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RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF OPERATIONAL CHARACTERISTICS OF J47 TURBOJET ENGINE

By Harry E. Bloomer

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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ALTITUDE-WIND-TUNNEL INVESTIGATION OF OPERATIONAL CHARACTERISTICS OF J47 TURBOJET ENGINE

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SUMMARY

An investigation has been conducted in the NACA Lewis altitude wind tunnel to determine the operational characteristics of a J47 turbojet engine over a wide range of simulated flight conditions at altitudes from 5000 to 50,000 feet. Operational characteristics investigated include operating range, starting, altitude and airspeed compensation of the fuel regulator, and acceleration.

At a flight Mach number of 0.21 and at approximately NACA standard temperatures corresponding to the simulated flight conditions, the engine could be operated at all engine speeds from idling (2000 rpm) to rated (7900 rpm) at all altitudes up to 15,000 feet. Above 15,000 feet, the maximum engine speed was limited by the maximum allowable turbine-outlet temperature. The minimum speed was limited by combustion blow-out at altitudes above 40,000 feet. At an altitude of 50,000 feet, the engine could be operated only between engine speeds of 4750 and 7400 rpm. At higher flight Mach numbers, limiting turbine-outlet temperature would cause less reduction in maximum engine speed. Engine windmilling starting characteristics with AN-F-32 fuel were poor with either of the two types of spark plug used. With AN-F-48 fuel and long electrode spark plugs, however, the engine could be started at altitudes up to 35,000 feet at the maximum windmilling speeds obtainable. The minimum speed from which throttle burst accelerations could be made to rated speed increased from 5000 rpm at an altitude of 5000 feet to 6700 rpm at 30,000 feet. A throttle burst acceleration from an engine speed of 7400 rpm to rated speed at an altitude of 35,000 feet resulted in combustion blow-out. The time required to accelerate from an engine speed of 6000 rpm to rated speed increased from 5.5 seconds at an altitude of 5000 feet to 8 seconds at 25,000 feet.

INTRODUCTION

The performance and operational characteristics of a J47 turbojet engine have been investigated over a range of simulated-flight conditions at altitudes from 5000 to 50,000 feet in the

NACA Lewis altitude wind tunnel. The engine-performance characteristics are presented in reference 1.

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Operational characteristics presented and discussed herein include engine operating range, starting, altitude and airspeed compensation of the fuel regulator, and acceleration. The effect of changes in the ignition system on starting characteristics are shown for two types of fuel. Engine-windmilling data relevant to the starting characteristics are also presented.

DESCRIPTION OF ENGINE

The J47 turbojet engine used in the altitude-wind-tunnel investigation has a sea-level thrust rating of 5000 pounds at an engine speed of 7900 rpm and a turbine-outlet temperature of 1275° F. The test limit for turbine-outlet temperature during accelerations was 1600° F. The engine (fig. 1) has a 12-stage axial-flow compressor, eight cylindrical direct-flow-type combustion chambers, and a single-stage impulse turbine. A fixed-area exhaust nozzle with an outlet area of 280 square inches was used during most of the investigation. A variable-area exhaust nozzle with a maximum outlet area of 452 square inches and a minimum outlet area of 288 square inches was used in part of the engine-acceleration investigation. A more detailed description of the engine is given in reference 1.

Fuel System

The main components of the engine fuel system (fig. 2) include a fuel regulator, a multipiston variable-displacement fuel pump, a flow divider, fuel manifolds, and duplex fuel nozzles. Fuel is supplied to the main fuel pump by means of a booster pump. The control system regulates the engine by modulating the fuel flow in response to changes in throttle setting, engine speed, and compressor-outlet pressure. These three variables are used by the regulator to produce the variable oil pressure from the constant-control oil pressure, which is generated by a small gear-type pump in the regulator. The variable-control oil pressure in turn governs the displacement of the main fuel pump and thereby determines the engine fuel flow. A wide-range speed governor within the regulator, which operates effectively at engine speeds above 3000 rpm, maintains constant engine speed for a given throttle position at all stabilized flight conditions and also provides overspeed protection.

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At engine speeds below 3000 rpm (starting speed range), the fuel flow is controlled by manual operation of the stopcock.

The engine throttle schedule is presented in figure 3. The curve obtained at an altitude of 5000 feet in the tunnel investigation is approximately the same as the manufacturer's estimated throttle schedule, except for the limits of stopcock operation. The range of stopcock operation was 0° to 23° throttle-traverse angle in the tunnel investigation, whereas the manufacturer's estimate was 0° to 19°. At an altitude of 45,000 feet, an engine speed of 7000 rpm was found to be slightly below the range of regulator operation at a throttle-traverse angle of 23°.

The fuel discharged from the main pump passes through an oil cooler into the flow divider, which controls the relation between the fuel flow to the large- and small-slot manifold of the duplex nozzle system in accordance with a predetermined pressure-flow schedule. Each combustion chamber contains a duplex fuel nozzle that has a small-slot and a large-slot element. At the low fuel flows that accompany the starting process and operation at high altitudes, all the fuel flows through the small slots, which are designed to provide a good spray pattern at the low fuel pressures. As the fuel-flow requirements of the engine increase, fuel proportioned by the flow divider is injected through the large-slot element of the nozzle. Upon engine shutdown, the fuel is drained from the fuel-nozzle manifolds through a solenoid-operated valve. The engine is also equipped with an emergency fuel system.

Ignition System

The engine ignition system consists of two 20,000-volt vibrator coils and two spark plugs. The vibrator coils are mounted on the upper half of the compressor casing and the spark plugs are installed in diametrically-opposite combustion chambers (2 and 7). The spark-plug electrodes are located within the design spray cone of the fuel nozzles. Ignition in other combustion chambers is accomplished through interconnecting crossfire tubes. During the investigation of starting characteristics, the standard spark plugs were replaced by spark plugs with longer electrodes but the same gap setting (fig. 4).

Lubrication System

In this investigation oil was supplied to the engine from a 200-gallon tank located outside the wind tunnel. Part of the inlet oil supply is pumped through the fuel regulator by an oil-pump element of the main fuel pump. The remainder of the oil passes through the main oil pump and is used to lubricate the bear- 1197 ings, the gears, and the accessory case. The main sump oil is scavenged by a separate pump and the accessory case oil is scavenged by an element of the main lubricating oil pump. On the return flow to the supply tank, oil scavenged from the main pump passes through or around the oil cooler, depending on the position of the thermostatic overpressure by-pass valve located at the oil-cooler inlet. Oil conforming to specification AAF 3606 was used during the entire altitude-wind-tunnel investigation.

INSTALLATION AND PROCEDURE

The engine was installed on a wing spanning the test section of the altitude wind tunnel (fig. 5). During most of the investigation, dry refrigerated air was supplied to the engine from the tunnel make-up air system through a duct connected to the engine inlet by means of a frictionless slip joint. The air flow through the duct was throttled from approximately sea-level pressure to a total pressure at the engine inlet corresponding to the desired flight speed at a given altitude. When engine-acceleration characteristics were investigated, a 5-foot section of the inlet-air duct forward of the engine inlet was removed and air was supplied to the engine directly from the wind-tunnel test section.

The engine-inlet temperature was approximately 40° F for the investigation of engine windmilling, altitude and airspeed compensation, and starting characteristics. For the acceleration data presented herein, the engine-inlet temperature varied from -13° to 41° F. Only the data for the engine operating range and one altitude compensation run were taken at approximately NACA standard temperature corresponding to the simulated-flight conditions, except that no temperatures lower than -23° F were obtained.

Engine operational characteristics were investigated over a range of altitudes from 5000 to 50,000 feet and ram pressures corresponding to flight Mach numbers from 0.10 to 1.10. Instrumentation for measuring pressures and temperatures was installed at several stations in the engine (fig. 1). Pressures were measured by alkazene and mercury manometers and were photographically recorded. Temperatures were measured and recorded by two self-balancing potentiometers. Fuel and oil pressures were measured by aircraft selsyn pressure gages. Engine speed was measured by means of an aircraft tachometer and a stroboscopic tachometer. The engine control panel was photographed with an aerial reconnaissance camera at intervals from 1 to 3 seconds to provide time histories of engine data during accelerations and starts.

RESULTS AND DISCUSSION

<u>Operating range</u>. - The variation of the operable range of engine speeds with altitude at a flight Mach number of 0.21 is shown in figure 6. The engine could be operated at all speeds from idling (2000 rpm) to rated speed (7900 rpm) at altitudes up to 15,000 feet. An increase in altitude above 15,000 feet resulted in an increase in the exhaust-gas temperature and thereby forced a reduction in the maximum engine speed dictated by the maximum allowable exhaust-gas temperature (1275° F). At an altitude of 50,000 feet the maximum temperature-limited engine speed was approximately 7400 rpm. Stable steady-state operation at an engine speed of 2000 rpm was obtained at altitudes up to 40,000 feet. An increase in altitude above 40,000 feet resulted in an increase in the minimum operable engine speed, which was limited by combustion blow-out. As a result of these limitations, the operable range of engine speeds at 50,000 feet was from 4750 to 7400 rpm at a flight Mach number of 0.21. The maximum engine speed at altitudes above 15,000 feet would be increased by an increase in flight Mach number above 0.21 because of the reduction in exhaust-gas temperature, as shown in reference 1.

<u>Starting characteristics</u>. - Altitude starting characteristics of the engine were investigated using the standard short electrode spark plugs with a gap of 0.165 inch and special spark plugs with longer electrodes than the standard spark plug but the same gap setting (fig. 4). Fuels conforming to specifications AN-F-32 and AN-F-48 were used in conjunction with both types of spark plug. Desired windmilling speeds were obtained by varying the ram pressure ratio at the engine inlet. The relation between the windmilling speed and the equivalent airspeed (defined in appendix) is presented in figure 7. After ignition was obtained in the combustion chambers, acceleration was usually helped by the starter and by increasing the ram pressure ratio to the engine inlet.

Windmilling starting data obtained over a range of altitudes and engine windmilling speeds with AN-F-32 and AN-F-48 fuels are shown in figure 8. With AN-F-32 fuel (fig. 8(a)) the engine could be started at all windmilling speeds up to the maximum obtainable at an altitude of 5000 feet. At 15,000 feet the maximum windmilling starting speed was approximately 2000 rpm for both types of spark plug. An increase in altitude above 15,000 feet resulted in a decrease in maximum windmilling starting speed; so that at an altitude of 25,000 feet, starting was marginal at a windmilling speed of approximately 1000 rpm with the standard plugs and at 1500 rpm with the longer electrode plugs. At an altitude of 35,000 feet, ignition was obtained in three combustion chambers, but the engine could not be accelerated from the starting speed even with an increase in airspeed simulating a dive. In general, the starting characteristics of the engine using AN-F-32 fuel were poor with either type of spark plug.

The starting characteristics of the engine using AN-F-48 fuel and standard spark plugs (fig. 8(b)) were approximately the same as those obtained with AN-F-32 fuel. Starting characteristics with AN-F-48 fuel and the longer electrode plugs, however, were considerably better than with AN-F-32 fuel. Successful starts were obtained at the maximum obtainable windmilling speeds at altitudes up to 35,000 feet. One successful start was made at an altitude of 45,000 feet and an engine speed of 4650 rpm, but all other attempts to start the engine at this altitude failed. The altitude was then decreased to 25,000 feet and the engine was successfully started at a windmilling speed of 4850 rpm.

Starting characteristics of a turbojet engine are affected by the temperature, the pressure, and the velocity of the air entering the combustion chambers. The most favorable conditions for igniting and burning a combustible mixture in the combustion chambers exists when the inlet air velocity is low and the pressure and the temperature are high. The combustion-chamber-inlet temperature was essentially constant throughout the investigation because the engine-inlet temperature was held at 500° F. Engine windmilling data presented in figure 9 show the decrease in compressor-outlet total pressure as the altitude was increased. Windmilling data are also presented (fig. 10) to show the increase of compressor-outlet velocity with engine speed independent of altitude. This decrease in pressure with increasing altitude and increase in velocity with increasing windmilling speed tends to limit the starting range of the engine to low altitudes and low windmilling speeds.

Altitude and airspeed compensation. - At a constant engine speed, the air flow through a turbojet engine varies with changes in altitude and airspeed. Some mechanism must therefore be provided to vary the fuel flow for a given throttle setting to maintain constant engine speed. The engine fuel regulator is designed to sense changes in compressor-outlet pressure and to make the required adjustment in fuel flow. Thus, if the compressor-outlet pressure should decrease due to an increase in altitude or a decrease in flight speed, the fuel regulator would reduce the fuel flow at a constant throttle setting.

The altitude compensation characteristics of the fuel regulator were investigated by simulating climbs and dives between altitudes of 5000 and 45,000 feet at a constant compressor-inlet indicated airspeed of 100 miles per hour, a constant compressor-inlet temperature of 500° R, and a constant throttle setting. The effectiveness of the regulator altitude compensation is shown in figure 11 by the effect of changes in altitude on engine speed, variable-control oil pressure, regulator sensing pressure, small-slot fuel pressure, and turbine-outlet gas temperature.

