RESEARCH MEMORANDUM

ALTITUDE-CHAMBER PERFORMANCE OF BRITISH
ROLLS-ROYCE NENE II ENGINE
II - 18.41-INCH-DIAMETER JET NOZZLE

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SUMMARY

An altitude-chamber investigation was conducted to determine the altitude performance characteristics of the British Rolls-Royce Nene II turbojet engine with an 18.41-inch-diameter jet nozzle. Results are presented for simulated altitudes from sea level to 60,000 feet and for ram-pressure ratios from 1.00 to 3.50 (corresponding to flight Mach numbers from 0 to 1.47, assuming 100-percent ram-pressure recovery).

Typical performance-data plots are presented to show graphically the effects of altitude and flight ram-pressure ratio. Conventional correction methods were applied to the data to determine the possibility of generalizing each performance parameter to a single curve. A complete tabulation of corrected and uncorrected engine-performance parameters is presented. A comparison of performance with the 18.75- and 18.41-inch-diameter jet nozzles is made to show the effect of small changes in nozzle size under simulated-flight conditions.

The investigation showed that engine performance obtained at one altitude could not be used to predict performance at other altitudes for altitudes above 20,000 feet. Performance at or below 20,000 feet could, however, be predicted from sea-level data or data obtained at any altitude in this range for any particular ram-pressure ratio. For varying ram-pressure ratios, performance can be predicted from other ram-pressure-ratio data only for conditions for which critical flow exists in the jet nozzle.

In comparison with the standard 18.75-inch-diameter jet nozzle, the 18.41-inch-diameter nozzle gave somewhat lower values of net-thrust specific fuel consumption at engine speeds below 11,000 rpm.
at a simulated altitude of 30,000 feet and a ram-pressure ratio of 1.30. Above 11,000 rpm this trend was reversed. Jet thrust, net thrust, fuel consumption, and tail-pipe indicated gas temperature generally increased when the smaller nozzle was used.

INTRODUCTION

Because the British Rolls-Royce Nene II engine is different in design from similar United States turbojet engines and has a high sea-level rating, the Nene engine was investigated in an altitude chamber at the NACA Lewis laboratory during 1948.

The effect on altitude performance of a small change in jet-nozzle size is of interest, particularly with reference to engine specific fuel consumption, because aircraft range is directly affected. At altitude, a jet nozzle smaller than standard can be used at cruise conditions without exceeding allowable temperatures; at a given flight condition, a smaller jet nozzle should give higher thrust and possibly lower specific fuel consumption.

In order to determine the change in altitude performance resulting from a small change in jet-nozzle size, three different jet-nozzle diameters (18.75, 18.41, and 18.00 in.) were used in this investigation of the Nene II engine.

The effects of altitude and flight speed on the over-all engine performance using the standard 18.75-inch-diameter jet nozzle are presented in reference 1. The over-all engine performance using an 18.41-inch-diameter jet nozzle is presented herein. Results are presented for simulated-flight conditions varying in altitude from sea level to 60,000 feet and in ram-pressure ratio from 1.00 to 3.50. These ram-pressure ratios correspond to flight Mach numbers from 0 to 1.47, assuming 100-percent ram-pressure recovery. The conventional method of reducing data to sea-level conditions (reference 2) was used to determine whether the performance parameters could be generalized to a single curve; that is, whether data obtained at one altitude and ram-pressure ratio can be used to predict performance at other conditions of altitude and ram-pressure ratio. Also, a comparison of engine performance with these two different jet-nozzle diameters is presented for a simulated-flight condition of 30,000 feet at a ram-pressure ratio of 1.30.
DESCRIPTION OF POWER PLANT

A cutaway view of the British Rolls-Royce Nene II power plant, which is a through-flow turbojet engine having nine combustion chambers, is shown in figure 1. The engine incorporates a single-stage double-entry centrifugal compressor (tip diameter, 28.80 in.) driven by a single-stage reaction turbine (tip diameter, 24.53 in.). The turbine-nozzle area is 126 square inches and the standard 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 13.36 square feet.

