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THE EFFECT OF INCREASE IN COMBUSTION-AIR INLET TEMPERATURE FROM 80° TO 130° F ON THE SEA-LEVEL PERFORMANCE OF A 22-INCH-DIAMETER PULSE-JET ENGINE

By Michael F. Valerino, Robert H. Essig
and Richard F. Hughes

Aircraft Engine Research Laboratory
Cleveland, Ohio

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Air Materiel Command, Army Air Forces

and the

Bureau of Aeronautics, Navy Department

THE EFFECT OF INCREASE IN COMBUSTION-AIR INLET TEMPERATURE FROM 80° TO 130° F ON THE SEA-LEVEL PERFORMANCE OF A 22 INCH-DIAMETER PULSE-JET ENGINE

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SUMMARY

Data from a sea-level investigation of a 22-inch-diameter pulse-jet engine installed on a thrust stand were analyzed to determine the effect on the engine performance of a change in combustion-air temperature from approximately 80° to 130° F. The tests at both combustion-air temperatures covered a range of simulated ram pressures from 19 to 58 inches of water for the fuel-flow range of resonant operation.

The results show that, when the combustion-air temperature was increased from 80° to 130° F for the same conditions of fuel flow and simulated ram pressure, the jet thrust was reduced about 6 to 10 percent, which is roughly equivalent to the percentage increase in absolute temperature of the combustion air. This reduction in jet thrust was accompanied by a reduction of only 0 to 4 percent in combustion-air flow thus indicating that the loss in engine performance with increase in combustion-air temperature is due to reduced engine thermal efficiency as well as decreased combustion-air consumption.

INTRODUCTION

At the request of the Air Materiel Command, Army Air Forces, and the Bureau of Aeronautics, Navy Department, an investigation is being conducted at the NACA Cleveland laboratory to improve the performance and to extend the operating life of the pulse-jet engine. As part of this investigation, thrust-stand tests were conducted to determine the sea-level performance of a 22-inch-diameter pulse-jet engine at simulated ram pressures of approximately 0, 18, 40, and 58 inches of water over the entire fuel-flow range of resonant operation (reference 1). The temperature of the combustion air in these tests was of the order of 80° F.

In addition to the tests of reference 1, endurance tests were conducted on the 22-inch-diameter pulse-jet engine equipped with a standard flapper-valve grid assembly that was modified by the use of a shock-absorbing neoprene coating over the grid surfaces (reference 2). Part of the endurance tests were conducted at comparable operating conditions with combustion-air temperatures of 80° and 130° F.

The test data obtained in reference 2 at combustion-air temperatures of approximately 80° and 130° F are analyzed herein to determine the effect of combustion-air temperature on the performance of the pulse-jet engine. In order to provide a further check on the effect of the combustion-air temperature, limited tests were conducted with a standard grid assembly at a combustion-air temperature of approximately 130° F and the test results are compared with those of reference 1.

APPARATUS AND METHODS

The data analyzed herein were obtained from tests of the 22-inch-diameter pulse-jet engine using both a standard grid assembly and a neoprene-coated grid assembly. The neoprene-coated grid assembly was made by coating the entire grid surfaces of a standard grid assembly with a thin layer of neoprene (reference 2). The principal dimensions of the engine shell and the positions of the flapper-valve grid assembly and venturi are shown in figure 1. The thrust stand, the method of simulating ram pressure, and other installation and instrumentation details are essentially the same as described in reference 1.

During the tests, the combustion-air temperature was varied and controlled by means of an air-tempering tank located in the combustion-air ducting system (reference 1). The air-tempering tank contained separate steam and water coils and automatically controlled louvers for regulating the relative flow of combustion air through the hot and cold portions of the tank. The lowest and highest temperatures obtainable in the tests were about 80° and 130° F, respectively. The nature of the temperature-control equipment did not permit precise regulation of the combustion-air temperature during the tests.

The range of simulated ram pressure, fuel flow, and combustion-air temperature covered is presented in the following table:

Grid assembly	Nominal simulated ram pressure (in. water)	Fuel-flow range (lb/hr)	Nominal combustion-air temperature (°F)	Source of test data
Neoprene-coated	19	2000-2400	80, 130	Reference 2
	38	2200-3000	80, 130	
	58	2400-3400	80, 130	
Standard	38	2000-3000	130	Subject Report
	57	2400-3200	130	
	40	2000-3000	80	Reference 1
	58	2200-3400	80	

The procedure followed insetting and obtaining stabilization of the test conditions and in recording the test data is described in reference 1.

In the tests with the neoprene-coated grid assembly, comparable operating conditions for the two values of combustion-air temperature were within 3 minutes of engine operation. This procedure assures that the measured effects of combustion-air temperature on engine performance do not include any effects of possible valve deterioration obtained during the tests.

The tests with the standard grid assembly were conducted at a combustion-air temperature of approximately 130° F in order to afford a comparison with the results of reference 1 obtained at a combustion-air temperature of 80° F. Because of the limited number of points obtained at 130° F, the performance comparison at the two values of combustion-air temperature is used only for qualitatively checking the trends indicated by the more complete test results obtained in the tests with the neoprene-coated grid assembly.

The jet thrust, which is calculated from the test measurements by the method described in reference 1, represents the gross thrust of only the exhaust jet and is therefore greater than the actual thrust that would be obtained in flight by an amount equal to the drag associated with the momentum of the air entering the engine. The jet thrust may be given by the expression

$$F_j = \frac{W}{g} V_j \tag{1}$$

where

F_j jet thrust developed by engine, pounds

W combustion-air weight flow through engine, pounds per second

g acceleration of gravity, 32.2 feet per second per second

V_j effective jet velocity, feet per second

The performance comparison at the two values of combustion-air temperature includes comparisons of combustion-air weight flow, effective jet velocity, and gross jet thrust for the same conditions of fuel flow and simulated ram pressure.

