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RESEARCH MEMORANDUM

COMBUSTION EFFICIENCY PERFORMANCE OF A MIL-F-5624 TYPE FUEL AND MONOMETHYLNAPHTHALENE IN A SINGLE VAPORIZING-TYPE COMBUSTOR

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SUMMARY

An investigation was conducted with a conventional turbojet fuel, MIL-F-5624 (JP-3), and a low-volatility, high-density hydrocarbon, monomethylnaphthalene, in a vaporizing-type combustor to determine (1) the combustion efficiency of both fuels for variations in inlet-air conditions and fuel flow and (2) to what extent fuel prevaporization would minimize the differences in combustion efficiency previously observed between widely dissimilar hydrocarbon fuels in a conventional atomizing combustor.

A single combustor from a developed turbine-propeller engine incorporating fuel-prevaporization principles and designed for kerosene fuel was used as the vaporizing combustor.

With the single vaporizing-type combustor the volatile MIL-F-5624 type fuel burned over a wider range of operating conditions and gave combustion efficiencies 2 to 16 percent higher than the low-volatility, high-density fuel, monomethylnaphthalene.

Heat-input rate had little effect on the combustion efficiency of each fuel in the vaporizing-type combustor, whereas with the same fuels in a conventional atomizing-type combustor a decrease in combustion efficiency was obtained with a decrease in heat input, the greater decrease occurring for the less volatile fuel. The trends indicated that the vaporizing combustor tends to eliminate the differences in fuel atomization and thus diminished the effect of fuel properties on combustion efficiency.

The vaporizer design and capacity were inadequate for the monomethylnaphthalene fuel, however, as evidenced by rich blow-out at rather low air-flow rates. The use of monomethylnaphthalene as a fuel resulted in substantial carbon formation on the liner and the outer surface of the vaporizer.

INTRODUCTION

Marked differences in combustion performance between widely dissimilar hydrocarbon fuels are apparent in conventional atomizing-type combustors at critical operating conditions. High-density hydrocarbon fuels are of low volatility, have low hydrogen-carbon ratios, and have been previously shown to give both low combustion efficiencies (references 1 and 2) and high carbon deposition (reference 3) in atomizing-type combustors. Nevertheless, high-density hydrocarbons are of interest in jet-engine operation since their high heat content per unit volume may be of importance in flight-range consideration of volume-limited aircraft.

Consideration of methods to utilize high-density fuels indicates that vaporization of the fuel may diminish the effects of fuel properties on combustor performance by eliminating the effects due to the atomization of the fuel directly into the flame zone. In order to determine the validity of such a hypothesis, the combustion performance of a conventional turbojet fuel, MIL-F-5624 (JP-3), and a low-volatility, high-density hydrocarbon, monomethylnaphthalene, was investigated in a single vaporizing-type combustor at the NACA Lewis laboratory. The combustor was from a turbine-propeller engine (reference 4) and may be considered an example of a current vaporizing-type combustor, although it was specifically developed for a kerosene fuel, not the high-density fuel of this investigation.

In order to compare the performance of the two fuels, combustion efficiency and blow-out were determined for variations in inlet-air conditions and fuel flow. Pressure-drop data for the vaporizing combustor are also presented. Because the study is a sequel to reference 1, in which the same two fuels were investigated in an atomizing-type combustor, some of the data for the atomizing-type combustor are presented herein for reference purposes.

APPARATUS AND PROCEDURE

The developed vaporizing-type combustor used in the investigation is shown in figure 1. Fuel is injected through four equally spaced 3/64-inch-diameter holes transversely into the air stream of the vaporizer-inlet scoop, and the fuel-air mixture is conducted into the vaporizer through a tangential entrance passage. A small auxiliary tube in the vaporizer passageway directs air to the center of the bottom of the vaporizer to reduce carbon formation. The vaporizer outlet is directed upstream, and the vaporized fuel and air mixture is ignited by a flame-throwing spark plug located in the center of the combustion liner dome.

The vaporizing-type combustor, combustor entrance section, and exhaust pipe were manufacturer's products and were installed vertically in a test cell and connected to the laboratory combustion-air and altitude-exhaust systems as shown in figures 2 and 3. The instrumentation was of a type similar to that reported in reference 5 and was located as shown in figure 3.

The method of conducting the investigation was similar to that used in reference 1 for the determination of the effect of combustor inlet-air conditions on combustion efficiency. The combustion efficiency was calculated for the MIL-F-5624 type fuel and the monomethylnaphthalene at each of the following operating conditions:

Condition	Variable parameter	Combustor inlet-air conditions			
		Pressure (in. Hg abs.)	Temperature (^{o}F)	Air flow[a] (lb/(sec)(sq ft))	Heat input (Btu/lb air)
1	Temperature	30.5	75,125,160, 225,300	2.92	315,366,420
2	Pressure	15.5,23,30.5, 38,46.5	160	2.92	315,366,420
3	Air flow	30.5	160	1.75,2.34,2.92, 3.26[b],3.5[b],4.09[b], 4.35[b],5.4[b],6.52[b]	315,366,420
4	Temperature rise	30.5	160	1.7,2.3,3.0,3.5, 4.3[b],6.5[b]	110 - 510

[a]Mass air-flow rate per unit maximum cross-sectional area of combustor. Maximum cross-sectional area of combustor taken as 0.274 sq ft.
[b]MIL-F-5624 type fuel only.

Fuel-flow rates at each combustor inlet-air condition were adjusted to give the desired heat-input rates. Actual heat-input rates were within 3 percent of the desired values. Heat input is the product of fuel-air ratio and the net heat of combustion of the fuel.

The combustion efficiency is defined as the ratio of the measured enthalpy rise across the combustor to the net heating value of the fuel and was calculated by the method described in reference 6.

The chemical and physical properties of the fuels used in the investigation are given in table I and the recorded and calculated data used in this report are presented in table II.

RESULTS AND DISCUSSION

Performance of Vaporizing-Type Combustor

The variation of combustion efficiency with the inlet-air variables of air flow, pressure, and temperature for the MIL-F-5624 type fuel and monomethylnaphthalene fuel in the single vaporizing-type combustor are presented in figures 4, 5, and 6, respectively. The data are given for heat-input rates of 315, 366, and 420 Btu per pound of air, corresponding to fuel-air ratios of approximately 0.017, 0.019, and 0.022 for the MIL-F-5624 type fuel and 0.019, 0.022, and 0.025 for the monomethylnaphthalene fuel, respectively.

The combustion efficiency of the MIL-F-5624 type fuel remained almost constant at a value of about 95 percent as the air flow was increased from 1.75 to about 5.5 pounds per second per square foot at the inlet-air pressure of 30.5 inches of mercury absolute and inlet-air temperature of 620° R, as indicated in figure 4. At higher air-flow rates, the combustion efficiency decreased rapidly. Similarly, the combustion efficiency of the monomethylnaphthalene was not affected greatly by variations in air flow but was 5 to 16 percent lower than the MIL-F-5624 type fuel performance. The operating range of the monomethylnaphthalene was rather limited, blow-out occurring at air-flow rates of about 3 pounds per second per square foot.

The air-flow rate of 2.92 pounds per second per square foot, representing the maximum air-flow rate at which a comparison can be made between the MIL-F-5624 type fuel and the monomethylnaphthalene fuel, was chosen for the studies of the effects of pressure and temperature on combustion efficiency.

Combustion efficiency decreased for the MIL-F-5624 type fuel and varied only slightly for monomethylnaphthalene fuel as the inlet-air pressure was reduced at a constant air flow of 2.92 pounds per second per square foot and inlet-air temperature of 620° R (fig. 5). The MIL-F-5624 type fuel gave combustion efficiencies 10 to 16 percent higher than those with monomethylnaphthalene and burned to lower values of pressure; blow-out occurred at about $15\frac{1}{2}$ inches of mercury absolute for the MIL-F-5624 type fuel and at about 28 inches of mercury absolute for the less-volatile, high-density fuel.

Variation of inlet-air temperature had little effect on combustion performance at heat-input rates of 315 and 420 Btu per pound of air (fig. 6). An increase in combustion efficiency with an increase in inlet-air temperature from 96° to about 220° F was noted for monomethylnaphthalene fuel at the intermediate value of heat-input rate. The MIL-F-5624 type fuel gave combustion efficiencies 2 to 12 percent higher than monomethylnaphthalene over the temperature range of 75° to 300° F investigated.

Variations in combustion efficiency with temperature rise for the two fuels in the vaporizing-type combustor were small for a range of air flow rates from 1.7 to 6.5 pounds per second per square foot, as shown in figure 7. With monomethylnaphthalene fuel an increase in combustion efficiency was obtained with increase in temperature rise at low values of temperature rise, but otherwise no effect of temperature rise on combustion efficiency was discernible in the range of conditions investigated. A slight decrease in combustion efficiency observed with an increase in temperature rise for the MIL-F-5624 type fuel is thought to be due to an over-rich mixture at the vaporizer and primary zone of the combustor. Rich blow-out was obtained with monomethylnaphthalene at the higher air-flow rates; the blow-out occurred at lower temperature rises as the air-flow rate was increased. Lean limit blow-out was obtained with MIL-F-5624 type fuel at an air-flow rate of 6.5 pounds per second per square foot, the highest air flow investigated.

Combustion efficiency of fuels in vaporizing-type and conventional atomizing-type combustors. - The combustion efficiency of the MIL-F-5624 type fuel and monomethylnaphthalene in the single vaporizing-type combustor is presented in figures 8 and 9; data for a conventional atomizing-type combustor from reference 1 are included to assist in the evaluation of the performance of the fuels.

