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RESEARCH MEMORANDUM

PERFORMANCE INVESTIGATION OF CAN-TYPE COMBUSTOR

I - INSTRUMENTATION, ALTITUDE OPERATIONAL LIMITS AND COMBUSTION EFFICIENCY

By Eugene V. Zettle and William P. Cook

Flight Propulsion Research Laboratory
Cleveland, Ohio

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SUMMARY

A brief investigation of the performance of a single can-type combustor designed for a turbojet engine having a military rating of 4000 pounds thrust at a rotor speed of 7700 rpm and equipped with an 11-stage axial-flow compressor and a single-stage turbine has been made. The investigation was conducted to determine: (a) the altitude operational limits of the engine for two fuels (AN-F-32 and AN-F-28), (b) combustion efficiencies at various simulated conditions of altitude and engine speed, (c) combustor-outlet temperature distribution for several altitudes at constant engine speed, and (d) the combustor total-pressure drop.

The limits with AN-F-32 fuel were found to be approximately 60,000 feet for an engine speed of 6000 rpm and approximately 38,000 feet for an engine speed of 4000 rpm. The results indicated that the altitude operational limits with AN-F-32 fuel are higher over the largest part of the engine-speed range than with AN-F-28 fuel. A combustion efficiency of 95 percent was obtained at rated engine speed (7600 rpm) and an altitude of 20,000 feet with AN-F-32 fuel. A change in altitude from 20,000 to 60,000 feet showed a 20-percent decrease in combustion efficiency while the engine was operating at 7600 rpm; whereas, at an engine speed of 4000 rpm a change of altitude from 10,000 to 40,000 feet showed a 52-percent decrease in combustion efficiency.

INTRODUCTION

The combustion processes in jet-propulsion engines are adversely affected by increased altitudes. For any given engine speed, there will be a certain altitude above which the engine will become limited because of combustion difficulties, that is, the engine will not operate under those conditions of engine speed and altitude that impose combustion difficulties. The combustor-design characteristics largely determine these limitations for any given engine. It is therefore of interest to know, for any given engine, the altitudes at which the engine will be limited because of combustion difficulties over its entire speed range.

The altitude operational limits of a single can-type combustor designed for a turbojet engine having a military rating of 4000 pounds thrust at a rotor speed of 7700 rpm and equipped with an 11-stage axial-flow compressor and a single-stage turbine were obtained at the NACA Cleveland laboratory. The altitude operational limits of this combustor were obtained for two fuels, AN-F-32 and AN-F-28. The combustion efficiencies at various simulated conditions of altitude and engine speed, the combustor-outlet temperature-distribution plots for several altitudes, and a combustor pressure-drop correlation are also presented.

APPARATUS AND INSTRUMENTATION

The combustor was connected to the laboratory-air supply, as diagrammatically shown in figure 1. Air quantity and pressure were regulated by remote-control valves upstream and downstream of the combustor. The desired inlet-air temperature was obtained by the use of an electric air preheater, which was automatically regulated to maintain a constant inlet-air temperature.

The combustor-inlet section and the combustor itself were furnished by the manufacturer. The combustor-outlet section, which was fabricated at the Cleveland laboratory, duplicates that of a standard contemporary engine using a can-type combustor. Two observation windows axially located along the combustor made possible the visual observation of combustion characteristics.

The number and location of instruments at the instrumentation planes shown in figure 1 are tabulated as follows:

Type of instrument	Number of instruments			
	Instrumentation plane			
	A	B	C	D
One-thermocouple rake	2	---	---	3
Three-tube total-pressure rake	3	---	---	---
Five-tube total-pressure rake	---	---	7	---
Five-thermocouple rake	---	7	---	---
Static-pressure orifice connection	1	1	1	1

All measurements were taken at the center of equal areas. Locations of the points of measurement at the respective instrumentation planes are shown in figure 2 and the instrumentation details are shown in figure 3. Temperatures were indicated by self-balancing potentiometers; air flow was measured by A.S.M.E. square-edge orifices and fuel flow by a rotameter. All instruments were calibrated. No attempt was made to correct the thermocouple readings for stagnation effects. A photograph of the combustor and instrumentation is shown in figure 4.

METHODS

Experiments were conducted on the combustor covering a range of simulated altitudes from 10,000 to 60,000 feet and simulated engine speeds from 3500 to 7600 rpm. Combustor inlet-air conditions were maintained for each altitude and engine-speed point selected at values determined from an engine-performance investigation made in the NACA Cleveland altitude wind tunnel (reference 1) at zero ram conditions (fig. 5). The required operating conditions from reference 1, the actual test conditions, and the results obtained are listed in table I. At each altitude and engine-speed point investigated, an attempt was made to obtain an average combustor-outlet temperature equal to or greater than that required for normal engine operation at that point. For each simulated engine-speed point, there was an altitude above which the required combustor-outlet-gas temperature could not be obtained. The altitude operational limits were determined for both AN-F-28 and AN-F-32 fuels. The combustion efficiencies over the range of engine operational speeds and altitudes were determined with AN-F-32 fuel.

RESULTS

The altitude operational limits obtained using AN-F-28 and AN-F-32 fuels are shown in figures 6 and 7, respectively, where altitude is plotted against engine speed. The solid curves separate the region where the combustor-outlet temperatures obtainable were sufficient for normal operation of the can-type combustor from the region where either the combustor-outlet temperatures obtainable were insufficient for operation of the engine or where burner blow-out occurred. Figure 7(b) includes lines of constant combustion efficiency. The constant temperature-rise efficiency lines were obtained by interpolating between the data points. The altitude operational limits using AN-F-32 fuel were found to be approximately 60,000 feet for an engine speed of 6000 rpm and approximately 38,000 feet for an

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engine speed of 4000 rpm (fig. 7). The results indicate that the altitude operational limits with AN-F-32 fuel are higher over the largest part of the engine-speed range than with AN-F-28 fuel. The maximum difference reaches 10,000 feet; however, as the rated engine speed (7600 rpm) is approached, the difference in limits between the two fuels is nearly eliminated.

The variation of the combustion efficiency with altitude for engine speeds of 4000 and 7600 rpm using AN-F-32 fuel is shown in figure 8. Combustion efficiency is defined as the ratio of the measured total-temperature rise across the combustor to the theoretical total-temperature rise across the combustor $\frac{\Delta T_m(A - B)}{\Delta T_t}$ (reference 2). A combustion efficiency of 95 percent was obtained at rated engine speed (7600 rpm) and an altitude of 20,000 feet. A change of altitude from 20,000 to 60,000 feet showed a 20-percent decrease in combustion efficiency while the engine was operating at a speed of 7600 rpm; whereas, at an engine speed of 4000 rpm a change of altitude from 10,000 to 40,000 feet showed a 52-percent decrease in combustion efficiency.

The effect of the variation of fuel-air ratio on combustor performance at an operating point chosen near the dead-band for AN-F-28 fuel is shown in figure 9.

The temperature distribution at instrumentation plane B-B (fig. 1) for a simulated engine speed of 7600 rpm and representing two simulated altitudes (50,000 and 55,000 ft) using AN-F-32 fuel is shown in figure 10. Three temperature-distribution patterns taken at simulated altitudes of 20,000, 50,000, and 55,000 feet and at a simulated speed of 7600 rpm using AN-F-28 fuel are presented in figure 11.

It can be shown from the momentum equation for a constant cross-sectional-area combustor that the total-pressure drop across the combustor expressed as a fraction of impact pressure is a linear function of the ratio of inlet-to-outlet gas densities. The impact pressure was calculated at the inlet to the combustor assuming that the inlet area was equal to the maximum cross-sectional area of the combustor. When the pressure drop is related to the maximum cross-sectional area of the combustor, useful comparisons can be made with the pressure drop in other combustors of different geometry. Figure 12 shows total-pressure drop expressed as a fraction of impact pressure $\Delta P/q$ plotted against inlet-to-outlet density ratio ρ_A/ρ_B.

SUMMARY OF RESULTS

From an investigation of the performance characteristics of a can-type combustor, the following results were obtained:

1. The altitude operational limits with AN-F-32 fuel were found to be approximately 60,000 feet for an engine speed of 6000 rpm and approximately 38,000 feet for an engine speed of 4000 rpm. The results indicated that the altitude operational limits with AN-F-32 fuel are higher over the largest part of the engine-speed range than with AN-F-28 fuel.

2. A combustion efficiency of 95 percent was obtained at rated engine speed (7600 rpm) and an altitude of 20,000 feet with AN-F-32 fuel. A change of altitude from 20,000 to 60,000 feet showed a 20-percent decrease in combustion efficiency while the engine was operating at 7600 rpm; whereas, at an engine speed of 4000 rpm a change of altitude from 10,000 to 40,000 feet showed a 52-percent decrease in combustion efficiency.

