RESEARCH MEMORANDUM

ALTITUDE-CHAMBER PERFORMANCE OF BRITISH ROLLS-ROYCE NENE II ENGINE

III - 18.00-INCH-DIAMETER JET NOZZLE

By Ralph E. Grey, Virginia L. Brightwell, and Zelmar Barson

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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ALTITUDE-CHAMBER PERFORMANCE OF BRITISH
ROLLS-ROYCE NENE II ENGINE
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SUMMARY

An altitude-chamber investigation was conducted at the NACA Lewis laboratory to determine the altitude performance characteristics of the British Rolls-Royce Nene II turbojet engine with an 18.00-inch-diameter jet nozzle. Results are presented for simulated altitudes from sea level to 65,000 feet and for ram pressure ratios from 1.10 to 3.50 (corresponding to flight Mach numbers from 0.37 to 1.47, assuming 100-percent ram pressure recovery).

Typical performance-data plots are presented to show graphically the effects of altitude and of 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 engine performance with the 18.75-, 18.41-, and 18.00-inch-diameter jet nozzles and without a jet nozzle is made to show the effect of changes in nozzle size under simulated-flight conditions.

The investigation showed that engine performance obtained at any one altitude could not be used to predict performance at other altitudes above 30,000 feet with the 18.00-inch-diameter jet nozzle. For varying ram pressure ratios at a given altitude, engine performance can be predicted from data representing other ram pressure ratios only when critical flow exists in the jet nozzle.

A comparison of the engine performance with the three jet-nozzle sizes and without a jet nozzle at an altitude of 30,000 feet and a ram pressure ratio of 1.70 indicated that the 18.00-inch-diameter jet nozzle gave the lowest values of net-thrust specific fuel consumption at practically all engine speeds. At lower ram pressure ratios, the 18.41-inch-diameter jet nozzle gave lower
values of net-thrust specific fuel consumption at high engine speeds. Jet thrust, net thrust, fuel consumption, and tail-pipe indicated gas temperature generally increased with use of the smaller nozzles.

INTRODUCTION

The altitude performance investigation of a British Rolls-Royce Nene II engine was conducted in an altitude chamber at the NACA Lewis laboratory during 1948. Three different jet-nozzle diameters were used in the investigation of this engine to determine the effect of nozzle size on engine performance. A limited amount of data was obtained without a jet nozzle attached to the engine tail pipe.

The principal objectives of the investigation were to determine the altitude performance with an 18.00-inch-diameter jet nozzle and to determine the range of simulated-flight conditions over which the performance parameters might be generalized to a single curve. The effect of change in jet-nozzle size on altitude performance was of interest, particularly with reference to engine specific fuel consumption, because a jet nozzle smaller than standard can be used at cruise conditions without exceeding allowable temperatures. A smaller jet nozzle should give higher thrust and possibly lower specific fuel consumption over nearly the entire range of engine speed.

The effects of altitude and flight speed on the over-all engine performance using the standard 18.75- and an 18.41-inch-diameter jet nozzle are presented in references 1 and 2, respectively. The over-all engine performance using an 18.00-inch-diameter jet nozzle is presented herein. Results are presented for simulated-flight conditions varying in altitude from sea level to 65,000 feet and in ram pressure ratio from 1.10 to 3.50. These ram pressure ratios correspond to flight Mach numbers from 0.37 to 1.47, assuming 100-percent ram pressure recovery. The conventional method of reducing data to sea-level conditions (reference 3) was used to determine whether performance could be generalized; 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. A comparison of performance with three jet-nozzle sizes and without a jet nozzle (open tail pipe) is presented as an indication of engine performance with a variable-area jet nozzle; generalization of performance with varying jet-nozzle area, however, is not included.
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); the maximum diameter (cold) is 49.50 inches, giving an effective frontal area of 13.36 square feet. The sea-level engine performance with the standard 18.75-inch-diameter jet nozzle (reference 4), based on Rolls-Royce static test-bed data, is:

<table>
<thead>
<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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<tbody>
<tr>
<td>Take-off</td>
<td>5000</td>
<td>12,250</td>
<td>1.04</td>
</tr>
<tr>
<td>Military</td>
<td>5000</td>
<td>12,250</td>
<td>1.04</td>
</tr>
<tr>
<td>Max. cruise</td>
<td>4000</td>
<td>11,500</td>
<td>1.02</td>
</tr>
<tr>
<td>Idle</td>
<td>120</td>
<td>2,600</td>
<td>----</td>
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</tbody>
</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 tailcone gas temperature is 1365° F with the standard 18.75-inch-diameter jet nozzle.

A sea-level acceptance run of the engine with the standard 18.75-inch-diameter jet nozzle, 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
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, considerable difficulty was encountered with condensation in the orifice differential-pressure lines despite repeated attempts to remedy this situation. Engine air consumption was therefore calculated from pressure and temperature measurements in the tail pipe, as described in the appendix.

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 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 direct circulation of heated air from the region of the tail pipe and combustion chambers into the aft inlet of the compressor. The air so heated 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 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 comprising 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 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. This instrumentation was located approximately 18 inches downstream of the tail cone. In addition, the four standard Nene engine tail-cone thermocouples supplied by Rolls-Royce Ltd. were mounted in the tail cone and were used for engine-control purposes. Pressure and temperature instrumentation was also located at other stations throughout the engine; measurements from this instrumentation are not reported.

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.

Engine speed was measured by an impulse counter, which operated on the frequency of a three-phase generator mounted on the accessory case of the engine. Actions of the counter and a timer were synchronized.

Fuel consumption was measured by a calibrated variable-area-orifice flow meter, which allowed 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 were, in general, reproducible only to within 5 percent with a few points showing even greater scatter.
Procedure

Performance characteristics of the engine were determined over a range of engine speeds at simulated altitudes from sea level to 65,000 feet and ram pressure ratios from 1.10 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 similar to those discussed in reference 1; that is, jet thrust, net thrust (except at low engine speeds), air consumption, and fuel consumption rapidly decrease with an increase in altitude and net-thrust specific fuel consumption generally decreases up to an altitude of approximately 30,000 feet, above which this trend reverses to give higher specific fuel consumption at higher altitudes. Although the data plotted for an altitude of 60,000 feet are too scattered to indicate this reversal conclusively (fig. 8), plots (not included herein) of other data from table II make the reversal in trend evident. This reversal, discussed in reference 1, is a result of decreasing inlet-air temperature, which increases the compressor-tip Mach number, thus 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 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 actual data points therefore in many cases do not fall on the computed curve.

At engine speeds below 10,000 rpm, tail-pipe indicated gas temperature (fig. 9) decreased as altitude was increased to the tropopause and then remained constant with further increase in altitude. At engine speeds above 10,000 rpm, this trend was reversed. This reversal in trend takes place at engine speeds lower than 10,000 rpm for ram pressure ratios greater than the sample 1.30 data 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 1.10 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).

The increase in air density at the engine inlet that accompanies an increase in ram pressure ratio generally increases jet thrust, air consumption, and fuel consumption throughout the range of engine speeds investigated. Net thrust increases with increasing ram pressure ratio at high engine speeds but decreases with increasing ram pressure ratio at low engine speeds. For the sample data shown (altitude of 30,000 ft), the reversal in trend occurs at approximately 10,000 rpm. Net-thrust specific fuel consumption increases with increasing ram pressure ratio. The tail-pipe indicated gas temperature in general decreases slightly with increasing ram pressure ratio. This decrease is small and somewhat inconsistent and could be interpreted as data scatter at the higher engine speeds. As would be expected, an appreciable decrease in temperature occurs at the lower engine speeds where there is a tendency for the engine to windmill.

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

Generalized Performance

Performance data representing engine operation at altitudes from sea level to 65,000 feet and at ram pressure ratios from
1.10 to 3.50 were reduced in the conventional manner (reference 3) 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 at a given corrected engine speed.