A simulated climb was started at 5000 feet at an engine speed of 7000 rpm with the throttle locked in position at 67° and was terminated at an altitude of 45,000 feet. During the climb, the engine speed increased gradually to a final value of 7200 rpm. The variable-control oil pressure and the small-slot fuel pressure decreased in the same manner as the regulator sensing pressure. The turbine-outlet temperature gradually increased from 1270° R at an altitude of 5000 feet to a final value of 1470° R at an altitude of 45,000 feet. When the altitude was decreased from 45,000 to 5000 feet, the engine speed returned to 7000 rpm. The other engine variables returned to the original values along the curves established in the simulated climb. The engine speed was then set at 7000 rpm, with the throttle locked in position at 23° at an altitude of 45,000 feet, and a simulated dive was made to an altitude of 5000 feet. The engine speed decreased as the altitude was decreased and reached a final value of 3600 rpm at an altitude of 5000 feet. The variable-control oil pressure and the small-slot fuel pressure remained constant, which indicated that the stopcock and not the regulator was controlling the fuel flow (fig. 3). When the altitude was increased to 45,000 feet, the engine speed increased to the original value of 7000 rpm.

One simulated dive was made from an altitude of 45,000 feet at a compressor-inlet temperature of 437° R, an indicated airspeed of 200 miles per hour, and an engine-speed setting of 7900 rpm with the throttle locked in position at 90°. As the altitude was decreased, the inlet air temperature increased and reached 518° R at an altitude of 5000 feet. The variation of several engine variables with altitude for this simulated dive is presented in figure 12. The engine fuel flow was controlled by the fuel regulator and the engine speed dropped approximately 100 rpm.

The airspeed compensation characteristics of the engine fuel regulator were investigated at constant throttle setting for a range of indicated airspeeds from 50 to approximately 550 miles per hour at an altitude of 25,000 feet. The effect of changes in airspeed on the engine variables are shown in figure 13 for engine-speed settings of 7895, 7500, and 6993 rpm. As the indicated airspeed was increased from 50 to 535 miles per hour, the engine speed remained almost constant for the 7895 and 7500 rpm settings. For the 6993 rpm setting, the engine speed dropped approximately 150 rpm over the same range of airspeeds. The small-slot fuel pressure and the variable-control oil pressure increased in the same manner as the regulator sensing pressure at each engine speed. As the airspeed was raised, the turbine-outlet temperature decreased at each engine-speed setting owing to the reduction in fuel-air ratio (reference 1). When the indicated airspeed was again reduced to the original value of 50 miles per hour, the engine variables returned to the original values with no significant hysteresis.

Engine acceleration. - All acceleration data presented herein were obtained by advancing the throttle as rapidly as possible between a specified initial and final position, which is referred to as "throttle burst" acceleration. The minimum engine speed from which a successful throttle burst acceleration to full speed was possible without encountering combustion blow-out or excessive exhaust-gas temperatures is shown in figure 14 as a function of altitude. The minimum speed increased linearly from a value of 5000 rpm at an altitude of 5000 feet to 6000 rpm at 25,000 feet. A further increase in altitude to 30,000 feet raised the minimum speed to 6700 rpm. A throttle burst acceleration from an engine speed of 7400 rpm at an altitude of 35,000 feet resulted in combustion blow-out. With a variable-area exhaust nozzle installed on the engine, a successful throttle burst acceleration was made at an altitude of 5000 feet from an engine speed of 3000 rpm, as compared with a minimum speed of 5000 rpm for the fixed-area exhaust nozzle. During the acceleration, the outlet area of the variable-area nozzle was automatically governed by an experimental control system provided by the engine manufacturer. Time histories of these two accelerations are presented in figure 15. The mean acceleration rate was approximately 500 rpm per second with the variable-area exhaust nozzle and 375 rpm per second with the fixed-area exhaust nozzle.

The variation of several engine variables with time is shown in figure 16 for altitudes of 5000, 15,000, and 25,000 feet. At each altitude the initial engine speed was 6000 rpm and the throttle was advanced to full-speed position in approximately 1 second. The time required to reach rated engine speed (7900 rpm) increased with altitude from 5.5 seconds at 5000 feet to 8 seconds at 25,000 feet. The acceleration time increased as the altitude was raised because the engine air flow was decreased by the reduction in air density while the inertia of the rotating parts of the engine remained constant. The equivalent true airspeed for the three altitudes shown was not constant. The effect of changes in airspeed on acceleration characteristics, however, is shown to be negligible in figure 17 for the range of airspeeds investigated. The engine was accelerated from 6500 rpm to rated speed at an altitude of 25,000 feet and true airspeeds of 88, 138, and 244 miles per hour. The time required to accelerate to rated speed was not appreciably affected by changes in airspeed. A change in airspeed from 88 to 244 miles per hour increased the time to accelerate to rated speed by 1 second. The characteristics of the engine are such that the exhaust-gas temperature decreased with an increase in airspeed.

The variation of engine variables with time for throttle burst accelerations to rated engine speed from different initial engine speeds is shown in figure 18 for an altitude of 25,000 feet and a true airspeed of 240 miles per hour. The time required to accelerate the engine to rated speed from initial engine speeds of 5500, 6000, and 6500 rpm was 11, 9.5, and 8 seconds, respectively. At an acceleration time of 3 seconds, the small-slot fuel pressure was the same for each acceleration. At an engine speed of 7250 rpm, however, for each acceleration the small-slot fuel pressure began to increase, reached a peak value at about 7750 rpm, and then decreased to a steady-state operating value at rated speed. The exhaust-gas temperature followed a similar pattern. This characteristic is associated with the response of the regulator to engine speed and compressor-outlet pressure.

At and above an altitude of 30,000 feet, the range of engine speeds from which throttle burst accelerations could be made was very limited (fig. 14). An effort was made at various initial engine speeds to find the maximum throttle advance angle permitted for a throttle burst acceleration without encountering combustion blow-out. The data obtained in this part of the investigation are presented in figure 19. The maximum allowable throttle advance angle was determined in the following manner: Accelerations were made to 7900 rpm from successively lower engine speeds until combustion blow-out was encountered. A throttle burst acceleration to rated speed was then made from an initial engine speed approximately 200 rpm higher than the blow-out-limited initial engine speed and a time history was taken. Thus, at an altitude of 30,000 feet, a successful throttle burst acceleration to rated engine speed could be made from initial engine speeds above 6700 rpm. With 6800 rpm as the final engine speed, the initial engine speed was again reduced until blow-out occurred during acceleration. A successful throttle burst acceleration could be made from an initial engine speed of 6200 rpm to a final speed of 6800 rpm. An initial speed of 6000 rpm for acceleration to a final speed of 6400 rpm was determined by the same method. The vertical distance between a line connecting the maximum allowable throttle position and a line through the minimum initial engine speed points represents the maximum throttle advance angle for successful throttle burst acceleration for a given initial engine speed; the horizontal distance between the two lines represents the speed range through which the engine could be safely accelerated. For example, at an altitude of 30,000 feet and an initial engine speed of 6600 rpm, a successful throttle burst acceleration could be made to a final engine speed of 7700 rpm. For the conditions investigated, the time required to accelerate from each initial engine speed to the maximum allowable engine speed was approximately 9.5 seconds. 1197

Turbine shroud. - During the investigation of the J47 engine in the altitude wind tunnel, interference between the turbine-blade tips and the shroud encasing the turbine rotor was experienced on several occasions (fig. 20). With the initially recommended blade-tip clearance of 0.040 inch, interference was noticed after relatively short periods of operation. An increase in the clearance to 0.060, as recommended by the manufacturer, permitted interference-free operation for longer periods of time.

Interference between the blade tips and the shroud was not always detectable during operation in that no sudden change in exhaust-gas temperature, engine speed, or vibration readings occurred. In some cases, however, sparks were observed in the exhaust jet. After shutdown the engine would not windmill even at the highest airspeeds obtainable. Clearances were checked and were found to vary greatly around the periphery of the turbine-blade tips. In all cases the shroud ring was scored, but the turbine blades were not appreciably damaged.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the operational characteristics of a J47 turbojet engine in the NACA Lewis altitude wind tunnel:

1. With the standard exhaust-nozzle area of 280 square inches, the engine could be operated at a flight Mach number of 0.21 at all engine speeds from idling (2000 rpm) to rated speed (7900 rpm) at altitudes up to 15,000 feet. At altitudes above 15,000 feet, the maximum engine speed was limited by the maximum allowable exhaust-gas temperature. The minimum engine speed at altitudes above 40,000 feet was limited by combustion blow-out. At an altitude of

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50,000 feet, the engine could be operated only between engine speeds of 4750 and 7400 rpm.

2. Engine-starting characteristics with AN-F-32 fuel and either standard or long electrode spark plugs were poor. Starting was marginal at an altitude of 25,000 feet at windmilling speeds of approximately 1500 rpm. With AN-F-48 fuel and high-altitude spark plugs, however, the engine could be started successfully at altitudes up to 35,000 feet at the maximum windmilling speeds obtainable (4900 rpm).

3. The altitude compensation of the fuel regulator was satisfactory for throttle positions greater than 19°, where the fuel regulator and not the stopcock regulated the fuel flow. The airspeed compensation of the fuel regulator was satisfactory for the range of flight conditions investigated.

4. The minimum speed from which throttle burst accelerations could be made without encountering combustion blow-out or excessive turbine-outlet temperatures increased from 5000 rpm at an altitude of 5000 feet to 6700 rpm at 30,000 feet. A throttle burst acceleration from an engine speed of 7400 rpm at an altitude of 35,000 feet resulted in combustion blow-out. At an altitude of 5000 feet, a throttle burst acceleration from 3000 rpm to rated speed was possible with a variable-area exhaust nozzle.

5. The time required to accelerate the engine from 6000 rpm to 7900 rpm increased from 5.5 seconds at an altitude of 5000 feet to 8 seconds at 25,000 feet. Changes in airspeed had no appreciable effect on acceleration time for the range of conditions investigated.

6. At an altitude of 30,000 feet and engine speeds below 6700 rpm, the maximum permissible throttle advance angle for throttle burst accelerations was a function of the initial engine speed.

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National Advisory Committee for Aeronautics,
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APPENDIX - CALCULATIONS

Symbols

The following symbols are used in this report:

A cross-sectional area, sq ft

g acceleration due to gravity, 32.2 ft/sec^2

N engine speed, rpm

P total pressure, lb/sq ft absolute

p static pressure, lb/sq ft absolute

R gas constant, 53.3 ft-lb/(lb)($^{\circ}$R)

T total temperature, $^{\circ}$R

T_i indicated temperature, $^{\circ}$R

t static temperature, $^{\circ}$R

V velocity, ft/sec

W_a air flow, lb/sec

γ ratio of specific heats

δ ratio of total pressure at engine inlet to absolute pressure of NACA standard atmosphere at sea level

θ ratio of total temperature at engine inlet to absolute temperature of NACA standard atmosphere at sea level

Subscripts:

0 free-air stream

1 engine inlet

3 compressor outlet

e equivalent

Methods of Calculation

In the calculation of the desired parameters, arithmetic average values of temperature and pressure were used.

Temperatures. - Static temperatures were determined from indicated temperatures by the adiabatic relation between temperature and pressure, using an impact recovery factor that has been determined to be 0.85 for the type of thermocouple used.

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

Airspeed. - Equivalent airspeed was calculated from ram-pressure ratio, assuming complete pressure recovery at the engine inlet, by the following equation:

$$V_{0,e} = \sqrt{\frac{2\gamma}{\gamma-1} gRt_{0,e}\left[\left(\frac{P_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

where

$$t_{0,e} = \frac{T_1}{\left(\frac{P_1}{p_0}\right)^{\frac{\gamma-1}{\gamma}}}$$

Compressor-outlet velocity. - Compressor-outlet velocity was determined by the equation

$$V_3 = \sqrt{\frac{2\gamma}{\gamma-1} gRt_3\left[\left(\frac{P_3}{p_3}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]}$$

Air flow. - Air flow through the engine was calculated from pressures and temperatures measured at the engine inlet (station 1) by the equation 1197

$$W_{a,1} = p_1 A_1 \sqrt{\frac{2\gamma g}{(\gamma-1)Rt_1}\left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma-1}{\gamma}} -1\right]}$$

Air-flow values obtained from measurements at the engine-inlet station agreed within approximately 1 percent with those obtained from the measurements at the exhaust nozzle.

REFERENCES

1. Conrad, E. William, and Sobolewski, Adam E.: Altitude-Wind-Tunnel Investigation of J47 Turbojet-Engine Performance. NACA RM E9G09, 1949.

2. Prince, William R., and Jansen, Emmert T.: Altitude-Wind-Tunnel Investigation of Compressor Performance on J47 Turbojet Engine. NACA RM E9G28, 1949.

