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RESEARCH MEMORANDUM

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ALTITUDE-WIND-TUNNEL INVESTIGATION OF TURBINE PERFORMANCE IN J47 TURBOJET ENGINE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

ALTITUDE-WIND-TUNNEL INVESTIGATION OF TURBINE PERFORMANCE IN J47 TURBOJET ENGINE

By H. Carl Thorman and John E. McAulay

SUMMARY

Performance characteristics of the turbine in a J47 turbojet engine were determined in an investigation of the complete engine in the NACA Lewis altitude wind tunnel. The engine was operated over a range of engine speeds at various simulated conditions of altitude and flight Mach number with three exhaust nozzles of different outlet area. Turbine performance variables are presented as functions of corrected engine speed.

The turbine operated at an efficiency of approximately 0.80 over a range of corrected engine speeds from 4000 to 8400 rpm at all flight conditions and with exhaust-nozzle-outlet areas ranging from 280 to 342 square inches. With the standard exhaust-nozzle-outlet area, the corrected turbine gas flow was limited to about 39.2 pounds per second by turbine-nozzle choking, and the maximum turbine pressure ratio at a flight Mach number of 0.85 was limited to 2.64 by choking at the exhaust-nozzle outlet. At a given corrected engine speed and with a given exhaust-nozzle-outlet area, the only turbine performance variable affected by changes in altitude at a given flight Mach number was the corrected turbine speed, which decreased as the altitude increased. Increases in flight Mach number at a given altitude raised the corrected turbine speed, the turbine pressure ratio, and the turbine temperature ratio at corrected engine speeds below 7500 rpm. At a given flight condition, enlarging the exhaust-nozzle-outlet area increased the corrected turbine speed, the turbine temperature ratio, and the turbine pressure ratio, and reduced the corrected turbine gas flow at corrected engine speeds above 5000 rpm.

INTRODUCTION

An investigation has been conducted in the NACA Lewis altitude wind tunnel to determine the over-all performance, the component performance, and the operational characteristics of

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a J47 turbojet engine. The investigation was conducted over a wide range of simulated altitudes and flight Mach numbers throughout the operable range of engine speeds. The use of three exhaust nozzles of different outlet area extended the range of engine operation over which the components could be investigated. Overall engine performance, compressor performance, and engine operational characteristics are presented in references 1, 2, and 3, respectively. 1211

Performance data are presented in this report to show the characteristics of the turbine operating as an integral part of the engine. Typical results are graphically presented to show the effects of changes in altitude, flight Mach number, and exhaust-nozzle-outlet area on turbine performance. All turbine-performance data obtained are given in tabular form.

ENGINE AND INSTALLATION

The J47 turbojet engine (fig. 1) used in this investigation has a static sea-level thrust rating of 5000 pounds at an engine speed of 7900 rpm and a turbine-outlet temperature of 1275° F. At this rating, the air flow is 94 pounds per second. The principal components of the engine are a 12-stage axial-flow compressor, eight cylindrical direct-flow-type combustion chambers, a single-stage impluse turbine, a tail pipe, and an exhaust nozzle. The standard exhaust-nozzle-outlet area for the engine investigated was 280 square inches, which was the area with which the limiting turbine-outlet temperature, 1275° F, could be obtained at rated engine speed and approximately static sea-level conditions. Exhaust nozzles having outlet areas of 302 and 342 square inches were also used.

The single-stage impulse turbine (fig. 2) used in this engine delivers approximately 12,000 horsepower at rated sea-level conditions. The turbine drives the compressor directly by means of a hollow shaft. Air is extracted from the compressor for turbine cooling.

The engine was mounted on a wing section that spanned the 20-foot-diameter test section of the altitude wind tunnel (fig. 1). Dry refrigerated air was supplied to the engine inlet through a duct from the tunnel make-up air system.

Pressure and temperature instrumentation was installed at several stations through the engine (fig. 3). Turbine-inlet total pressure was measured by tubes located in the leading edges of five turbine stator blades (fig. 4). Pressure and temperature instrumentation at the turbine outlet is shown in figure 5. Compressor instrumentation is shown in reference 2. Instrumentation at each station was sufficiently extensive to minimize the effects of nonuniform radial and circumferential flow
1211 distribution.

PROCEDURE

Dry refrigerated air was supplied to the engine at the standard temperature for each flight condition, except that the minimum temperature obtained was about -20° F. The air was throttled from approximately sea-level pressure to the total pressure that would exist at the engine inlet with complete free-stream ram-pressure recovery at each flight condition.

Turbine-performance data were obtained with each of the three exhaust nozzles over a range of pressure altitudes from 5000 to 50,000 feet and a range of simulated flight Mach numbers from 0.21 to 0.97. All the turbine data obtained with each exhaust nozzle are presented in table I. The symbols and the methods used to calculate the results are given in the appendix.

