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RESEARCH MEMORANDUM

PRELIMINARY RESULTS OF NENE II ENGINE ALTITUDE-CHAMBER

PERFORMANCE INVESTIGATION

I - ALTITUDE PERFORMANCE USING STANDARD

18.75-INCH-DIAMETER JET NOZZLE

By Zelmar Barson and H. D. Wilsted

Flight Propulsion Research Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY   British

An investigation is being conducted to determine the altitude
performance characteristics of the British Nene II engine and its components.
The present paper presents the preliminary results obtained using a
standard jet nozzle. The test results presented are for conditions
simulating altitudes from sea level to 60,000 feet and ram pressure
ratios from 1.0 to 2.3. These ram pressure ratios correspond to
flight Mach numbers between zero and 1.16 assuming a 100 percent ram
recovery.

Values of jet thrust, air consumption, and tail-pipe tempera-
ture, corrected to sea-level conditions, were essentially independent
of the altitude at which the data were obtained. It is particularly
noteworthy that, at the higher engine speeds, changes in simulated
altitude had only a small effect on corrected fuel consumption.

INTRODUCTION

The altitude performance of the British Nene II engine with several
sizes of jet nozzle is being determined in order to investigate the
degree of matching of the components and the effects of changes in
the characteristics of the various engine components on altitude
performance. This investigation is being conducted at the Cleveland
laboratory of the NACA.

This paper contains the preliminary over-all engine performance
results obtained using the standard 18.75-inch-diameter jet nozzle.
The test results presented are for conditions varying from sea level
to approximately 60,000 feet altitude and ram pressure ratios from
1.0 to 2.3. These ram pressure ratios correspond to flight Mach

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numbers between zero and 1.16 assuming a 100 percent ram recovery. The data are so presented as to show the effects of altitude and ram pressure ratio on engine performance. The conventional method of correcting data to sea-level conditions (reference 1) was used to generalize the data, in order that data indicating performance at any altitude can be used to determine performance at various other altitudes. The applicability of this method is briefly discussed.

DESCRIPTION OF POWER PLANT

Figure 1 is a cutaway view of the Nene power plant, which is a through-flow turbojet engine having 9 combustion chambers. The engine incorporates a single-stage, double-entry, centrifugal compressor of 28.80 inches diameter driven by a single-stage, reaction turbine of 24.53 inches diameter. The turbine-nozzle area is 126 square inches and the jet-nozzle area is 276 square inches.

The dry engine weight is approximately 1720 pounds (starting panel and generator included) and the maximum diameter (cold) is 49.50 inches, giving an effective frontal area of 13.37 square feet. The standard sea-level engine ratings (reference 2) are as follows:

Rating	Jet thrust lbs.	Rotor speed rpm	S.F.C. lb/hr/lb thrust
Take-off	5000	12,300	1.12
Military	5000	12,300	1.12
Normal	4000	11,600	1.09
Cruise	2700	10,500	1.11
Cruise	2250	10,000	1.14
Idle	120	2,600	6.5

From these values it can be seen that the rated military thrust per unit weight of engine is 2.91 pounds per pound, and the rated military thrust per unit of frontal area is 374 pounds per square foot.

The engine, obtained from Rolls Royce Ltd., was a Nene series I engine. Parts necessary for converting to a series II engine were

received shortly after arrival of the power plant and modifications affecting altitude performance were made early in the altitude test program. These modifications included:

(a) Replacement of engine fuel pumps with bronze-rotor-type fuel pumps to allow higher fuel-pump pressures and operation without the addition of 1 percent of lubricating oil to standard AN-F-32 fuel as required with the earlier type pumps.

(b) Replacement of barometric fuel-flow control with improved unit to allow higher fuel delivery pressures (1300 pounds per square inch at sea-level static conditions) and to provide better altitude metering. The higher fuel pressures allowed simulation of higher flight speeds without fuel-flow limitations.

(c) Replacement of throttle valve by an improved unit having a lower pressure loss.

TEST APPARATUS AND PROCEDURE

Altitude Test Chamber

The engine was installed in a 10-foot diameter by 60-foot long altitude test chamber (shown schematically in figure 2) on a thrust frame connected through linkage to a balanced-pressure-diaphragm type thrust indicator located outside the test chamber.

The engine air consumption was measured by an ASME type sharp-edged plate orifice mounted in a straight run of 42-inch diameter pipe at the approach to the altitude chamber.

However, due to the large variation in atmospheric conditions investigated, considerable difficulty was experienced with condensation in the orifice differential-pressure lines even though traps were installed to collect this moisture. The engine air consumption was therefore calculated from other engine measurements as described in the appendix. The ram air pressure was controlled by pneumatically-operated butterfly valves in the air supply line near the entrance to the altitude chamber. Air was supplied from either a combustion air or refrigerated air system at temperatures near those desired. Final control and adjustment of air temperatures was made by use of electric heaters in the bypass line immediately preceding the entrance to the test chamber. The air enters the

test chamber, passes through straightening vanes, and enters an
engine cowl. The engine cowl was installed to prevent circulation
of hot air from the region of the tail pipe into the rear inlet of
the compressor.

The test section of the altitude chamber was separated from
the exhaust portion by a bulkhead seal. The tail pipe passed
through the bulkhead through a seal composed of three floating
transite rings so installed as to allow axial movement required by
engine expansion and to allow a reasonable amount of lateral motion
to prevent binding. Leakage through this seal was calibrated and
engine air consumption was corrected by this amount. A similar
correction was made for leakage into the test chamber through the
main hatch seals and access door seal.

The engine jet was discharged into the exhaust portion of the
chamber, in which the high velocity gases entered a diffuser located
directly downstream of the jet nozzle. The exhaust gases passed
from the diffuser into a dry gas cooler and thence through the
exhaust-pressure control valves to the system exhausters.

Instrumentation

Total-pressure tubes and iron-constantan thermocouples were
equally spaced around the periphery of the compressor-inlet screens,
four of each on the front screen and four of each on the rear
screen. Control of ram pressure and ram temperature was based on
the average readings of these 8 pressure tubes and 8 thermocouples,
respectively.

A bayonet-type chromel-alumel thermocouple was installed in
each combustor outlet and connected to dial-type indicators in order
that flame blowout in any of the combustors could be easily detected.

Engine tail-pipe temperatures were measured by means of
25 chromel-alumel thermocouples located in a 48-inch length of
straight tailpipe immediately ahead of the jet nozzle. The exhaust
pressure was measured by a static pressure tube mounted in the
exhaust portion of the chamber near the bulkhead.

Fuel consumption was measured by a calibrated variable-area-
orifice flow meter which allowed readings well up on the flow scale
for any flow rate by changing the orifice setting.

Test Procedure

Because rapid inlet-air temperature changes could not be
obtained, the method of testing used was that of maintaining
constant inlet-air temperature over a wide range of altitude condi-
tions. The operation with constant inlet-air temperature results
in increasing ram pressure ratio as altitude is increased. At each
simulated altitude condition engine speed was varied between
8000 and 12,300 rpm, within operating limits.

PRESENTATION OF DATA

Preliminary performance results are presented as corrected in
the conventional manner to NACA standard sea-level temperature and
pressure conditions. A set of typical uncorrected altitude data
is also presented.

Uncorrected Altitude Performance

Sample altitude data are presented for the 30,000 foot altitude
test runs. The jet thrust is seen from figure 3 to have increased
with an increase in engine speed and an increase in ram pressure
ratio. The net thrust (fig. 4) also increases with engine speed
and above 10,000 rpm increases with ram pressure ratio. The dis-
parities of the two points off the curve result from inaccuracy of
the air flow at these two test points as can be seen in figure 5.

Engine air consumption, cooling air excluded, increases with
both engine speed and ram pressure ratio (fig. 5). Fuel consumption
(fig. 6) also increased with engine speed and ram pressure ratio.
The specific fuel consumption (fig. 7) increased with decreasing
engine speed and with increasing ram pressure ratio. The indicated
exhaust gas temperature in the tailpipe (fig. 8) increased rapidly
with increasing engine speed but decreased with increasing ram
pressure ratio.

Generalized Performance

Effect of altitude. - The engine performance was generalized
by correcting all data to standard sea-level pressure and tempera-
ture conditions. The corrected jet thrust (fig. 9) reduced to
constant ram-pressure-ratio curves that were essentially independent
of altitude. In general, there appears to be a small decrease in

corrected jet thrust with increasing altitude, but this trend is of nearly the same magnitude as the disparities in the test data. An increase in altitude from 30,000 to 60,000 feet (ram-pressure ratio of 2.3) accentuates this trend.

The corrected net thrust curves (fig. 10) were placed on separate plots of constant ram-pressure ratio because the curves intersect and on a composite plot the spread of the data could not be seen. The corrected net thrust reduced to constant ram-pressure-ratio lines that were independent of altitude.

The corrected air consumption curves are shown in figure 11 to have reduced to constant ram-pressure-ratio curves that were nearly independent of altitude to altitudes of 30,000 feet. Inasmuch as the air flow was calculated using the measured jet thrust, it is to be expected that the corrected air consumption would show the same decrease with altitude as was shown by the corrected jet thrust. This trend was substantiated by calculation of the 2.3 ram-pressure-ratio curves using data from the tailpipe rake only, thus eliminating the influence of the measured jet thrust. The large decrease in air consumption at 60,000 feet altitude appears to be the reason for the comparatively large decrease in corrected jet thrust shown in figure 9.

The corrected fuel consumption (figure 12) is seen at the low corrected engine speed to increase rapidly with an increase in altitude above an altitude of 20,000 feet. At the higher engine speeds there is a comparatively small increase in fuel consumption with increasing altitude.

The corrected specific fuel consumption based on corrected net thrust is shown in figure 13. The general trend is for corrected net thrust specific fuel consumption to increase with increasing altitude. The corrected tailpipe indicated temperature (fig. 14) is seen to increase with increasing altitude at the higher engine speeds, but at the lower engine speeds the temperature tends to approach a single curve independent of altitude.

Effect of ram pressure ratio. - For the performance character-istics that had to be plotted separately for each ram-pressure ratio, curves are presented showing the effect of ram-pressure ratio on corrected engine performance for an altitude of 30,000 feet. The corrected jet thrust and corrected air consumption plots are not repeated as the effect of ram pressure ratio can be seen on the composite plots of figures 9 and 11. Figures 9 and 11 show that

corrected jet thrust and corrected air consumption increase rapidly with an increase in ram-pressure ratio. This trend increases in magnitude as the corrected engine speed is increased.

The corrected net thrust is seen from figure 15 to increase with increasing ram-pressure ratio at the higher corrected engine speeds. The corrected fuel consumption (fig. 16) increases rapidly with increasing ram-pressure ratio at the higher corrected engine speeds. The corrected net thrust specific fuel consumption curve (fig. 17) is essentially independent of ram-pressure ratio. The corrected tailpipe indicated gas temperature (fig. 18) is seen to decrease rapidly with increasing ram-pressure ratio at the lower corrected engine speeds, but change in ram-pressure ratio shows a comparatively small effect at the higher engine speeds.

CONCLUDING REMARKS

The generalizations of jet thrust, air consumption, and tail-pipe temperature parameters indicate that performance data obtained at one altitude can be used to predict these performance parameters at other altitudes. It is particularly noteworthy that, at the higher engine speeds, changes in simulated altitude resulted in only small changes in corrected fuel consumption. This fact indicates that the combustion efficiency of the engine is not greatly affected by change in altitude at these engine speeds.

The foregoing presentation of trends of the performance parameters are necessarily quite general because of the preliminary nature of the analysis made. There were no unusual trends observed that would indicate operational peculiarities or limitations. Low-engine-speed blowout of one burner was occasionally encountered, but at high ram pressure ratios, and only when the tailpipe indicated temperatures were below 350° F. High-engine-speed burner blowout was not encountered at any time in these tests.

Flight Propulsion Research Laboratory,
    National Advisory Committee for Aeronautics,
        Cleveland, Ohio, May 12, 1948.

British

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18.75-INCH-DIAMETER JET NOZZLE

Zelmar Barson,
Mechanical Engineer.

H. Dean Wilsted,
Aeronautical Research
Scientist.

Approved:

John C. Sanders,
Aeronautical Research
Scientist.

John H. Collins, Jr.,
Aeronautical Research
Scientist.

APPENDIX - CALCULATIONS

Symbols

The following symbols are used in this report:

A_s effective area of tailpipe seal, sq ft

B thrust scale reading, lb

F_J jet thrust, lb

F_n net thrust, lb

G acceleration of gravity, 32.2 ft/sec^2

J mechanical equivalent of heat, 778 ft-lb/Btu

M_o flight Mach number

N engine speed, rpm

P absolute total pressure, lb/ft^2

p absolute static pressure, lb/ft^2

R gas constant, 53.3 ft-lb/(lb)(^{o}F)

T indicated temperature, ^{o}F

t static temperature, ^{o}R

V velocity, ft/sec

W_a air consumption, lb/sec

W_f fuel consumption, lb/sec

W_g gas flow, lb/sec

W_f/F_n specific fuel consumption based on net thrust, lb/hr/lb thrust

γ ratio of specific heats

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

θ ratio of absolute ambient indicated temperature to absolute
          static temperature of NACA standard atmosphere at sea
          level

Subscripts:

0   free air stream

2   compressor inlet

7   upstream of jet nozzle

8   jet-nozzle exit

Methods of Calculation

Thrust. - Thrust was determined by means of the altitude chamber thrust indicator with a correction factor added to account for the pressure differential across the tailpipe seal. The relation used was:

$$F_j = B + A_s \ (P_2 - p_8)$$

Air consumption. - Engine air consumption was calculated from the jet thrust and the computed jet velocity by use of the following relation:

$$W_g = \frac{Kg \ F_j}{V_j} = \frac{Kg \ F_j}{\sqrt{2gR \ \frac{\gamma}{\gamma-1} \ T_7 \left[1 - \left(\frac{p_8}{P_7}\right)^{\frac{\gamma-1}{\gamma}}\right]}}$$

in which γ was assumed equal to 1.35 and K is a factor containing both the jet-nozzle velocity coefficient and an instrumentation correction factor. The factor K was determined from the ratio of air flows measured by means of orifice (in cases where orifice measurements were not rendered inaccurate by instrumentation errors) to flows calculated by the above equation. Fuel flow was in each case added to the orifice-measured air flows, as shown in the following relation:

$$K = \cfrac{\mathscr{F}_j}{\left(W_a + \dfrac{W_f}{3600}\right)\sqrt{2gR\,\dfrac{\gamma}{\gamma-1}\,T_7\left[1 - \left(\dfrac{p_8}{P_7}\right)^{\frac{\gamma-1}{\gamma}}\right]}}$$

$= \dfrac{g\,F_J}{W_g\,V_j} = \dfrac{F_j}{m_g\,v_g}$

$F_j = m_g V_j \cdot K$

where W_a and W_f are measured values. From W_g, the air consumption, W_a, was calculated for all conditions by the relation:

$$W_a = W_g - \frac{W_f}{3600}$$

Simulated flight speed. - The simulated flight speed at which the engine operated was determined from the ram-pressure ratio by the following relation:

$$V_o = \sqrt{2gR\,\frac{\gamma}{\gamma-1}\,t_o\left[\left(\frac{P_2}{P_o}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

Net thrust. - Net thrust was calculated from the jet thrust by subtracting the momentum of the free air stream approaching the engine inlet, according to the relation:

$$F_n = F_j - \frac{W_a V_o}{g}$$

Flight Mach number. - The flight Mach number was calculated from the compressor-inlet total pressure, assuming complete ram recovery.

$$M_o = \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{P_2}{P_o}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

