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RESEARCH MEMORANDUM

PRELIMINARY RESULTS OF NENE II ENGINE ALTITUDE-CHAMBER PERFORMANCE INVESTIGATION

III - ALTITUDE PERFORMANCE USING 18.00-INCH-DIAMETER JET NOZZLE

By Ralph E. Grey and Virginia L. Brightwell

Flight Propulsion Research Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation is being conducted to determine the altitude performance characteristics of the Nene II engine and its components. The present paper presents the preliminary results obtained using a jet nozzle 18.00 inches in diameter, with an area equal to 92.2 percent of the area of the standard jet nozzle for this engine. The experimental results presented are for conditions simulating altitudes from 20,000 to 60,000 feet and ram-pressure ratios from 1.1 to 3.5. These ram-pressure ratios correspond to flight Mach numbers between 0.374 and 1.466.

Data obtained with the 18.00-inch-diameter jet nozzle and corrected to standard sea-level conditions showed substantially the same trends with altitude as the data previously obtained with an 18.75-inch-diameter nozzle and with an 18.41-inch-diameter nozzle.

Jet thrust, air consumption, and fuel consumption, corrected to standard sea-level conditions, increased rapidly with increasing ram-pressure ratio. In general, corrected net thrust specific fuel consumption increased with increase in ram-pressure ratio. Corrected net thrust decreased with an increase in ram-pressure ratio at an engine speed of 8000 rpm. At corrected engine speeds between 8000 and 10,800 rpm, net thrust first decreased with an increase in ram-pressure ratio and then increased with further increase in ram-pressure ratio; at corrected engine speeds above 10,800 rpm, net thrust increased continuously with increase in ram-pressure ratio. Tail-pipe temperature decreased with an increase in ram-pressure ratio.

Comparison of engine operation with the 18.41- and with the 18.00-inch-diameter nozzle to operation with the standard 18.75-inch-diameter jet nozzle under similar flight conditions showed that use of a smaller nozzle gave an appreciable reduction in net thrust specific consumption at engine speeds below 11,500 rpm. The jet thrust, net thrust, fuel consumption, and tail-pipe temperature were highest with the smallest nozzle. Air consumption was unaffected by nozzle size at engine speeds below 9000 rpm but decreased with a decrease in nozzle size at the higher engine speeds.

INTRODUCTION

The altitude performance of the Nene II engine, using several sizes of jet nozzle, is being determined in order to investigate the degree of matching of the components and the effects of change in the characteristics of the various engine components on altitude performance. This investigation is being conducted in an altitude test chamber at the Cleveland laboratory of the NACA.

This paper presents data showing performance of the engine using a jet nozzle 18.00 inches in diameter. The area of this nozzle is 92.2 percent of the standard jet nozzle. Data obtained with the standard jet nozzle and with an 18.41-inch-diameter jet nozzle were presented in references 1 and 2, respectively. The results presented herein were obtained at simulated altitudes from 20,000 to 60,000 feet and ram-pressure ratios from 1.1 to 3.5. These ram-pressure ratios correspond to flight Mach numbers between 0.374 and 1.466, assuming 100-percent ram recovery. The data are so presented as to show the effects of altitude, ram-pressure ratio, and jet-nozzle size on engine performance.

The power plant is rated at 5000 pounds thrust at static sea-level conditions with an 18.75-inch-diameter jet nozzle. The power plant, altitude test chamber, and instrumentation are described in reference 1.

SYMBOLS

The following symbols are used in this report:

F_j jet thrust, pounds

F_n net thrust, pounds

N engine speed, rpm

P absolute total pressure, pounds per square foot

p absolute static pressure, pounds per square foot

T indicated temperature, °R

W_a air consumption, pounds per second

W_f fuel consumption, pounds per hour

W_f/F_n specific fuel consumption based on net thrust, pounds per hour per pound thrust

δ ratio of ambient absolute static pressure to absolute static pressure of NACA standard atmosphere at sea level

θ ratio of compressor-inlet absolute total temperature to absolute static temperature of NACA standard atmosphere at sea level

Subscripts:

0 free air stream

2 compressor inlet

7 tail-pipe instrumentation station

PROCEDURE AND PRESENTATION OF DATA

The experimental procedure and the processing of the data for this report were similar to the methods described in reference 1 except for the air-consumption measurements, which were obtained by the method described in reference 2.

The preliminary performance results are presented as corrected in the conventional manner to NACA standard sea-level temperature and pressure conditions. Cross plots of these data are included to demonstrate the variation of corrected engine performance with change in ram-pressure ratio. A typical set of uncorrected altitude data is also presented to demonstrate the change in engine performance that results from a change in jet-nozzle size. These data are compared with data obtained using a standard jet nozzle, having a diameter of 18.75 inches, and a jet nozzle having a diameter of 18.41 inches. The engine performance was generalized by correcting all data to standard sea-level pressure and temperature conditions as described in reference 3.

Effects of altitude. - Corrected jet thrust (fig. 1), corrected net thrust (fig. 2), corrected air consumption (fig. 3), corrected fuel consumption (fig. 4), and corrected net thrust specific fuel consumption (fig. 5) show no consistent trend with variations in altitude. Corrected tail-pipe indicated temperature (fig. 6) increased slightly with increase in altitude. These altitude effects are in general agreement with those reported in reference 2. It should be noted that when altitude data are corrected to standard sea-level conditions the decreasing accuracy of measurement (due to reading small values) can produce an apparently wide scatter in the data that may obscure any altitude trends that exist.

Effects of ram-pressure ratio. - The corrected data of figures 1 to 6 have been cross-plotted in figures 7 to 12 to show more clearly the effect of change in ram-pressure ratio on engine performance. These figures represent the average effect at all altitudes investigated. The corrected jet thrust (fig. 7) increases rapidly with ram-pressure ratio. The corrected net thrust (fig. 8) decreases with increase in ram-pressure ratio for an engine speed of 8000 rpm. For engine speeds between 8000 and 10,800 rpm, corrected net thrust first decreases and then increases at a rapid rate with increase in ram-pressure ratio. Above these engine speeds, corrected net thrust does not decrease at the low ram-pressure ratios but rises rapidly throughout the entire range. Corrected air consumption (fig. 9) increases with increase in ram-pressure ratio.

The corrected fuel consumption (fig. 10) is seen to rise at an increasing rate with increase in ram-pressure ratio. The corrected net thrust specific fuel consumption (fig. 11) in general increases with increase in ram-pressure ratio.

The corrected tail-pipe indicated temperature (fig. 12) decreases with increase in ram-pressure ratio. The effect is greatest at the lower engine speeds.

In general, these ram-pressure-ratio effects are in agreement with those reported in reference 2.

Effect of jet-nozzle size. - Data are presented for the 18.75-, 18.41-, and 18.00-inch-diameter jet nozzles at a ram-pressure ratio of 1.70 and a simulated altitude of 30,000 feet. A decrease in jet-nozzle size is seen from figure 13 to give an increase in jet thrust. A similar increase in net thrust is apparent (fig. 14).

Figure 15 indicates that air consumption decreases for engine speeds above 9000 rpm with a decrease in nozzle size. In general, the fuel consumption (fig. 16) increases when jet-nozzle size decreases. The net thrust specific fuel consumption for the three nozzle sizes was nearly equal at an engine speed of 11,500 rpm (fig. 17). At engine speeds below 11,500 rpm, a decrease in jet-nozzle size gave lower net thrust specific fuel consumption. At engine speeds above 11,500 rpm, a decrease in nozzle size gave a slight increase in net thrust specific fuel consumption. The tail-pipe indicated temperature (fig. 18) was considerably increased when the nozzle size was decreased.

If, from figure 14, engine speeds at approximately cruise conditions are selected that will give equal net thrust for the jet nozzles, for instance 1000 pounds, it may be seen that the speeds at which this thrust occurs are 10,550, 10,410, and 10,160 rpm for the 18.75-, 18.41-, and 18.00-inch-diameter jet nozzles, respectively. Net thrust specific fuel consumption was 1.56, 1.45, and 1.46 for the 18.75-, 18.41-, and 18.00-inch-diameter nozzles, respectively. The net thrust specific fuel consumption is approximately 7 percent less with the 18.41-inch nozzle and 6 percent less with the 18.00-inch nozzle than with the 18.75-inch nozzle. This example indicates that a nozzle size between 18.75 and 18.00 inches in diameter would give a minimum net thrust specific fuel consumption for the conditions stated. Tail-pipe temperature (fig. 18) increases, however, from 1210° to 1230° and to 1225° R for the changes in nozzle size from 18.75 to 18.41 and to 18.00 inches in diameter, respectively. These rises in temperature of 20° and 15° for the 18.41- and 18.00-inch nozzles, respectively, would probably not be serious in this temperature range. A nozzle smaller than that currently used would, therefore, be advantageous at medium engine speeds. During take-off, however, the smallest nozzle would operate at temperatures that would probably be quite detrimental to engine life. In order to take advantage of improved performance at altitude conditions it would, therefore, be necessary to provide an efficient variable-area nozzle or other means of keeping temperatures within reasonable limits during take-off operation.

SUMMARY OF RESULTS

An investigation of the performance of a Nene II engine in one of the Cleveland altitude test chambers has been partly completed and the following results were indicated for the engine equipped with an 18.00-inch-diameter jet nozzle.

(1) Changes in simulated altitude in general had little effect on corrected engine performance. It was possible to generalize the jet thrust, net thrust, air consumption, fuel consumption, and net thrust specific fuel consumption throughout the range of altitudes investigated. Tail-pipe indicated temperature could not be accurately generalized; it increased slightly with increase in altitude.

(2) The general effect of increasing ram-pressure ratio was to rapidly increase corrected jet thrust, corrected air consumption, and corrected fuel consumption. Corrected net thrust decreased with an increase in ram-pressure ratio for an engine speed of 8000 rpm. For engine speeds between 8000 and 10,800 rpm, corrected net thrust first decreased and then increased rapidly with increase in ram-pressure ratio. At higher speeds, the increase in net thrust with increase in ram-pressure ratio was continuous over the range investigated. Corrected net thrust specific fuel consumption in general increased with increase in ram-pressure ratio. Corrected tail-pipe indicated temperatures were affected most at the lower engine speeds at which the temperatures rapidly decreased with increasing ram-pressure ratio.

(3) A comparison of experimental data for the 18.75-, 18.41-, and 18.00-inch-diameter jet nozzles at a ram-pressure ratio of 1.70 and an altitude of 30,000 feet gave the following results: Jet thrust, net thrust, fuel consumption, and tail-pipe temperatures increased when the jet-nozzle size was decreased. Air consumption decreased slightly at engine speeds above 9000 rpm when the nozzle size was decreased. At engine speeds below 11,500 rpm, decreasing nozzle size gave a reduction in net thrust specific fuel consumption.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, August 6, 1948.

REFERENCES

1. Barson, Zelmar, and Wilsted, H. D.: Preliminary Results of Nene II Altitude-Chamber Performance Investigation. I - Altitude Performance Using Standard 18.75-Inch-Diameter Jet Nozzle. NACA RM No. E8E12.

2. Armstrong, J. C., Wilsted, H. D., and Vincent, K. R.: Preliminary Results of Nene II Engine Altitude-Chamber Performance Investigation. II - Altitude Performance Using 18.41-Inch-Diameter-Jet Nozzle. NACA RM No. E8F14,

3. Sanders, Newell D.: Performance Parameters for Jet-Propulsion Engines. NACA TN No. 1106, 1946.

PRELIMINARY RESULTS OF NENE II ENGINE ALTITUDE-CHAMBER

PERFORMANCE INVESTIGATION

III - ALTITUDE PERFORMANCE USING 18.00-INCH-DIAMETER

JET NOZZLE

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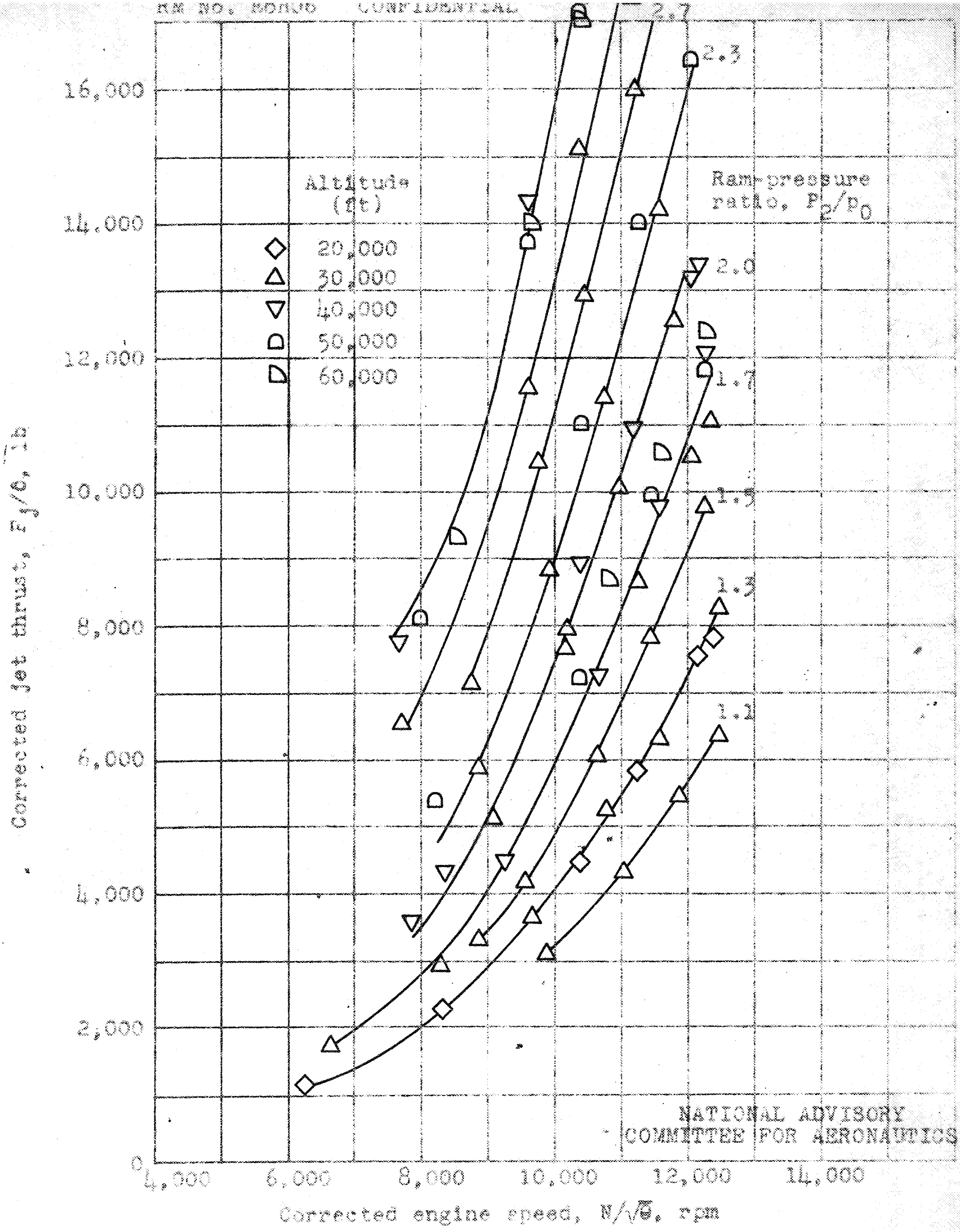
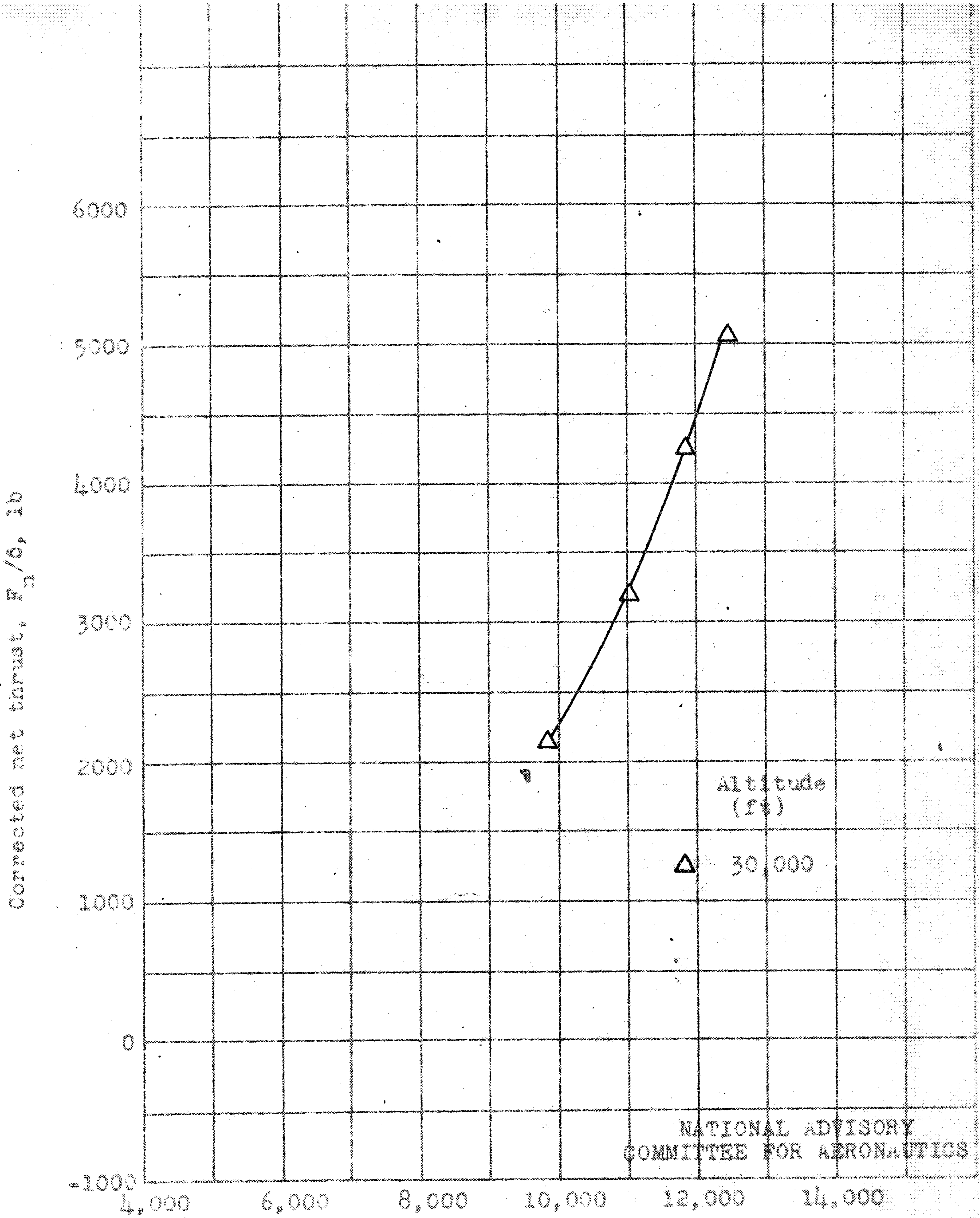
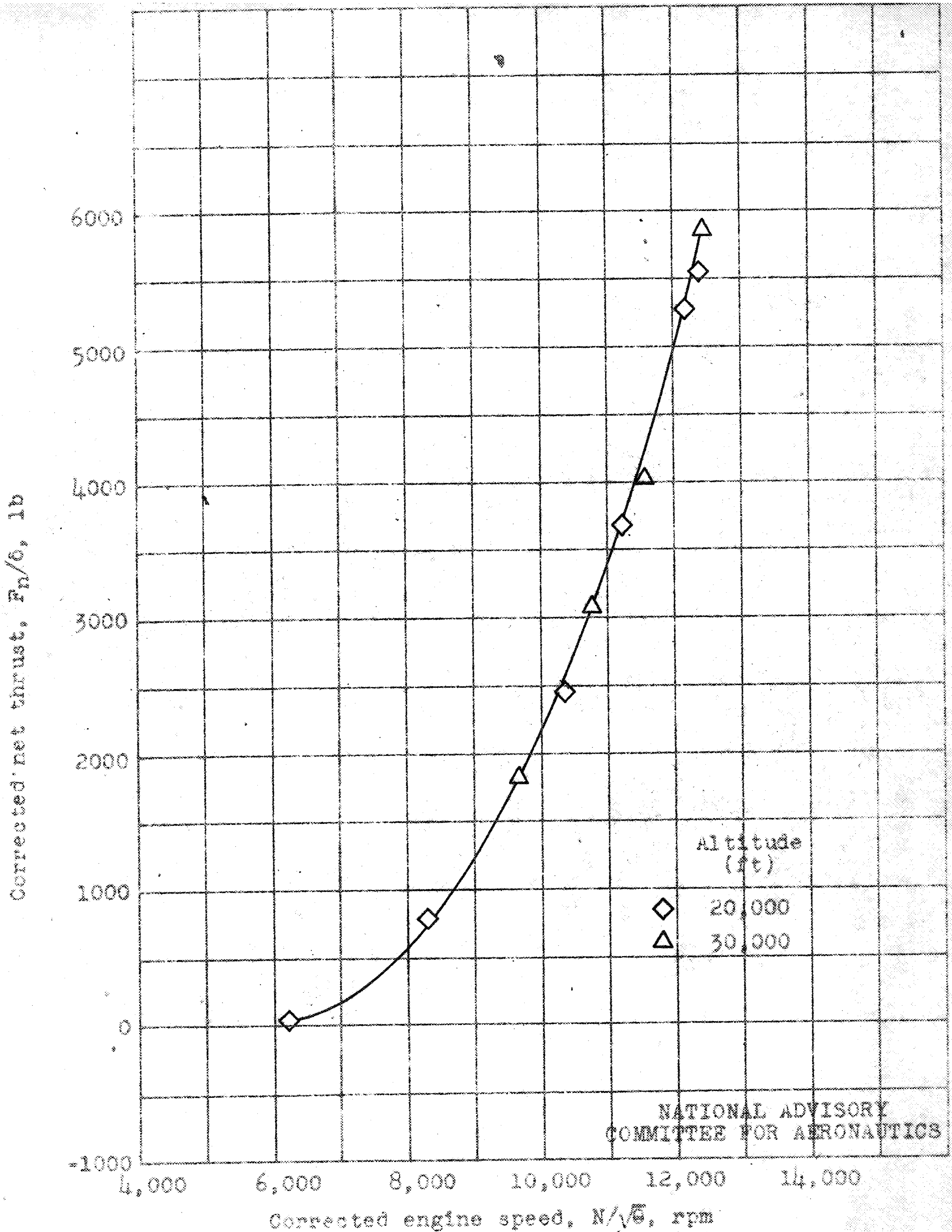


Figure 1. - Effect of altitude and corrected engine speed on corrected jet thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



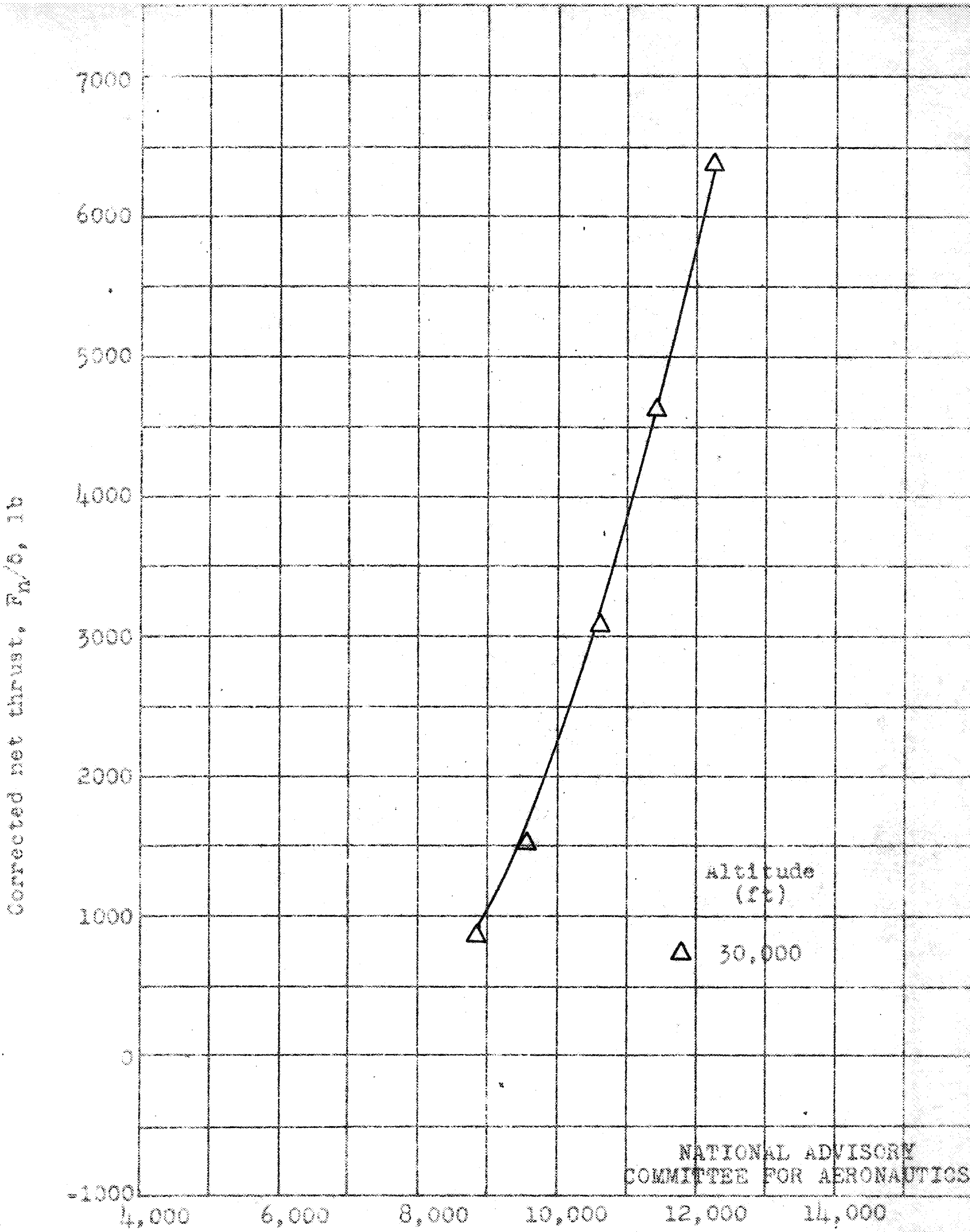
(a) Ram-pressure ratio, P_2/p_0, 1.1.