The sea-level engine performance (reference 3), based on Rolls-Royce static test-bed data with the standard 18.75-inch-diameter jet nozzle, is:

<table>
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<tr>
<th>Rating</th>
<th>Jet thrust (lb)</th>
<th>Engine speed (rpm)</th>
<th>Specific fuel consumption (lb/(hr)(lb thrust))</th>
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<td>1.04</td>
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<tr>
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<tr>
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<tr>
<td>Idle</td>
<td>120</td>
<td>2,600</td>
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</table>

From these values it can be seen that the rated military thrust per unit weight of engine is 2.91 pounds thrust per pound weight, and the rated military thrust per unit of frontal area is 374 pounds thrust per square foot. The maximum allowable tail-cone gas temperature is 1365° F with the standard 18.75-inch-diameter jet nozzle.

A sea-level acceptance run of the engine with minimum research instrumentation installed showed a thrust of 5110 pounds and a specific fuel consumption of 1.01 pounds per hour per pound of thrust at an engine speed of 12,261 rpm.

APPARATUS AND PROCEDURE

Altitude Test Chamber

The engine was installed in an altitude test chamber 10 feet in diameter and 60 feet long (schematically shown in fig. 2). The inlet section of the chamber (surrounding the engine) was separated from the exhaust section by a steel bulkhead; the engine tail pipe
passed through the bulkhead by means of a low-friction seal. The seal was composed of three floating asbestos-board rings so mounted on the tail pipe as to allow thermal expansion in both radial and axial directions, as well as a reasonable amount of lateral movement to prevent binding.

Engine thrust was measured by a balanced-pressure-diaphragm-type thrust indicator outside the test chamber, connected by a linkage to the frame on which the engine was mounted in the chamber.

An A.S.M.E. type flat-plate orifice mounted in a straight run of 42-inch-diameter pipe at the approach to the test chamber was provided for measuring engine air consumption. Because of the large variation in atmospheric conditions investigated, however, considerable difficulty was encountered with condensation in the orifice differential-pressure lines despite repeated attempts to remedy the situation. The engine air consumption was therefore calculated from engine pressure and temperature measurements in the tail pipe, as described in the appendix.

The ram-air pressure was controlled by a main, electrically operated butterfly valve in the 42-inch air-supply line, bypassed by a 12-inch, pneumatically operated V-port valve. Air was supplied by either a combustion-air (moist, room-temperature) system or a refrigerated-air (dry, cooled) system at temperatures near those desired. Final control of air temperature was accomplished by means of a set of electric heaters in the bypass line immediately preceding the entrance to the test chamber. The air entered the test chamber, passed through a set of straightening vanes, and then entered the engine cowl. The purpose of the cowl was to prevent circulation of heated air from the region of the tail pipe and combustion chambers directly into the aft inlet of the compressor. This heated air was therefore mixed with the cooler air supply before entering the compressor.

The exhaust jet was discharged into a diffusing elbow mounted in the exhaust section of the chamber. This elbow ducted the gases into a dry-type primary cooler. Control of the exhaust pressure was obtained by means of a main, electrically operated butterfly valve, bypassed by a 20-inch, pneumatically operated butterfly valve. The gases then passed through a dry-type secondary cooler and thence into the system exhausters.
Instrumentation

Compressor-inlet temperature and total pressure were measured by eight probes, each consisting of an iron-constantan thermocouple and a total-pressure tube. Four probes were equally spaced around the periphery of the front compressor-inlet screen, and four around the back screen, (station 2, fig. 3). Control of ram pressure and temperature was based on the averaged readings of the eight probes. Compressor-discharge pressures were measured at the exit of compressor-discharge elbows 1, 4, and 7 by seven total-pressure tubes in each elbow.

Engine tail-pipe temperatures at station 6 were measured by means of 25 chromel-alumel, stagnation-type thermocouples located in an instrument ring. The instrument ring also included 24 total-pressure probes, 14 static-pressure probes, and 4 wall static-pressure taps. (See fig. 4, reference 1.) This instrumentation was located approximately 18 inches downstream of the tail cone. In addition, four Nene engine standard tail-cone thermocouples supplied by Rolls-Royce Ltd. were mounted in the tail cone and were used for engine-control purposes.