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REFERENCES

1. Fleming, William A.: Altitude-Wind-Tunnel Investigation of a 4000-Pound-Thrust Axial-Flow Turbojet Engine. I - Performance and Windmilling Drag Characteristics. NACA RM No. E8F09, 1948.

2. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Charts for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN No. 1086, 1946.

TABLE I - SUMMARY OF STATIC PERFORMANCE DATA FOR CAN-TYPE COMBUSTOR

Run (1)	Simulated conditions		Required operating conditions[2]				Actual test conditions and results						
	Engine speed (rpm)	Altitude (ft)	Mass flow (lb/sec)	Inlet static pressure (in. Hg absolute)	Combustor-outlet average temperature (°F)	Combustor-inlet average temperature (°F)	Mass flow (lb/sec)	Inlet static pressure (in. Hg absolute)	Combustor-outlet average temperature (°F)	Fuel-air ratio	Combustor-inlet average temperature (°F)	Average temperature rise (°F)	Temperature-rise efficiency (percent)
1	4500	40,000	1.12	10.5	620	39	1.11	10.4	420	0.0152	35	385	0.35
2	5000	40,000	1.29	12.4	670	68	1.30	12.4	627	.0107	66	561	.72
3	5000	45,000	1.04	10.0	670	67	1.00	9.7	616	.0117	67	549	.65
4	5500	45,000	1.20	11.8	750	97	1.24	11.7	897	.0194	90	807	.63
5	5000	50,000	.82	7.7	670	68	.82	7.5	579	.0112	67	512	.63
6	5500	50,000	.95	8.9	750	97	.96	8.8	------	.0158	--------	-------	--------
7	6000	50,000	1.05	10.9	860	130	1.05	10.7	965	.0219	120	845	.57
8	6500	50,000	1.13	11.4	1010	162	1.14	11.4	1137	.0212	160	977	.68
9	7600	50,000	1.26	16.9	1465	240	1.27	16.9	1464	.0237	238	1226	.78
10	5000	55,000	.67	6.4	670	67	.68	6.3	558	.0107	67	491	.63
11	6000	55,000	.86	8.5	860	129	.86	8.3	780	.0170	132	648	.54
12	6500	55,000	.93	9.7	1010	162	.93	9.9	1145	.0223	162	983	.65
13	7000	55,000	.97	11.0	1180	196	.98	10.6	1111	.0210	196	915	.64
14	7600	55,000	1.01	12.5	1465	239	1.04	12.2	1317	.0246	240	1077	.66
15	6000	60,000	.66	6.8	860	130	.68	6.8	586	.0126	136	450	.50
16	6500	60,000	.71	7.9	1010	162	.71	7.7	982	.0187	164	818	.63
17	7000	60,000	.75	9.1	1182	198	.76	9.1	1068	.0232	198	870	.56
18	4000	30,000	1.45	14.1	650	34	1.43	13.9	767	.0166	35	732	.62
19	4500	35,000	1.37	13.2	625	40	1.38	13.1	755	.0167	39	716	.60
20	7600	30,000	3.17	42.1	1440	262	3.12	40.0	1636	.0225	251	1385	.93
21	7000	30,000	2.98	36.0	1200	218	3.04	35.8	1741	.0249	223	1518	.93
22	6000	30,000	2.56	26.9	900	150	2.56	27.0	1620	.0250	148	1472	.89
23	5000	30,000	1.96	19.1	710	87	1.98	19.3	1306	.0222	87	1219	.81
24	4000	30,000	1.45	14.1	650	34	1.45	14.2	703	.0140	34	669	.67
25	4000	35,000	1.20	11.5	600	14	1.20	11.5	669	.0139	14	655	.66
26	7600	40,000	2.04	27.3	1465	240	1.98	26.9	1540	.0223	242	1298	.87
27	7000	40,000	1.94	23.6	1180	198	1.96	23.6	1581	.0234	194	1387	.88
28	6000	40,000	1.69	17.6	860	130	1.66	17.4	1303	.0214	129	1174	.81
29	5000	40,000	1.29	12.4	670	68	1.30	12.4	1115	.0219	64	1051	.70
30	4500	40,000	1.12	10.5	625	39	1.12	10.4	611	.0124	28	583	.65
31	4000	40,000	.95	9.0	600	14	.95	-------	-------	.0208	14	-------	--------
32	5000	45,000	1.04	10.0	670	67	1.06	9.9	656	.0131	64	592	.64

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33	4500	45,000	0.90	8.5	625	39	0.91	8.6	753	0.0181	44	709	0.56
34	7600	50,000	1.26	16.9	1465	240	1.26	16.9	1559	.0268	240	1319	.76
35	7000	50,000	1.20	14.6	1180	198	1.18	14.4	1172	.0203	203	969	.71
36	6000	50,000	1.05	10.9	860	130	1.00	9.9	1177	.0236	125	1052	.67
37	5000	50,000	.82	7.7	670	68	.83	7.6	794	.0208	68	726	.52
38	4500	50,000	.69	6.6	625	39	.69	6.6	-------	------	39	-------	--------
39	5000	55,000	.67	6.4	670	67	.67	6.2	627	.0193	68	553	.42
40	7600	60,000	.76	10.5	1465	240	.76	10.5	1333	.0260	240	1093	.65
41	7000	60,000	.75	9.1	1180	198	.75	9.2	1139	.0248	195	944	.58
42	6000	60,000	.66	6.8	860	130	.66	6.9	1005	.0239	130	875	.55
43	5000	60,000	.50	4.8	670	68	.51	4.8	612	.0218	76	536	.36
44	4000	20,000	2.02	21.0	740	67	2.02	20.7	779	.0132	76	703	.76
45	3000	20,000	1.46	17.1	750	28	1.46	16.9	777	.0146	22	755	.72
46	5500	60,000	.59	5.7	750	97	.60	5.7	-------	.0119	102	-------	--------
47	5500	55,000	.80	7.3	750	97	.80	7.3	692	.0174	100	592	.49
48	7000	55,000	.97	11.0	1180	197	.98	10.9	1133	.0220	198	1035	.71
49	7600	55,000	1.04	12.6	1465	239	1.05	12.6	1375	.0259	243	1132	.67
50	4000	25,000	1.76	17.4	700	50	1.77	17.3	690	.0129	49	641	.70
51	4000	15,000	2.38	24.9	780	83	2.39	24.8	752	.0113	82	670	.83
52	4000	10,000	2.78	29.1	840	99	2.79	29.1	837	.0119	94	743	.88
53	4000	40,000	.95	9.0	600	14	.98	8.7	495	.0168	14	481	.41
54	4000	35,000	1.18	11.6	600	14	1.18	11.5	614	.0162	13	601	.52
55	4000	30,000	1.45	14.1	650	34	1.44	13.9	679	.0154	34	645	.59
56	4000	20,000	2.02	21.0	740	67	2.03	20.9	778	.0121	68	710	.82
57	7600	60,000	.76	10.5	1465	240	.77	10.4	1412	.0234	242	1170	.76
58	7600	55,000	1.00	12.4	1465	240	1.00	12.5	1500	.0265	240	1260	.73
59	7600	50,000	1.26	16.9	1465	240	1.27	16.8	1490	.0242	238	1252	.79
60	7600	45,000	1.63	20.7	1465	240	1.64	20.8	1506	.0235	238	1268	.82
61	7600	40,000	2.04	27.3	1465	240	2.05	27.1	1476	.0209	239	1237	.88
62	7600	35,000	2.59	34.6	1465	240	2.60	34.7	1489	.0207	242	1247	.90
63	7600	30,000	3.17	42.1	1440	262	3.15	42.0	1383	.0191	260	1123	.87
64	7600	25,000	3.86	51.2	1460	278	3.89	50.5	1433	.0195	279	1154	.88
65	7600	20,000	4.57	60.6	1475	299	4.57	60.4	1454	.0180	299	1155	.95
66	6000	50,000	1.05	10.9	860	130	1.06	10.9	920	.0159	131	789	.70
67	6000	50,000	1.05	10.9	860	130	1.07	11.0	997	.0191	131	866	.65
68	6000	50,000	1.05	10.9	860	130	1.05	10.9	1097	.0232	132	965	.61
69	6000	50,000	1.05	10.9	860	130	1.06	10.7	1176	.0252	130	1046	.62
70	6000	50,000	1.05	10.9	860	130	1.05	10.9	------	.0263	130	-------	--------
71	3500	30,000	1.11	8.0	650	11	1.11	8.0	437	.0189	12	1125	.32
72	6500	60,000	.71	7.9	1010	162	.73	7.8	1096	.0220	163	933	.64
73	6000	50,000	1.06	10.9	860	131	1.06	11.0	586	.0095	131	455	.66
74	6000	50,000	1.06	10.9	860	132	1.06	11.0	796	.0122	132	664	.75

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[1]Runs 1-19, 66-70, 73, and 74 with AN-F-28 fuel; other runs with AN-F-32 fuel.
[2]From Cleveland altitude-wind-tunnel investigation, reference 1.

