NACA

RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF THRUST AUGMENTATION OF A TURBOJET ENGINE

II - PERFORMANCE WITH WATER INJECTION AT COMPRESSOR INLET

By Robert O. Dietz and William A. Fleming

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Thrust augmentation of a standard turbojet engine by water injection at the inlet of the axial-flow compressor has been investigated in the Cleveland altitude wind tunnel. Engine performance at an engine speed of 7600 rpm was obtained over a wide range of water-air ratios at pressure altitudes of 5000 and 20,000 feet and at a ram-pressure ratio corresponding to a flight Mach number of about 0.265. A fixed-area tail-pipe nozzle $16\frac{3}{8}$ inches in diameter was used for this investigation. Data are presented to show the effect of water injection on engine performance. A discussion of the effect of water injection on the pressure and temperature distribution at the compressor outlet of the turbojet engine is included.

At flight conditions for which the inlet air must be heated to avoid icing during the process of water injection, thrust augmentation by the use of water injection is not practical. The net thrust of the engine with an inlet-air temperature of 520° R at a pressure altitude of 5000 feet was increased 15 percent by means of water injection in the compressor inlet at a water-air ratio of 0.0407 and a simulated flight Mach number of 0.265. The specific liquid consumption, defined as the pounds of fuel and water consumed by the engine per pound of net thrust, was 220 percent greater than the specific fuel consumption for the engine without water injection. These net-thrust and specific-liquid-consumption data represent engine operation at limiting turbine-outlet temperature (1680° R). Water injection markedly changed the pressure, temperature, and velocity distributions at the compressor outlet.

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INTRODUCTION

Thrust augmentation is of importance in increasing the usefulness and the range of application of turbojet engines. An investigation of thrust augmentation by various methods is in progress at the NACA Cleveland laboratory. Three methods of thrust augmentation have been investigated: (1) tail-pipe burning, (2) water injection, and (3) bleed-off cycle combined with water injection. The results of investigations of tail-pipe burning on a turbojet engine are presented in references 1 and 2.

The injection of water into the inlet of a turbojet engine increases the thrust of the engine by increasing the mass flow through the engine and decreasing the temperature of the air flowing through the compressor as the water vaporizes. The lower temperature of the air flowing through the compressor increases the compressor pressure ratio by increasing the compressor Mach number and also increases the difference between the temperatures at which the work of compression is added to and taken from the working fluid in the engine.

Results of an investigation of water injection at the inlet of a turbojet engine having an axial-flow compressor are reported. This investigation was made at a ram-pressure ratio corresponding to a flight Mach number of 0.265 at pressure altitudes of 5000 and 20,000 feet. The water-air ratio was varied from 0 to 0.0418 at 5000 feet and from 0 to 0.0677 at 20,000 feet while the engine speed was maintained at 7600 rpm. A fixed-area tail-pipe nozzle was used on the engine.

Performance results with water injection at the compressor inlet of a standard turbojet engine and a discussion of the effect of water injection on the pressure, temperature, and velocity distributions at the compressor outlet are presented.

INSTALLATION FOR WATER INJECTION

A standard turbojet engine having an 11-stage axial-flow compressor, eight cylindrical combustion chambers, a single-stage turbine, a tail pipe, and an exhaust nozzle was used in this investigation. The over-all length of the engine is 14 feet and the maximum diameter is 36 inches.

Water was injected at a station 6 inches upstream of the engine inlet through 24 nozzles installed circumferentially around the inlet duct. (See fig. 1.) Very fine drop size was desirable in order to avoid erosion of the compressor blades. The commercial air-atomizing spray nozzle used to inject the water is shown in figure 2. This nozzle has an air jet in the center that is 0.063 inch in diameter and a main orifice diameter of 0.089 inch. Water is introduced through the annular passage in the nozzle where swirl is induced by several turning vanes. Air discharged from the center jet strikes the water inside the mixing chamber just before entering the orifice and the mixture is discharged in the form of a fine spray. With a water pressure of 60 pounds per square inch and an air pressure of 100 pounds per square inch, the drop size of the resulting spray is approximately 50 microns.

WIND-TUNNEL INSTALLATION AND TEST PROCEDURE

The engine was suspended from a wing section installed in the 20-foot-diameter test section of the altitude wind tunnel. Dry air was supplied to the engine through a duct from the tunnel make-up air system. A frictionless labyrinth slip joint in the inlet-air duct 40 feet upstream of the engine inlet made possible the measurement of thrust with the wind-tunnel balance. The air was throttled from approximately sea-level pressure to the desired pressure at the engine inlet while the pressure in the wind-tunnel test section was maintained at the desired pressure altitude. The temperature of the air supplied to the engine was maintained at approximately 520° R in order to prevent icing when water was injected.

This investigation was conducted at pressure altitudes of 5000 and 20,000 feet and a ram-pressure ratio of 1.05, which corresponds to a flight Mach number of 0.265. At both pressure altitudes, the engine was operated at a speed of 7600 rpm and data were obtained at various water flows. A maximum water flow of 2.65 pounds per second was limited by the pumping equipment. A fixed-area tail-pipe nozzle $16\frac{3}{8}$ inches in diameter was installed on the engine.

A survey rake was mounted in the inlet duct upstream of the engine inlet to measure temperatures and pressures from which the air flow was calculated. The pressure and the temperature of the gases were measured at several stations in the engine (fig. 3) and thrust was determined from the balance scales. The methods used to calculate thrust and air flow are presented in the appendix. The engine was operated with kerosene (AN-F-32).

DISCUSSION OF RESULTS

Engine Performance

The effect of water injection on the performance of a turbojet engine with a fixed-area tail-pipe nozzle at pressure altitudes of 5000 and 20,000 feet and a flight Mach number of 0.265 is shown in figures 4 to 11. The relation between water-air ratio and tail-pipe-nozzle outlet total pressure and temperature is shown in figure 4. Throughout most of the range of water-air ratios investigated, the total temperature of the gas at the tail-pipe-nozzle outlet was below the limiting value (1680° R). With the fixed-area tail-pipe nozzle used in this investigation, the tail-pipe total temperature was higher than the limiting value at very low and very high water-air ratios. In order to maintain limiting tail-pipe temperature and thereby obtain the maximum available thrust at all water-air ratios, a variable-area tail-pipe nozzle should be used.

The effect of water injection on jet thrust, net thrust, percentage increase in net thrust, fuel consumption, air flow, fuel-air ratio, and specific fuel and liquid consumption is shown in figures 5 to 11. At limiting tail-pipe temperatures and at a simulated flight Mach number of 0.265, the net thrust was increased 15 percent at a pressure altitude of 5000 feet and a water-air ratio of 0.0407 and 12 percent at a pressure altitude of 20,000 feet and a water-air ratio of 0.0535 (fig. 7). The respective specific liquid consumptions under these conditions were 220 and 280 percent greater than the specific fuel consumption without water injection (fig. 11).

The data discussed in the previous paragraph indicate that water injection affords limited gains in thrust accompanied by large increases in specific liquid consumption. As previously mentioned, an inlet-air temperature of approximately 520° R was maintained during the water-injection investigation in order to avoid icing at the engine inlet. For the flight conditions investigated at a pressure altitude of 20,000 feet, this temperature was considerably higher than the standard atmospheric temperature at that altitude. The engine thrust was therefore reduced. Calculations show that if the compressor-inlet temperature was maintained at the NACA standard value corresponding to an altitude of 20,000 feet, the net thrust of the engine with no water injection would be 13.5 percent higher than the thrust obtainable at limiting turbine-outlet temperature with water injection and an inlet-air temperature of 520° R. Thus for flight conditions at which the inlet air must be heated to avoid icing during the process of water injection, thrust augmentation by the use of water injection is not practical.

Engine-Component Performance

An analysis of temperature and pressure surveys at several stations in the engine has been made to determine the effect of water injection on the engine components. The data show that water injection had no apparent effect on combustion efficiency and turbine efficiency throughout the range of water-air ratios investigated at pressure altitudes of 5000 and 20,000 feet. Combustion-efficiency data are presented in figure 12 and the method used to determine combustion efficiency is explained in the appendix. Turbine efficiency could not be accurately calculated, but as an indirect approach the data were plotted on a turbine characteristic curve (fig. 13) determined from a previous investigation of the engine in the altitude wind tunnel. It is assumed that injection of water does not affect these characteristics. Because the turbine operating points with water injection fell between the 78-percent and 80-percent efficiency contours in figure 13, it is concluded that the turbine efficiency remained essentially constant.

Compressor performance could not be accurately determined because of the nonuniform temperature and pressure distribution across the compressor-outlet annulus as well as the nonuniform distribution of water vapor at the compressor outlet. An analysis of the changes in compressor-outlet pressure, temperature, and velocity distributions results, however, in the formation of tentative estimates regarding compressor performance. Although limited in scope, the temperature and pressure surveys obtained show the important effects of water injection on the flow through the compressor.

Average compressor-outlet pressures, temperatures, and total-pressure ratios for different operating conditions are shown in figures 14 and 15. These temperatures and pressures were integrated with respect to the mass-flow distribution at the compressor outlet. This method of integrating the temperatures and pressures is fully discussed in the appendix. The compressor-outlet total and static pressures increased and the total temperature decreased as the water-air ratio was increased (fig. 14). The compressor total-pressure ratio increased with water-air ratio (fig. 15).

Surveys of temperature, pressure, and velocity at the compressor outlet are shown in figures 16, 17, and 18, respectively, for various water-air ratios at pressure altitudes of 5000 and 20,000 feet. Large variations in temperature, total pressure, and velocity distribution at the compressor outlet indicate a wide departure from the design operating conditions of the compressor blading. The compressor-outlet temperatures are lower at the blade tips than at the blade roots when water is injected, which indicates that the centrifugal action of the compressor throws the water toward the blade tips. (See fig. 16.) Changes in total- and static-pressure distributions at the compressor outlet for various water-air ratios with a uniform compressor-inlet total-pressure distribution are shown in figure 17.

Compressor-outlet velocity distributions were markedly changed by water injection as shown in figure 18. These velocities were calculated by substituting values of temperature and pressure obtained from figures 16 and 17 into the compressible-flow-velocity equation.

So long as the flow conditions over the compressor blading do not deviate very far from the design conditions, water injection should improve the adiabatic compressor efficiency because vaporization of the water reduces the temperature during compression. As the water-air ratio was increased, the volume flow through the last few stages of the compressor decreased as indicated by the decrease in axial velocity at the compressor outlet. As a result, the effective angle of attack of the blades in the latter stages increased because the rotational velocity was not changed. Because at design conditions axial-flow-compressor blading operates as highly loaded airfoils, a small increase in the angle of attack of some of the blades would decrease the compressor efficiency and possibly cause some of the blading to reach a condition of stalling. At the same time, the decrease in temperature of the fluids flowing through the compressor increases the blade Mach number. If the Mach number reaches too high a value, compressibility losses may occur over the blades and cause a decrease in compressor efficiency.

An example of a condition at which the compressor blades in the latter stages are probably stalled is a water-air ratio of 0.0677 and a pressure altitude of 20,000 feet (fig. 16(b)). At this condition, the temperature distribution across the compressor-outlet annulus was almost uniform instead of varying as at lower water-air ratios. This test condition was later repeated and the uniform temperature distribution was again observed. This uniform distribution indicates mixing of the two fluids at some point in the compressor, which may have been the result of compressor-blade stall.

Changes in compressor efficiency are indicated by the relation between water-air ratio and tail-pipe-nozzle outlet total temperature (fig. 4). As small amounts of water are injected, the tail-pipe temperature decreases because of the increase in cycle efficiency and the possible increase in compressor efficiency. The discussion of the effect of water injection on the engine components, which shows that the turbine and combustion efficiency are apparently unaffected, indicates that the increase in tail-pipe temperature at the higher water-air ratios is probably caused by a decrease in compressor efficiency.

SUMMARY OF RESULTS

Results from an investigation in the Cleveland altitude wind tunnel of thrust augmentation by injecting water at the inlet of the axial-flow compressor of a turbojet engine with a fixed-area tail-pipe nozzle $16\frac{3}{8}$ inches in diameter at an inlet-air temperature of approximately 520° R are as follows:

1. Water injection in the compressor inlet afforded limited gains in thrust accompanied by large increases in specific liquid consumption. With a tail-pipe temperature of 1680° R and at a simulated flight Mach number of 0.265, the net thrust was increased 15 percent at a pressure altitude of 5000 feet and a water-air ratio of 0.0407 and 12 percent at a pressure altitude of 20,000 feet and a water-air ratio of 0.0535. These thrust increases were based on the thrust available from a standard turbojet engine at a simulated flight Mach number of 0.265 and pressure altitudes of 5000 and 20,000 feet with an inlet-air temperature of 520° R. The respective specific liquid consumptions under these conditions were 220 and 280 percent greater than the specific fuel consumption without water injection.

