MR No. E6E15

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

June 1946 as
Memorandum Report E6E15

EFFECT OF A LOW-LOSS AIR VALVE ON PERFORMANCE OF A 22-INCH-DIAMETER PULSE-JET ENGINE

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WASHINGTON

NACA MR No. E6E15

NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

and the

Air Materiel Command, Army Air Forces

EFFECT OF A LOW-LOSS AIR VALVE ON

PERFORMANCE OF A 22 INCH-DIAMETER

PULSE-JET ENGINE

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SUMMARY

The performance of a 22-inch-diameter pulse-jet engine using a set of low-loss modified air valves was determined in thrust-stand tests at ram pressures equivalent to simulated flight speeds of 0 to 330 miles per hour and for a range of fuel-air ratios at each simulated flight speed. The results of these tests are compared with tests of the standard pulse-jet engine.

In general, the modified engine showed an improvement in performance only at low simulated flight speeds. The predicted flight thrust at high simulated flight speeds was slightly lower than that for the standard engine, and the specific fuel consumption was higher. From the results of these tests, it appears that only a negligible change in the over-all performance of the engine can be expected from low-loss valves.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, and the Air Materiel Command, Army Air Forces, the NACA has undertaken a study of methods of increasing the power and the efficiency of the pulse-jet engine. The nonreturn air valves in the engine have been found to have relatively high losses and it was therefore decided to investigate the possibilities of a low-loss valve to improve the performance of this engine. Valves with reduced losses as compared with the standard valves should permit the flow of larger masses of charge air, which would result in higher combustion-chamber densities at the start of combustion and higher peak combustion pressures. The higher peak pressures should result in an increase in both the power and the efficiency of the engine. (See reference 1.)

An investigation of various types of air valve was conducted in an apparatus that tested a small section of a pulse- or intermittent-jet engine valve grid (reference 2) and a low-loss valve was developed that could be substituted for the standard valve without further alteration to the engine.

The performance of a 22-inch-diameter pulse-jet engine with the low-loss modified air valves was determined by thrust-stand tests at the NACA Cleveland laboratory in May 1945. The results of the tests at simulated flight velocities varying from 0 to 330 miles per hour and a range of fuel flows are compared with the tests of the standard engine reported in reference 3.

DESCRIPTION OF LOW-LOSS MODIFIED VALVE

The low-loss modified air valve for direct application to the pulse-jet engine grid and the standard valve are shown in figure 1. The modified valve consists of two pieces of blue spring steel fastened together by rivets. The valve spring is 0.006 inch thick and the valve body is 0.015 inch thick. The 0.006-inch spring is so preformed that the valve in the normal position fits the contour of the grid. Because the valve spring and body are lapped with the spring beneath, a gap 0.006 inch high exists initially between the valve and the grid contour in the closed position. This gap is decreased by operation because the 0.006-inch spring material cuts into the soft aluminum-alloy grid, thereby reducing any leakage. The general dimensions of the modified valve are the same as the standard valve and the modified valve can be installed without alteration to the grid or the support plates. The natural frequency of the standard valve is approximately 125 cycles per second; whereas that of the modified valve is 55 cycles per second.

TEST PROCEDURE

The standard valves in a grid assembly were replaced by a set of the modified valves and the modified grid was mounted in a standard engine shell. Details of the thrust-stand installation of the pulse-jet engine and the testing procedure are fully described in reference 3.

For normal operation the engine was started by maintaining a gage pressure of 20 inches of water in the surge tank upstream of the engine and turning on the fuel and the spark. In the first four runs listed in table I, starting was attempted with surge-tank pressures decreasing from 20 to 10 inches of water. In each case above a starting pressure of 10 inches of water, the burning was essentially steady. In the rest of the tests run by starting with a pressure of 10 inches of water, the unit cycled successfully.

TEST RESULTS

In order to provide a direct comparison, the results of the modified engine tests are plotted with the performance curves for the standard unit taken from the data in reference 3.

Combustion-air weight flow. - The pulse-jet engine with the modified valves was first tested with a steady flow of air. The pressure in the large surge tank upstream of the engine was set and the corresponding flow through the unit was measured by an orifice upstream of the surge tank. The curves of variation in air flow with upstream surge-tank pressure for the standard and modified engines are shown in figure 2. For the same upstream pressure, the modified unit permitted a flow of about 4.5 pounds of air per second more than the standard unit.

The variation in combustion-air weight flow with fuel-air ratio during actual operation for several simulated flight speeds is shown in figure 3. At lean fuel-air ratios, the air flow for the modified unit was greater than that of the standard engine but approached that of the standard engine at high fuel-air ratios.

Flight thrust. - Predicted flight thrust is shown in figure 4 as a function of fuel-air ratio for several simulated flight speeds. The static thrust is approximately 14 percent greater for the modified engine than for the standard engine. At low flight speeds the modified valves would permit engine operation at lower fuel-air ratios than the standard valves. At a speed of 190 miles per hour, the thrust appeared to be approximately the same in either engine. At speeds of 280 and 340 miles per hour and a fuel-air ratio of 0.070, the thrust of the modified engine was slightly lower than that of the standard engine.

Maximum combustion-chamber pressure. - Peak combustion-chamber pressure as a function of fuel-air ratio for a range of simulated flight speeds is shown in figure 5. Data at speeds of 0 and 190 miles per hour for the standard engine were not available for comparison. The peak pressure of the modified engine appeared to be slightly higher than that for the standard engine at speeds of 280 and 340 miles per hour and at a fuel-air ratio of 0.070. A comparison of the plots of peak pressure and thrust for the test points of the modified engine indicated that these parameters varied in a similar manner with fuel-air ratio and flight speed. Although the peak pressure for the modified unit appeared to be somewhat higher than that for the standard unit, the flight thrust at high speeds was lower. This anomaly may have been due to small errors in each set of measurements that did not compensate each other.

