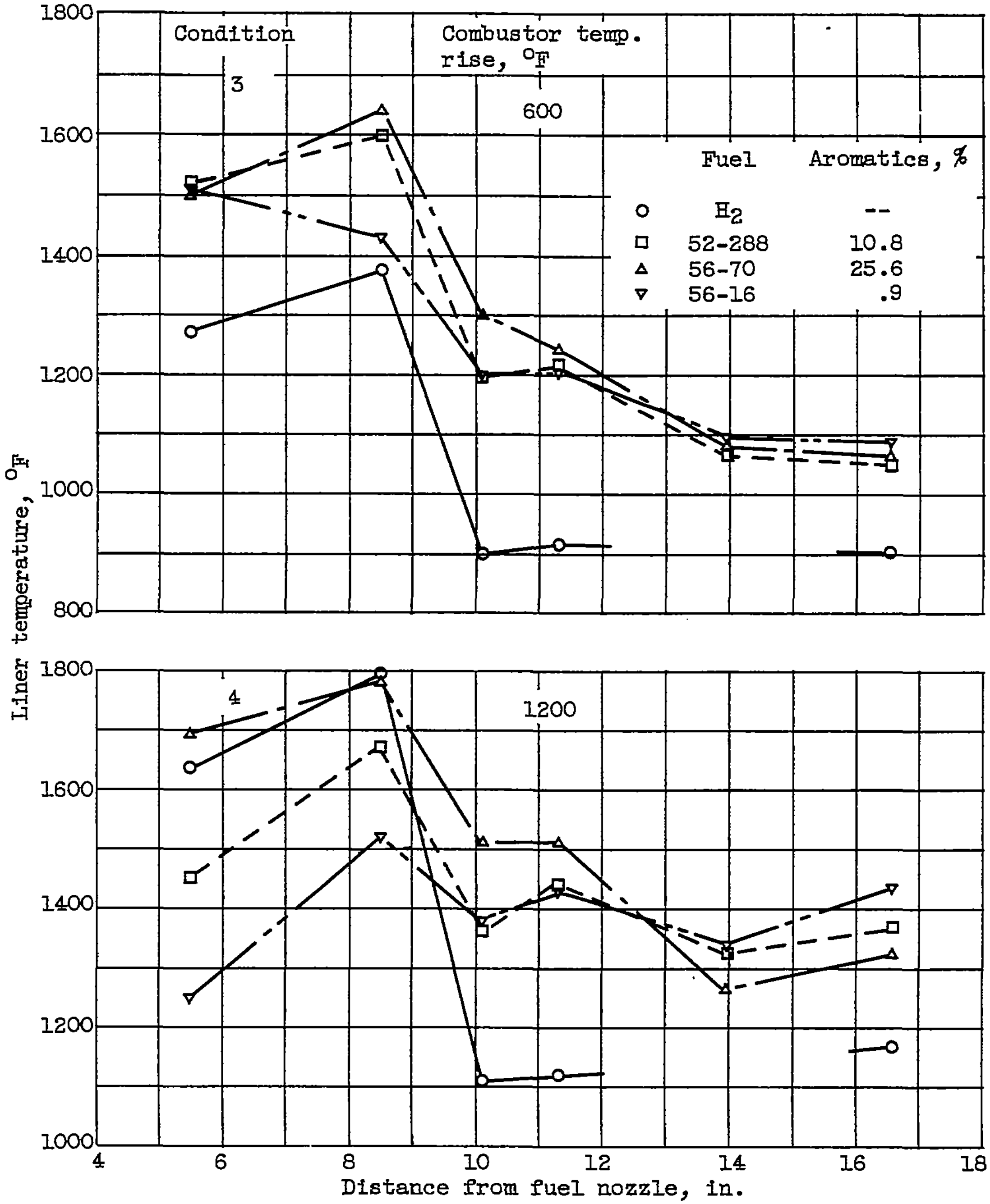
CF-3 back



(b) Inlet-air total pressure, 85 pounds per square inch absolute; inlet-air temperature, 640° F; inlet-air reference velocity, 150 feet per second.

Figure 5. - Concluded. Effect of fuel characteristics on temperatures of ceramic-coated liner in single tubular turbojet combustor. Thermocouples in line with louvers.