RESULTS AND DISCUSSION

A summary of the test results obtained with the neoprene-coated grid assembly at variable conditions of fuel flow and simulated ram pressure for combustion-air temperatures of approximately 80° and 130° F is presented in table I. Reference 2 shows that no noticeable valve deterioration occurred during the total period of operation; hence, the test results give a true picture of the performance of the engine at the two values of combustion-air temperature for the range of ram pressures and fuel flows tested. The variations of combustion-air flow, effective jet velocity, and jet thrust with fuel flow are presented in figures 2, 3, and 4, respectively, for simulated ram pressures of 19, 38, and 58 inches of water and for combustion-air temperatures of approximately 80° and 130° F. Although the reproducibility of the test data is shown to be only of the same order of magnitude as the measured effects of the change in combustion-air temperature on the engine performance, a sufficient number of data points was obtained to permit determination of an average effect of change in combustion-air temperature on the engine performance.

It is evident from figures 2 to 4 that the increase in combustion-air temperature from 80° to 130° F has a detrimental effect on the engine performance. This loss of engine performance may be conveniently summarized as follows:

Simulated ram pressure (in. water)	Average reduction due to change of inlet combustion-air temperature from 80° to 130° F (percent)		
	Combustion-air flow	Effective jet velocity	Jet thrust
19	0	10	10
38	4	2	6
58	2	7	9

The reduction in jet thrust from 6 to 10 percent obtained with the increase of combustion-air temperature from approximately 80° to 130° F is roughly equivalent to the percentage increase in the absolute temperature of the combustion air. The loss of engine thrust due to the increase of combustion-air temperature is much greater than that accounted for by the reduction of combustion-air consumption; this result indicates that a loss of engine thermal efficiency is also involved, as reflected by a reduction in effective jet velocity.

A summary of the test data obtained with a standard grid assembly at simulated ram pressures of 40 and 58 inches of water for a combustion-air temperature of approximately 130° F is presented in table II. A total of about 20 minutes operating time was accumulated. In this interval no evidence of serious valve deterioration was noted. A comparison of these results with those of reference 1, which were established for a combustion-air temperature of 70° to 80° F, is made in figures 5 to 7. The performance results of reference 1 are represented by solid lines; dashed lines are faired through the limited data points obtained for a combustion-air temperature of 130° F. Trends similar to those obtained with the neoprene-coated grid assembly are shown for a change in combustion-air temperature.

A comparison of the frequency values given in table II with those obtained in the tests of reference 1 shows that the engine-cycle frequency is not affected by the change of combustion-air temperature.

SUMMARY OF RESULTS

The results of a sea-level thrust-stand investigation conducted on a 22-inch-diameter pulse-jet engine show that, when the combustion-air temperature is increased from 80° to 130° F for the same conditions of simulated ram pressure and fuel flow, the following losses in engine performance are obtained:

Nominal simulated ram pressure (in. water)	Fuel-flow range (lb/hr)	Average reduction due to change of inlet combustion-air temperature from 80° to 130° F (percent)		
		Combustion-air flow	Effective jet velocity	Jet thrust
19	2000-2400	0	10	10
38	2200-3000	4	2	6
58	2400-3400	2	7	9

The percentage reduction in jet thrust is approximately equivalent to the percentage increase in absolute temperature of the combustion air for the same conditions of fuel flow and simulated ram pressure over the range tested.

The reduction of engine thrust is due to decreases in both combustion-air consumption and engine thermal efficiency.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio

REFERENCES

1. Manganiello, Eugene J., Valerino, Michael F, and Essig, Robert H.: Sea-Level Performance Tests of a 22-Inch-Diameter Pulse-Jet Engine at Various Simulated Ram Pressures. NACA MR No. E5J02, 1945.

2. Manganiello, Eugene J., Valerino, Michael F., and Breisch, John H.: Endurance Tests of a 22-Inch-Diameter Pulse-Jet Engine With Neoprene-Coated Valve Grid. NACA MR No. E5J03, 1945.

TABLE I - SUMMARY OF RESULTS OBTAINED WITH

NEOPRENE-COATED GRID ASSEMBLY

Run	Simulated ram pressure (in. water)	Fuel flow (lb/hr)	Fuel-nozzle pressure (lb/sq in.)	Combustion-air temperature (°F)	Barometric pressure (in. Hg abs.)	Combustion-air flow (lb/hr)	Fuel-air ratio	Jet thrust (lb)	Effective jet velocity (ft/sec)	Total operating time at end of run (min)
1	58.5	3400	58	80	29.33	39,960	0.085	842	2444	
	58.7	3200	53	77	29.33	40,320	.079	883	2540	
	59.0	2800	41	78	29.33	37,800	.074	866	2655	
	58.6	2400	31	79	29.33	36,360	.066	805	2566	3.1
2	59.1	3400	59	128	29.33	39,600	0.086	753	2205	
	58.5	3200	53	128	29.33	38,880	.082	858	2557	
	55.5	2800	40	131	29.33	37,440	.075	786	2433	
	59.3	2400	32	133	29.33	36,000	.067	692	2227	6.0
3	38.4	3000	37	139	29.33	35,640	0.084	728	2368	
	36.4	2800	33	137	29.33	32,400	.086	699	2501	
	39.9	2400	24	138	29.33	30,960	.078	599	2244	
	40.8	2200	20	137	29.33	30,240	.073	551	2111	9.0
4	37.6	3000	46	88	29.33	36,360	0.083	758	2418	
	38.0	2800	40	86	29.33	35,280	.079	731	2402	
	40.0	2400	30	87	29.33	32,040	.075	699	2529	
	40.2	2200	25	86	29.33	31,320	.070	652	2412	12.0
5	58.8	3400	58	86	29.33	40,320	0.084	867	2494	
	58.9	2800	51	86	29.33	37,800	.074	847	2598	13.6
6	38.8	3000	------	135	29.33	33,840	0.089	709	2429	
	37.8	2800	40	135	29.33	35,280	.079	738	2425	
	37.8	2400	31	136	29.33	31,320	.077	650	2404	
	40.1	2200	27	136	29.33	30,960	.071	639	2394	16.4
7	19.1	2400	------	135	29.33	30,960	0.078	531	1990	17.3