Figure 2. - Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(b) Ram-pressure ratio, P_2/p_0, 1.3.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(c) Ram-pressure ratio, P_2/p_0, 1.5.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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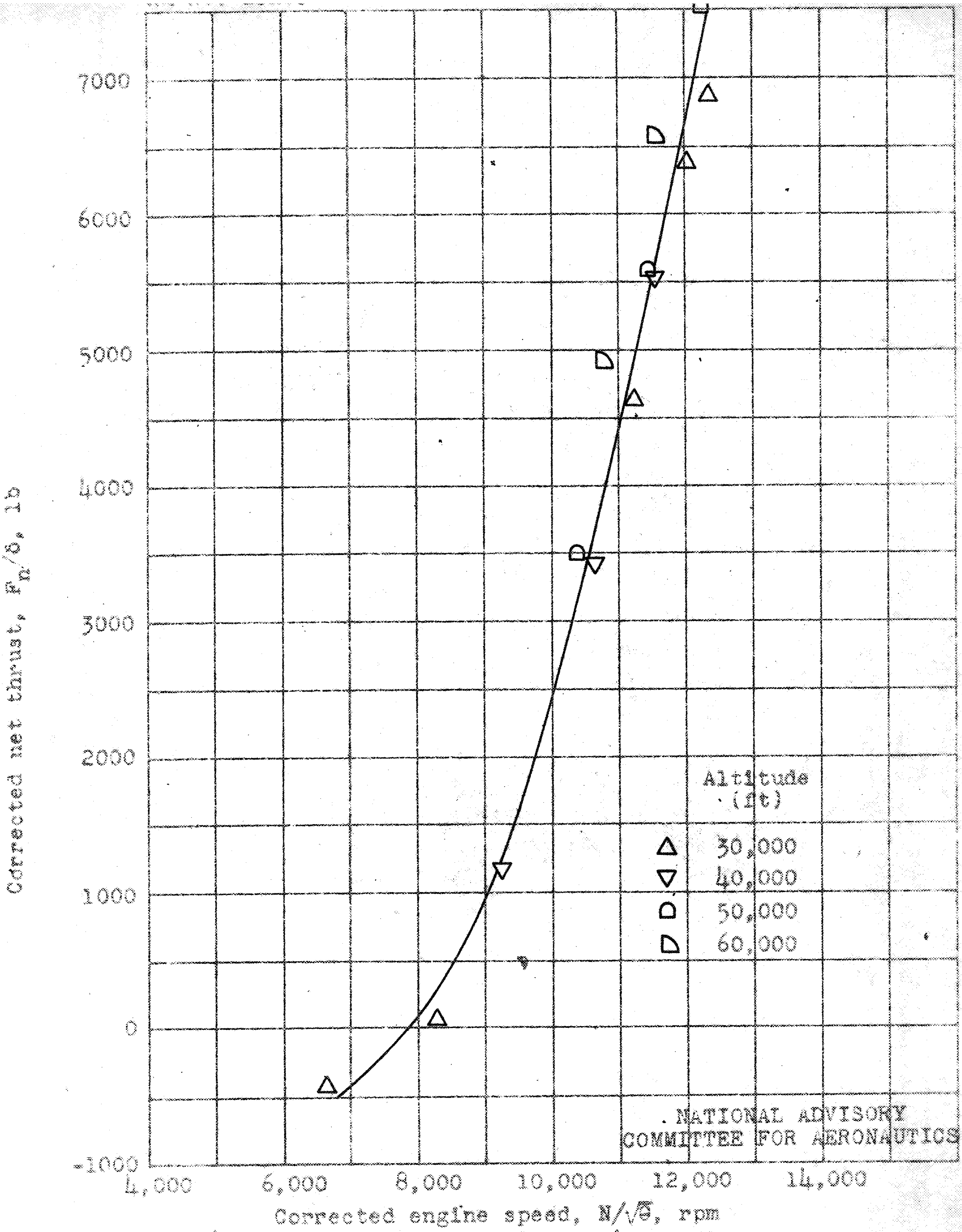
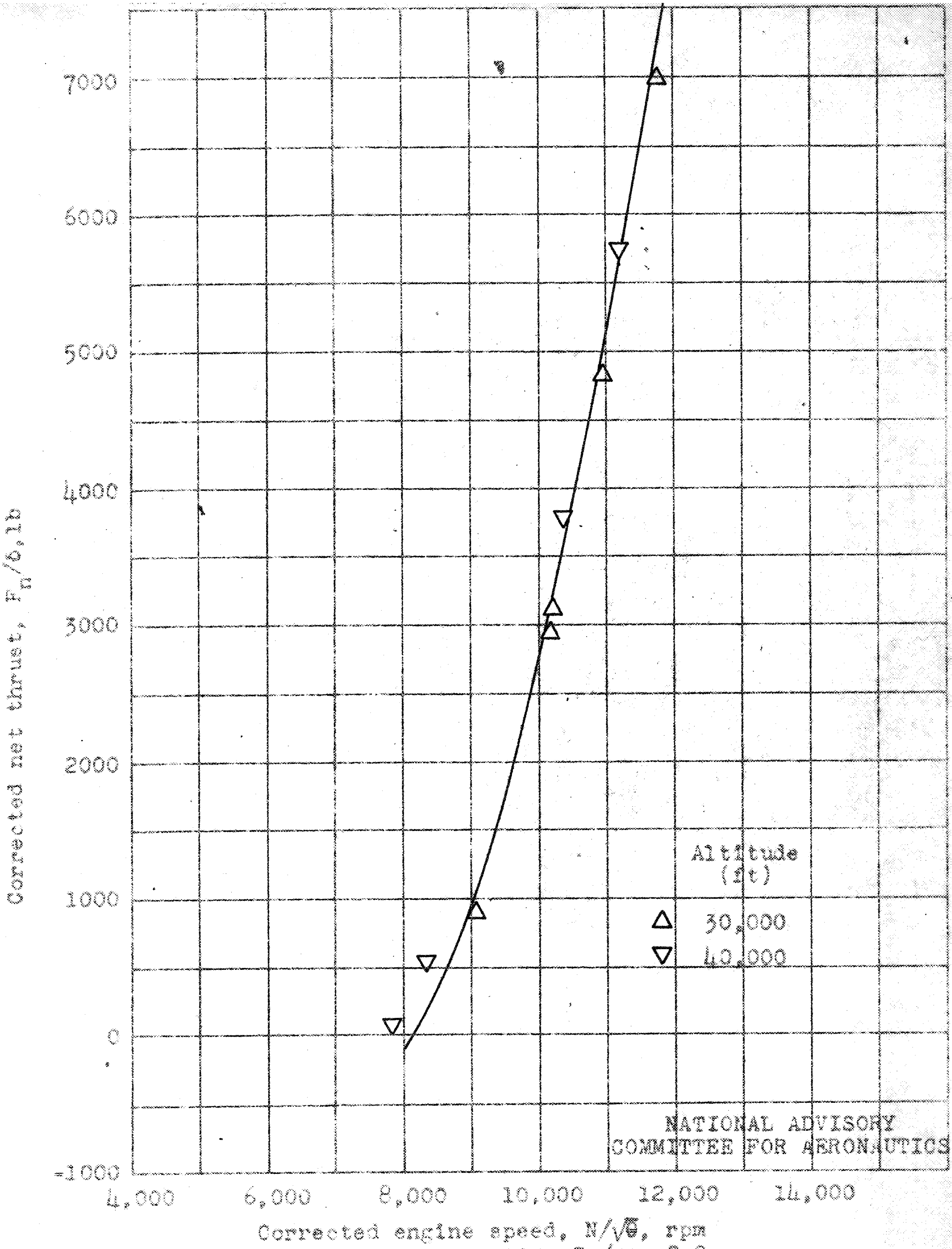


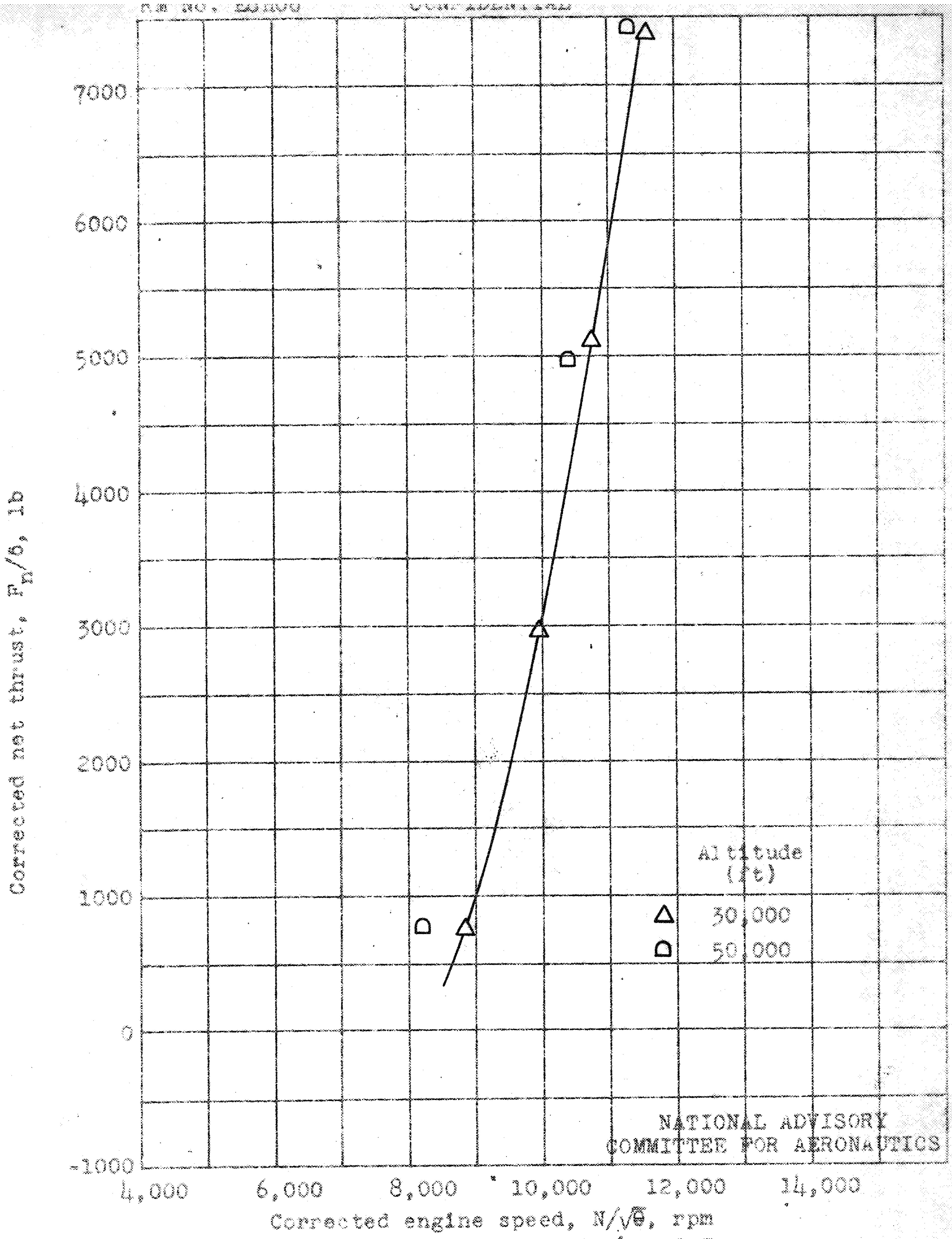
(d) Ram-pressure ratio, P_2/P_0, 1.7.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



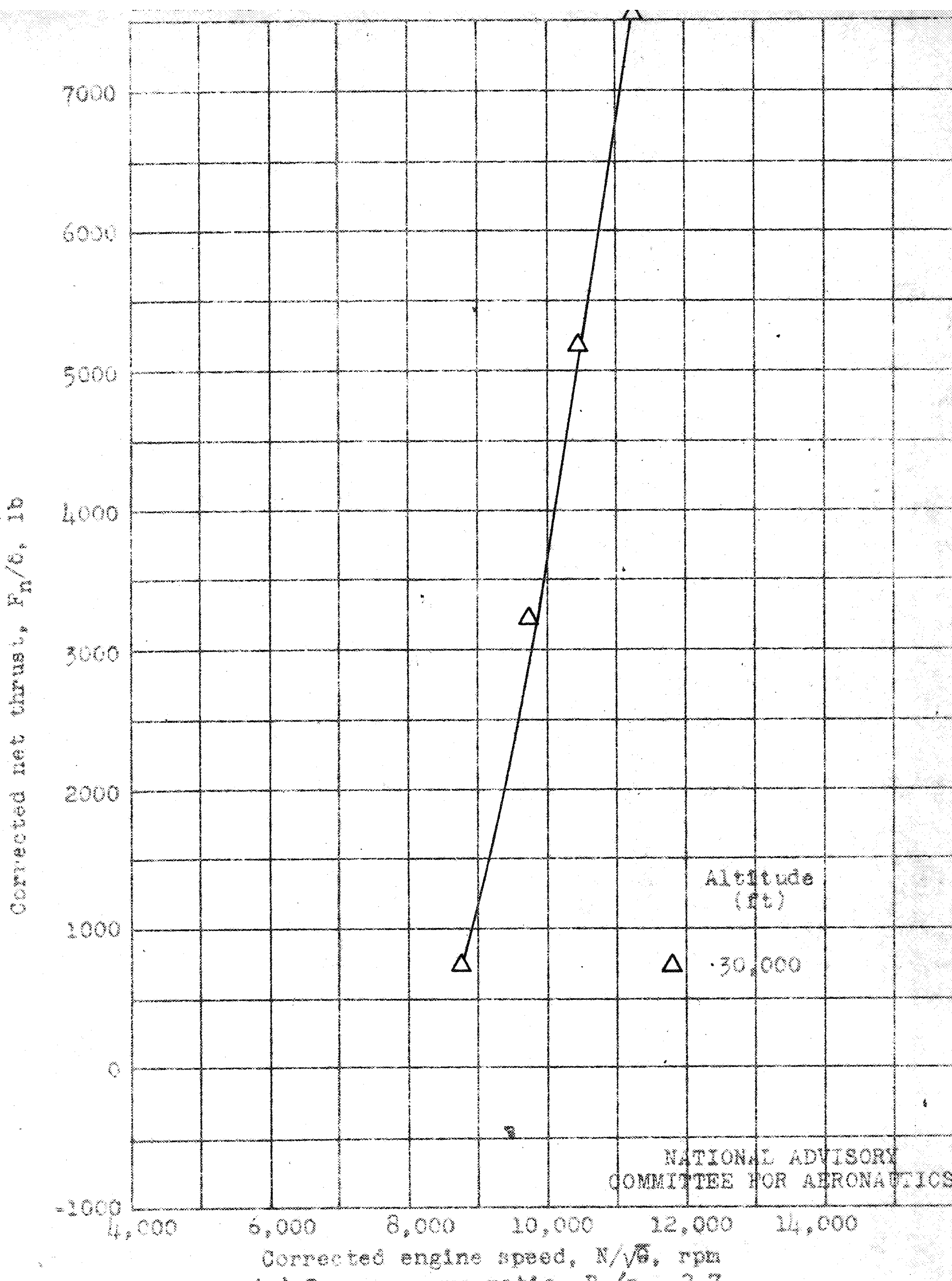
(e) Ram-pressure ratio, P_2/p_0, 2.0.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(f) Ram-pressure ratio, P_2/p_0, 2.3.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



Corrected engine speed, $N/\sqrt{\theta}$, rpm

(g) Ram-pressure ratio, P_2/p_0, 2.7.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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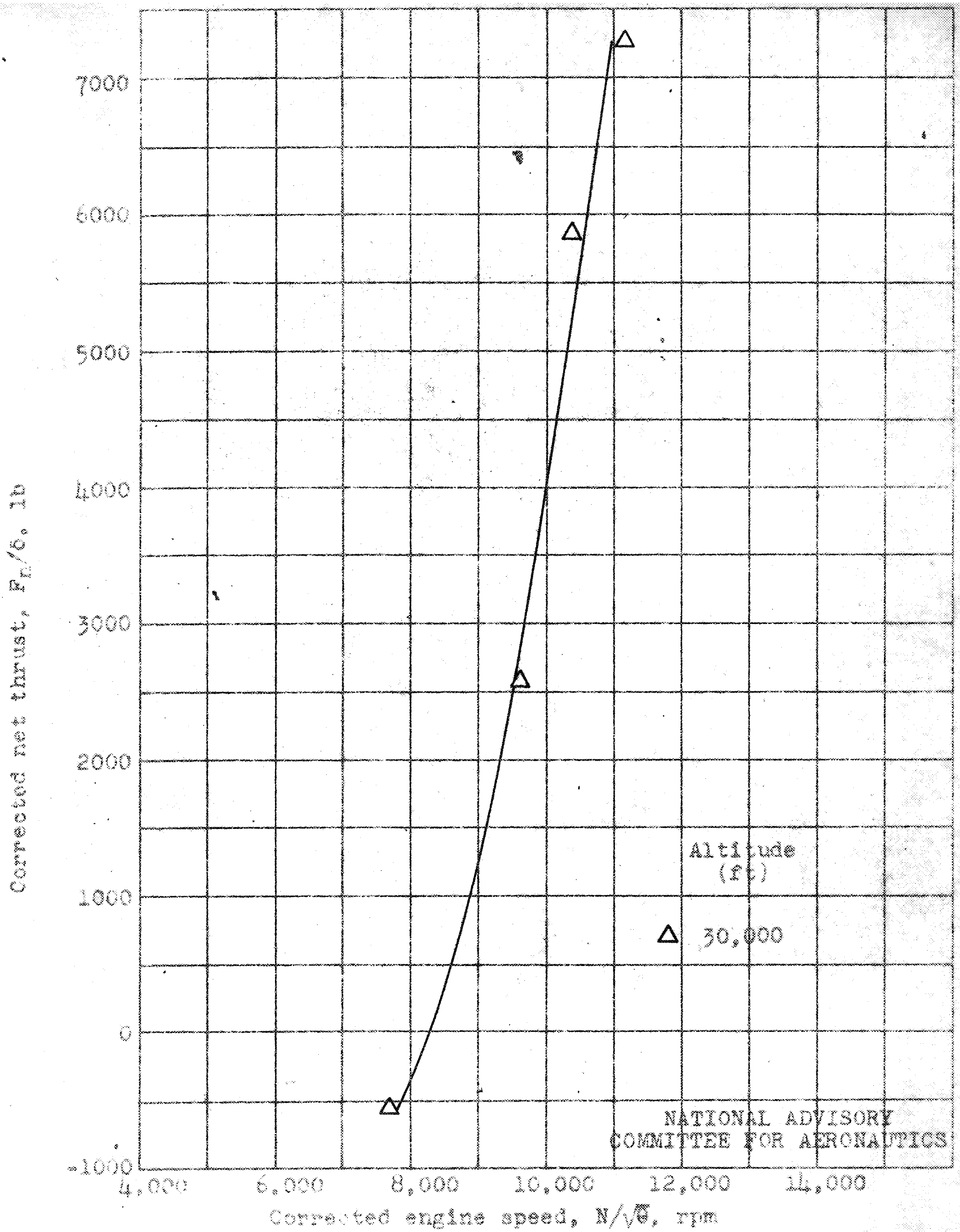
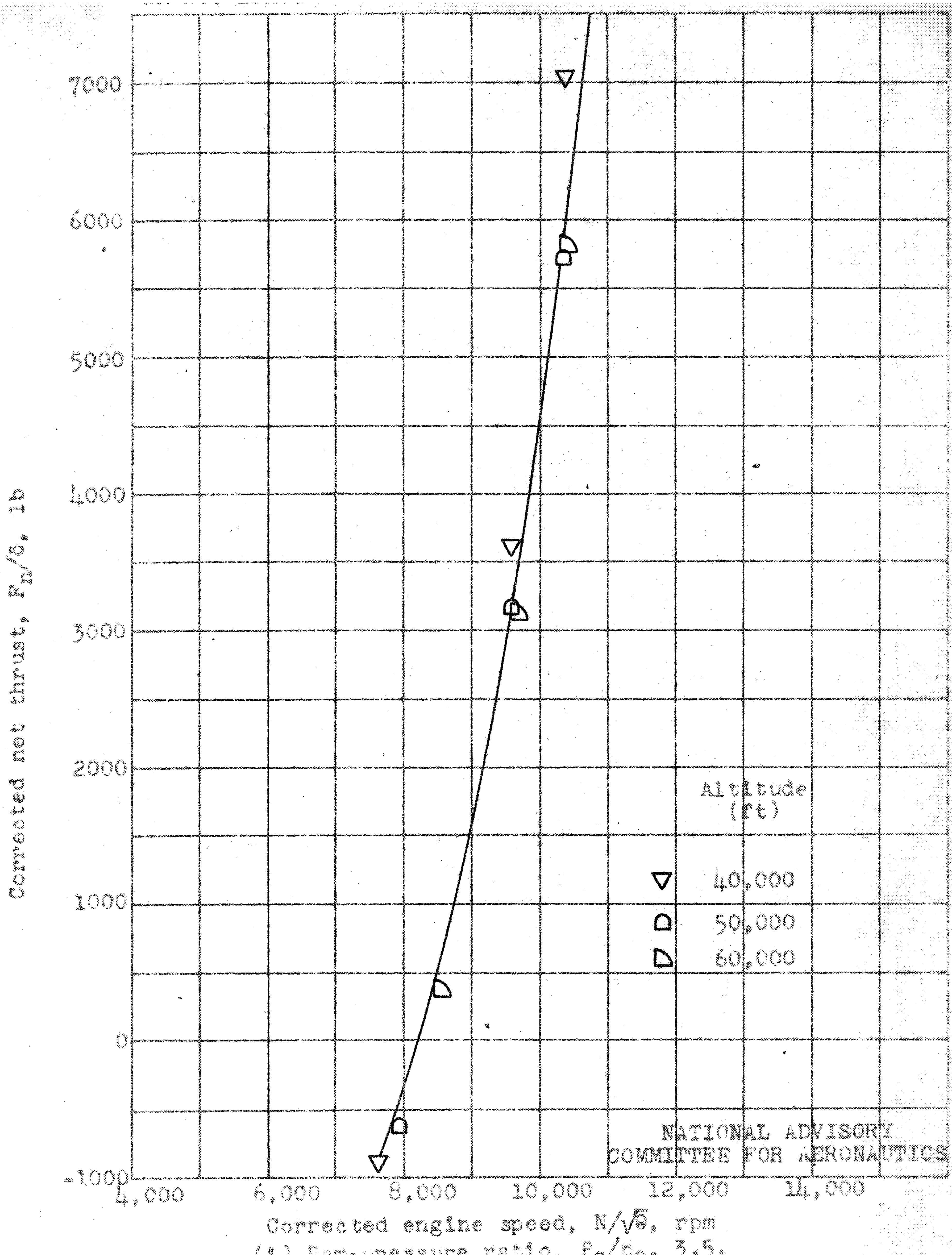


(h) Ram-pressure ratio, P_2/p_0, 3.0.

Figure 2. - Continued. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(i) Ram-pressure ratio, P_2/p_0, 3.5.