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REFERENCES

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

2. Anon.: Model Specification Engine, Aircraft, Turbo-Jet XJ-42-TT-2.
    Nene I. Spec. No. M-002, Taylor Turbine Corp., Nov. 15, 1946,
    and Rev. A, April 2, 1947.
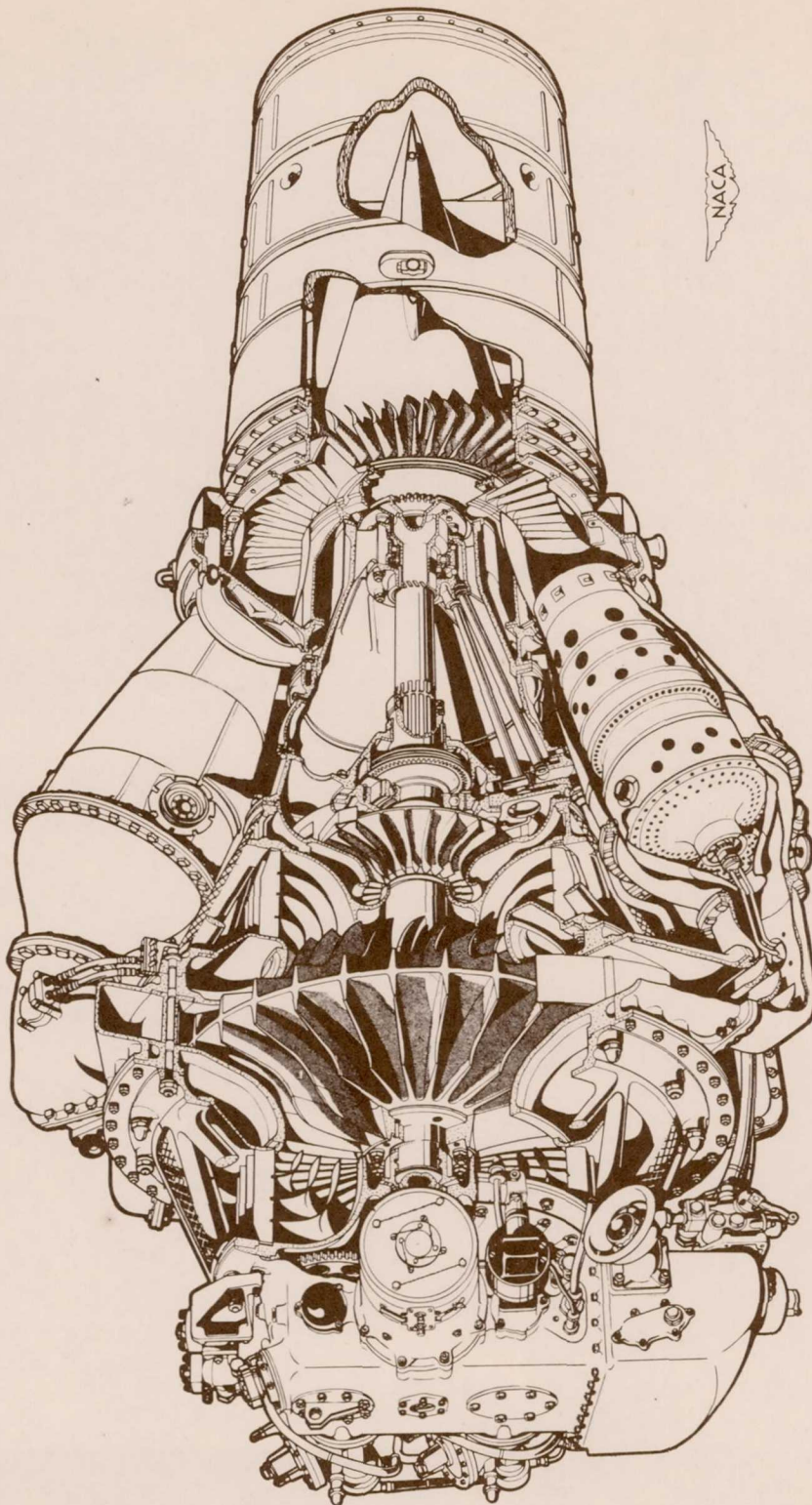
Figure 1. – Cutaway view of Nene Turbojet engine.
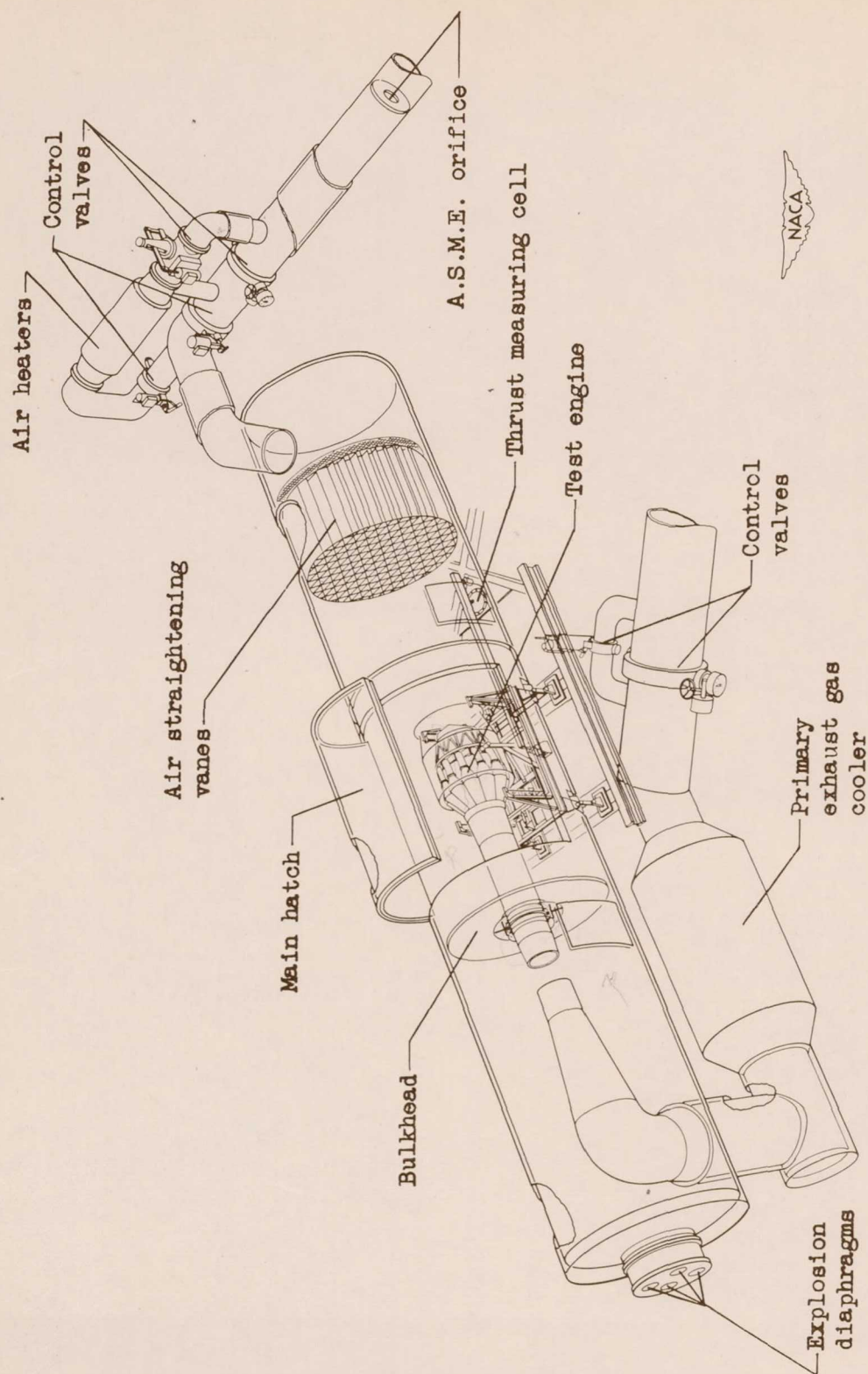
Figure 2. - Sketch of altitude chamber showing engine installed in test section.
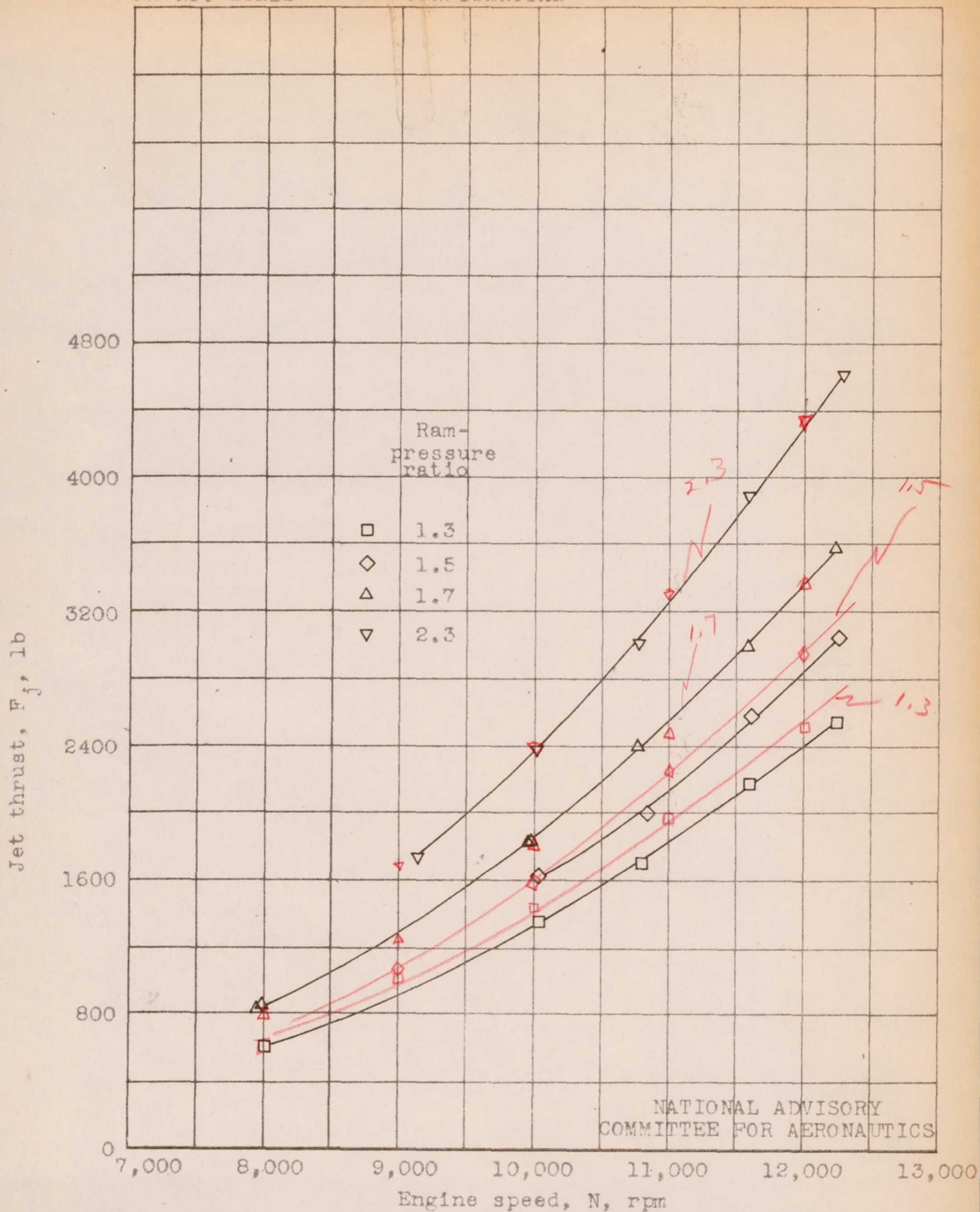
Figure 3. - Effect of engine speed and ram-pressure ratio on jet thrust at altitude of 30,000 feet.
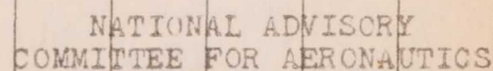
Figure 4. - Effect of engine speed and ram-pressure ratio on net thrust at altitude of 30,000 feet.

Figure 5. - Effect of engine speed and ram-pressure ratio on air consumption at altitude of 30,000 feet.
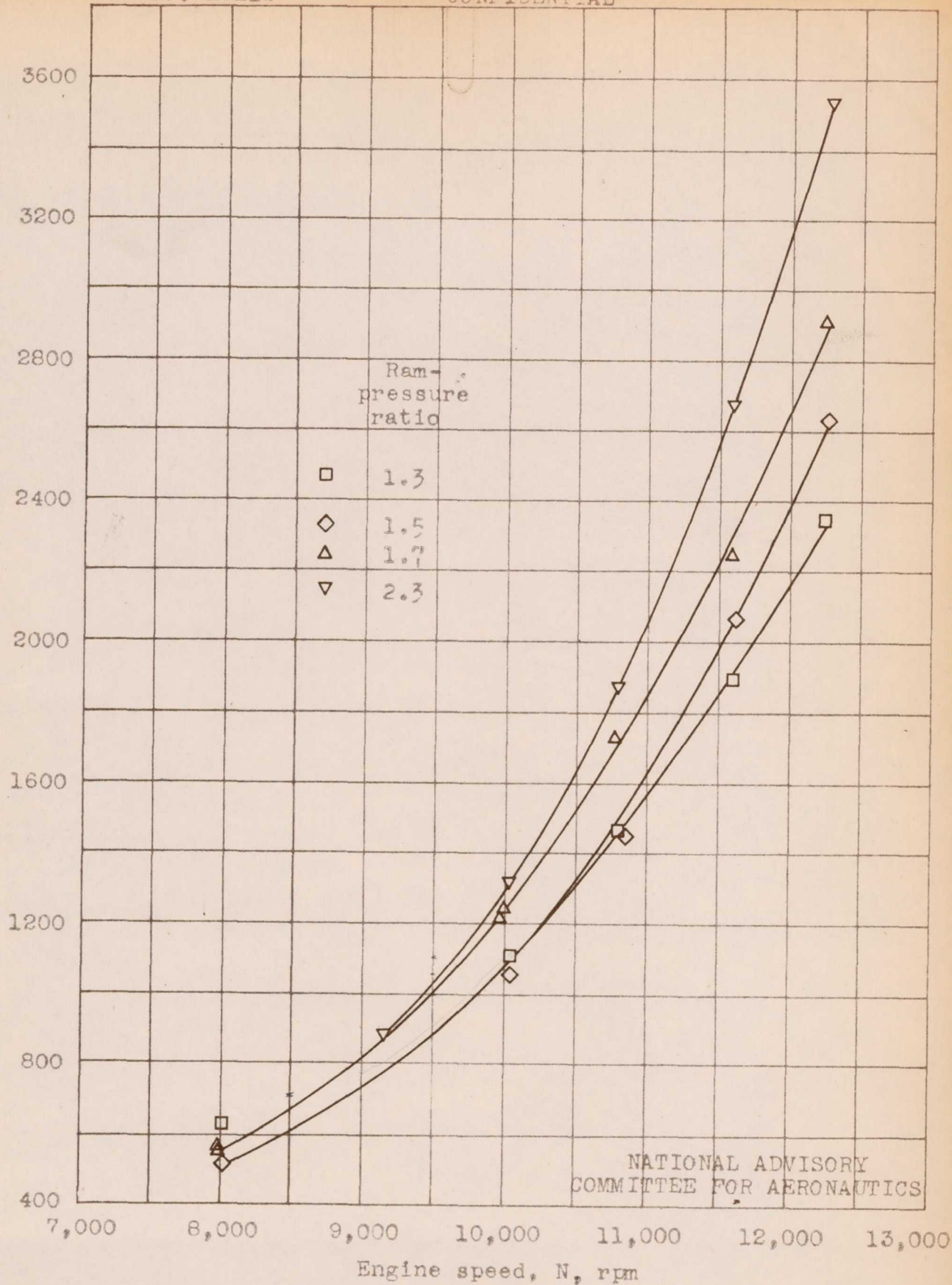
Figure 6. - Effect of engine speed and ram-pressure ratio on fuel consumption at altitude of 30,000 feet.
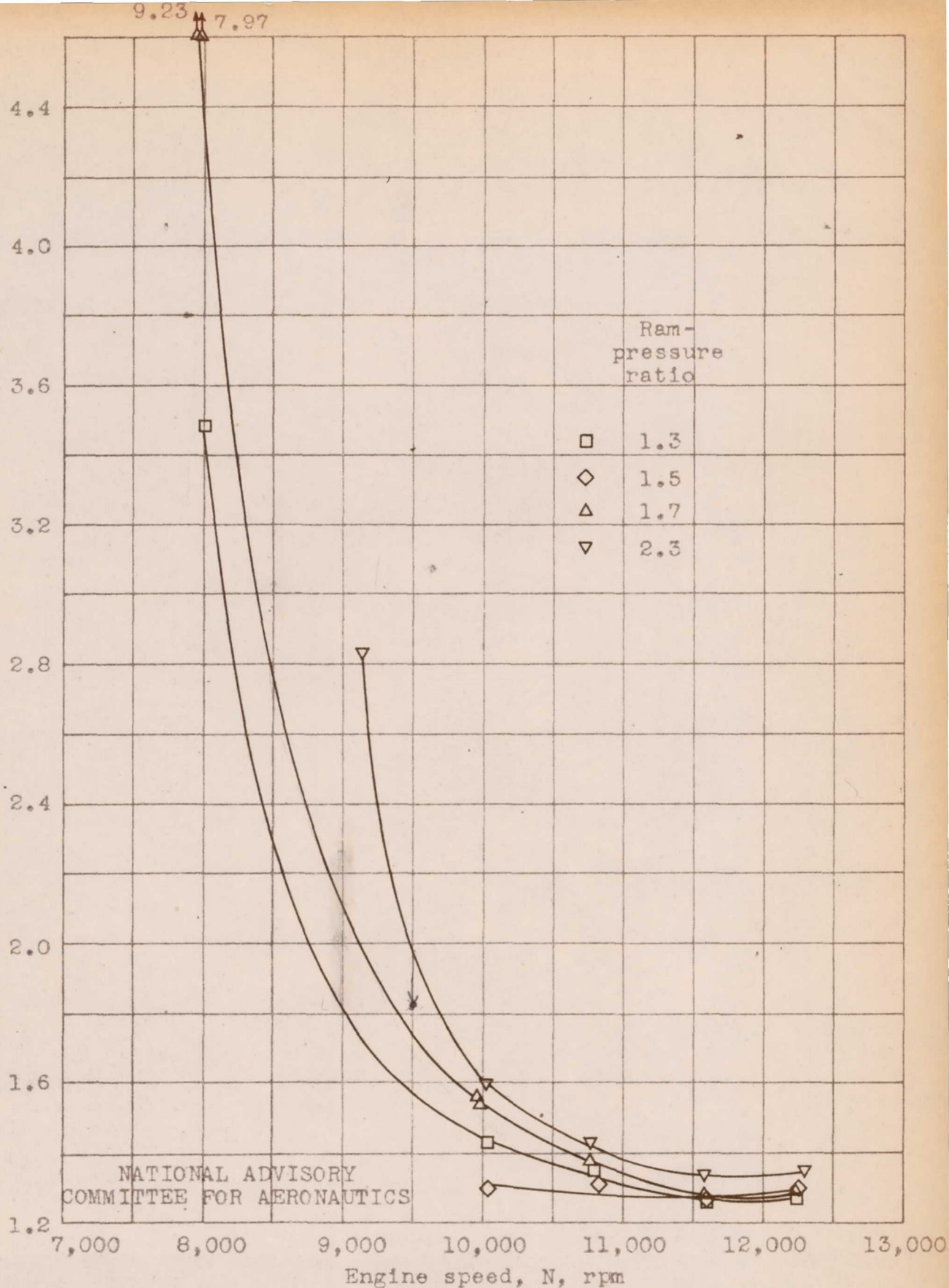
Figure 7. - Effect of engine speed and ram-pressure ratio on net thrust specific fuel consumption at altitude of 30,000 feet.