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TABLE I - SUMMARY OF RESULTS OBTAINED WITH

NEOPRENE-COATED GRID ASSEMBLY - Concluded

Run	Simulated ram pressure (in. water)	Fuel flow (lb/hr)	Fuel-nozzle pressure (lb/sq in.)	Combustion-air temperature (°F)	Barometric pressure (in. Hg abs.)	Combustion-air flow (lb/hr)	Fuel-air ratio	Jet thrust (lb)	Effective jet velocity (ft/sec)	Total operating time at end of run (min)
8	57.4	3200	------	85	29.05	39,600	0.081	794	2325	
	57.6	2800	------	84	29.05	37,800	.074	843	2585	
	59.0	2400	31	85	29.05	36,000	.067	743	2392	19.9
9	58.0	3200	51	130	29.05	38,160	0.084	774	2350	
	58.7	2400	31	133	29.05	35,640	.067	728	2367	22.4
10	38.7	2800	37	134	29.05	33,480	0.084	725	2509	
	38.9	2200	25	135	29.05	30,960	.071	640	2397	25.0
11	37.6	2800	39	94	29.05	35,280	0.079	761	2502	
	36.7	2400	30	93	29.05	32,040	.075	723	2616	
	40.3	2200	25	93	29.05	31,320	.070	646	2391	27.5
12	15.8	2400	25	79	29.18	28,080	0.086	644	2660	
	20.4	2000	21	79	29.18	26,640	.075	558	2430	
	18.7	2400	25	126	29.18	28,080	.086	586	2418	
	19.3	2000	21	128	29.18	27,360	.073	509	2155	
	38.5	3000	43	134	29.18	33,480	.090	703	2433	
	38.7	2800	39	135	29.18	34,200	.082	737	2499	
	37.6	2400	31	136	29.18	31,680	.076	696	2545	35.4
13	37.5	3000	42	91	29.18	35,640	0.084	773	2515	
	37.1	2800	40	89	29.18	34,920	.080	764	2536	
	37.4	2400	31	89	29.18	32,040	.075	702	2540	38.2
14	57.9	3200	50	85	29.17	39,960	0.080	781	2267	
	57.2	2800	41	84	29.17	37,440	.075	821	2542	
	60.3	2400	------	83	29.17	36,000	.067	749	2411	40.9
15	58.4	3200	50	135	29.17	38,520	0.083	788	2370	
	57.4	2800	41	136	29.17	37,800	.074	784	2404	
	60.3	2400	31	137	29.17	35,640	.067	694	2256	43.6

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TABLE II - SUMMARY OF RESULTS OBTAINED WITH STANDARD GRID ASSEMBLY

Run	Simulated ram pressure (in. water)	Fuel flow (lb/hr)	Fuel nozzle pressure (lb/sq in.)	Combustion-air temperature (°F)	Barometric pressure (in. Hg abs.)	Combustion-air flow (lb/hr)	Fuel-air ratio	Jet thrust (lb)	Effective jet velocity (ft/sec)	Frequency (cycles/sec)	Total operating time at end of run (min)
1	57.7 52.7	3200 2400	60 36	130 130	29.08 29.08	40,310 37,090	0.079 .065	906 716	2603 2237	39 42	10.8
2	57.8 56.6	3400 2800	70 49	134 133	29.08 29.08	40,310 38,520	0.084 .073	841 825	2416 2487	38 40	12.6
3	37.3 39.5	2800 2000	47 27	128 128	28.99 28.99	34,560 31,320	0.081 .064	779 673	2614 2489	--------- ---------	19.0
4	33.3	3000	52	124	29.13	34,560	0.087	766	2571	39	20.7

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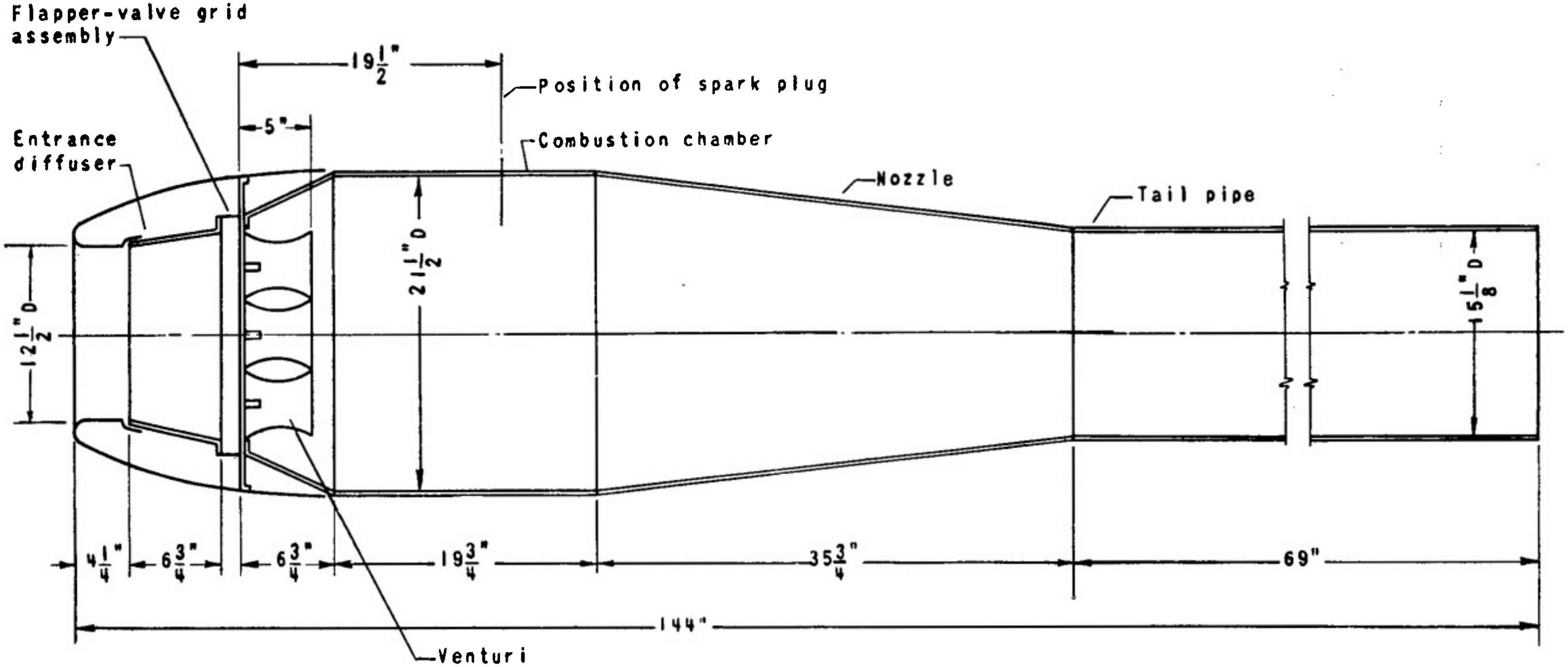