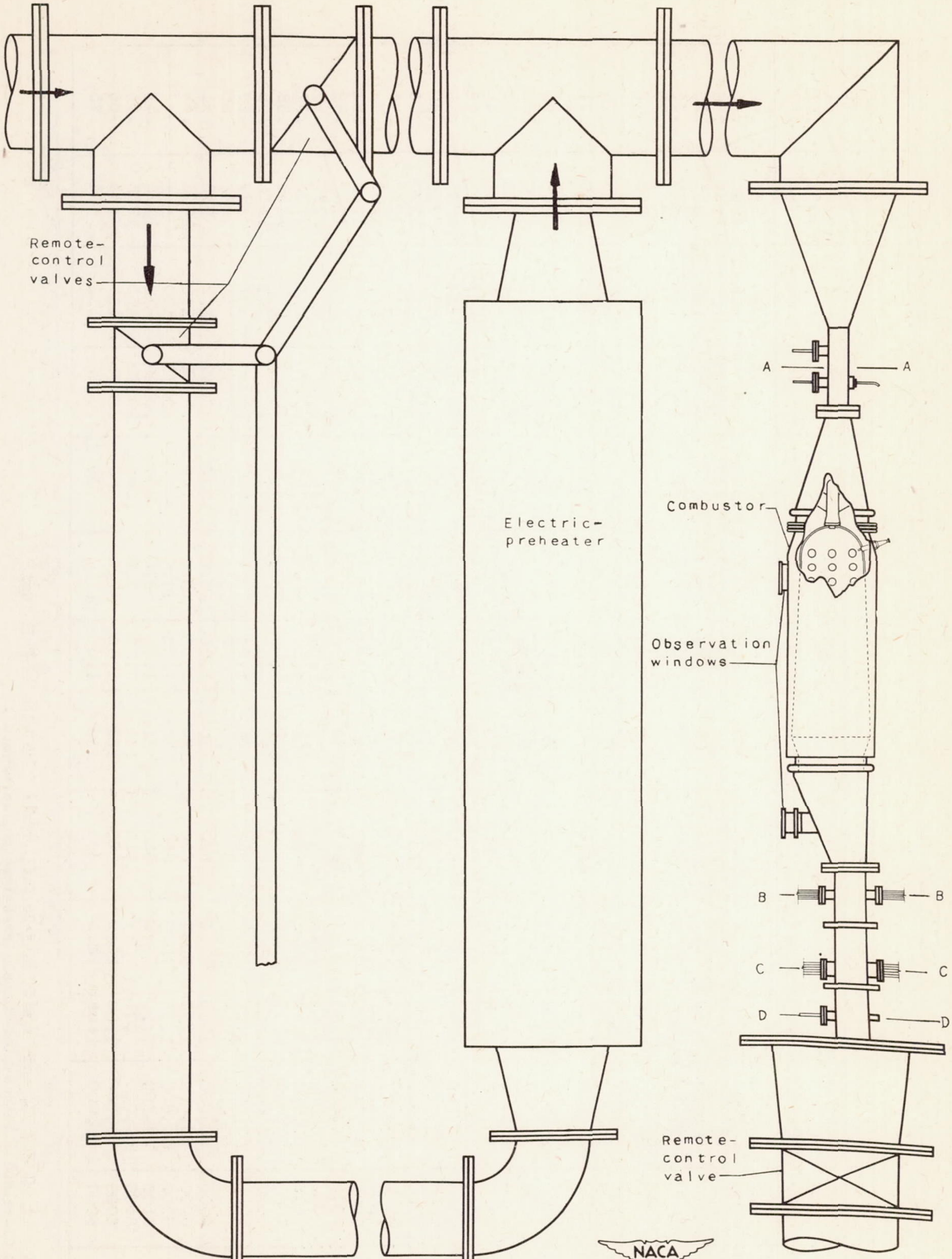

Figure 1. - Schematic diagram showing test rig and instrumentation positions used in investigation of can-type combustor.

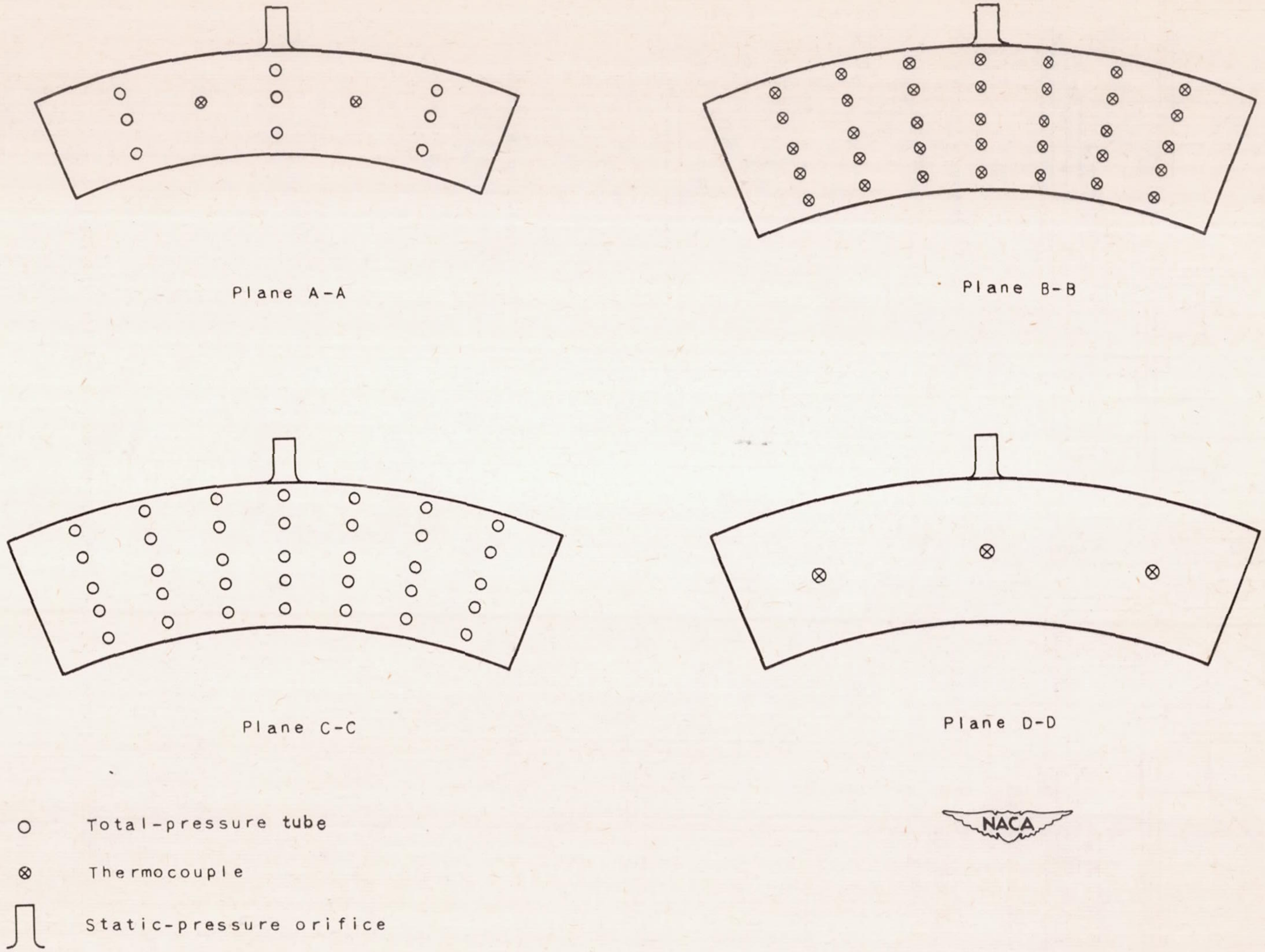

Figure 2. - Location of instruments at several instrumentation planes.