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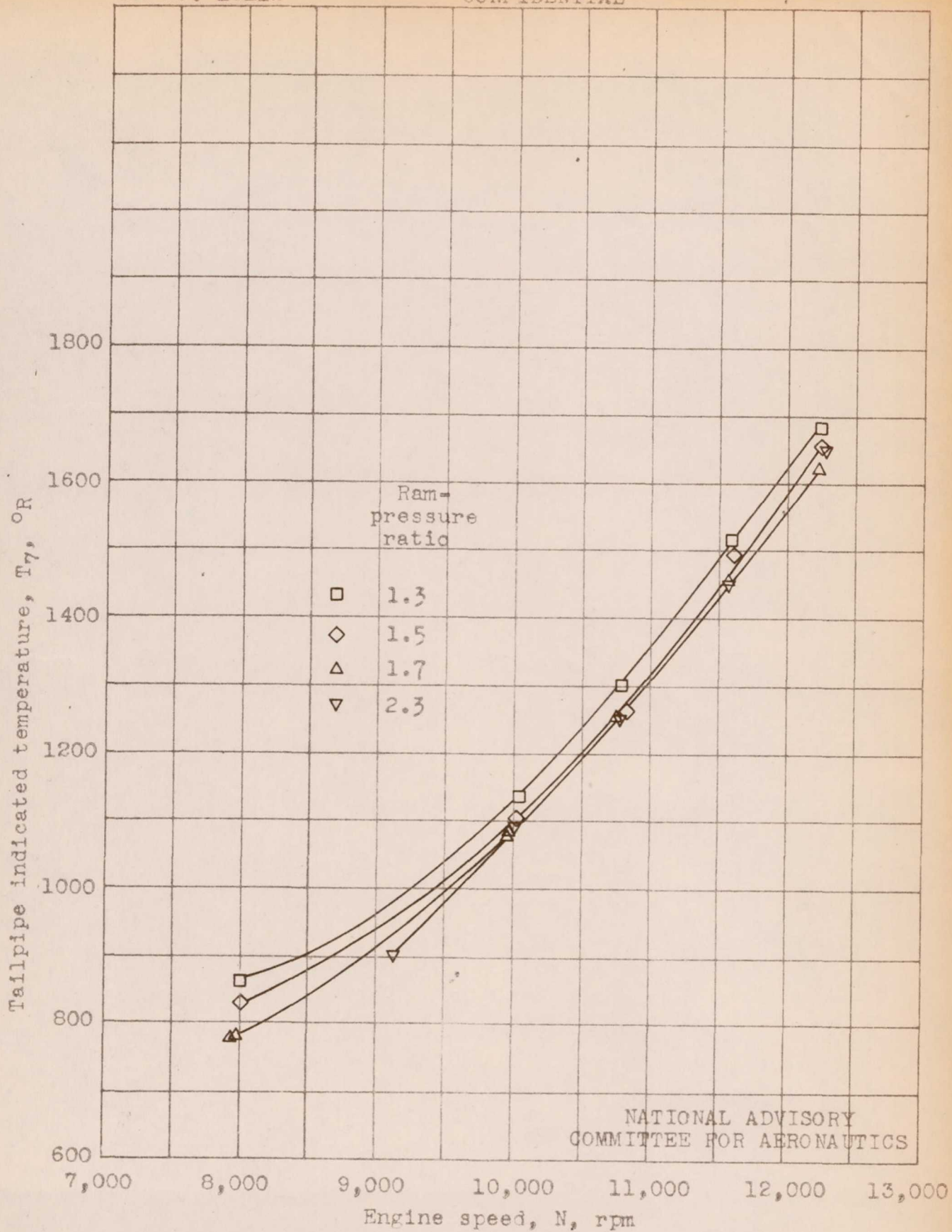
Figure 8. - Effect of engine speed and ram-pressure ratio on tail-
pipe indicated temperature at altitude of 30,000 feet.
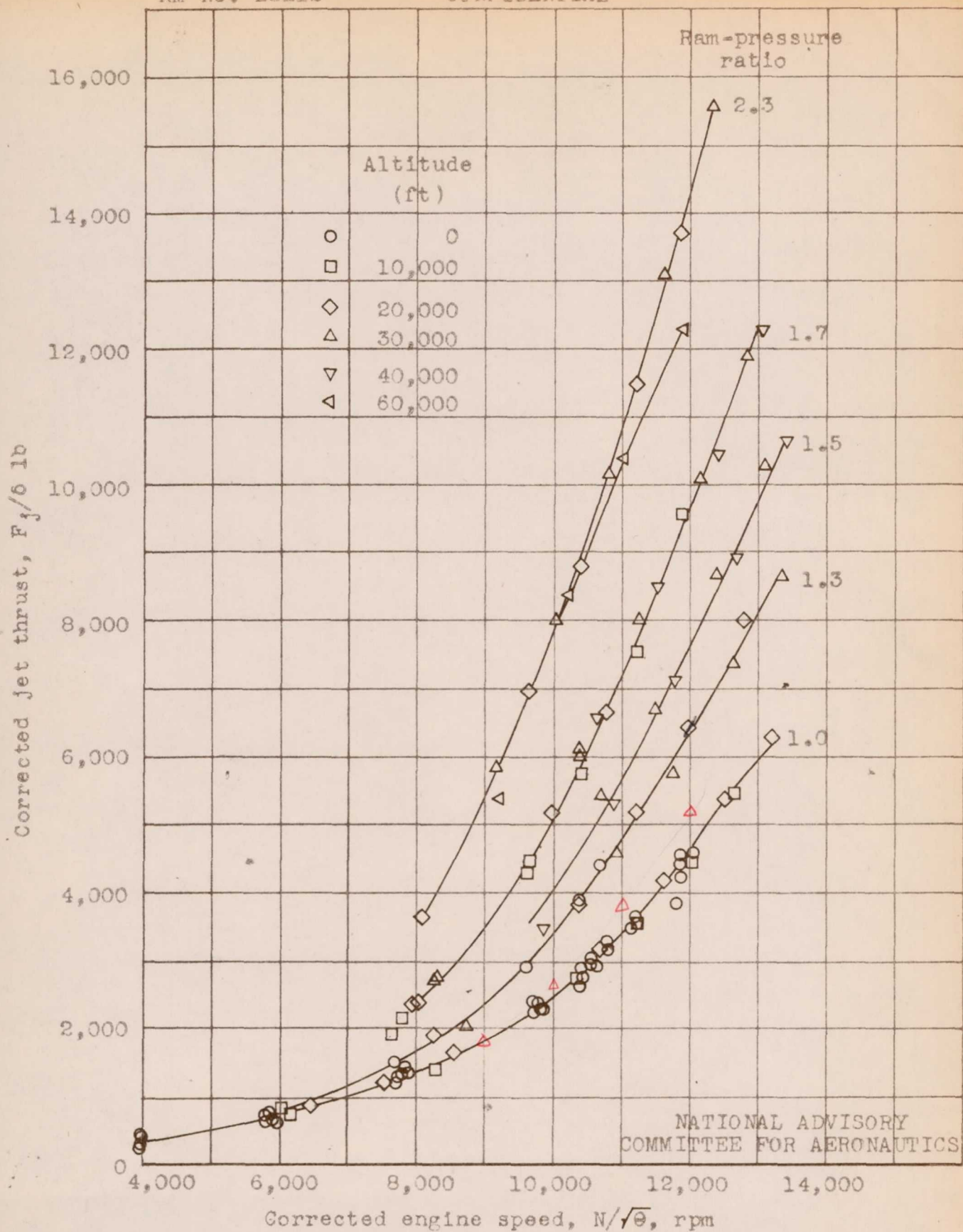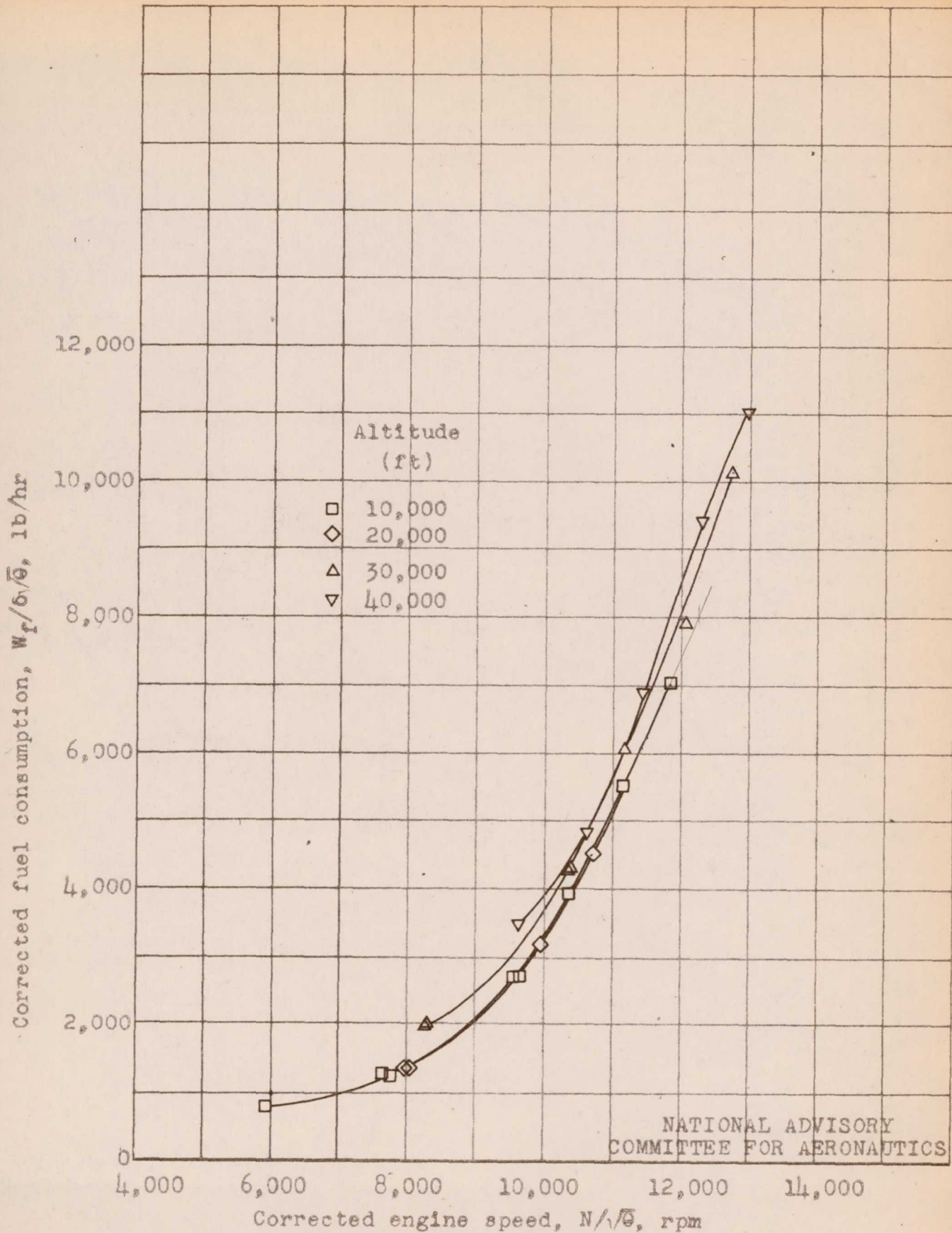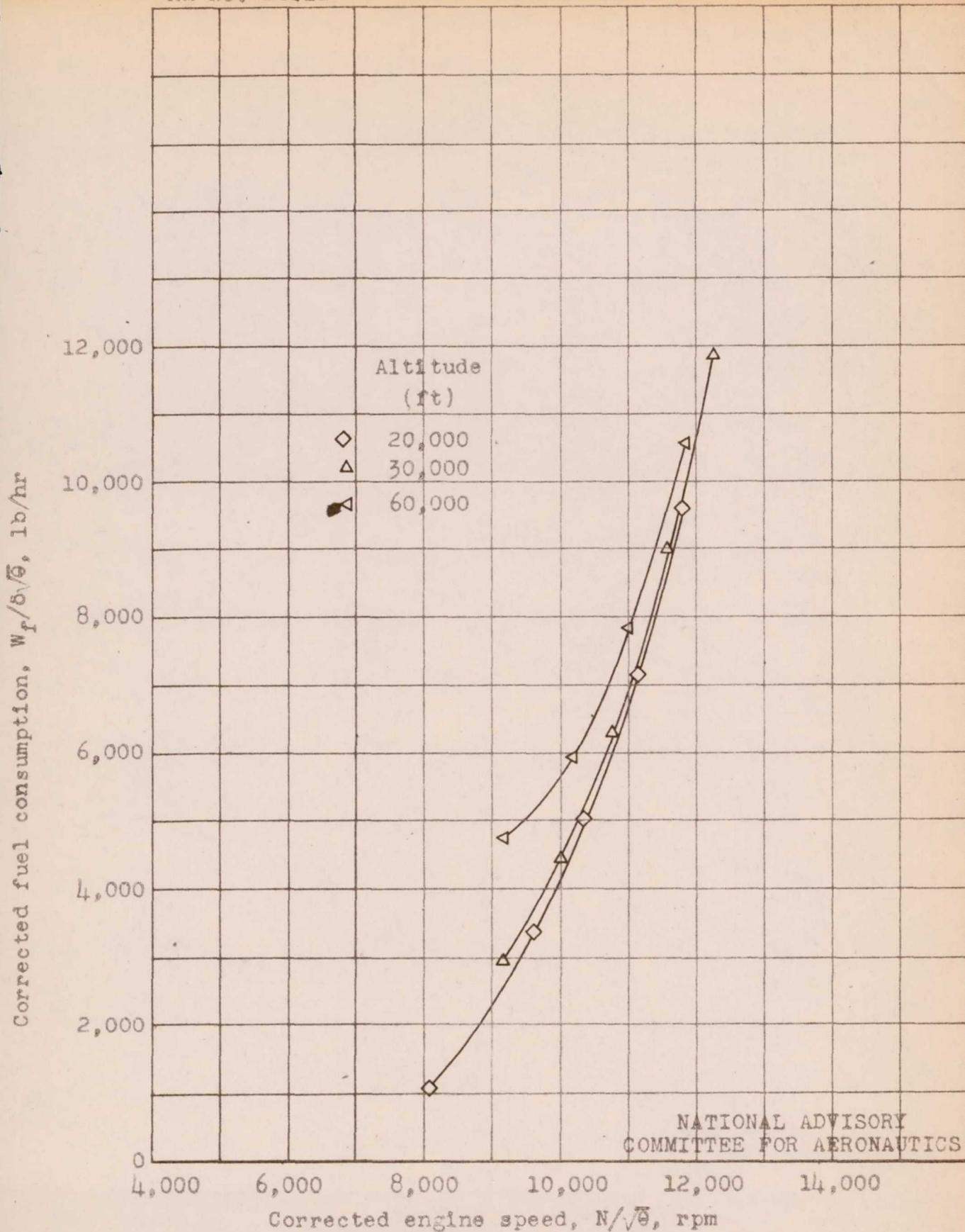
Figure 9. - Effect of altitude on corrected jet thrust at various ram-pressure ratios.
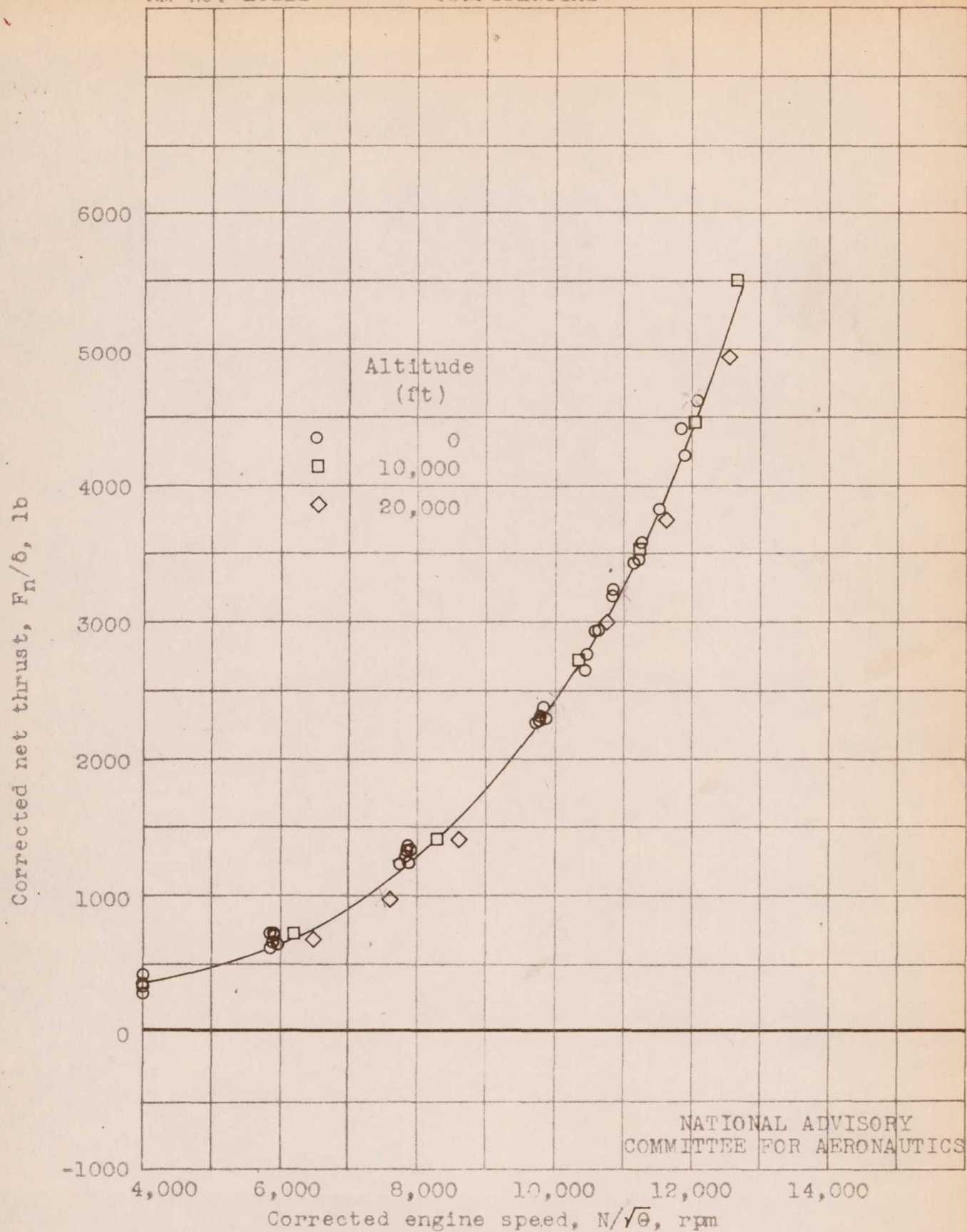
(a) Ram-pressure ratio, 1.0.