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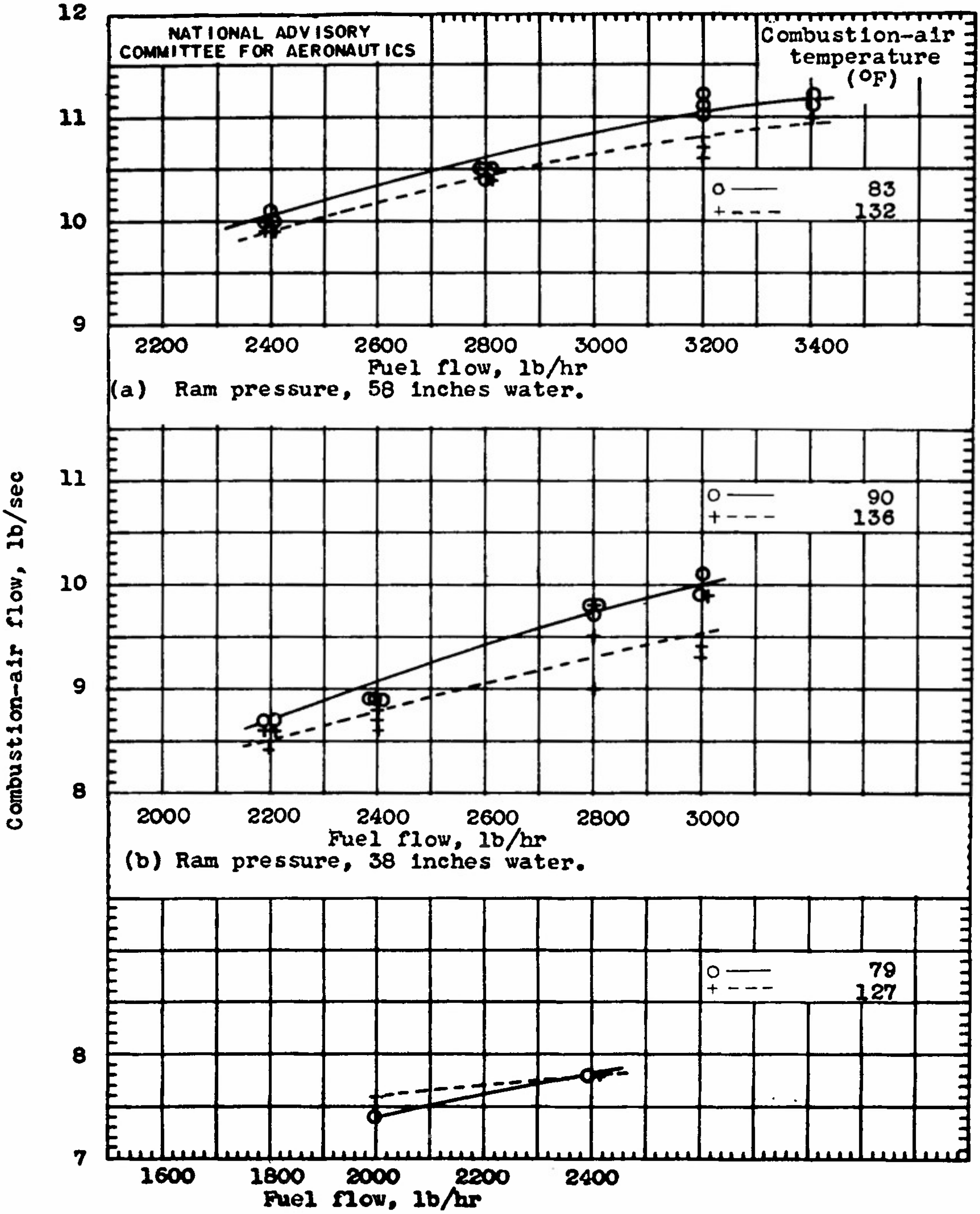
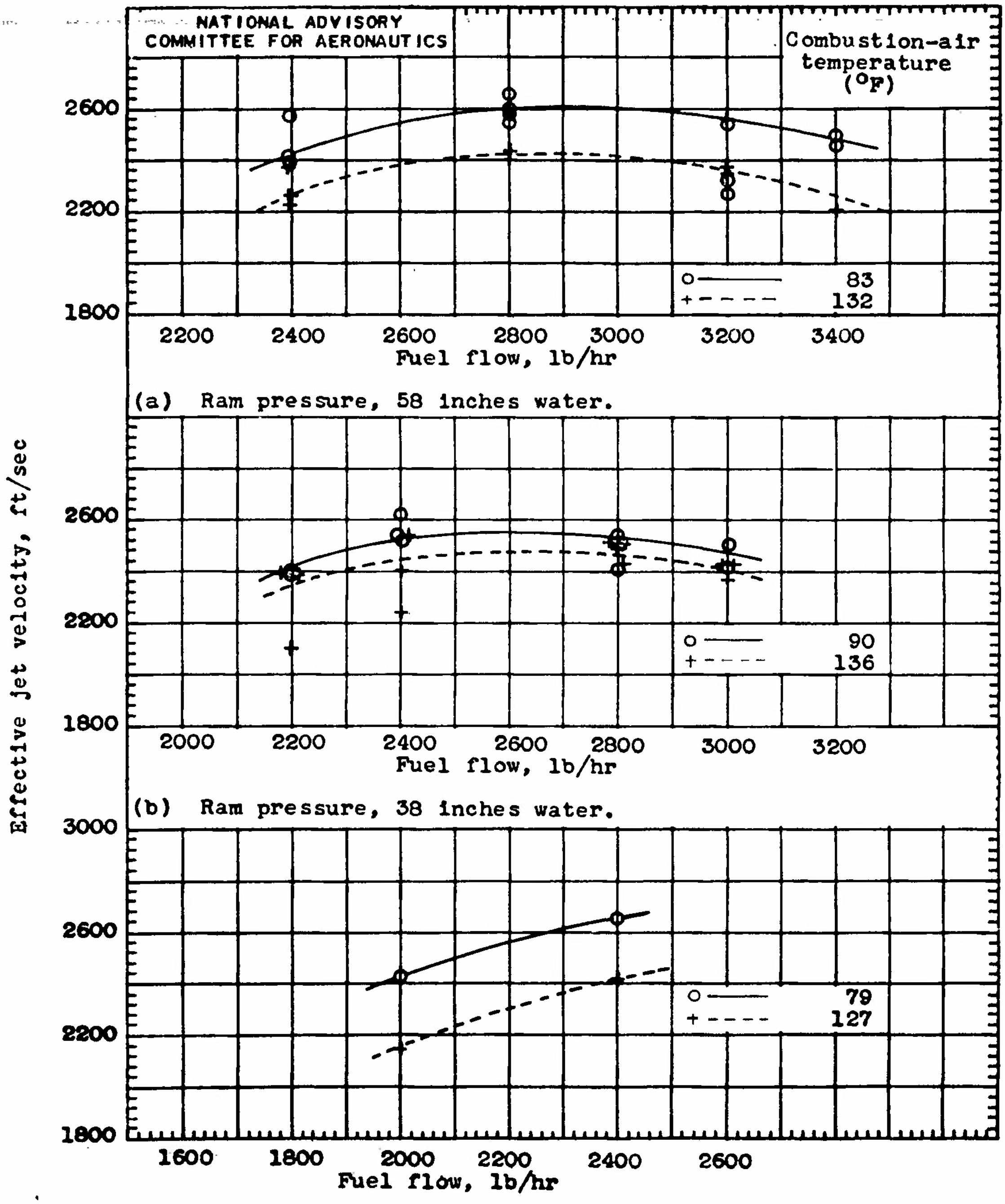
Figure 1. - Dimensions of 22-inch-diameter pulse-jet engine.