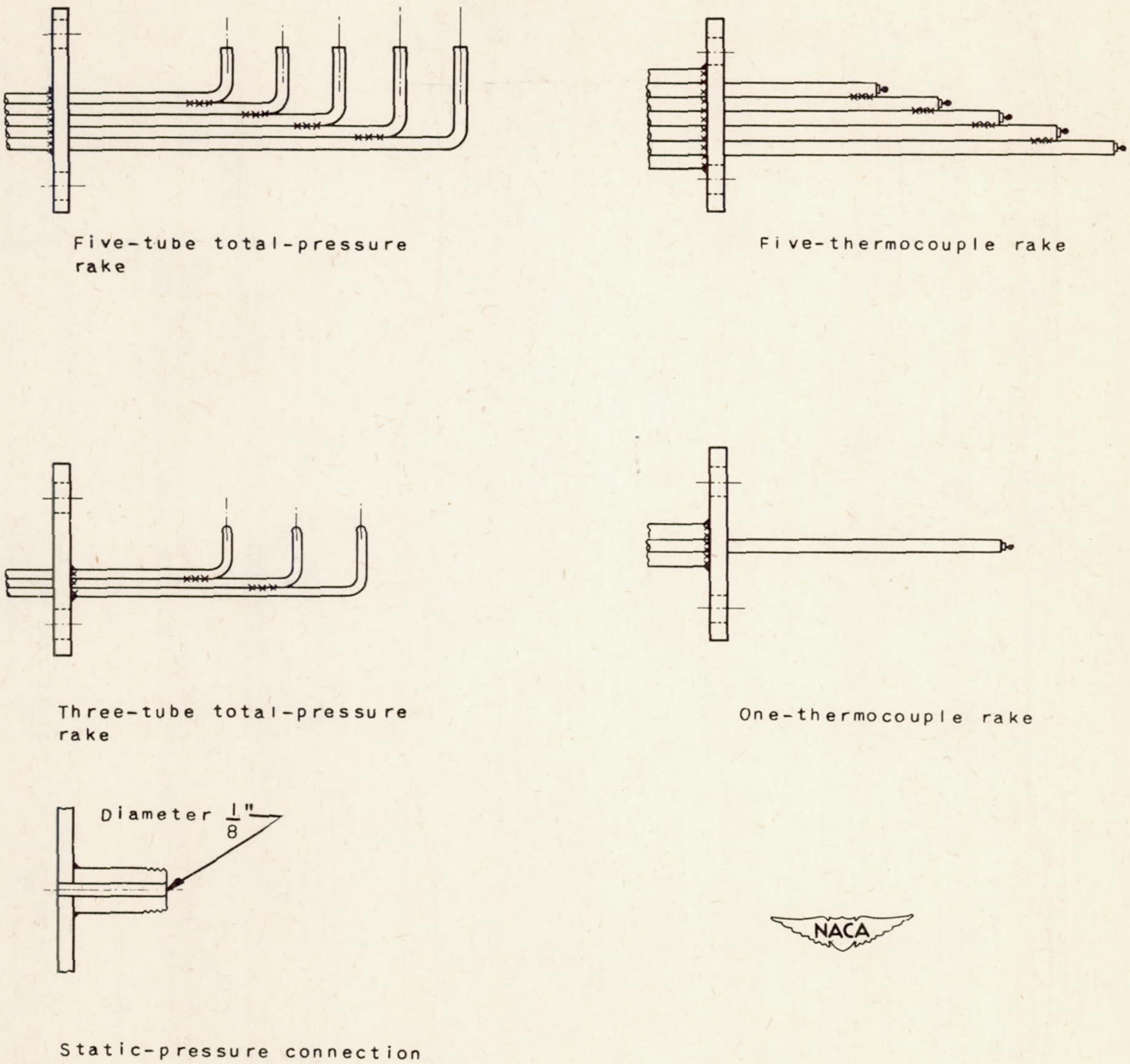

Figure 3. - Instrumentation details.

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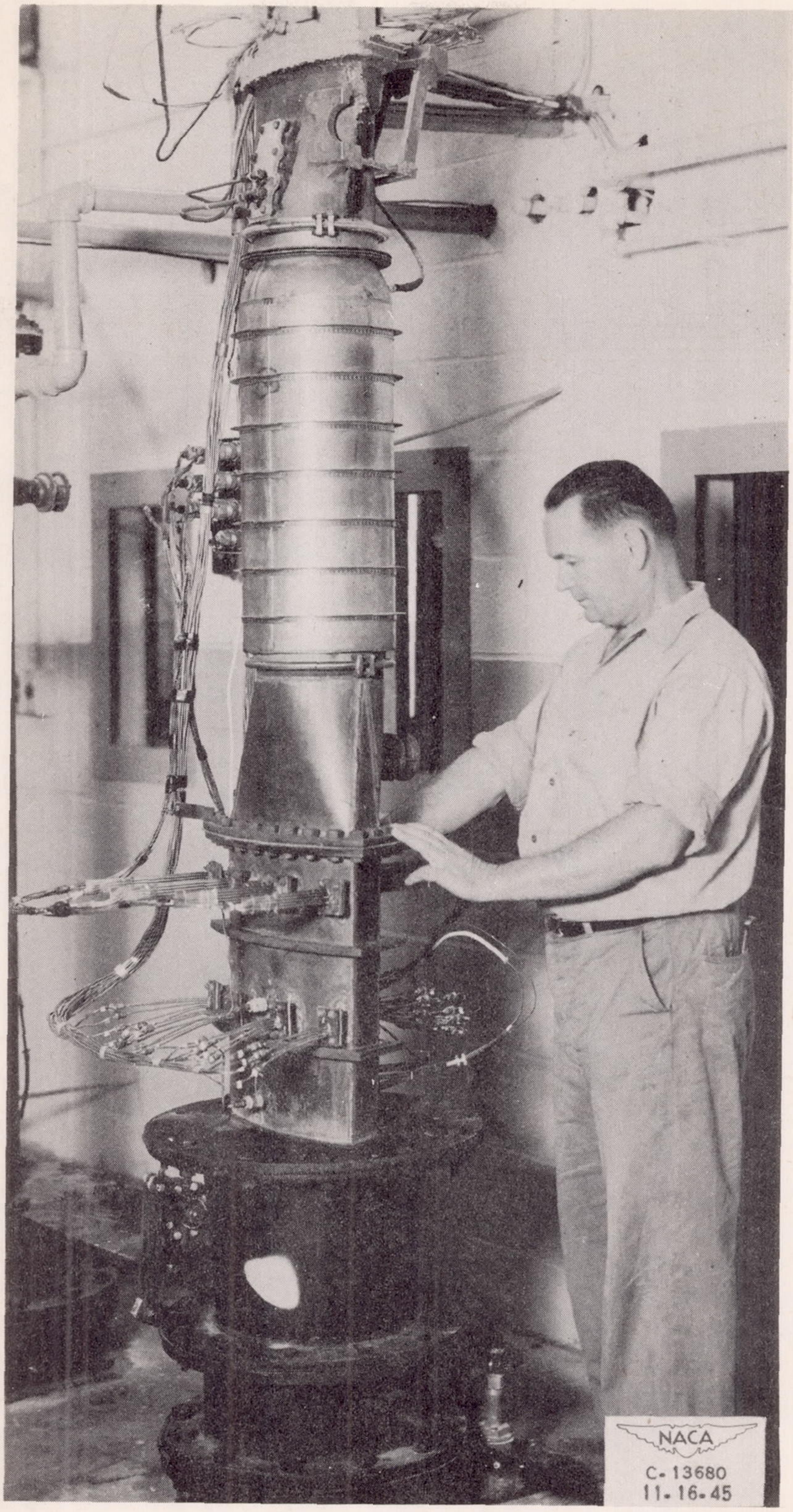

Figure 4. - Photograph of test rig, showing instrumentation positions.