2. Injection of water resulted in large changes in the compressor-outlet temperature and pressure distributions, which were probably accompanied by a reduction in compressor efficiency.

3. In order to maintain limiting tail-pipe temperature and thereby obtain the maximum available thrust at all water-air ratios, a variable-area tail-pipe nozzle should be used.

4. At flight conditions at which the inlet air must be heated to avoid icing during the process of water injection, thrust augmentation by the use of water injection is not practical.

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APPENDIX - CALCULATIONS

Symbols

The following symbols are used in this report:

A	cross-sectional area, sq ft
B	thrust scale reading, lb
C_D	external drag coefficient of installation (determined from power-off tests)
c_p	specific heat of gas at constant pressure, Btu/lb/°F
F_j	jet thrust, lb
F_n	net thrust, lb
g	acceleration of gravity, ft/sec^2
h	enthalpy, Btu/lb
J	mechanical equivalent of heat, ft-lb/Btu
P	total pressure, lb/sq ft absolute
p	static pressure, lb/sq ft absolute
q	dynamic pressure, lb/sq ft
R	gas constant, ft-lb/lb °R
S	wing-section area, sq ft
T	total temperature, °R
T_i	indicated temperature, °R
t	static temperature, °R
V	velocity, ft/sec
W_a	air flow, lb/sec

W_f fuel consumption, lb/hr

W_g gas flow, lb/sec

W_l liquid consumption, lb/hr

W_w water consumption, lb/hr

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

W_l/F_n specific liquid consumption based on net thrust, (lb of fuel + water)/hr/lb thrust

f/a fuel-air ratio

p_1/p_0 ram-pressure ratio

w/a water-air ratio

γ ratio of specific heats for gases

δ_4 pressure correction factor, $P_4/2116$ (turbine-inlet total pressure divided by NACA standard sea-level pressure)

η efficiency, percent

θ_4 temperature correction factor, $\gamma_4 T_4/1.40 \times 519$ (product of γ and total temperature at turbine inlet divided by product of γ and total temperature for air at NACA standard sea-level conditions)

ρ mass density of gas, slugs/cu ft

Subscripts:

a air

b combustion

g gas

m mixture of steam and gas

r inlet duct at survey rake, station r

t turbine

w water

x inlet duct at slip joint, station x

0 tunnel test-section free-air stream

1 cowl inlet

3 compressor outlet

4 turbine inlet

5 turbine outlet

6 tail-pipe-nozzle outlet

Methods of Calculation

<u>Temperature.</u> - A cold calibration of a sample thermocouple up to a Mach number of about 0.8 showed that the thermocouple measured the static temperature plus approximately 85 percent of the adiabatic temperature rise owing to the impact of the air on the thermocouple. Static temperature may be determined from indicated temperature by applying this factor to the adiabatic relation between temperature and pressure in the following manner:

$$t = \frac{T_i}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (1)$$

and the total temperature

$$T = t\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} = \frac{T_i\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}}}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (2)$$

Air flow. - The air flow through the engine was determined from pressure and temperature measurements obtained with a vertical survey rake installed in the inlet duct $11\frac{1}{4}$ feet ahead of the engine inlet. Air flow was calculated by

$$W_a = \rho_r A_r V_r g = \frac{p_r A_r}{R} \sqrt{\frac{2Jgc_p}{t_r}\left[\left(\frac{P_r}{p_r}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \qquad (3)$$

The static temperature in equation (3) was obtained by use of equation (1).

Jet thrust. - Jet thrust was determined from the balance-scale measurements by combining the forces on the installation in the following equation:

$$F_j = B + C_D q_0 S + \frac{W_a V_x}{g} + A_x(p_x - p_0) \qquad (4)$$

The second term in the right-hand side of equation (4) represents the external drag of the installation and the third and fourth terms combined represent the force on the installation at the frictionless slip joint in the inlet-air duct.

Equivalent airspeed. - Inasmuch as all calculations are based on 100-percent ram recovery, the equivalent airspeed corresponding to the ram-pressure ratio at the engine inlet can be expressed by

$$V_0 = \sqrt{2Jgc_p\, T_{1,1}\left[1 - \left(\frac{p_0}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]} \qquad (5)$$

Because the adiabatic temperature rise due to the cowl-inlet velocity was low, the equivalent free-stream total temperature can be assumed equal to the cowl-inlet indicated temperature. The use of this assumption introduces an error in airspeed of less than 1 percent.

Net thrust. - When the equivalent free-stream momentum of the inlet air is subtracted from the jet thrust, the following equation for net thrust is obtained:

$$F_n = F_j - \frac{W_a V_0}{g} \qquad (6)$$

Combustion efficiency. - Combustion efficiency was calculated by making a thermal heat balance of the entire engine. The enthalpy at the compressor inlet included the enthalpy of the dry air upstream of the engine and of the water injected. The enthalpy at the tail-pipe-nozzle outlet included the enthalpy of the burned gas and of the superheated steam. These values are combined in the following equation, which expresses combustion efficiency as

$$\eta_b = \frac{h_{w,6}\, W_w + h_{g,6}\, W_g - h_{a,1}\, W_a - h_{w,1}\, W_w}{18,600\, W_f} \qquad (7)$$

Method of integration. - Compressor-outlet temperatures and pressures were averaged with respect to the radial mass-flow distribution. Temperature and pressure profiles (figs. 16 and 17) were used to calculate the mass flow through six incremental annuli at the compressor outlet. Each incremental mass flow was then divided by the total mass flow to obtain the integrating factors. Each incremental value of temperature and pressure was multiplied by the corresponding mass-flow integrating factor. The sum of these products was used as the average value.

REFERENCES

1. Fleming, W. A., and Dietz, R. O.: Altitude-Wind-Tunnel Investigations of Thrust Augmentation of a Turbojet Engine. I - Performance with Tail-Pipe Burning. NACA RM No. E6I20, 1946.

2. Lundin, Bruce T., Dowman, Harry W., and Gabriel, David S.: Experimental Investigation of Thrust Augmentation of a Turbojet Engine at Zero Ram by Means of Tail-Pipe Burning. NACA RM No. E6J21, 1946.

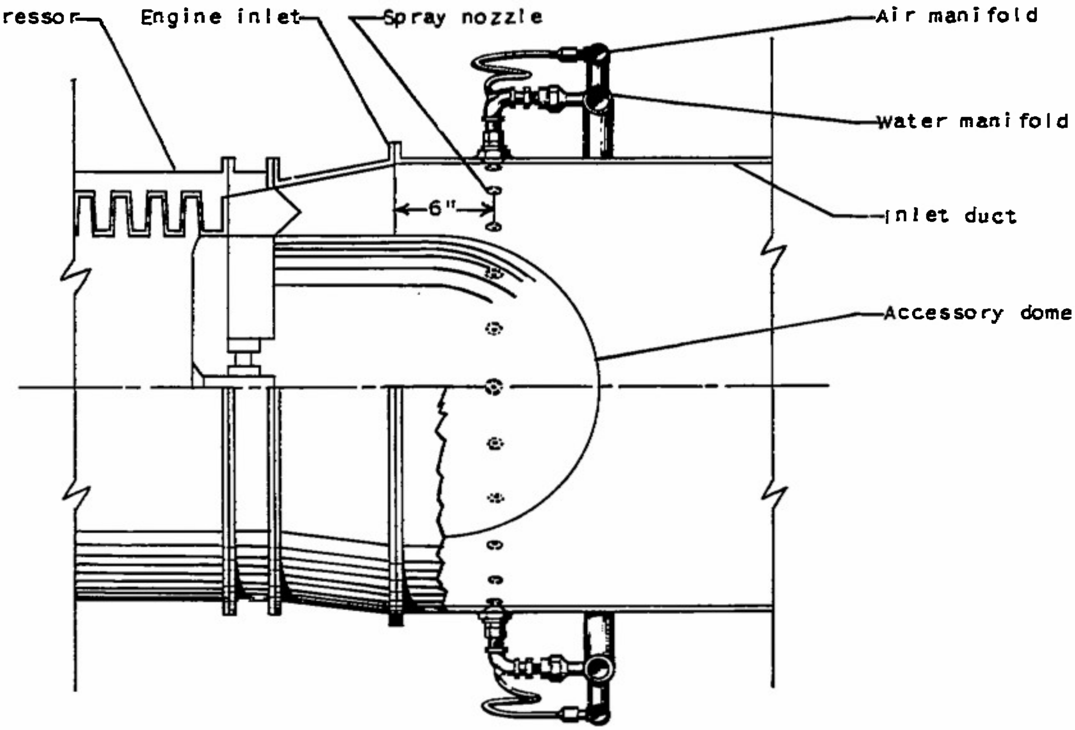

Figure 1. - Installation of water-injection manifold ahead of compressor inlet.

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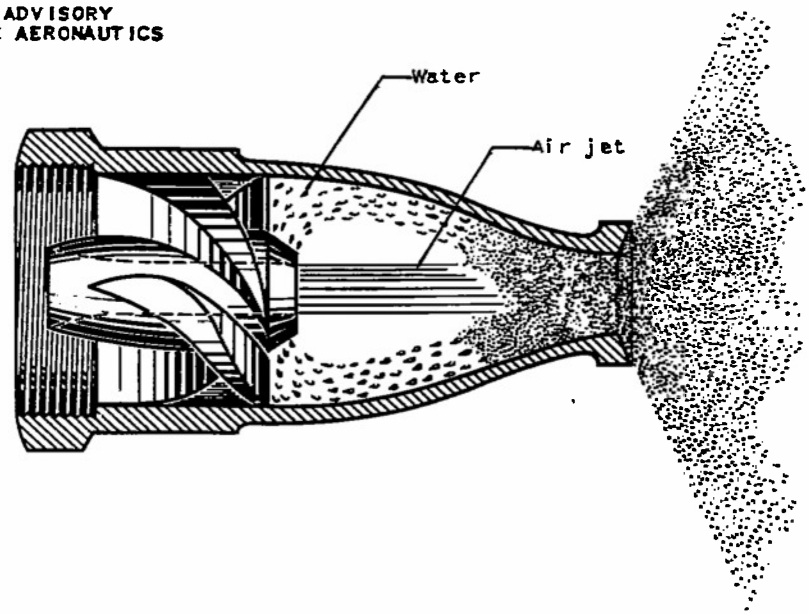

Figure 2. - Cross-section of air-atomizing spray nozzle used for water injection.