Small errors in the pressure and temperature measurements can result in relatively large random errors in the individual values of turbine efficiency and corrected turbine gas flow calculated by the methods shown in the appendix. An analysis of estimated possible errors indicated that the maximum error in the turbine efficiency varies from ±3 percent at high pressure levels to ±8 percent at low pressure levels and the maximum error in the corrected turbine gas flow is approximately ±4 percent. The maximum error in the position of faired curves shown in the graphical presentation of results, however, is considerably less than the maximum error in the individual values of table I.

RESULTS AND DISCUSSION

The performance variables, turbine efficiency, turbine pressure ratio, turbine temperature ratio, corrected turbine speed, and corrected turbine gas flow, are presented as functions of corrected engine speed. By this method of presentation the turbine performance characteristics at any given condition of engine operation may be obtained and correlated with the performance characteristics of the other components. Typical data 1211 are presented in figures 6 to 8 to show the effects of altitude, flight Mach number, and exhaust-nozzle-outlet area on the performance of the turbine operating as an integral part of the engine.

Effect of Altitude

Turbine performance data are presented in figure 6 for engine operation with the standard exhaust-nozzle-outlet area at a flight Mach number of 0.21 over a range of altitudes from 5000 to 45,000 feet. At a given corrected engine speed, changes in altitude had no effect on any of the turbine performance variables except the corrected turbine speed, which was reduced as the altitude increased.

As the corrected engine speed was increased from about 2000 to 8400 rpm, with the standard exhaust-nozzle-outlet area and at a flight Mach number of 0.21, the turbine performance at all altitudes was as follows:

Turbine efficiency. - Within the accuracy of measurement, a constant turbine efficiency of approximately 0.80 was obtained at all corrected engine speeds above 4000 rpm.

Turbine pressure and temperature ratios. - Turbine pressure ratio reached a peak value of 2.60 at a corrected engine speed of 7750 rpm, the speed at which choking occurred in the exhaust nozzle. A peak turbine temperature ratio of 1.21 was obtained at a corrected engine speed of approximately 7000 rpm. The relation between turbine pressure ratio and turbine temperature ratio after exhaust-nozzle choking occurred is discussed subsequently.

Corrected turbine speed. - The reduction in corrected turbine speed when the pressure altitude was increased above 15,000 feet at a constant corrected engine speed was caused by a rise in the ratio of turbine-inlet temperature to engine-inlet temperature. The rise in this temperature ratio was brought about by a decrease in compressor efficiency (reference 2), which was associated with a decrease in compressor-inlet Reynolds number (reference 4). The decrease in compressor efficiency forced the turbine to extract more energy per pound of gas in order to maintain a fixed corrected engine speed; an increase in the ratio of turbine-inlet temperature to engine-inlet temperature was therefore required.

Corrected turbine gas flow. - The corrected turbine gas flow increased with corrected engine speed until the engine reached the corrected speed at which the turbine pressure ratio was about 1.8. At all higher speeds and pressure ratios the corrected gas flow was approximately constant with an average value of 39.2 pounds per second, which indicated that the flow in the turbine-nozzle throat had reached sonic velocity.

Effect of Flight Mach Number

Turbine performance data obtained from engine operation with the standard exhaust-nozzle-outlet area at an altitude of 25,000 feet over a range of flight Mach numbers from 0.21 to 0.97 are presented in figure 7. The effects of flight Mach number on the performance of the turbine operating as an integral part of the engine were as follows:

Turbine efficiency. - Variation of flight Mach number had no apparent effect on the turbine efficiency at a given corrected engine speed.

Turbine pressure and temperature ratios. - At any given corrected engine speed below 7750 rpm, the turbine pressure and temperature ratios were raised as the flight Mach number increased. At corrected engine speeds above 7750 rpm, increases in flight Mach number had no appreciable effect on the turbine pressure and temperature ratios. As the flight Mach number was increased from 0.21 to 0.85, the peak turbine pressure ratio increased from 2.60 at a corrected engine speed of 7750 rpm to 2.64 at 6300 rpm. The peak turbine pressure ratio at each flight Mach number was reached at the corrected engine speed at which exhaust-choking occurred. The peak turbine temperature ratio increased from approximately 1.21 at a corrected engine speed of 7000 rpm to about 1.23 at 6200 rpm as the flight Mach number increased from 0.21 to 0.85.

<u>Corrected turbine speed.</u> - When the flight Mach number was increased at any given corrected engine speed below 7500 rpm, a reduction in the ratio of turbine-inlet temperature to engine-inlet temperature occurred, which increased the corrected turbine speed. At corrected engine speeds above 7500 rpm the corrected turbine speed was raised by an increase in flight Mach number from 0.21 to 0.52, but was unaffected by further increases in flight Mach number. The peak corrected turbine speed at an altitude of 25,000 feet was approximately 4010 rpm at a flight Mach number of 0.21 and approximately 4080 rpm at all flight Mach numbers above 0.52. 1211

<u>Corrected turbine gas flow.</u> - Over the range of corrected engine speeds in which the turbine pressure ratio was greater than 1.8, variations in flight Mach number had no effect on corrected turbine gas flow. At lower corrected engine speeds, corrected gas flow may have been affected by changes in flight Mach number; however, sufficient data to clearly define the trend in this region were not obtained.