**Effect of altitude.** - Typical 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, and tail-pipe indicated gas temperature (figs. 16 to 21, respectively).

The corrected values of jet thrust and net thrust (figs. 16 and 17) generalize for all altitudes up to 30,000 feet. At higher altitudes, the thrust decreases with increase in altitude. This decrease in thrust with altitude is less than that shown in references 1 and 2 because with the 18.00-inch-diameter jet nozzle the engine operates at higher pressure and temperature levels. The decrease in air density with increase in altitude therefore has less effect. Also, because an appreciable scatter exists in the available data for high altitudes, no consistent trend in air consumption with increase in altitude is indicated (fig. 18). Corrected fuel consumption (fig. 19) increases slightly with increase in altitude at high values of corrected speed. Plots of other data from table II show that at low engine speeds, fuel consumption increases rapidly with increase in altitude, as is also shown in references 1 and 2. The corrected net-thrust specific fuel consumption curves (fig. 20) generalize up to an altitude of 20,000 feet. Above 20,000 feet, the corrected specific fuel consumption increases with increase in altitude. The 60,000-foot data points do not fall on the computed curve, as explained in the discussion of figure 8. The corrected tail-pipe indicated gas temperature (fig. 21) generalizes for all altitudes investigated.

**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 submerged. A variation in ram pressure ratio (flight speed) changes the performance characteristics because it has the effect of changing the compression ratio of the engine. In general, the increase in operating pressure that accompanies increase in 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 further increase in ram pressure ratio. The engine is then effectively submerged 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 1.10 to 3.00 are compared to show the effect of ram pressure ratio on the corrected values of jet thrust, jet-thrust parameter $\frac{F_j + P_0 A_j}{S}$, net thrust, air consumption, fuel consumption, net-thrust specific fuel consumption, and tail-pipe indicated gas temperature (figs. 22 to 27, respectively).

Corrected jet thrust (fig. 22(a)) does not generalize but corrected jet-thrust parameter (fig. 22(b)), for which the development is given in reference 1, generalizes for all conditions for which the jet nozzle is choked. The corrected net thrust of figure 23 appears to generalize for ram pressure ratios greater than 1.30 at the higher speeds, but data for ram pressure ratios less than 1.30 do not generalize. Inasmuch as net thrust is a function of jet thrust and air consumption and jet thrust did not generalize, there is no reason to expect net thrust to generalize. At higher flight speeds (ram pressure ratios), however, the momentum of the incoming air is greater for a given mass flow; this larger quantity, when subtracted from the higher jet-thrust values of figure 22(a), causes the corrected net thrust to generalize for ram pressure ratios above 1.30. Corrected air consumption (fig. 24) apparently generalizes at all ram pressure ratios. Corrected fuel consumption generalizes at the high engine speeds when critical flow exists in the jet nozzle (fig. 25). At lower engine speeds the fuel consumption decreases with increase in ram pressure ratio. Net-thrust specific fuel consumption (fig. 26) shows reasonable generalization for ram pressure ratios of 1.30 and above. Data for a ram pressure ratio of 1.10 show slightly lower values of specific fuel consumption. The tail-pipe indicated gas temperature (fig. 27) also generalizes 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 decreases with increase in ram pressure ratio.
Effect of Jet-Nozzle Area on Performance