(c) Ram pressure, 19 inches water.

Figure 2. - Effect of combustion-air temperature on combustion-air flow for various test conditions. 22-inch-diameter pulse-jet engine (neoprene-coated valve grid).



(c) Ram pressure, 19 inches water.

Figure 3. - Effect of combustion-air temperature on effective jet velocity for various test conditions. 22-inch-diameter pulse-jet engine (neoprene-coated valve grid).

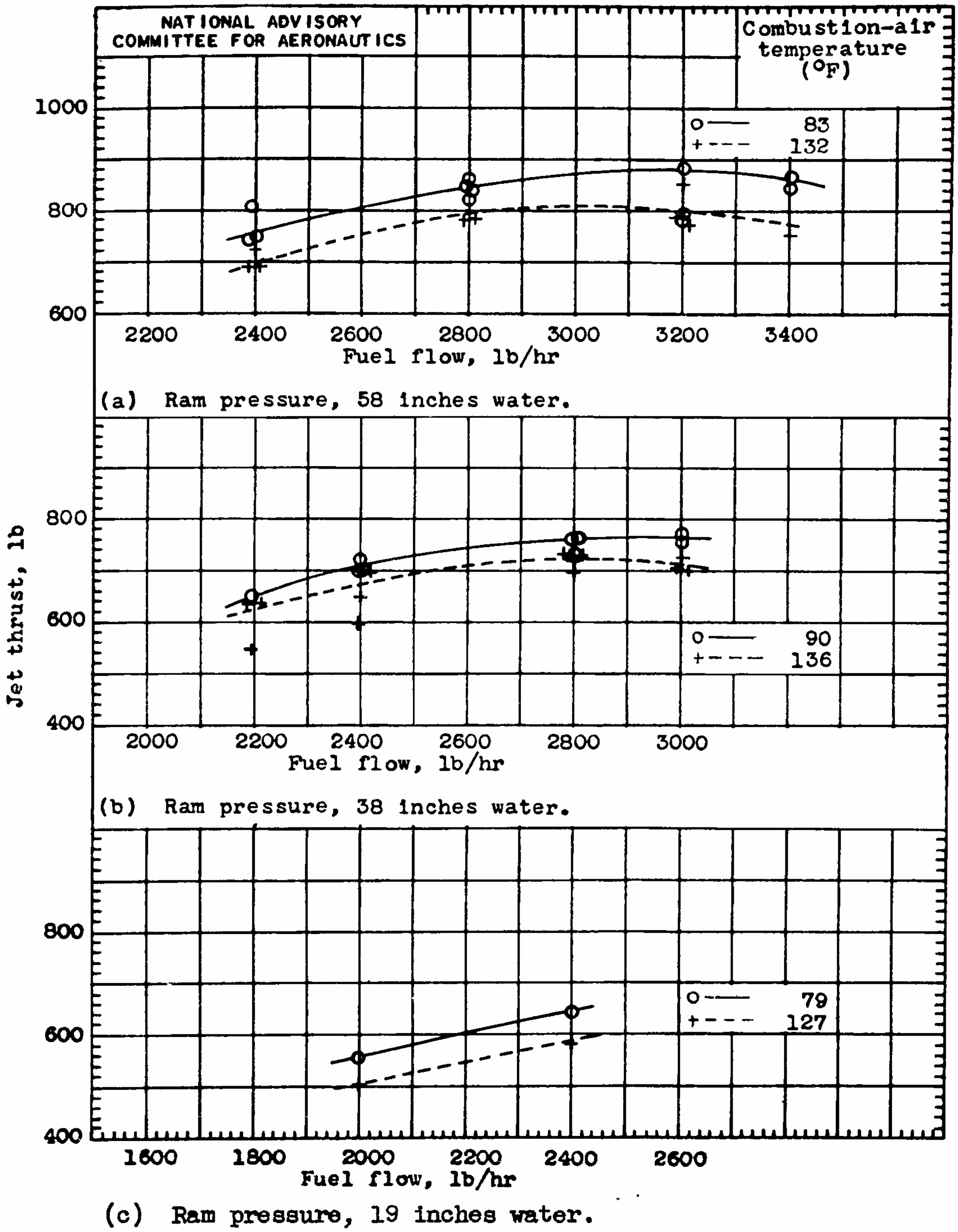
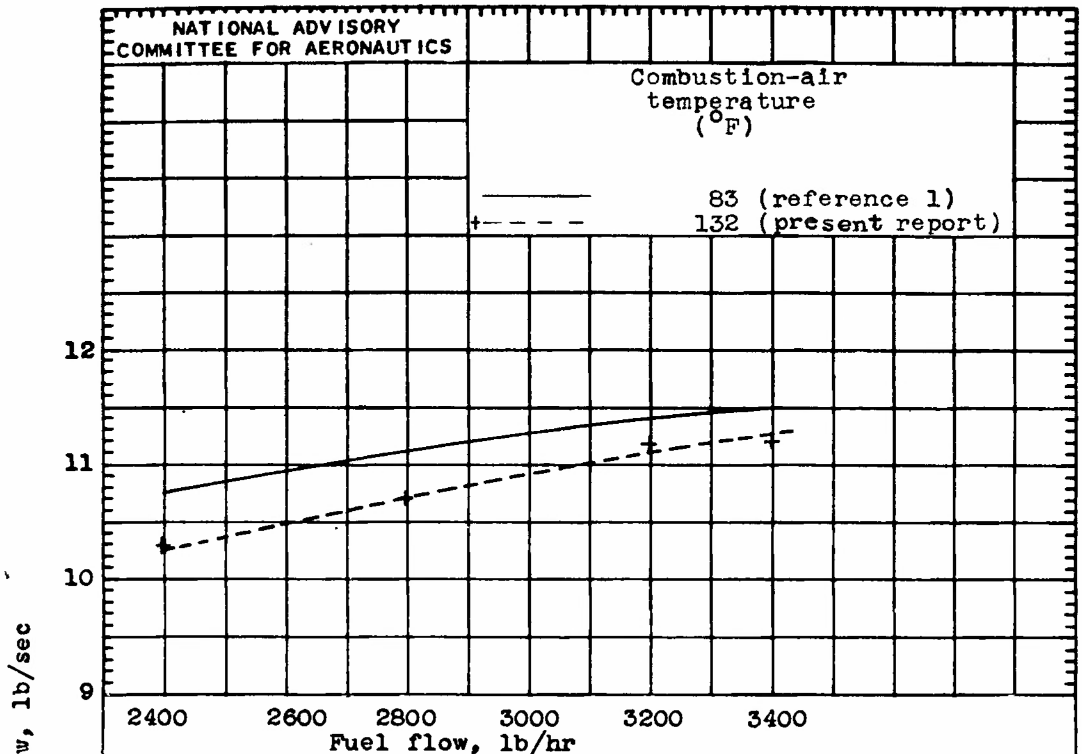
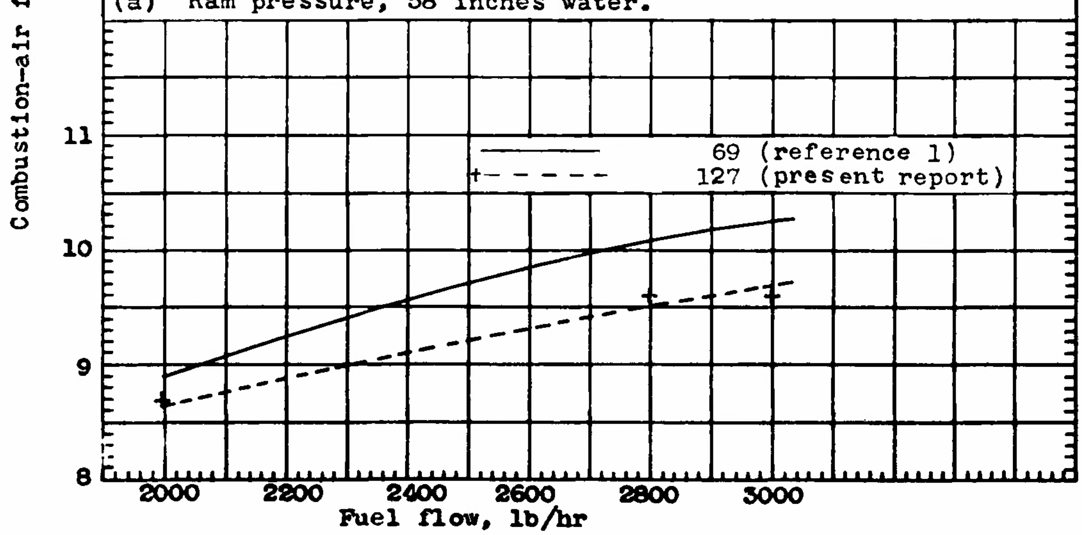


Figure 4. - Effect of combustion-air temperature on jet thrust for various test conditions. 22-inch-diameter pulse-jet engine (neoprene-coated valve grid).