Effect of Exhaust-Nozzle Area

Turbine performance data are shown in figure 8 for engine operation with each of the three exhaust-nozzle areas at an altitude of 25,000 feet and a flight Mach number of 0.21. The effects of variation in exhaust-nozzle-outlet area on the turbine performance variables were as follows:

<u>Turbine efficiency.</u> - Within the accuracy of measurement, increases in exhaust-nozzle-outlet area had no discernible effect on turbine efficiency.

<u>Turbine pressure and temperature ratios.</u> - At any given corrected engine speed above 5000 rpm, the turbine pressure and temperature ratios increased when the exhaust-nozzle area was enlarged. When the exhaust-nozzle-outlet area was enlarged from 280 to 342 square inches, the maximum turbine pressure ratio increased from 2.60 to approximately 3.10. At the flight condition for which data are shown in figure 8, exhaust-nozzle choking was encountered only with the standard exhaust-nozzle-outlet area; therefore, with the two larger exhaust-nozzle-outlet areas, maximum turbine pressure ratio was obtained at the highest corrected

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engine speed. The peak turbine temperature ratio increased from 1.21 to 1.26 as the exhaust-nozzle-outlet area increased from 280 to 342 square inches, and the corrected engine speed at which the peak temperature ratio occurred increased from 7000 rpm to approximately 7500 rpm.

Corrected turbine speed. - At any given corrected engine speed, increasing the exhaust-nozzle-outlet area lowered the turbine-inlet temperature and thereby raised the corrected turbine speed. The maximum corrected turbine speed increased from 4000 to 4550 rpm when the exhaust-nozzle-outlet area was enlarged from 280 to 342 square inches at an altitude of 25,000 feet and a flight Mach number of 0.21.

Corrected turbine gas flow. - The corrected turbine gas flow curves shown in figure 8 were obtained by fairing through data for engine operation with each of the three exhaust-nozzle-outlet areas at several altitudes and flight Mach numbers. In the range of corrected engine speeds at which turbine pressure ratios were greater than 1.8, enlarging the exhaust-nozzle-outlet area from 280 to 342 square inches caused a decrease of approximately 2.5 percent in the corrected turbine gas flow. The analytical expression derived in reference 5 indicates that when the turbine nozzle is choked the corrected turbine gas flow is directly proportional to the effective throat area. On the basis of such an analysis, the reduction in corrected turbine gas flow that accompanied an increase in exhaust-nozzle-outlet area can be attributed only to a reduction in the effective flow area at the turbine-nozzle throat.

Effect of Exhaust-Nozzle Choking

The effect of the simultaneous choking of the turbine nozzle and the exhaust nozzle on the turbine temperature and pressure ratios can be shown by means of the following analysis: When the turbine nozzle is choked,

$$\frac{W_g \sqrt{T_4}}{\sqrt{\gamma}\, P_4} = K_4 \qquad (1)$$

where K_4 is proportional to the effective turbine-nozzle throat area modified by a function of γ. Similarly, for a choked exhaust nozzle,

$$\frac{W_g\sqrt{T_6}}{\sqrt{\gamma}\ P_6} = K_6 \tag{2}$$

Dividing equation (2) by equation (1) gives

$$\frac{P_4/P_6}{\sqrt{T_4/T_6}} = C \tag{3}$$

where C is a constant nearly equal to the ratio of the exhaust-nozzle-outlet area to the effective turbine-nozzle throat area.

In addition to the relation between the turbine pressure and temperature ratios given in equation (3), a relation exists among these two variables and the turbine efficiency. Turbine efficiency is defined as

$$\eta_t = \frac{1 - \dfrac{T_6}{T_4}}{1 - \left(\dfrac{P_6}{P_4}\right)^{\frac{\gamma_t - 1}{\gamma_t}}} \tag{4}$$

When the relation shown in equation (3) is applied to equation (4),

$$\eta_t = \frac{1 - C^2\left(\dfrac{P_6}{P_4}\right)^2}{1 - \left(\dfrac{P_6}{P_4}\right)^{\frac{\gamma_t - 1}{\gamma_t}}} \tag{5}$$

Because the effective turbine-nozzle-throat area cannot be accurately measured, experimental values of $\dfrac{P_4/P_6}{\sqrt{T_4/T_6}}$ were plotted as a function of exhaust-nozzle pressure ratio in figure 9 to determine the value of C for operation with the standard exhaust nozzle. For exhaust-nozzle pressure ratios above 1.92 (choking), the value of C was constant at about 2.38.