Figure 10. - Effect of corrected engine speed and ram-pressure ratio on corrected net thrust.
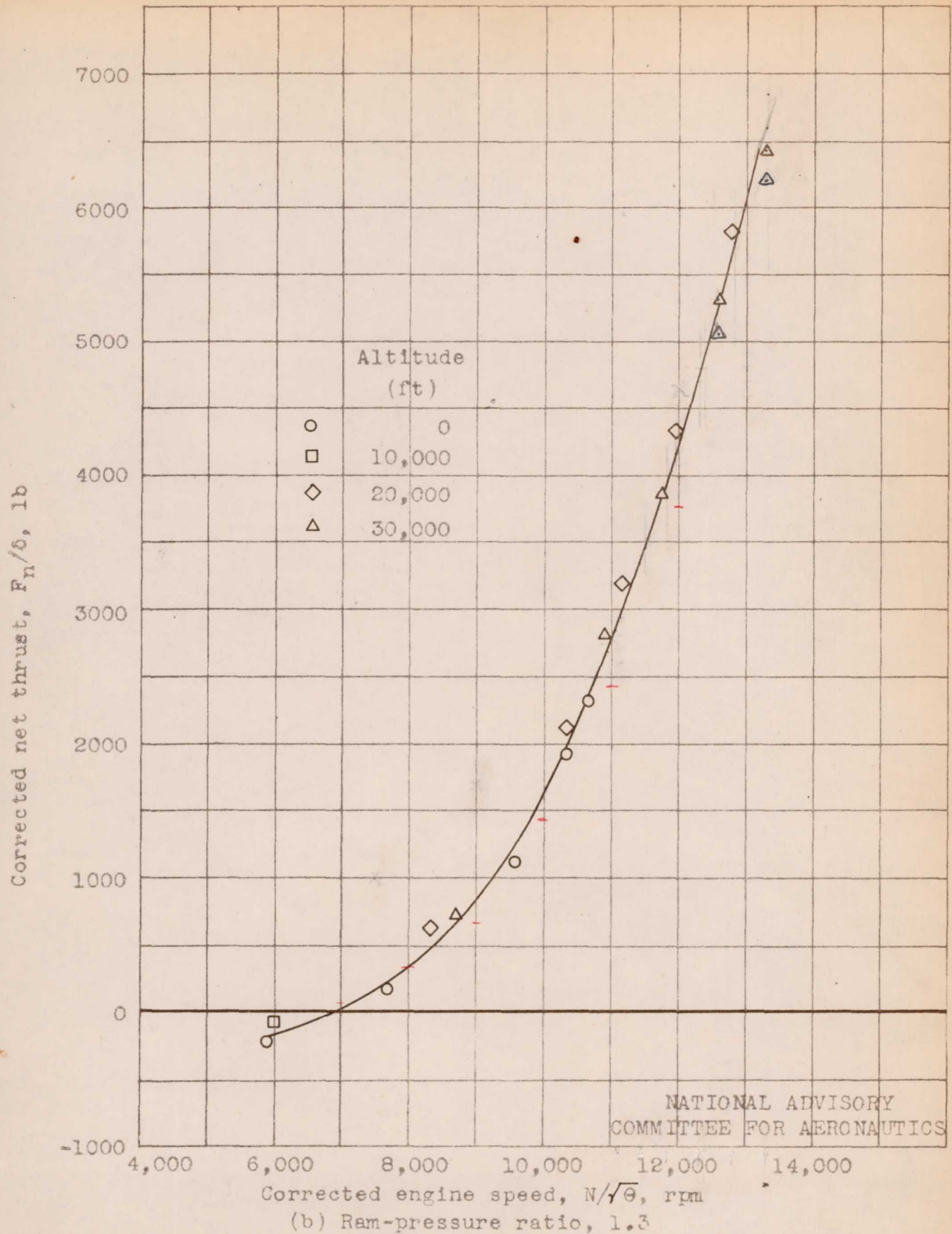
(b) Ram-pressure ratio, 1.3

Figure 10. - Continued. Effect of corrected engine speed and
ram-pressure ratio on corrected net thrust.

Altitude
(ft)

□   10,000
△   30,000
▽   40,000

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Corrected net thrust, Fn/δ, lb

Corrected engine speed, N/√θ, rpm

(c) Ram-pressure ratio, 1.5.

Figure 10. - Continued. Effect of corrected engine speed and
ram-pressure ratio on corrected net thrust.
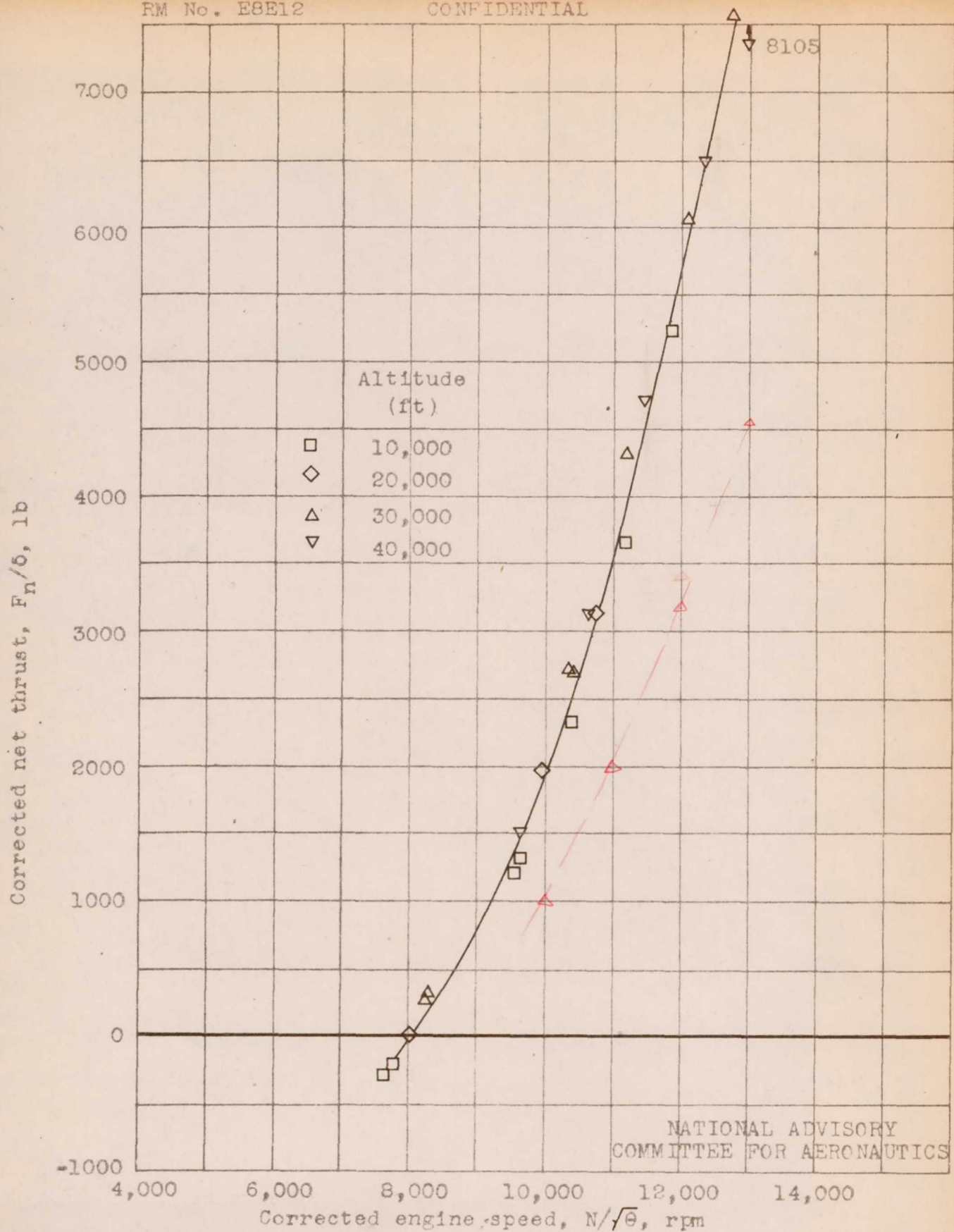
(d) Ram-pressure ratio, 1.7.

Figure 10. - Continued. Effect of corrected engine speed and ram-pressure ratio on corrected net thrust.
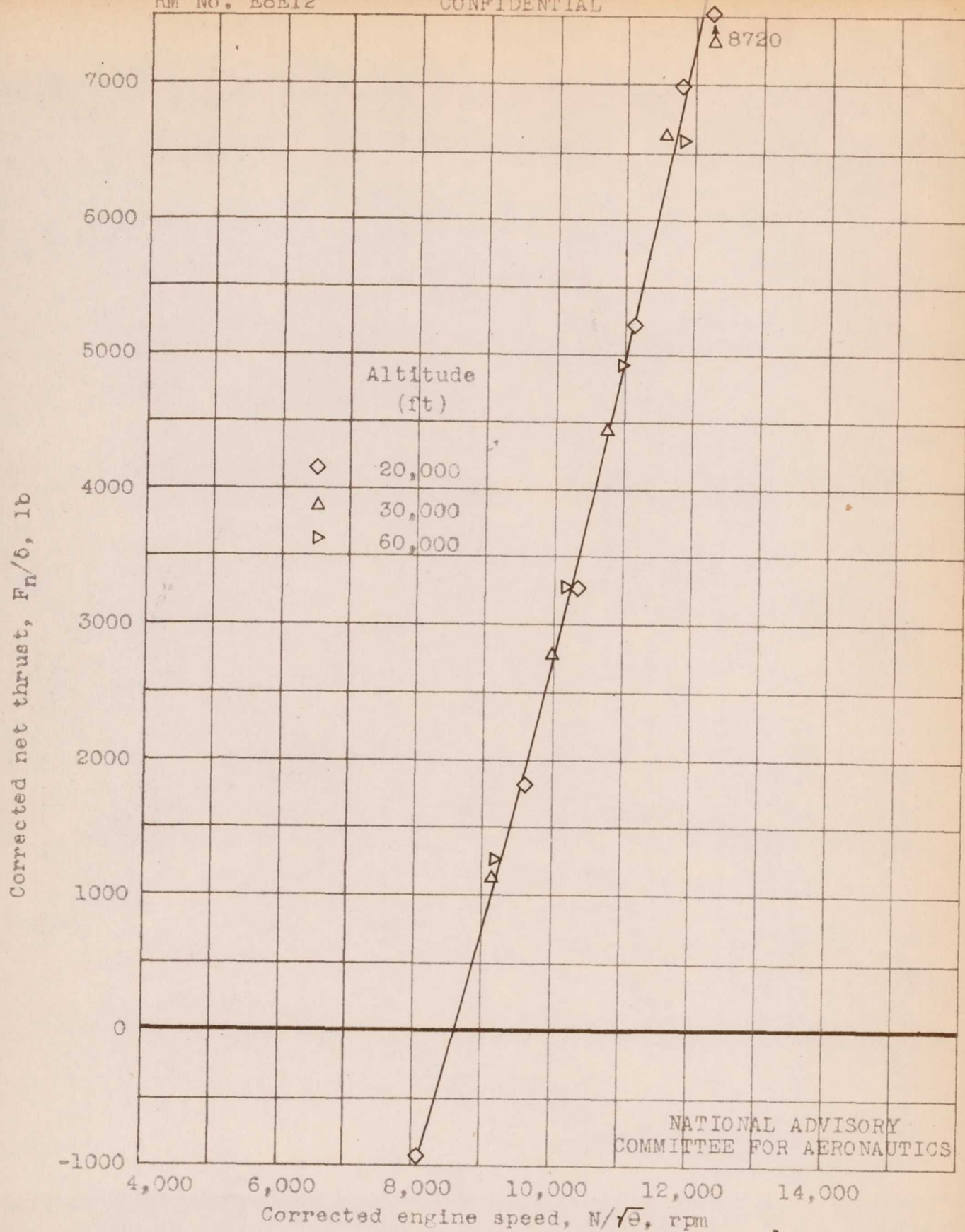
(e) Ram-pressure ratio, 2.3.