The combustion efficiency of the two fuels in the two types of combustor at heat-input rates of 315 and 420 Btu per pound of air over a range of air flows is shown in figure 8. As previously noted, the two fuels gave nearly constant values of combustion efficiency over most of the range in the vaporizing combustor, with monomethylnaphthalene experiencing blow-out at rather low air-flow rates. When evaluated in the atomizing-type combustor, the combustion efficiencies of the two fuels were nearly constant at air-flow rates between 3.5 and 5.25 pounds per second per square foot but decreased steadily at lower air-flow rates, except that monomethylnaphthalene gave nearly constant values at the lower heat input.

Combustion efficiencies are compared in figure 9 for the two fuels in the vaporizing-type combustor and the conventional atomizing-type combustor as a function of heat input at a constant air flow, inlet-air pressure, and inlet-air temperature. The values of combustion efficiency for the two fuels in the vaporizing-type combustor are average values obtained from figures 4 to 6.

The data presented in figure 9 show that the combustion efficiencies obtained for the fuels in the atomizing-type combustor increase with an increase in heat input (or fuel-air ratio), the differences between the two fuels being less at the high heat-input values. This trend has been observed in previous investigations to be due mainly to improvements in fuel-atomization characteristics with increase in fuel-flow rates (reference 7). In the vaporizing-type combustor, combustion efficiency is not affected by heat input for the range of conditions of figure 9. At low heat-input rates, the vaporizing-type combustor eliminates the effect of poor atomization, resulting in higher efficiency; at higher heat inputs, the atomizing combustor performs equally as well as this particular design of vaporizing combustor. In general, the results substantiate the hypothesis expressed in the INTRODUCTION that vaporization tends to decrease the difference in combustion performance between hydrocarbon fuels as compared with atomization of the fuel directly into the flame zone.

Correlation Parameter P_1T_1/V_r

The MIL-F-5624 type fuel data of this investigation on the basis of the correlation parameter P_1T_1/V_r developed in reference 8 are presented in figure 10.

Pressure-Drop Characteristics

High combustion efficiency may be obtained at the expense of increased pressure drop. Figure 11 presents the pressure-drop characteristics of the vaporizing-type combustor and a conventional atomizing-type combustor. The presentation is made on the basis of $\Delta P/q_r$ (ratio of total-pressure loss across the combustor to reference inlet dynamic pressure based on the maximum cross-sectional area of the combustor air passage) as a function of ρ_1/ρ_2 (combustion-chamber inlet-to-outlet density ratio). The vaporizing-type combustor has about twice the pressure loss of the conventional atomizing-type combustor.

Miscellaneous Observations

No data were recorded for carbon formation in the investigation. Visual inspection of the combustor liner disclosed substantial evenly distributed carbon deposition on the liner and outer surface of the vaporizer when monomethylnaphthalene fuel was used. The evidence of carbon formation with the low hydrogen-carbon ratio and low-volatility fuel was in agreement with the results of reference 3.

Difficulty in ignition of the monomethylnaphthalene fuel was experienced throughout the investigation because of carbon formation either on the insulation or between the two electrodes of the flame-throwing spark plug.

SUMMARY OF RESULTS

The following results were obtained with a conventional turbojet fuel, MIL-F-5624 (JP-3), and a low-volatility, high-density hydrocarbon, monomethylnaphthalene, in a single vaporizing combustor developed for kerosene-type fuel:

1. The volatile MIL-F-5624 type fuel burned over a wider range of operating conditions and gave combustion efficiencies from 2 to 16 percent higher than monomethylnaphthalene.

2. Heat-input rate had little effect on the combustion efficiency of each fuel, whereas for the same fuels in a conventional atomizing combustor a decrease in combustion efficiency was obtained with a decrease in heat input, the greater decrease occurring for the less volatile fuel. These trends indicated that the vaporizing-type combustor tends to diminish the effect of fuel properties on combustion efficiency in contrast to the conventional atomizing combustor in which fuel is sprayed into the combustion zone.

3. As the operating variables became adverse in the vaporizing-type combustor, rich blow-out occurred with the monomethylnaphthalene fuel, indicating that the vaporizer design and capacity of this combustor were inadequate for the low-volatility, high-density fuel. With monomethylnaphthalene, the vaporizing combustor experienced blow-outs well within the operative range of conditions for the atomizing-type combustor.

4. Substantial quantities of carbon were found when monomethylnaphthalene was used. The carbon was evenly distributed over the liner and the outer surface of the vaporizer.

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TABLE I - CHEMICAL AND PHYSICAL PROPERTIES OF FUELS

Fuel	MIL-F-5624 type	Monomethylnaphthalene[a]
Boiling range (°F)	108 - 483	440 - 461
Volumetric average boiling temperature (°F)	294	454
Reid vapor pressure (lb/sq in. at 60° F)	6.3	Negligible
Hydrogen-carbon ratio	0.170	0.076
Specific gravity	0.755	1.014
Net heat of combustion (Btu/lb)	18,700	16,830
Volumetric energy content[b] (Btu/cu ft)	866,000	1,068,000

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[a]Mixture of α-methylnaphthalene and β-methylnaphthalene.
[b]Volumetric energy content is defined as product of net heat of combustion in Btu/pound and density in lb/cu ft.

TABLE II - PERFORMANCE DATA FROM VAPORIZING-TYPE COMBUSTOR

(a) Monomethylnaphthalene fuel

Run	Combustor-inlet static pressure P_1 (in. Hg abs)	Combustor-inlet temperature T_1 (°R)	Air flow W (lb/sec)	Reference air flow[a] W_a $\left(\frac{lb}{(sec)(sq\ ft)}\right)$	Reference combustor inlet-air velocity[b] V_r (ft/sec)	Fuel flow W_f (lb/hr)	Heat input Q (Btu/lb air)	Mean-combustor outlet temperature T_2 (°R)	Mean-temperature rise through combustor ΔT (°R)	Combustion efficiency η_b (percent)
Effect of pressure on combustion efficiencies $T = 620^{\circ}$ R; W_a = 2.92 lb/(sec)(sq ft)										
31	46.5	620	0.793	2.89	29.1	62.9	372	1760	1140	81.5
30	38.0	619	.793	2.89	35.5	62.9	372	1785	1166	83.4
29	30.5	621	.793	2.89	44.4	62.9	372	1760	1139	81.4
28	27.5	620	.793	2.89	49.5	62.9	372		No combustion	
36	46.5	622	.793	2.89	29.1	73.2	431	1930	1308	82.1
35	38.0	622	.793	2.89	35.7	73.2	431	1930	1308	82.1
34	30.5	622	.793	2.89	44.4	73.2	431	1910	1288	80.7
33	28.5	622	.793	2.89	47.6	73.2	431		No combustion	
85	46.5	622	.795	2.90	29.2	54.3	320	1645	1023	84.0
86	38.0	621	.795	2.90	35.7	54.4	320	1640	1019	83.6
87	30.5	622	.795	2.90	44.6	54.4	320	1610	988	80.9
88	27.8	622	.795	2.90	49.0	54.4	320		No combustion	
Effect of temperature on combustion efficiencies P_1 = 30.5 in. Hg abs; W_a = 2.92 lb/(sec)(sq ft)										
80	30.5	552	0.795	2.90	39.5	54.6	322	1575	1023	82.7
81	30.5	585	.794	2.90	41.9	54.4	320	1570	985	80.2
82	30.5	624	.801	2.92	45.1	54.4	318	1620	996	82.0
83	30.5	685	.795	2.90	49.1	54.3	320	1660	975	84.9
84	30.5	762	.795	2.90	54.6	54.3	320	1735	973	81.3
37	30.5	557	.800	2.92	40.2	62.9	368	1675	1118	79.8
38	30.5	584	.800	2.92	42.1	62.9	368	1745	1161	83.4
39	30.5	620	.800	2.92	44.7	62.9	368	1770	1150	82.9
40	30.5	678	.800	2.92	48.9	62.9	368	1890	1212	88.5
41	30.5	760	.797	2.91	54.6	62.9	370	1945	1185	87.0
42	30.5	541	.800	2.92	39.0	73.2	427	1845	1304	81.5
43	30.5	585	.797	2.91	42.1	73.2	429	1910	1325	83.1
44	30.5	621	.800	2.92	44.8	73.2	427	1935	1314	83.0
45	30.5	682	.800	2.92	49.2	73.2	427	1960	1278	81.3
46	30.5	764	.797	2.91	54.9	73.2	429	2035	1271	81.5

[a]Based on maximum cross-sectional area of combustor flow passage.

[b]Based on inlet density and maximum cross-sectional area of combustor flow passage.