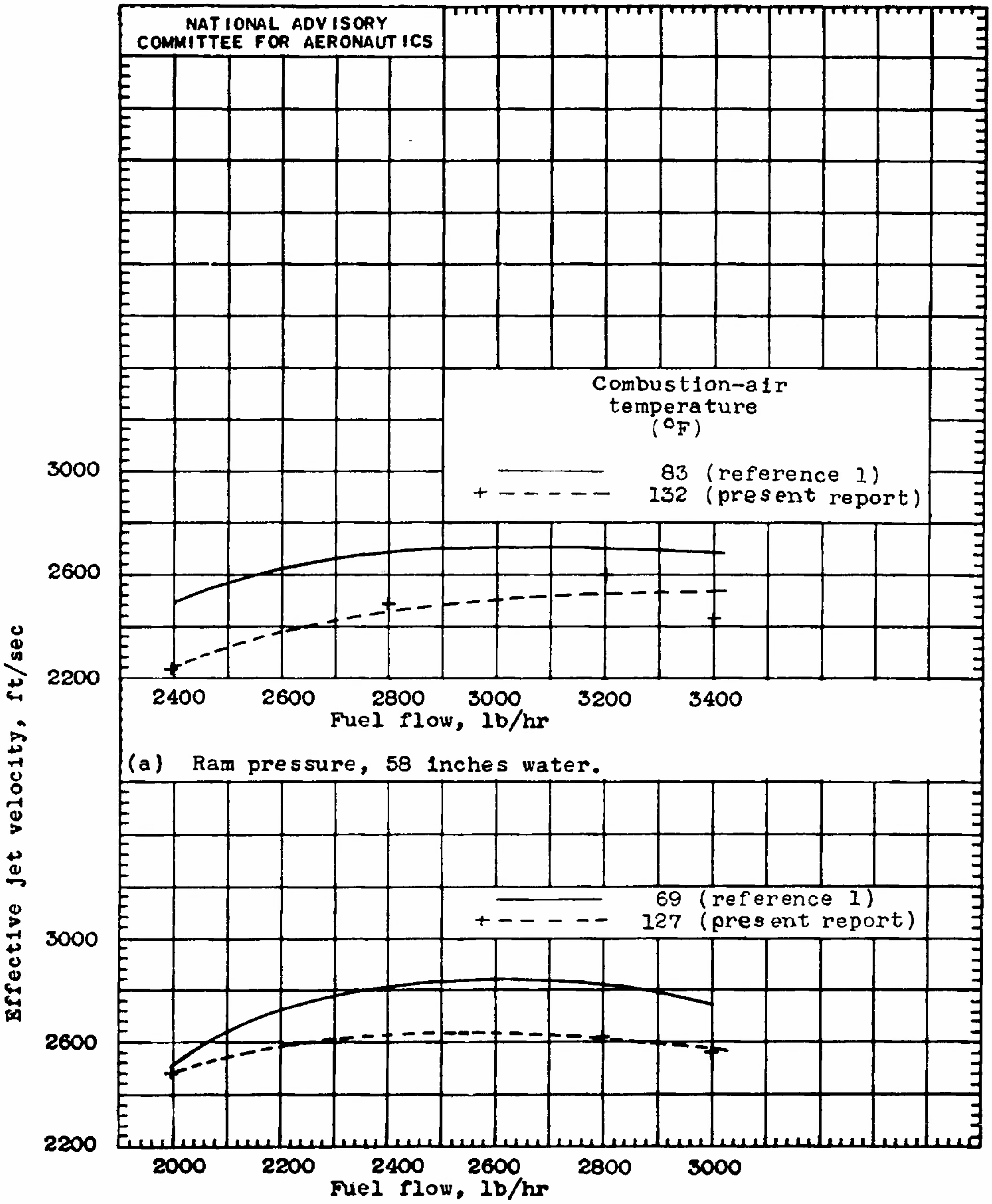


(a) Ram pressure, 58 inches water.



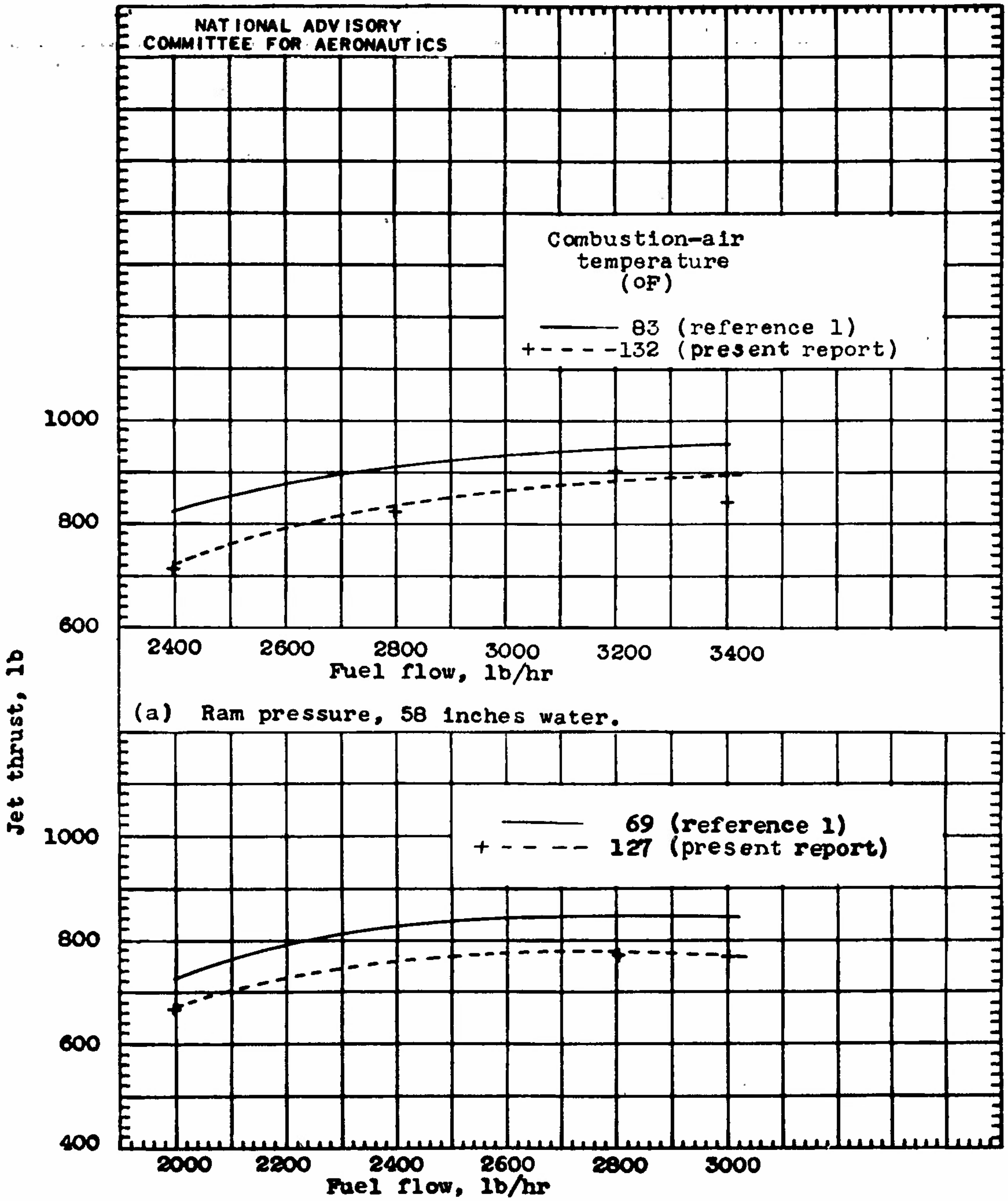
(b) Ram pressure, 40 inches water.