Figure 10. - Concluded. Effect of corrected engine speed and ram-pressure ratio on corrected net thrust.
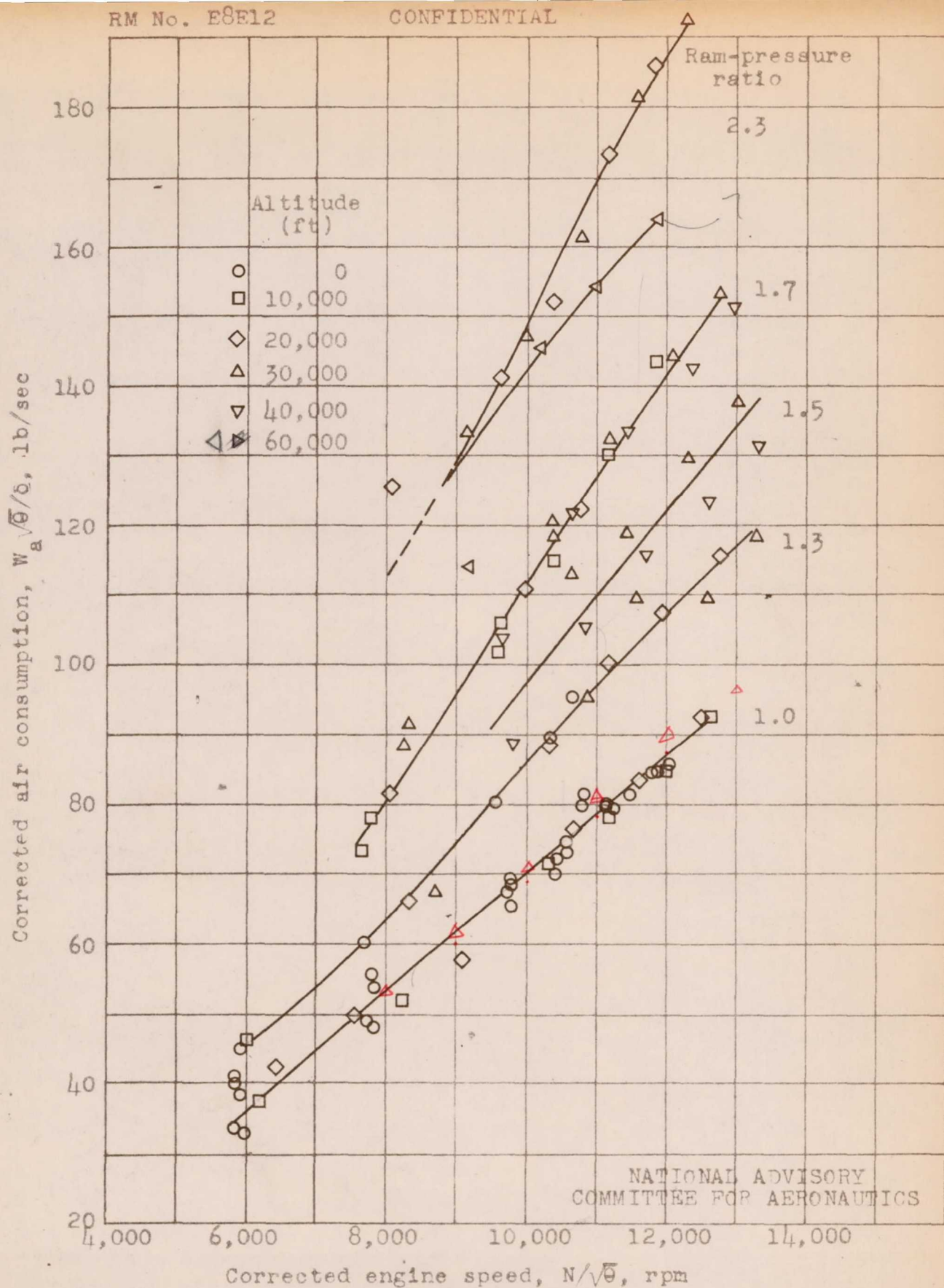
Figure 11.- Effect of altitude on corrected air consumption at various ram-pressure ratios.

(a) Ram-pressure ratio, 1.0.
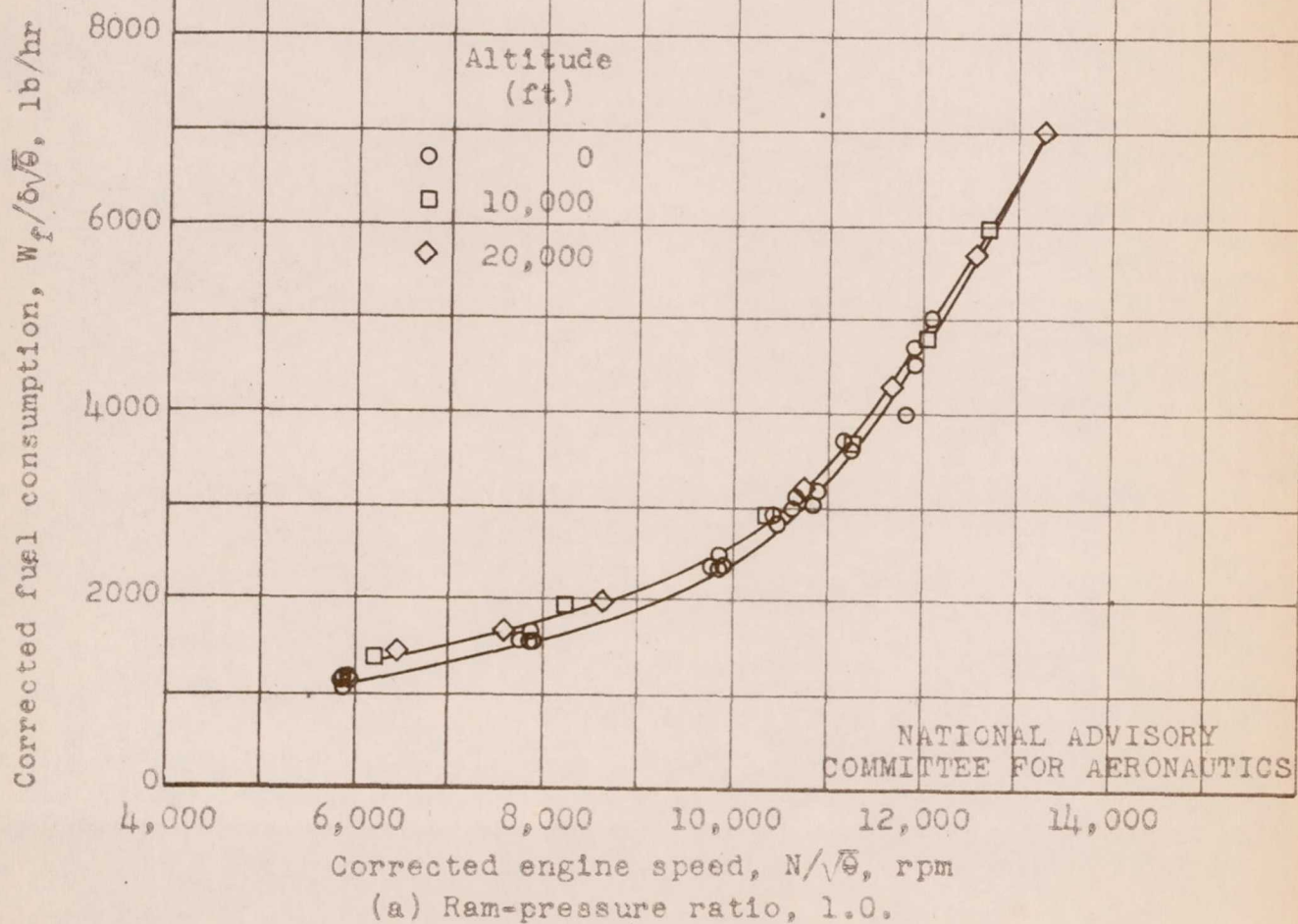
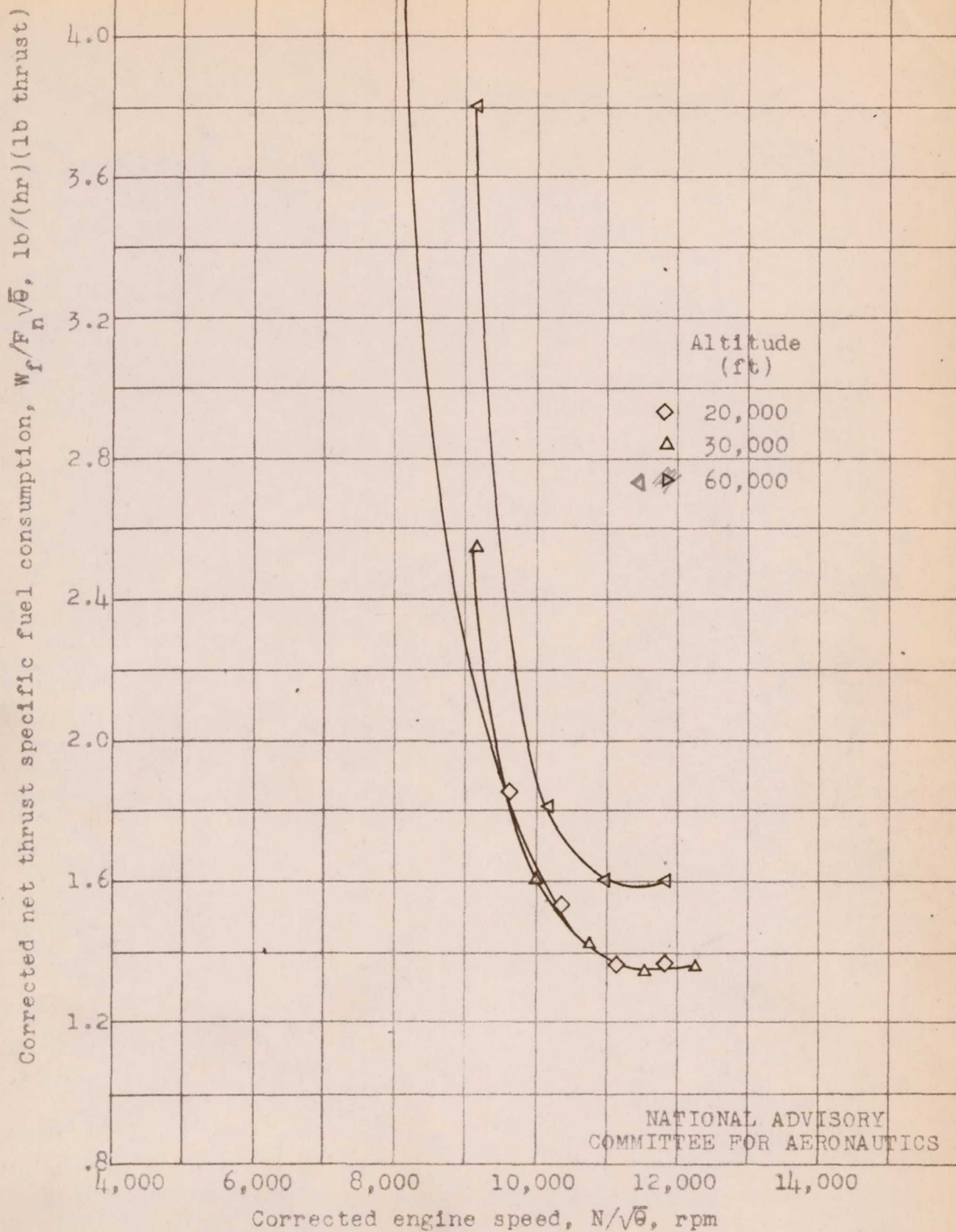Figure 12. - Effect of altitude on corrected fuel consumption
at various ram-pressure ratios.
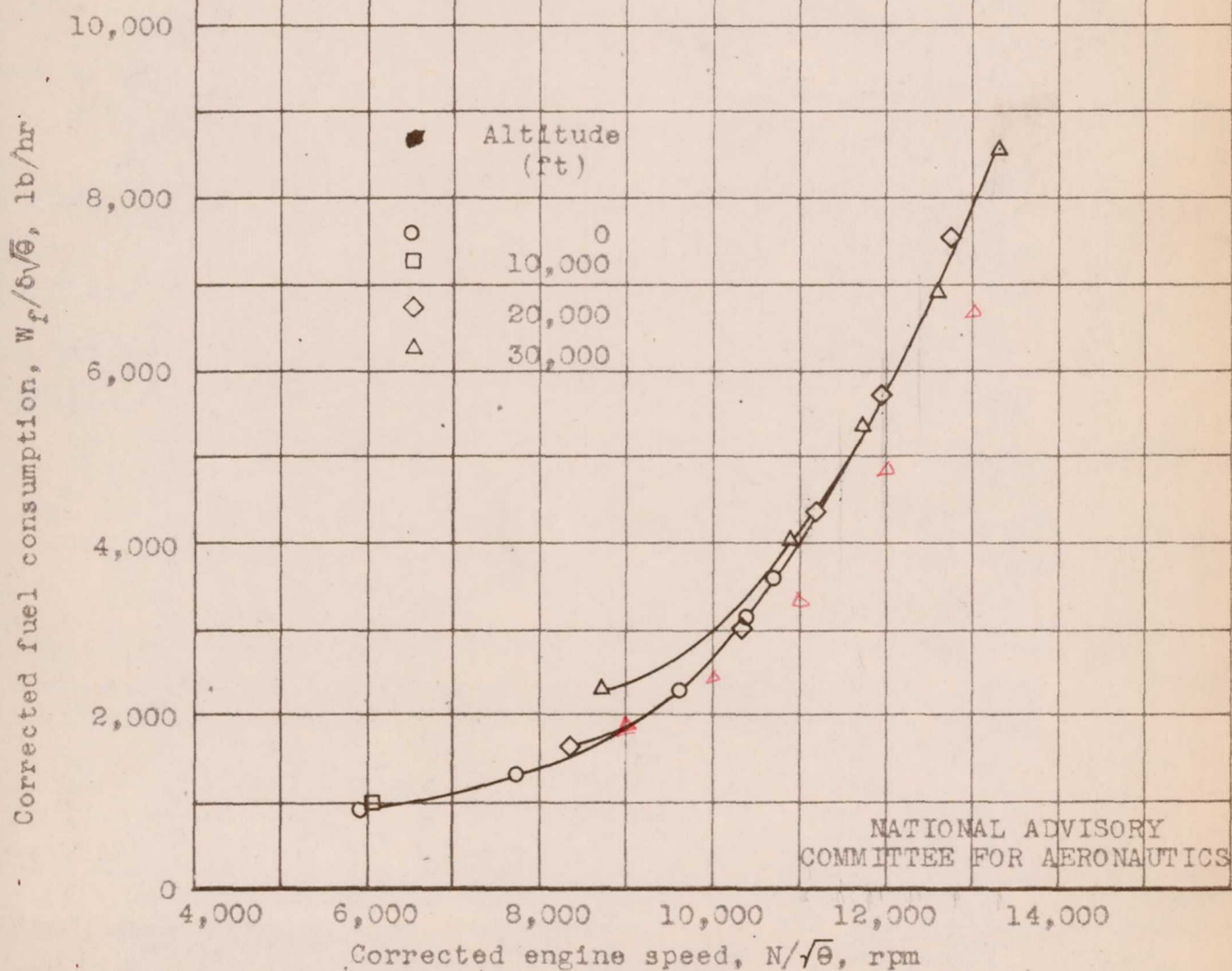
(b) Ram-pressure ratio, 1.3.

Figure 12. - Continued. Effect of altitude on corrected fuel
consumption at various ram-pressure ratios.