TABLE II - PERFORMANCE DATA FROM VAPORIZING-TYPE COMBUSTOR - Continued

(a) Monomethylnaphthalene fuel

Run	Combustor-inlet static pressure P_1 (in. Hg abs)	Combustor-inlet temperature T_1 (^{o}R)	Air flow W (lb/sec)	Reference air flow[a] W_a $\left(\frac{lb}{(sec)(sq\ ft)}\right)$	Reference combustor inlet-air velocity[b] V_r (ft/sec)	Fuel flow W_f (lb/hr)	Heat input Q (Btu/lb air)	Mean-combustor outlet temperature T_2 (^{o}R)	Mean-temperature rise through combustor ΔT (^{o}R)	Combustion efficiency η_b (percent)
Effect of air flow on combustion efficiencies P_1 = 30.5 in. Hg abs; T_1 = 620° R										
96	30.5	624	0.492	1.795	27.7	43.9	418	1935	1311	84.8
93	30.5	622	.638	2.33	35.7	58.6	429	1900	1278	80.3
50	30.5	625	.795	2.90	44.8	73.6	433	1960	1335	83.5
19	30.5	625	.810	2.96	45.6	72.8	420		No combustion	
95	30.5	618	.467	1.705	26.0	37.9	379	1810	1192	84.0
92	30.5	622	.638	2.33	35.7	50.4	369	1745	1123	80.9
48	30.5	620	.800	2.92	44.7	63.3	370	1760	1140	81.9
49	30.5	620	.830	3.03	46.4	64.9	366		No combustion	
94	30.5	620	.473	1.73	26.4	32.7	323	1600	980	79.4
91	30.5	620	.638	2.33	35.6	43.2	317	1585	965	79.7
90	30.5	620	.795	2.90	44.4	54.4	320	1620	1000	82.0
18	30.5	620	.850	3.10	47.5	57.2	315		No combustion	
53	30.5	619	.479	1.75	26.7	15.3	149	990	371	61.6
54	30.5	618	.497	1.81	27.7	18.9	178	1145	527	74.4
55	30.5	623	.493	1.80	27.7	24.7	234	1360	737	80.5
56	30.5	620	.477	1.74	26.6	35.2	345	1635	1015	77.4
57	30.5	620	.477	1.74	26.6	44.8	439	1910	1290	79.4
58	30.5	621	.470	1.72	26.3	52.1	509	2085	1464	77.8
59	30.5	620	.642	2.34	35.9	16.9	123	910	290	58.1
60	30.5	620	.642	2.34	35.9	22.1	161	1060	440	68.2
61	30.5	620	.642	2.34	35.9	29.3	213	1260	640	76.0
62	30.5	621	.642	2.34	35.9	41.5	302	1510	889	76.4
63	30.5	621	.642	2.34	35.9	49.6	361	1685	1064	77.9
64	30.5	622	.642	2.34	36.0	60.1	438	1870	1248	76.9
65	30.5	621	.642	2.34	35.9	65.6	478	2010	1389	79.4
66	30.5	622	.800	2.92	44.9	19.4	113	935	313	68.0
67	30.5	620	.785	2.87	43.8	27.1	161	1110	490	75.8
68	30.5	619	.800	2.92	44.6	38.0	222	1300	681	77.9
69	30.5	619	.800	2.92	44.6	52.7	306	1545	926	78.7
70	30.5	619	.800	2.92	44.6	64.5	377	1740	1121	79.0
71	30.5	619	.800	2.92	44.6	71.5	417		No combustion	
72	30.5	620	.960	3.50	53.6	24.0	117	905	285	60.0
73	30.5	620	.960	3.50	53.6	29.6	138	1080	460	79.5
74	30.5	620	.960	3.50	53.6	43.4	204	1300	680	81.4
75	30.5	620	.960	3.50	53.6	46.1	269		No combustion	

[a]Based on maximum cross-sectional area of combustor flow passage.

[b]Based on inlet density and maximum cross-sectional area of combustor flow passage.

TABLE II - PERFORMANCE DATA FROM VAPORIZING-TYPE COMBUSTOR - Continued

(b) MIL-F-5624 type fuel

Run	Combustor-inlet static pressure P_1 (in. Hg abs)	Combustor-inlet temperature T_1 (^{o}R)	Air flow W (lb/sec)	Reference air flow[a] W_a $\left(\frac{lb}{(sec)(sq\ ft)}\right)$	Reference combustor inlet-air velocity[b] V_r (ft/sec)	Fuel flow W_f (lb/hr)	Heat input Q (Btu/lb air)	Mean-combustor outlet temperature T_2 (^{o}R)	Mean-temperature rise through combustor ΔT (^{o}R)	Combustion efficiency η_b (percent)
Effect of pressure on combustion efficiencies $T_1 = 620^{o}$ R; W_a = 2.92 lb/(sec)(sq ft)										
604	46.5	621	0.802	2.93	29.4	48.8	316	1745	1124	94.6
607	38.0	620	.810	2.96	36.3	48.3	310	1745	1125	96.5
610	30.5	622	.805	2.94	45.2	48.3	312	1700	1078	91.7
613	23.0	620	.805	2.94	59.7	48.0	310	1660	1040	88.8
616	15.5	623	.805	2.94	89.0	48.8	315	1600	977	81.8[c]
605	46.5	620	.805	2.94	29.5	57.2	369	1920	1300	95.3
608	38.0	617	.805	2.94	35.9	56.4	364	1915	1298	96.4
611	30.5	619	.805	2.94	44.9	57.1	368	1880	1261	92.4
614	23.0	620	.805	2.94	59.7	56.4	364	1835	1215	89.8
630	15.5	620	.805	2.94	88.6	56.4	364	←	No combustion	→
606	46.5	622	.805	2.94	29.6	66.2	427	2085	1463	94.3
609	38.0	619	.805	2.94	36.1	66.8	431	2075	1456	92.9
612	30.5	618	.805	2.94	44.9	65.8	425	2030	1412	91.2
615	23.0	620	.802	2.93	59.4	65.8	426	1995	1375	88.4
631	15.5	620	.805	2.94	88.6	65.8	426	←	No combustion	→
Effect of temperature on combustion efficiencies P_1 = 30.5 in. Hg abs; W_a = 2.92 lb/(sec)(sq ft)										
582	30.5	535	0.817	2.98	39.4	48.3	307	1605	1070	91.1
585	30.5	584	.804	2.93	42.3	48.3	312	1655	1071	90.5
588	30.5	619	.811	2.96	45.3	48.3	310	1680	1061	90.8
591	30.5	686	.801	2.92	49.6	48.8	316	1745	1059	89.5
594	30.5	760	.813	2.96	55.7	48.8	312	1785	1025	88.7
583	30.5	535	.812	2.96	39.2	56.4	361	1770	1235	91.0
586	30.5	586	.810	2.96	42.8	56.4	362	1830	1244	92.2
589	30.5	620	.811	2.96	45.4	57.2	368	1840	1220	89.7
592	30.5	685	.800	2.92	49.4	57.2	371	1910	1225	89.7
595	30.5	763	.806	2.94	55.4	57.2	369	1950	1187	88.4
584	30.5	535	.808	2.95	39.0	66.2	426	1975	1440	91.9
587	30.5	583	.810	2.96	42.6	66.2	424	2000	1417	91.1
590	30.5	620	.804	2.93	45.0	66.2	428	2015	1395	89.4
593	30.5	683	.808	2.95	49.8	66.2	426	2055	1372	89.1
596	30.5	760	.808	2.95	55.4	65.8	425	2090	1330	87.6

[a]Based on maximum cross-sectional area of combustor flow passage.

[b]Based on inlet density and maximum cross-sectional area of combustor flow passage.

[c]Very unsteady to no combustion.