All pressures, including the thrust-indicator-diaphragm pressure, were instantaneously recorded by photographing the manometer panel. Temperatures were recorded by two self-balancing, scanning potentiometers, which required about 3 minutes to record all engine temperatures. Pressure and temperature instrumentation was also located at other stations throughout the engine; measurements from this instrumentation are not reported.

Engine speed was measured by means of an impulse counter, which operated on the frequency of an alternating-current three-phase generator mounted on the accessory case of the engine. Action of the counter and the timer was synchronized by a single mechanism.

Fuel consumption was measured by a calibrated variable-area-orifice flow meter, which allowed near full-scale readings for various ranges of fuel flow by changing the orifice flow area.

With the exception of air consumption, performance data were generally reproducible within 2 percent. Air-consumption data scattered appreciably at high engine speeds and was reproducible only to within 5 percent with a few points showing even greater scatter.
Procedure

Performance characteristics of the engine were obtained over a range of engine speeds at simulated altitudes from sea level to 60,000 feet and ram-pressure ratios from 1.00 to 3.50. Inlet-air temperatures were, in general, held to within 3°F of NACA standard values corresponding to the simulated-altitude and ram-pressure-ratio conditions. Compressor-inlet total pressures were held at values corresponding to the simulated flight conditions, assuming 100-percent ram-pressure recovery.

RESULTS AND DISCUSSION

A summary of performance and operational data obtained at simulated-altitude conditions is presented in table I. Altitude data corrected for small variations in compressor-inlet pressure and temperature settings and for variations in exhaust-pressure settings are summarized in table II. Table II also includes the data corrected to conditions of NACA standard sea-level static pressure and temperature at the compressor inlet.

Simulated Flight Performance

Effect of altitude. - Typical performance data from table II, obtained at a ram-pressure ratio of 1.30 and simulated altitudes from sea level to 60,000 feet, are presented to show the effect of altitude on jet thrust, net thrust, air consumption (cooling air excluded), fuel consumption, net-thrust specific fuel consumption, and tail-pipe indicated gas temperature (figs. 4 to 9, respectively). The trends shown are identical to those discussed in reference 1; that is, a rapid decrease in jet thrust, net thrust, air consumption, and fuel consumption with increasing altitude and a decrease in specific fuel consumption up to an altitude of approximately 30,000 feet, after which this trend reversed to give an increase in specific fuel consumption as altitude continued to increase. This reversal, as discussed in reference 1, is a result of decreasing inlet temperature, which increases the compressor Mach number thereby producing an increase in the compressor pressure ratio and cycle efficiency. The reversal therefore apparently takes place at the tropopause (35,332 ft based on NACA standard atmosphere). The specific-fuel-consumption curves are computed from values obtained from the faired-in fuel-consumption and net-thrust curves; any discrepancies that occur between the fuel-consumption and net-thrust data and the faired curves are carried over to the specific-fuel-consumption curves. The data points therefore in many cases
do not fall on the faired curve. The tail-pipe indicated gas temperature (fig. 9) at engine speeds below 10,800 rpm decreased rapidly with increasing altitude to about 40,000 feet, after which there was no further change with altitude. At the engine speeds above 10,800 rpm, there was a reversal in this trend, with tail-pipe temperature increasing with increasing altitude. This reversal in trend takes place at lower engine speeds for ram-pressure ratios greater than 1.30, and at higher engine speeds for lower ram-pressure ratios.

Effect of ram-pressure ratio. - Performance data obtained at a simulated altitude of 30,000 feet and at ram-pressure ratios from 1.30 to 3.00 are presented to show the effect of ram-pressure ratio on jet thrust, net thrust, air consumption, fuel consumption, net-thrust specific fuel consumption, and tail-pipe indicated gas temperature (figs. 10 to 15, respectively).