Figure 5. - Effect of combustion-air temperature on combustion-air flow for various test conditions. 22-inch-diameter pulse-jet engine (standard valve grid).



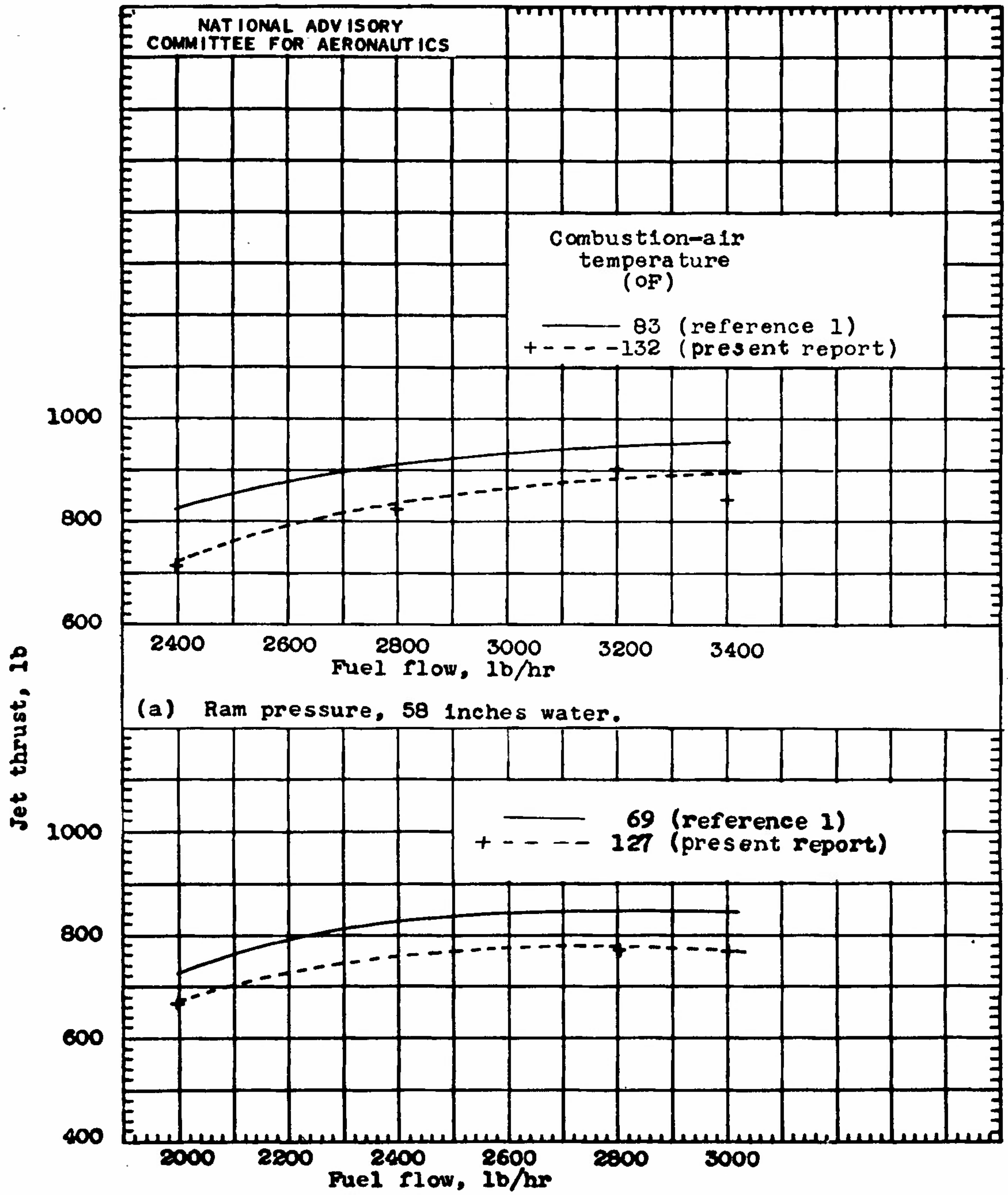
(b) Ram pressure, 40 inches water.

Figure 6. - Effect of combustion-air temperature on effective jet velocity for various test conditions. 22-inch-diameter pulse-jet engine (standard valve grid).



(b) Ram pressure, 40 inches water.

Figure 7. - Effect of combustion-air temperature on jet thrust for various test conditions. 22-inch-diameter pulse-jet engine (standard valve grid).



(b) Ram pressure, 40 inches water.

Figure 7. - Effect of combustion-air temperature on jet thrust for various test conditions. 22-inch-diameter pulse-jet engine (standard valve grid).