TABLE II - PERFORMANCE DATA FROM VAPORIZING-TYPE COMBUSTOR - Concluded

(b) MIL-F-5624 type fuel

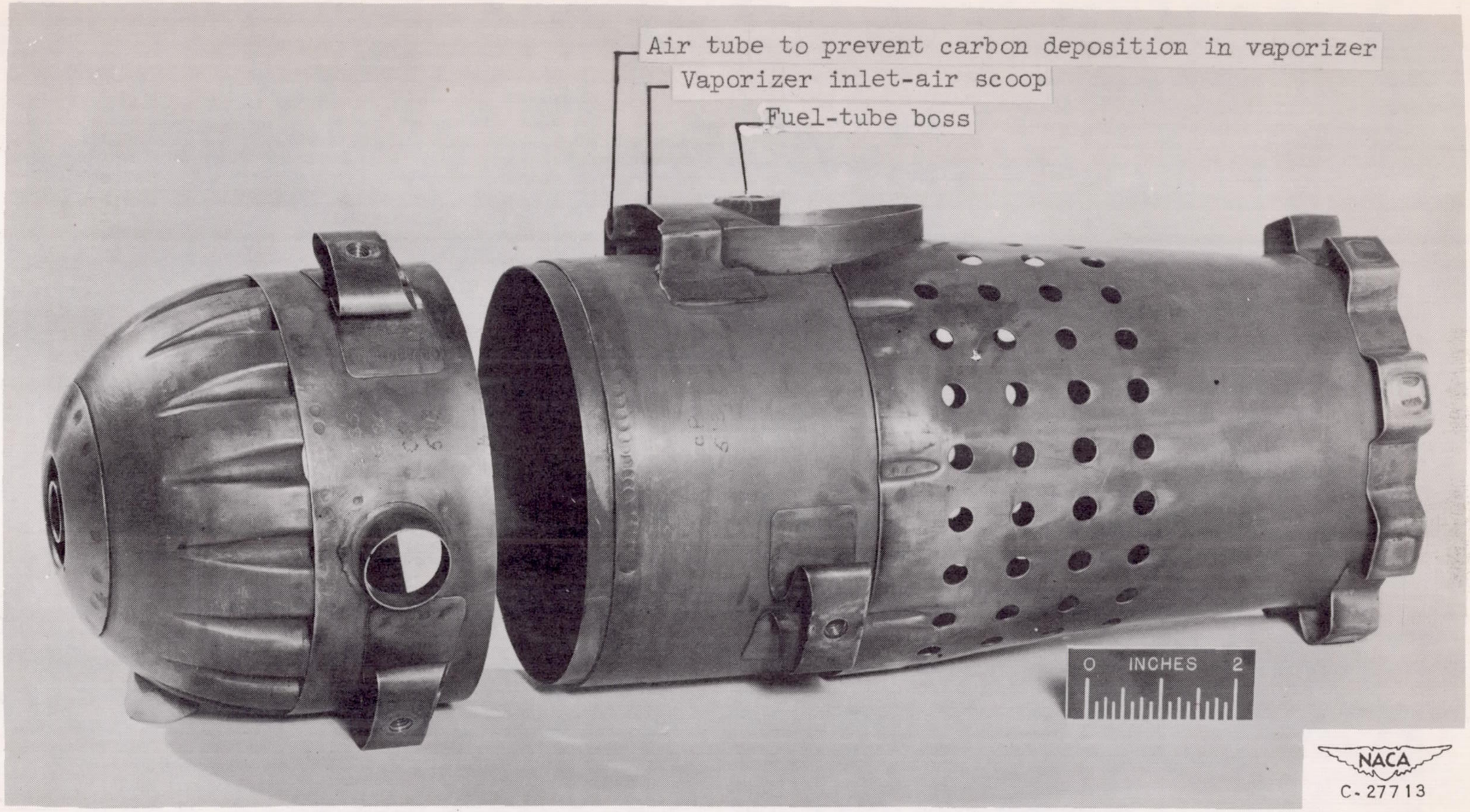
Run	Combustor-inlet static pressure P_1 (in. Hg abs)	Combustor-inlet temperature T_1 (^{o}R)	Air flow W (lb/sec)	Reference air flow[a] W_a $\left(\frac{lb}{(sec)(sq\ ft)}\right)$	Reference combustor inlet-air velocity[b] V_r (ft/sec)	Fuel flow W_f (lb/hr)	Heat input Q (Btu/lb air)	Mean-combustor outlet temperature T_2 (^{o}R)	Mean-temperature rise through combustor ΔT (^{o}R)	Combustion efficiency η_b (percent)
Effect of air flow on combustion efficiencies P_1 = 30.5 in. Hg abs; T_1 = 620° R										
476	30.5	620	1.122	4.10	62.8	68.9	319	1770	1150	96.1
479	30.5	620	.972	3.55	54.4	58.5	313	1740	1120	95.2
482	30.5	620	.804	2.93	45.0	48.5	313	1740	1120	95.0
485	30.5	618	.683	2.49	38.1	39.7	302	1690	1072	93.9
520	30.5	620	.486	1.77	27.2	29.0	310	1735	1115	95.5
419	30.5	619	.893	3.26	49.9	55.6	323	1750	1131	93.1
422	30.5	621	1.179	4.31	66.1	71.9	317	1750	1129	94.8
425	30.5	620	1.490	5.44	83.3	89.7	313	1745	1125	95.7
337	30.5	621	1.483	5.41	83.1	89.8	315	1760	1139	96.4
428	30.5	621	1.787	6.52	100.0	108.4	315	1685	1064	89.5
340	30.5	620	1.783	651	99.6	107.9	315	1675	1055	88.9
521	30.5	623	.479	1.75	26.5	33.8	367	1870	1247	91.8
486	30.5	618	.683	2.49	38.1	45.0	342	1800	1182	92.5
483	30.5	620	.803	2.93	44.9	56.3	364	1900	1280	94.9
332	30.5	620	.907	3.31	50.7	61.8	354	1870	1250	95.1
480	30.5	620	.968	3.53	54.2	67.9	364	1905	1285	95.3
477	30.5	621	1.125	4.11	63.0	79.4	367	1905	1284	94.7
423	30.5	620	1.186	4.33	66.4	83.8	367	1910	1290	95.0
426	30.5	622	1.478	5.40	83.0	105.2	370	1905	1283	93.9
338	30.5	620	1.483	5.41	83.0	105.0	368	1925	1305	96.0
429	30.5	621	1.787	6.52	100.1	126.6	368	1770	1149	83.7
341	30.5	620	1.794	6.55	100.3	126.6	367	1780	1160	84.9
522	30.5	620	.484	1.77	27.1	39.5	424	2025	1405	90.9
487	30.5	619	.700	2.55	39.1	52.9	393	1960	1341	93.0
484	30.5	621	.803	2.93	45.0	65.8	425	2080	1459	94.3
333	30.5	620	.907	3.31	50.7	73.7	422	2080	1460	95.1
481	30.5	620	.969	3.54	54.2	79.5	426	2085	1465	94.6
478	30.5	619	1.117	4.08	62.4	93.2	433	2105	1486	94.5
424	30.5	619	1.192	4.35	66.6	97.5	425	2085	1466	94.9
427	30.5	621	1.474	5.38	82.6	127.3	431	2075	1454	92.8
339	30.5	620	1.472	5.38	82.3	122.7	433	2100	1480	94.2
430	30.5	621	1.787	6.52	100.1	148.0	431	1865	1244	78.6
342	30.5	621	1.804	6.58	100.5	148.0	426	1845	1224	78.0
523	30.5	620	.481	1.75	26.9	14.9	161	1260	640	100.0
524	30.5	618	.480	1.75	26.7	21.9	237	1500	882	96.5
525	30.5	620	.481	1.75	26.9	28.9	312	1740	1120	95.4
526	30.5	620	.482	1.76	27.0	35.9	386	1910	1290	90.4
527	30.5	620	.488	1.78	27.3	42.9	457	2100	1480	89.6
510	30.5	618	.64	2.33	35.7	11.7	95	1010	392	100.0
511	30.5	619	.645	2.35	36.0	19.3	155	1200	581	94.2
512	30.5	617	.694	2.46	38.6	26.5	198	1360	743	95.8
513	30.5	622	.650	2.37	36.5	33.5	168	1570	948	92.6
514	30.5	621	.630	2.30	35.3	41.3	340	1810	1189	93.5
515	30.5	620	.650	2.37	36.3	50.5	403	1950	1330	89.7
516	30.5	621	.664	2.42	37.2	59.8	468	2175	1554	92.4
502	30.5	620	.805	2.94	45.0	12.1	78	940	320	100.0
503	30.5	620	.801	2.92	44.8	19.3	125	1095	475	94.8
504	30.5	620	.801	2.92	44.8	26.3	171	1265	645	95.8
505	30.5	619	.805	2.94	44.9	34.0	219	1420	801	94.0
506	30.5	618	.805	2.94	44.9	42.4	274	1590	972	93.1
507	30.5	620	.805	2.94	45.0	49.4	319	1745	1125	93.9
508	30.5	618	.805	2.94	44.9	58.0	374	1910	1292	93.4
509	30.5	621	.805	2.94	45.1	68.5	442	2115	1494	93.4
495	30.5	622	.970	3.54	54.4	13.2	71	910	288	100.0
496	30.5	620	.966	3.53	54.0	20.7	111	1060	440	98.4
497	30.5	620	.970	3.54	54.2	33.4	179	1290	670	95.2
498	30.5	620	.970	3.54	54.2	41.7	223	1430	810	93.5
499	30.5	620	.966	3.53	54.0	54.2	292	1660	1040	94.1
500	30.5	620	.971	3.54	54.3	66.9	358	1865	1245	93.7
501	30.5	619	.971	3.54	54.2	80.0	428	2080	1461	94.0
447	30.5	620	1.183	4.32	66.1	19.0	83	900	280	82.6
448	30.5	620	1.183	4.32	66.1	29.4	129	1115	495	95.8
449	30.5	620	1.183	4.32	66.1	42.1	185	1310	690	95.1
450	30.5	621	1.187	4.33	66.4	53.8	236	1480	859	94.5
451	30.5	618	1.187	4.33	66.1	65.3	286	1640	1022	94.1
452	30.5	620	1.180	4.31	65.9	77.0	339	1830	1210	95.7
453	30.5	619	1.180	4.31	65.8	93.4	411	2040	1421	94.7
461	30.5	621	1.772	6.47	99.2	48.3	142	1115	494	87.4
462	30.5	620	1.783	6.50	99.6	63.2	184	1255	635	87.5
463	30.5	620	1.800	6.57	100.6	78.4	226	1385	765	87.0
464	30.5	620	1.800	6.57	100.6	95.8	276	1560	940	89.0
465	30.5	620	1.820	6.58	101.8	115.4	320	1710	1090	88.0
466	30.5	620	1.820	6.51	99.6	143.8	348	1860	1240	80.3
467	30.5	620	1.783	6.51	99.6	41.5	121	←No combustion→		

[a]Based on maximum cross-sectional area of combustor flow passage.

[b]Based on inlet density and maximum cross-sectional area of combustor flow passage.