As would be expected with increasing air density at the engine inlet, an increase in ram-pressure ratio generally increased jet thrust, air consumption, and fuel consumption throughout the range of engine speeds investigated. The net thrust increased with increasing ram-pressure ratio for high engine speeds, but decreased with increasing ram-pressure ratio for low engine speeds. For the data shown in figure 11 (30,000 ft altitude), the reversal in trend occurred at approximately 10,000 rpm. The net-thrust specific fuel consumption increased with increasing ram-pressure ratio. The curve for a ram-pressure ratio of 1.50 coincides with the curve for a ram-pressure ratio of 1.70; however, this coincidence is attributable to a slightly high value of fuel consumption for a ram-pressure ratio of 1.50, as indicated by figure 13. The tail-pipe indicated gas temperature, in general, decreased slightly with increasing ram-pressure ratio. (fig. 15). This decrease was small and somewhat inconsistent and could well be interpreted as data scatter at the higher engine speeds. As would be expected, an appreciable decrease in temperature occurred at the lower engine speeds, where there was a tendency for the engine to windmill.

These trends with varying ram-pressure ratio are identical to those discussed in greater detail in reference 1.

Generalized Performance

Performance data varying in altitude from sea level to 60,000 feet and in ram-pressure ratio from 1.00 to 3.50 were reduced in the conventional manner (reference 2) to NACA standard sea-level
conditions. The development of this method of generalizing data involves the concept of flow similarity and the application of dimensional analysis to the performance of turbojet engines. In this development, the efficiencies of engine components are considered to be unaffected by changes in flight conditions.

Effect of altitude. - Typical sea-level corrected engine performance data (table II) obtained at a ram-pressure ratio of 1.30 and simulated altitudes from sea level to 60,000 feet are compared to show the effect of altitude on the corrected values of jet thrust, net thrust, air consumption, fuel consumption, net-thrust specific fuel consumption, tail-pipe indicated gas temperature, and tail-cone indicated gas temperature (figs. 16 to 21, respectively).

The corrected values of jet thrust and net thrust (figs. 16 and 17) did not generalize but decreased with increasing altitude for all altitudes above 20,000 feet. This decrease was attributed, in part, to the decrease in compressor pressure ratio and efficiency as altitude was increased, as discussed in reference 1. Because of the decrease in compressor pressure ratio, a comparable decrease in air consumption would be expected. Although there is an appreciable scatter in the data, a decrease in air consumption with increasing altitude is indicated (fig. 18). The data for 50,000 feet indicate an appreciable decrease at a corrected engine speed of 13,300 rpm after a peak air consumption at 12,800 rpm. This trend and similar trends indicated by other high-altitude data in reference 1 are attributed to scatter in the data at high altitude, where small errors in reading instrumentation are appreciable percentages of the absolute values. Corrected fuel consumption (fig. 19) increased only a small amount with increasing altitude at high values of corrected engine speed. At low engine speeds, the fuel consumption increased very rapidly with increasing altitude. The corrected net-thrust-specific-fuel-consumption curves (fig. 20) generalized up to an altitude of 20,000 feet. Above 20,000 feet the corrected specific fuel consumption increased with increasing altitude. The corrected tail-pipe and tail-cone indicated gas temperature (fig. 21) generalized at all engine speeds. The difference between tail-pipe and tail-cone temperatures is attributed to the differences in the location and the number of thermocouples used.

The failure of the altitude data to generalize to single curves for each parameter for altitudes above 20,000 feet is in agreement with the results of the investigation using the standard 18.75-inch jet nozzle (reference 1).
Effect of ram-pressure ratio. - The conventional method of generalizing data was specifically developed to adjust for changes in the pressure and the temperature of the atmosphere in which the engine is operating. Variations in ram-pressure ratio (flight speed) change the performance characteristics by effectively changing the compression ratio of the engine. In general, the increased operating pressure with increasing ram-pressure ratio raises the total expansion pressure ratio of the engine (from turbine inlet to jet-nozzle throat) until critical flow is established in the jet nozzle. After critical flow is established, the expansion pressure ratio of the engine remains constant with increasing ram-pressure ratio. The engine is then effectively operating in an atmosphere having a static pressure equal to the pressure existing in the jet-nozzle throat, and is operating at a constant effective ram-pressure ratio. The effective ram-pressure ratio is then equal to the ratio of the compressor-inlet total pressure to the jet-nozzle-throat static pressure. With critical flow in the jet nozzle, generalization of flow characteristics within the engine should be possible within the limitations discussed in connection with altitude effects.