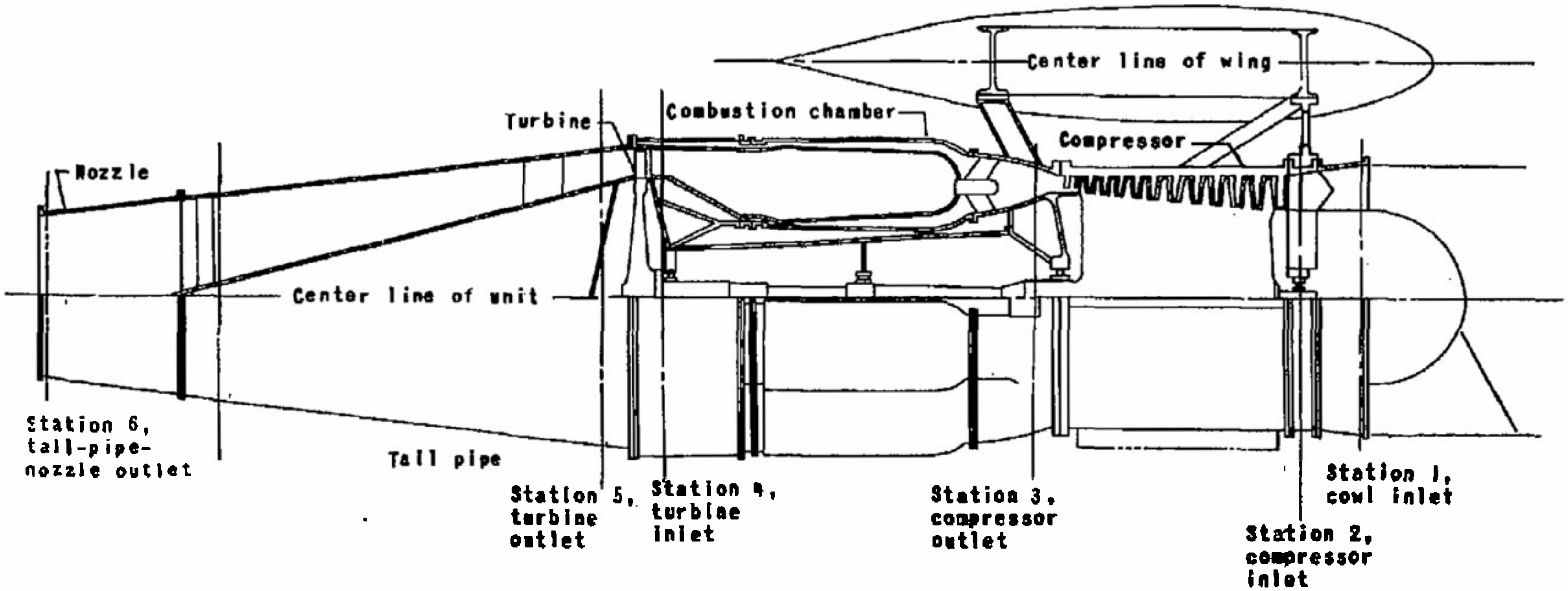

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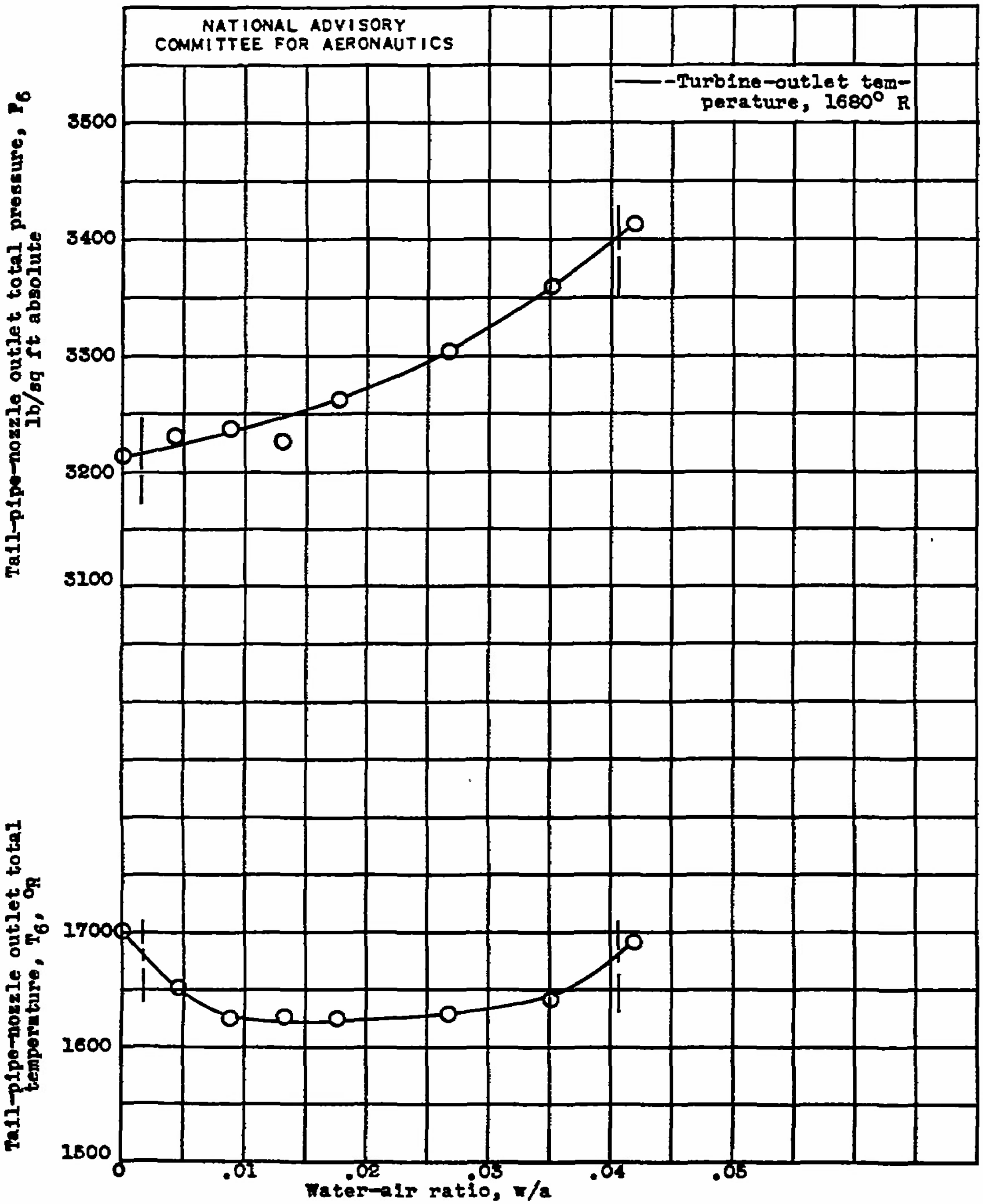
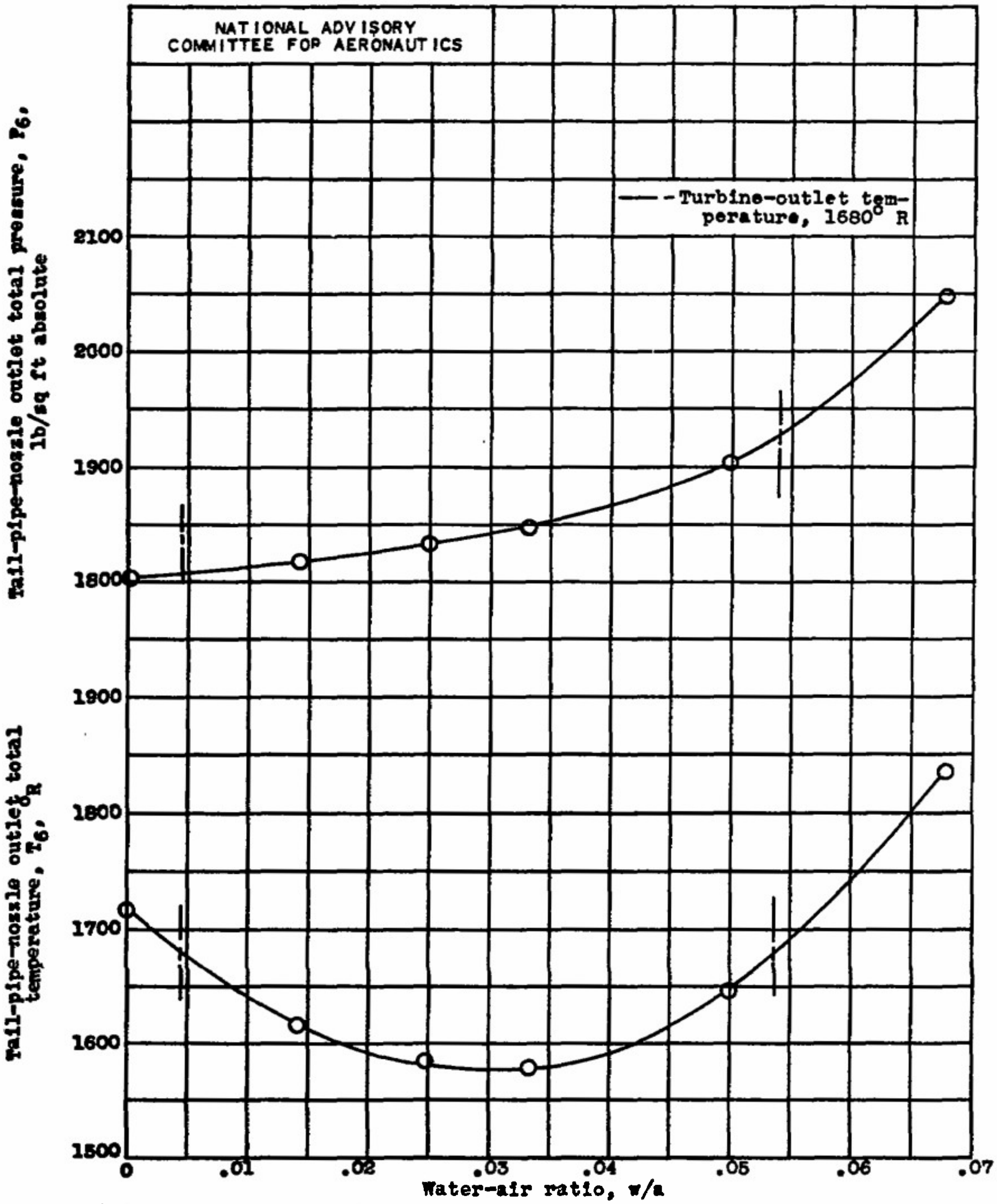
Figure 3. – Cross section of turbojet engine showing stations at which instrumentation was located.



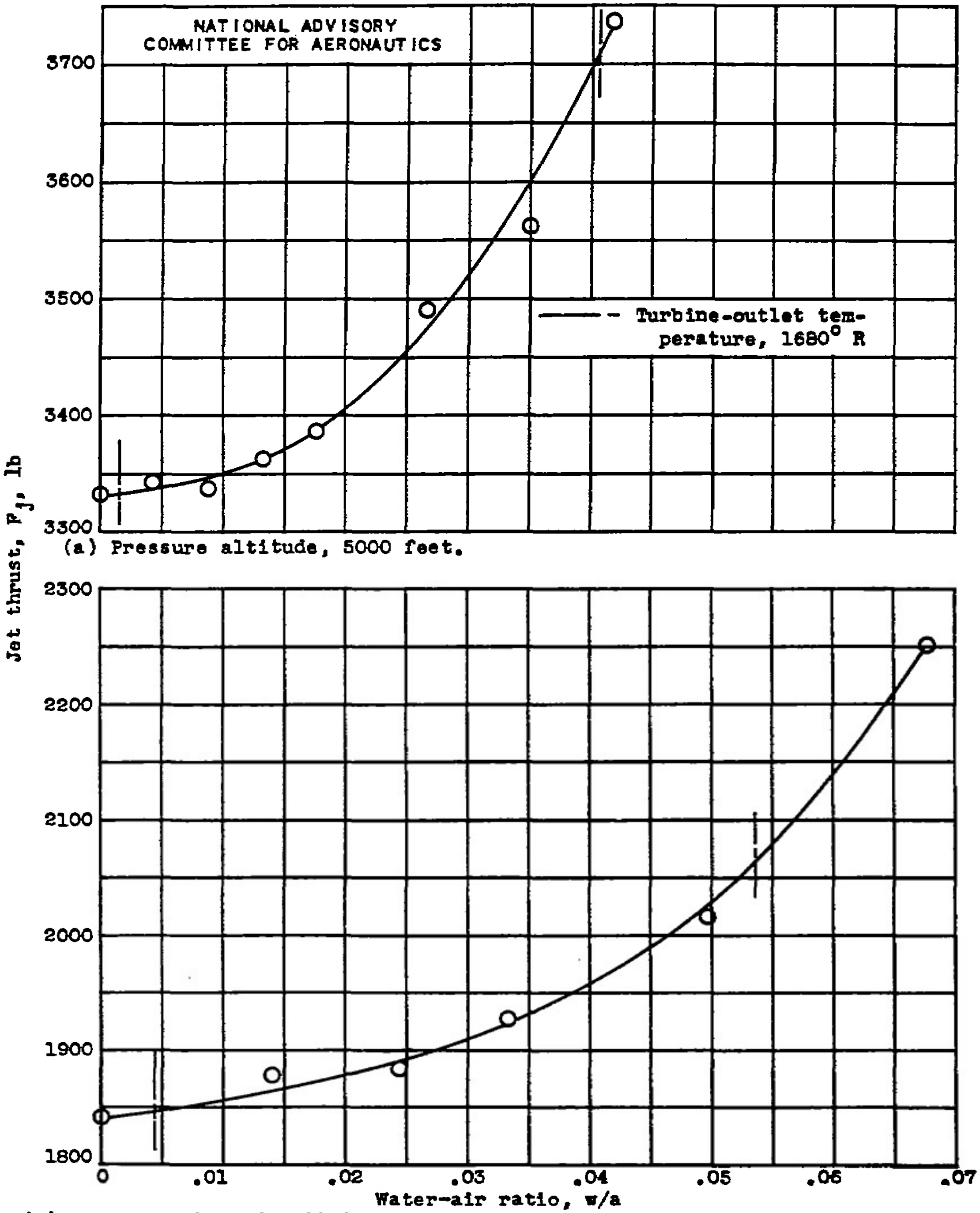
(a) Pressure altitude, 5000 feet; free-stream static pressure, p_0, 1757 pounds per square foot.

Figure 4.- Effect of water injection on tail-pipe-nozzle outlet pressure and temperature of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(b) Pressure altitude, 20,000 feet; free-stream static pressure, p_0, 972 pounds per square foot.