Figure 2. - Concluded. Effect of altitude and corrected engine speed on corrected net thrust at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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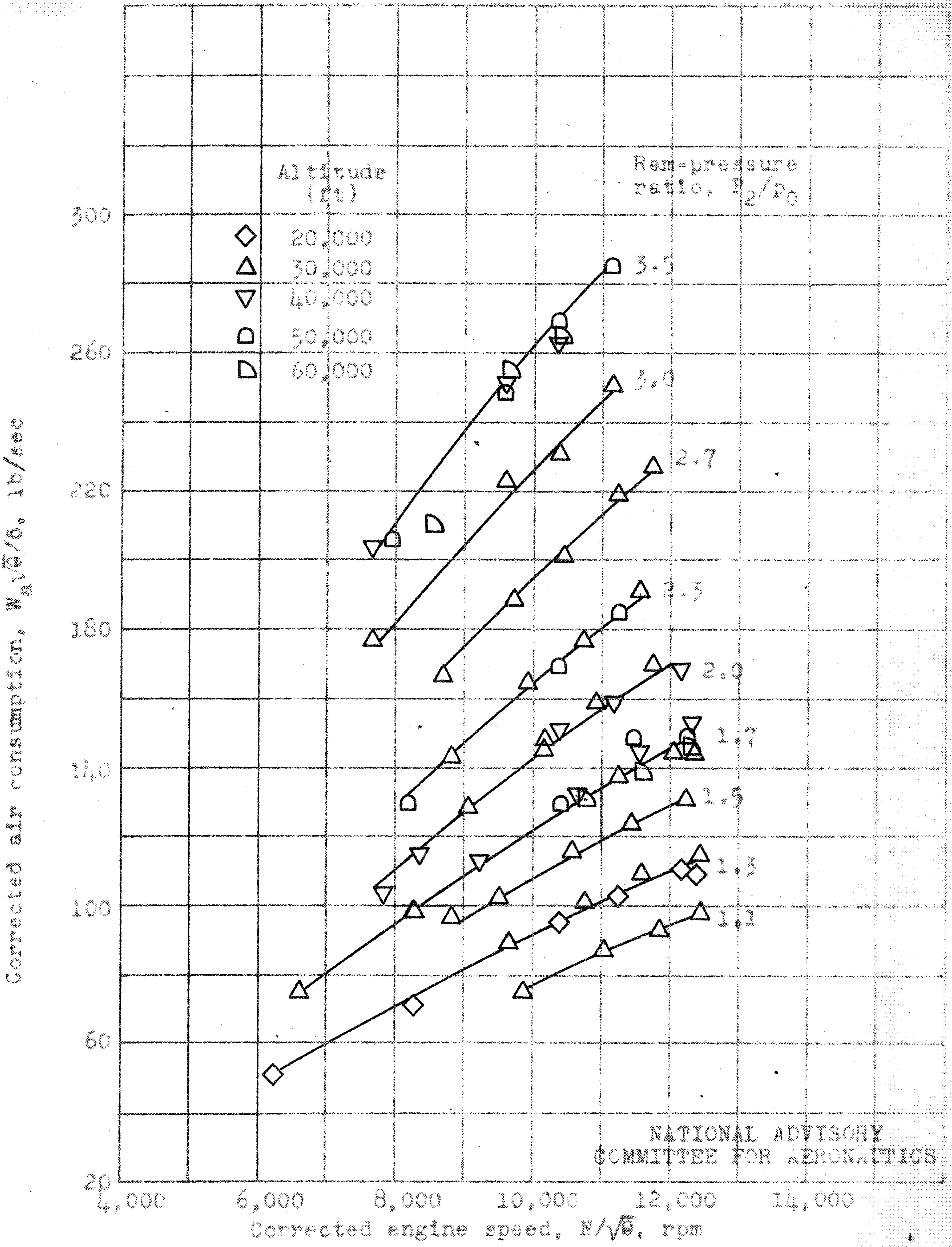
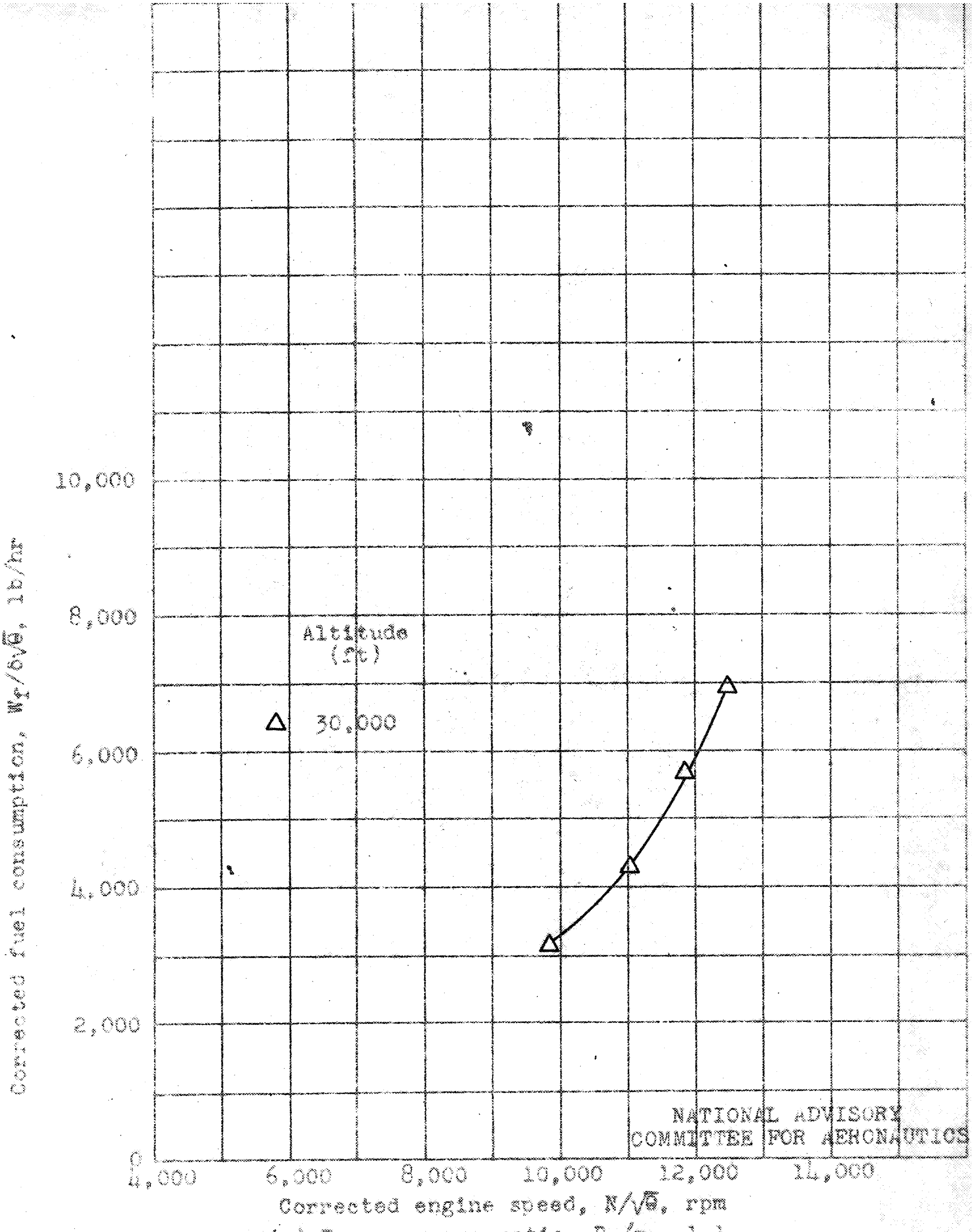
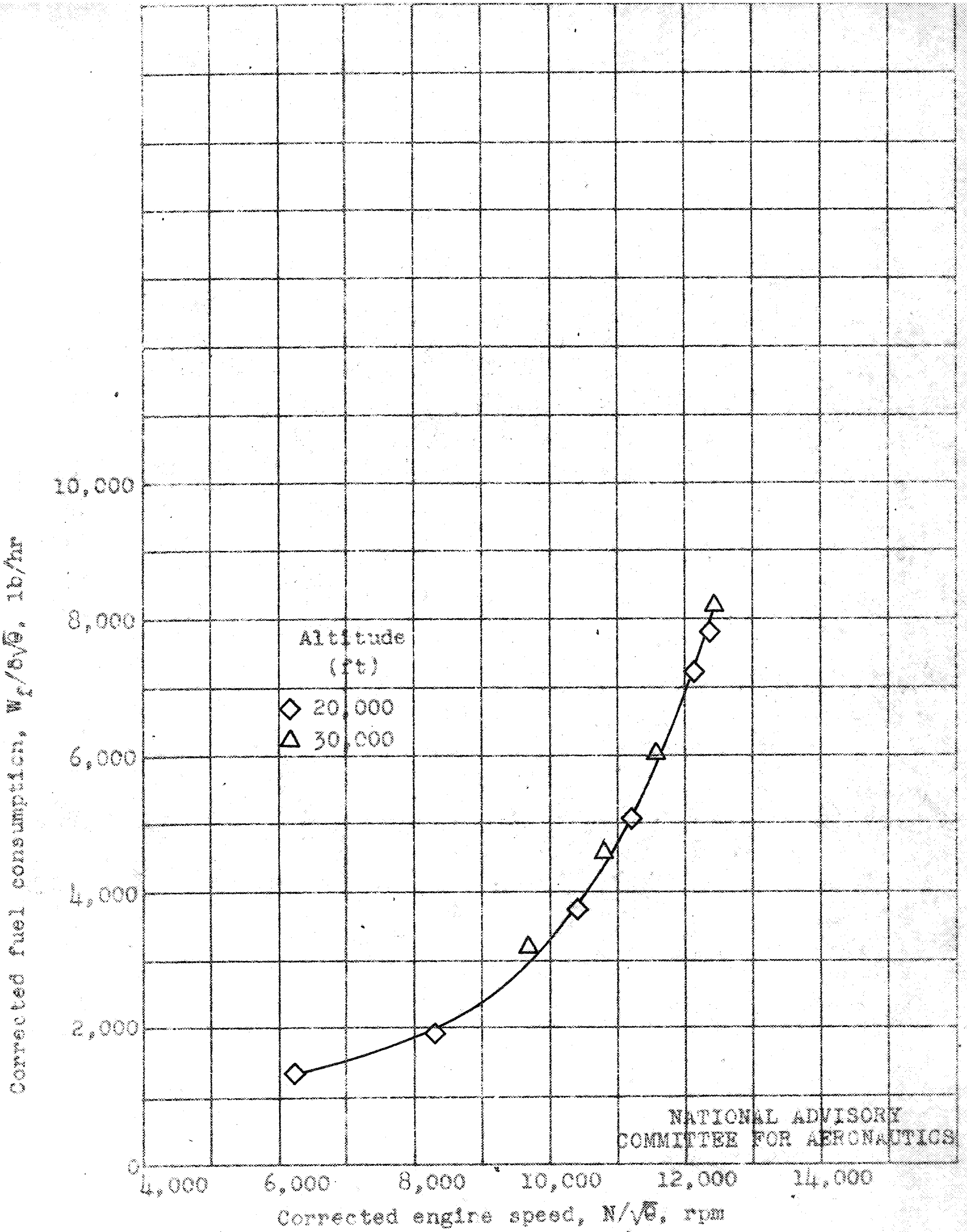


Figure 3. - Effect of altitude and corrected engine speed on corrected air consumption at various ram-pressure ratios. Jet-nozzle diameter, 15.00 inches.



(a) Ram-pressure ratio, P_2/P_0, 1.1.

Figure 4. - Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(b) Ram-pressure ratio, P_2/P_0, 1.3.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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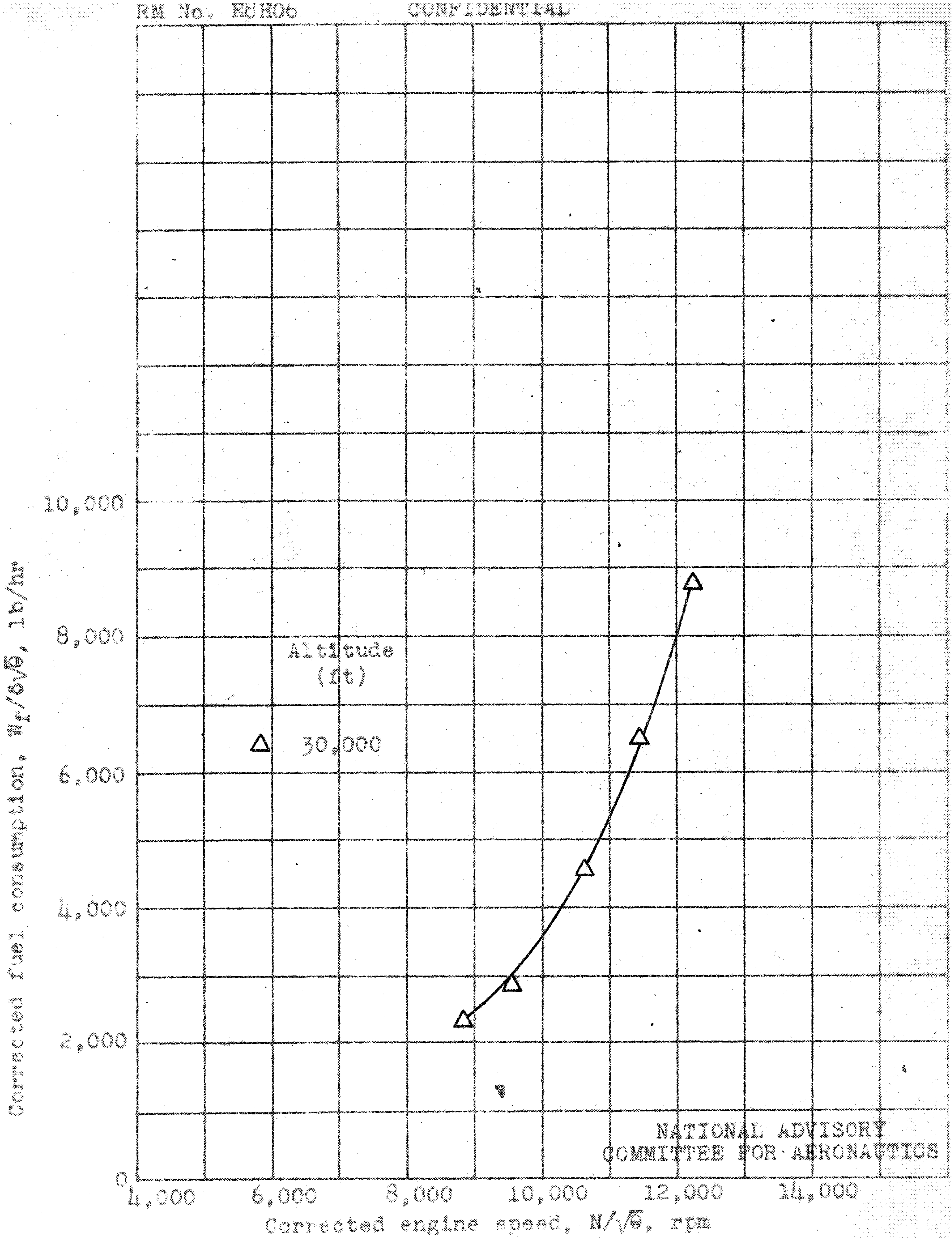
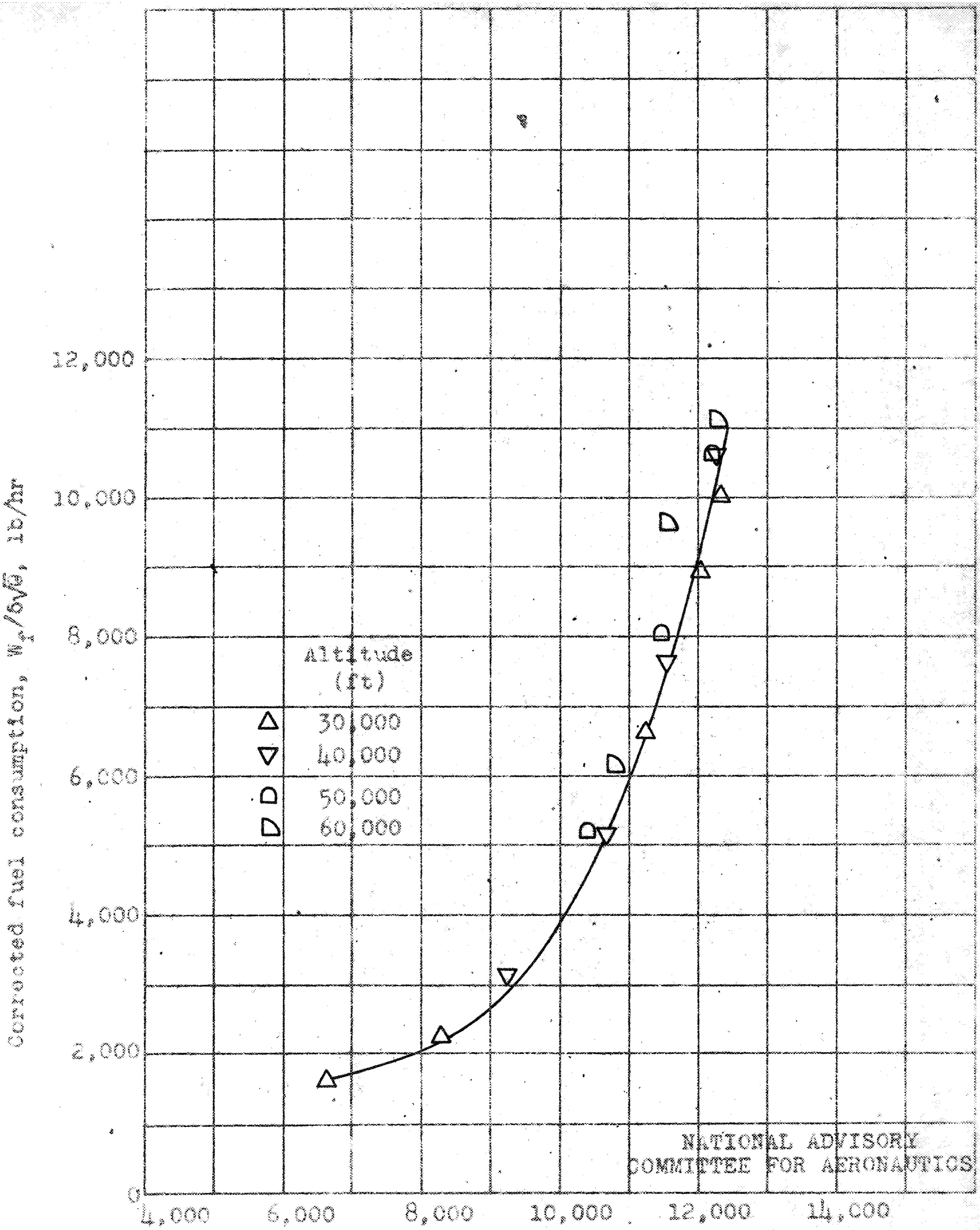


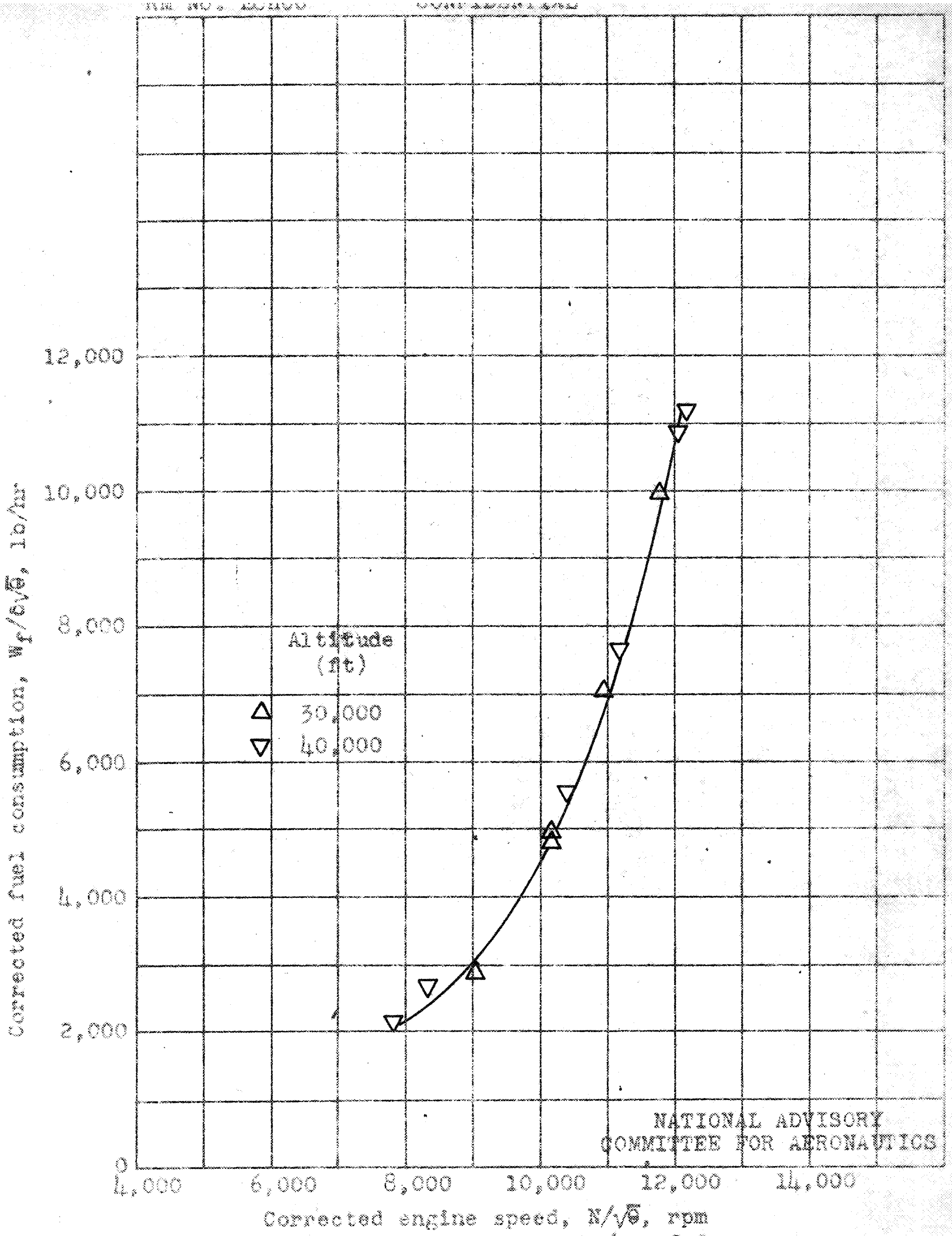
(c) Ram-pressure ratio, P_2/P_0, 1.5.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



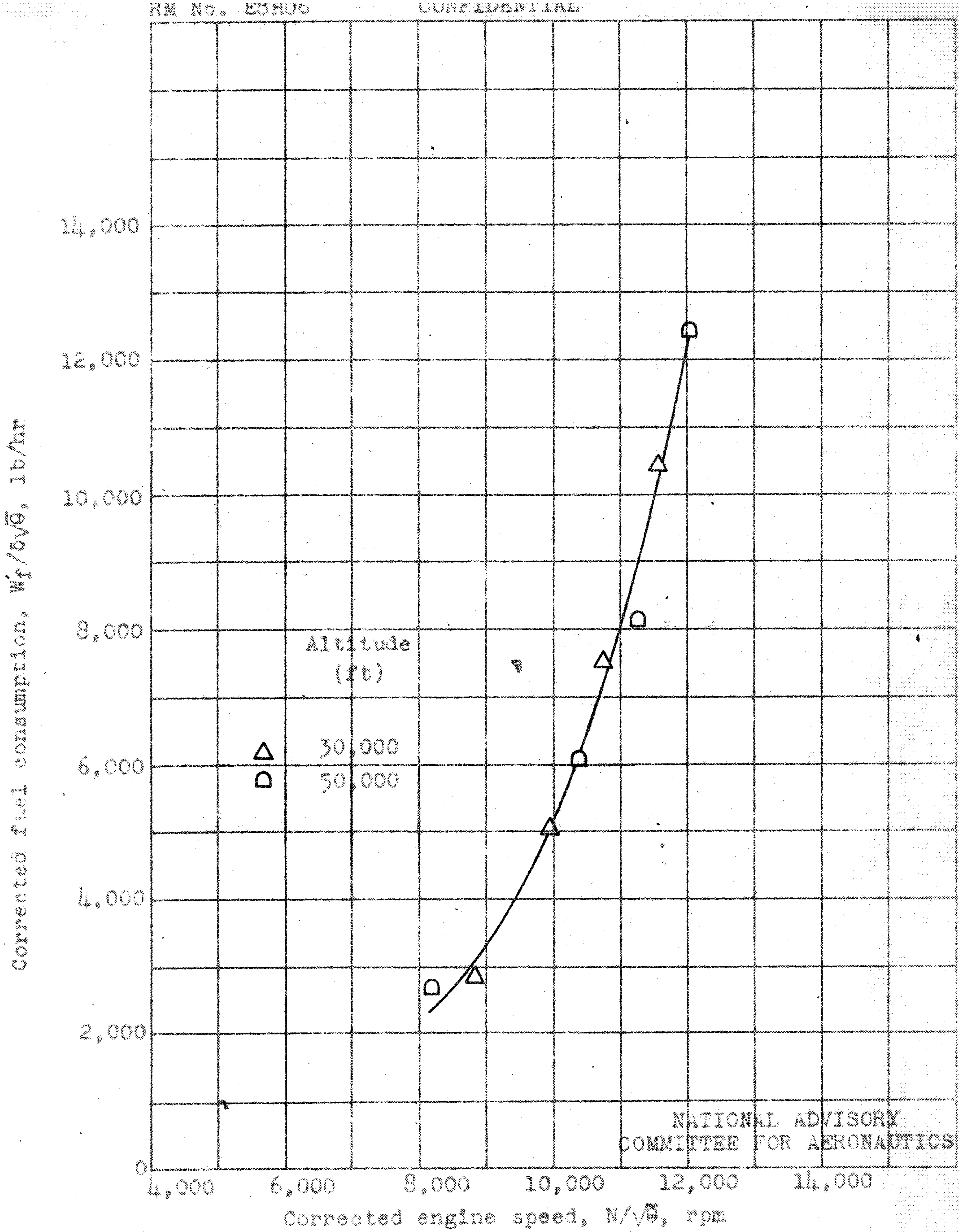
(d) Ram-pressure ratio, P_2/p_0, 1.7.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