The relation between turbine efficiency η_t and turbine pressure ratio P_4/P_6 as given by equation (5) is shown graphically in figure 10 for operation with the standard exhaust nozzle, where C was 2.38 and γ_t ranged from 1.31 to 1.35. This relation shows analytically that when the turbine nozzle and exhaust nozzle are simultaneously choked any appreciable change in the pressure ratio
1211 across the turbine must result from large changes in turbine efficiency. If the turbine efficiency range is limited to the range between 0.76 and 0.84 shown in figures 6(a) and 7(a), the pressure ratio must be between 2.58 and 2.65 and the corresponding limits on the temperature ratio, as calculated from equation (3), are 1.18 and 1.24. This analysis is confirmed by the experimental data presented in figures 6 and 7.

SUMMARY OF RESULTS

From an investigation of a complete J47 turbojet engine in the NACA Lewis altitude wind tunnel, the turbine performance is summarized as follows:

1. A constant turbine efficiency of approximately 0.80 was obtained over a range of corrected engine speeds from 4000 to 8400 rpm at all flight conditions and with exhaust-nozzle-outlet areas ranging from 280 to 342 square inches.

2. When the engine was operated with the standard exhaust-nozzle-outlet area, choking at the turbine-nozzle throat limited the corrected turbine gas flow to approximately 39.2 pounds per second, and choking at the exhaust-nozzle outlet limited the maximum turbine pressure ratio to a value of 2.64 at a flight Mach number of 0.85.

3. Increases in altitude at a given flight Mach number and corrected engine speed caused a decrease in the corrected turbine speed, but had no effect on turbine pressure ratio, turbine temperature ratio, or corrected turbine gas flow.

4. Increases in flight Mach number at a given altitude increased the corrected turbine speed at any corrected engine speed below 7500 rpm. When the exhaust nozzle was not choked, the

turbine pressure and temperature ratios at a given corrected engine speed were also raised by increases in flight Mach number. At turbine pressure ratios above 1.8, variations in flight Mach number had no effect on the corrected turbine gas flow.

5. At any given corrected engine speed above 5000 rpm at a given flight condition, enlarging the exhaust-nozzle-outlet area increased the corrected turbine speed and the turbine pressure and temperature ratios and decreased the corrected turbine gas flow.

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6. In the region of exhaust-nozzle choking the turbine pressure ratio was approximately proportional to the square root of the turbine temperature ratio, and increases in corrected engine speed caused very little change in these two variables.

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APPENDIX - CALCULATIONS

Symbols

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

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A	cross-sectional area, sq ft
C	constant derived in equation (3)
c_p	specific heat at constant pressure, Btu/(lb)(°R)
g	acceleration due to gravity, 32.17 ft/sec^2
H	enthalpy, Btu/lb
K	constant of proportionality
M_0	Flight Mach number
N	engine speed, rpm
P	total pressure, lb/sq ft absolute
P_1/p_0	ram-pressure ratio
P_4/P_6	turbine pressure ratio
P_6/p_0	exhaust-nozzle pressure ratio
p	static pressure, lb/sq ft absolute
R	gas constant, 53.3 ft-lb/(lb) (°R)
T	total temperature, °R
T_4/T_6	turbine temperature ratio
T_i	indicated temperature, °R
t	static temperature, °R
V	velocity, ft/sec

W_a air flow, lb/sec

W_f fuel flow, lb/hr

W_g gas flow, lb/sec

W_y compressor leakage air flow, lb/sec

W_z aft turbine cooling-air flow, lb/sec 1211

γ ratio of specific heats for gases

δ pressure correction factor, P/2116 (total pressure divided by NACA standard sea-level pressure)

η_t turbine adiabatic efficiency

θ temperature correction factor, $\gamma T/(1.4)(519)$ (product of γ and total temperature divided by product of γ and temperature for air at NACA standard sea-level conditions)

Subscripts:

0 free-stream conditions

1 engine inlet

2 compressor inlet

3 compressor outlet

4 turbine inlet

6 turbine outlet

7 exhaust-nozzle outlet

c compressor

n turbine-nozzle throat

t turbine

Generalized parameters:

$\dfrac{W_{g,4}\sqrt{\theta_4}}{\delta_4\gamma_4/1.4}$ corrected turbine gas flow, lb/sec

$N/\sqrt{\theta_1}$ corrected engine speed, rpm

$N/\sqrt{\theta_4}$ corrected turbine speed, rpm

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Methods of Calculation

Flight Mach number. - Simulated flight Mach number was calculated from ram-pressure ratio by the following relation, in which complete ram-pressure recovery at the engine inlet is assumed:

$$M_0 = \sqrt{\frac{2}{\gamma_1 - 1}\left[\left(\frac{P_1}{p_0}\right)^{\frac{\gamma_1 - 1}{\gamma_1}} - 1\right]} \tag{6}$$

Temperatures. - Static temperature was calculated from indicated temperature, using the impact recovery factor of 0.85 for the type of thermocouple used.

$$t = \frac{T_i}{1 + 0.85\left[\left(\frac{P}{p}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]} \tag{7}$$

Total temperature was calculated by the use of the adiabatic relation between temperatures and pressures.