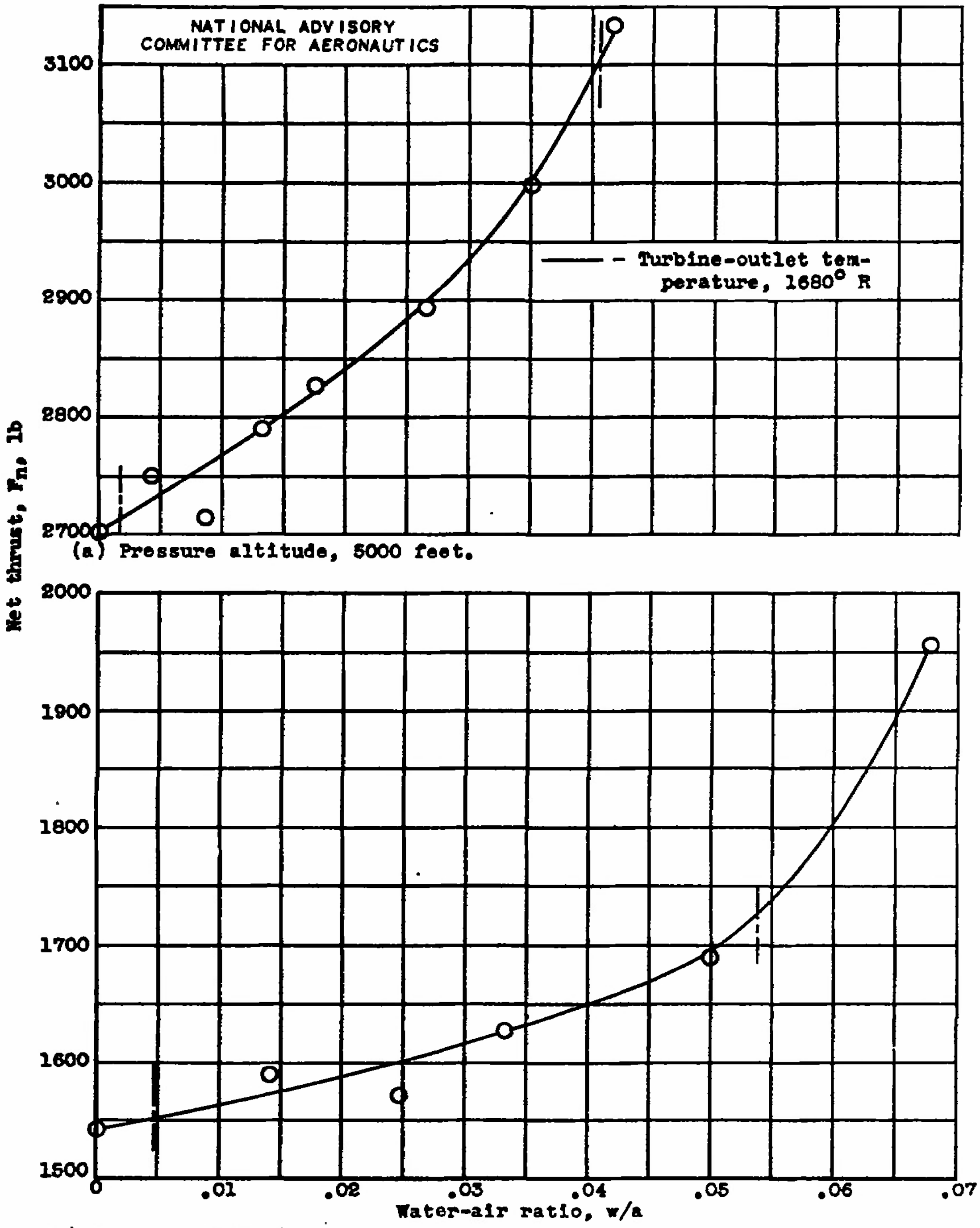
Figure 4.- Concluded. Effect of water injection on tail-pipe-nozzle outlet total pressure and temperature of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

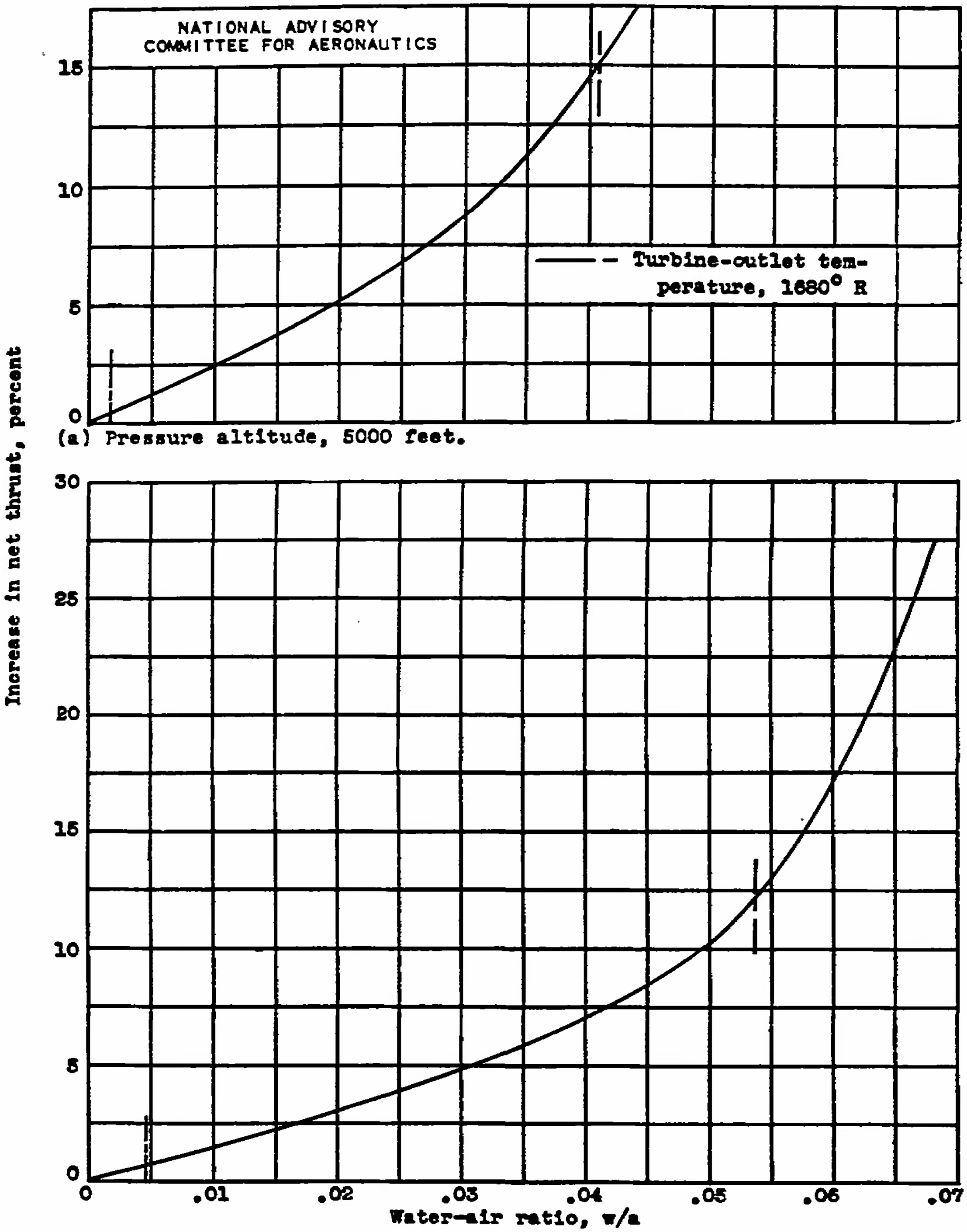
(b) Pressure altitude, 20,000 feet.

Figure 5.- Effect of water injection on jet thrust of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(b) Pressure altitude, 20,000 feet.

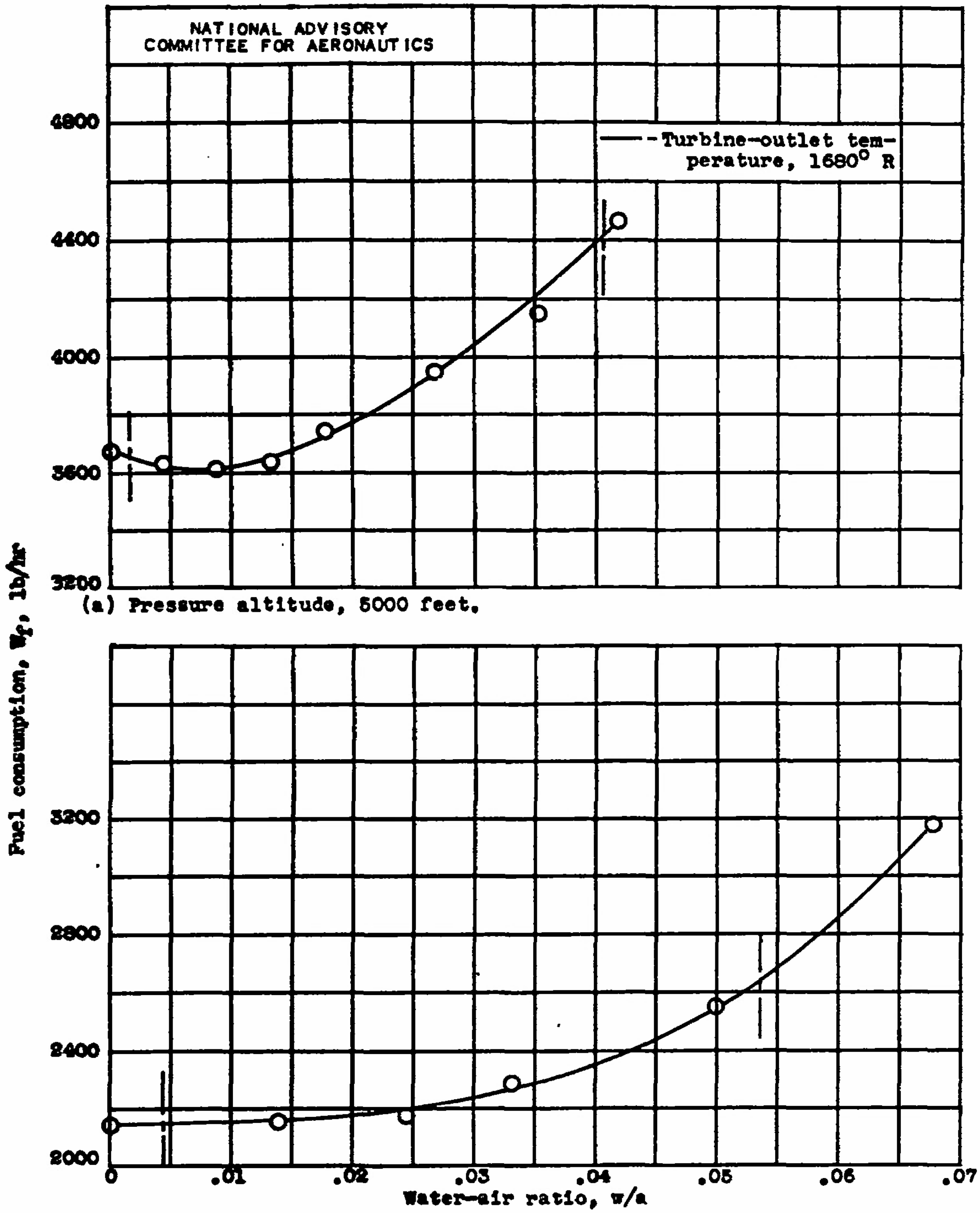
Figure 6.- Effect of water injection on net thrust of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

(b) Pressure altitude, 20,000 feet.