The performance of the engine using an 18.00-inch-diameter jet nozzle is compared at an altitude of 30,000 feet and a ram pressure ratio of 1.70 with performance using: (a) the standard 18.75-inch-diameter jet nozzle (reference 1); (b) an 18.41-inch-diameter jet nozzle (reference 2); and (c) engine tail pipe without a jet nozzle. The tail-pipe diameter is 22 inches; therefore, the data without a jet nozzle will be referred to as the "22-inch nozzle data." These results are presented in figures 28 to 38. The changes in performance caused by changes in jet-nozzle area follow the expected trends discussed in reference 2. Tail-pipe total pressure increases with decrease in nozzle size (fig. 28). Compressor pressure ratio at a given engine speed remains nearly constant for the range of air flow encountered in this investigation (fig. 29) except at the lower engine speeds. Because turbine-inlet pressure remains nearly constant and tail-pipe total pressure increases with decreasing jet-nozzle area, total-pressure ratio across the turbine decreases with a decrease in jet-nozzle area (fig. 30). In order to maintain the required compressor work per pound of air, which is independent of nozzle size (fig. 31) and represents nearly the entire turbine power output, it is necessary to operate the turbine at a higher temperature level as the jet area is decreased, which results in an increase in both turbine-inlet total temperature (fig. 32) and tail-pipe temperature (fig. 33). Except at the high engine speeds, the increases in turbine-inlet total temperature and in tail-pipe indicated gas temperature are nearly equal.

For critical flow in the turbine nozzles, air flow is essentially proportional to the turbine-inlet pressure, which is nearly constant, and inversely proportional to the square root of turbine-inlet temperature, which increases with a decrease in nozzle size; therefore, air consumption decreases with decreasing jet-nozzle area (fig. 34). Because the air-consumption data included herein, as well as those of references 1 and 2, were not sufficiently consistent to indicate trends of small magnitude, the curves of figure 34 were obtained from a single faired curve for each nozzle size, using corrected data for altitudes up to 30,000 feet at a ram pressure ratio of 1.70. Air consumption generalizes with altitude up to 30,000 feet, as is shown in figure 18; it is therefore possible to invert the correction factors and to apply them to the corrected parameters to obtain a smooth curve of proper magnitude through the actual altitude data points. The air-consumption values of figure 29 were obtained from these same faired curves. The data points of figure 34 are actual altitude data, and when plotted alone, they do not indicate the trend too clearly. The expected increase in fuel consumption accompanies a decrease in
nozzle size (fig. 35). Jet thrust increases with a decrease in nozzle size (fig. 36) because of the increase in tail-pipe total pressure. The trend followed by net thrust (fig. 37) is similar to that for jet thrust. At a ram pressure ratio of 1.70, net-thrust specific fuel consumption (fig. 38) decreases with decrease in nozzle area at most engine speeds; at high engine speeds, the three smaller nozzle sizes give similar values of net-thrust specific fuel consumption, whereas the 22-inch nozzle gives a much higher value. At lower ram pressure ratios (flight speeds), however, the 18.41-inch-diameter jet nozzle gives the lowest value of net-thrust specific fuel consumption over a larger portion of the high-engine-speed range.

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 18.00-inch-diameter jet nozzle:

1. Engine-performance parameters, except for air consumption and tail-pipe indicated gas temperature, could not be predicted for altitudes above 30,000 feet from data obtained at one particular altitude.

2. 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. The 18.00-inch-diameter jet nozzle indicated a lower value of net-thrust specific fuel consumption over substantially the entire range of engine speed investigated than either an 18.41- or the standard 18.75-inch-diameter jet nozzle at an altitude of 30,000 feet and a ram pressure ratio of 1.70. At a ram pressure ratio of 1.30, however, the 18.41-inch-diameter jet nozzle gave the lowest values at high engine speeds. The engine operating without a jet nozzle attached to the tail pipe gave a much higher value of net-thrust specific fuel consumption. Jet thrust, fuel consumption, and tail-pipe indicated gas temperature all increased when smaller jet nozzles were used, whereas air consumption showed a slight decrease.

Lewis Flight Propulsion Laboratory,  
National Advisory Committee for Aeronautics,  
Cleveland, Ohio.
APPENDIX - CALCULATIONS

Symbols

The following symbols are used in the calculations and on the figures:

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)(°F)
T  total temperature, °R
t  static temperature, °R
V  velocity, ft/sec
W_a  air consumption, lb/sec
W_f  fuel consumption, lb/hr
W_g  gas flow, lb/sec
γ  ratio of specific heats
Ratio of compressor-inlet absolute total pressure to absolute static pressure of NACA standard atmosphere at sea level.