Temperature measurements were obtained by means of thermocouples at all stations except the turbine inlet, station 4. Because direct measurement of temperature at this station was not practical, turbine-inlet total temperature was evaluated by the following method:

Neglecting accessory power and bearing friction, the turbine power equals the power requirements of the compressor.

$$W_{g,4}(H_4-H_6) = W_{a,1}(H_3-H_1) \tag{8}$$

or

$$H_4 = H_6 + \frac{W_{a,1}}{W_{g,4}}(H_3-H_1) \tag{8a}$$

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With measured values of T_1, T_3, and T_6, values of H_1, H_3, and H_6 were obtained from a temperature-enthalpy chart and used in equation (8a) to calculate H_4. The turbine-inlet temperature T_4 was then determined from H_4 by means of the temperature-enthalpy chart.

Turbine gas flow. - The gas flow through the turbine is given by the following equation:

$$W_{g,4} = W_a - W_y - W_z + \frac{W_f}{3600} \tag{9}$$

Compressor leakage air flow W_y and aft turbine cooling-air flow W_z were determined from temperature and pressure measurements. Fuel flow W_f was measured by a calibrated rotameter. Engine-inlet air flow W_a was determined from temperature and pressure measurements in the inlet cowl by use of the equation

$$W_a = p_1 A_1 \sqrt{\frac{2\gamma_1 g}{(\gamma_1-1)Rt_1}\left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma_1-1}{\gamma_1}}-1\right]} \tag{10}$$

Turbine efficiency. - Adiabatic efficiency of the turbine was calculated as follows:

$$\eta_t = \frac{c_{p,t}(T_4-T_6)}{c_{p,t}T_4\left[1-\left(\frac{P_6}{P_4}\right)^{\frac{\gamma_t-1}{\gamma_t}}\right]} \qquad (11)$$

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The numerator is the actual enthalpy drop across the turbine and the denominator is the adiabatic enthalpy drop across the turbine. From equation (11), the turbine efficiency may be expressed as follows:

$$\eta_t = \frac{1-\frac{T_6}{T_4}}{1-\left(\frac{P_6}{P_4}\right)^{\frac{\gamma_t-1}{\gamma_t}}} \qquad (11a)$$

Values of γ_t were based on the average temperature $\left(\frac{T_4+T_6}{2}\right)$ and the fuel-air ratio of the gases flowing through the turbine.

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TABLE I - TURBINE PERFORMANCE