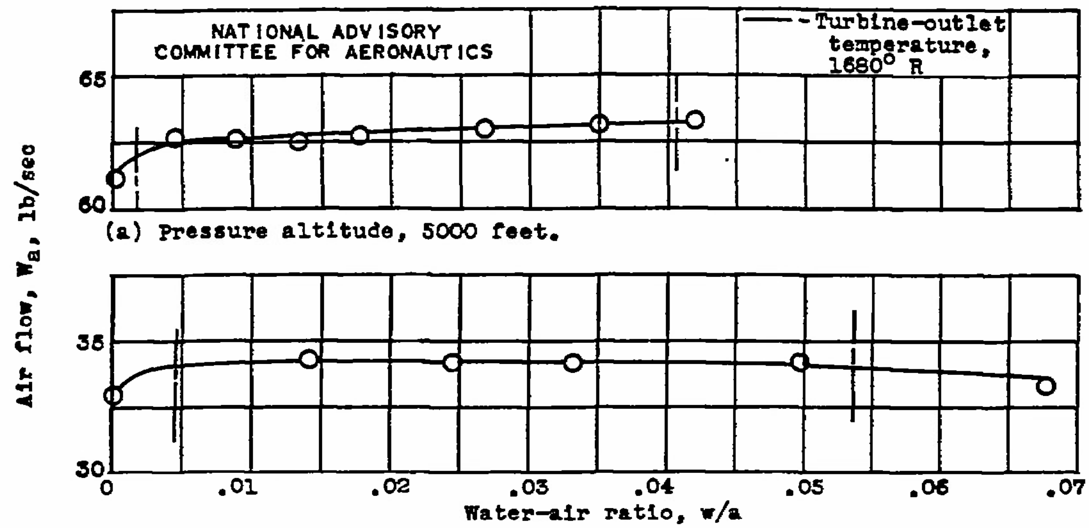
Figure 7.- Increase in net thrust of turbojet engine obtained with water injection. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

(b) Pressure altitude, 20,000 feet.

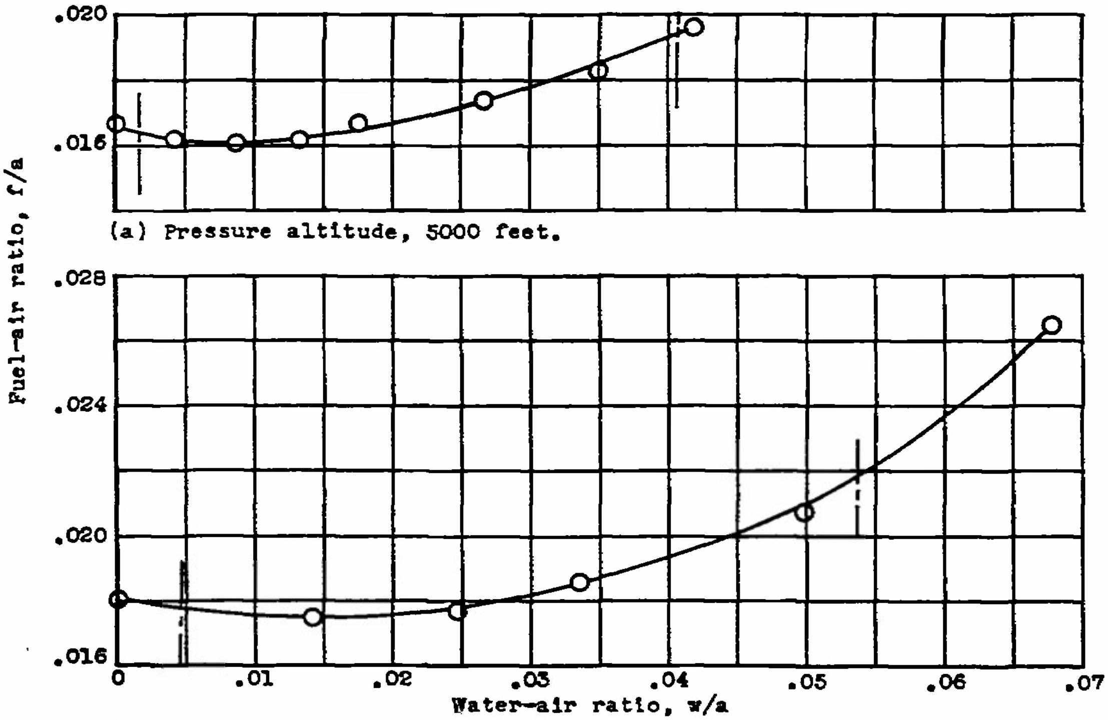
Figure 8.- Effect of water injection on engine fuel consumption of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

(b) Pressure altitude, 20,000 feet.

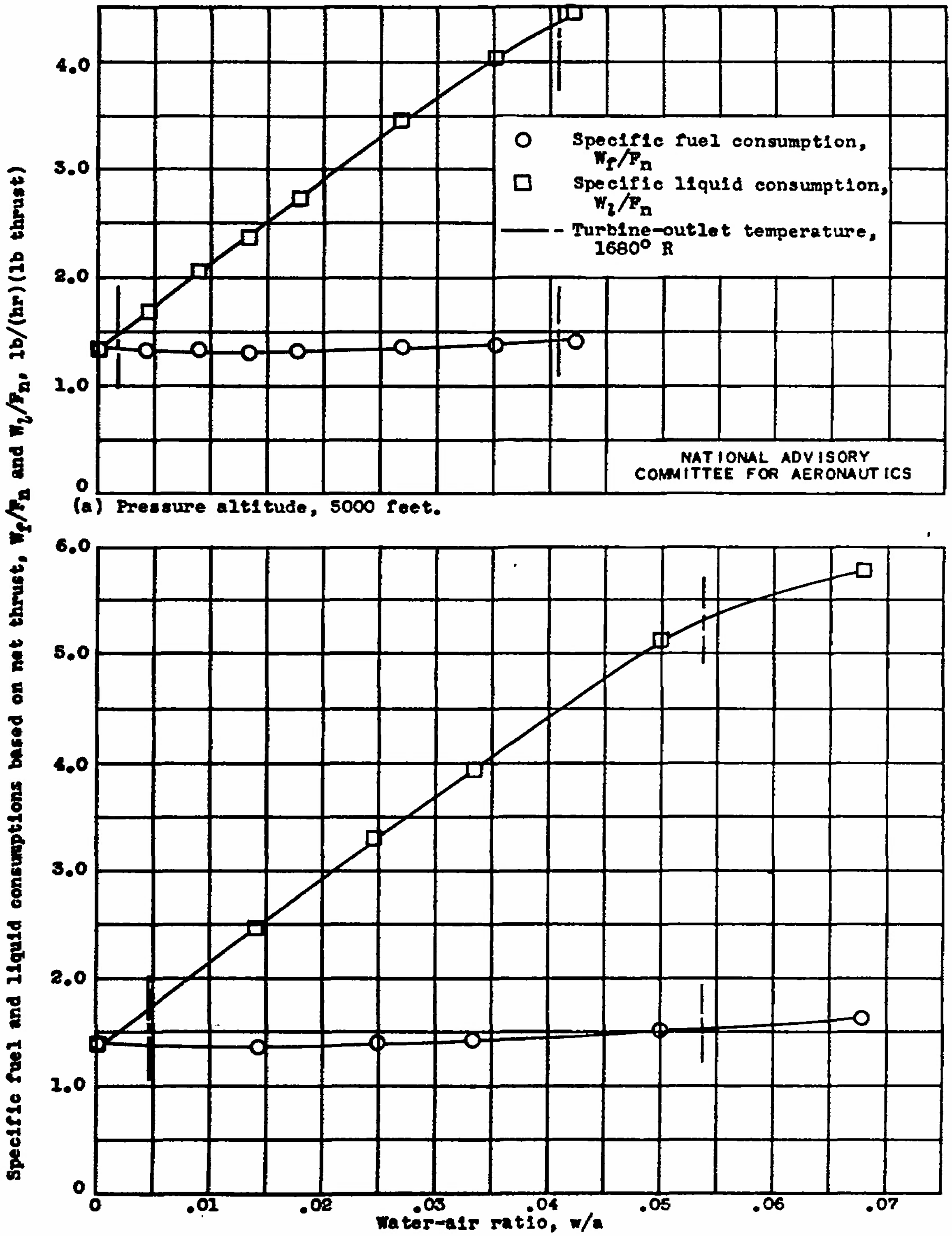
Figure 9.- Effect of water injection on air flow of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

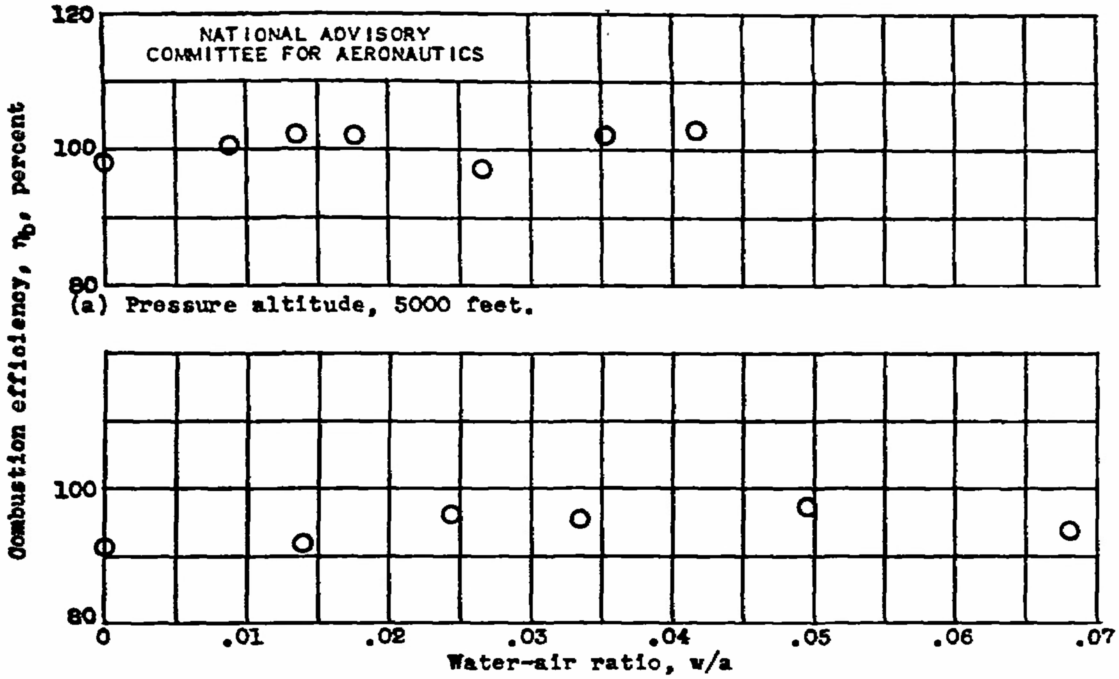
(b) Pressure altitude, 20,000 feet.

Figure 10.- Effect of water injection on fuel-air ratio of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(b) Pressure altitude, 20,000 feet.

Figure 11.- Effect of water injection on specific fuel consumption and specific liquid consumption of turbojet engine. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

(b) Pressure altitude, 20,000 feet.

Figure 12.- Effect of water injection on combustion efficiency of turbojet engine.