(c) Ram-pressure ratio, 1.5.
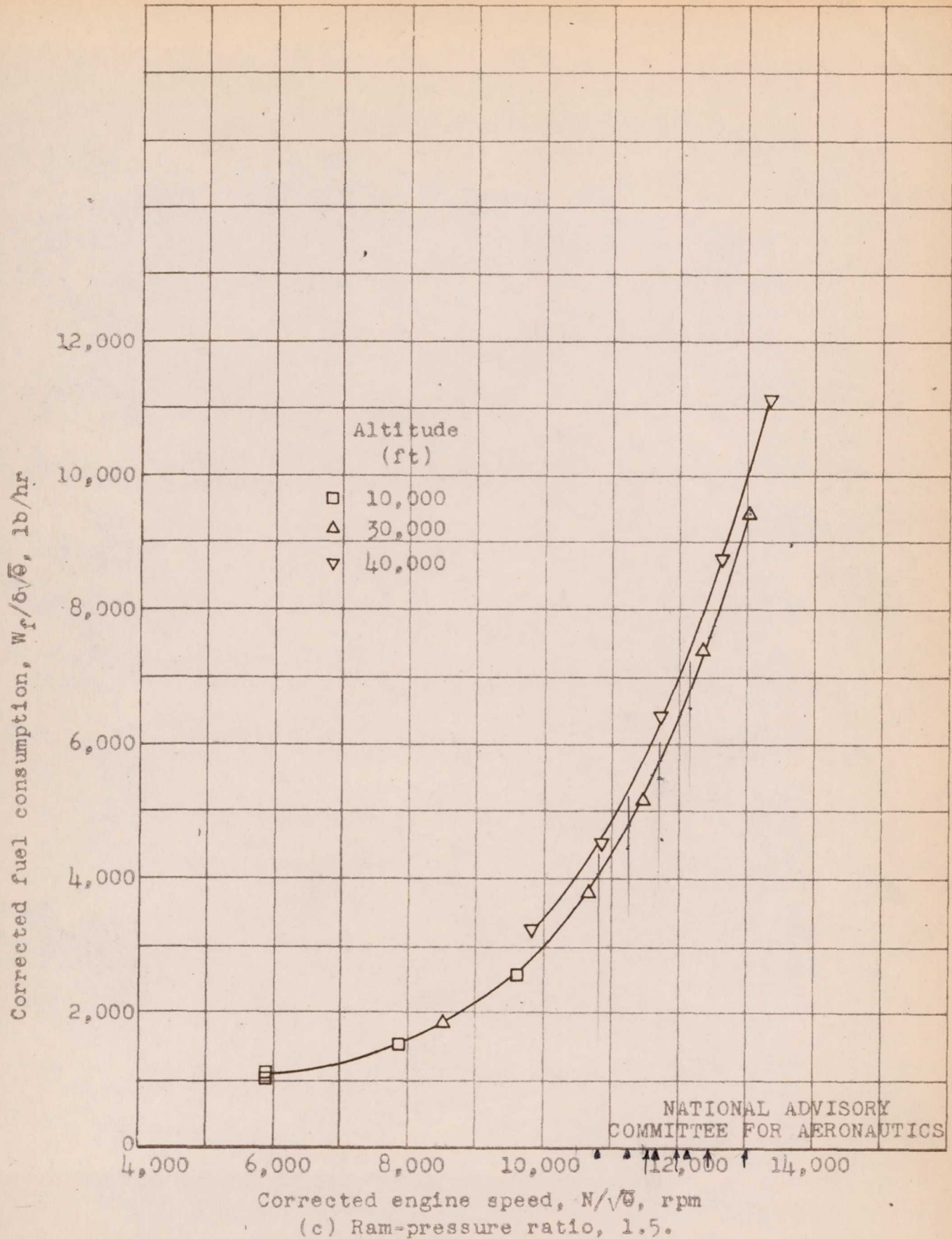
Figure 12. - Continued. Effect of altitude on corrected fuel
     consumption at various ram-pressure ratios.

(d) Ram-pressure ratio, 1.7.

Figure 12. - Continued.   Effect of altitude on corrected fuel
consumption at various ram-pressure ratios.

(e) Ram-pressure ratio, 2.3.

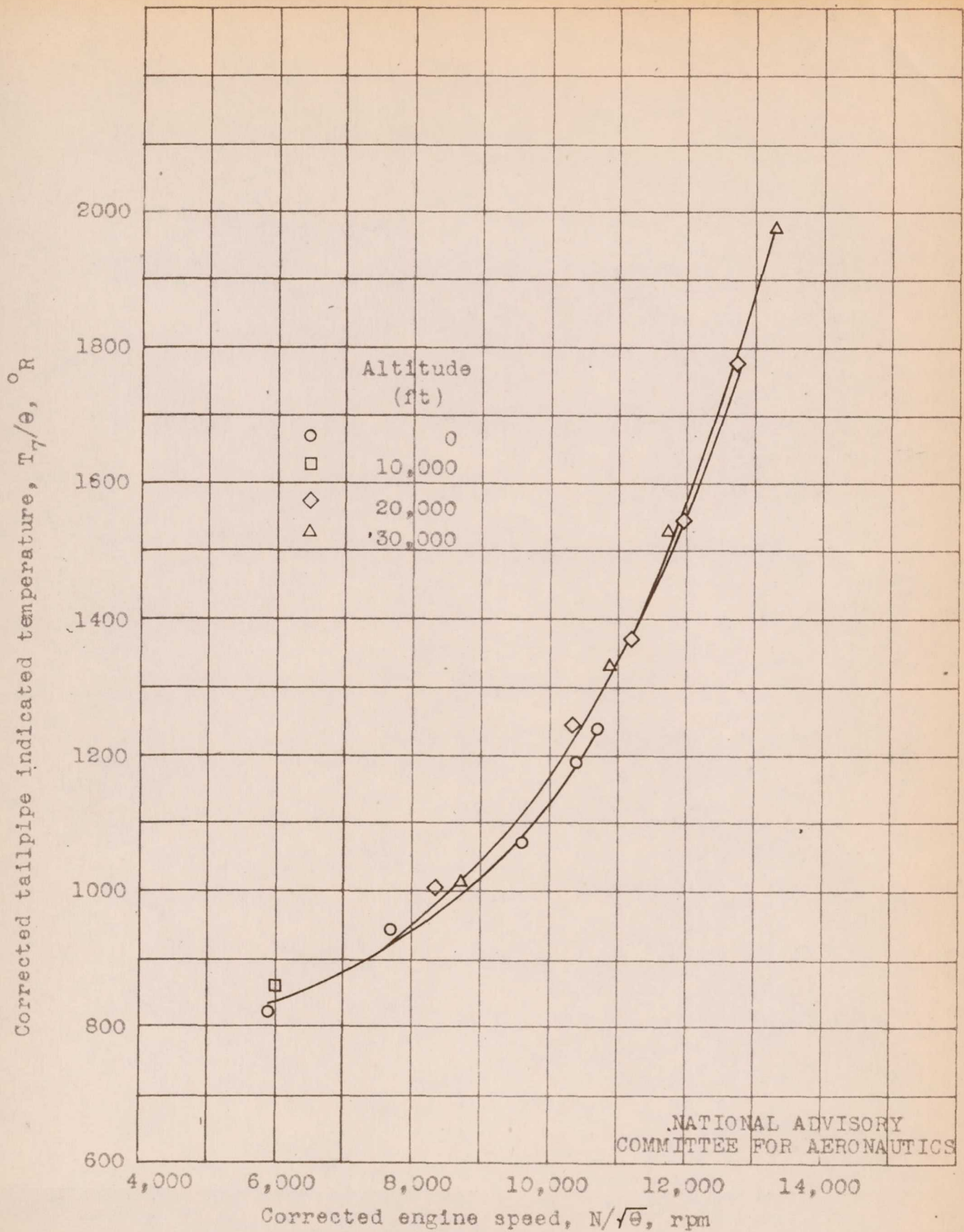Figure 12. - Concluded. Effect of altitude on corrected fuel consumption at various ram-pressure ratios.
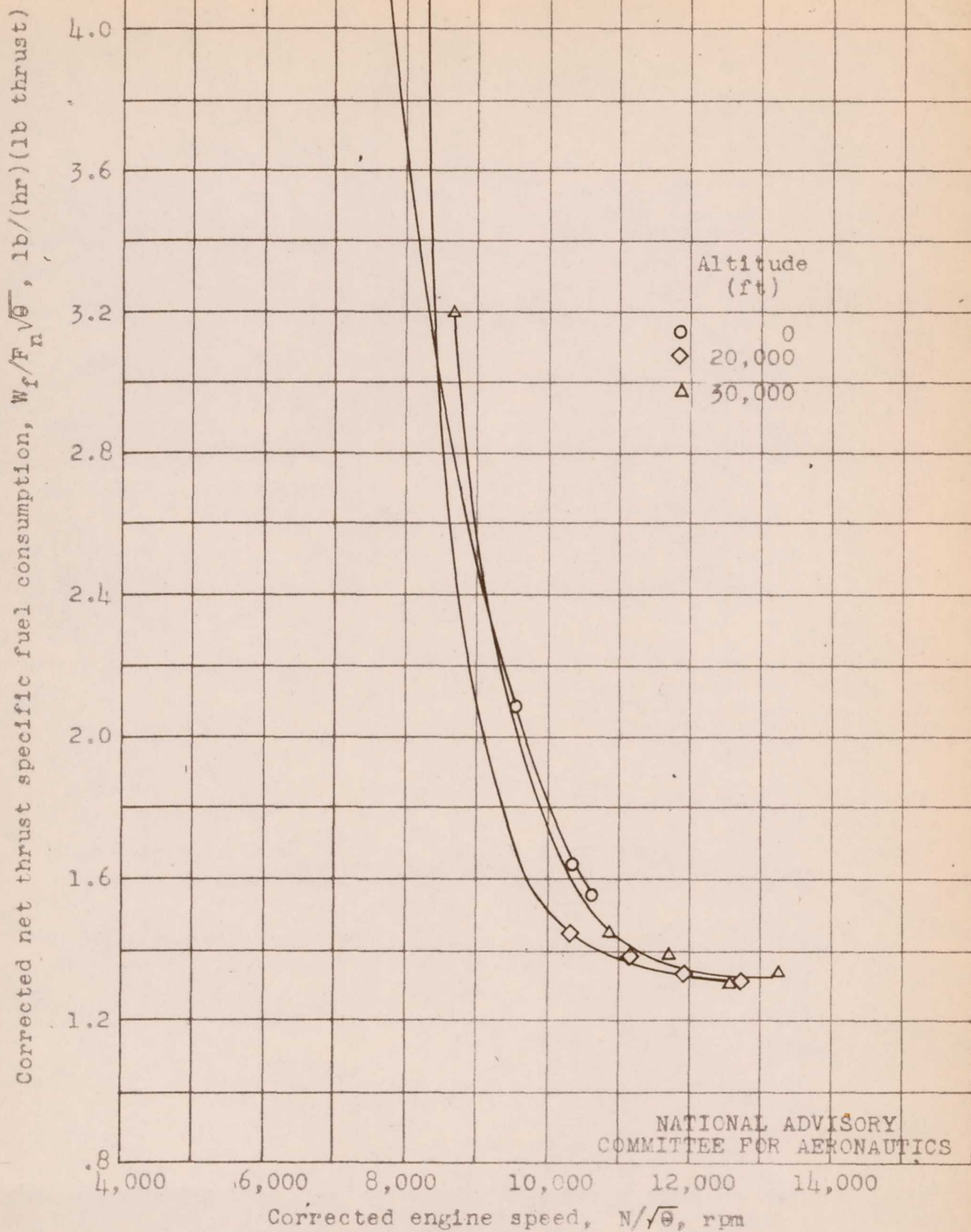
(a) Ram-pressure ratio, 1.3.

Figure 13.- Effect of corrected engine speed and ram-pressure ratio on corrected net thrust specific fuel consumption.
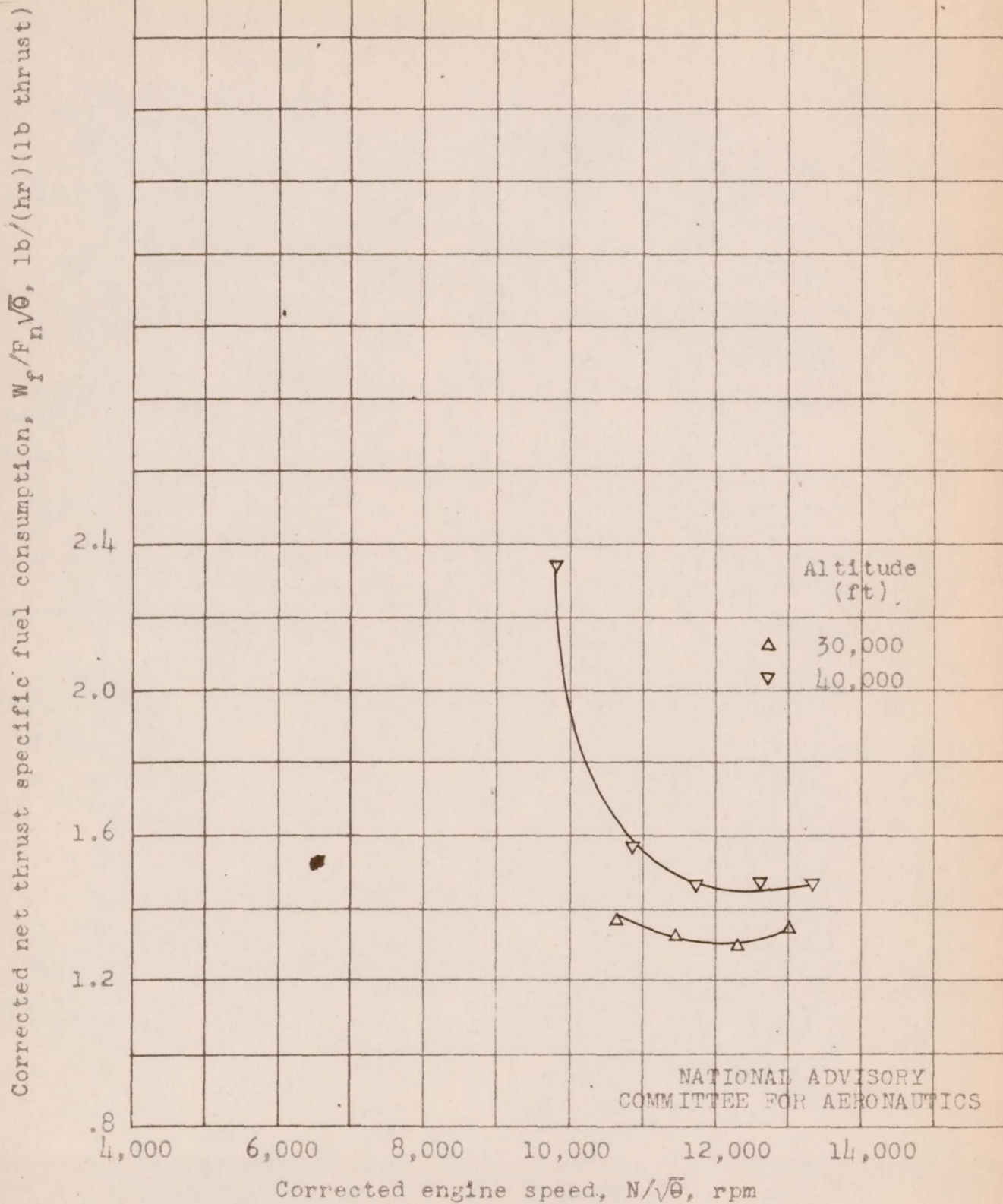
(b) Ram-pressure ratio, 1.5.