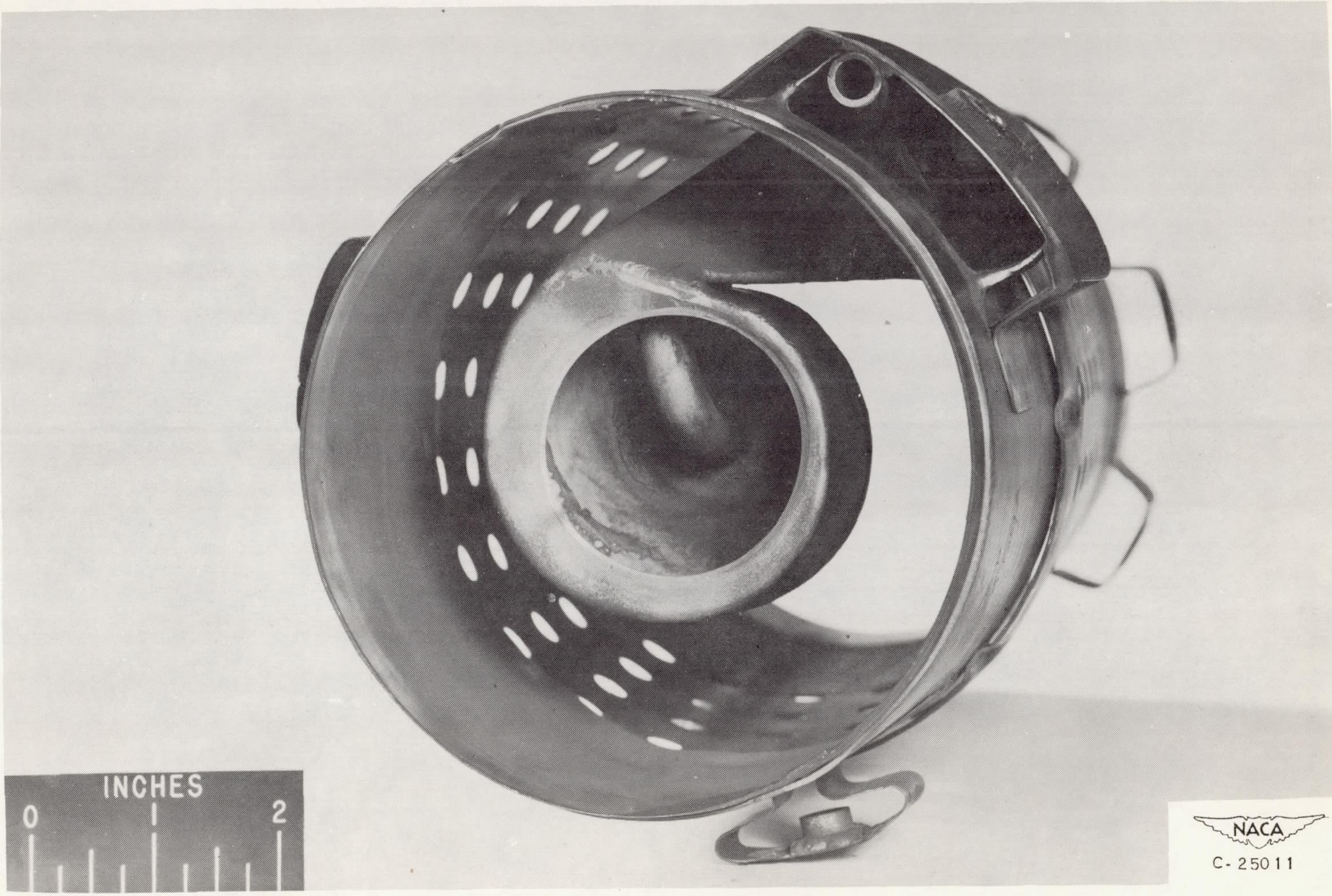
(a) Combustor outer housing.

Figure 1. - Vaporizing-type combustor.



(b) Combustor inner liner showing vaporizer inlet-air scoop and air tube for carbon removal.

Figure 1. - Continued. Vaporizing-type combustor.



(c) Part of inner liner showing vaporizer, vaporizer inlet-air scoop, and auxiliary air tube.

Figure 1. - Concluded. Vaporizing-type combustor.

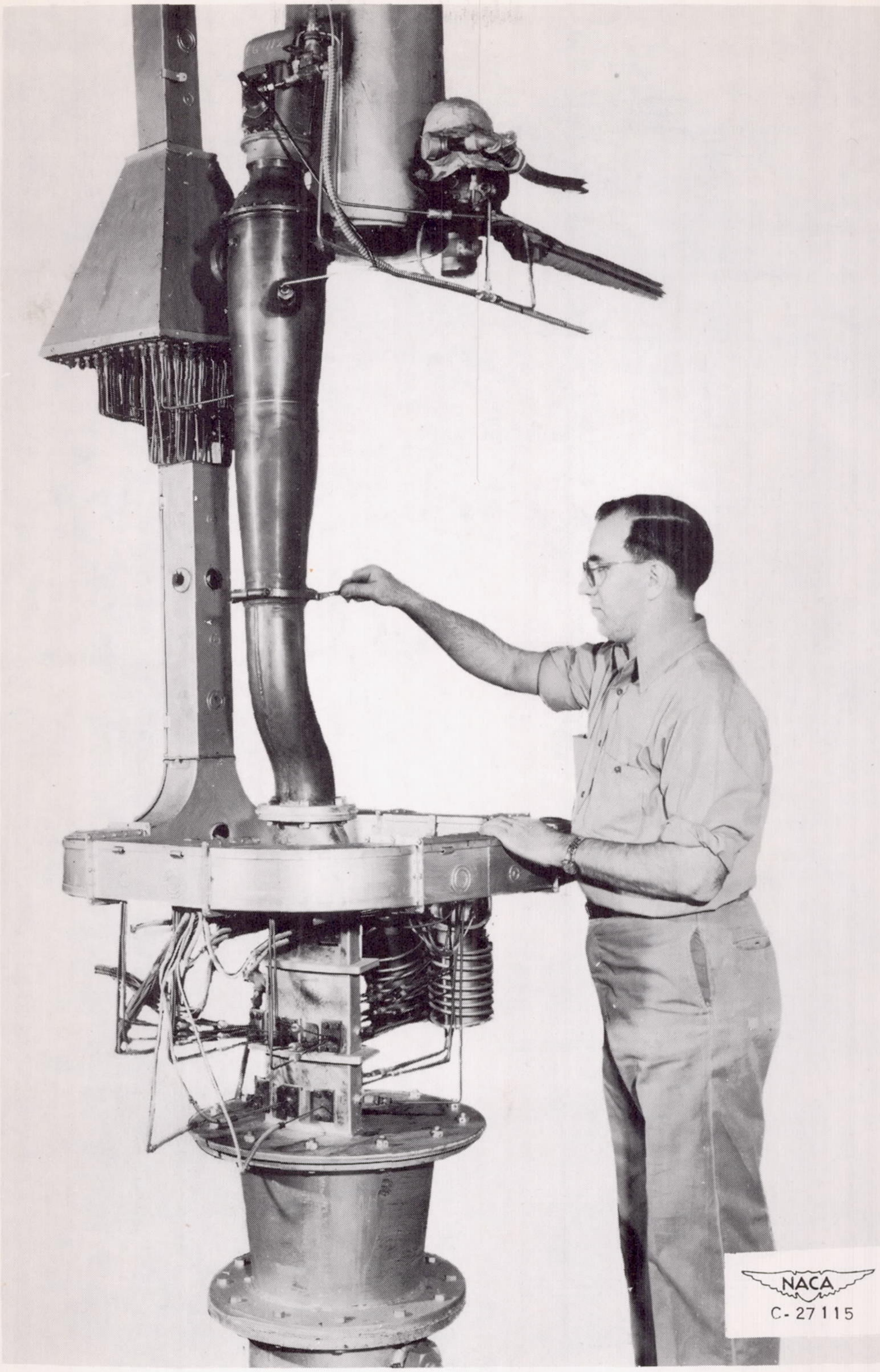


Figure 2. - Test rig.

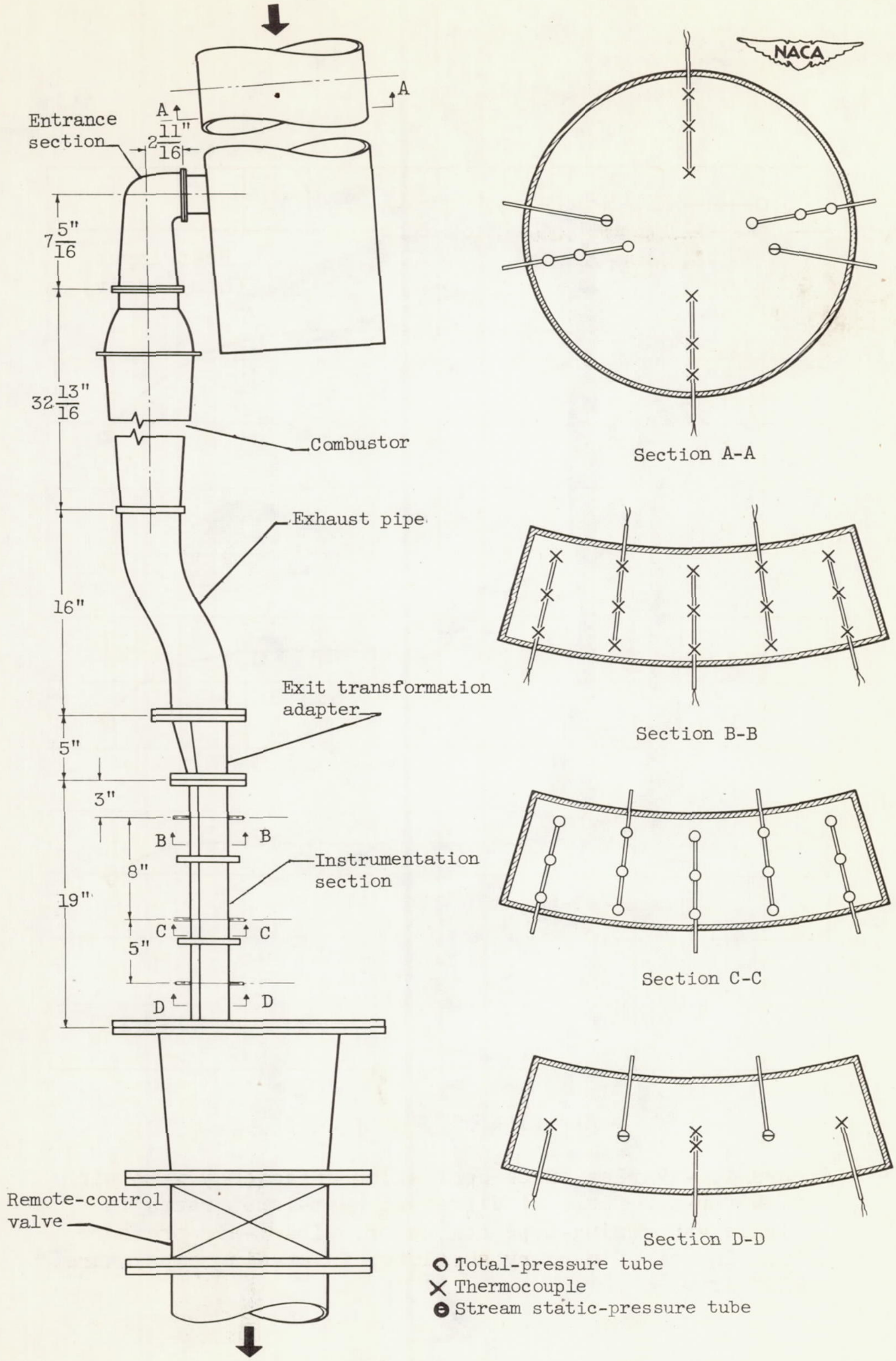


Figure 3. - Location of instrumentation for vaporizing-type-combustor investigation.