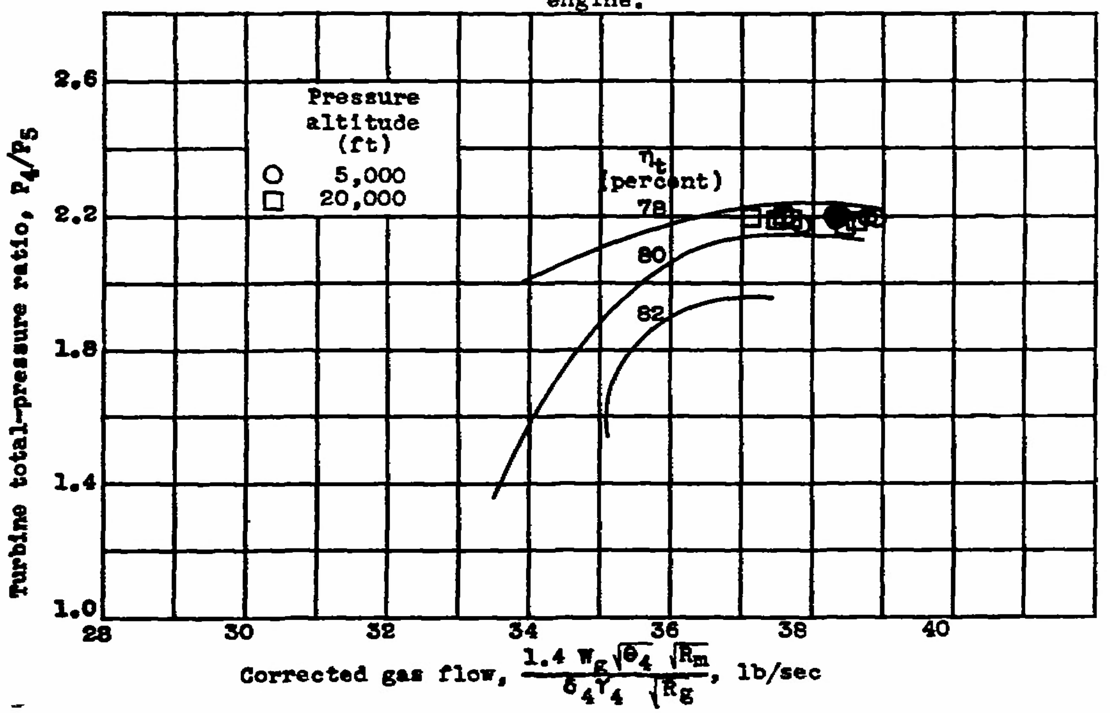
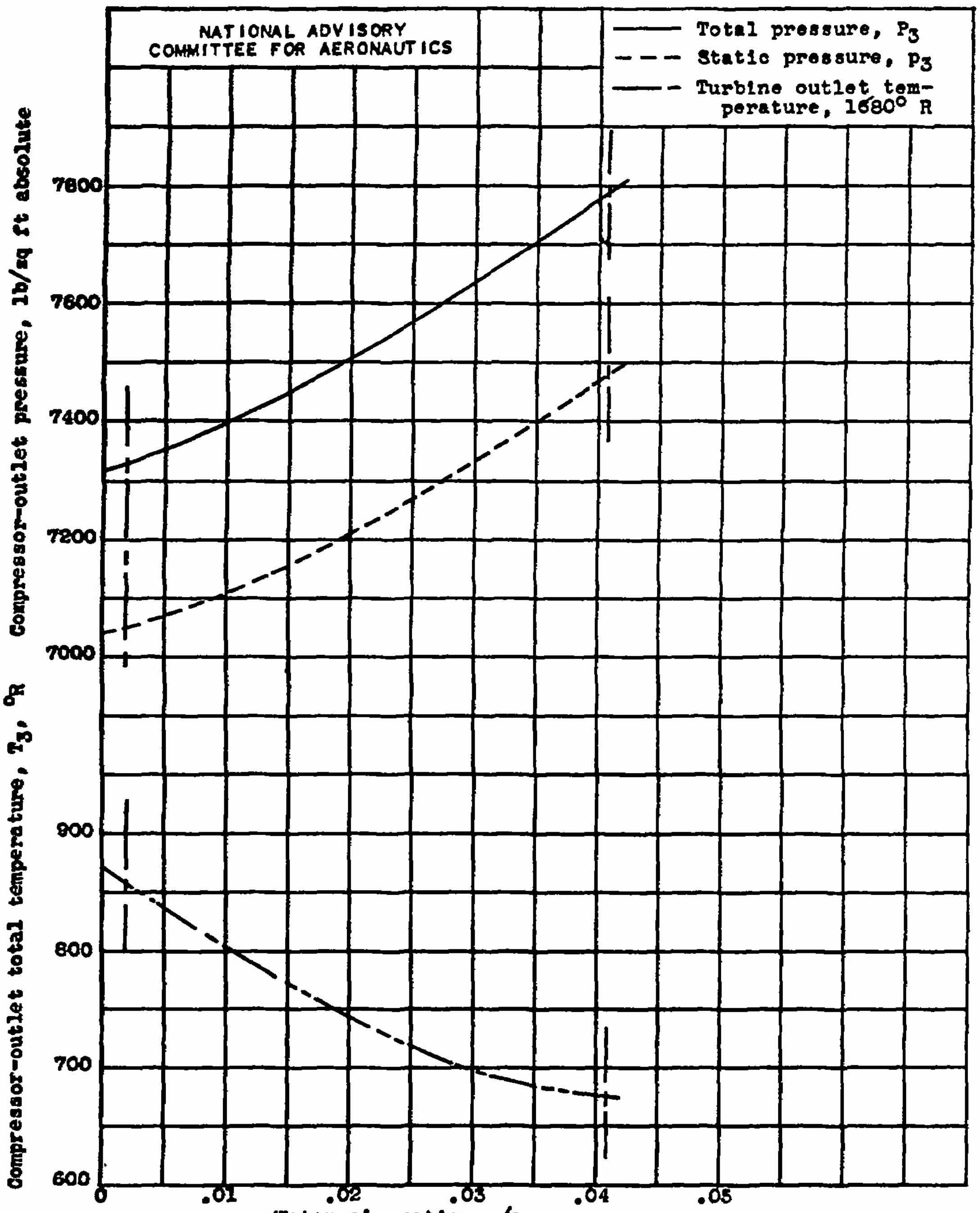
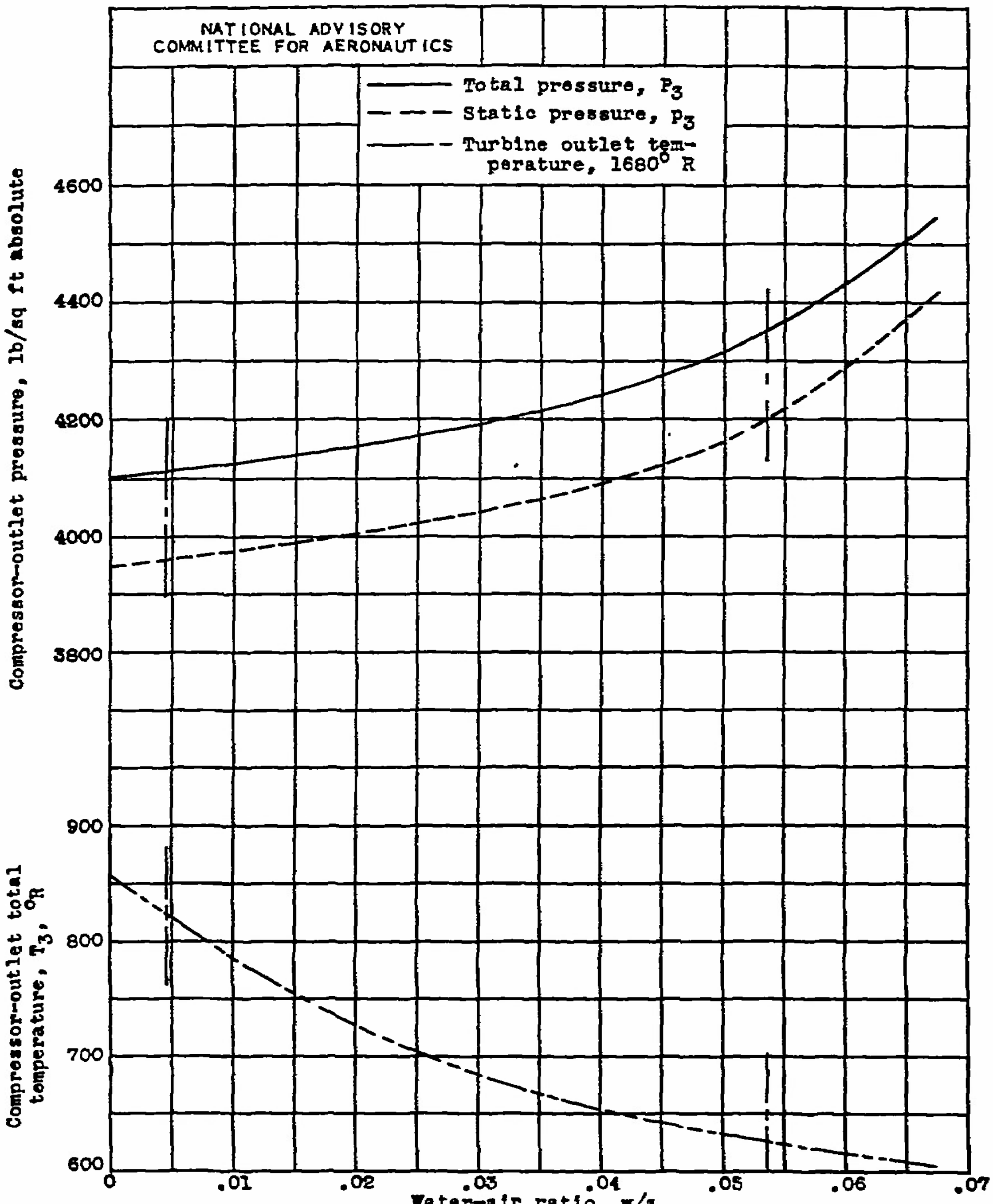


Figure 13.- Relation between corrected gas flow and turbine total-pressure ratio with water injection. Turbine-characteristic efficiency contours obtained from previous investigation.



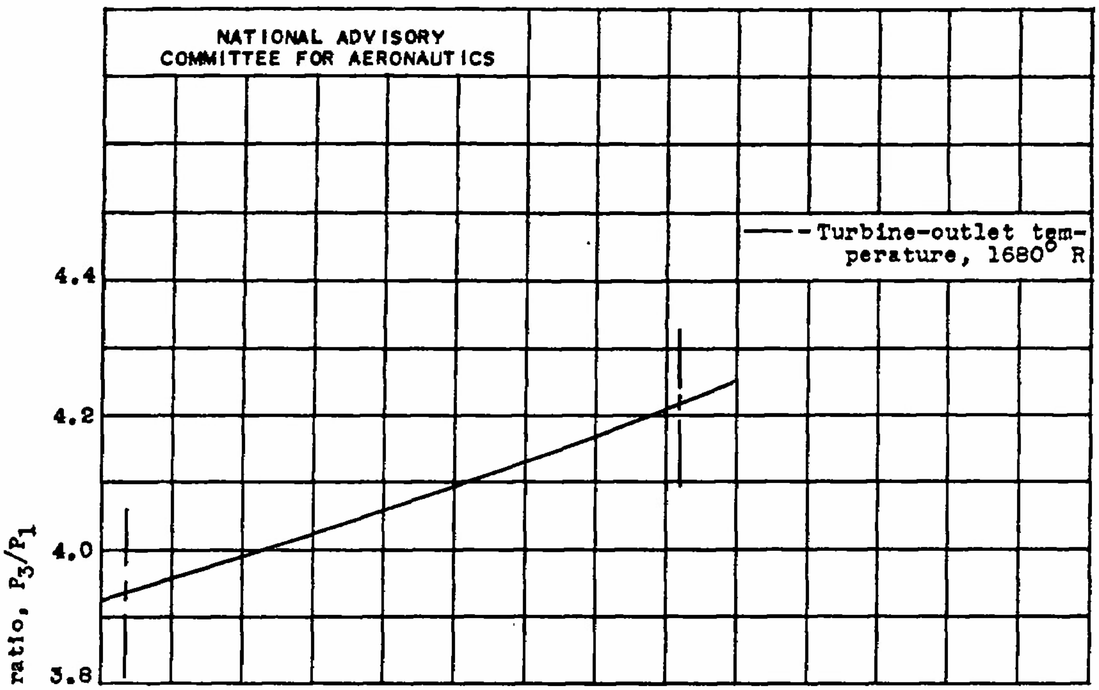
(a) Pressure altitude, 5000 feet.

Figure 14.- Effect of water injection on compressor-outlet total pressure, static pressure, and total temperature. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

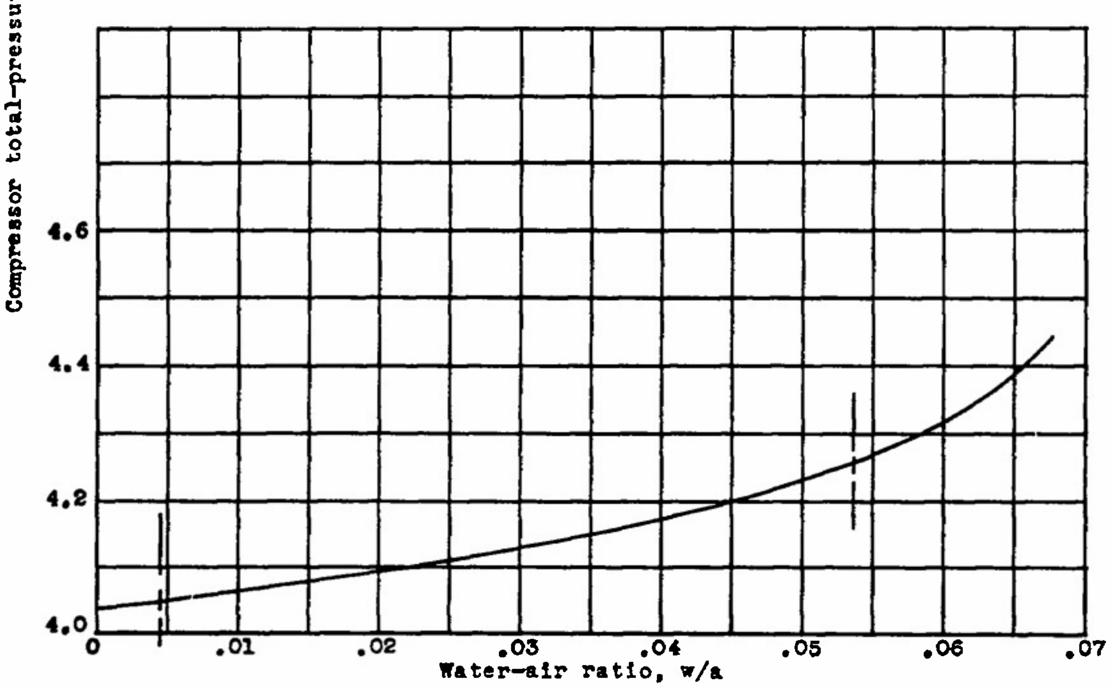


(b) Pressure altitude, 20,000 feet.