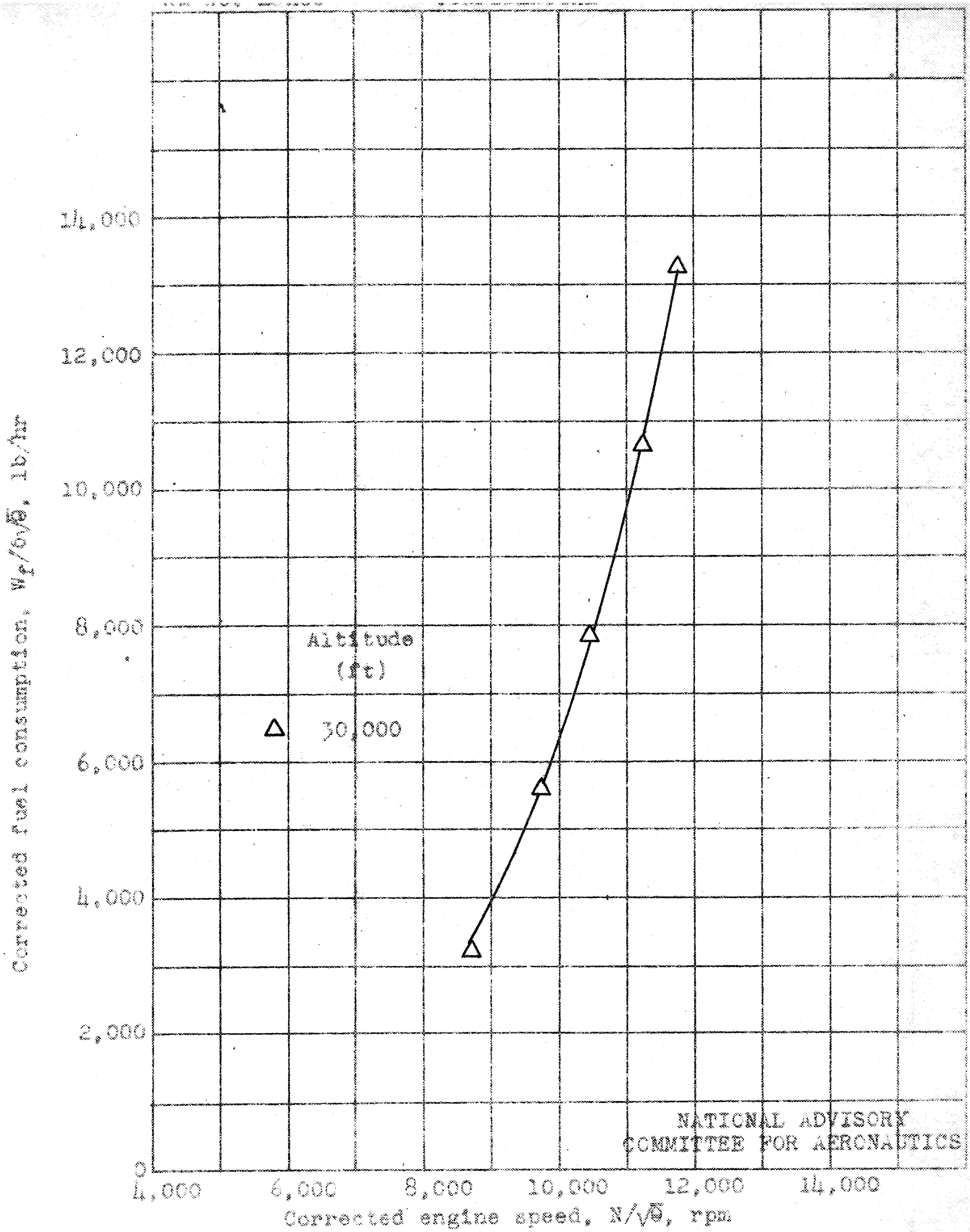
(e) Ram-pressure ratio, P_2/p_0, 2.0.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



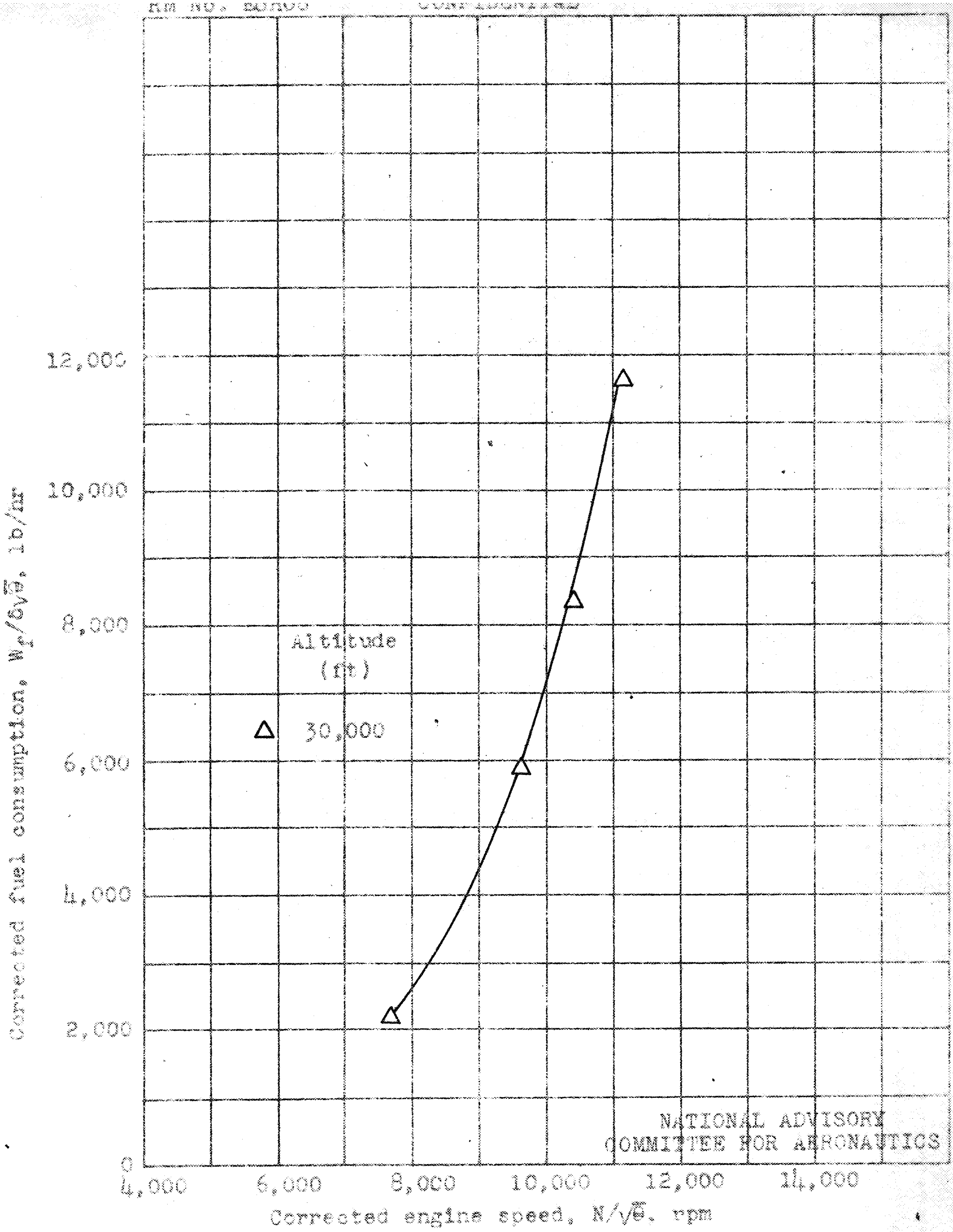
(f) Ram-pressure ratio, P_2/P_0, 2.3.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



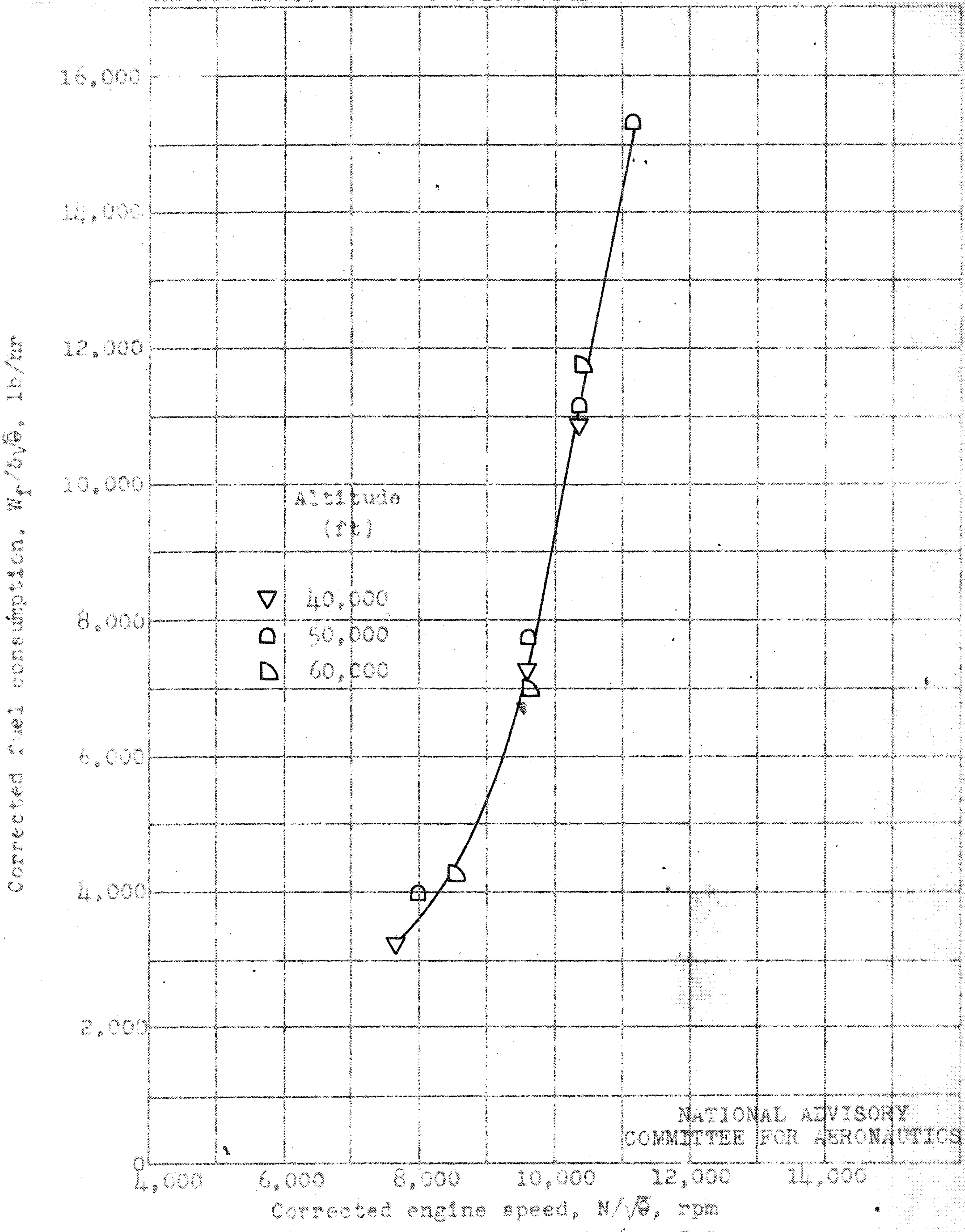
(g) Ram-pressure ratio, P_2/P_0, 2.7.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



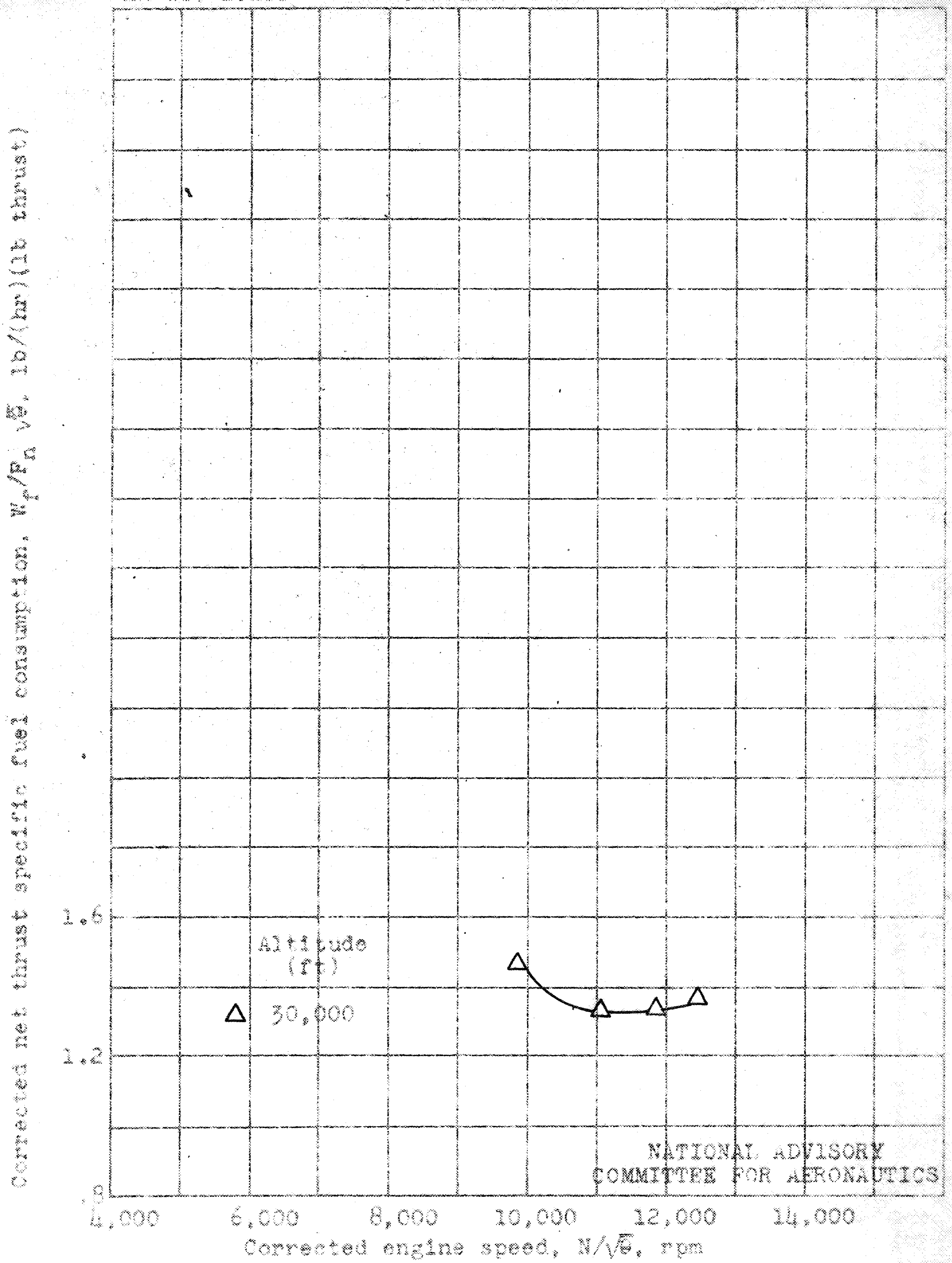
(h) Ram-pressure ratio, P_2/p_0, 3.0.

Figure 4. - Continued. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



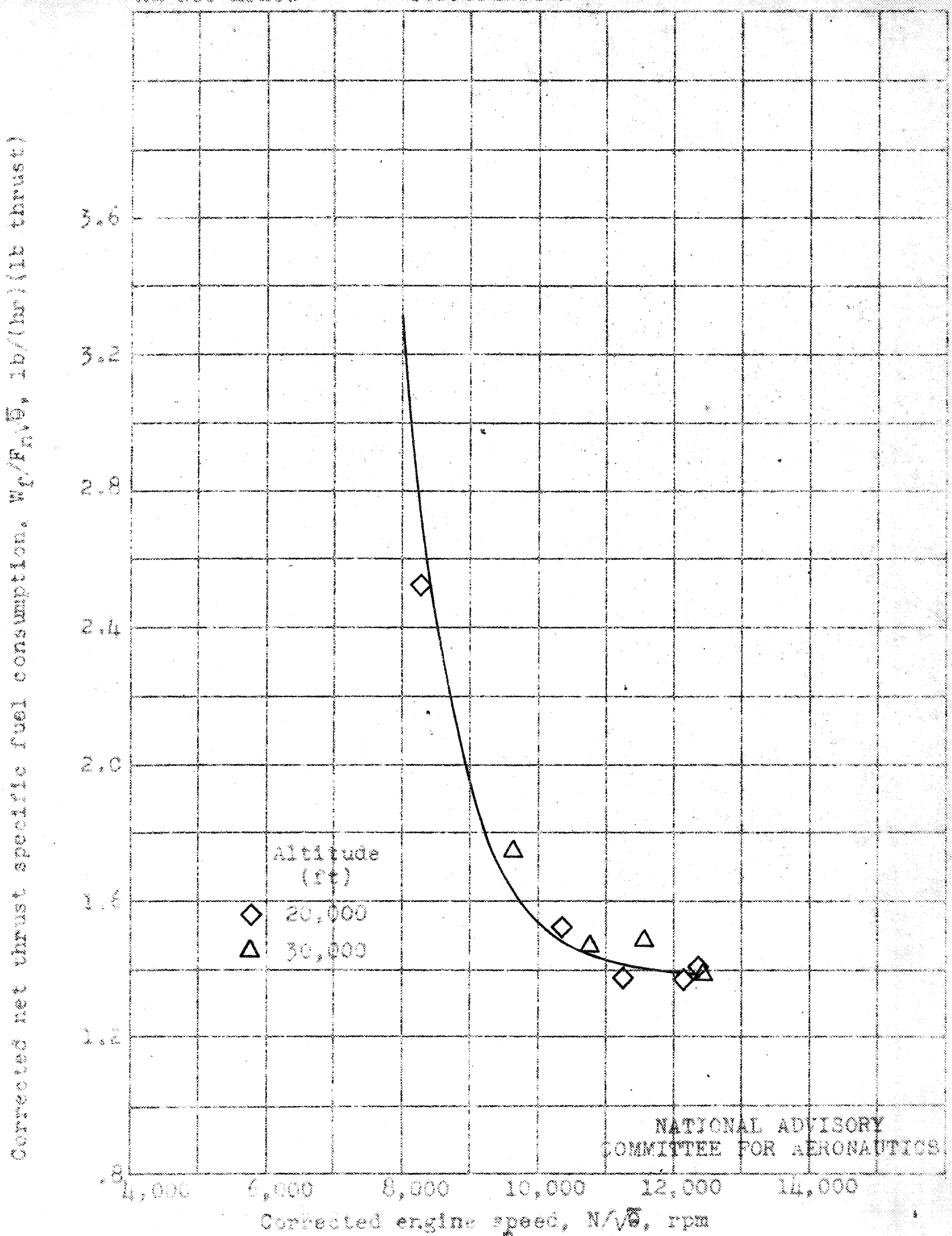
(i) Ram-pressure ratio, P_2/p_0, 3.5.

Figure 4. - Concluded. Effect of altitude and corrected engine speed on corrected fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



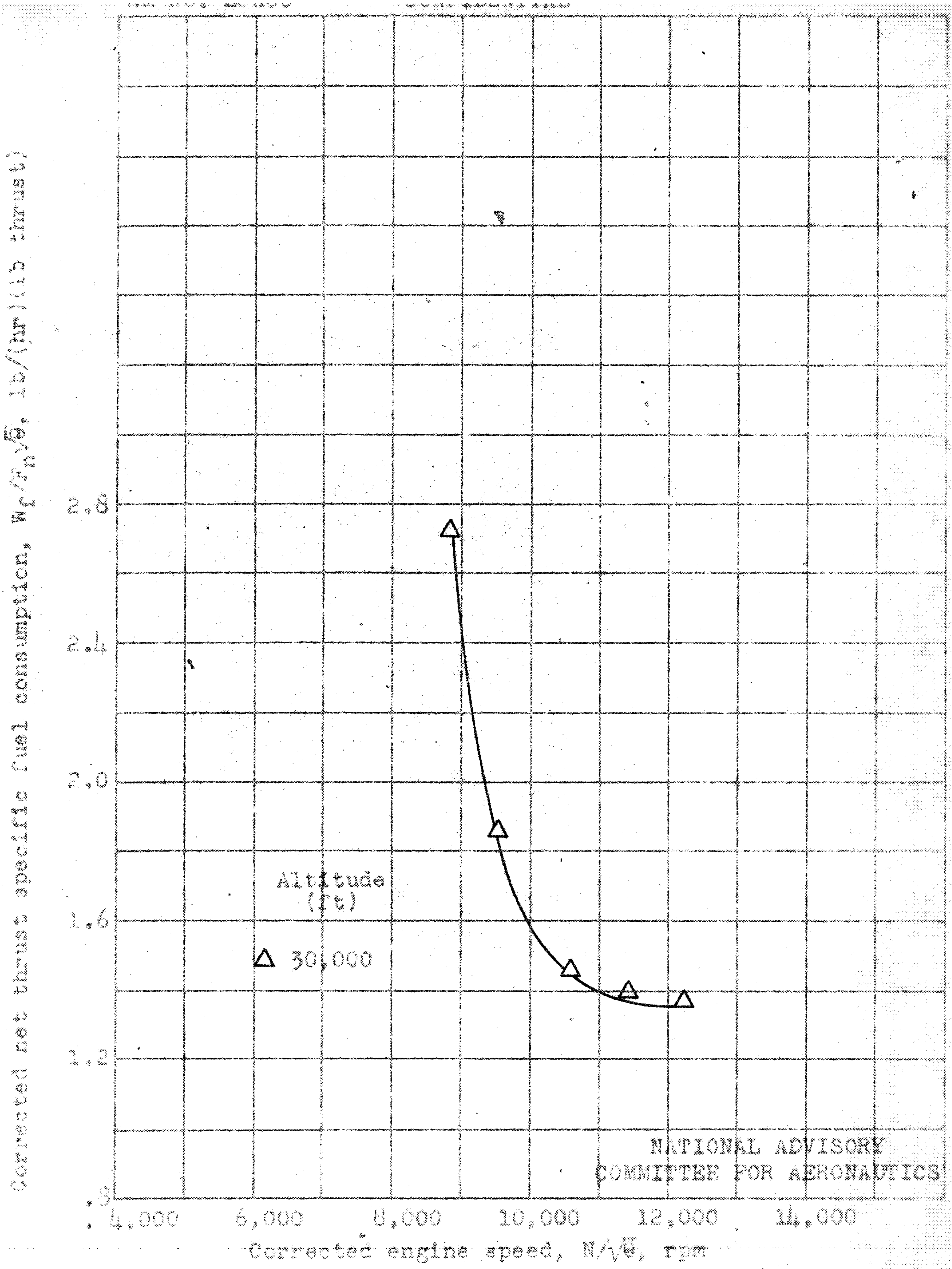
(a) Ram-pressure ratio, P_2/p_0, 1.1.