Specific fuel consumption. - The power specific fuel consumption and thrust specific fuel consumption are shown in figure 6. The power specific fuel consumption for the modified engine was roughly the same as for the standard engine at a simulated flight speed of 190 miles per hour at fuel-air ratios above 0.070 but became greater at the higher speeds. The thrust specific fuel consumption for the modified engine was lower than that for the standard engine at a simulated flight speed of 0 miles per hour, approximately the same at 190 miles per hour, and greater at the higher speeds of 280 and 340 miles per hour.

Pressure cycle. - No change in cycle frequency was noted with the change in valves. Photographs of the pressure cycle are shown in figure 7 for several simulated flight speeds and fuel-air ratios. Photographs of the pressure cycle for the standard engine are given in reference 3. In general, the shape of the cycle was the same for both engines and no difference could be noted in the time required for various cycle events, such as induction of air, pressure rise, and expansion.

Valve life. - The life of the modified valves was considerably shorter than the life of the standard valves. After test run 9 (table I), the valve grid assembly was removed and examined. Two valves had separated, with the 0.015-inch pieces flying out the rear. Approximately 7 percent of the valves were replaced after $6\frac{1}{2}$ minutes of operation because they appeared about to split or fray. The engine with the repaired grid was run for an additional $4\frac{1}{4}$ minutes at the high simulated flight speeds and the grid was again removed. One valve had separated and 50 percent of the valves were in various stages of fraying, ranging from incipient fraying to the loss of as much as half of the valve body. Photographs of the grid after the high-flight-speed runs are shown in figure 8. The valve deterioration appears to be greater at high simulated flight speeds than at the low flight speeds. With a different thickness, with a different body material than spring steel, or with the impact absorbed by a substance such as rubber, the life of the modified valve might possibly be considerably increased.

DISCUSSION OF RESULTS

On the performance curves it can be seen that one of the results of the low-loss valve was to reduce the effect of fuel-air ratio on the variables, such as combustion-air weight flow, thrust, and power and thrust specific fuel consumptions; that is, the performance curves for the modified engine are flatter than those for the standard engine.

In general, an improvement in power and thrust specific fuel consumptions with low-loss valves seems possible at low flight velocities but, at higher velocities, this improvement so diminishes that the over-all effect on the performance is negligible.

The total air flow taken into the engine in one cycle may be divided into three parts: that taken in during the period in which the valve is opening, that taken in while the valve is fully open, and that entering while the valve is closing. The loss in total pressure occurring in any of these periods will be a function of the mass flow entering during that period and the flow losses per unit mass flow. The total loss for the intake portion of the cycle is, then, the sum of the three individual losses.

The flow loss in a valve of the type used in the pulse-jet engine, aside from that resulting from the grid-support structure, is a function of the valve position, which affects the contraction of the fluid jet through the valve. For two similar valves, such as the standard and modified valves, operating under identical conditions, the total loss for the period during which the valve is opening is proportional to the time required for opening. Because the modified valve is less stiff and therefore opens more quickly, the loss for this valve should be smaller in the opening period.

For the period in which the valve is fully open, the flow losses in the two valves should be the same. A visual inspection of the side of the valve exposed to the combustion chamber indicated that both valves opened fully and hit the upper support plate.

In the last portion of the intake cycle, because the valves close very rapidly (as evidenced by the fraying) and the pressure in the combustion chamber is rising, the air entering may be assumed to be only a very small percentage of the total air intake. Consequently, the loss occurring during this period may be neglected.

At low flight speeds, the valves do not open until the combustion-chamber pressure has fallen below the free-stream static pressure; whereas at high flight speeds, the valves will open when the combustion-chamber pressure falls below ram pressure. The valves will therefore open earlier in the cycle at high speeds, as compared with the cycle at low speeds. The time required to open the valve at high flight speeds will be a smaller percentage of the total time for air intake and a smaller percentage of the total mass flow enters while the valve is opening. Inasmuch as the effect of a low-loss valve is noted only during the period when the valve is opening, the over-all effect of reduced losses in this period becomes smaller as the flight velocity is increased.

CONCLUDING REMARKS

Comparison of the performance of a 22-inch-diameter pulse-jet engine with standard valves and with modified low-loss valves at ram pressures equivalent to flight velocities of 0 to 330 miles per hour and for a range of fuel-air ratios at each simulated flight speed shows that the modification resulted in only a negligible change in the over-all performance of the engine. Qualitatively, the changes were as follows for the various performance parameters: Predicted flight thrust was higher for the modified engine than for the standard engine at low speeds and slightly lower at high speeds. Combustion-air weight flow and peak combustion-chamber pressures were generally slightly higher for the modified unit. The power and the thrust specific fuel consumptions were higher for the modified unit, except at low velocities. The life of the modified valve was considerably shorter than that of the standard valve.

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2. Bressman, Joseph R., and McCready, Robert J.: Tests of Air Valves for Intermittent-Jet Engines at Speeds of 20 and 25 Cycles Per Second. NACA MR No. E5E08, 1945.

3. 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.