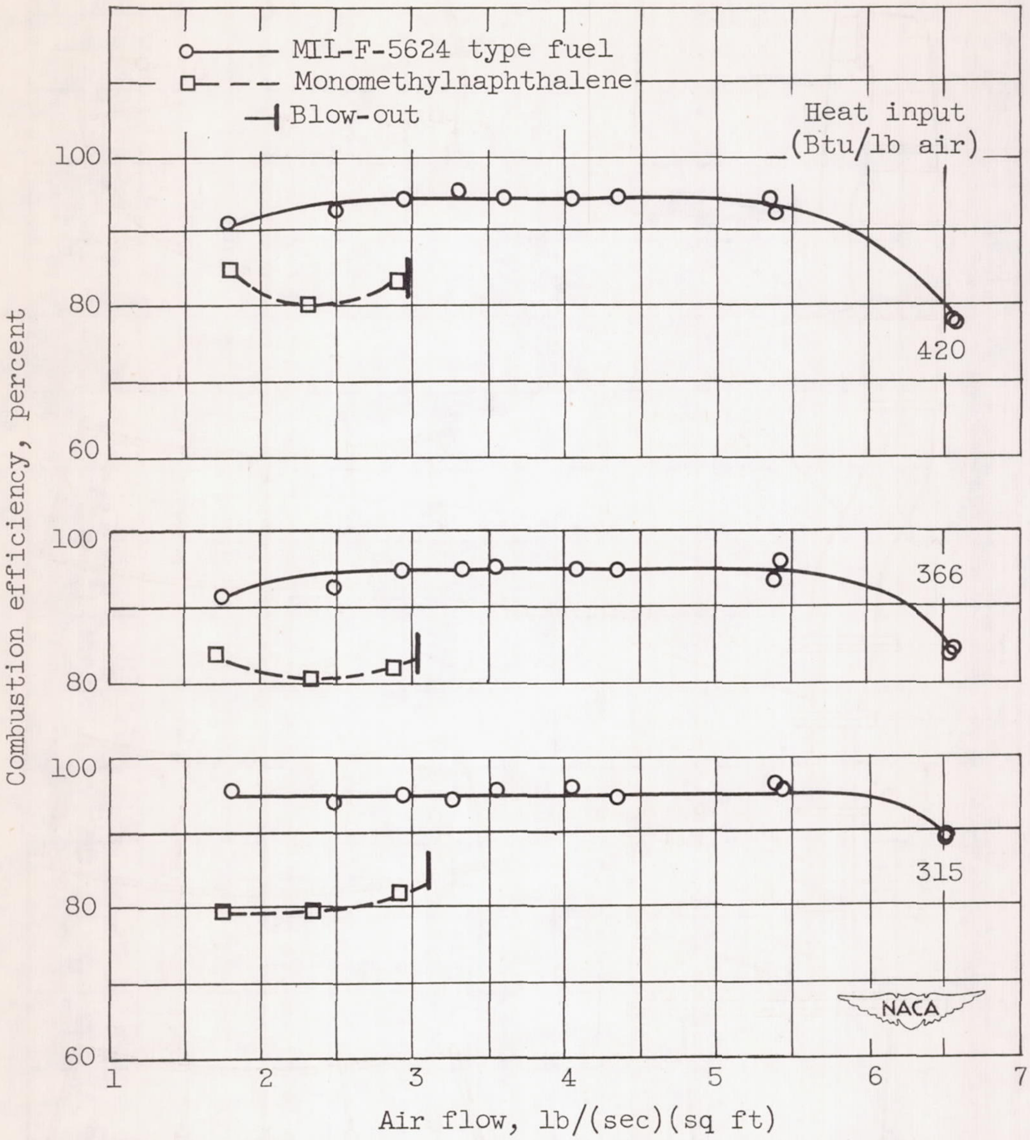


Figure 4. - Variation of combustion efficiency with air flow for two fuels at different heat-input rates in single vaporizing-type combustor. Inlet-air pressure, 30.5 inches of mercury absolute; inlet-air temperature, 620° R.

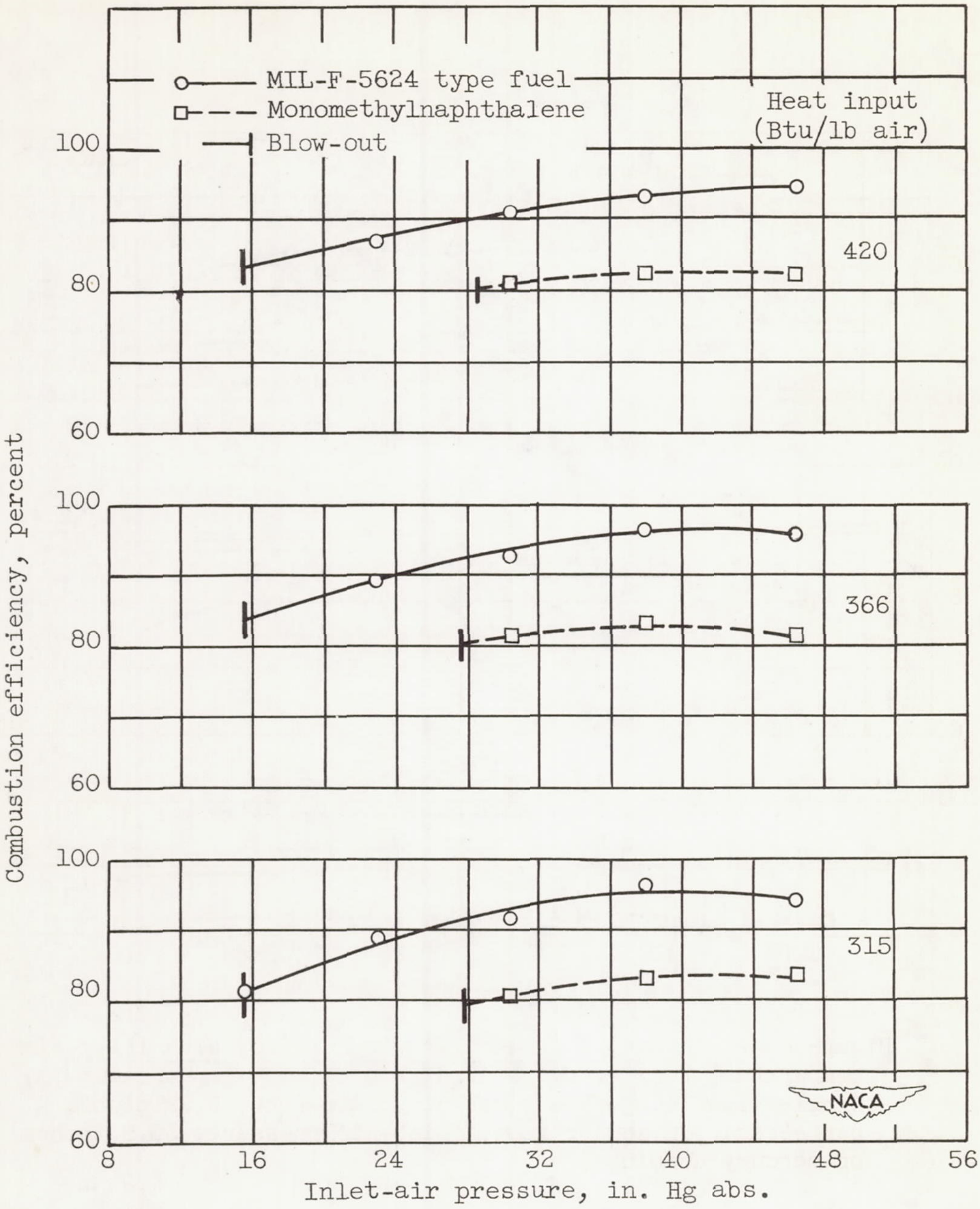


Figure 5. - Variation of combustion efficiency with inlet-air pressure for two fuels at different heat-input rates in single vaporizing-type combustor. Air flow, 2.92 pounds per second per square foot; inlet-air temperature, 620° R.