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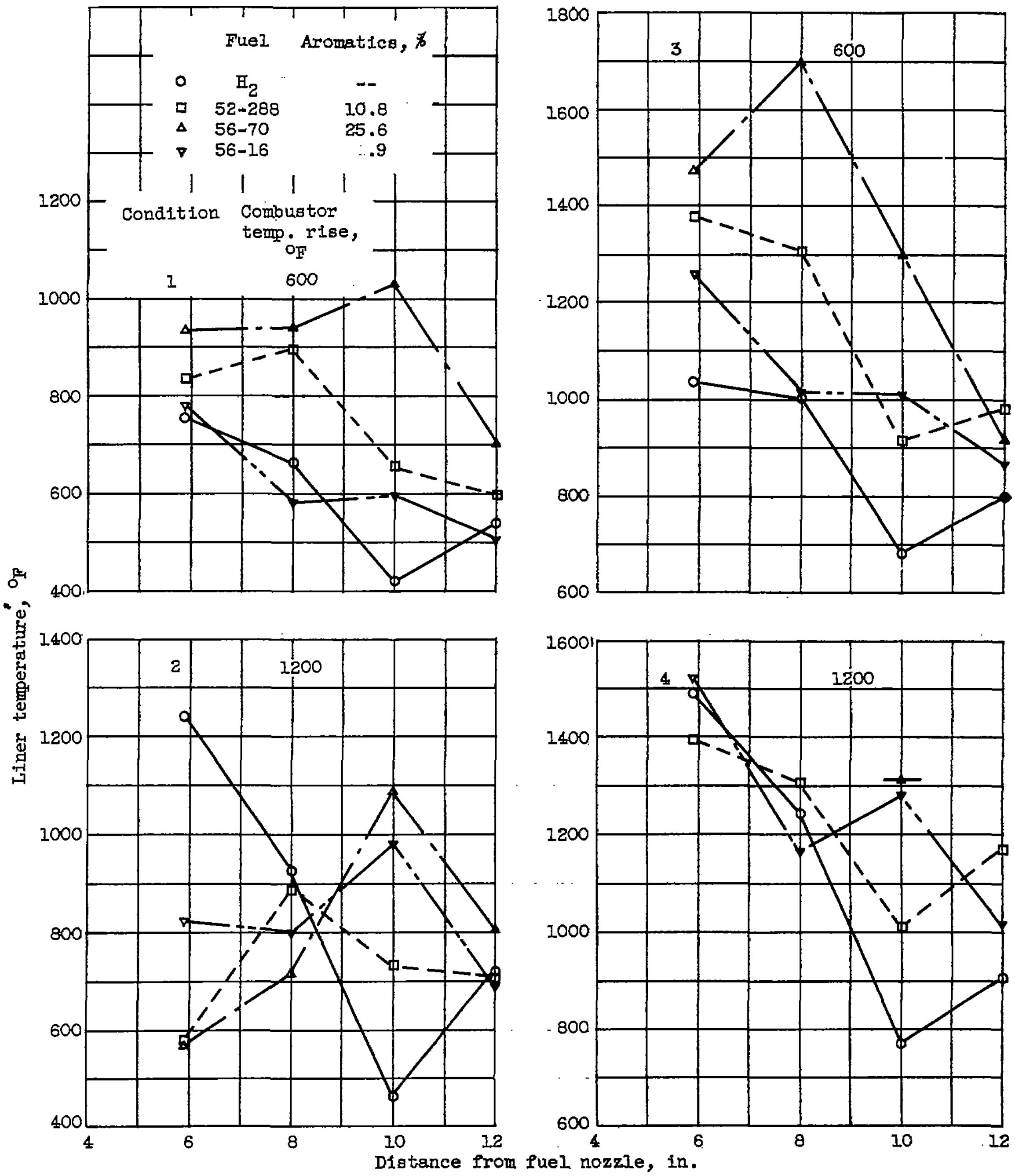

(a) Inlet-air total pressure, 30 pounds per square inch absolute; inlet-air temperature, 350° F; inlet-air reference velocity, 111 feet per second.

(b) Inlet-air total pressure, 85 pounds per square inch absolute; inlet-air temperature, 640° F; inlet-air reference velocity, 150 feet per second.