TABLE I. - PERFORMANCE OF 22-INCH-DIAMETER PULSE-JET ENGINE WITH MODIFIED VALVES

Run	Surge-tank pressure (in. water)	Fuel flow (lb/hr)	Fuel-nozzle pressure (lb/sq in. gage)	Atmospheric pressure (in. Hg absolute)	Combustion-air temperature (°F)	Combustion-air weight flow (lb/hr)	Fuel-air ratio	Test thrust (lb)	Effective jet velocity (ft/sec)	Predicted flight thrust (lb)	Frequency (cps)	Maximum combustion pressure (in. Hg gage)	Minimum combustion pressure (in. Hg gage)	Total time at end of run (min)
[a]1	19.4	2200	29	29.08	67	15,500	0.140	36	279	0				
[a]2	19.3	1800	19	29.08	67	15,120	.120	32	261	0				1.6
[a]3	19.4	2000	20	29.08	66	16,920	.120	32	238	0				
[a]4	19.5	1500	15	29.08	66	15,500	.100	36	282	0				2.7
5	18.8	1500	15	29.08	68	27,000	.056	457	1988	396	40	21.0	-7.4	
6	18.2	2000	22	29.08	67	29,160	.069	627	2522	563	40	28.6	-7.6	4.4
7	2.8	1400	14	29.08	64	22,320	.063	401	2106	384	40	16.0	-7.0	5.1
8	-2.5	1700	18	29.08	65	24,500	.069	477	2284	482	40	23.1	-8.0	
[b]9	-4.5	2100	25	29.08	66	25,560	.082	562	2578	568	40	27.8	-7.4	6.4
10	36.3	2000	20	29.39	72	34,920	.057	604	2039	494	41	30.5	-------	
11	34.7	2500	30	29.39	71	34,920	.072	788	2650	681	40	45.8	-------	1.65
12	19.2	2400	28	29.39	71	30,600	.078	711	2724	656	40	37.6	-------	2.5
13	55.4	2300	27	29.39	75	40,320	.057	722	2114	564	41	43.6	-------	
14	53.7	2800	40	29.39	72	40,320	.069	884	2578	728	40	55.8	-------	4.15

[a]Unit not cycling; starting ram pressures too high.
[b]After this run, grid repaired and replaced.

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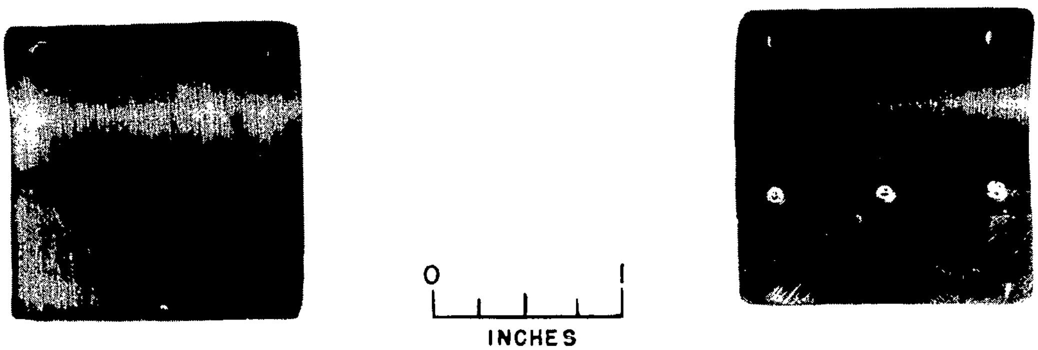

(a) Photographs of standard valve (left) and low-loss modified valve (right).

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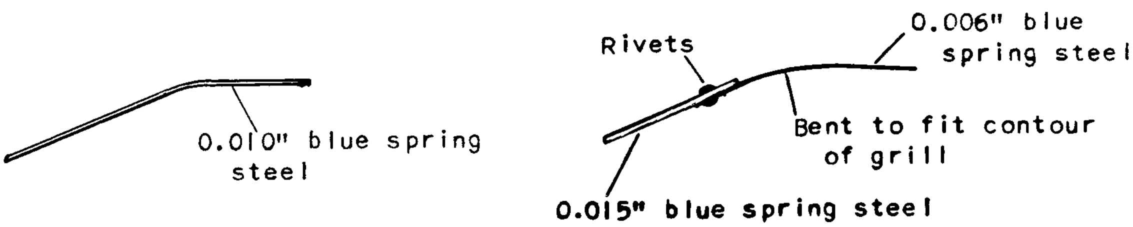


(b) Sketches of cross section of standard valve (left) and low-loss modified valve (right).

Figure 1. - Photographs and sketches of standard valve and low-loss modified valve for 22-inch-diameter pulse-jet engine.