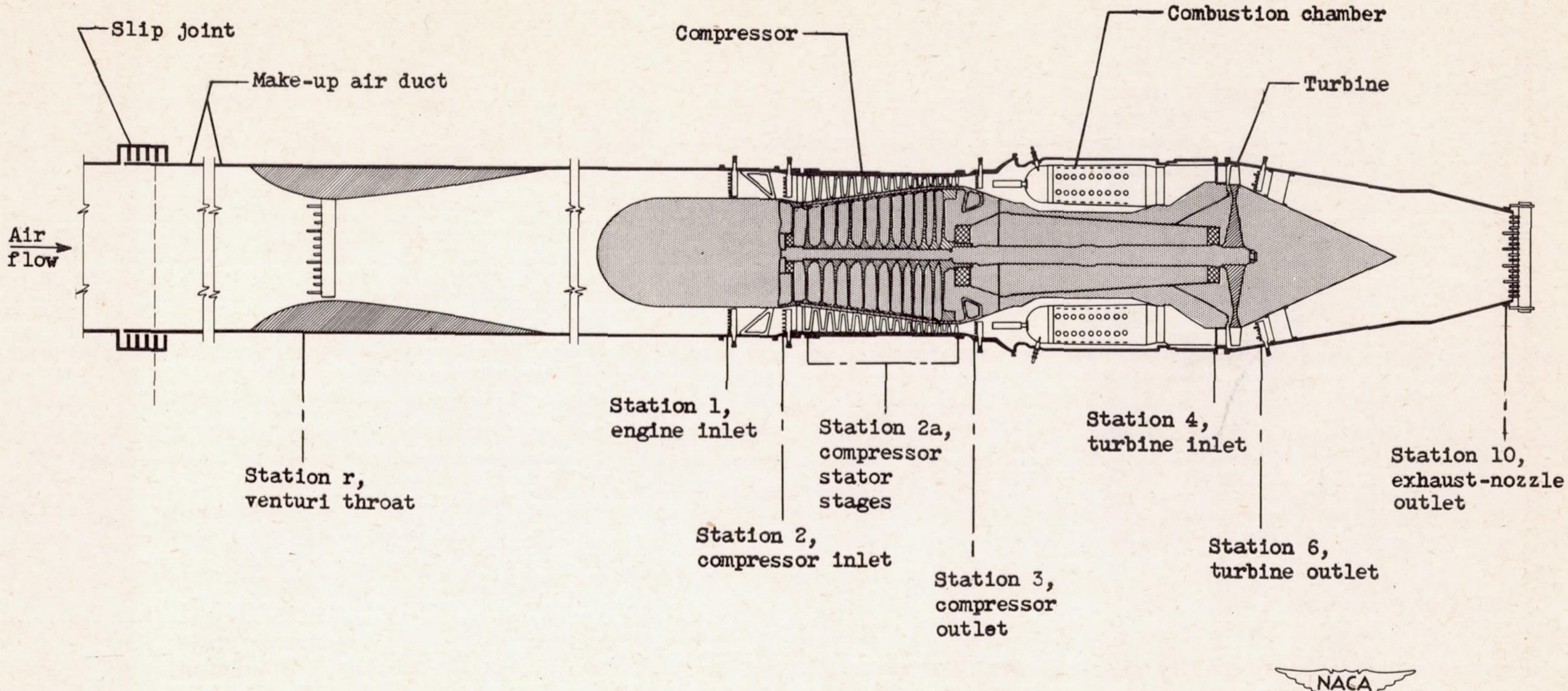

Figure 1. - Cross section of turbojet engine showing sections at which instrumentation was installed.

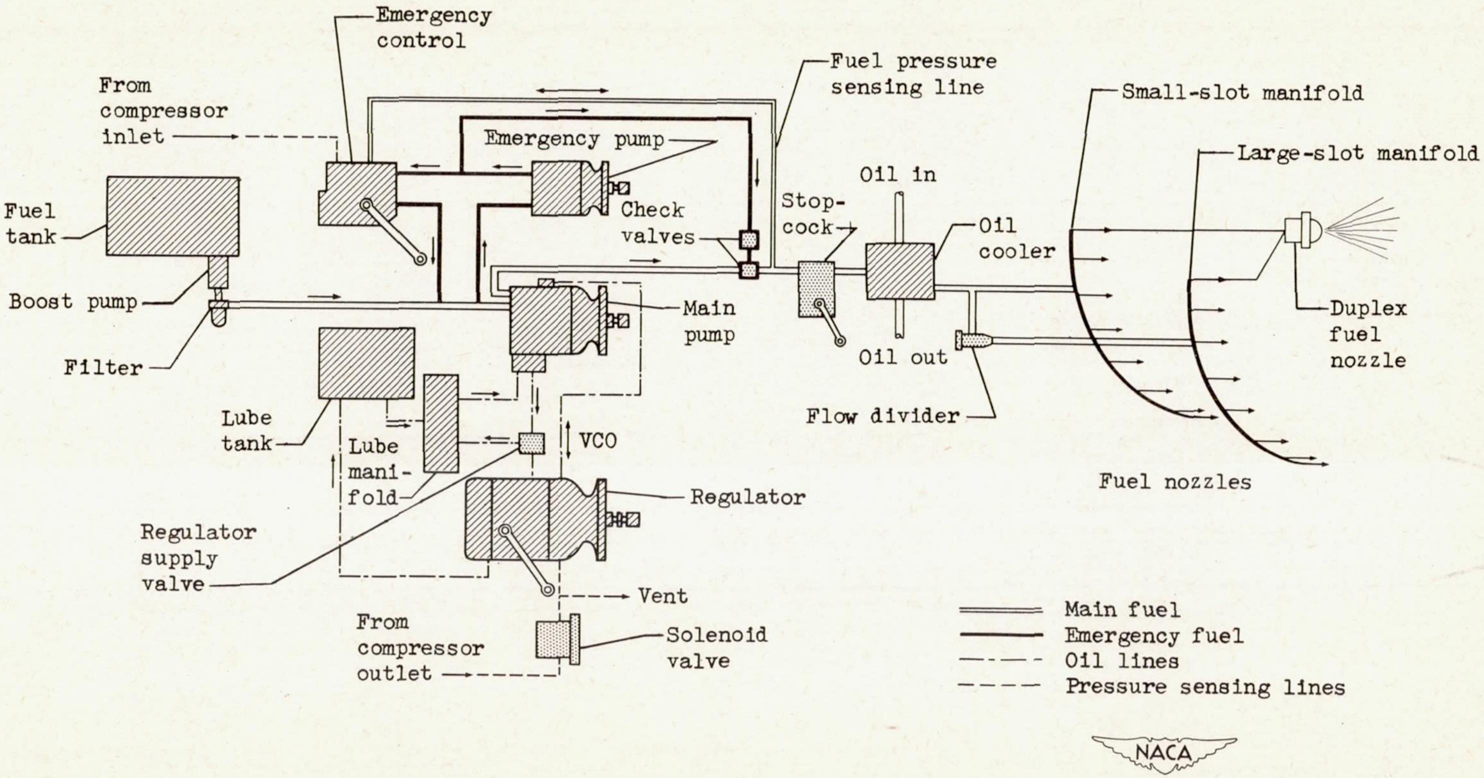

Figure 2. - Schematic diagram of fuel system.

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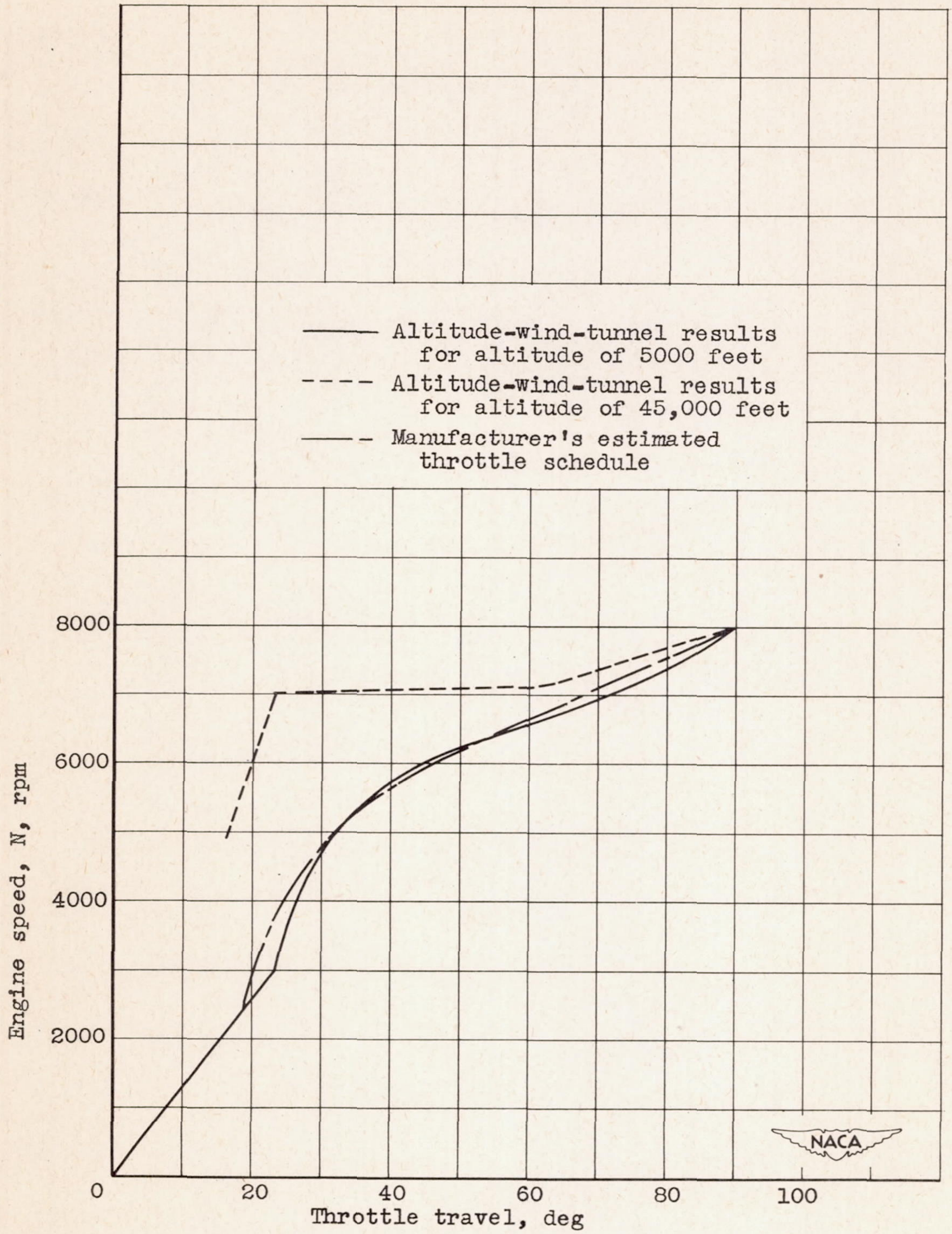

Figure 3. - Throttle schedule of turbojet engine with F-4 regulator installed.

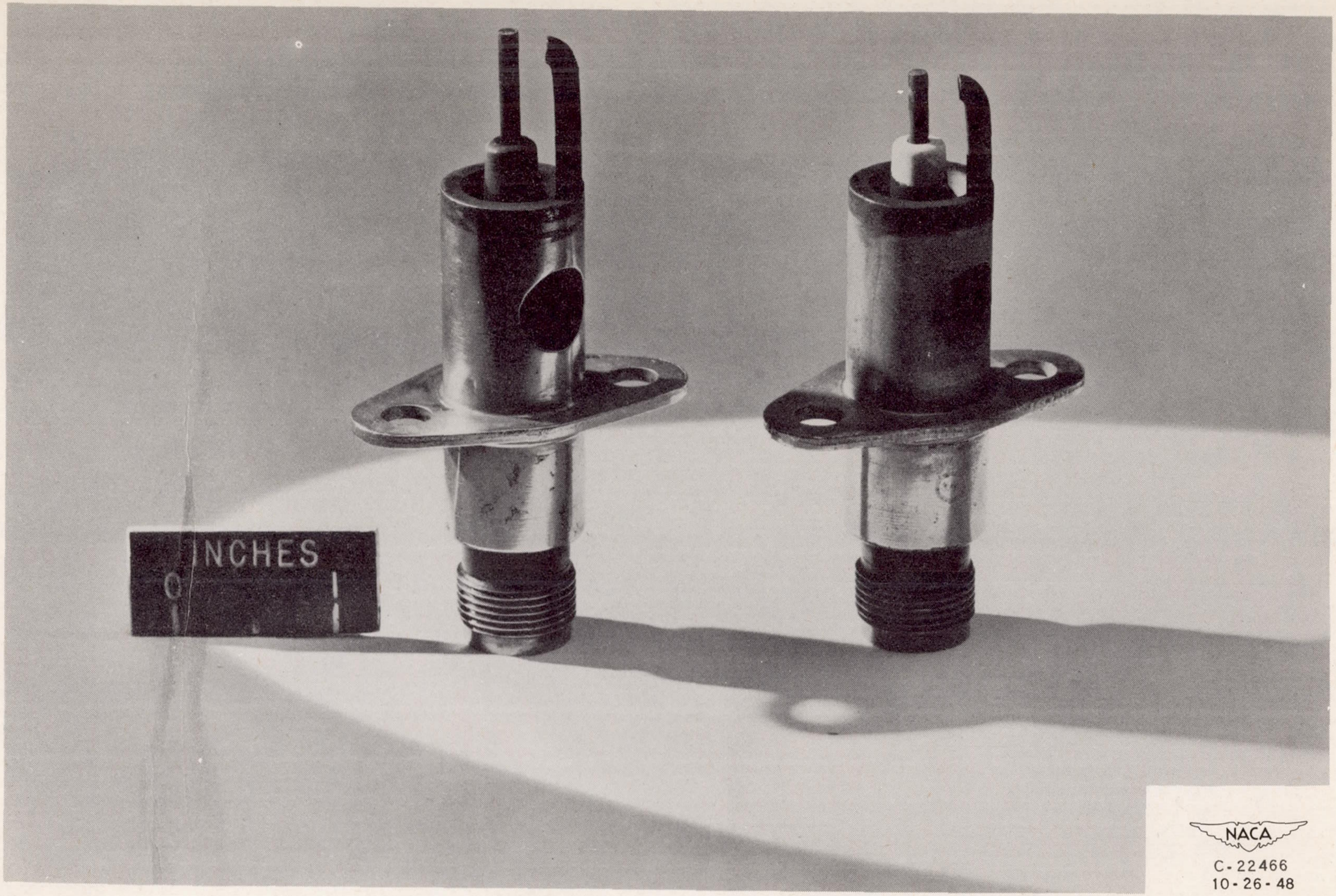

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Figure 4. - Long electrode and standard spark plugs used in starting investigation.