Run	Altitude (ft)	Ram-pressure ratio P_1/p_0	Flight Mach number M_0	Tunnel static pressure p_0 (lb/sq ft abs.)	Engine speed N (rpm)	Corrected engine speed $N/\sqrt{\theta_1}$ (rpm)	Compressor-inlet total temperature T_1 (°R)	Compressor-outlet total temperature T_3 (°R)	Turbine-inlet total pressure P_4 (lb/sq ft abs.)	Turbine-inlet total temperature T_4 (°R)	Turbine-outlet total pressure P_6 (lb/sq ft abs.)
Exhaust-nozzle outlet area, 280 square inches											
1	5,000	1.038	0.230	1740	7895	7950	512	902	8977	2080	3465
2	5,000	1.037	.225	1756	7692	7730	514	885	8726	1960	3352
3	5,000	1.039	.230	1740	7500	7553	512	873	8599	1868	3247
4	5,000	1.036	.220	1748	6993	7035	513	837	7657	1694	2984
5	5,000	1.034	.215	1742	6459	6504	512	798	6650	----	2679
6	5,000	1.033	.210	1744	5944	5992	511	755	5627	1597	2403
7	5,000	1.033	.210	1740	5024	5069	510	684	4043	1263	2083
8	5,000	1.034	.215	1749	4091	4132	509	622	2954	1238	1924
9	5,000	1.032	.210	1745	3147	3178	509	574	2563	1230	1832
10	5,000	1.032	.210	1738	2046	2066	509	532	1966	1151	1769
11	15,000	1.034	.215	1188	6993	7252	483	806	5447	1675	2102
12	15,000	1.030	.205	1188	6459	6698	483	769	4807	1507	1896
13	15,000	1.030	.205	1188	5944	6188	479	726	4148	1370	1707
14	15,000	1.030	.205	1186	5024	5250	475	650	2973	1197	1454
15	15,000	1.028	.195	1186	4091	4275	475	587	2111	1160	1320
16	15,000	1.031	.205	1190	3147	3292	474	537	1644	1179	1261
17	15,000	1.028	.195	1188	2046	2146	472	497	1374	1130	1213
18	15,000	1.204	.525	1186	7895	8045	500	902	7002	2100	2685
19	15,000	1.210	.530	1186	7692	7808	504	877	6898	1945	2625
20	15,000	1.211	.530	1186	7500	7590	507	867	6681	1865	2549
21	15,000	1.205	.525	1190	6993	7084	506	830	6101	1658	2334
22	15,000	1.203	.520	1188	6459	6530	508	790	5237	1459	2029
23	15,000	1.203	.520	1190	5944	6021	506	745	4369	1287	1765
24	15,000	1.204	.525	1185	5024	5094	505	666	3028	1065	1458
25	15,000	1.203	.520	1190	4091	4140	507	604	2162	975	1340
26	15,000	1.203	.520	1190	3147	3194	504	552	1642	850	1258
27	25,000	1.037	.225	777	7692	8238	452	846	4300	2120	1661
28	25,000	1.037	.225	774	7500	8010	455	819	4028	1899	1549
29	25,000	1.036	.220	777	6993	7462	456	779	3713	1680	1435
30	25,000	1.033	.210	779	6459	6898	455	742	3345	1500	1310
31	25,000	1.033	.210	778	5944	6342	456	703	2856	1350	1155
32	25,000	1.031	.205	778	5024	5366	455	633	2021	1190	972
33	25,000	1.030	.205	777	4091	4365	456	575	1442	1150	870
34	25,000	1.030	.205	774	3147	3358	456	521	1098	1155	815
35	25,000	1.030	.205	774	2046	2185	455	485	895	1185	790
36	25,000	1.207	.525	761	7895	8513	468	879	4955	2135	1900
37	25,000	1.209	.530	774	7692	8115	466	851	4793	2000	1834
38	25,000	1.211	.530	781	7500	8003	456	817	4717	1867	1811
39	25,000	1.213	.535	774	6993	7462	456	774	4340	1642	1658
40	25,000	1.211	.530	778	6459	6872	458	737	3848	1450	1469
41	25,000	1.208	.530	785	5944	6313	460	698	3283	1266	1269
42	25,000	1.203	.520	778	5024	5300	466	628	2251	1060	999
43	25,000	1.202	.520	781	4091	4316	466	586	1506	936	885
44	25,000	1.204	.525	781	3147	3323	465	520	1179	843	833
45	25,000	1.199	.515	778	2727	2888	463	499	1024	790	816
46	25,000	1.412	.720	774	7895	8306	469	869	5717	2106	2199
47	25,000	1.403	.715	776	7692	8038	475	856	5546	2005	2133
48	25,000	1.403	.715	781	7500	7815	478	835	5308	1845	2022
49	25,000	1.413	.720	780	6993	7287	478	799	4909	1649	1867
50	25,000	1.410	.720	783	6459	6737	477	758	4295	1432	1631
51	25,000	1.415	.725	781	5944	6182	480	716	3498	1208	1350
52	25,000	1.406	.720	781	5024	5240	477	635	2366	935	1036
53	25,000	1.603	.850	778	7895	8116	491	---	----	----	2411
54	25,000	1.567	.830	776	7692	7869	496	875	6155	1985	2351
55	25,000	1.611	.855	774	7500	7658	498	860	5872	1863	2237
56	25,000	1.611	.855	781	6993	7119	501	823	5395	1651	2048
57	25,000	1.609	.850	781	6459	6575	501	780	4625	1417	1744
58	25,000	1.603	.850	781	5944	6069	498	727	3724	1155	1416
59	25,000	1.612	.855	781	5024	5109	502	654	2468	875	1059
60	25,000	1.857	.982	746	7895	8029	502	887	6909	2038	2659
61	25,000	1.817	.965	778	7692	7754	511	882	6803	1955	2598
62	25,000	1.839	.975	774	7500	7545	513	874	6620	1870	2532
63	25,000	1.840	.975	774	6993	7028	514	838	5974	1655	2292
64	25,000	1.837	.975	773	6459	----	---	794	5060	----	1917
65	25,000	1.820	.965	774	5944	----	---	740	3960	----	1498
66	35,000	1.032	.210	496	7692	8318	444	845	2766	2150	1063
67	35,000	1.034	.215	493	7500	8100	445	825	2616	2015	1010
68	35,000	1.036	.220	496	6993	7545	448	777	2414	1725	928
69	35,000	1.032	.210	496	6459	6976	445	738	2170	1535	846
70	35,000	1.030	.205	493	5944	6420	445	697	1827	1370	740
71	35,000	1.030	.205	494	5024	5426	445	627	1329	1190	617
72	35,000	1.028	.195	497	4091	4414	446	568	944	1185	563
73	35,000	1.204	.525	494	7692	8277	448	841	3124	2060	1199

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DATA FOR J47 TURBOJET ENGINE