Ratio of compressor-inlet absolute total temperature to absolute static temperature of NACA standard atmosphere at sea level.

Subscripts:
- b: barometer
- c: compressor
- 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
- 4: turbine inlet (combustion-chamber discharge)
- 5: tail cone (turbine discharge)
- 6: tail pipe (upstream of jet nozzle)
- 7: jet-nozzle outlet (throat)
Methods of Calculation

Thrust. - Thrust was calculated by adding to the indicated thrust (obtained from the altitude-chamber thrust indicator) a correction factor accounting for the pressure differential across the tail-pipe seal. The relation used was

\[ F'_t = F_t + A_s(P_2 - P_0) \]

where

\[ F_t = K(P_d - P_b) \]

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:

\[ \dot{W}_g = \frac{P_6 A}{\dot{R} t_6} \sqrt{\frac{2 g \Delta H}{A}} \]

where

\[ A = \frac{1}{4} \times \text{tail-pipe area (cold)} \]

\[ \Delta H = \text{enthalpy difference between total- and static-pressure conditions, determined from reference 5} \]

The static temperature in the formula was calculated from the indicated temperature by

\[ t_6 = \frac{T_{6,1}}{1 + 0.8 \left( \frac{T_6}{t_6} - 1 \right)} \]
where the temperature ratio was determined from the tail-pipe total to static pressure ratio by means of reference 5. The factor 0.8 is the selected average value of thermocouple recovery factor based on instrument calibrations.

Engine air consumption was then determined from the following relation by adding the gas flows through the four annular areas and subtracting the fuel flow:

$$\dot{W}_a = \dot{W}_g - \frac{\dot{W}_f}{3600}$$

**Simulated flight speed.** - The simulated flight speed at which the engine was operated was determined from:

$$V_p = \sqrt{\frac{2gR}{\gamma-1} \frac{\gamma}{\gamma-1} t_0 \left[ \left( \frac{P_2}{P_0} \right) \gamma - 1 \right]}$$

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 simulated flight speed.

**Flight Mach number.** - Flight Mach number was calculated from the compressor-inlet total pressure, assuming 100-percent ram pressure recovery

$$M_p = \sqrt{\frac{2}{\gamma-1} \left[ \left( \frac{P_2}{P_0} \right) \frac{\gamma-1}{\gamma} - 1 \right]}$$

where $\gamma$ was assumed to be 1.40.
REFERENCES


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<tr>
<th>Path</th>
<th>Altitude (ft)</th>
<th>Compressibility-factor,</th>
<th>Temperature, °F</th>
<th>Velocity, kn</th>
<th>Atm. pressure, psig</th>
<th>Air composition, %</th>
<th>Viscosity (cst)</th>
<th>Density (lb/ft³)</th>
<th>Weight, lb</th>
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<th>Rolling resistance, hp</th>
<th>Total weight, lb</th>
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**Table I - Performance and Operational Data**

- **Average representing time in altitude chamber. Approximately 23 hr had been accumulated at time of installation in altitude chamber.**