Typical performance data obtained at a simulated altitude of 30,000 feet and ram-pressure ratios from 1.30 to 3.00 are compared to show the effect of ram-pressure ratio on the corrected values of jet thrust, jet-thrust parameter \( \frac{F_1 + P_0 A_7}{8} \), (reference 1), net thrust, air consumption, fuel consumption, net-thrust specific fuel consumption, and tail-pipe indicated gas temperature (figs. 22 to 27, respectively). (The symbols are defined in the appendix.)

The corrected jet thrust (fig. 22(a)) did not generalize but the corrected jet-thrust parameter (fig. 22(b)) generalized for all conditions for which the jet nozzle was choked. The corrected net thrust of figure 23 appears to generalize at the higher speeds; however, examination of plots of the data of table II at other altitudes shows that the data for ram-pressure ratios lower than 1.30 do not generalize. Although the corrected air consumption of figure 24 generalized, the jet thrust did not generalize and thus, there is apparently no reason to expect the net thrust to generalize. At higher flight speeds (ram-pressure ratios), however, the momentum of the incoming air is greater at a given mass flow; this larger quantity, when subtracted from the higher jet-thrust values of figure 22, causes the corrected net thrust to generalize for ram-pressure ratios above 1.30. Corrected fuel consumption generalized
at the high engine speeds when critical flow existed in the jet nozzle (fig. 25). At lower engine speeds, the fuel consumption decreased with increasing ram-pressure ratio. The corrected net-thrust specific fuel consumption (fig. 26) showed reasonable agreement for ram-pressure ratios above 1.30. Examination of plots of the data of table II at other altitudes show appreciably lower values of specific fuel consumption at a ram-pressure ratio of 1.00. The corrected tail-pipe indicated gas temperature (fig. 27) also generalized to a single curve for engine speeds at which critical flow existed in the jet nozzle. At lower engine speeds, the corrected tail-pipe indicated gas temperature decreased with increasing ram-pressure ratio.

Effect of Jet-Nozzle Area on Performance

A rational examination of the effect of jet-nozzle area on engine performance, neglecting secondary effects, indicates that a reduction in jet-nozzle area increases the resistance to flow through the nozzle, thus raising the tail-pipe pressure. Because, from considerations of typical centrifugal-compressor performance, the compressor pressure ratio remains nearly constant for small changes in air flow, the higher tail-pipe pressure caused by a reduction in jet-nozzle area results in a decreased expansion pressure ratio across the turbine. In order to maintain the required turbine power output, it is then necessary to raise the turbine-inlet temperature, which results in an increased tail-pipe temperature as well. The engine air consumption is essentially proportional to the turbine-inlet pressure and inversely proportional to the square root of the turbine-inlet temperature. Because the turbine-inlet pressure, as previously explained, remains nearly constant and the turbine-inlet temperature rises, a small decrease in air consumption would be expected. This decrease would cause the turbine-inlet temperature to rise slightly at the same fuel flow used with the larger jet nozzle, but an increase in fuel flow to the engine is probably necessary to attain the turbine-inlet temperature required by the smaller jet nozzle. The higher tail-pipe pressure caused by a reduction in jet-nozzle area results in an increase in jet-nozzle-throat velocity in the subcritical flow range, or in a greater excess of nozzle-throat static pressure over ambient static pressure in the critical flow range. In either case, the jet thrust for a given gas flow would increase. Because the jet-nozzle-throat velocity varies directly as the square root of the tail-pipe temperature and the engine air consumption varies inversely as the square root of the turbine-inlet temperature, these effects tend to cancel each other and should not have much effect on the jet thrust. The net result should therefore be an increase in jet thrust due to the higher tail-pipe pressure.
Performance parameters at a simulated altitude of 30,000 feet and a ram-pressure ratio of 1.30 using the 18.41-inch-diameter jet nozzle are compared with the engine performance using the standard nozzle (18.75-in. diameter) data from reference 1 (figs. 28 to 33). The decrease in area of 3.5 percent showed the expected trends, causing a small increase in jet thrust, net thrust, and tail-pipe indicated gas temperature over the entire speed range. At an engine speed of 12,000 rpm these increases amount to approximately 4, 5, and 3 percent, respectively. Fuel consumption (fig. 31) also increased over most of the speed range (about 9 percent at an engine speed of 12,000 rpm). Air consumption, because of the scatter in the data, was obtained from the faired curves of figure 24 herein and figure 27 of reference 1. These data show the expected decrease in air consumption when using the smaller jet nozzle, (approximately 1 percent at an engine speed of 12,000 rpm). The net-thrust specific fuel consumption (fig. 32) was somewhat lower for the smaller nozzle at engine speeds below 11,000 rpm (about 5 percent lower at an engine speed of 10,000 rpm); above 11,000 rpm the smaller nozzle gave a slightly higher specific fuel consumption (about 3 percent higher at an engine speed of 12,000 rpm).