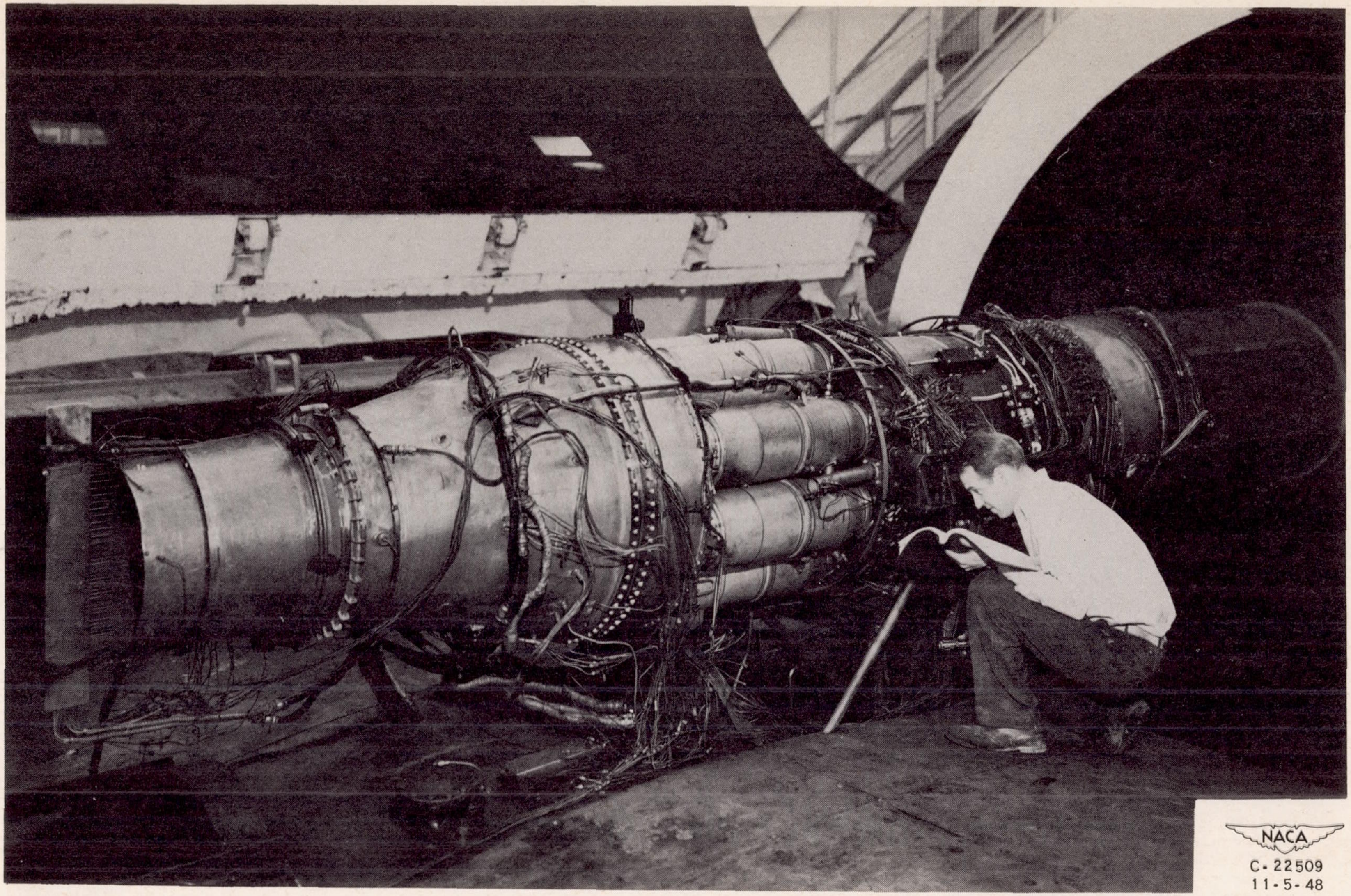

Figure 5. - Installation of turbojet engine in altitude wind tunnel.

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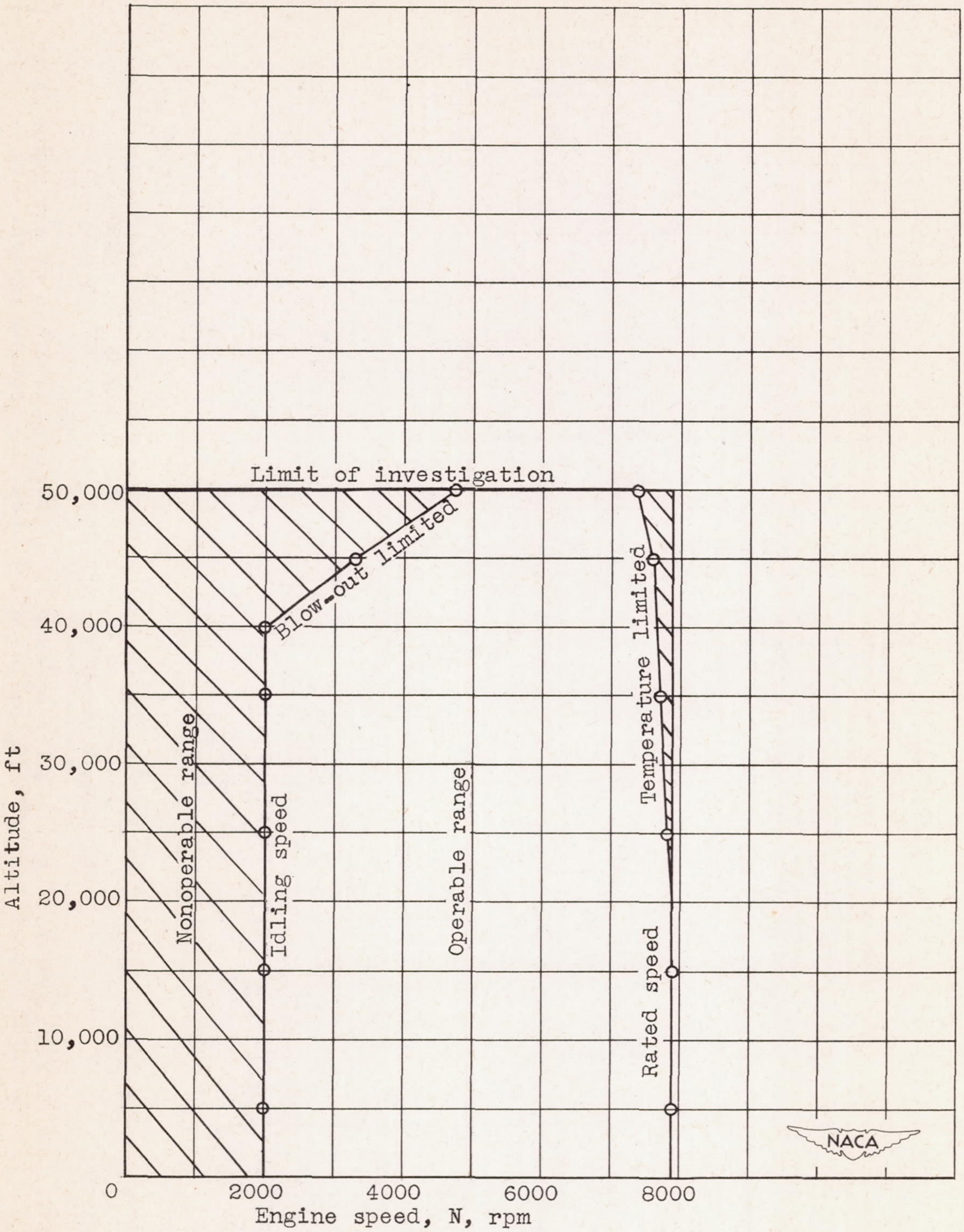

Figure 6. - Effect of altitude on operable range of engine speeds. Flight Mach number, 0.21; exhaust-nozzle outlet area, 280 square inches.

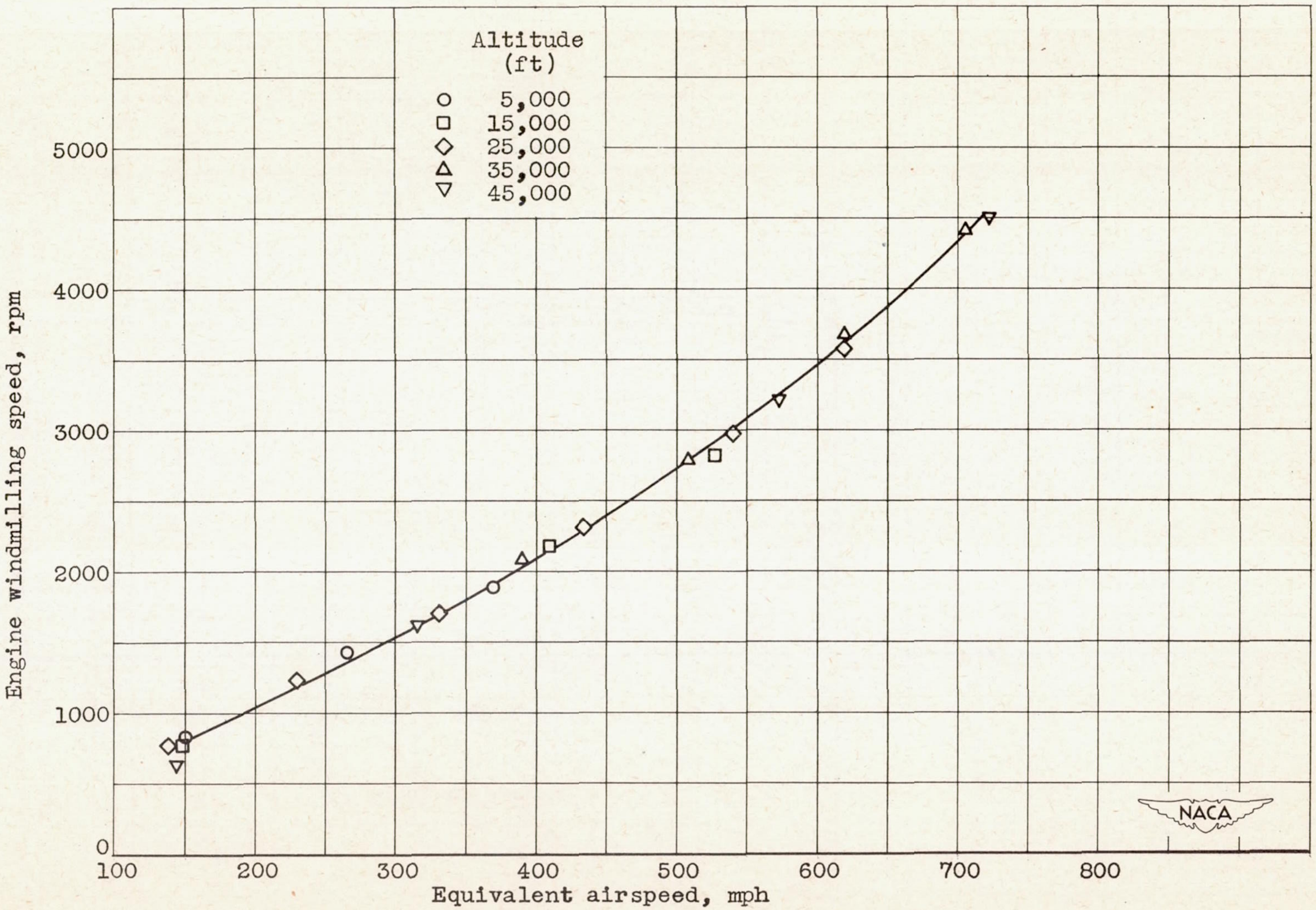

Figure 7. - Variation of engine windmilling speed with equivalent airspeed at altitudes from 5000 to 45,000 feet. Exhaust-nozzle-outlet area, 280 square inches.