Figure 6. - Effect of fuel characteristics on temperatures of uncoated liner in single tubular turbojet combustor. Thermocouples between air-entry holes.

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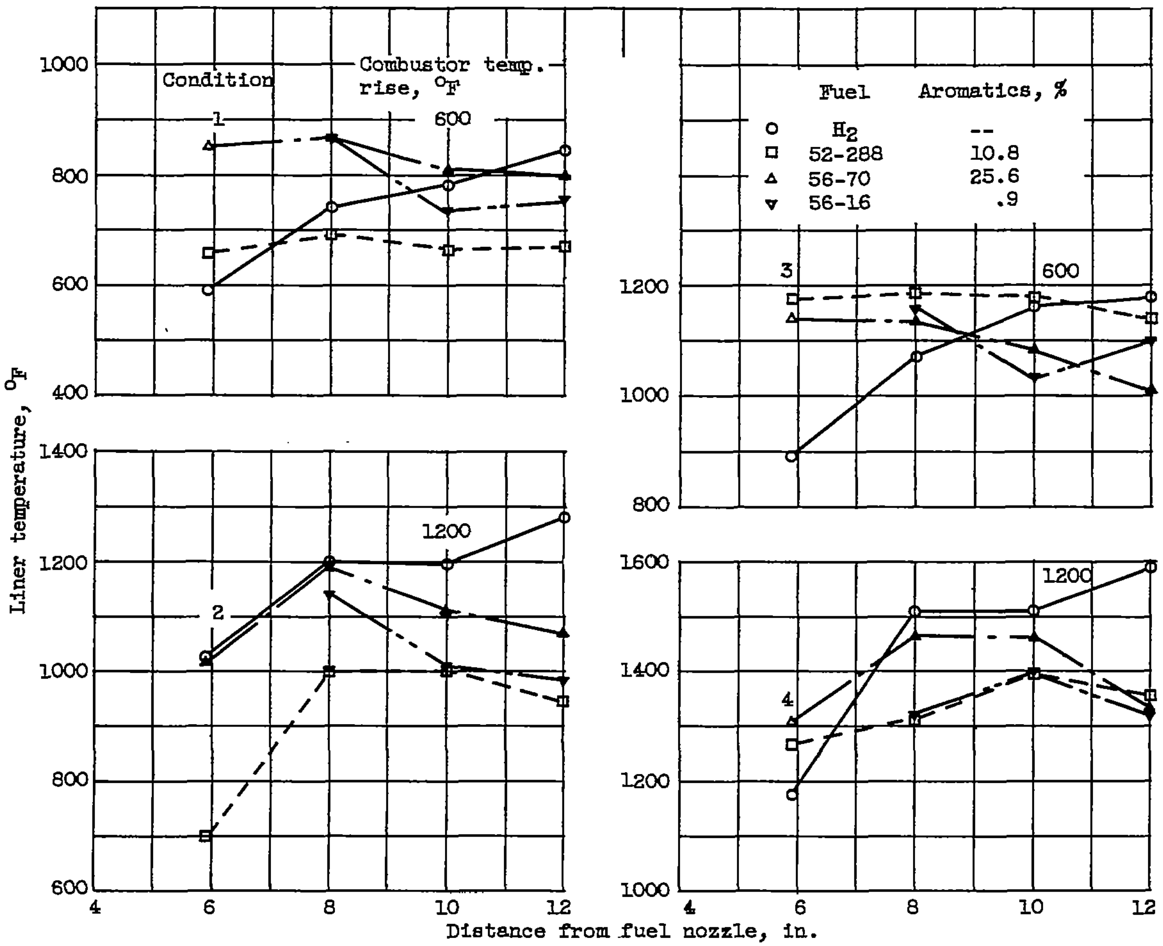
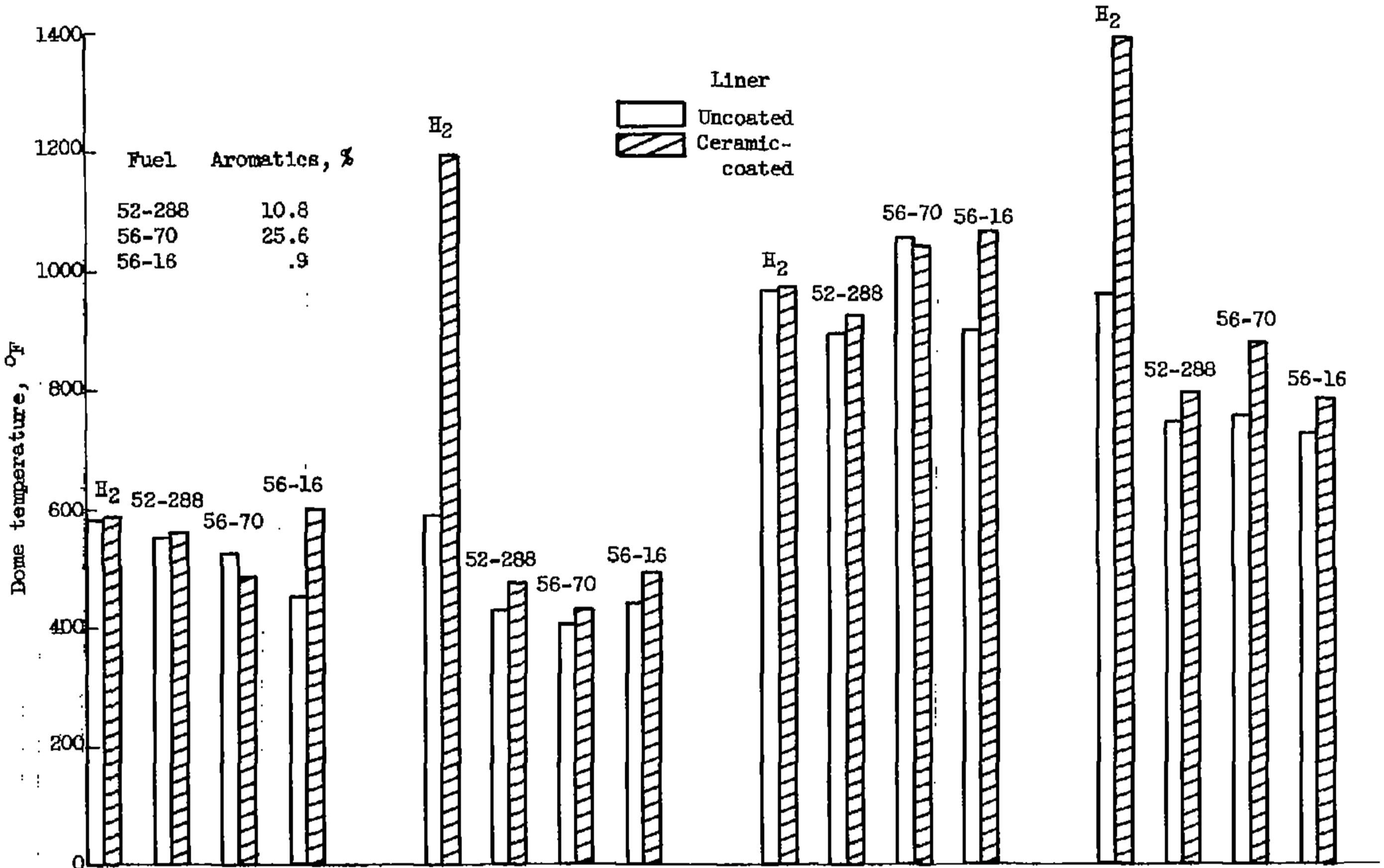