SUMMARY OF RESULTS

The following results were obtained from an altitude-chamber investigation of the performance of a British Rolls-Royce Nene II turbojet engine using an 18.41-inch-diameter jet nozzle:

1. Engine-performance parameters could not be predicted for altitudes above 20,000 feet from data obtained at one particular altitude, because of a progressive decrease in compressor pressure ratio and efficiency at high engine speeds at altitudes above 20,000 feet.

2. At a given altitude, performance data at any ram-pressure ratio for which critical flow existed in the jet nozzle could be used to predict performance at any other ram-pressure ratio in the critical flow range within the limits of this investigation.

3. In comparison with the standard 18.75-inch-diameter jet nozzle, the 18.41-inch-diameter jet nozzle (a decrease in area of approximately 3.5 percent) indicated a slightly lower value of net-thrust specific fuel consumption at engine speeds below 11,000 rpm (5 percent lower at an engine speed of 10,000 rpm) at a simulated altitude of 30,000 feet and a ram-pressure ratio of 1.30. At engine
speeds above 11,000 rpm, the smaller nozzle indicated a slightly higher specific fuel consumption. Jet thrust, net thrust, fuel consumption, and tail-pipe indicated gas temperature all increased slightly when the smaller nozzle was used (approximately 4, 5, 9, and 3 percent, respectively), whereas air consumption showed a small decrease (about 1 percent).

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APPENDIX - CALCULATIONS

Symbols

A  area, sq ft
D  diameter, ft
F  thrust, lb
g  acceleration due to gravity, 32.2 ft/sec^2
H  enthalpy, Btu/lb
J  mechanical equivalent of heat, 778 ft-lb/Btu
K  thrust constant
M  Mach number
N  engine speed, rpm
P  absolute total pressure, lb/sq ft
p  absolute static pressure, lb/sq ft
R  gas constant, 53.3 ft-lb/(lb)(^O_R)
T  total temperature, ^O_R
T  static temperature, ^O_R
V  velocity, ft/sec
W_a  air consumption, lb/sec
W_f  fuel consumption, lb/hr
W_g  gas flow, lb/sec
\gamma  ratio of specific heats
\delta  ratio of compressor-inlet absolute total pressure to absolute static pressure of NACA standard atmosphere at sea level.
\[ \theta = \text{ratio of compressor-inlet absolute total temperature to absolute static temperature of NACA standard atmosphere at sea level} \]

Subscripts:
- \( b \) barometer
- \( d \) thrust-measuring diaphragm
- \( i \) indicated
- \( j \) jet
- \( n \) net
- \( p \) airplane
- \( s \) seal

Station notation (fig. 3):
- \( 0 \) free stream
- \( 2 \) compressor inlet
- \( 3 \) compressor discharge
- \( 5 \) tail cone (turbine discharge)
- \( 6 \) tail pipe (upstream of jet nozzle)
- \( 7 \) jet-nozzle outlet (throat)

Methods of Calculation

**Thrust.** - Thrust was determined from the altitude-chamber thrust indicator (by multiplying the diaphragm pressure by a constant) with an added correction factor to account for the pressure differential across the tail-pipe seal. The relation used was

\[ F_j = F_1 + A_s(p_2 - p_0) \]

where

\[ F_1 = K(p_d - p_b) \]
and the seal area

$$A_s = \frac{\pi D_s^2}{4}$$

Air consumption. - Engine air consumption was calculated from measurements of temperature and total and static pressure in the tail pipe. Total-pressure profiles across the tail pipe were plotted for each data point; the profiles were then read at eight points, so selected as to divide the tail-pipe area into four equal concentric, annular areas. The following formula was then applied to each of the four areas:

$$W_g = \frac{p_g A}{RT_6} \sqrt{\frac{2gJ\Delta H}{\Delta H}}$$

where

$A$ \(1/4\times\) tail-pipe area (cold)