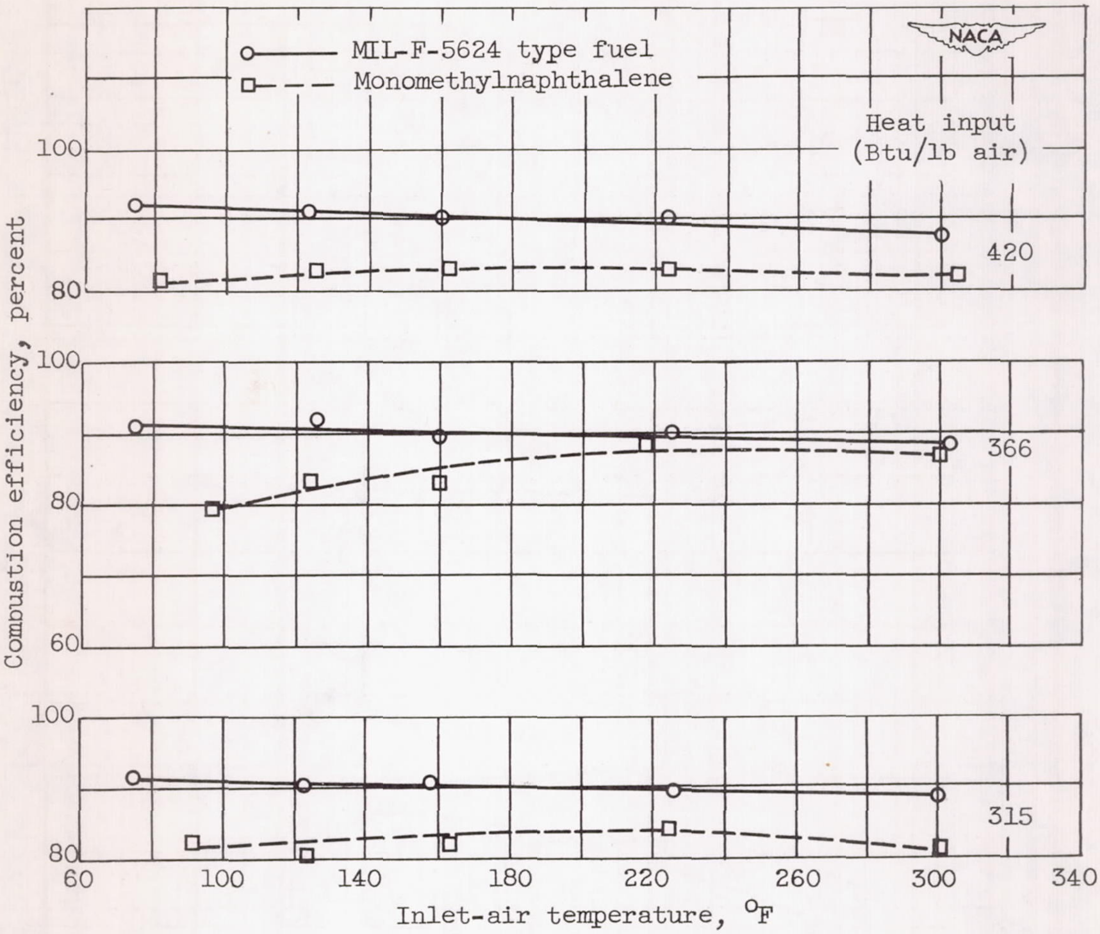
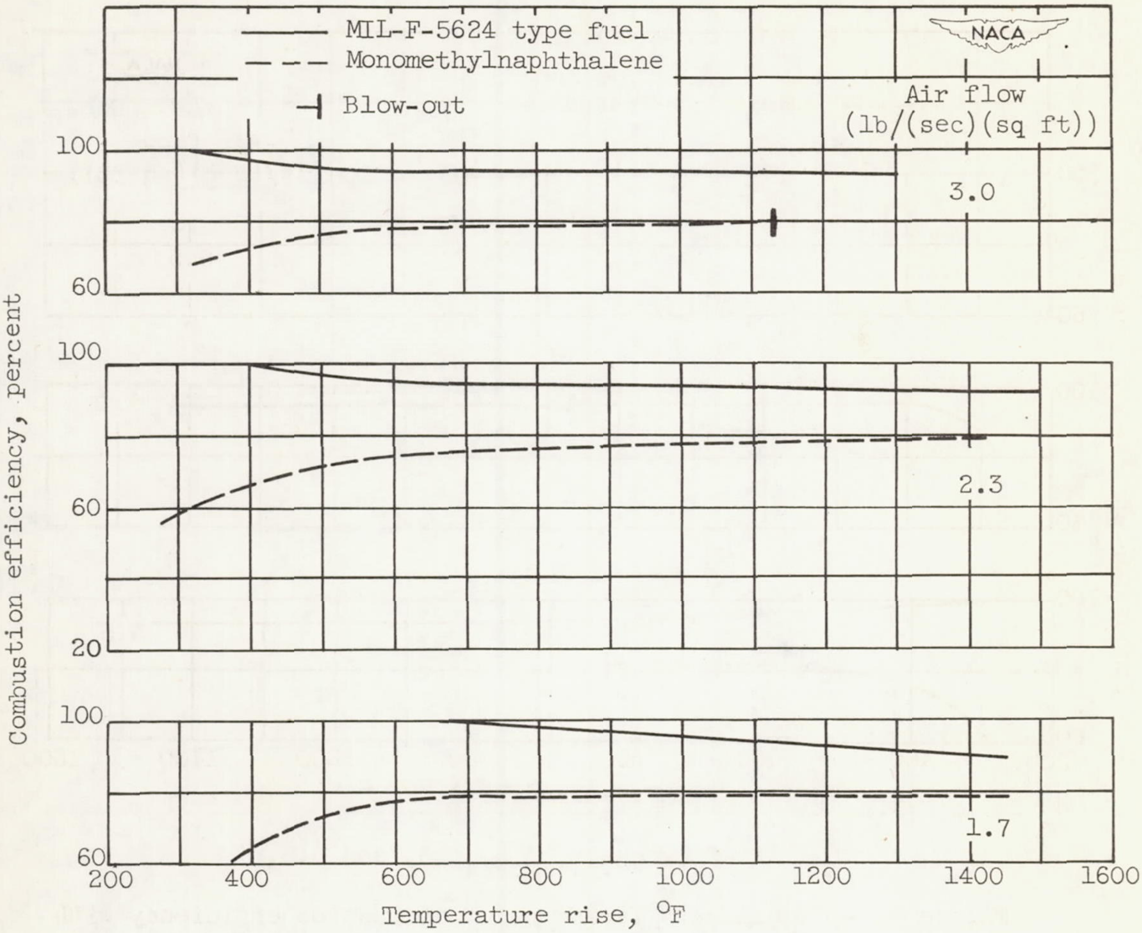
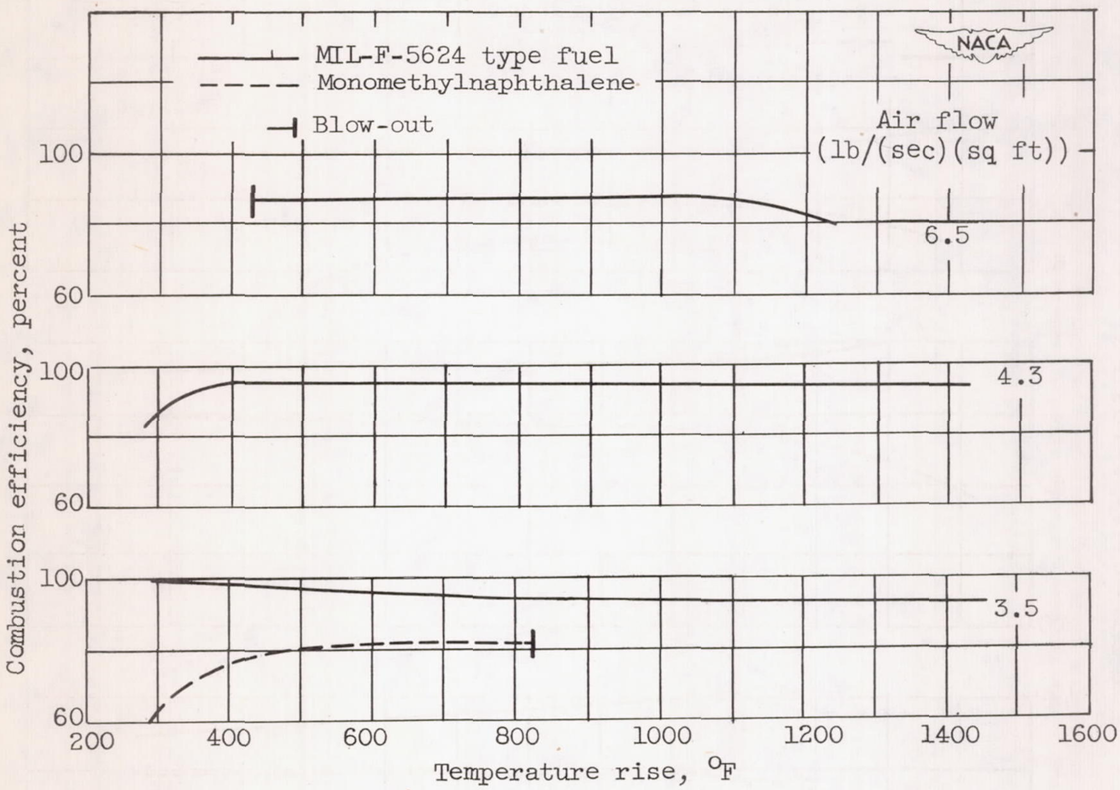


Figure 6. - Variation of combustion efficiency with inlet-air temperature for two fuels at different heat-input rates in single vaporizing-type combustor. Air flow, 2.92 pounds per second per square foot; inlet-air pressure, 30.5 inches of mercury absolute.



(a) Air-flow rates, 1.7, 2.3, and 3.0.

Figure 7. - Variation of combustion efficiency with temperature rise for two fuels at different air-flow rates in vaporizing-type combustor. Inlet-air pressure, 30.5 inches of mercury absolute; inlet-air temperature, 620° R.



(b) Air-flow rates, 3.5, 4.3, and 6.5.

Figure 7. - Concluded. Variation of combustion efficiency with temperature rise for two fuels at different air-flow rates in vaporizing-type combustor. Inlet-air pressure, 30.5 inches of mercury absolute; inlet-air temperature, 620° R.