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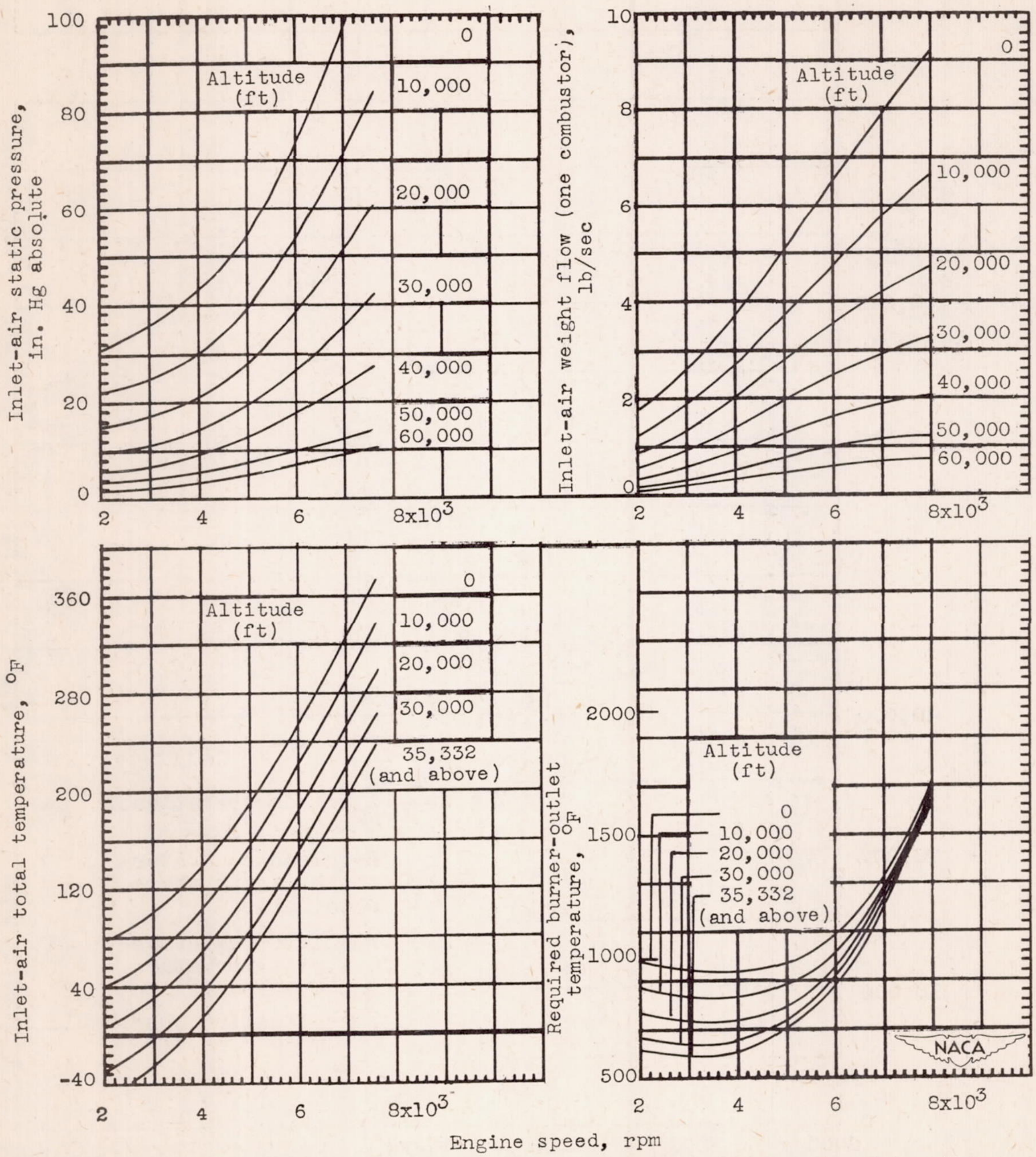

Figure 5. - Combustor inlet-air conditions and required temperature rise. Nozzle diameter, $16\frac{3}{4}$ inches; zero ram. (Data from Cleveland altitude-wind-tunnel investigation, reference 1.)

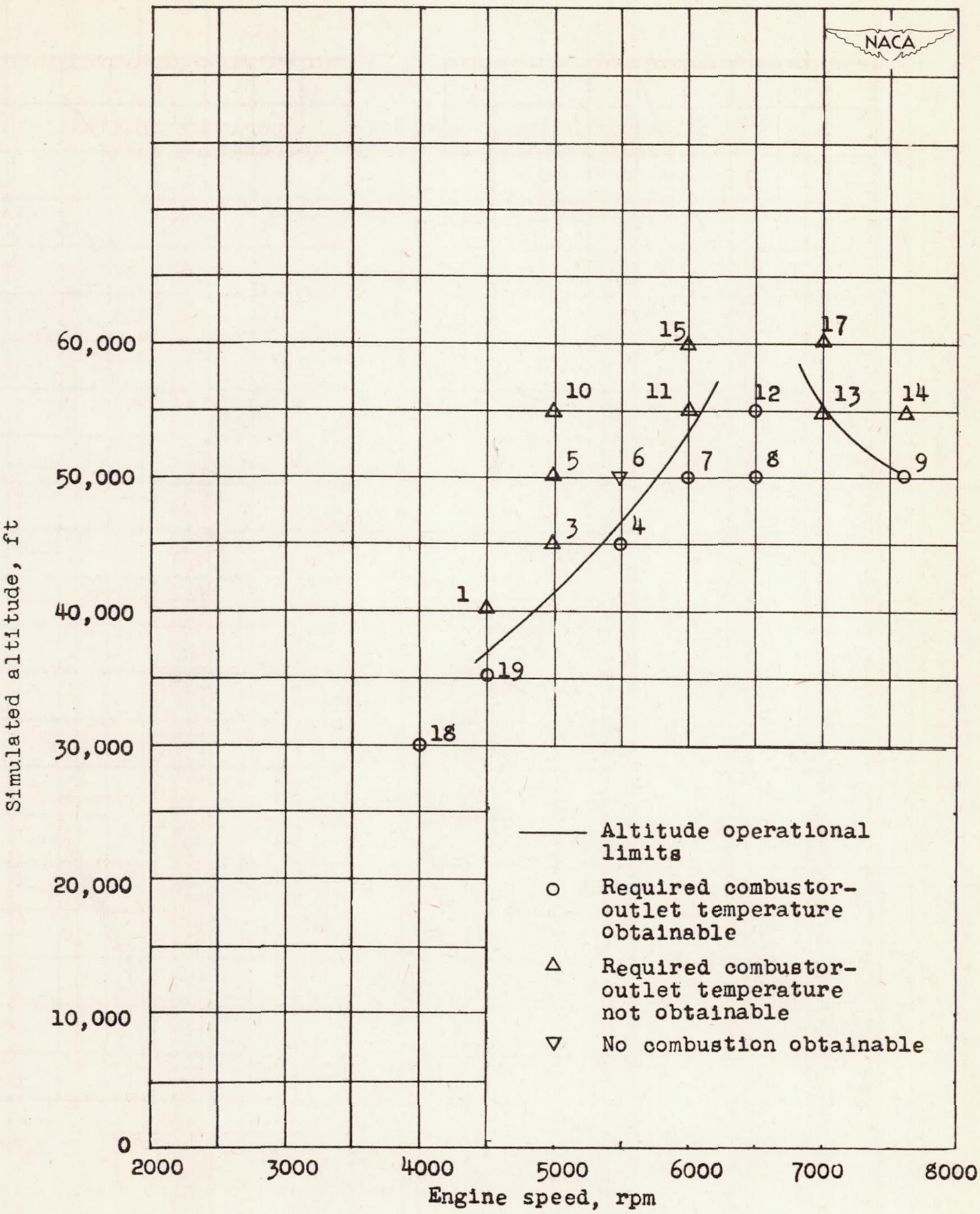

Figure 6. - Altitude operational limits for can-type combustor using AN-F-28 fuel. Zero ram. (Numbers refer to run numbers in table I.)