$\Delta H$ enthalpy difference between total- and static-pressure conditions, determined from reference 4

The static temperature in the formula was calculated from the indicated temperature by the following relation:

$$t_6 = \frac{T_{6,1}}{1 + 0.8 \left( \frac{T_{6,1}}{t_6} - 1 \right)}$$

where the temperature ratio was determined from the tail-pipe total-to-static pressure ratio by means of reference 4. The factor 0.8 is the selected average value of thermocouple recovery factor based on instrument calibrations.

The engine air consumption was then determined by adding the gas flows through the four annular areas and subtracting the fuel flow:

$$W_a = W_g - \frac{W_f}{3600}$$
Simulated flight speed. - The simulated flight speed at which the engine was operated was determined from the following relation:

\[ V_p = \sqrt{\frac{2gR}{\gamma - 1} \frac{\gamma-1}{\gamma} \left( \frac{p_2}{p_0} \right)^{\frac{\gamma-1}{\gamma}} - 1} \]

where \( \gamma \) was assumed to be 1.40.

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

\[ F_n = F_j - \frac{W_a V_p}{g} \]

where \( V_p \) is the simulated flight speed as previously calculated.

Flight Mach number. - The flight Mach number was calculated from the compressor-inlet total pressure, assuming 100-percent ram-pressure recovery, by the following relation:

\[ M_p = \sqrt{\frac{2}{\gamma - 1} \left[ \left( \frac{p_2}{p_0} \right)^{\frac{\gamma-1}{\gamma}} - 1 \right]} \]

where \( \gamma \) was assumed to be 1.40.

REFERENCES


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Table I - Performance and Operational Data Obtained at Simulated-Altitude Conditions

Average representing time in altitude chamber. Approximately 22 hr had been accumulated at time of installation in altitude chamber.
### TABLE I - PERFORMANCE AND OPERATIONAL DATA OBTAINED AT SIMULATED-ALTITUDE - Concluded

<table>
<thead>
<tr>
<th>Altitude (ft)</th>
<th>Temperature (deg F)</th>
<th>Pressure (in. Hg)</th>
<th>Density Altitude (ft)</th>
<th>Mach Number</th>
<th>Reynolds Number</th>
<th>Mach Number</th>
<th>Reynolds Number</th>
<th>Mach Number</th>
<th>Reynolds Number</th>
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<th>Reynolds Number</th>
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*Average representing time in altitude chamber. Approximately 22 hr had been accumulated at time of installation in altitude chamber.

*Dashes indicate that values are unknown.
<table>
<thead>
<tr>
<th>Point (Altitude) (ft)</th>
<th>Engine speed (rpm)</th>
<th>Jet thrust (lb)</th>
<th>Net thrust (lb)</th>
<th>Fuel thrust specific consumption (lb/hr)</th>
<th>Indicated gas temperature</th>
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Note: F_p/F_r represents the ratio of fuel pressure to ram pressure. FL = P/F represents the fuel load per engine. Alt. Curr. refers to altitude current.
## TABLE II - PERFORMANCE DATA ADJUSTED TO STANDARD ALTITUDE AND CONNECTED TO STANDARD SEA-LEVEL ATMOSPHERIC CONDITIONS - Concluded

(Adjusted for variations in ram-pressure ratio)