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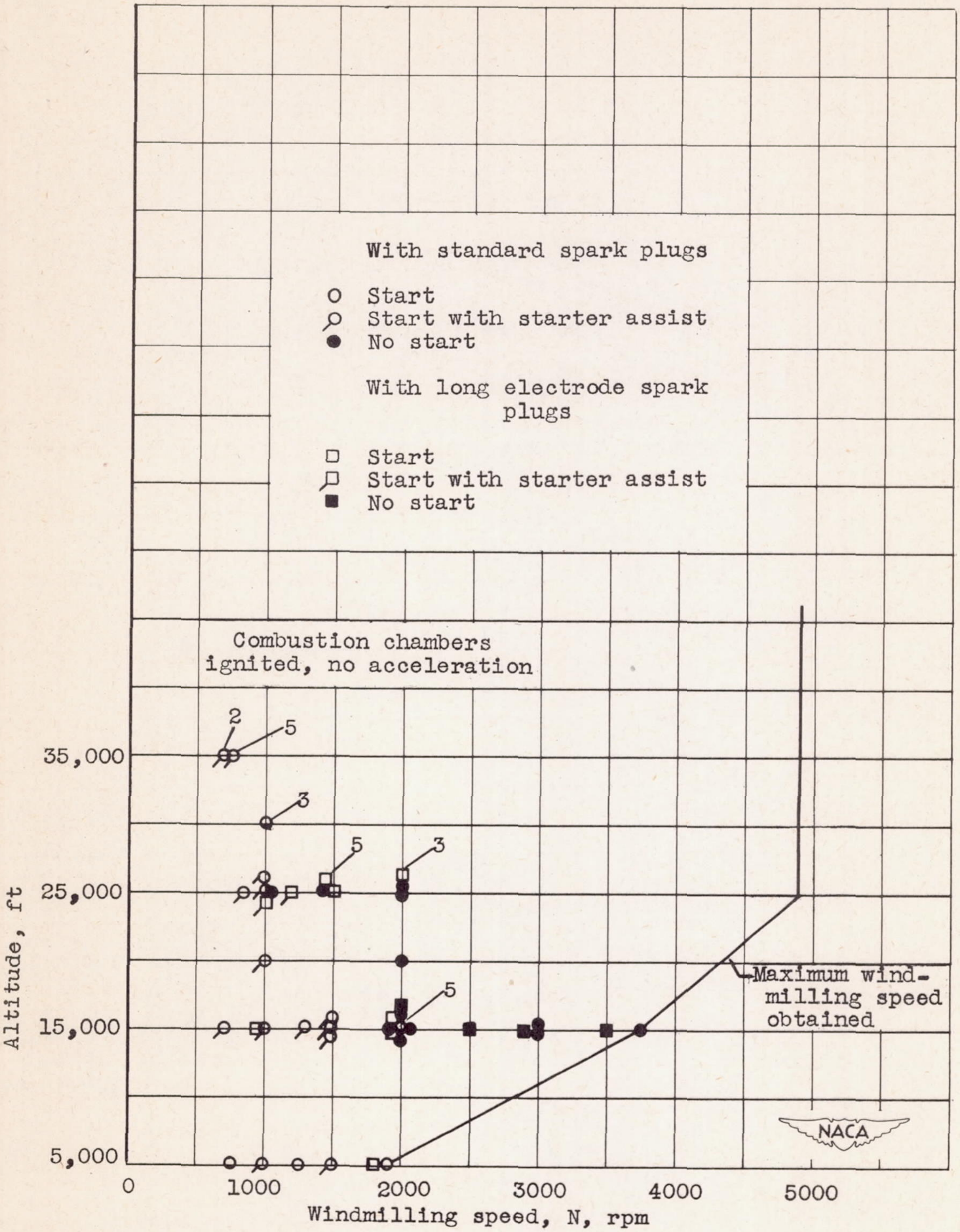
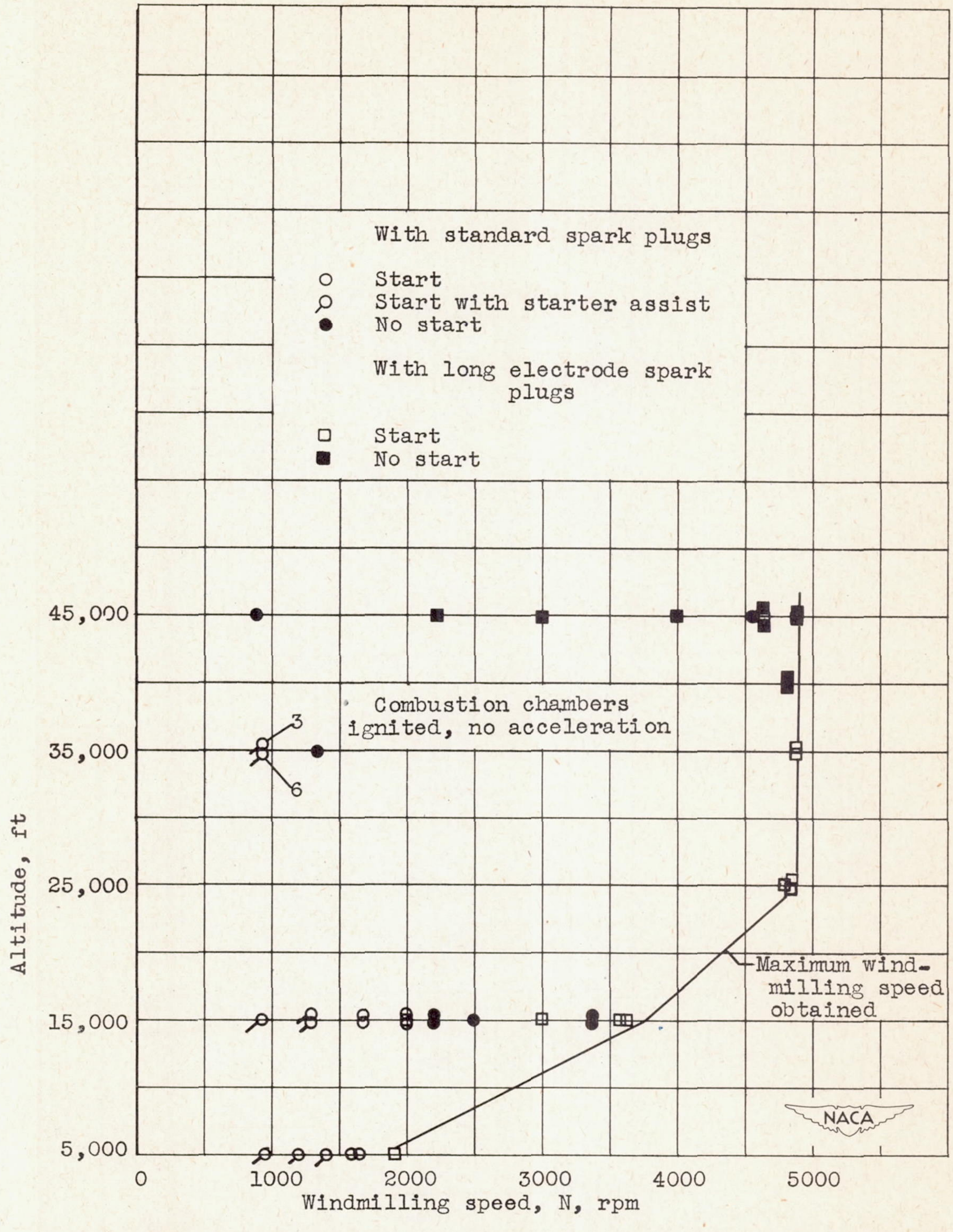


(a) AN-F-32 fuel; exhaust-nozzle-outlet area, 280 square inches.

Figure 8. - Effect of altitude and windmilling speed on engine starting characteristics. Engine-inlet temperature, approximately 40° F.



(b) AN-F-48 fuel; exhaust-nozzle-outlet area, 288 square inches with standard spark plugs and 280 square inches with long electrode spark plugs.

Figure 8. - Concluded. Effect of altitude and windmilling speed on engine starting characteristics. Engine-inlet temperature, approximately 40° F.

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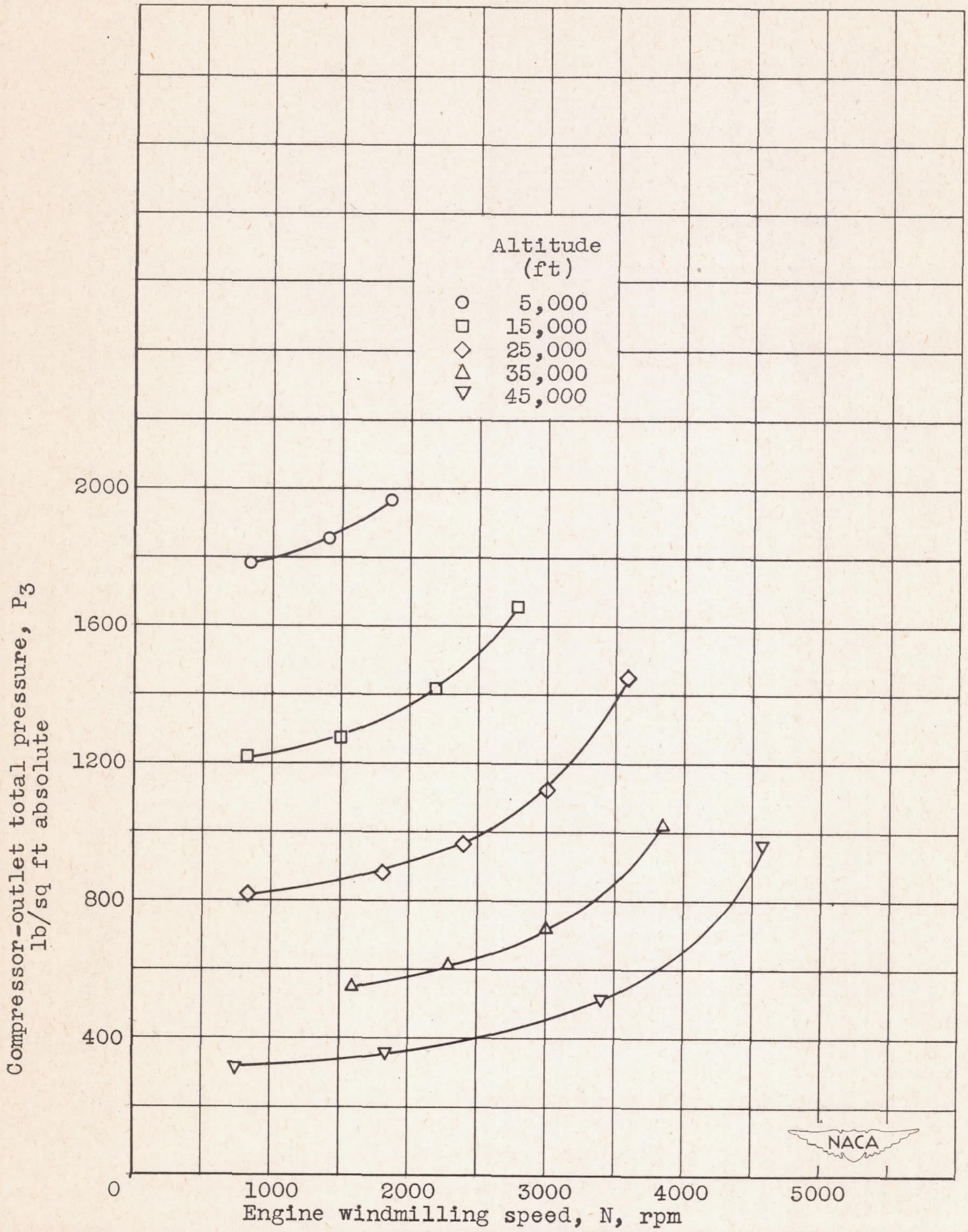

Figure 9. - Variation of compressor-outlet total pressure with windmilling speed at altitudes from 5000 to 45,000 feet.

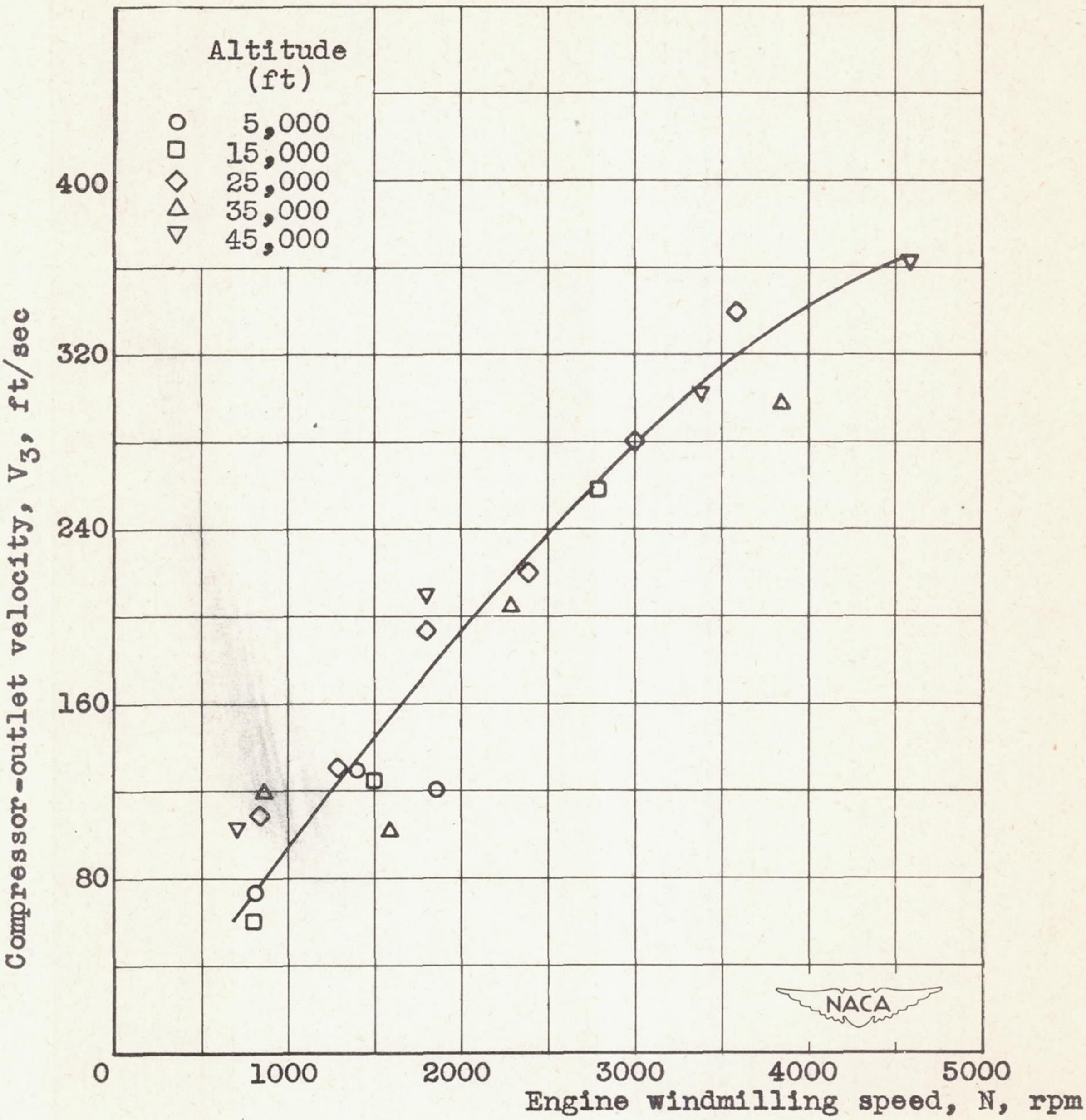

Figure 10. - Variation of compressor-outlet velocity with engine windmilling speed at altitudes from 5000 to 45,000 feet. Exhaust-nozzle-outlet area, 280 square inches; engine-inlet temperature approximately 40° F.