Figure 14.- Concluded. Effect of water injection on compressor-outlet total pressure, static pressure, and total temperature. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

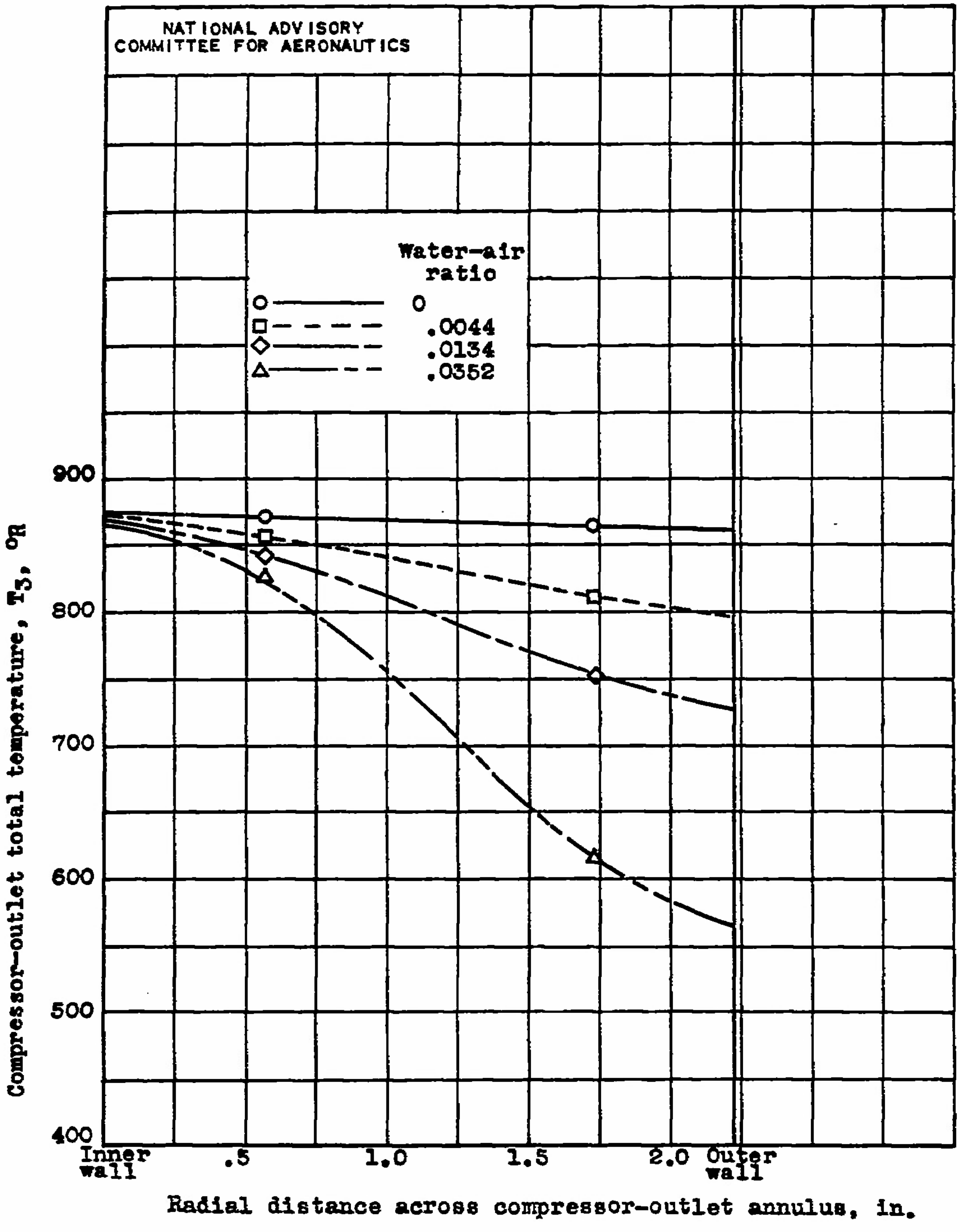


(a) Pressure altitude, 5000 feet.



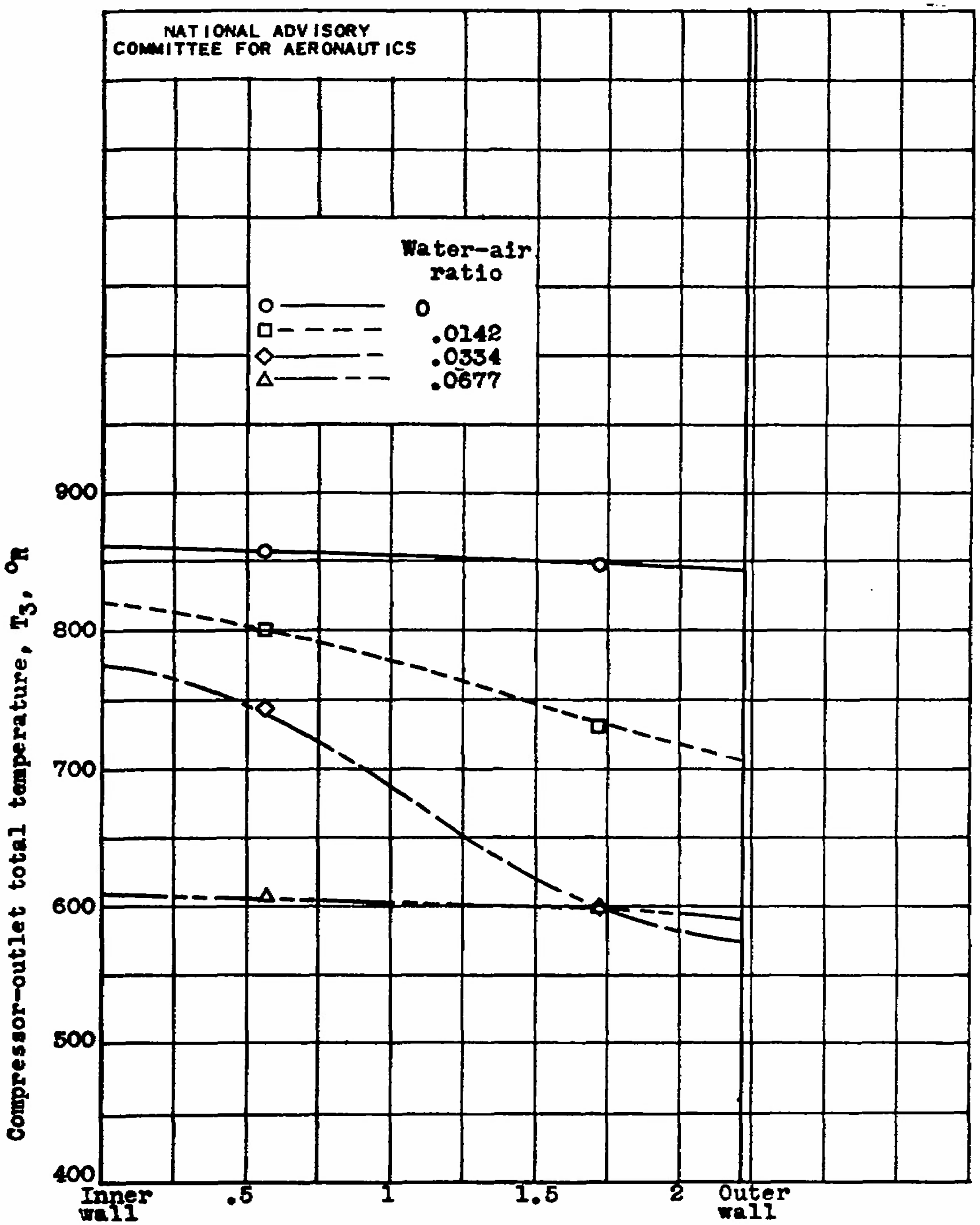
(b) Pressure altitude, 20,000 feet.

Figure 15.- Effect of water injection on compressor total-pressure ratio. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(a) Pressure altitude, 5000 feet.

Figure 16.- Effect of water injection on compressor-outlet total-temperature distribution. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(b) Pressure altitude, 20,000 feet.

Figure 16.- Concluded. Effect of water injection on compressor-outlet total-temperature distribution. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

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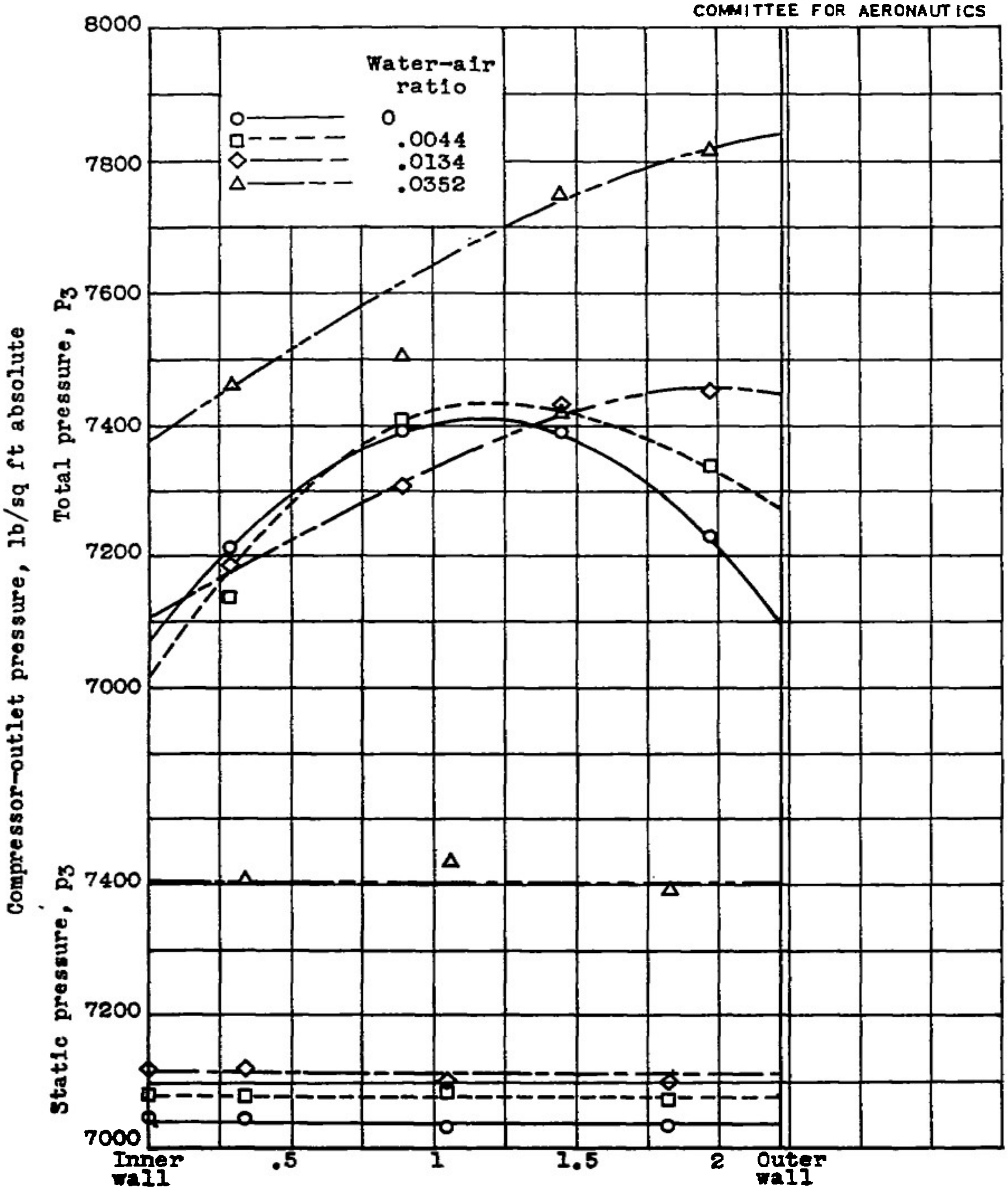

Radial distance across compressor-outlet annulus, in.

(a) Pressure altitude, 5000 feet.