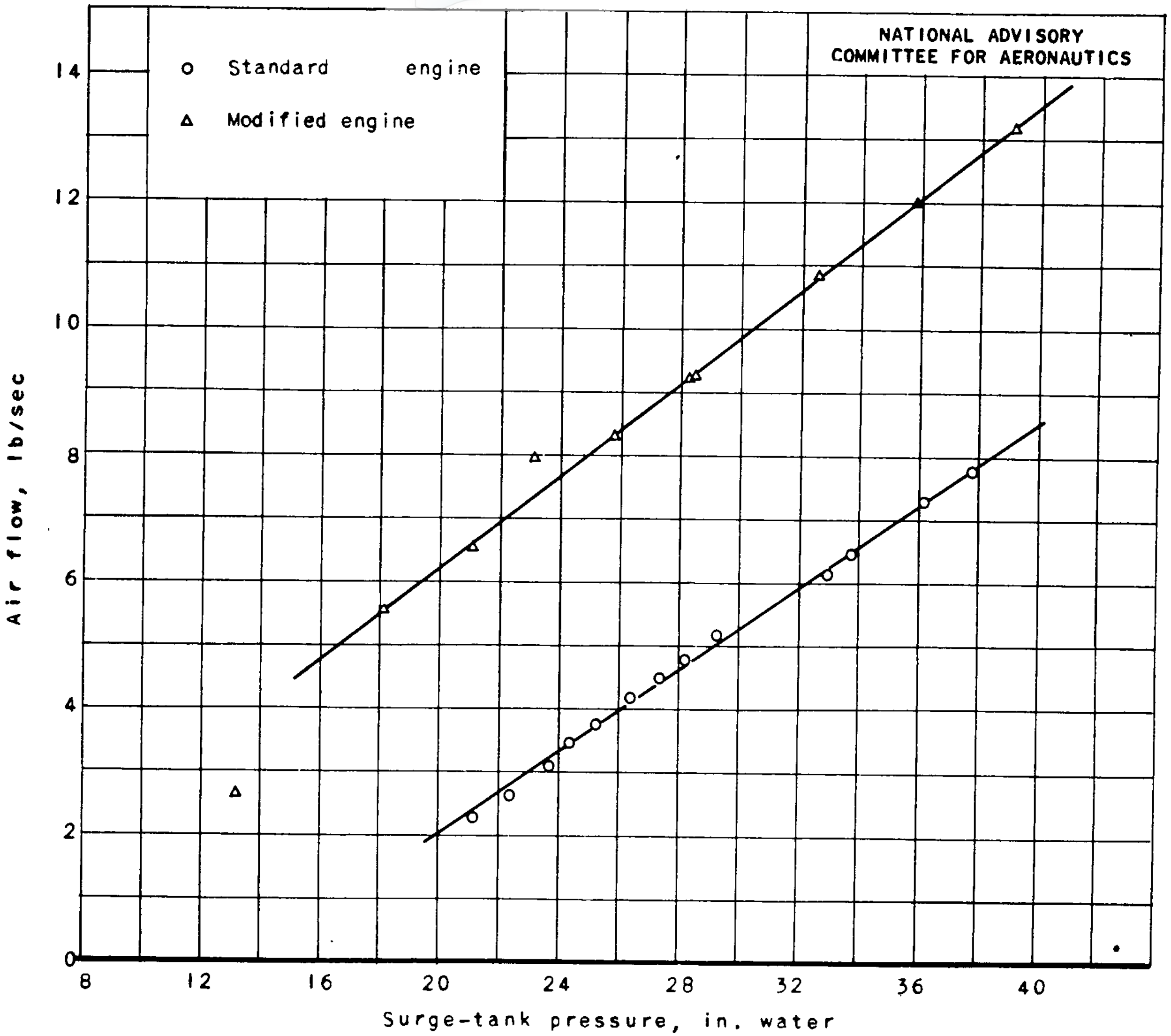


Figure 2. - Variation in steady air flow with surge-tank pressure for standard and for modified pulse-jet engines.

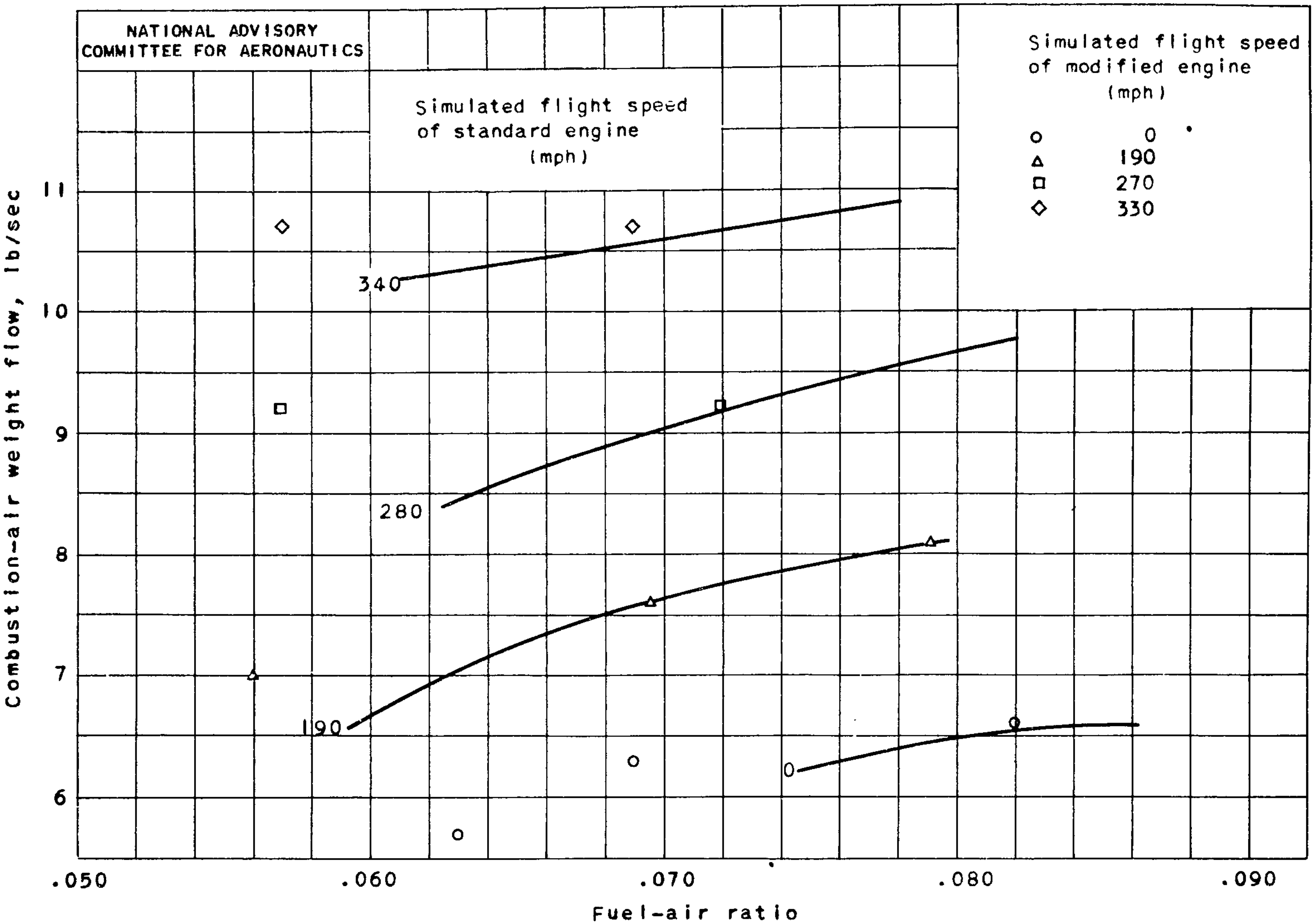


Figure 3. - Variation of combustion-air weight flow with fuel-air ratio for several simulated airspeeds. Test data for modified pulse-jet engine spotted on performance curves for standard engine.