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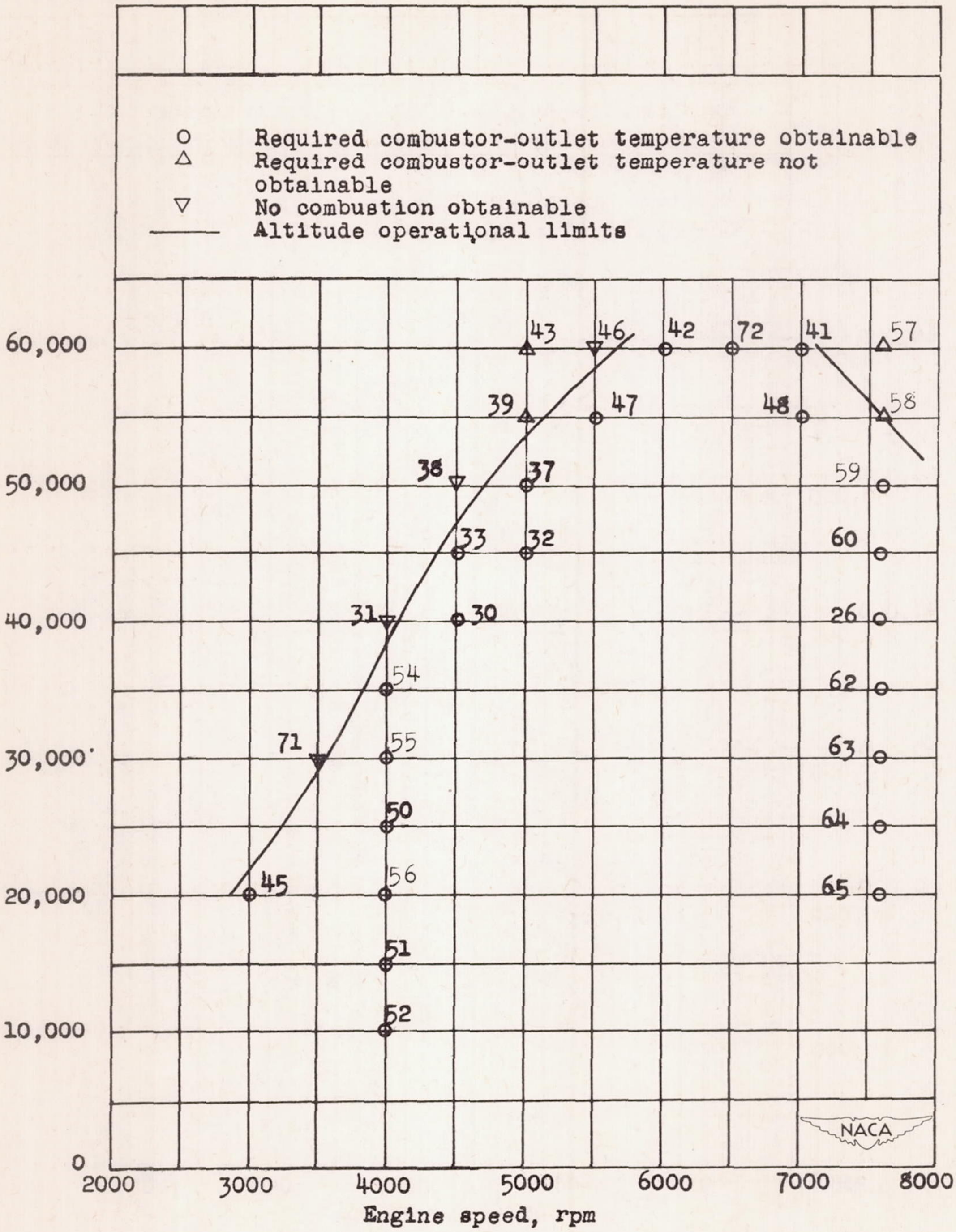
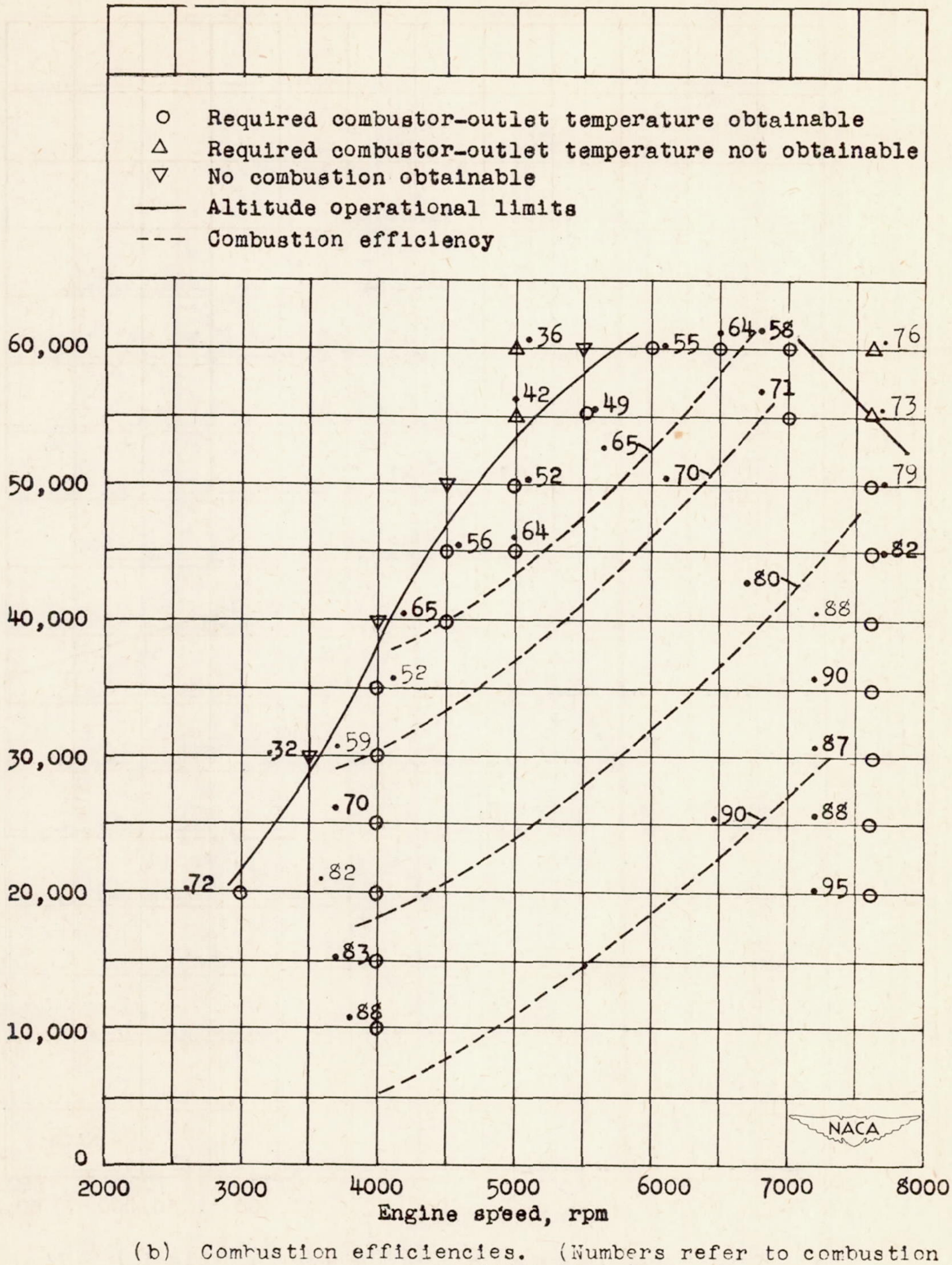


(a) Runs. (Numbers refer to run numbers in table I.)

Figure 7. - Altitude operational limits for can-type combustor using AN-F-32 fuel. Zero ram.



(b) Combustion efficiencies. (Numbers refer to combustion efficiencies.)

Figure 7. - Concluded. Altitude operational limits for can-type combustor using AN-F-32 fuel. Zero ram.

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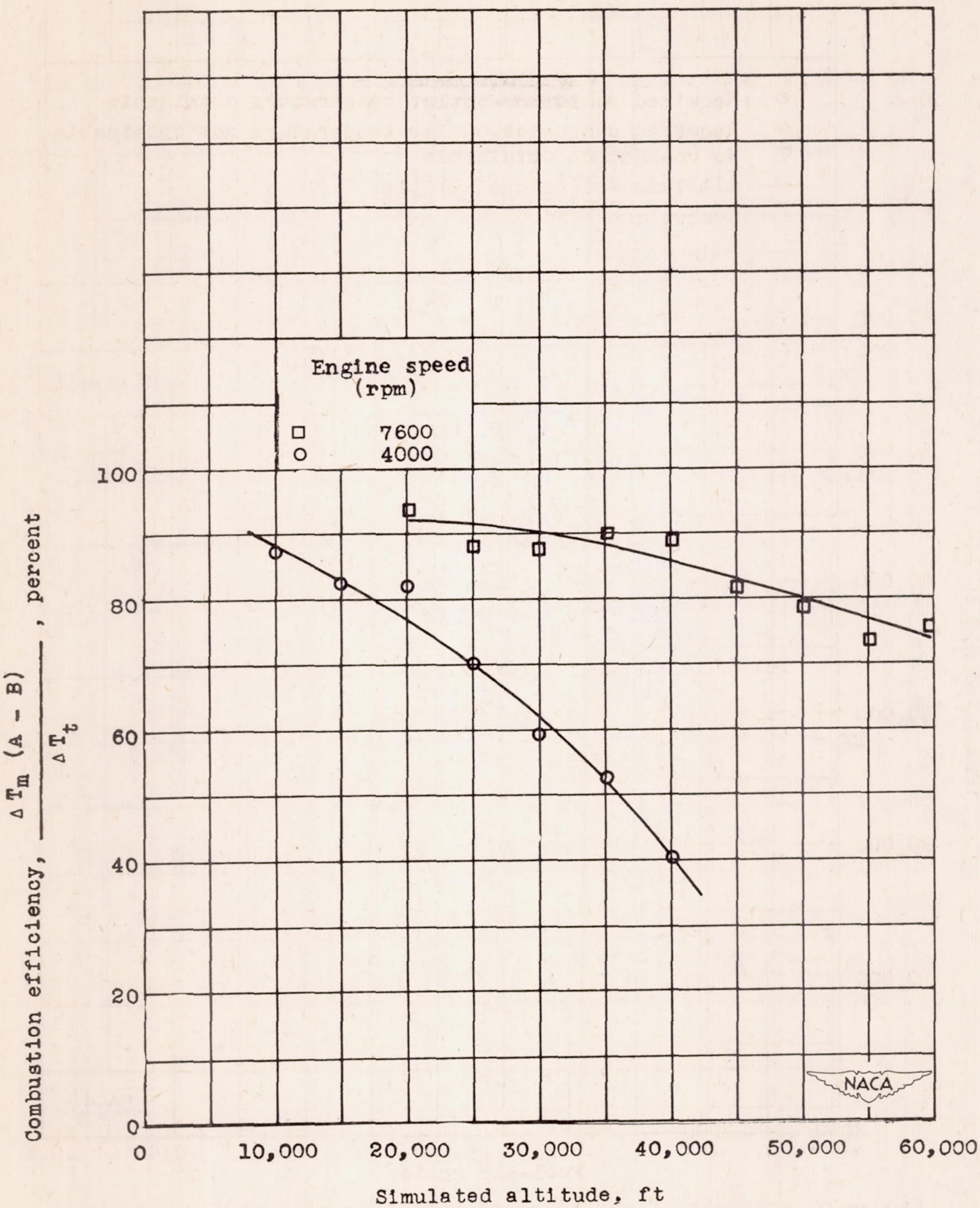


Figure 8. - Effect of variation of altitude on combustion efficiency in can-type combustor using AN-F-32 fuel. Zero ram.