Figure 5. - Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



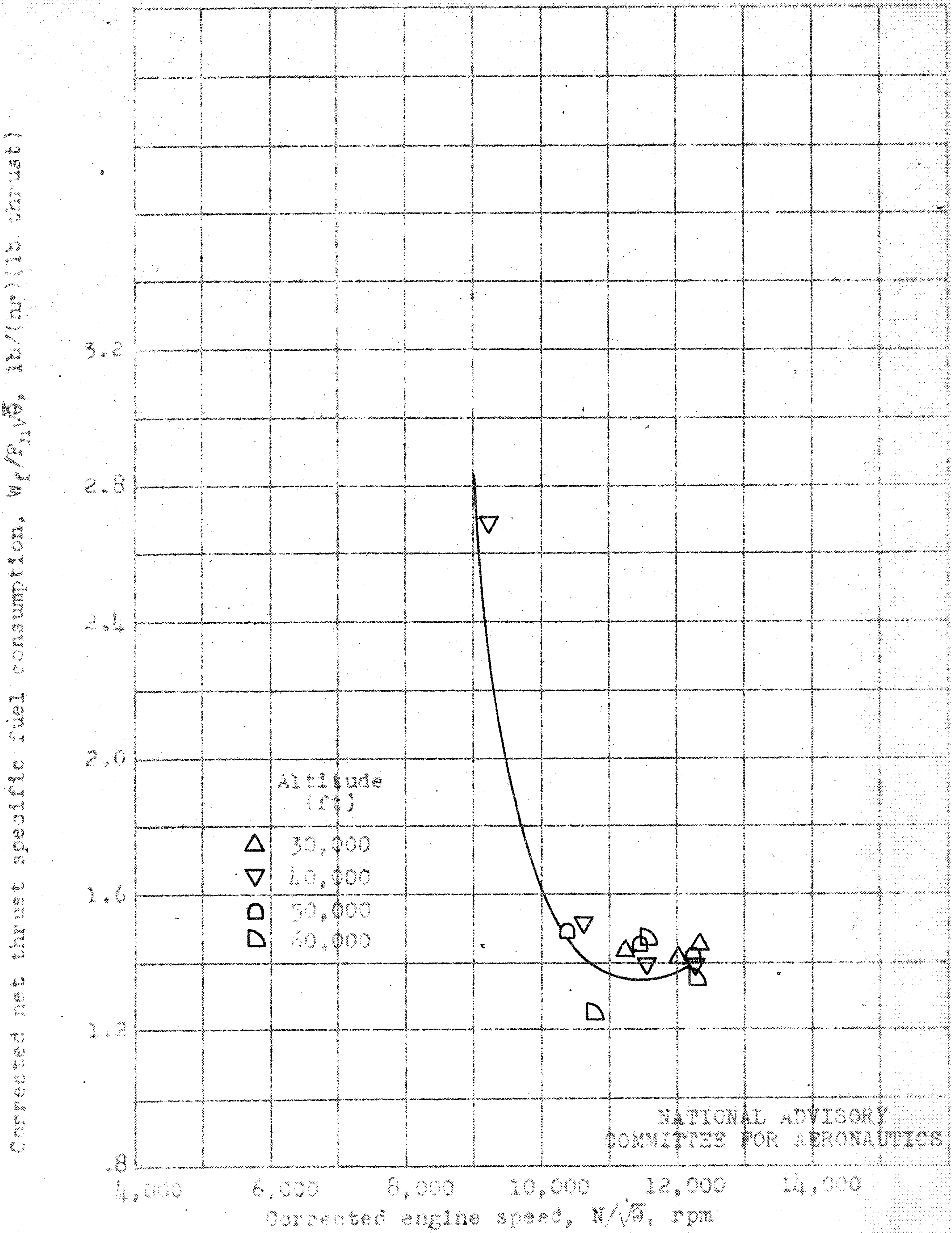
(b) Ram-pressure ratio, P_2/p_0, 1.3.

Figure . - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



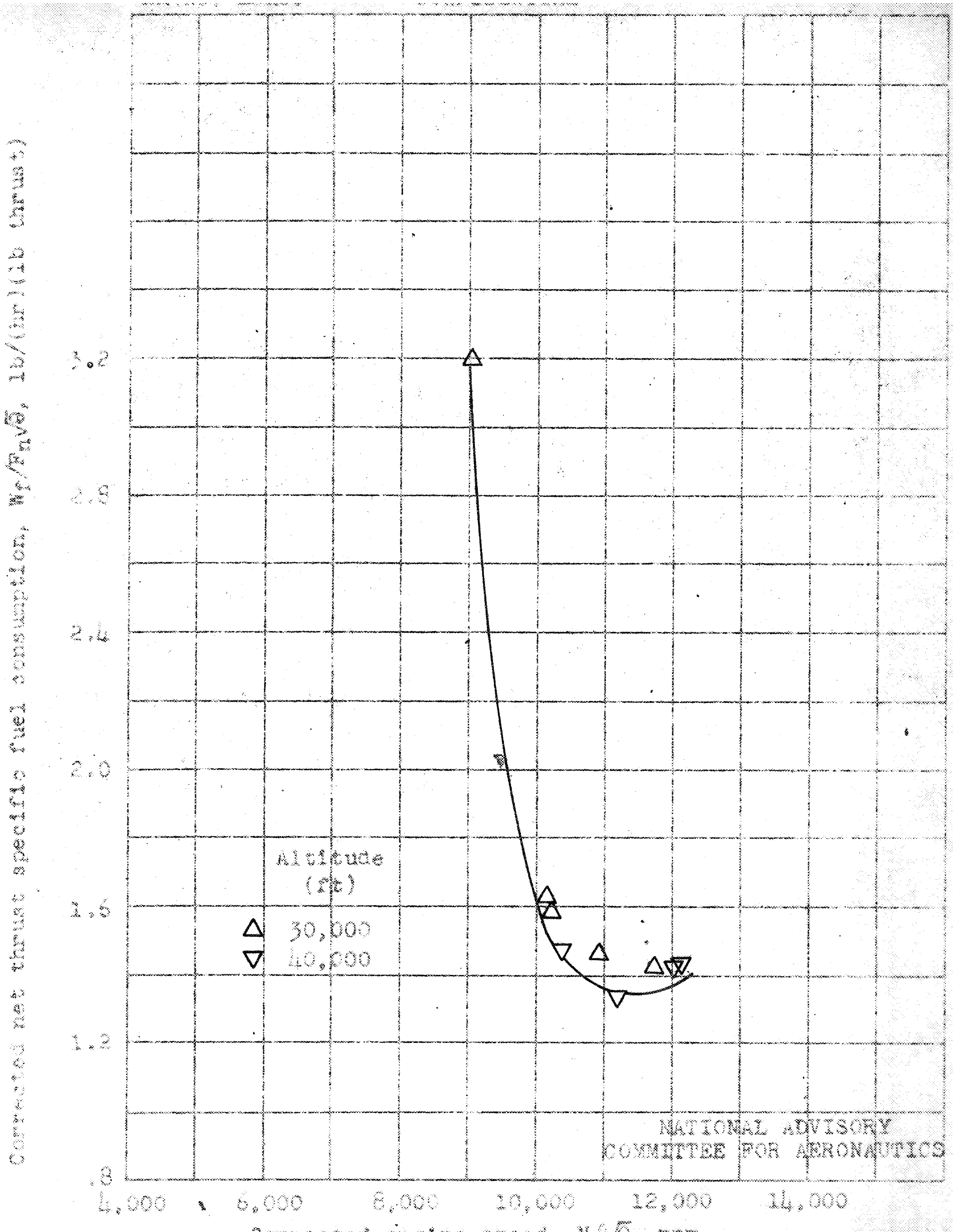
(c) Ram-pressure ratio, P_2/p_0, 1.5.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(d) Ram-pressure ratio, P_7/p_0, 1.7.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(e) Ram-pressure ratio, P_2/p_0, 2.0.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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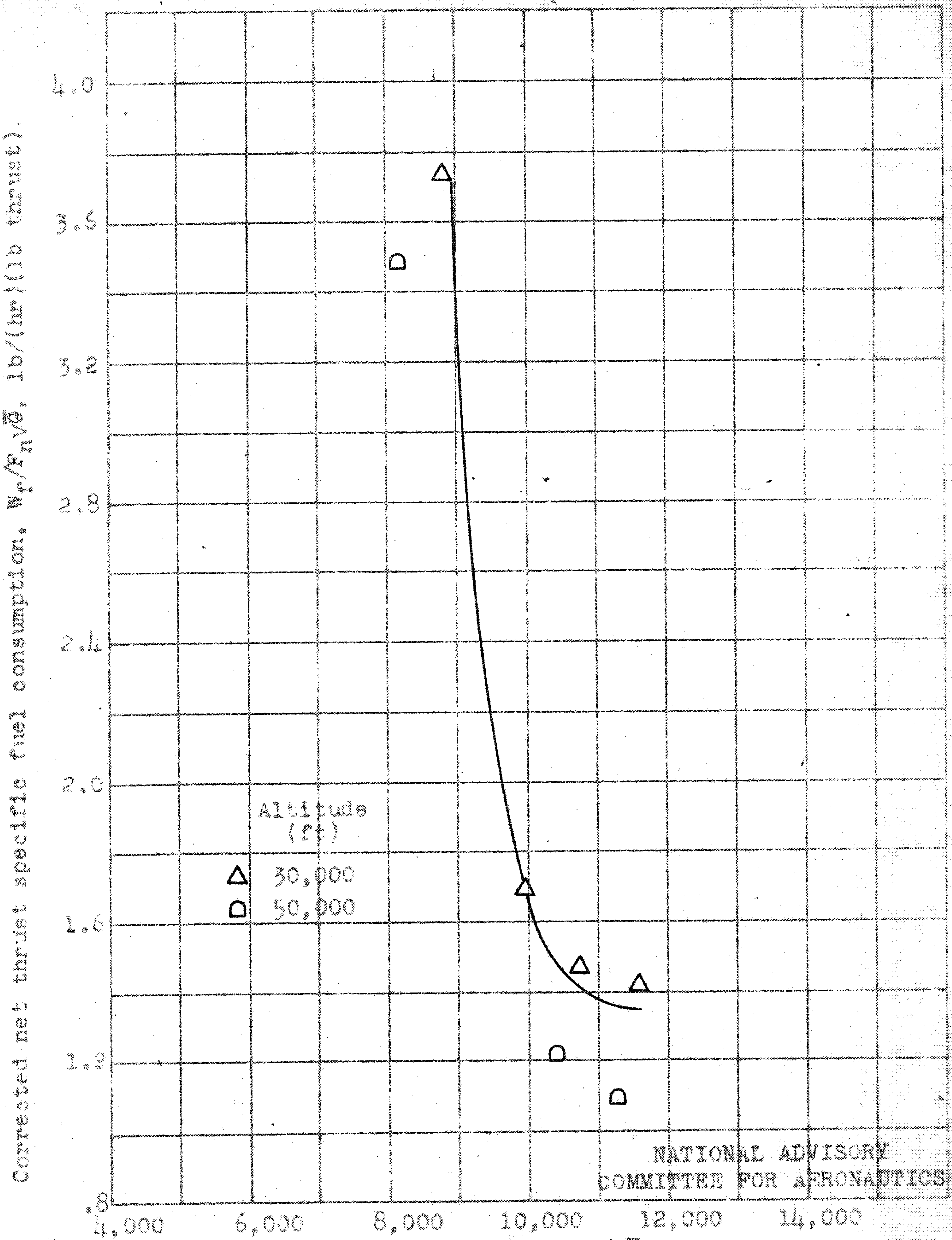
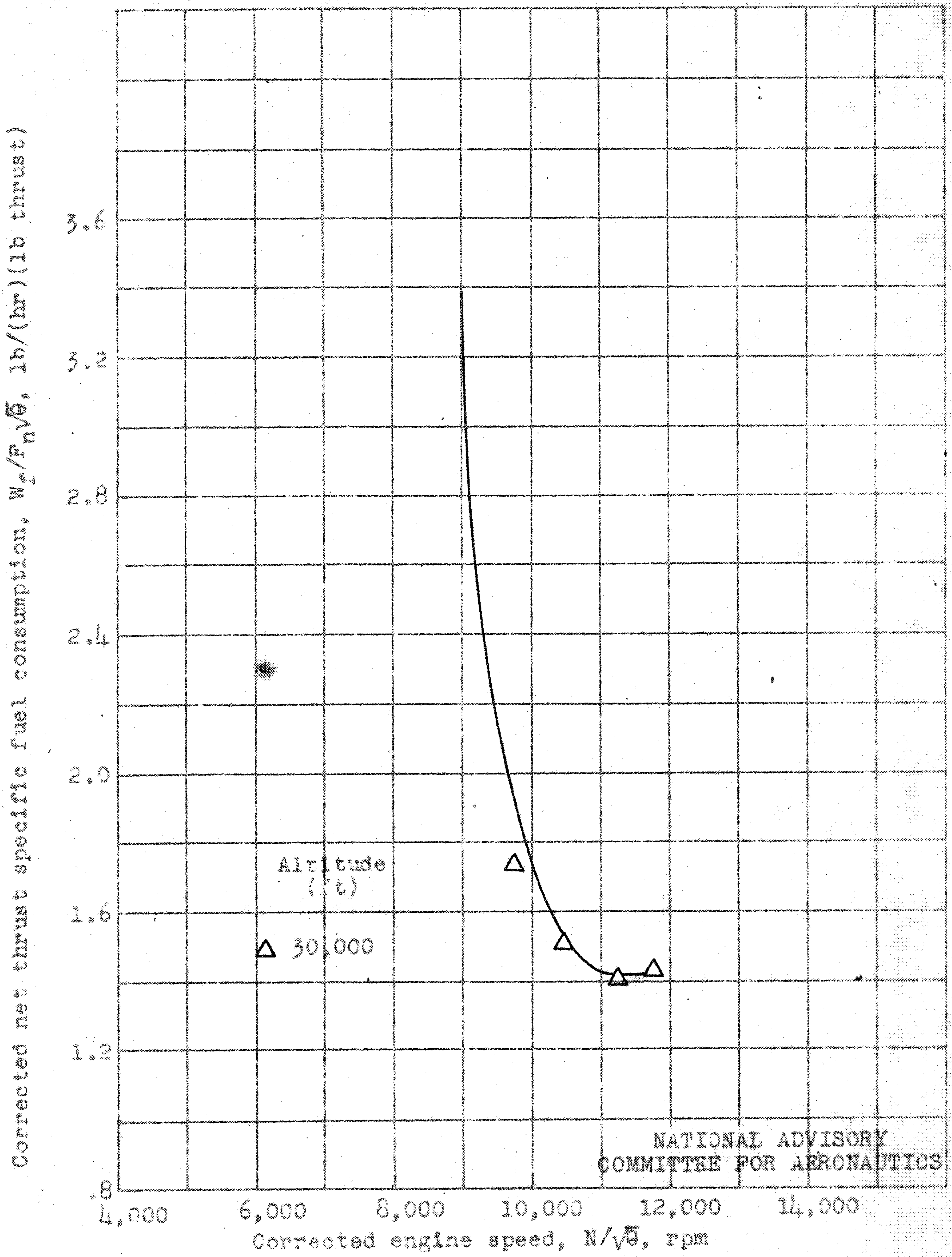


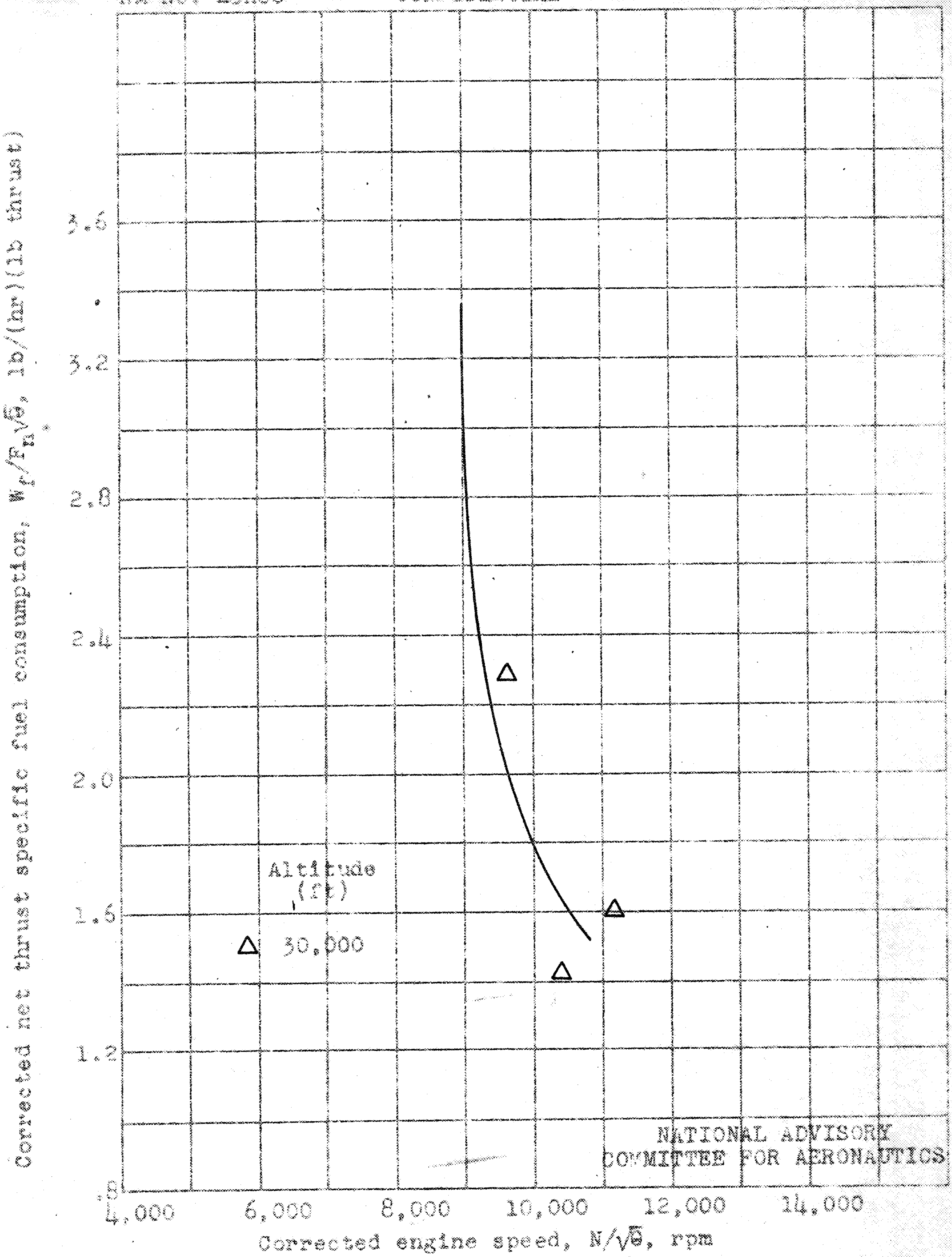
(f) Ram-pressure ratio, P_2/p_0, 2.3.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



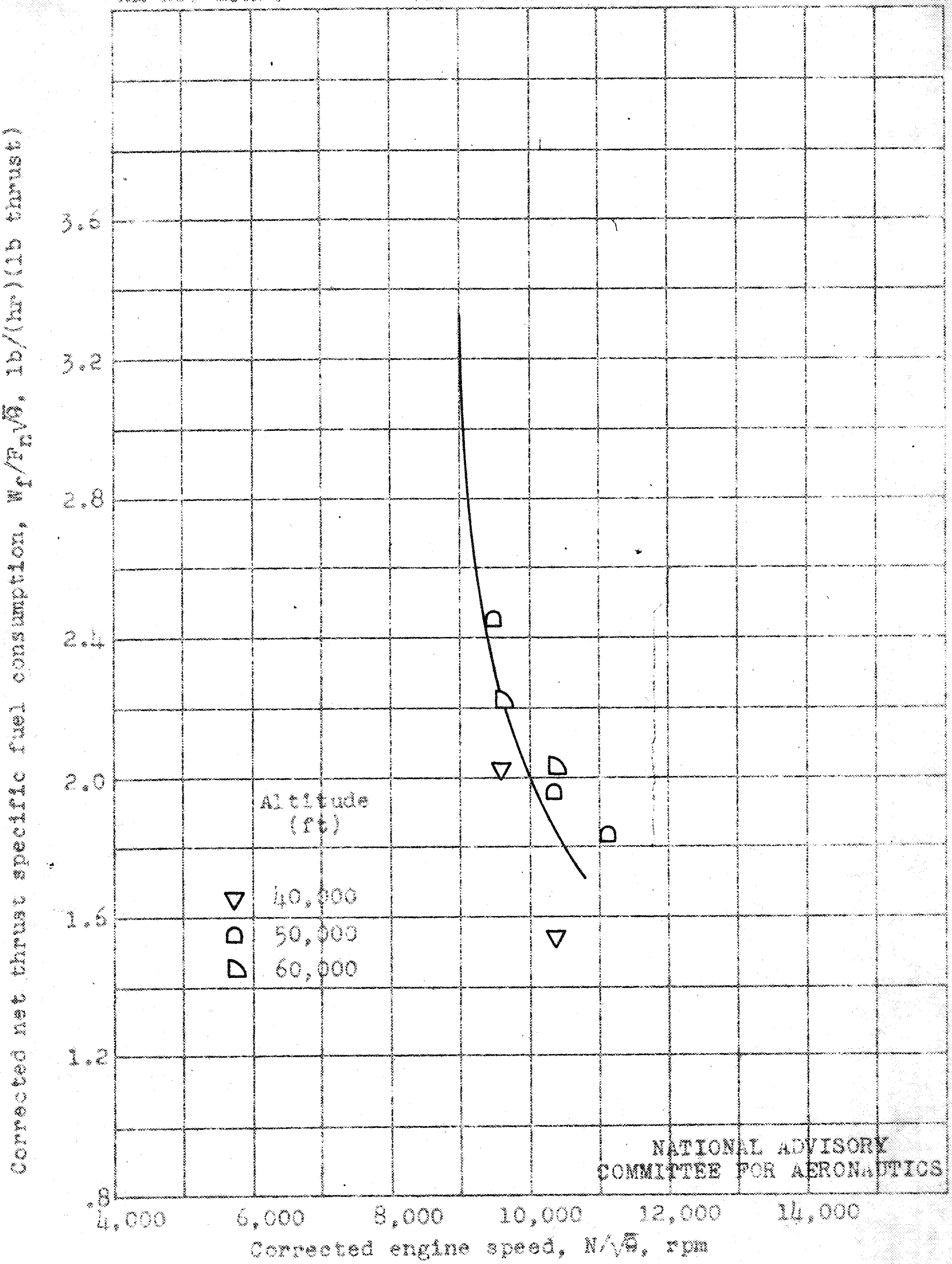
(g) Ram-pressure ratio, P_2/p_0, 2.7.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



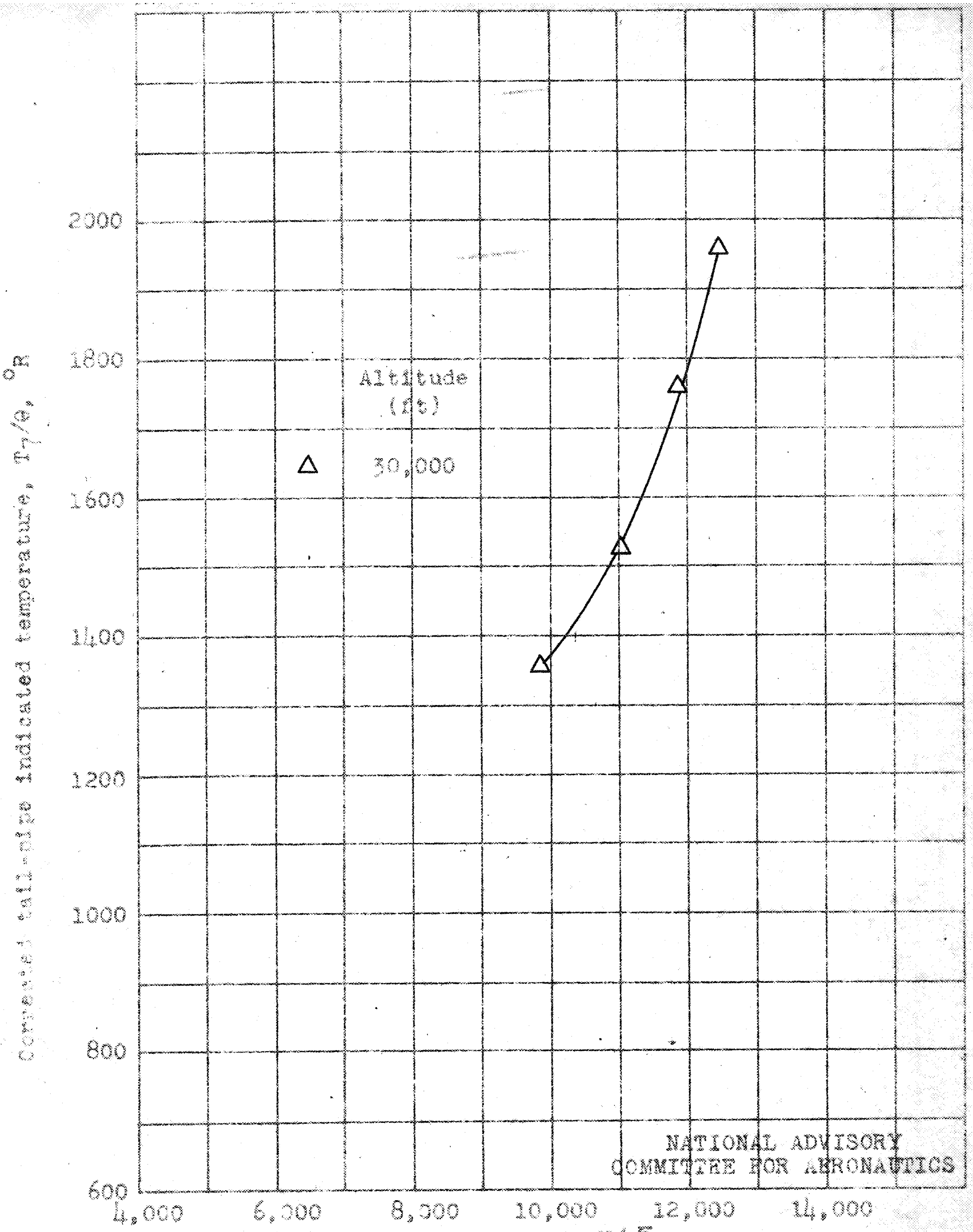
(h) Ram-pressure ratio, P_2/p_0, 3.0.