Figure 17.- Effect of water injection on compressor-outlet total- and static-pressure distributions. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

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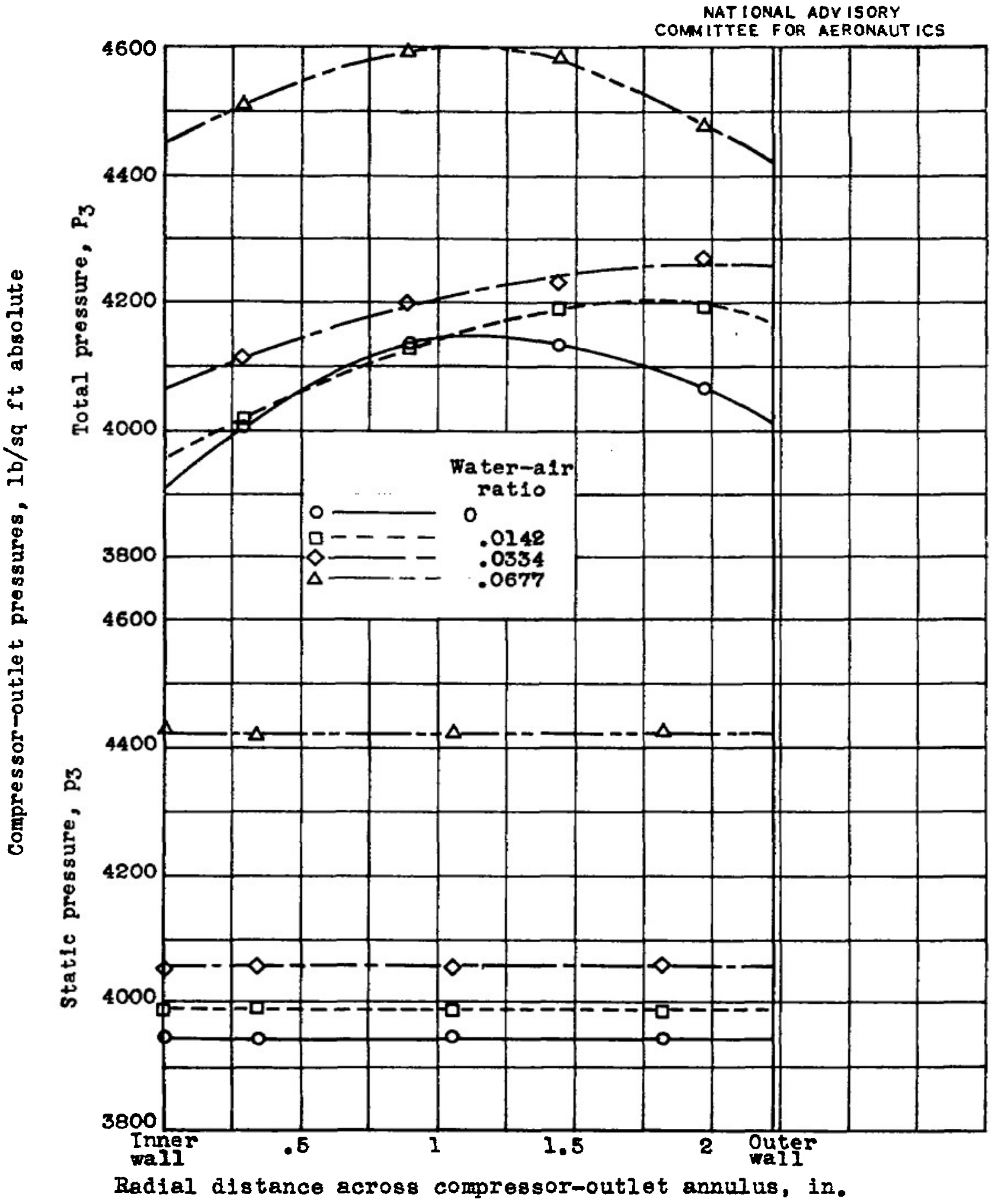

(b) Pressure altitude, 20,000 feet.

Figure 17.- Concluded. Effect of water injection on compressor-outlet total- and static-pressure distributions. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

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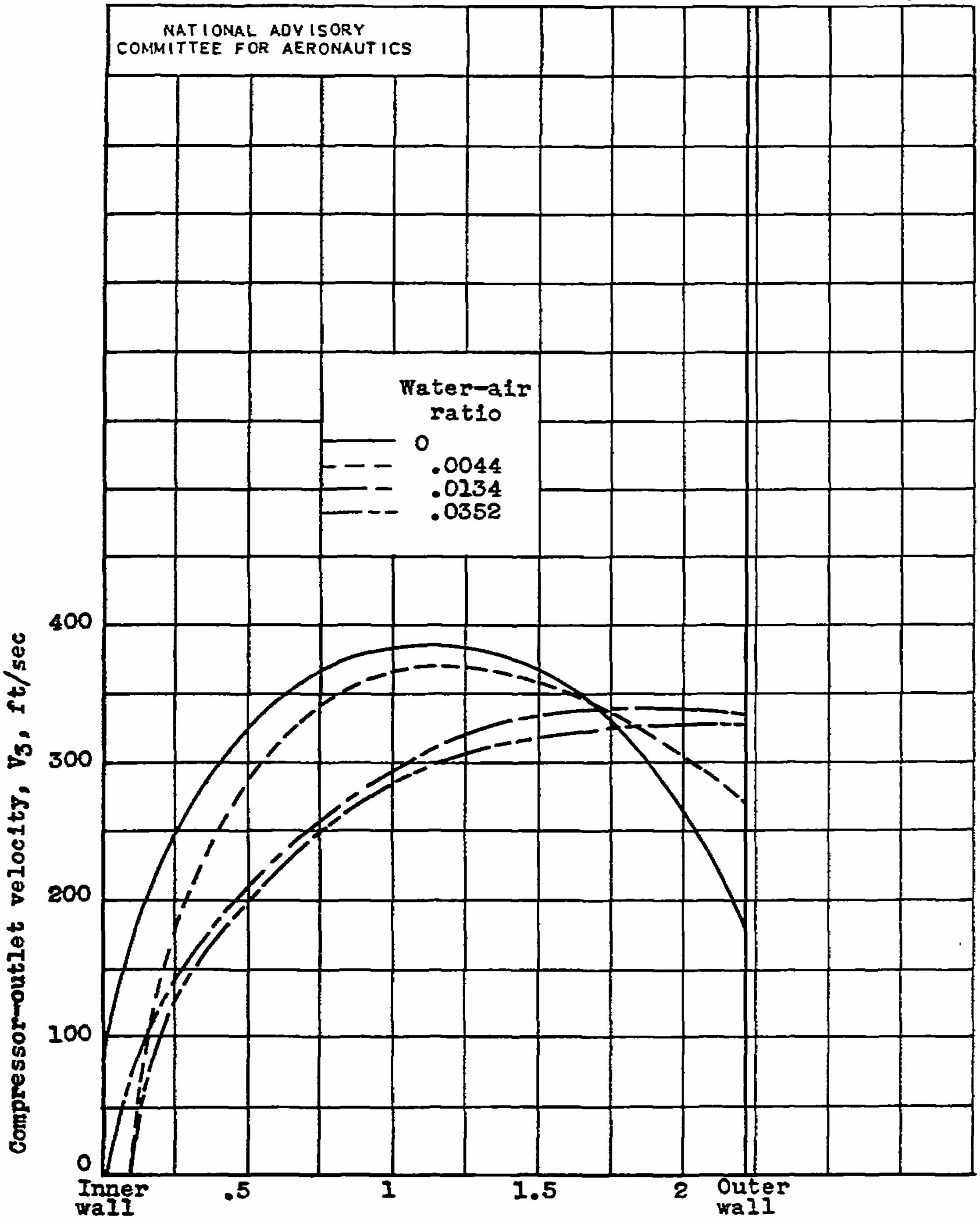
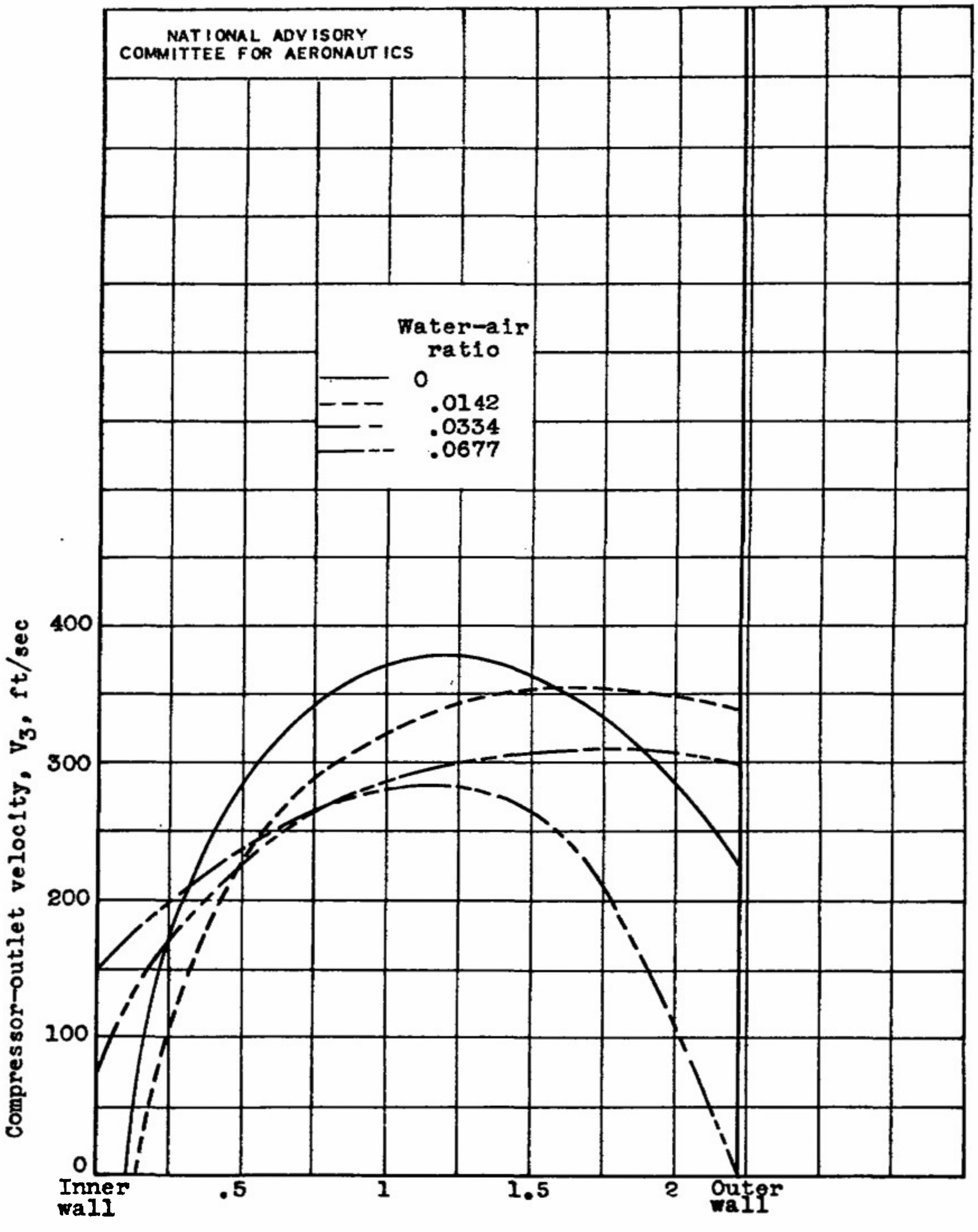


Radial distance across compressor-outlet annulus, in.

(a) Pressure altitude, 5000 feet.

Figure 18.- Effect of water injection on compressor-outlet velocity distribution. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.



(b) Pressure altitude, 20,000 feet.

Figure 18. - Concluded. Effect of water injection on compressor-outlet velocity distribution. Engine speed, 7600 rpm; equivalent flight Mach number, 0.265; inlet-air temperature, approximately 520° R.

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ABSTRACT

Wind-tunnel tests were conducted on thrust augmentation by injecting water at the inlet of tha axial-flow comprassor of a turbojat angine with a fixed-area tail-pipe nozzle 16 3/8 in. in diameter at an inlet-air tamperatura of 520°R. With a tail-pipe tamperatura of 1680°R and at a simulatad flight Mach number of 0.265, the net thrust was incrsased 15% at a prassure altitude of 5000 ft and a water-air ratio of 0.0407 and 12% at a prassura altituda of 20,000 ft and a watar-air ratio of 0.0535. Specific fuel consumption waa 22 and 28% greatar, rsspectivaly, with water injection.

NOTE: Requests for copies of this report must be addressed to N.A.C.A., Washington, D. C.

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