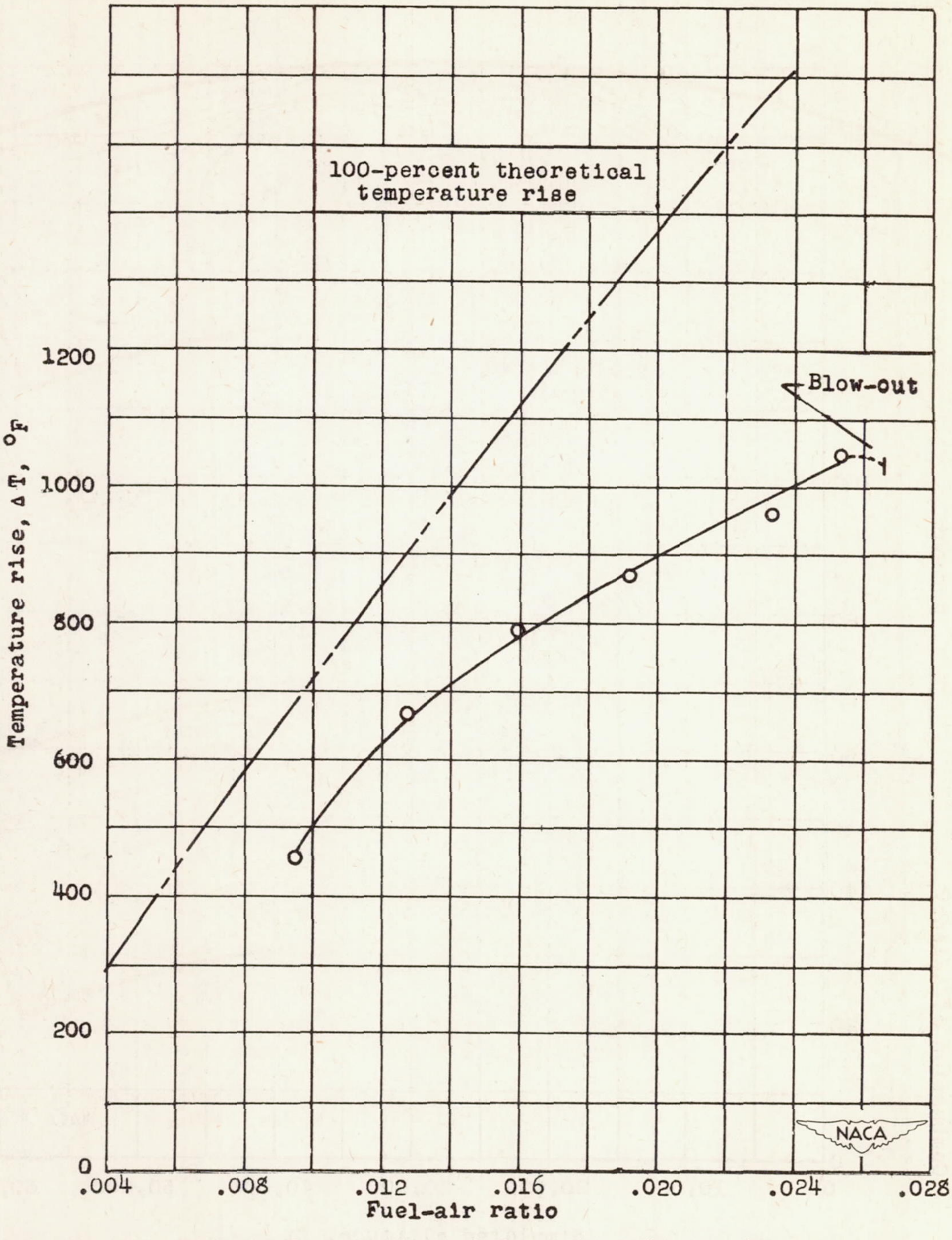
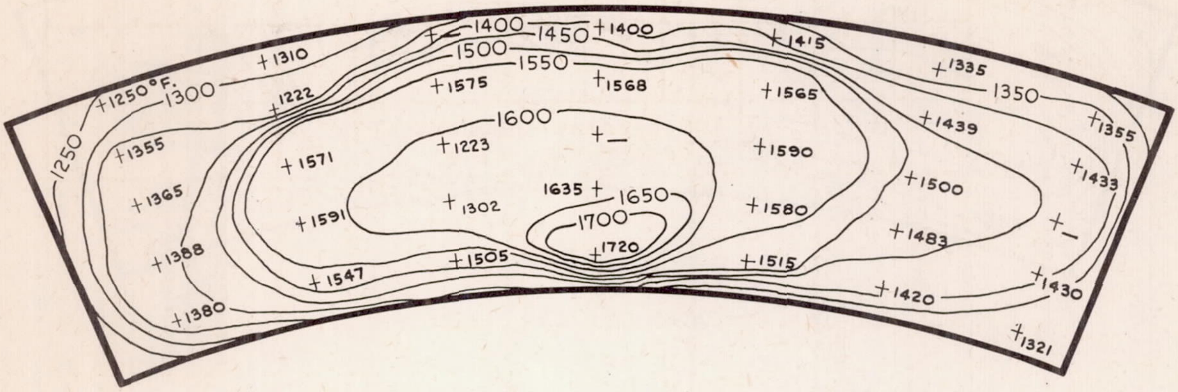
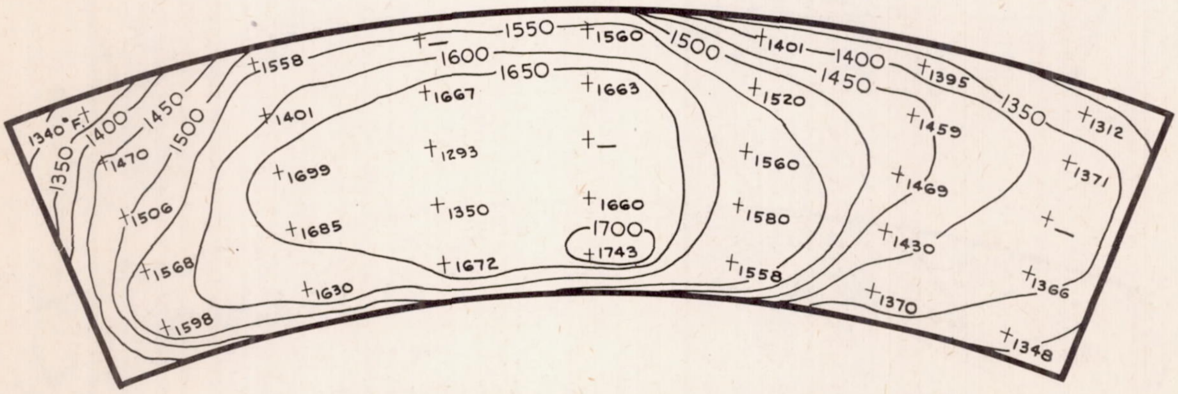


Figure 9. - Effect of variation of fuel-air ratio on temperature rise at operating conditions near dead-band in can-type combustor. Fuel, AN-F-28; engine speed, 6000 rpm; simulated altitude, 50,000 feet.