Turbine-outlet total temperature T_6 (°R)	Fuel flow W_f (lb/hr)	Engine-inlet air flow W_a (lb/sec)	Compressor leakage air flow W_y (lb/sec)	Aft turbine cooling-air flow W_z (lb/sec)	Turbine gas flow $W_{g,4}$ (lb/sec)	Turbine pressure ratio P_4/P_6	Turbine temperature ratio T_4/T_6	Corrected turbine speed $N/\sqrt{\theta_4}$ (rpm)	Corrected turbine gas flow $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4(\gamma_4/1.4)}$ (lb/sec)	Adiabatic turbine efficiency η_t	Run
Exhaust-nozzle outlet area, 280 square inches											
1740	5300	81.08	1.74	0.42	80.39	2.591	1.196	4076	39.16	0.798	1
1631	4800	81.07	1.66	.40	80.34	2.603	1.202	4085	39.11	.799	2
1542	4390	80.28	1.71	.39	79.40	2.587	1.211	4072	39.09	.835	3
1396	3550	76.94	1.55	.36	76.02	2.566	1.213	3971	38.93	.830	4
1268	2710	70.23	----	.32	-----	2.482	-----	----	-----	----	5
1170	2060	63.66	.98	.24	63.01	2.342	1.194	3692	39.64	.816	6
1096	1350	48.05	.80	.22	47.41	1.941	1.152	3271	39.34	.817	7
1125	1050	34.21	.82	.16	33.52	1.535	1.100	2690	37.69	.848	8
1167	820	23.73	.84	.10	23.02	1.290	1.054	2076	32.26	.787	9
1134	474	16.42	.87	.06	15.62	1.111	1.015	1393	25.39	.531	10
1386	2550	56.41	1.01	.26	55.85	2.591	1.209	3992	39.99	.806	11
1254	2020	51.80	.87	.22	51.27	2.535	1.202	3875	39.30	.789	12
1145	1550	46.67	.78	.20	46.12	2.430	1.197	3727	38.97	.789	13
1034	980	36.00	.39	.15	35.73	2.045	1.158	3356	39.20	.782	14
1060	768	24.58	.38	.10	24.31	1.599	1.094	2775	36.91	.730	15
1119	605	19.42	.36	.05	19.18	1.304	1.054	2118	37.73	.742	16
1105	371	8.58	.39	.02	8.27	1.110	1.023	1405	19.45	.822	17
1754	4130	62.37	1.44	.33	61.75	2.608	1.197	4057	38.82	.800	18
1614	3730	64.50	1.42	.32	63.80	2.628	1.205	4096	39.08	.809	19
1544	3395	64.09	1.39	.31	63.33	2.621	1.208	4074	39.14	.812	20
1362	2720	61.72	1.27	.28	60.93	2.614	1.217	4010	38.73	.827	21
1200	1990	56.77	1.04	.25	56.03	2.581	1.216	3931	38.76	.811	22
1058	1380	50.82	.85	.22	50.13	2.475	1.216	3837	38.89	.830	23
914	770	38.87	.54	.16	38.38	2.077	1.165	3548	38.84	.783	24
880	549	27.95	.50	.11	27.49	1.613	1.108	3010	37.16	.789	25
801	361	21.99	.20	.05	21.84	1.305	1.061	2472	36.23	.783	26
1783	2610	38.38	.70	.20	38.21	2.589	1.189	3937	39.31	.780	27
1580	2200	38.02	.55	.20	37.88	2.600	1.202	4039	39.24	.806	28
1388	1780	37.39	.59	.18	37.11	2.587	1.210	3987	39.06	.816	29
1244	1420	35.39	.33	.16	35.29	2.554	1.206	3884	38.84	.793	30
1121	1070	31.96	.55	.14	31.57	2.473	1.204	3752	38.43	.801	31
1011	702	24.64	.41	.11	24.32	2.079	1.177	3356	39.03	.844	32
1034	560	18.10	.44	.07	17.75	1.658	1.112	2785	39.33	.795	33
1095	440	12.24	.45	.04	11.87	1.347	1.055	2139	34.63	.678	34
1152	366	8.70	.46	.02	8.32	1.133	1.029	1375	30.18	.847	35
1781	3025	44.26	.95	.24	43.91	2.608	1.199	4026	39.34	.810	36
1661	2725	44.25	.82	.23	43.96	2.614	1.204	4048	39.31	.815	37
1549	2550	45.17	.76	.22	44.90	2.605	1.205	4072	39.36	.810	38
1359	2030	44.24	.55	.20	44.05	2.618	1.208	4031	39.17	.798	39
1200	1590	41.79	.52	.18	41.53	2.619	1.208	3946	38.99	.781	40
1045	1139	38.14	.44	.16	37.86	2.571	1.211	3867	38.95	.786	41
900	600	28.06	.43	.12	27.68	2.233	1.178	3553	37.91	.766	42
851	425	21.02	.45	.08	20.61	1.702	1.126	3069	39.20	.820	43
785	306	15.02	.50	.05	14.56	1.415	1.074	2484	33.52	.746	44
753	266	13.71	.51	.03	13.24	1.255	1.049	2221	33.93	.760	45
1763	3410	51.82	1.20	.28	51.28	2.600	1.195	4051	39.54	.796	46
1673	3150	50.79	1.12	.27	50.28	2.600	1.198	4040	38.93	.802	47
1530	2750	50.75	1.05	.26	50.20	2.625	1.206	4096	38.80	.805	48
1358	2220	50.34	.96	.23	49.77	2.630	1.214	4021	39.21	.812	49
1174	1660	47.59	.79	.21	47.05	2.634	1.220	3968	39.28	.806	50
982	1020	43.26	.63	.18	42.73	2.591	1.230	3952	39.96	.827	51
780	469	32.96	.38	.14	32.57	2.284	1.199	3769	39.33	.808	52
1701	3660	57.76	1.41	.30	57.07	-----	-----	----	-----	----	53
1655	3440	49.44	1.33	.29	48.78	2.618	1.199	4059	33.88	.801	54
1546	3050	56.50	1.24	.28	55.83	2.625	1.205	4074	39.27	.803	55
1359	2420	54.06	1.13	.25	53.35	2.634	1.215	4019	38.26	.812	56
1157	1680	50.99	.92	.22	50.32	2.652	1.225	3985	38.77	.844	57
941	970	45.33	.69	.19	44.72	2.630	1.227	4035	38.43	.805	58
717	346	35.63	.45	.14	35.14	2.330	1.220	3889	39.35	.854	59
1705	4000	63.45	1.51	.33	62.72	2.598	1.195	4114	39.30	.793	60
1629	3730	63.95	1.47	.32	63.20	2.618	1.200	4087	39.33	.795	61
1554	3400	63.83	1.35	.30	63.12	2.614	1.203	4070	39.36	.801	62
1365	2640	61.07	1.28	.27	60.25	2.606	1.212	4015	39.07	.812	63
----	1790	-----	1.01	---	-----	2.639	-----	----	-----	----	64
----	930	-----	.68	---	-----	2.643	-----	----	-----	----	65
1814	1719	24.42	.43	.12	24.35	2.602	1.185	3911	39.24	.767	66
1681	1505	24.43	.46	.12	24.27	2.590	1.199	3929	39.96	.805	67
1428	1184	24.05	.46	.11	23.81	2.601	1.208	3938	39.10	.809	68
1273	944	22.87	.47	.10	22.56	2.565	1.206	3842	38.71	.794	69
1138	723	20.57	.35	.09	20.33	2.469	1.204	3727	39.01	.806	70
1018	497	15.99	.35	.07	15.71	2.154	1.169	3367	38.44	.778	71
1062	381	11.23	.31	.05	10.98	1.677	1.116	2748	37.75	.804	72
1723	1870	28.55	.51	.15	28.41	2.606	1.196	3988	39.60	.794	73