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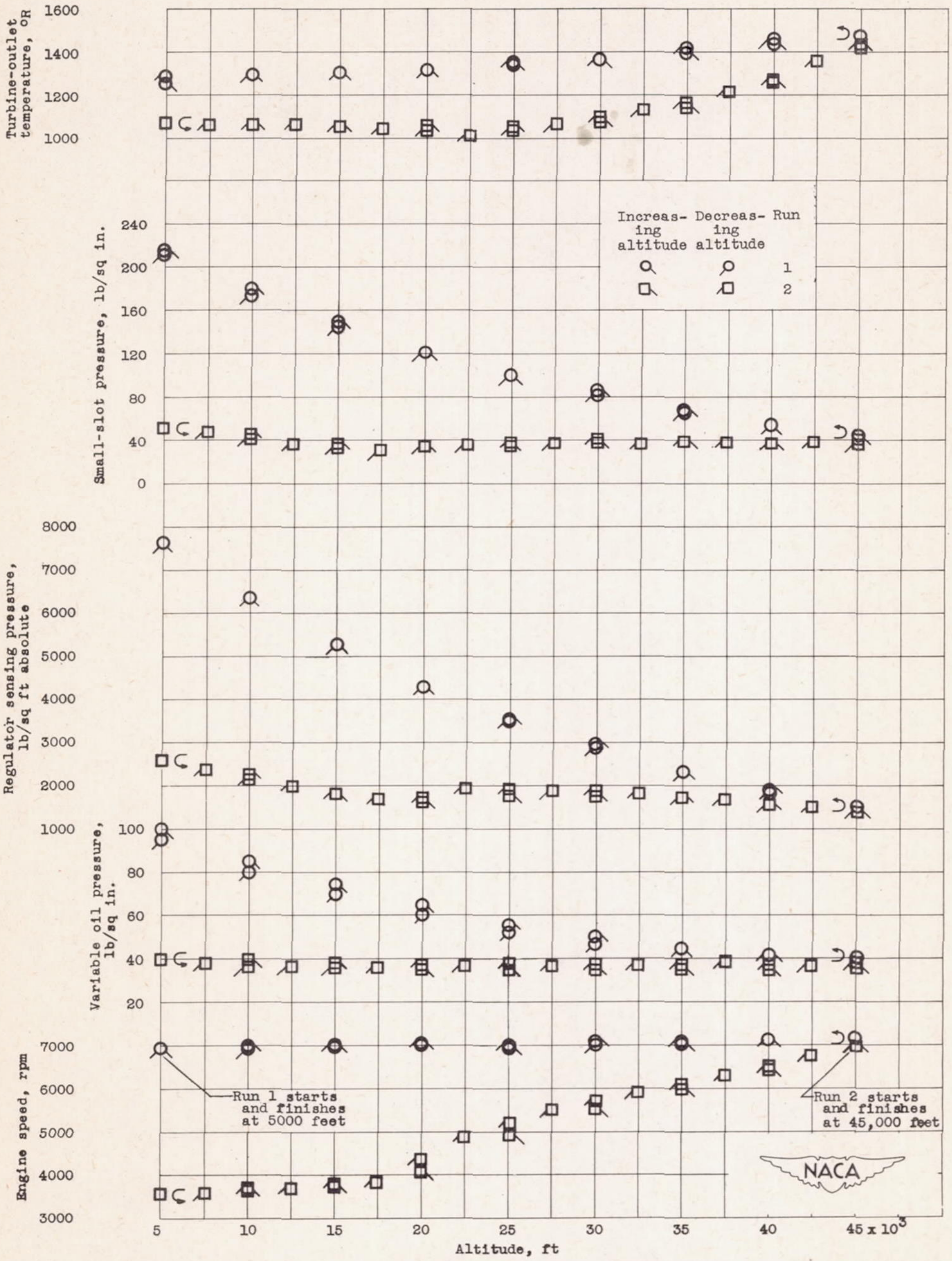

Figure 11. - Altitude compensation of fuel-control system at constant engine-inlet indicated airspeed of 100 miles per hour. Exhaust-nozzle-outlet area, 280 square inches; engine-inlet temperature, approximately 40° F.

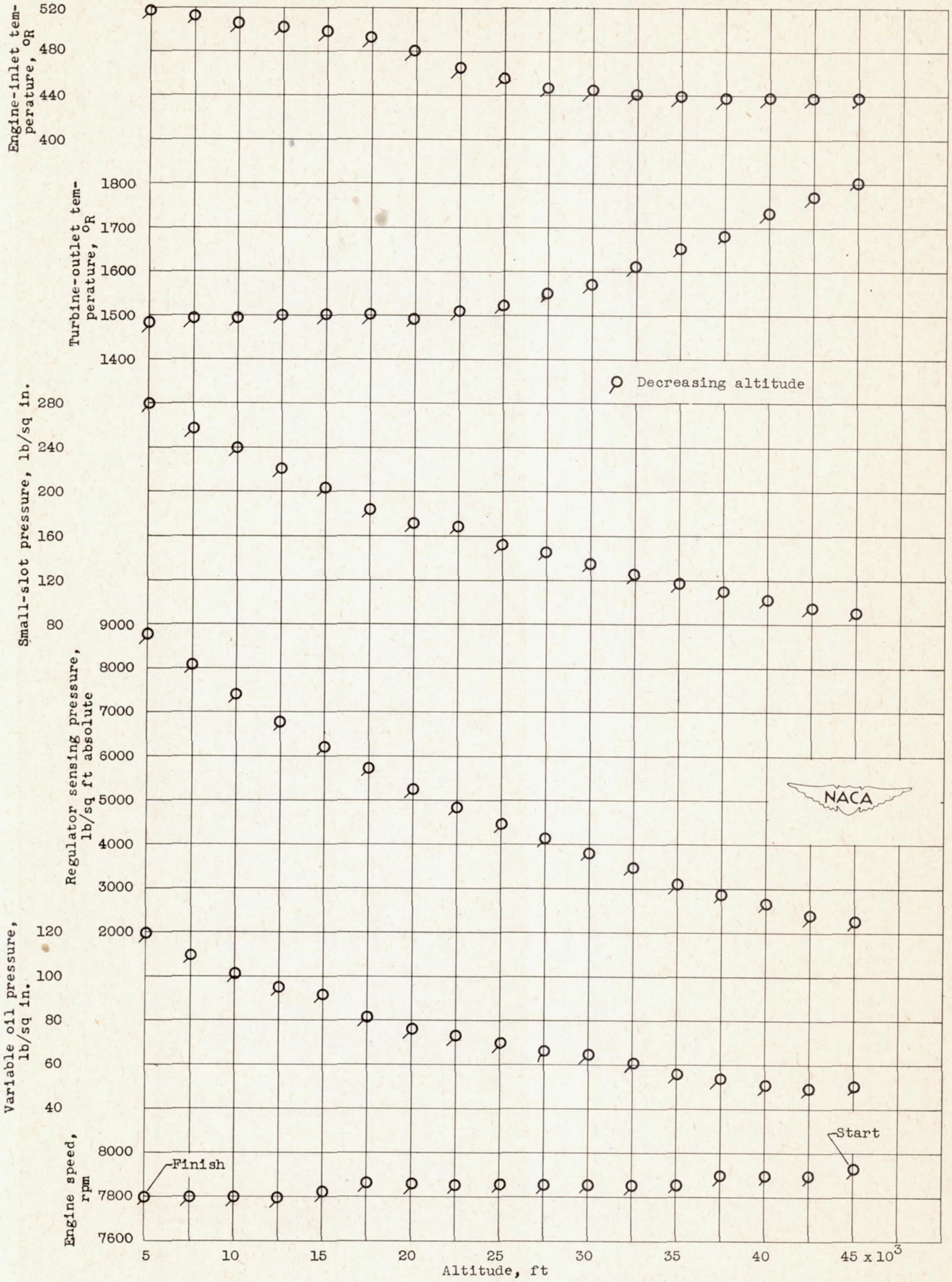

Figure 12. - Altitude compensation of fuel-control system at constant engine-inlet indicated airspeed of 200 miles per hour. Exhaust-nozzle-outlet area, 280 square inches.

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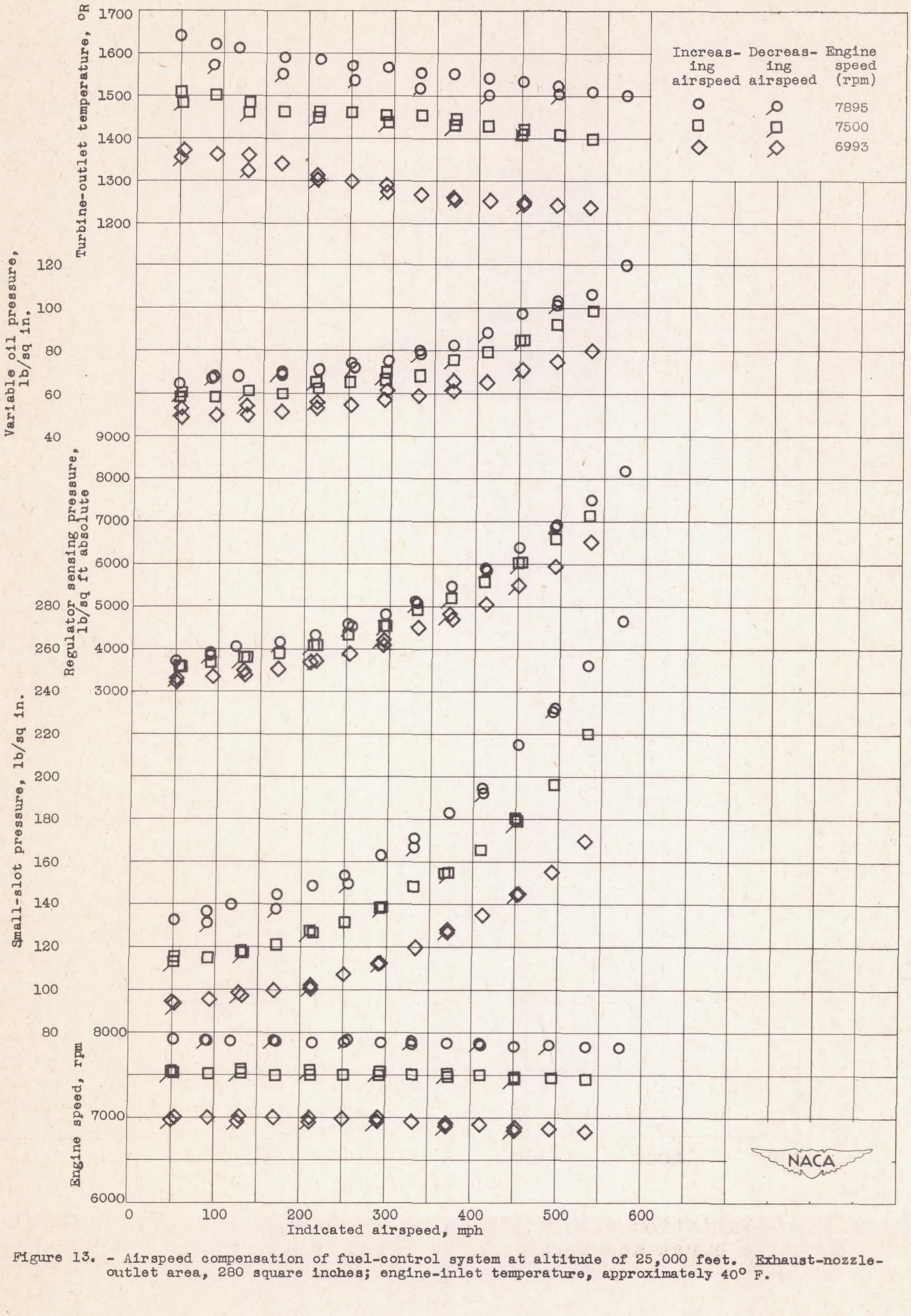

Figure 13. - Airspeed compensation of fuel-control system at altitude of 25,000 feet. Exhaust-nozzle-outlet area, 280 square inches; engine-inlet temperature, approximately 40° F.