Figure 5. - Continued. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(i) Ram-pressure ratio, P_2/p_0, 3.5.

Figure 5. - Concluded. Effect of altitude and corrected engine speed on corrected net thrust specific fuel consumption at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(a) Ram-pressure ratio, P_2/p_0, 1.1.

Figure 6. - Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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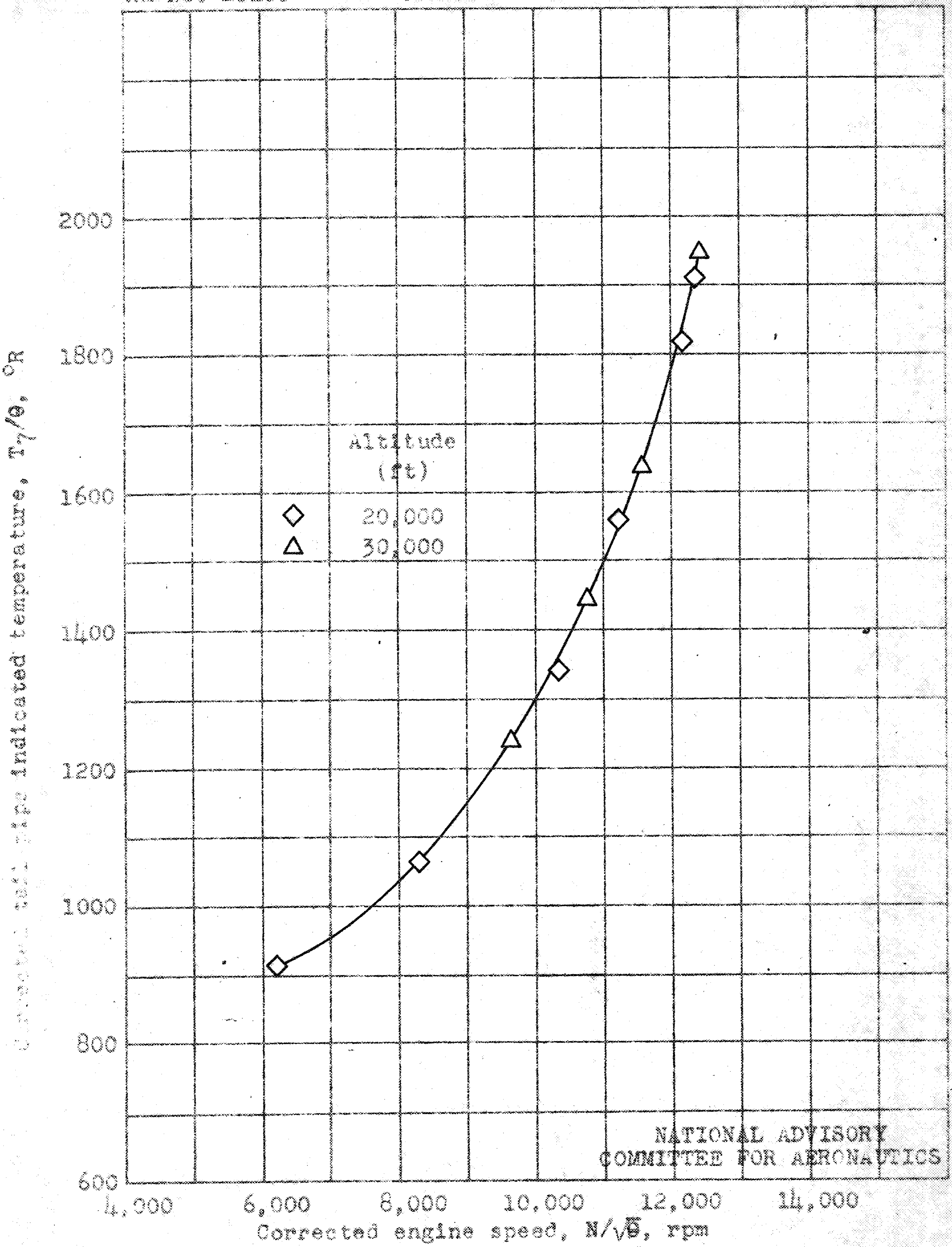
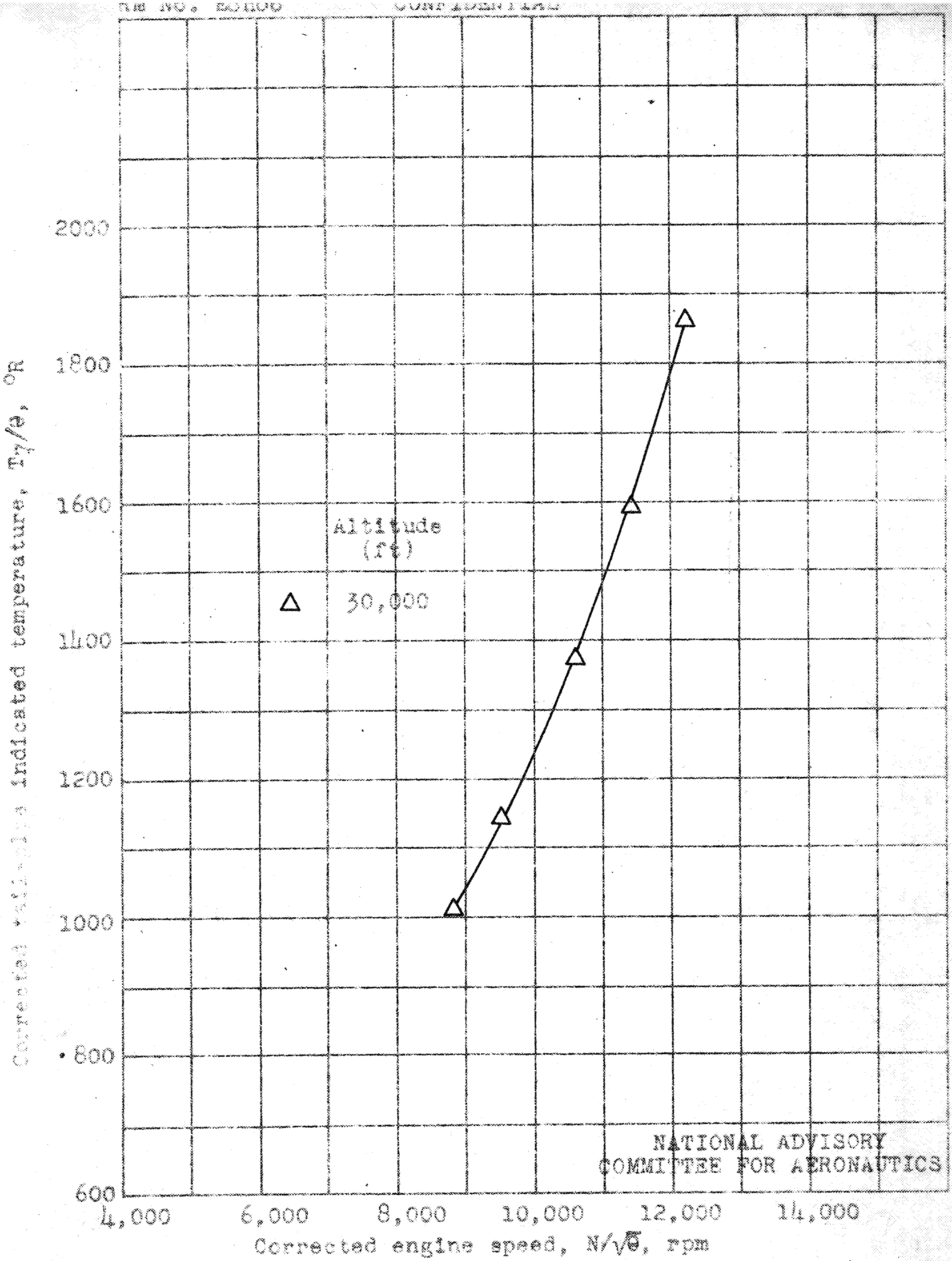


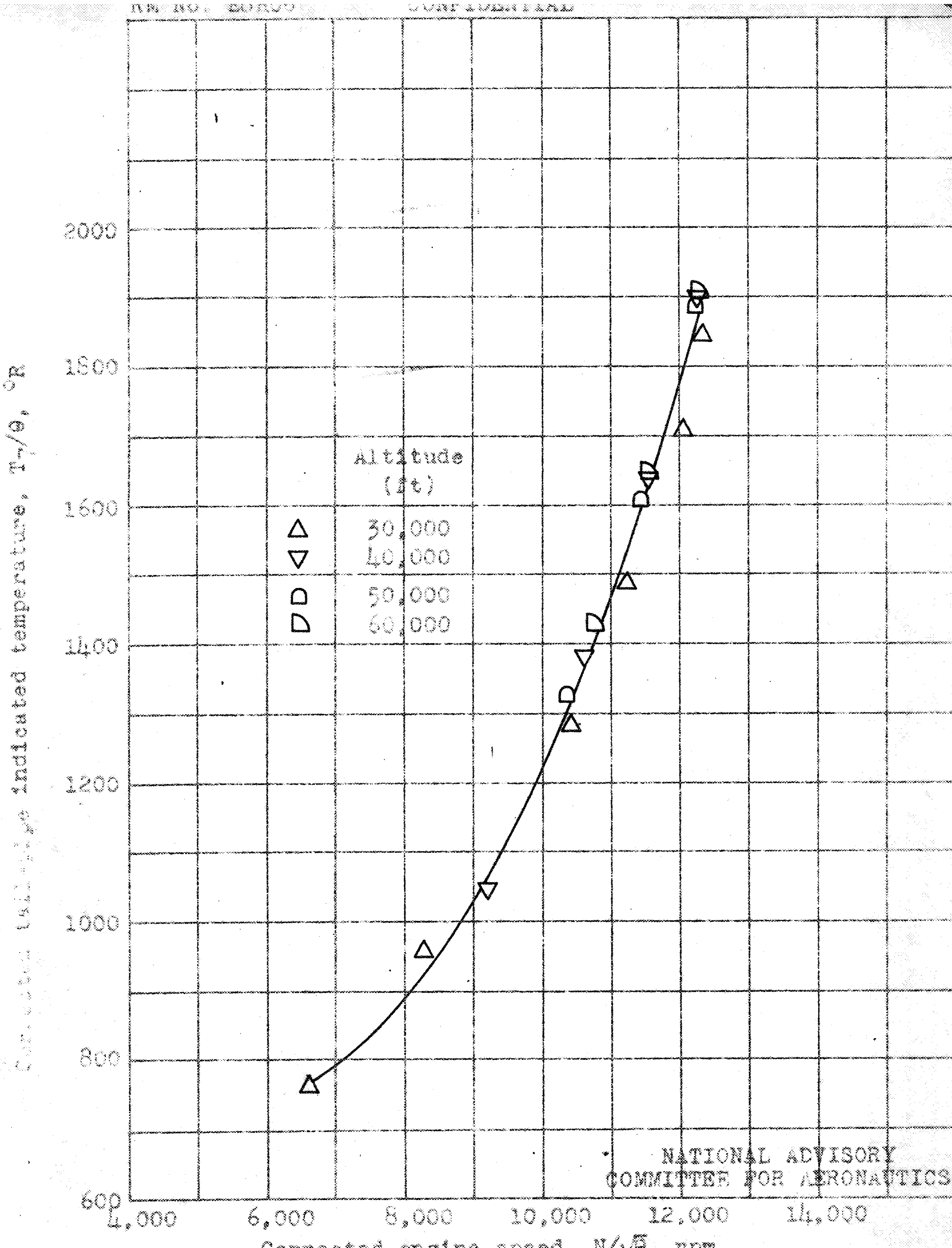
(b) Ram-pressure ratio, P_2/p_0, 1.3.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



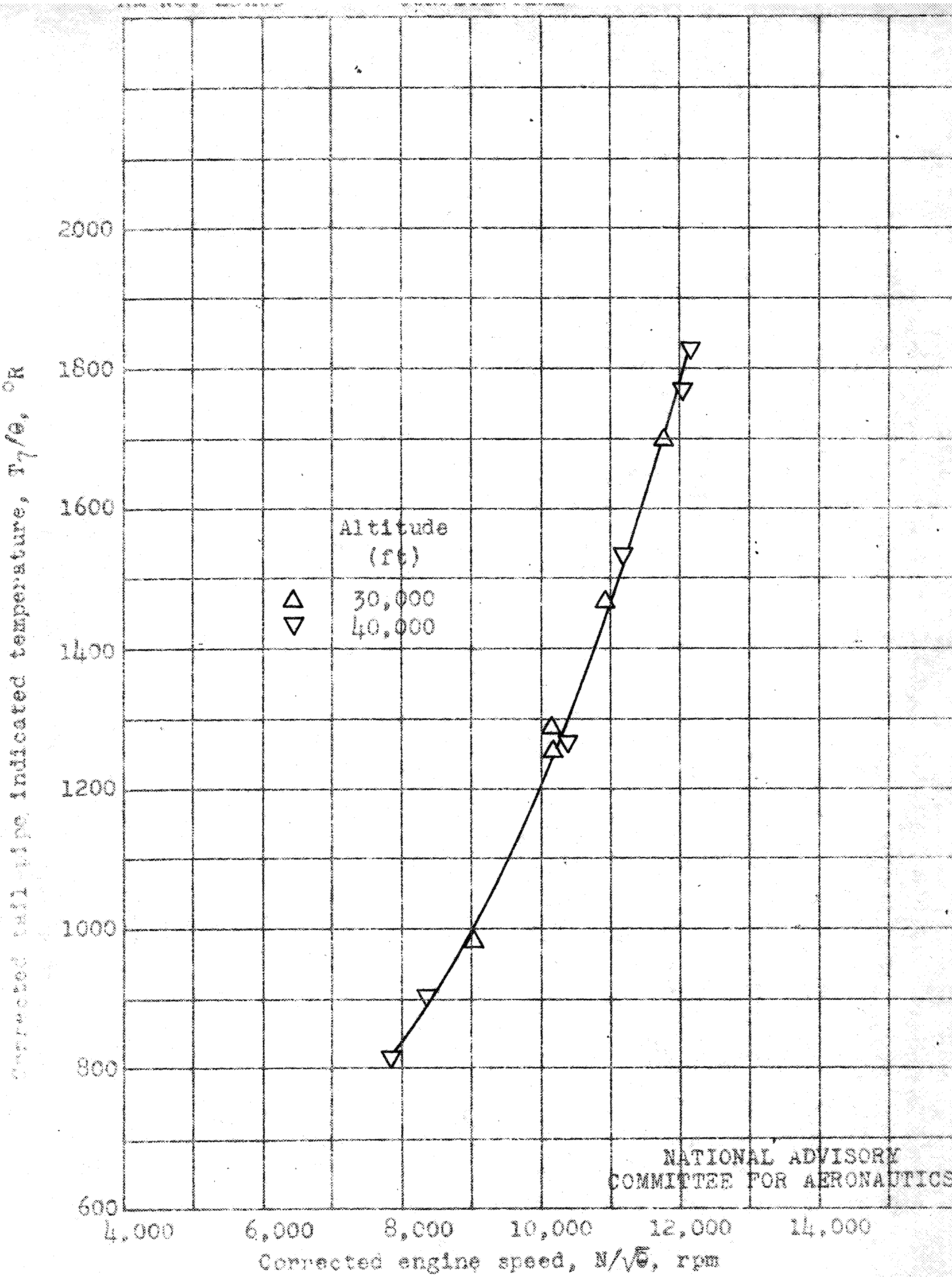
(c) Ram-pressure ratio, P_2/p_0, 1.5.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



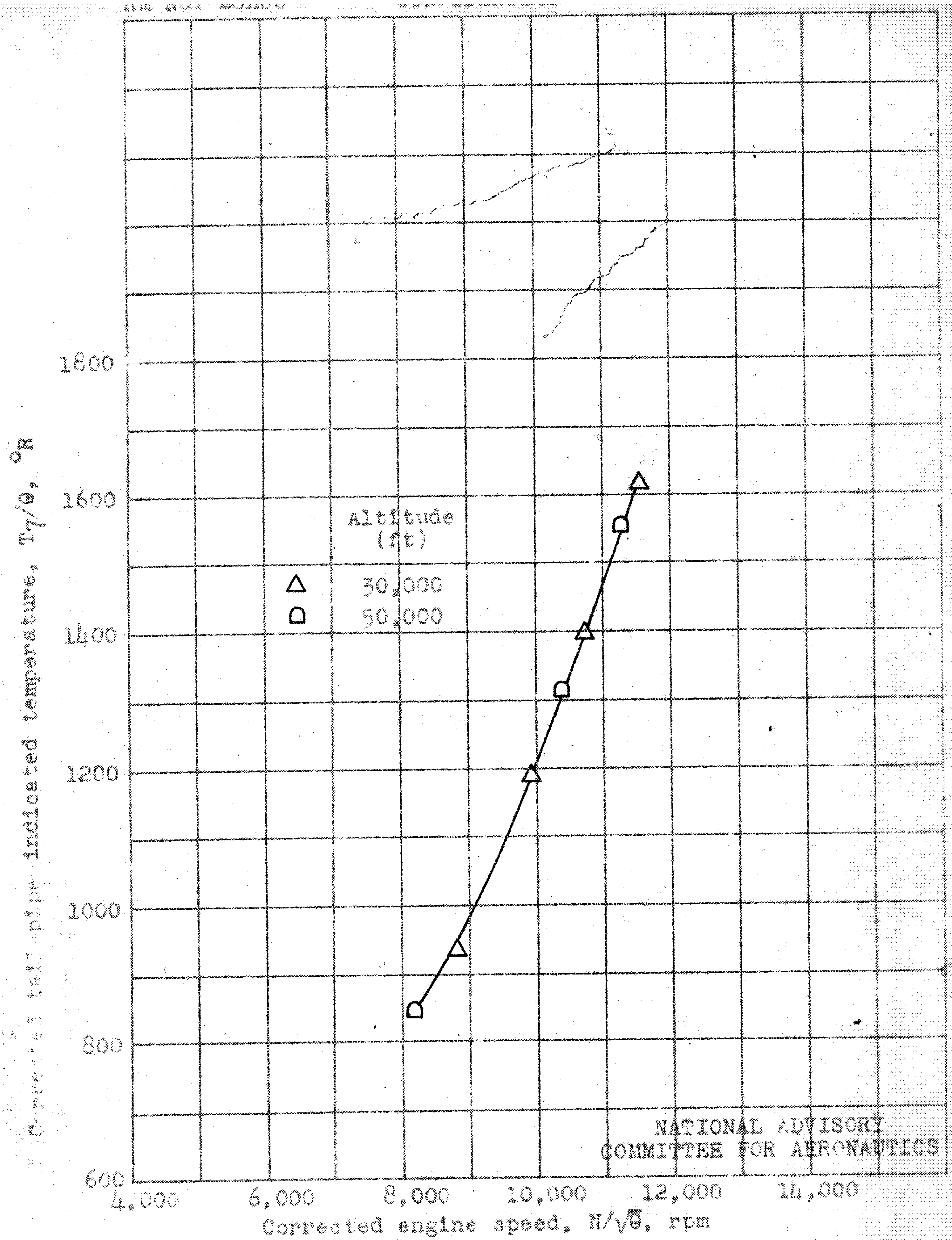
(d) Ram-pressure ratio, P_2/p_0, 1.7.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(e) Ram-pressure ratio, P_2/p_0, 2.0.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(f) Ram-pressure ratio, P_2/p_0, 2.3.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

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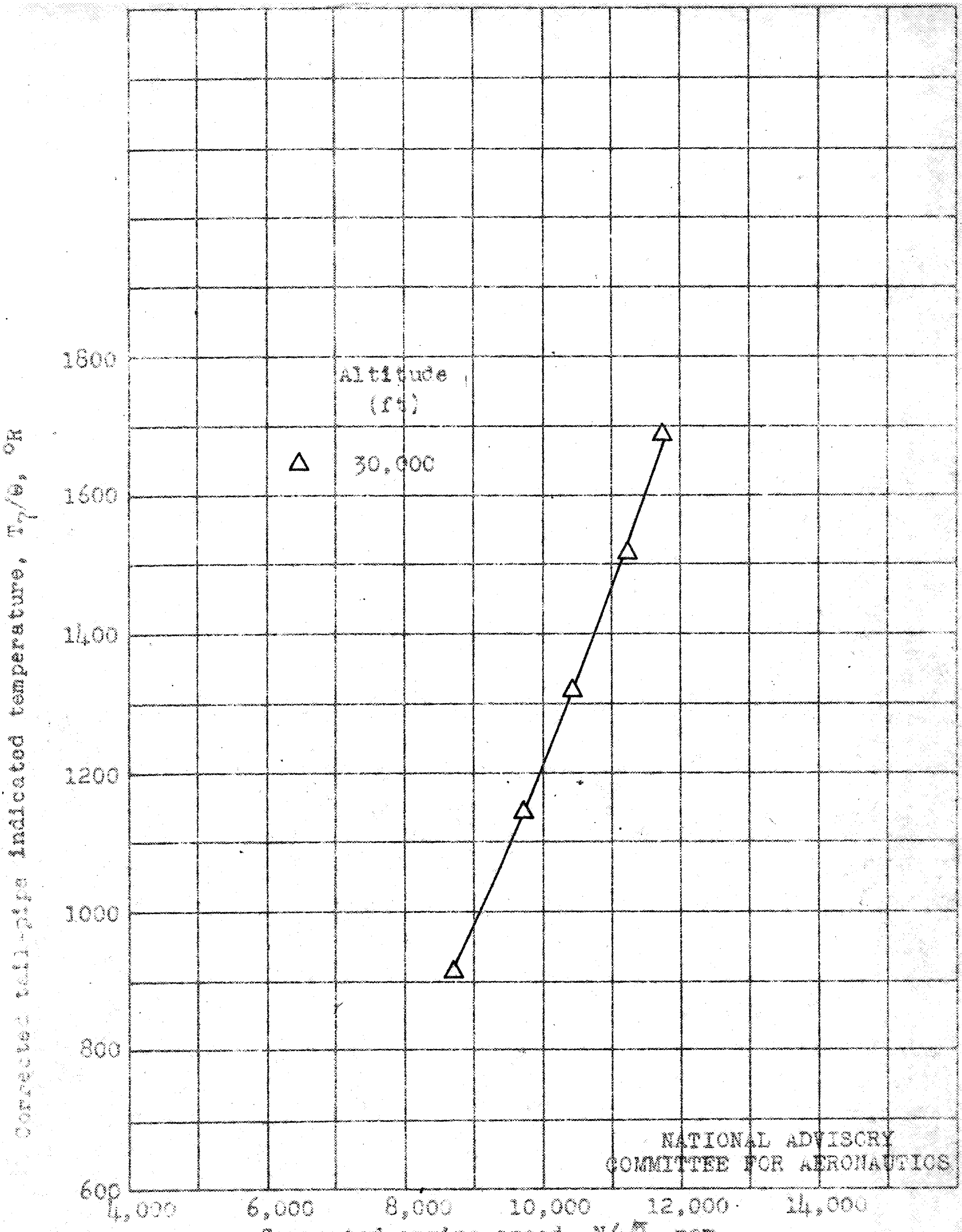
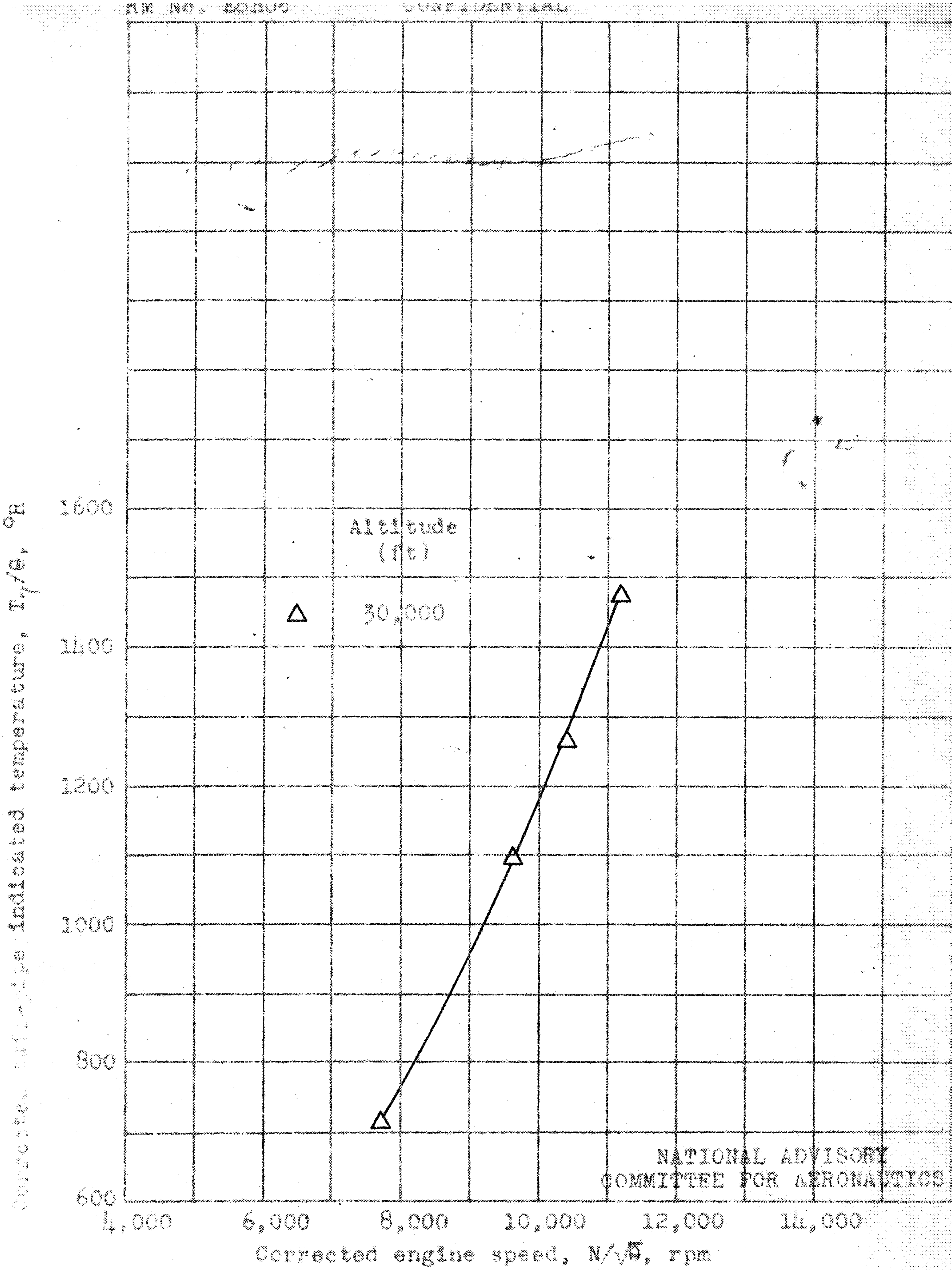


(g) Ram-pressure ratio, P_2/p_0, 2.7.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.