Figure 13.- Continued. Effect of corrected engine speed and ram-pressure ratio on corrected net thrust specific fuel consumption.
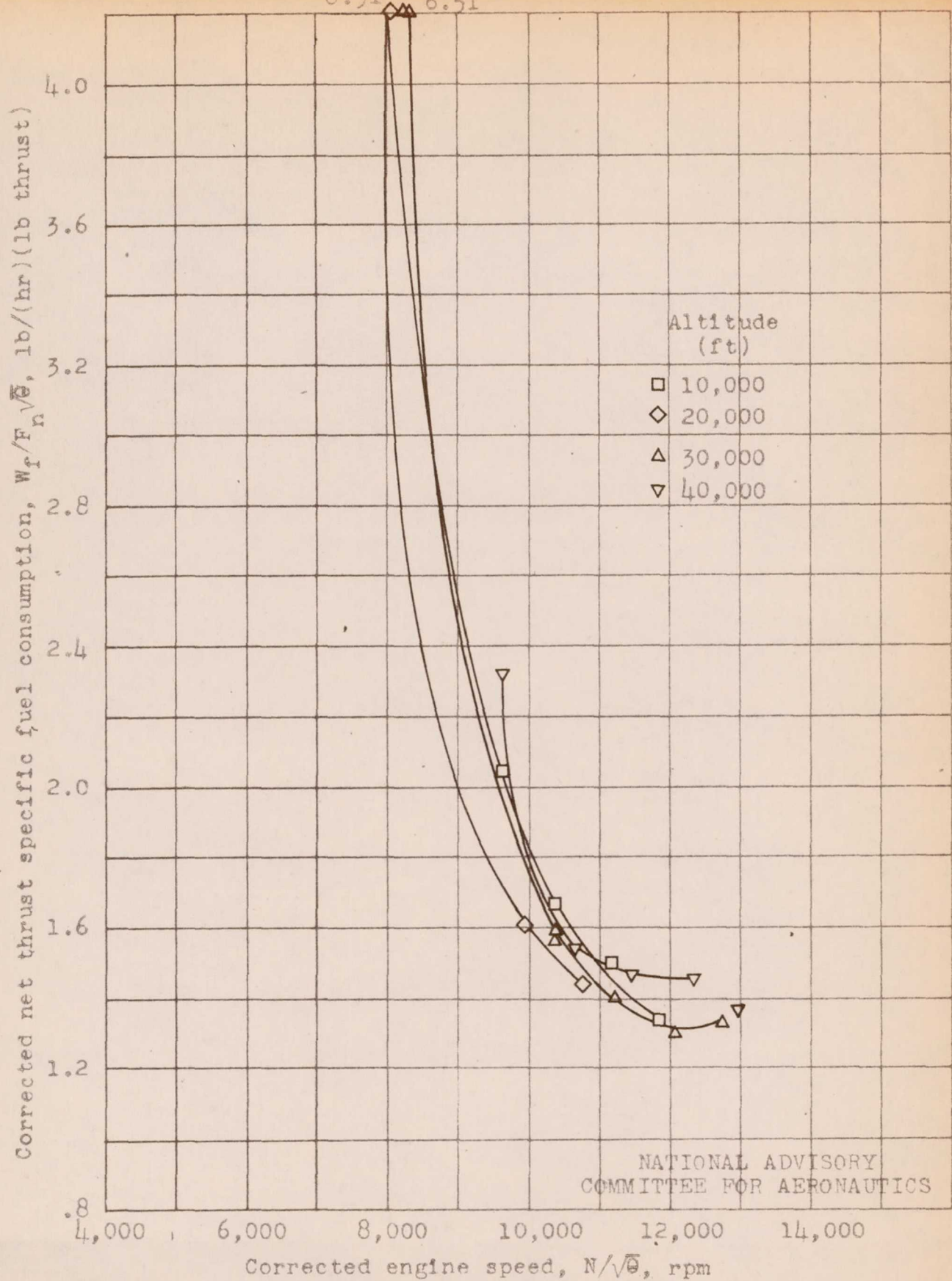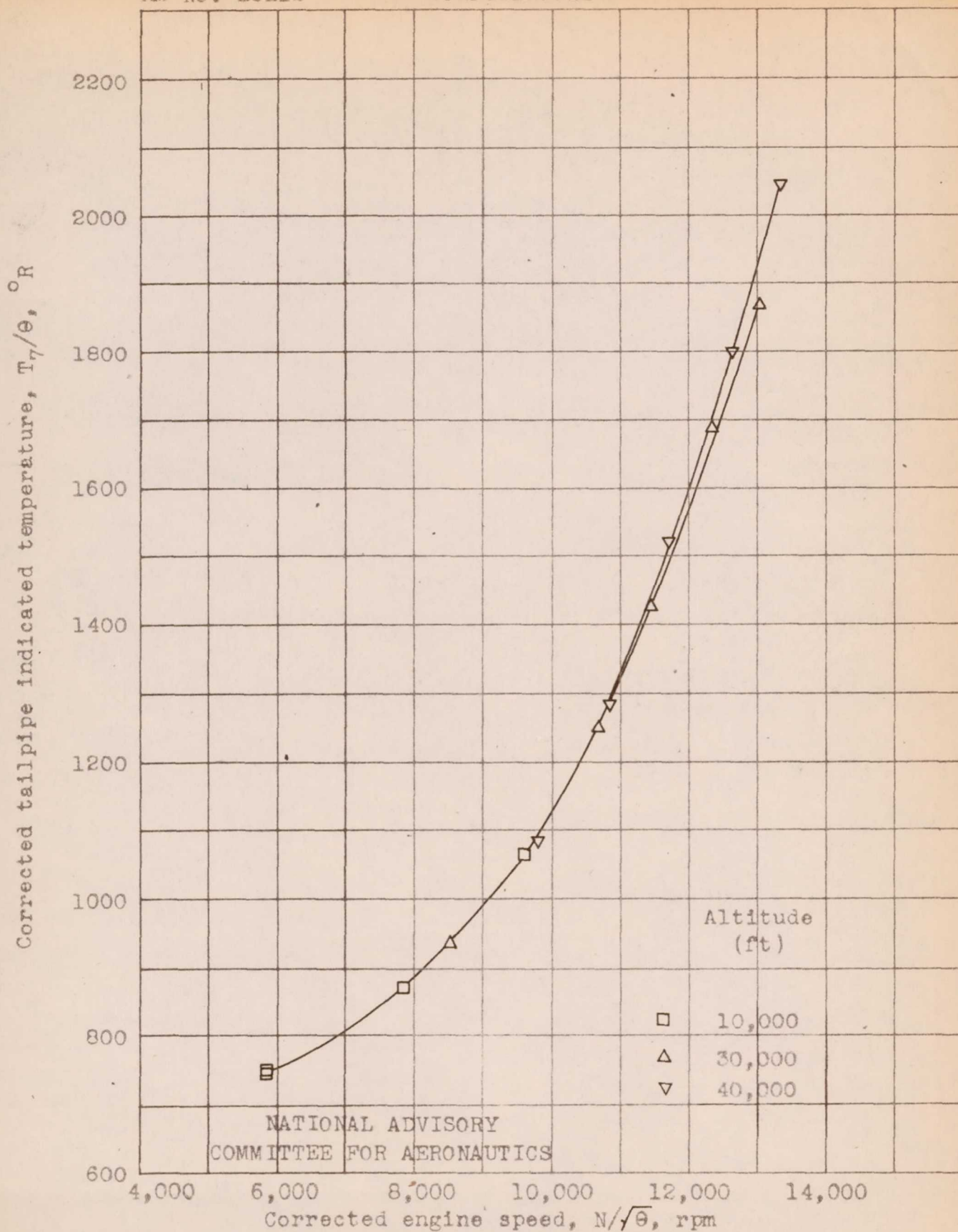
(c) Ram-pressure ratio, 1.7.

Figure 13.- Continued. Effect of corrected engine speed and ram-pressure ratio on corrected net thrust specific fuel consumption.

(d) Ram-pressure ratio, 2.3.

Figure 13.- Concluded. Effect of corrected engine speed and ram-pressure ratio on corrected net thrust specific fuel consumption.
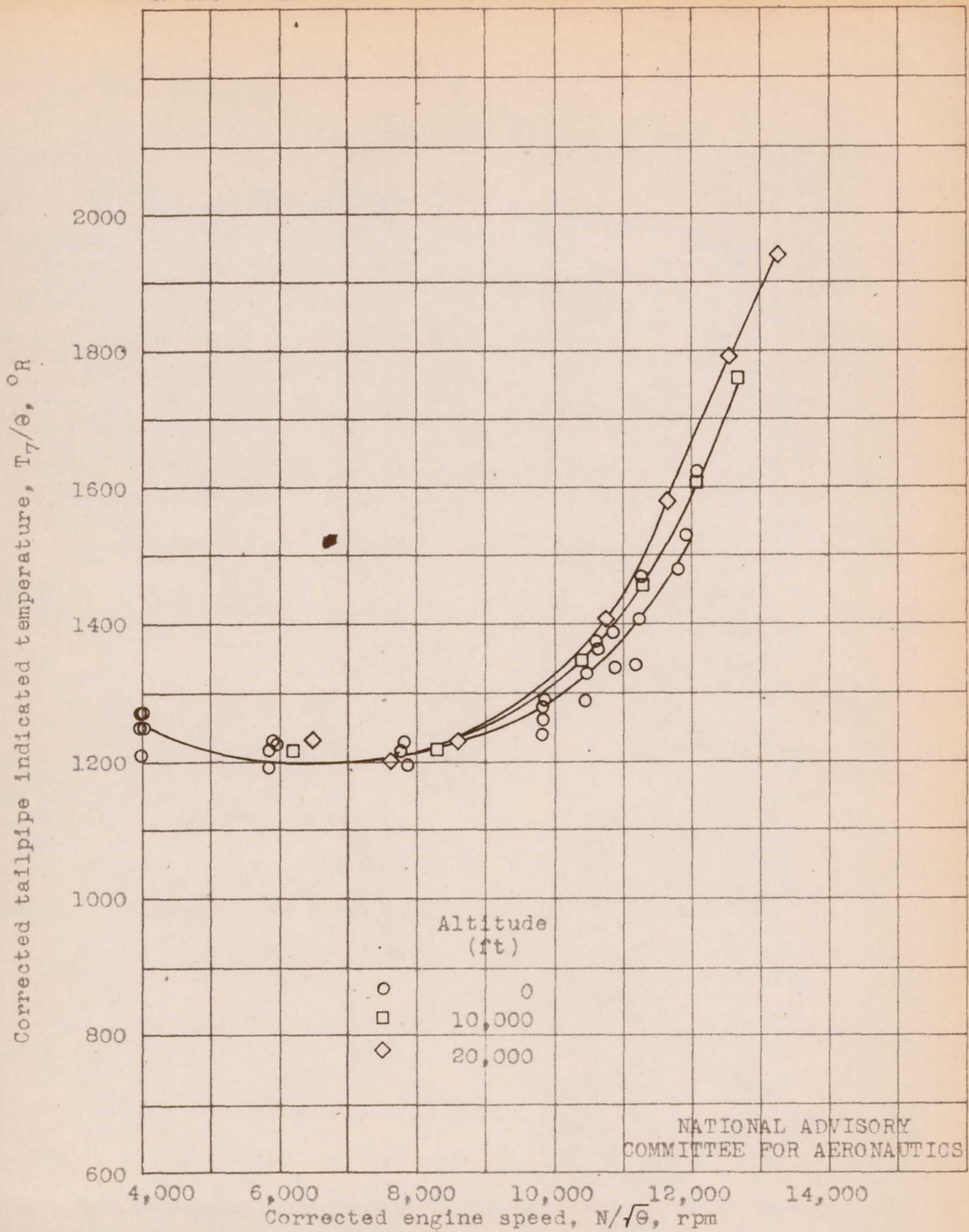
(a) Ram-pressure ratio, 1.0.

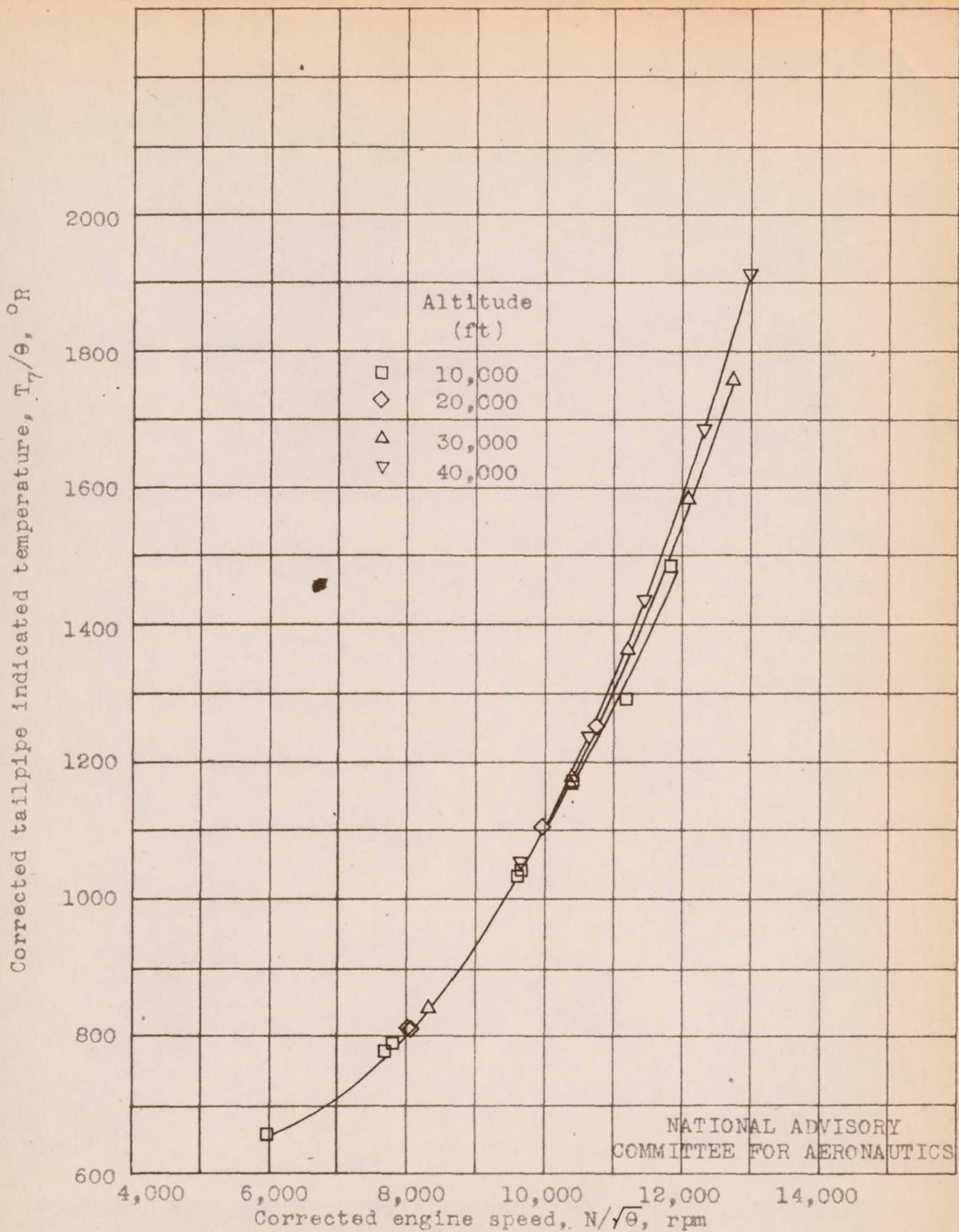Figure 14. - Effect of altitude on corrected tailpipe indicated temperature at various ram-pressure ratios.

(b) Ram-pressure ratio, 1.3.