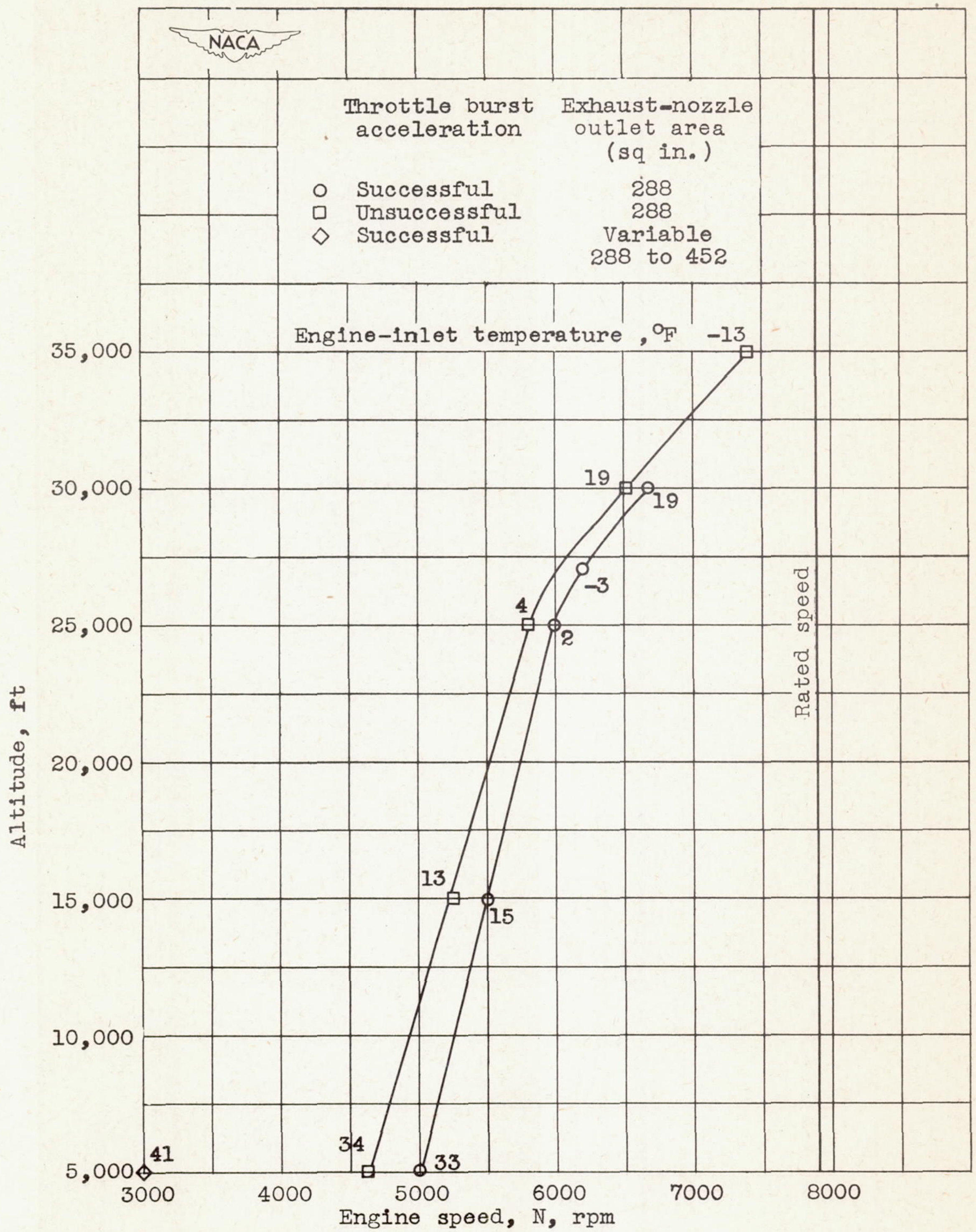

Figure 14. - Variation with altitude of minimum engine speed for throttle burst accelerations to rated engine speed.

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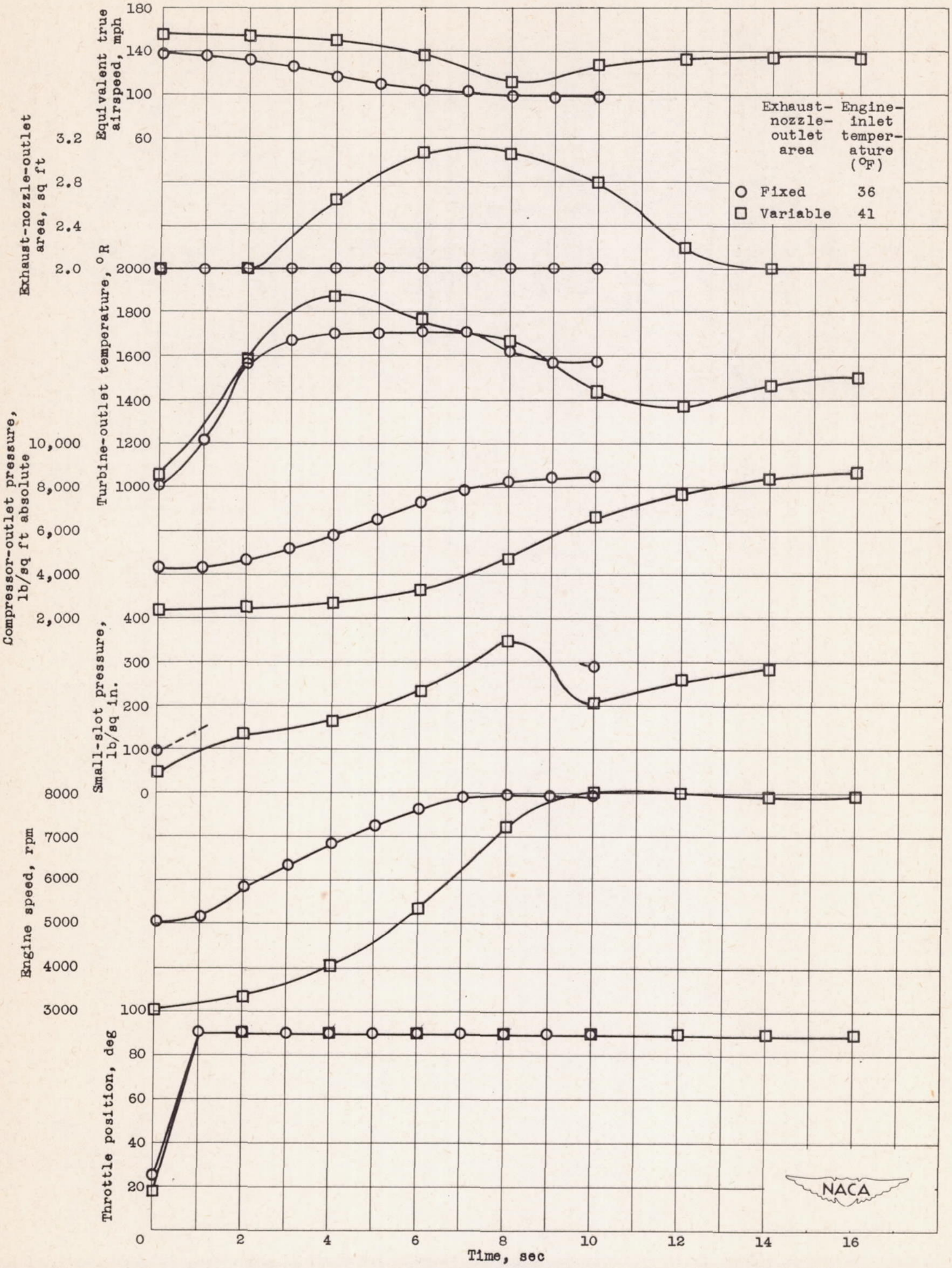

Figure 15. - Variation of several engine variables during throttle burst accelerations at altitude of 5000 feet with fixed- and variable-area exhaust nozzles.

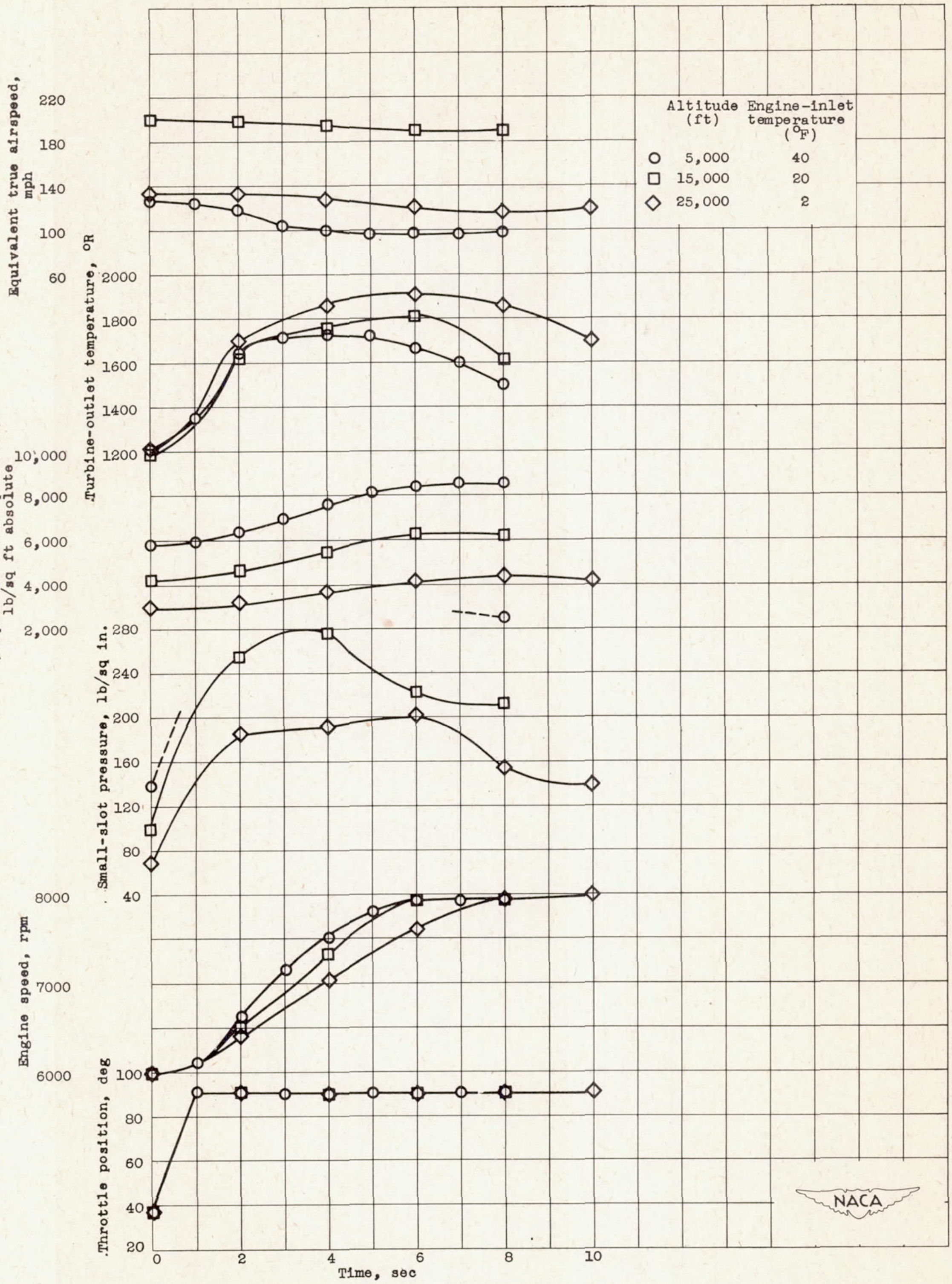

Figure 16. - Variation of several engine variables during throttle burst accelerations at altitudes of 5000, 15,000, and 25,000 feet.

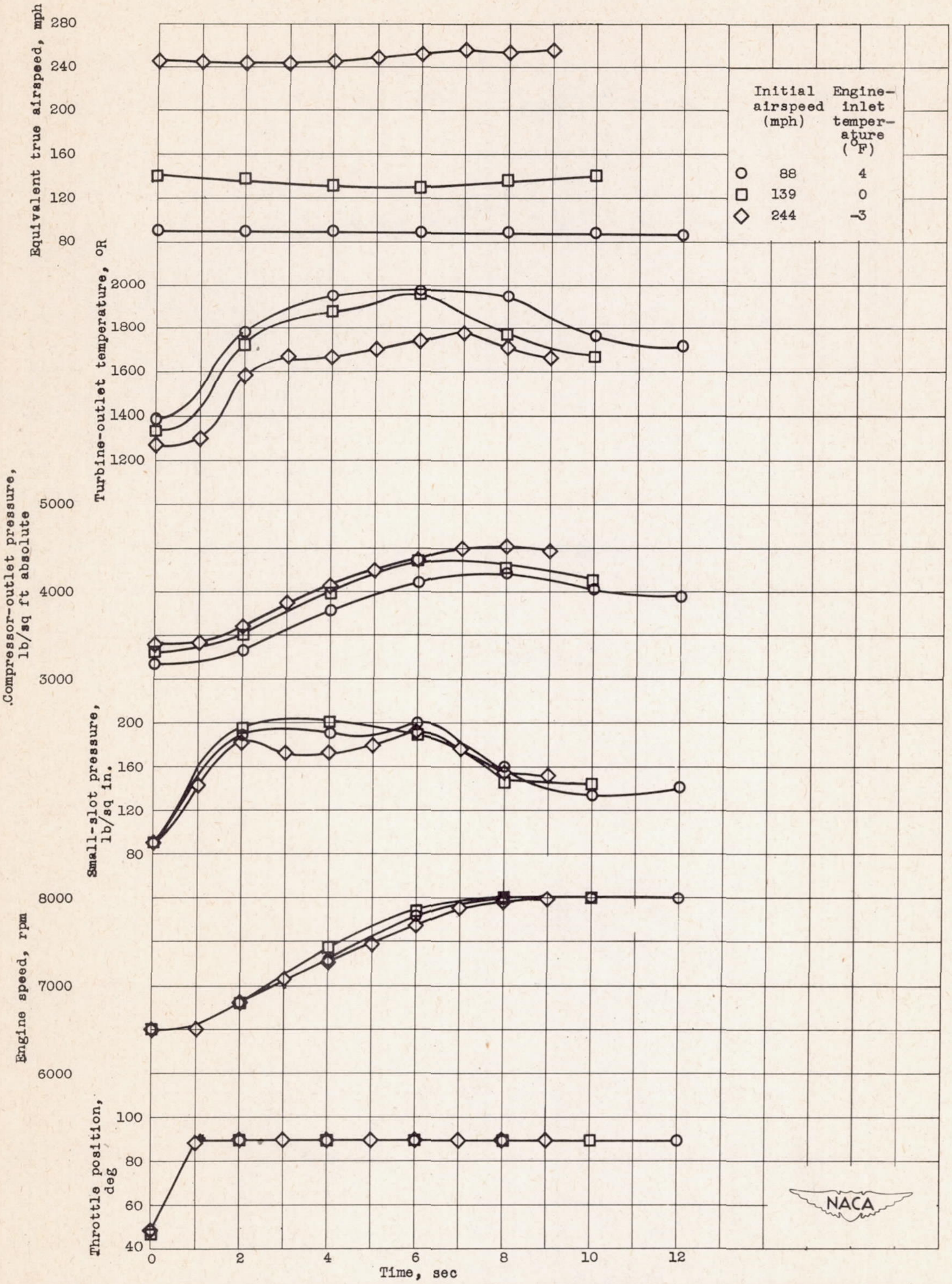

Figure 17. - Effect of airspeed during throttle burst accelerations on relation of engine variables with time at an altitude of 25,000 feet.