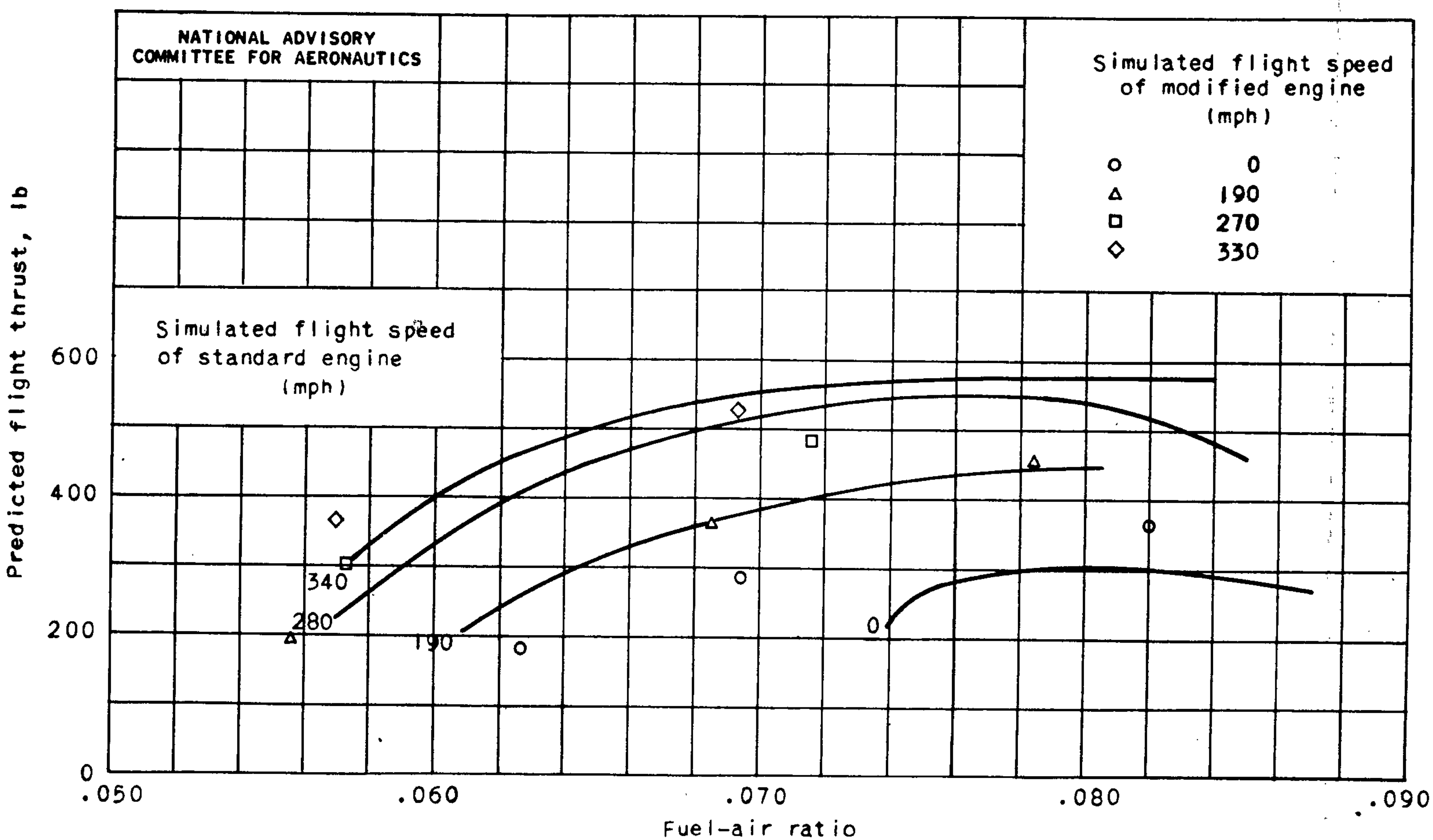


Figure 4. – Variation of predicted flight thrust with fuel-air ratio for several simulated flight speeds. Test data for modified pulse-jet engine spotted on performance curves for standard engine.