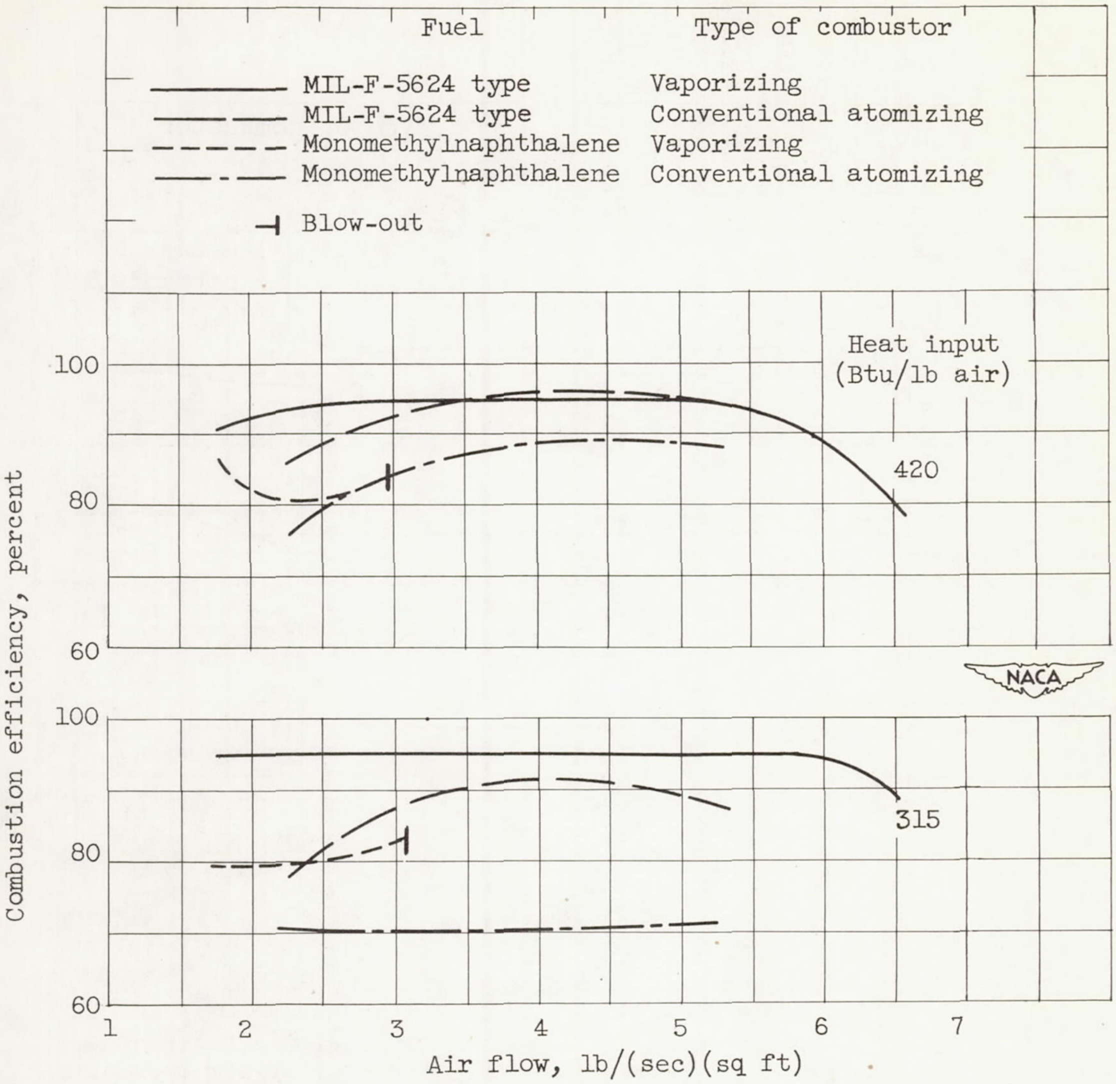


Figure 8. - Variation of combustion efficiency with air flow for two fuels at different heat-input rates in single vaporizing-type and single conventional atomizing-type combustor. Inlet-air pressure, 30.5 inches of mercury absolute; inlet-air temperature, 620° R.

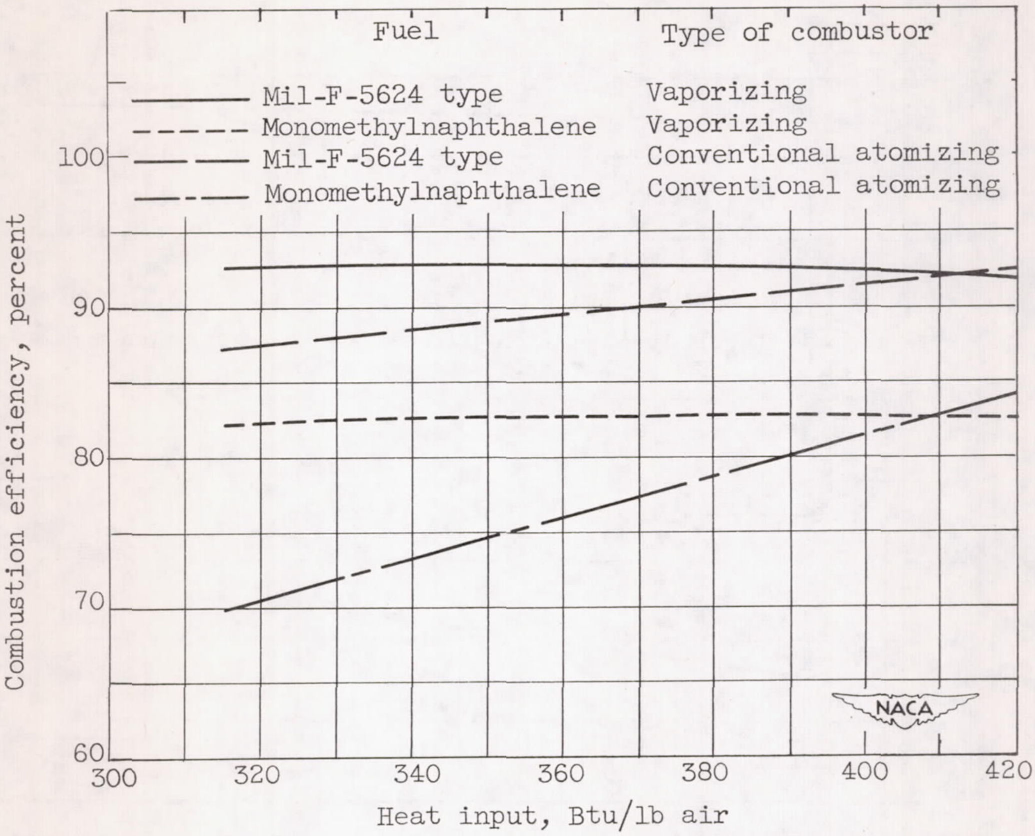


Figure 9. - Variation in combustion efficiency with heat input for two fuels in single vaporizing-type combustor and in single conventional atomizing-type combustor. Air flow, 2.92 pounds per second per square foot; inlet-air pressure, 30.5 inches of mercury absolute; inlet-air temperature, 620° R.

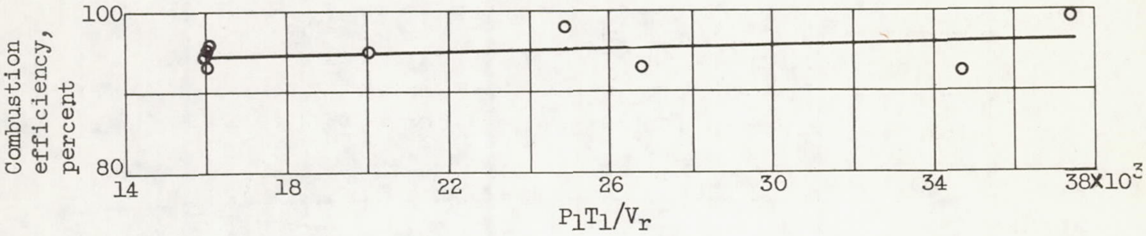


Figure 10. - Variation in combustion efficiency with correlation parameter P_1T_1/V_r for vaporizing-type combustor.

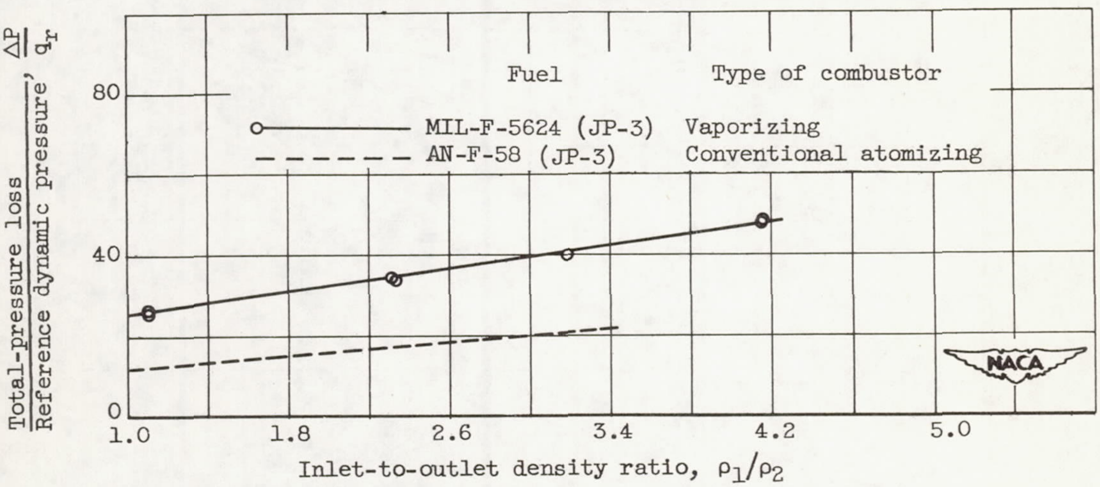


Figure 11. - Total-pressure loss for vaporizing-type combustor and conventional atomizing-type combustor.