Figure 14. - Continued. Effect of altitude on corrected tailpipe
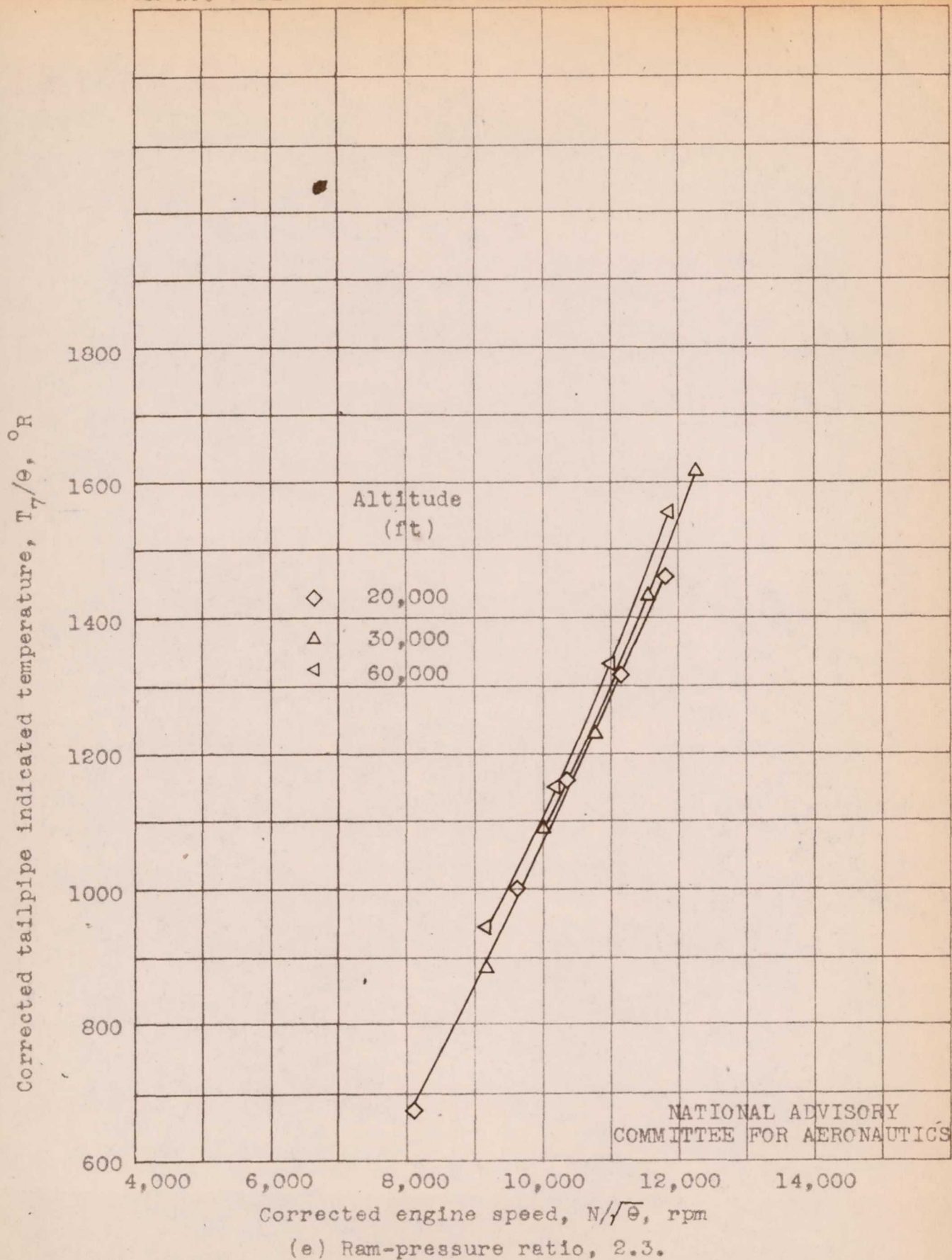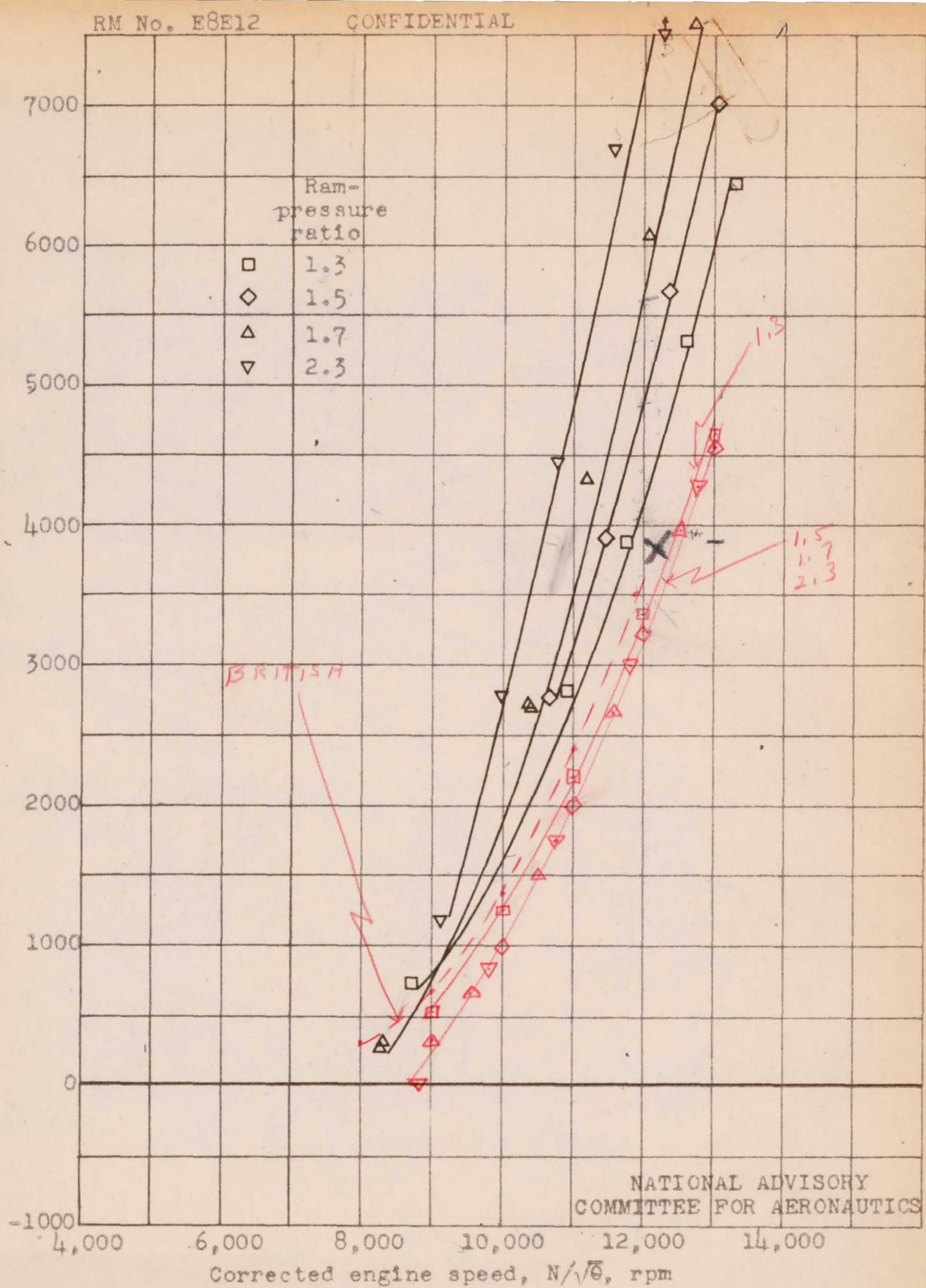indicated temperature at various ram-pressure ratios.

(c) Ram-pressure ratio, 1.5.

Figure 14. - Continued. Effect of altitude on corrected tailpipe indicated temperature at various ram-pressure ratios.

(d) Ram-pressure ratio, 1.7.

Figure 14. - Continued. Effect of altitude on corrected tailpipe indicated temperature at various ram-pressure ratios.

(e) Ram-pressure ratio, 2.3.

Figure 14. - Concluded. Effect of altitude on corrected tailpipe indicated temperature at various ram-pressure ratios.

Figure 15. - Effect of ram-pressure ratio on corrected net
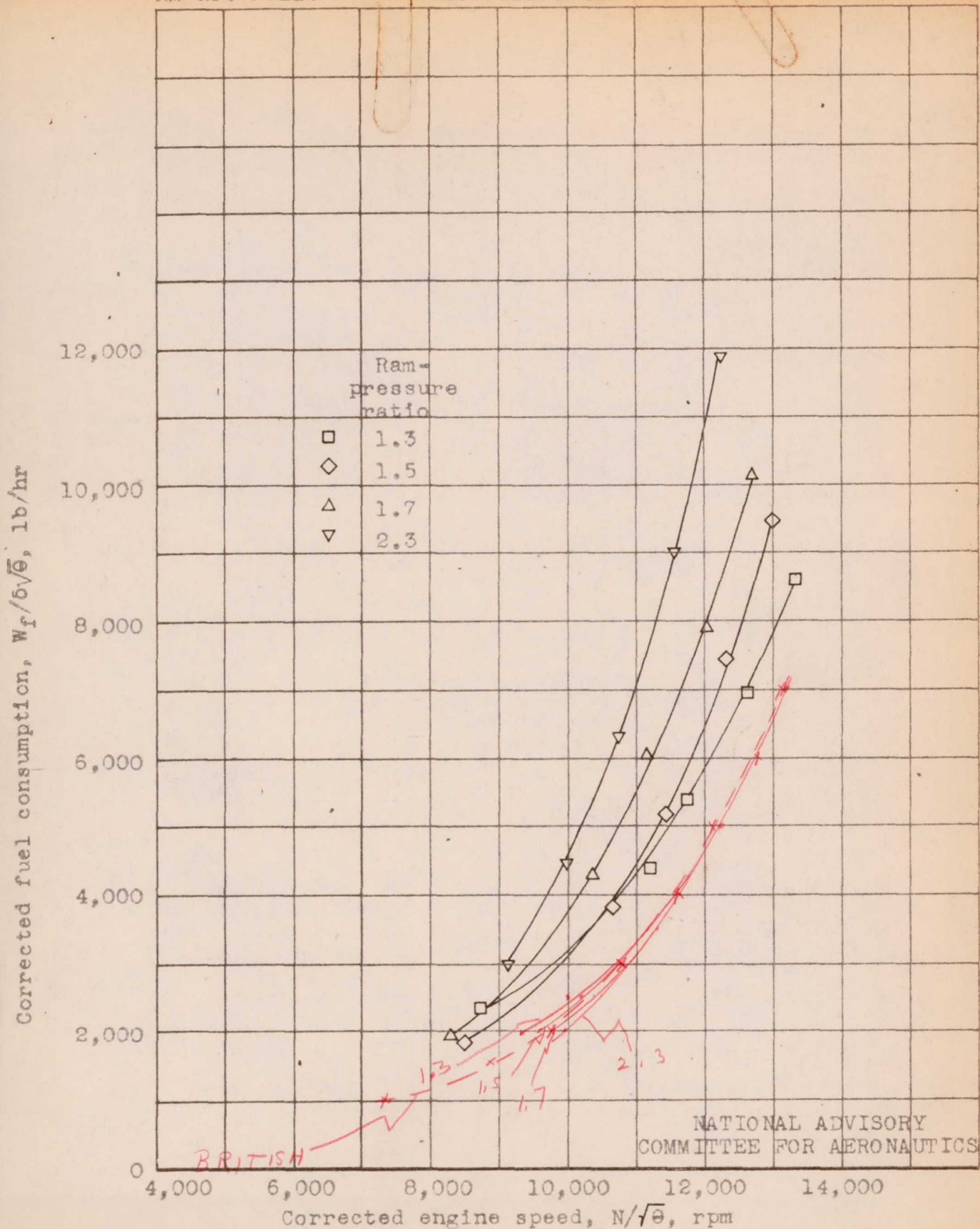thrust at altitude of 30,000 feet.

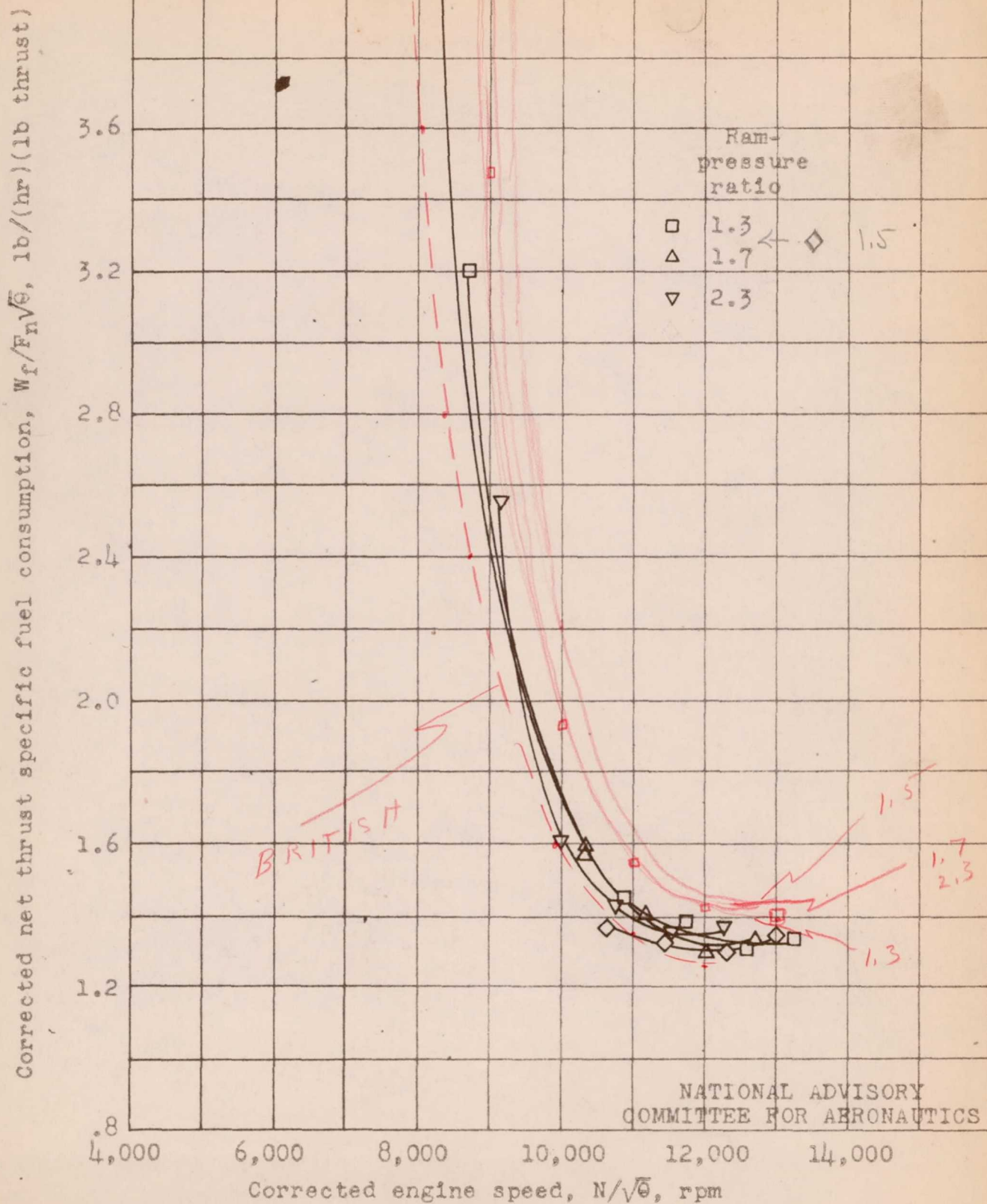Figure 16. - Effect of ram-pressure ratio on corrected fuel consumption at altitude of 30,000 feet.

Figure 17. - Effect of ram-pressure ratio on corrected net
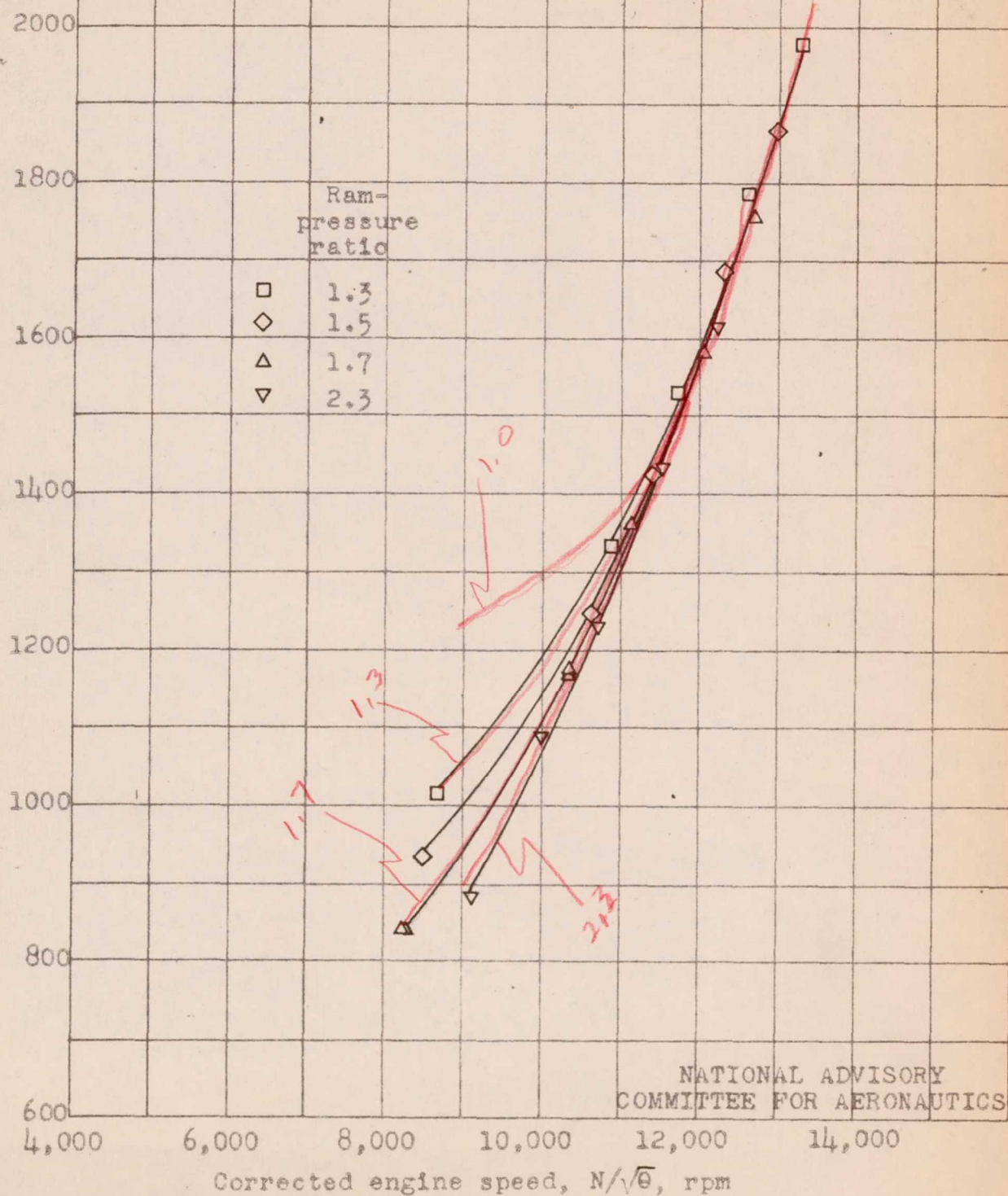thrust specific fuel consumption at altitude of 30,000
feet.

Figure 18. - Effect of ram-pressure ratio on corrected tailpipe indicated temperature at altitude of 30,000 feet.