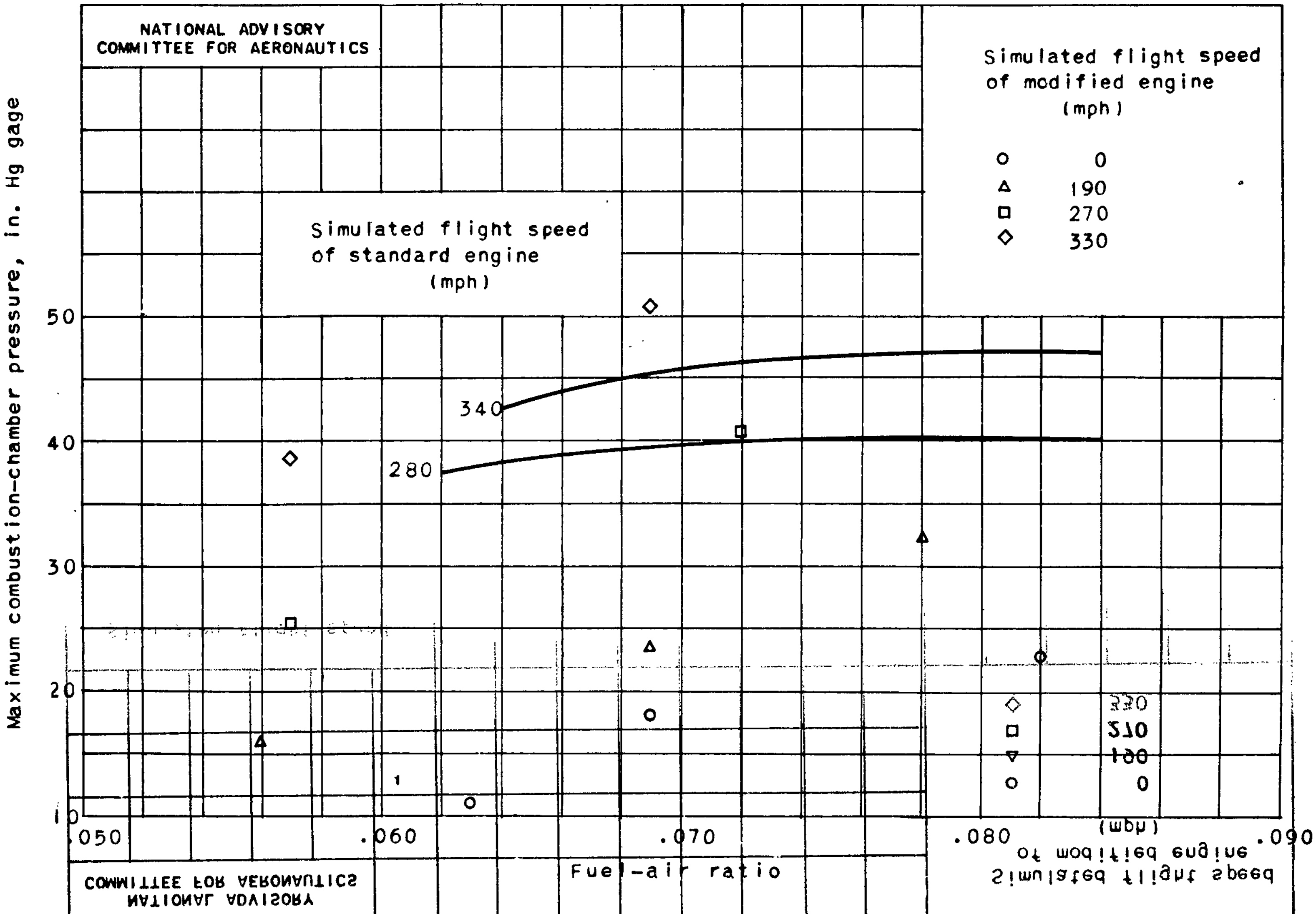
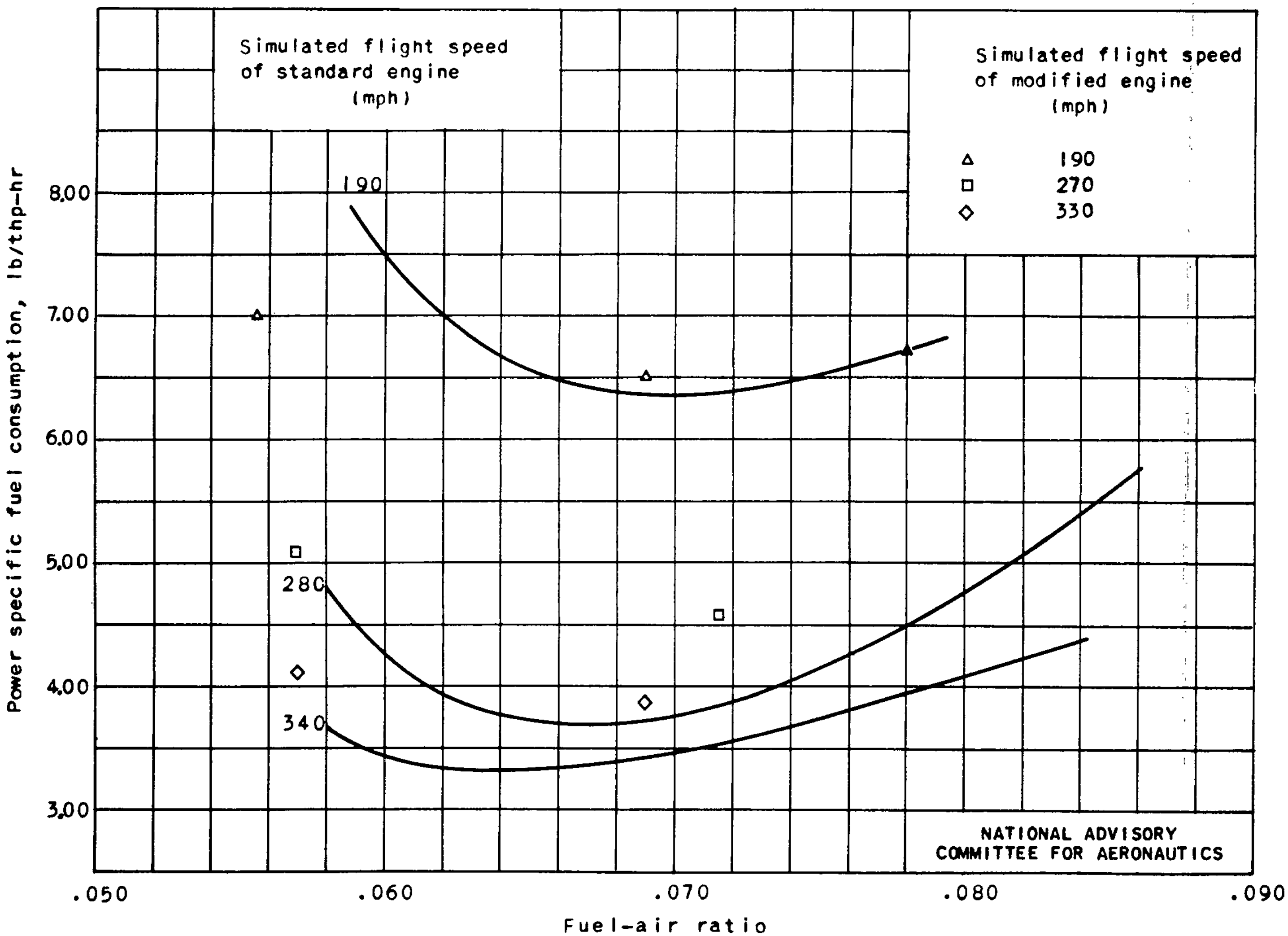