**NACA RM E50A3**
### Obtained at Simulated-Altitude Conditions

| Point | Altitude (ft) | Compressor inlet stagnation pressure, \(P_0\) (psia) | Compressor inlet total pressure, \(P_{0T}\) (psia) | Exit stagnation pressure, \(P_{e0}\) (psia) | Exit total pressure, \(P_{eT}\) (psia) | Exit Mach number, \(M_{e}\) | Air flow, \(Q\) (lbm/s) | Power consumption, \(W_p\) (kW) | Ambient temperature, \(T_a\) (°F) | Fuel consumption, \(W_f\) (lbm/hr) | Special fuel consumption, \(W_{fS}\) (lbm/hr) | Engine oil pressure, \(P_o\) (psi) | Engine oil temperature, \(T_o\) (°F) | Oil temperature, \(T_{oil}\) (°F) | Compressor efficiency, \(\eta_{comp}\) | Oil pressure, \(P_{oil}\) (psi) | Oil temperature, \(T_{oil}\) (°F) | Compressor efficiency, \(\eta_{comp}\) | Oil pressure, \(P_{oil}\) (psi) | Oil temperature, \(T_{oil}\) (°F) | Compressor efficiency, \(\eta_{comp}\) | Oil pressure, \(P_{oil}\) (psi) | Oil temperature, \(T_{oil}\) (°F) |
|-------|---------------|---------------------------------|---------------------------------|-------------------------------|-------------------------------|-----------------|------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1     | 10            | 24.00                            | 58.00                           | 10100                          | 10100                          | 0.78            | 580.25          | 100.00            | 100.00            | 0.05              | 0.05              | 120.00            | 120.00            | 20.00             | 20.00             | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              |
| 2     | 20            | 24.00                            | 58.00                           | 10100                          | 10100                          | 0.78            | 580.25          | 100.00            | 100.00            | 0.05              | 0.05              | 120.00            | 120.00            | 20.00             | 20.00             | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              |
| 3     | 30            | 24.00                            | 58.00                           | 10100                          | 10100                          | 0.78            | 580.25          | 100.00            | 100.00            | 0.05              | 0.05              | 120.00            | 120.00            | 20.00             | 20.00             | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              |
| 4     | 40            | 24.00                            | 58.00                           | 10100                          | 10100                          | 0.78            | 580.25          | 100.00            | 100.00            | 0.05              | 0.05              | 120.00            | 120.00            | 20.00             | 20.00             | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              |
| 5     | 50            | 24.00                            | 58.00                           | 10100                          | 10100                          | 0.78            | 580.25          | 100.00            | 100.00            | 0.05              | 0.05              | 120.00            | 120.00            | 20.00             | 20.00             | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              | 1.00              |

*Average representing time in altitude chamber. Approximately 22 hr had been accumulated at time of installation in altitude chamber.

**Dashes indicate unknown values.**

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<table>
<thead>
<tr>
<th>Point</th>
<th>Altitude (ft)</th>
<th>Ramp pressure ratio</th>
<th>Engine speed (rpm)</th>
<th>Jet thrust (lb)</th>
<th>Net thrust (lb)</th>
<th>Fuel consumption (1b/hr)</th>
<th>Fuel consumption (1b/hr)/(1b/hr)/10000 ft</th>
<th>Net-thrust specific fuel consumption (1b/lb/hr)</th>
<th>Indicated gas temperature (°F)</th>
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Note: The table provides performance data adjusted to standard altitude for various points with different altitude, ramp pressure ratio, engine speed, jet thrust, net thrust, fuel consumption, net-thrust specific fuel consumption, and indicated gas temperature.
<table>
<thead>
<tr>
<th>Point</th>
<th>Altitude (ft)</th>
<th>Engine speed (rpm)</th>
<th>Jet thrust (lb)</th>
<th>Net thrust (lb)</th>
<th>Fuel consumption (lb/hr)</th>
<th>Fuel-thrust specific consumption (lb/hr/lb thrust)</th>
<th>Indicated gas temperature 1000°F</th>
<th>Fall-pipe fall-one 1000°F</th>
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*Numbers indicate unknown values.*
Figure 1. - Cutaway view of British Rolls-Royce Nene II turbojet engine. (Photographed from Rolls-Royce Manual on Nene engine.)
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Ram pressure ratio, 1.30.
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Ram pressure ratio, 1.30.
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Altitude, 30,000 feet.
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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.
Corrected engine speed, $N/\sqrt{\Theta}$, rpm

Figure 16. - Effect of altitude on corrected jet thrust.
Ram pressure ratio, 1.30.
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Figure 19. - Effect of altitude on corrected fuel consumption.
Ram pressure ratio, 1.30.
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Altitude, 30,000 feet; ram pressure ratio, 1.70.
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Altitude, 30,000 feet; ram pressure ratio, 1.70.
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