(h) Ram-pressure ratio, P_2/p_0, 3.0.

Figure 6. - Continued. Effect of altitude and corrected engine speed on corrected tail-pipe indicated temperature at various ram-pressure ratios. Jet-nozzle diameter, 18.00 inches.

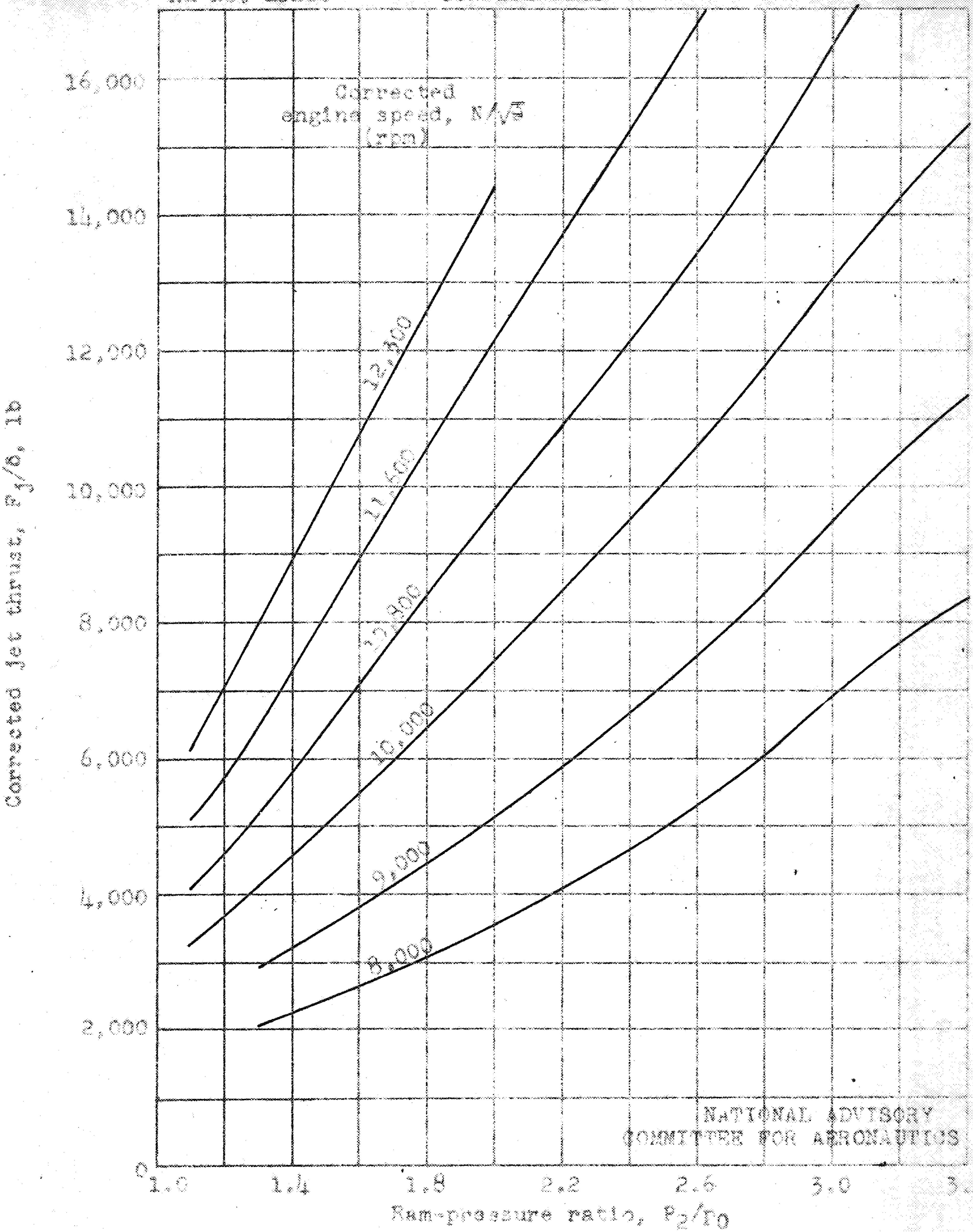


Figure 7. - Effect of ram-pressure ratio on corrected jet thrust. (Cross-plotted from fig. 1.)

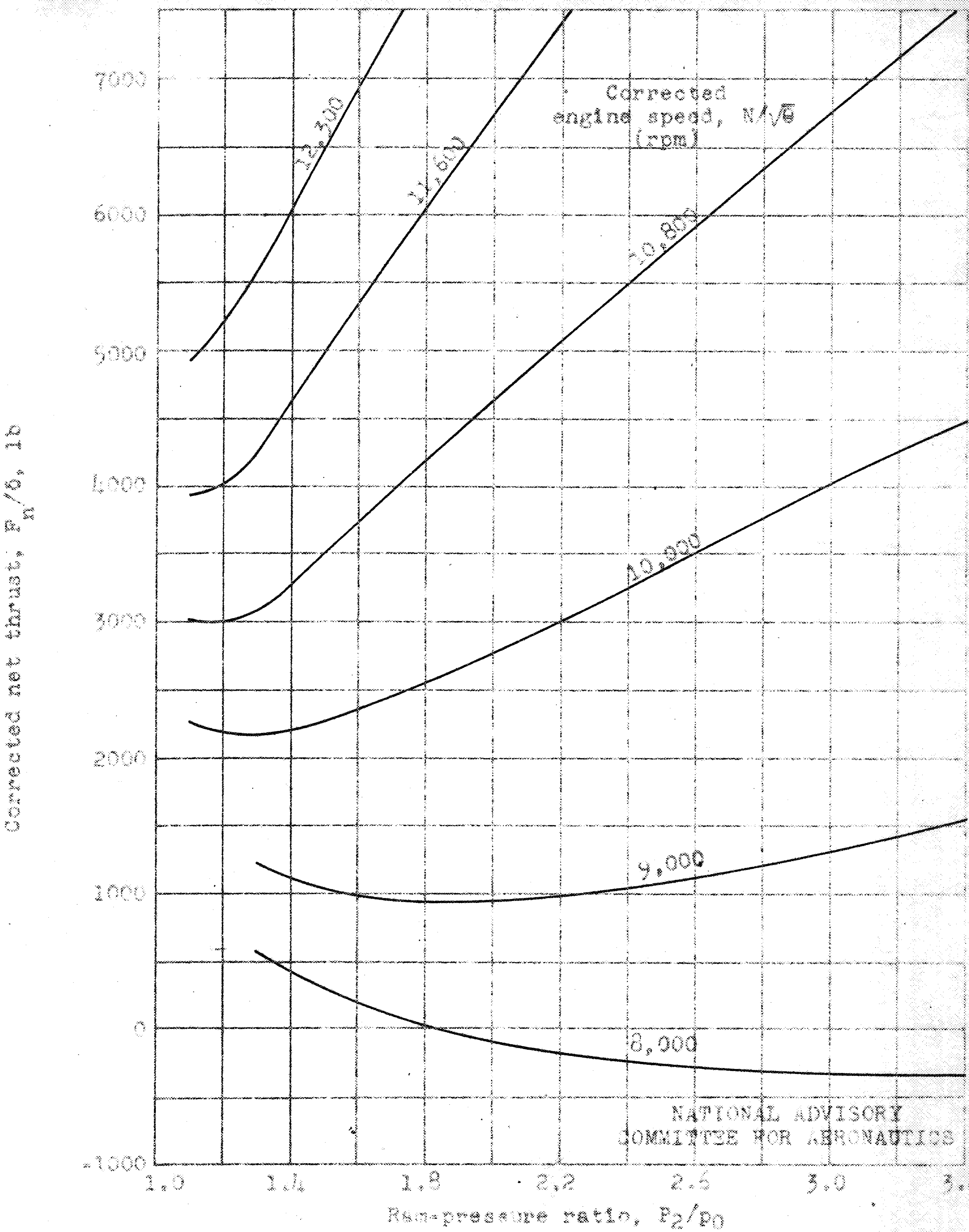


Figure 8. - Effect of ram-pressure ratio on corrected net thrust. (Cross-plotted from fig. 2.)

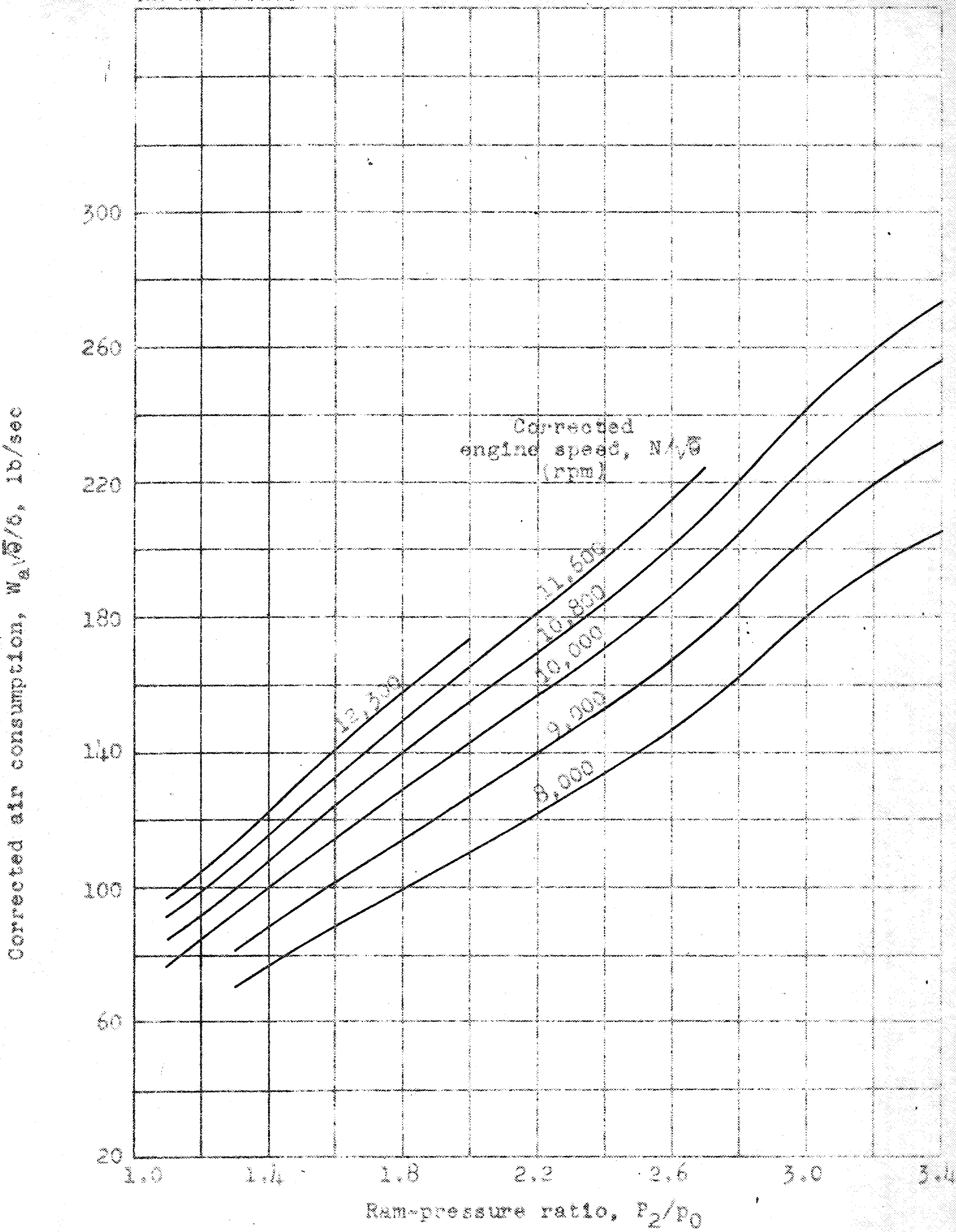


Figure 9. - Effect of ram-pressure ratio on corrected air consumption. (Cross-plotted from fig. 3.)

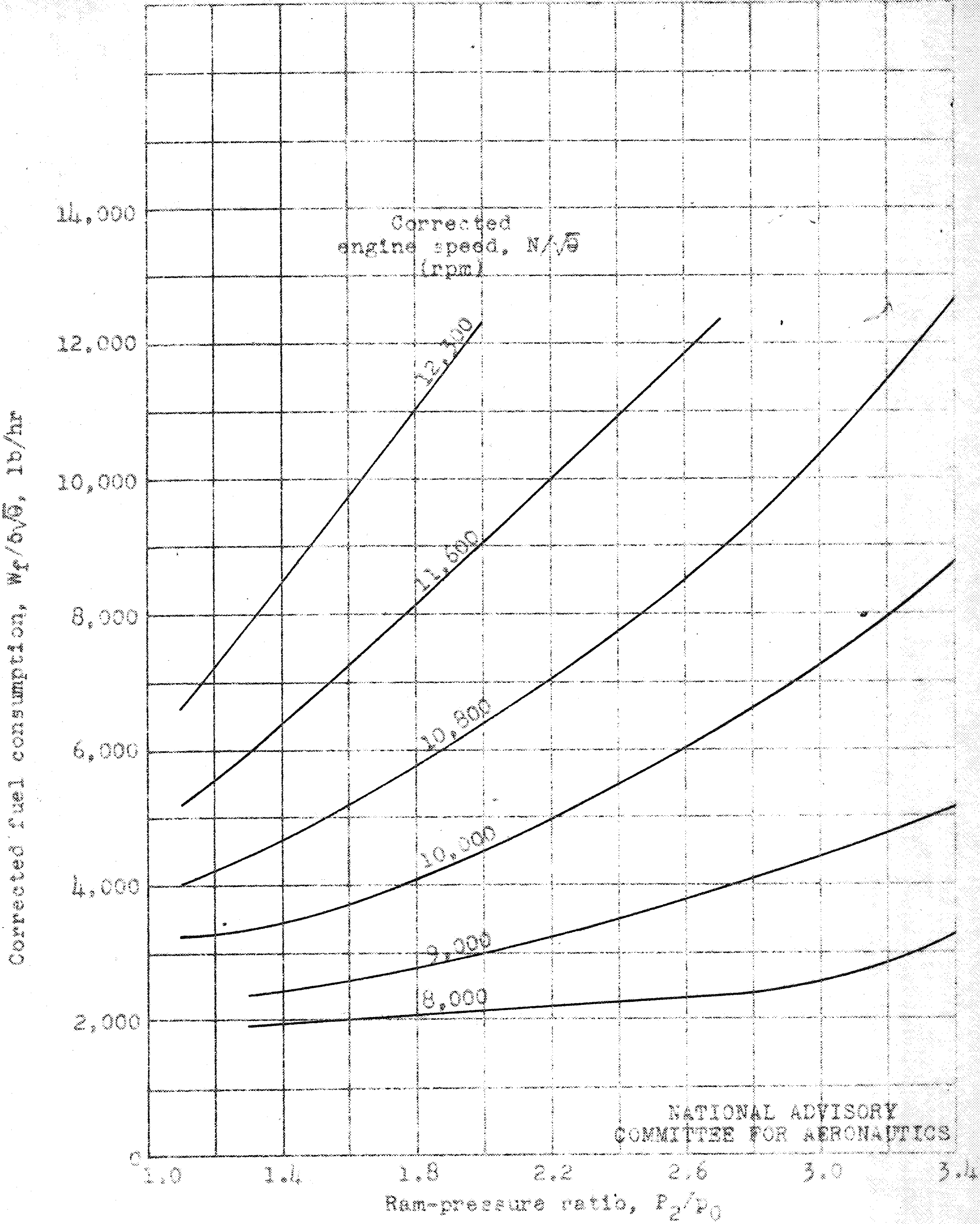


Figure 10. - Effect of ram-pressure ratio on corrected fuel consumption. (Cross-plotted from fig. 4.)

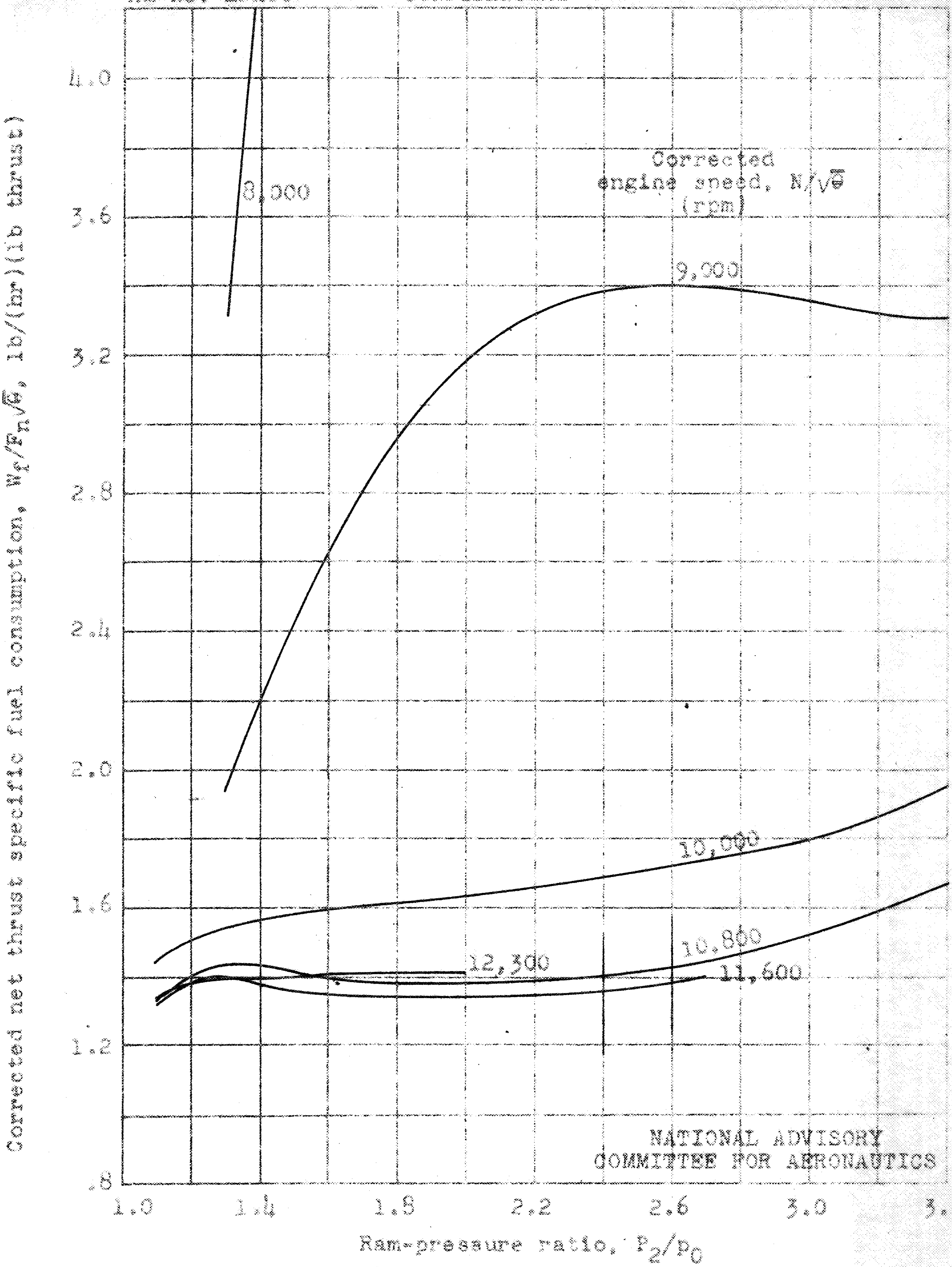


Figure 11. - Effect of ram-pressure ratio on corrected net thrust specific fuel consumption. (Cross-plotted from figs. 8 and 10.)