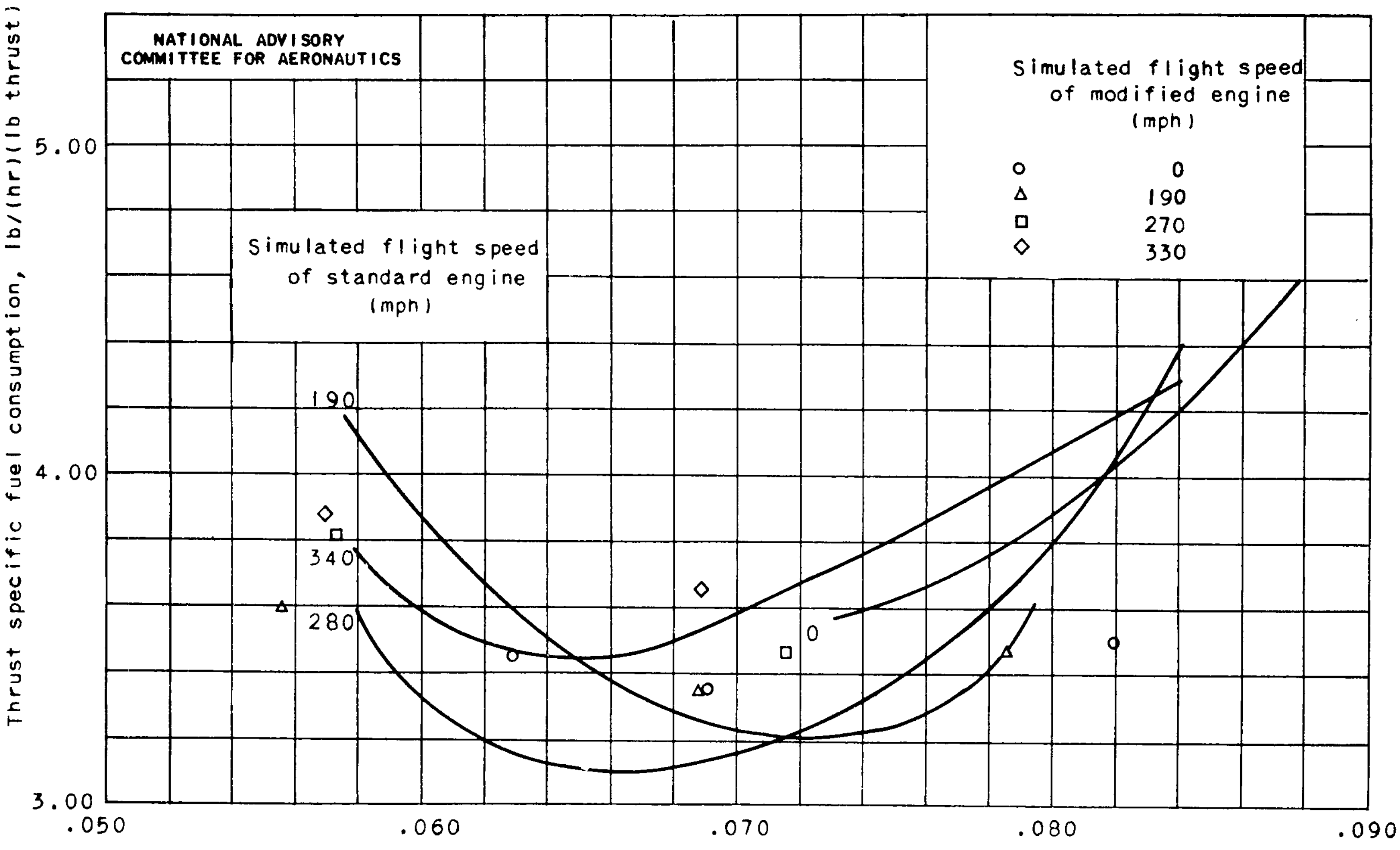