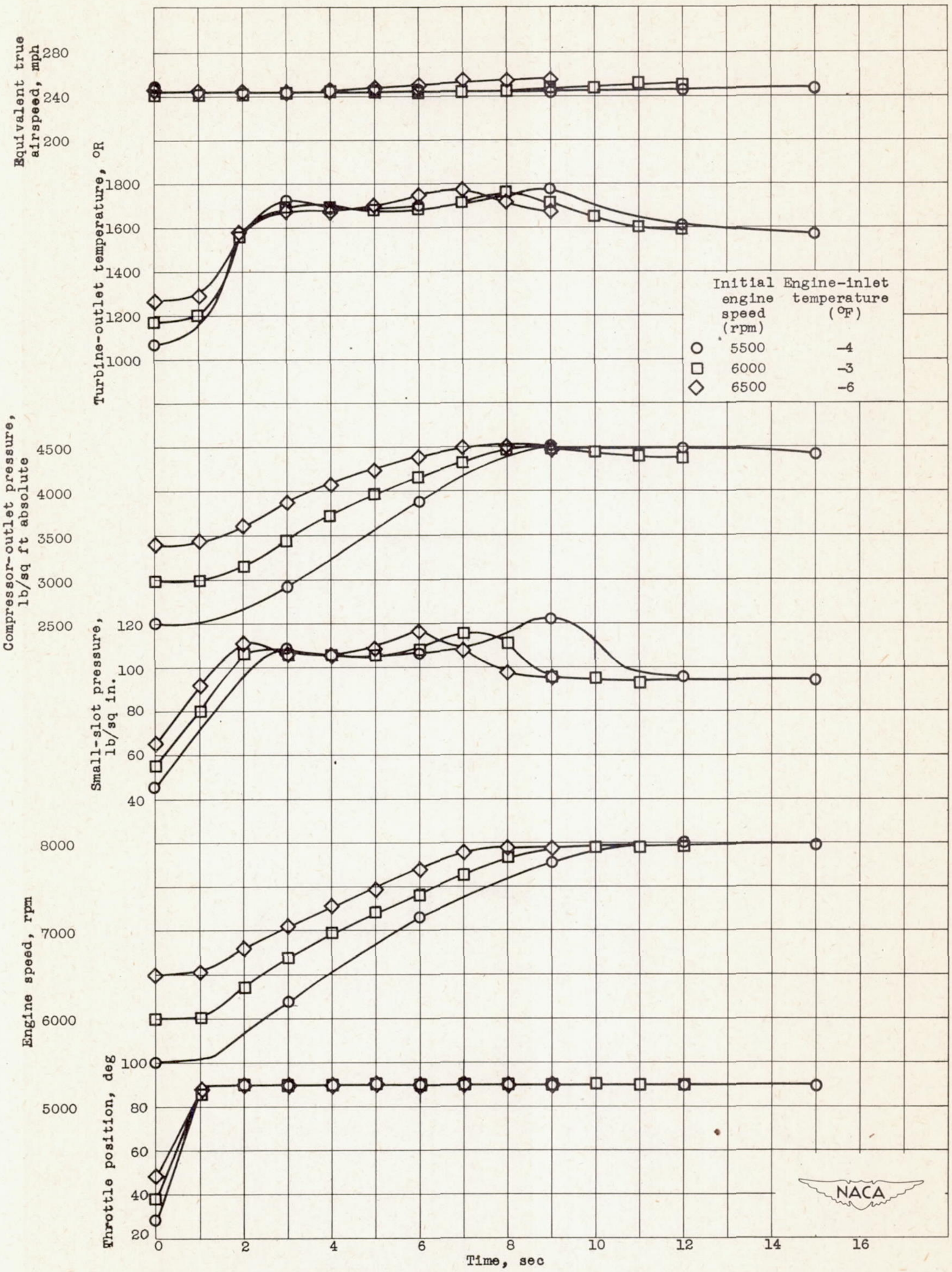

Figure 18. - Variation of engine variables with time during throttle burst accelerations for three initial engine speeds at altitude of 25,000 feet and true airspeed of 240 miles per hour.

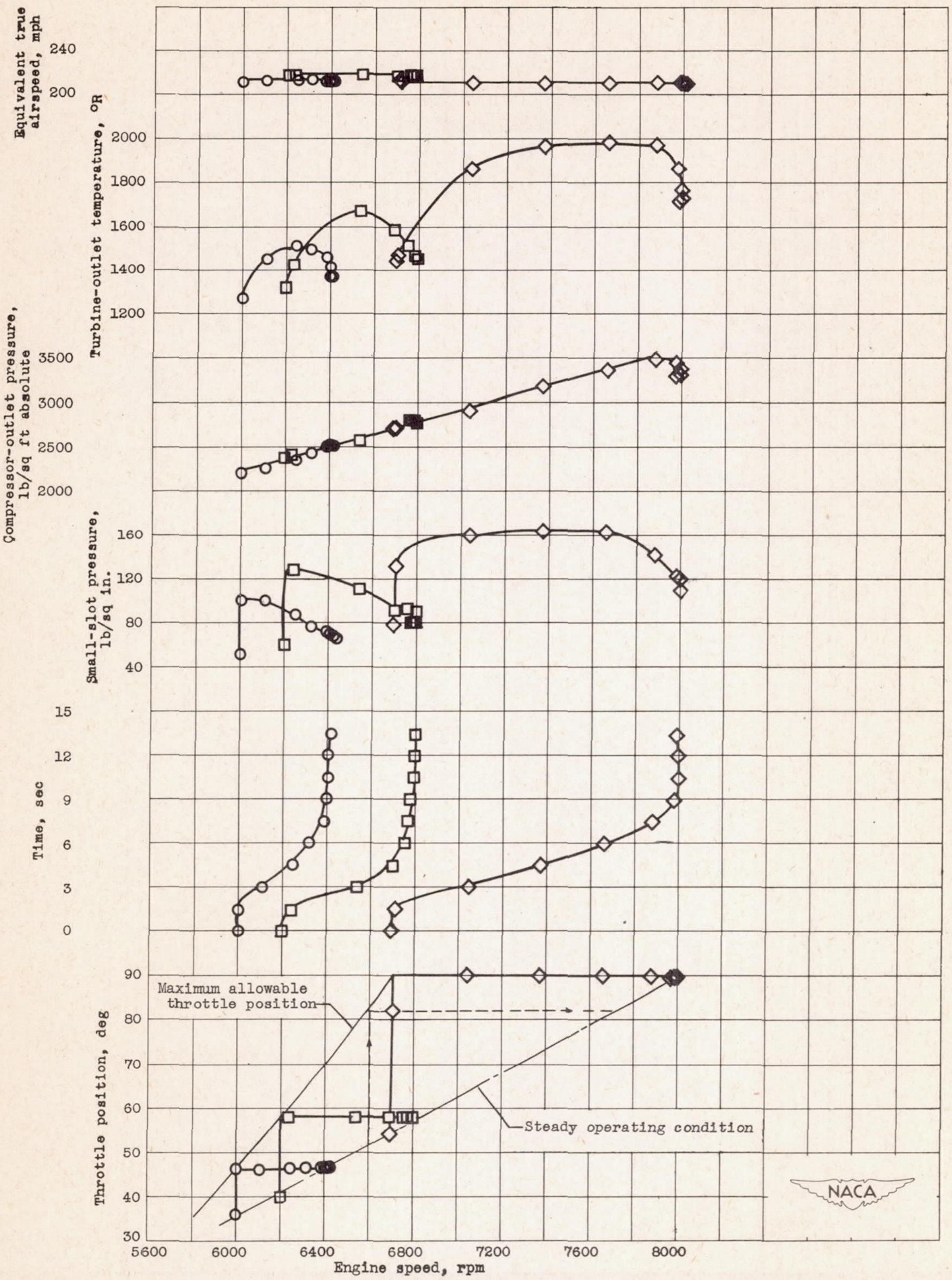

Figure 19. - Maximum allowable throttle advance for throttle burst accelerations at altitude of 30,000 feet. Engine-inlet temperature, approximately 20° F.

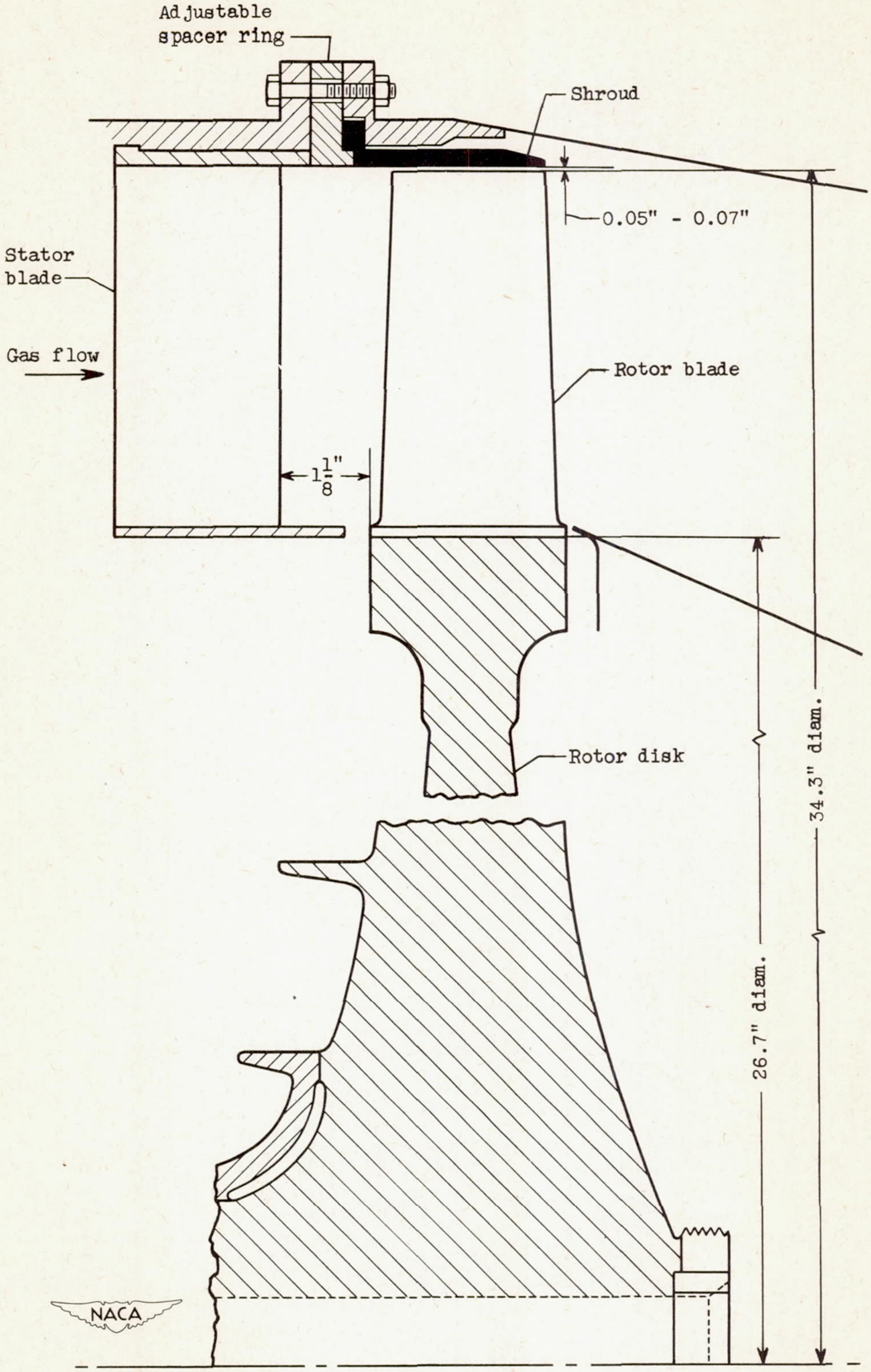

Figure 20. - Sectional view of turbine showing principal dimensions.

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