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<tr>
<th>Point Altitude (ft)</th>
<th>Ram-Pressure Ratio (rpm)</th>
<th>Jet thrust (lb)</th>
<th>Net thrust (lb)</th>
<th>Net-thrust specific fuel consumption (lb/hr/1b thrust)</th>
<th>Indicated gas temperature (°F)</th>
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Figure 1. - Cutaway view of British Rolls-Royce Nene II turbojet engine. (Photographed from Rolls-Royce Manual on Nene engine.)
Figure 2. - Altitude chamber with engine installed in test section.
Figure 3. - Sectional side view of British Rolls-Royce Nene II engine showing instrumentation stations.
Figure 4. - Effect of altitude on jet thrust. Ram-pressure ratio, 1.30.
Figure 5. - Effect of altitude on net thrust. Ram-pressure ratio, 1.30.
Figure 6. - Effect of altitude on air consumption. Ram-pressure ratio, 1.30.
Figure 7. - Effect of altitude on fuel consumption. Ram-pressure ratio, 1.30.
Figure 8. - Effect of altitude on net-thrust specific fuel consumption. Ram-pressure ratio, 1.30.
Figure 9. - Effect of altitude on tail-pipe indicated gas temperature. Ram-pressure ratio, 1.30.
Figure 10. - Effect of ram-pressure ratio on jet thrust. Altitude, 30,000 feet.
Figure 11. - Effect of ram-pressure ratio on net thrust. Altitude, 30,000 feet.
Figure 12. - Effect of ram-pressure ratio on air consumption. Altitude, 30,000 feet.
Figure 13. - Effect of ram-pressure ratio on fuel consumption. Altitude, 30,000 feet.
Figure 14. - Effect of ram-pressure ratio on net-thrust specific fuel consumption. Altitude, 30,000 feet.
Figure 15. - Effect of ram-pressure ratio on tail-pipe indicated gas temperature. Altitude, 30,000 feet.
Figure 16. - Effect of altitude on corrected jet thrust. Ram-pressure ratio, 1.30.
Figure 17. - Effect of altitude on corrected net thrust. Ram-pressure ratio, 1.30.
Figure 18. - Effect of altitude on corrected air consumption. Ram-pressure ratio, 1.30.
Figure 19. - Effect of altitude on corrected fuel consumption. Ram-pressure ratio, 1.30.
Figure 20. - Effect of altitude on corrected net-thrust specific fuel consumption. Ram-pressure ratio, 1.30.
Figure 21. - Effect of altitude on corrected indicated gas temperatures. Ram-pressure ratio, 1.30.
Figure 21. - Concluded. Effect of altitude on corrected indicated gas temperatures. Ram-pressure ratio, 1.30.
Figure 22. - Effect of ram-pressure ratio on corrected jet thrust. Altitude, 30,000 feet.
Corrected engine speed, \( N/\sqrt{\rho} \), rpm

(b) Corrected jet-thrust parameter, \( \frac{F_1 + P_0 A_7}{\delta} \)

Figure 22. - Concluded. Effect of ram-pressure ratio on corrected jet thrust. Altitude, 30,000 feet.
Figure 23. - Effect of ram-pressure ratio on corrected net thrust. Altitude, 30,000 feet.
Figure 24. - Effect of ram-pressure ratio on corrected air consumption. Altitude, 30,000 feet.
Figure 25. - Effect of ram-pressure ratio on corrected fuel consumption. Altitude, 30,000 feet.
Figure 26. - Effect of ram-pressure ratio on corrected net-thrust specific fuel consumption. Altitude, 30,000 feet.
Figure 27. - Effect of ram-pressure ratio on corrected tail-pipe indicated gas temperature. Altitude, 30,000 feet.
Figure 28. - Effect of jet-nozzle size on jet thrust. Altitude, 30,000 feet; ram-pressure ratio, 1.30.
Figure 29. - Effect of jet-nozzle size on net thrust. Altitude, 30,000 feet; ram-pressure ratio, 1.30.
Figure 30. - Effect of jet-nozzle size on air consumption. Altitude, 30,000 feet; ram-pressure ratio, 1.30.
Figure 31. - Effect of jet-nozzle size on fuel consumption. Altitude, 30,000 feet; ram-pressure ratio, 1.30.
Figure 32. - Effect of jet-nozzle size on net-thrust specific fuel consumption. Altitude, 30,000 feet; ram-pressure ratio, 1.30.
Figure 33. - Effect of jet-nozzle size on tail-pipe indicated gas temperature. Altitude, 30,000 feet; ram-pressure ratio, 1.30.