Figure 5. - Variation in peak combustion-chamber pressure with fuel-air ratio for several simulated flight speeds. Test data for modified pulse-jet engine spotted on performance curves for standard engine.



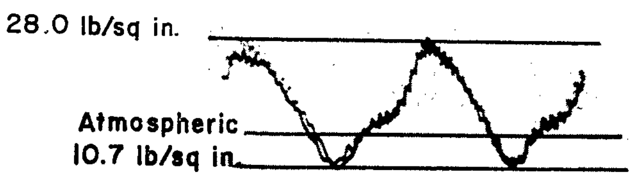
(a) Power specific fuel consumption.

Figure 6. - Variation of specific fuel consumption with fuel-air ratio for several simulated flight speeds. Test data for modified pulse-jet engine spotted on performance curves for standard engine.

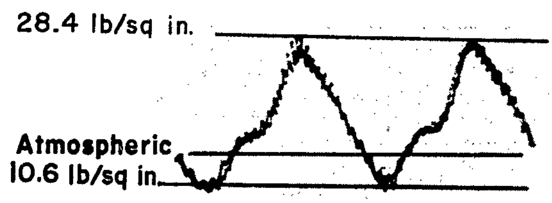


(b) Thrust specific fuel consumption.

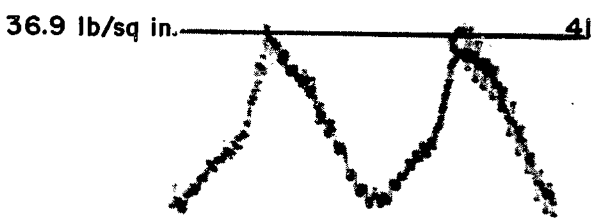
Figure 6. - Concluded. Variation of specific fuel consumption with fuel-air ratio for several simulated flight speeds. Test data for modified pulse-jet engine spotted on performance curves for standard engine.



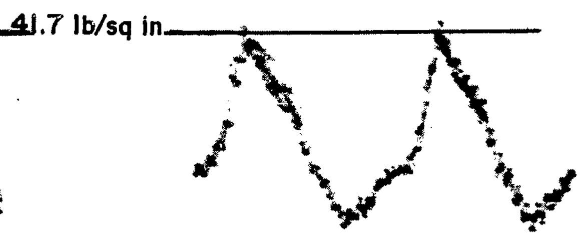
Simulated flight speed, 0 miles per hour; fuel-air ratio, 0.082.



Simulated flight speed, 190 miles per hour; fuel-air ratio, 0.069.



Simulated flight speed, 270 miles per hour; fuel-air ratio, 0.072.



Simulated flight speed, 330 miles per hour; fuel-air ratio, 0.069.

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Figure 7. - Photographs of oscilloscope trace of pressure cycle for pulse-jet engine with modified valves.

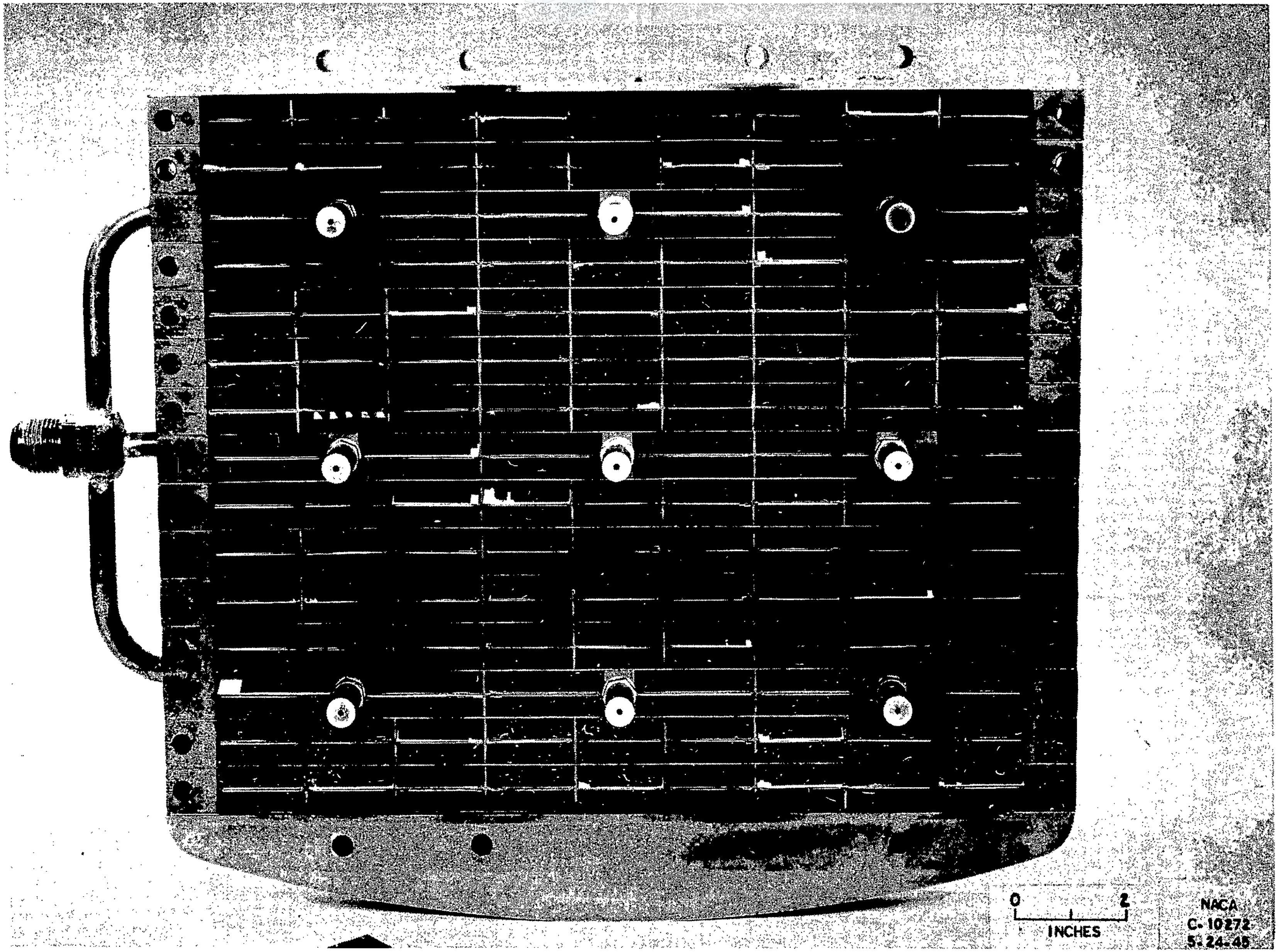

Figure 8. - Photograph of modified valve grid after repair and operation for 4 minutes at high simulated flight speeds.