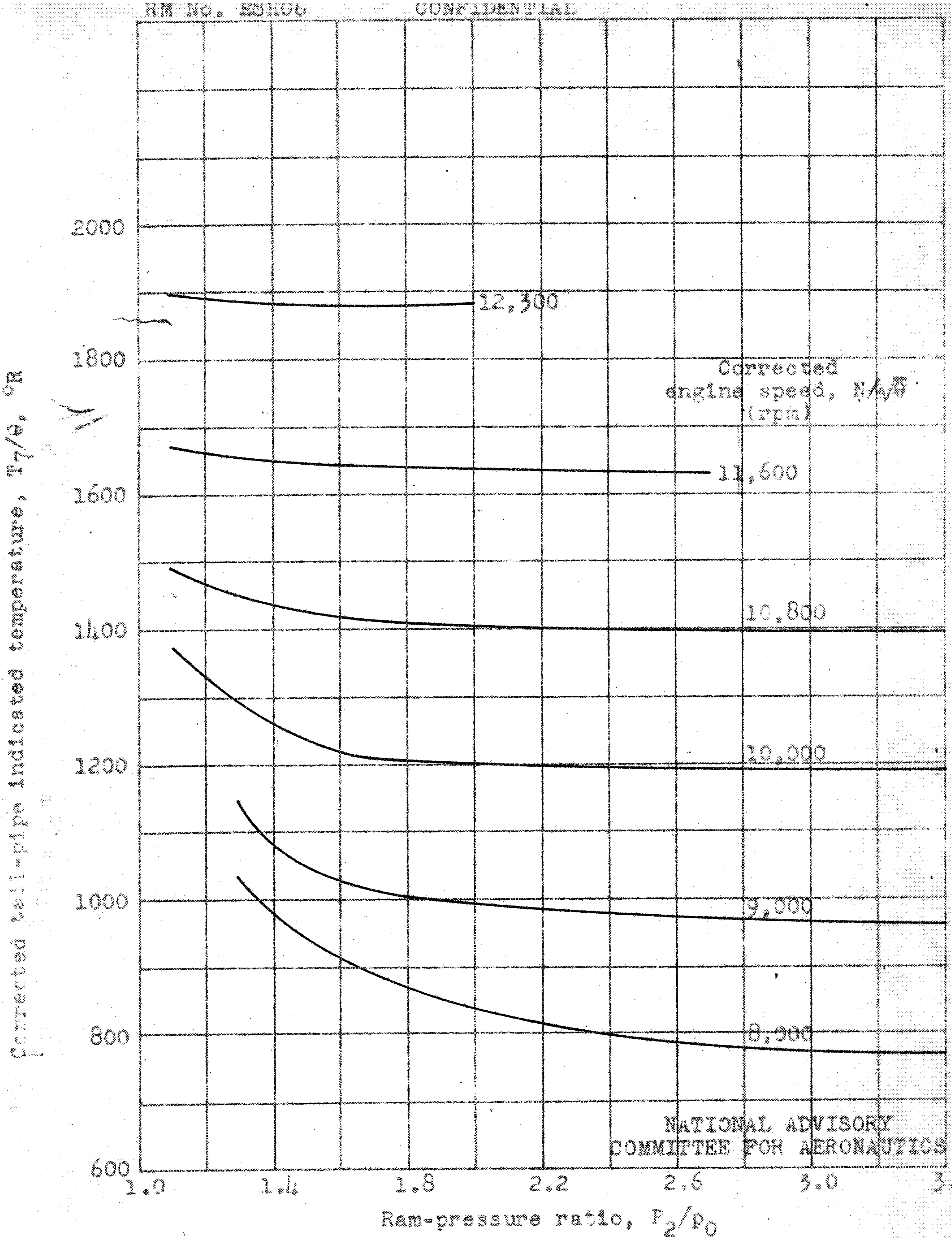


Figure 12. - Effect of ram-pressure ratio on corrected tail-pipe indicated temperature. (Cross-plotted from fig. 6.)

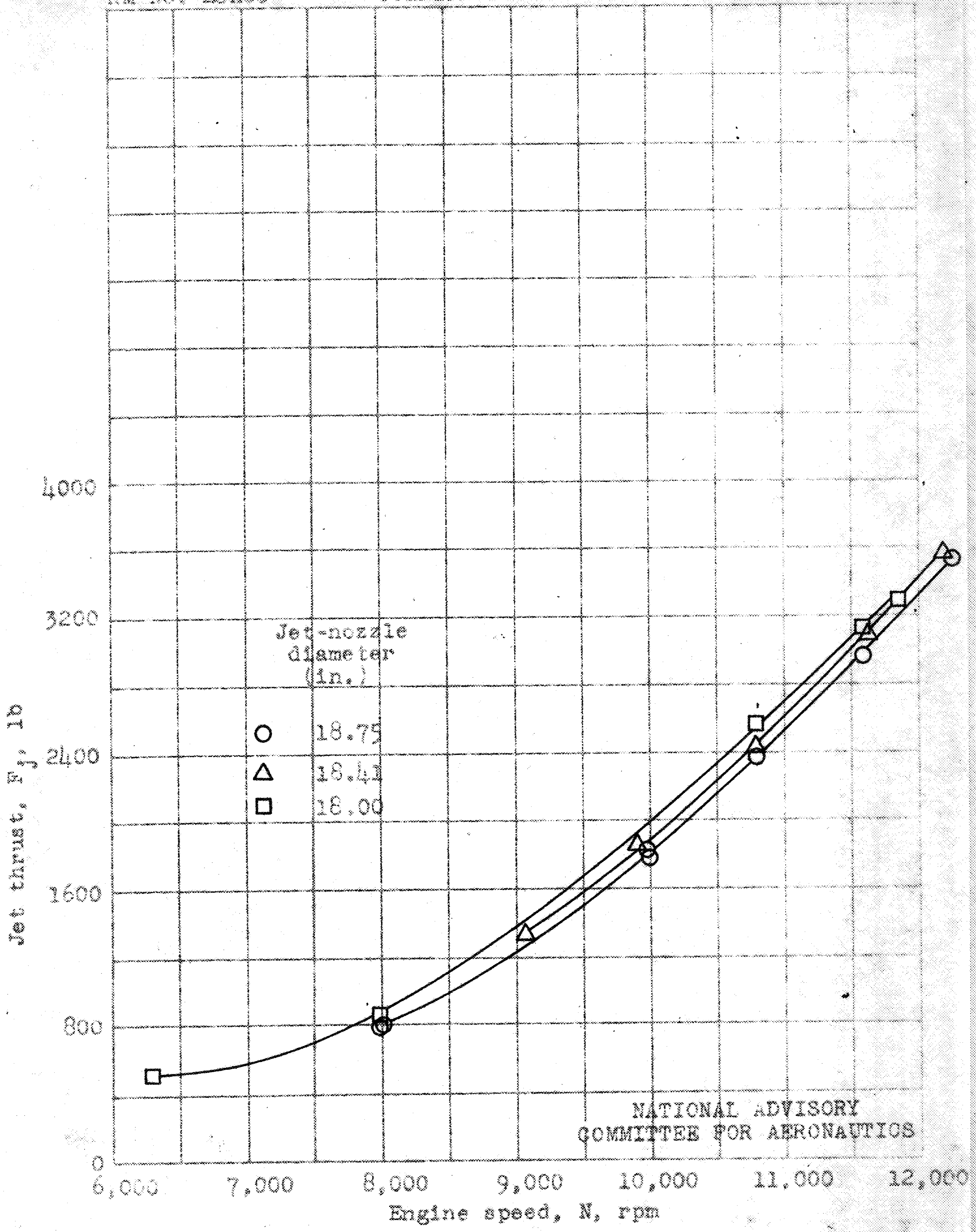


Figure 13. - Effect of jet-nozzle size on jet thrust at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.

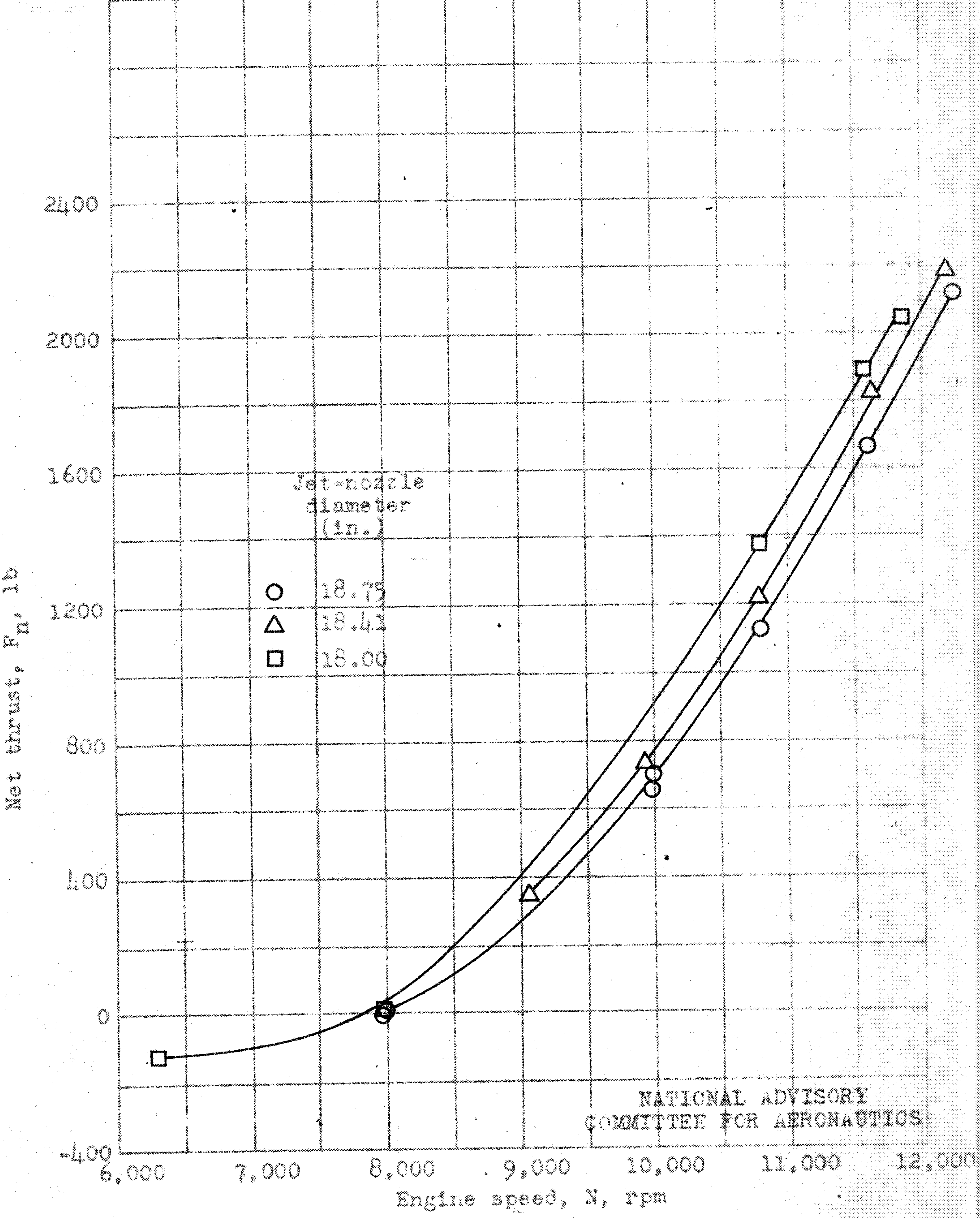


Figure 14. - Effect of jet-nozzle size on net thrust at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.

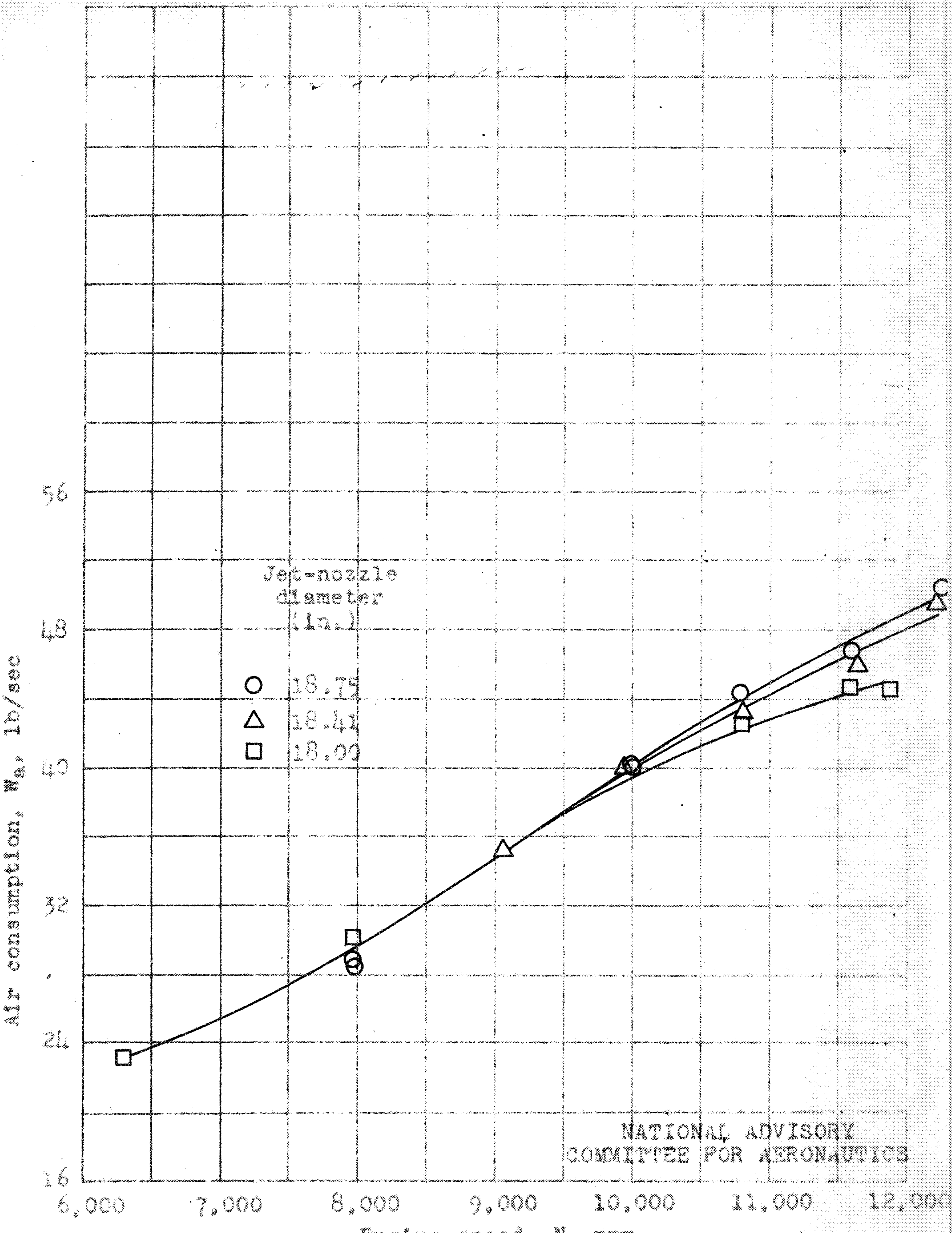


Figure 15. - Effect of jet-nozzle size on air consumption at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.

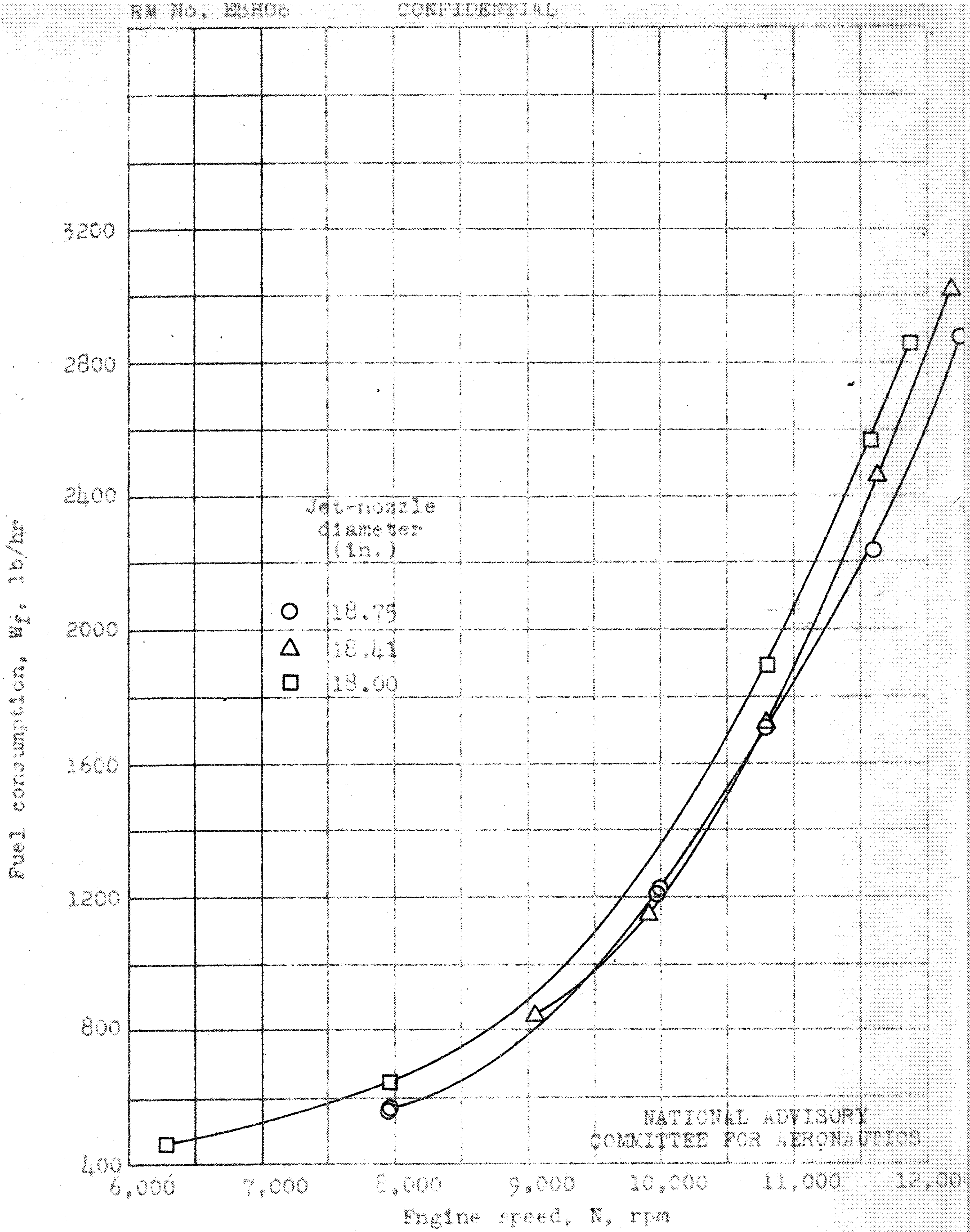


Figure 16. - Effect of jet-nozzle size on fuel consumption at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.

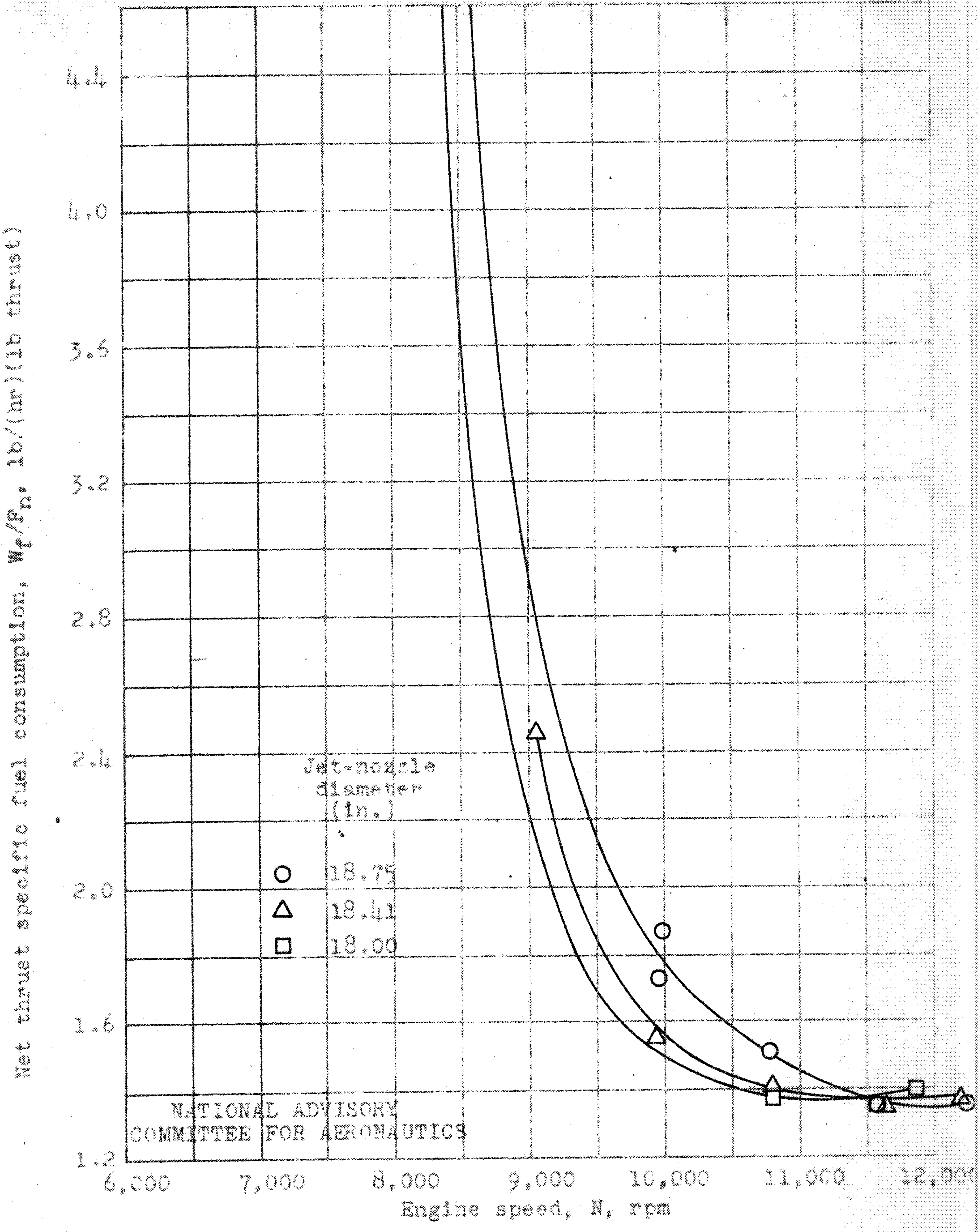


Figure 17. - Effect of jet-nozzle size on net thrust specific fuel consumption at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.

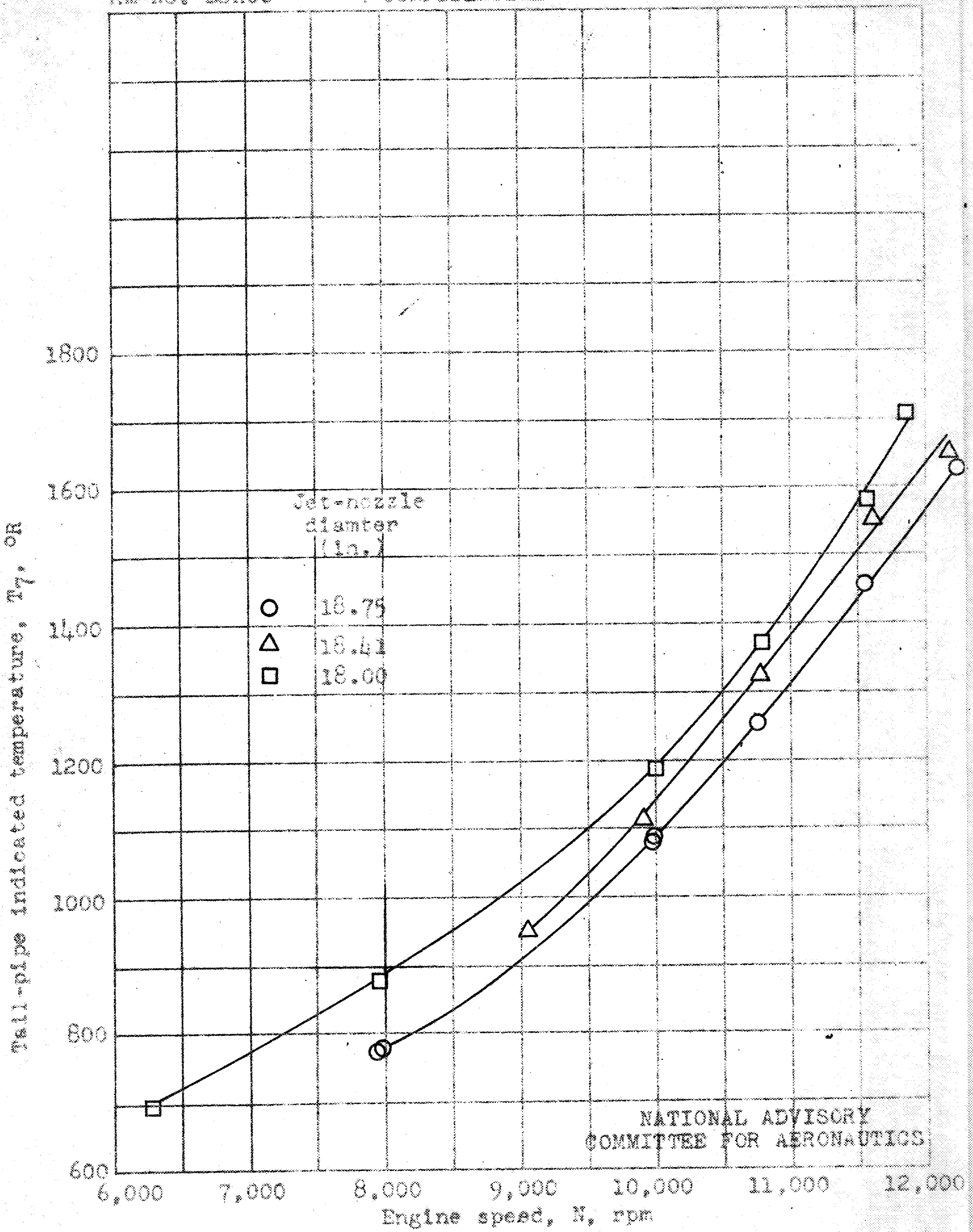


Figure 18. - Effect of jet-nozzle size on tail-pipe indicated temperature at simulated altitude of 30,000 feet and ram-pressure ratio of 1.7.