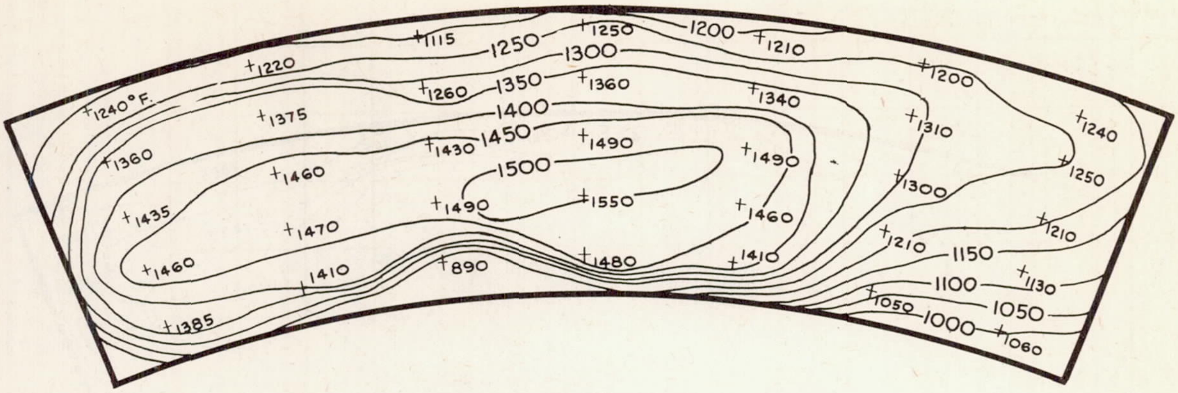


(a) Simulated altitude, 55,000 feet.

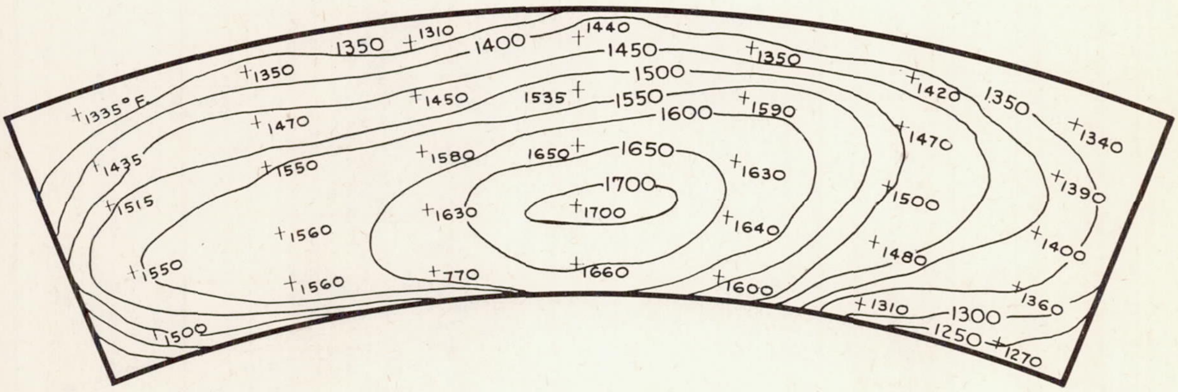


(b) Simulated altitude, 50,000 feet.

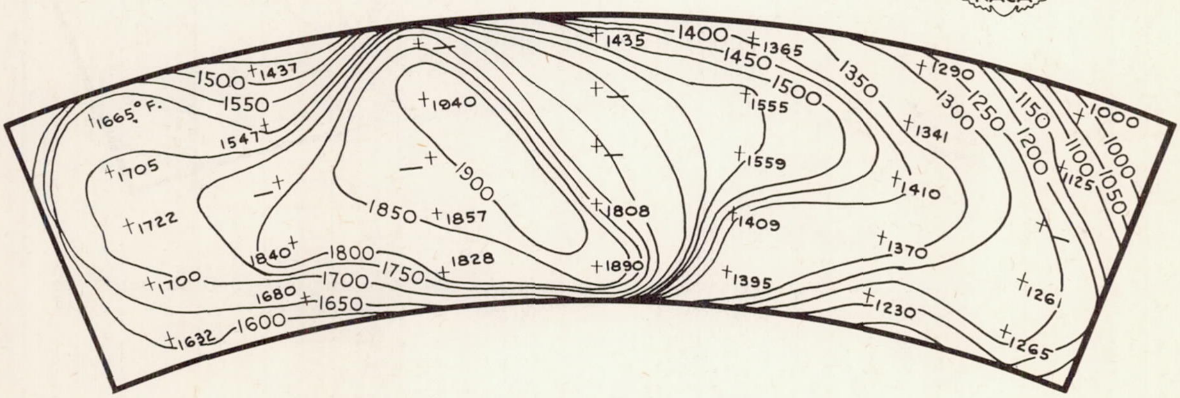
Figure 10. - Temperature-distribution pattern at instrumentation plane B-B in can-type combustor using AN-F-32 fuel. Engine speed, 7600 rpm.



(a) Simulated altitude, 55,000 feet.



(b) Simulated altitude, 50,000 feet.



(c) Simulated altitude, 20,000 feet.

Figure 11. - Temperature-distribution pattern at instrumentation plane B-B in can-type combustor using AN-F-28 fuel. Engine speed, 7600 rpm.

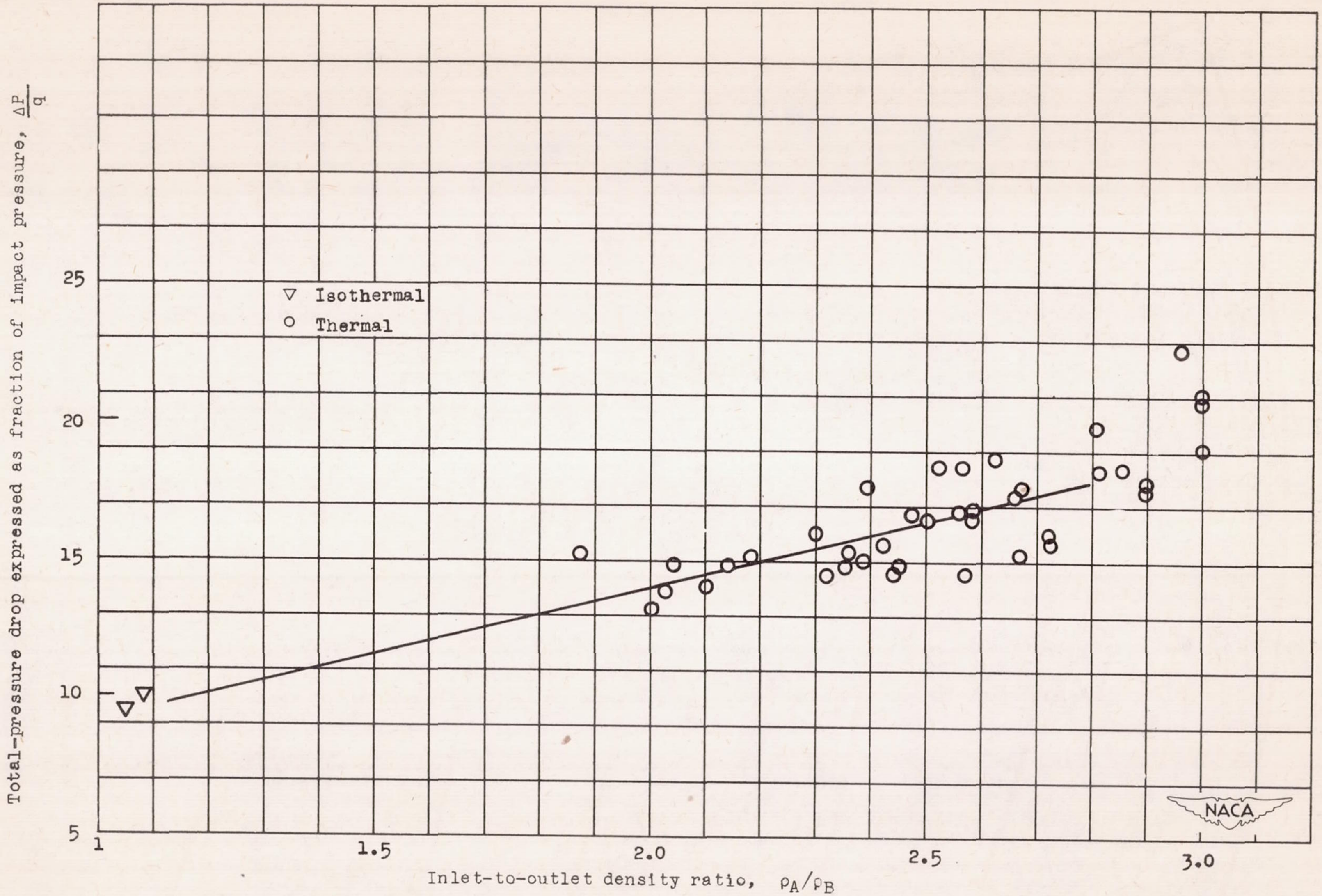


Figure 12. - Total-pressure drop across can-type combustor expressed as fraction of impact pressure plotted against inlet-to-outlet density ratio.