(a) Inlet-air total pressure, 30 pounds per square inch absolute; inlet-air temperature, 350° F; inlet-air reference velocity, 111 feet per second.

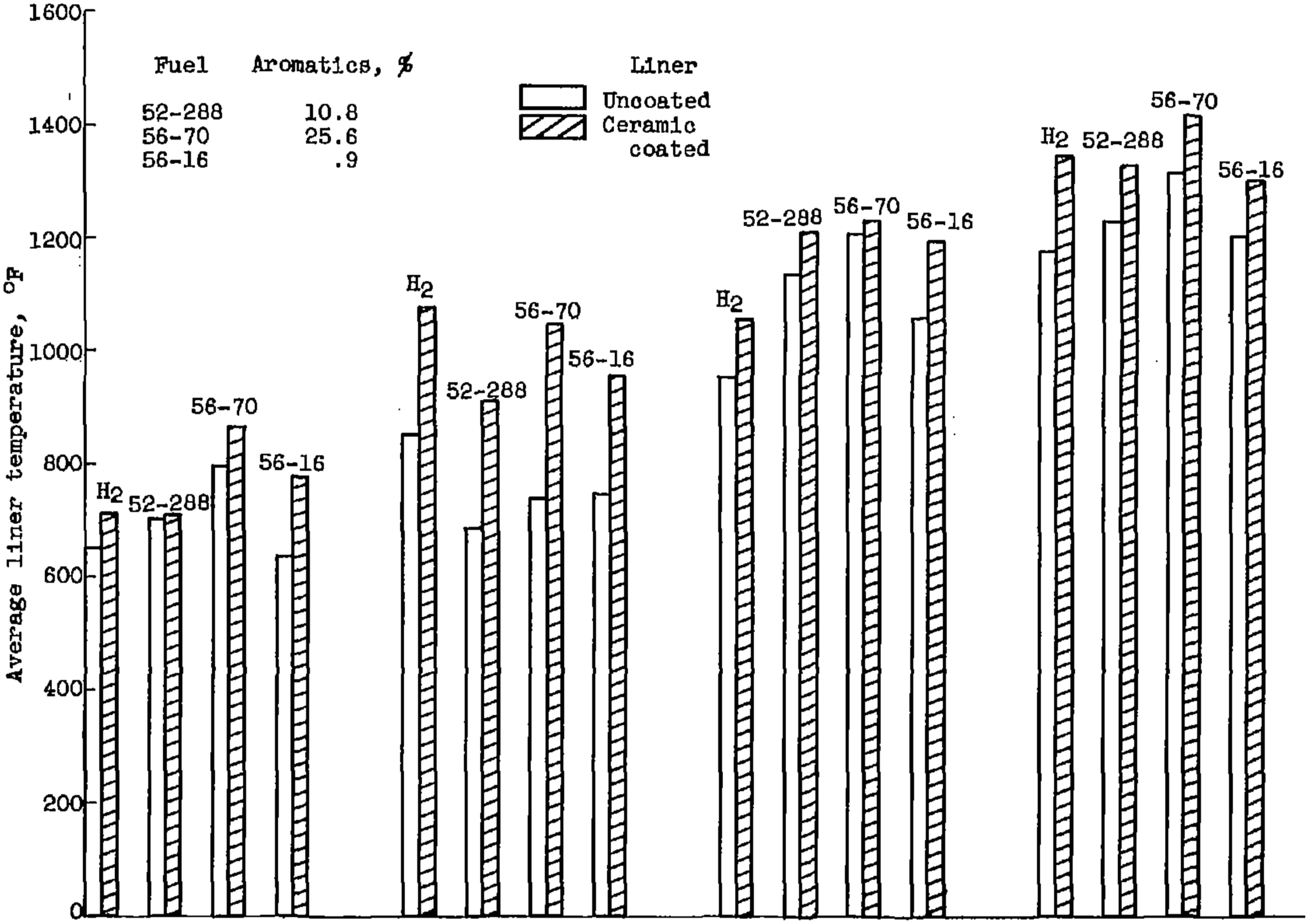
(b) Inlet-air total pressure, 85 pounds per square inch absolute; inlet-air temperature, 640° F; inlet-air reference velocity, 150 feet per second.

Figure 7. - Effect of fuel characteristics on temperatures of ceramic-coated liner in single tubular turbojet combustor. Thermocouples between air-entry holes.



Combustor-inlet condition	1	2	3	4
Total pressure, lb/sq in. abs	30	30	85	85
Temperature, °F	350	350	640	640
Reference velocity, fps	111	111	150	150
Temperature rise, °F	600	1200	600	1200

Figure 8. - Effect of fuel type on dome temperature in single tubular turbojet combustor.



Combustor-inlet condition	1	2	3	4
Total pressure, lb/sq in. abs	30	30	85	85
Temperature, °F	350	350	640	640
Reference velocity, fps	111	111	150	150
Temperature rise, °F	600	1200	600	1200

Figure 9. - Effect of fuel type on average liner temperature in single tubular turbojet combustor.