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TABLE I - TURBINE PERFORMANCE DATA

Run	Altitude (ft)	Ram-pressure ratio P_1/p_0	Flight Mach number M_0	Tunnel static pressure p_0 (lb/sq ft abs.)	Engine speed N (rpm)	Corrected engine speed $N/\sqrt{\theta_1}$ (rpm)	Compressor-inlet total temperature T_1 (°R)	Compressor-outlet total temperature T_3 (°R)	Turbine-inlet total pressure P_4 (lb/sq ft abs.)	Turbine-inlet total temperature T_4 (°R)	Turbine-outlet total pressure P_6 (lb/sq ft abs.
Exhaust-nozzle outlet area, 280 square inches											
74	35,000	1.211	0.530	493	7500	8070	448	818	3023	1915	1159
75	35,000	1.208	.530	495	6993	7517	449	774	2754	1675	1056
76	35,000	1.200	.520	496	6459	6956	447	734	2463	1470	945
77	35,000	1.202	.520	496	5944	6396	448	692	2091	1276	817
78	35,000	1.198	.515	495	5024	5421	446	615	1438	1037	644
79	35,000	1.409	.720	494	7800	8393	448	853	3705	2124	1427
80	35,000	1.411	.720	494	7692	8284	447	839	3652	2061	1403
81	35,000	1.411	.720	496	7500	8093	446	812	3522	1902	1350
82	35,000	1.413	.720	496	6993	7552	445	766	3270	1655	1236
83	35,000	1.407	.720	496	6459	6982	444	727	2900	1449	1101
84	35,000	1.411	.720	494	5944	6443	442	682	2450	1230	924
85	35,000	1.405	.715	496	5455	5913	442	638	1982	1032	772
86	45,000	1.037	.225	298	7500	8130	442	836	1657	2130	637
87	45,000	1.029	.200	308	6993	7545	446	787	1505	1810	582
88	45,000	1.037	.225	297	6459	6995	443	741	1322	1585	510
89	45,000	1.033	.210	306	5944	6420	445	702	1134	1415	466
90	45,000	1.030	.205	305	5024	5431	444	632	802	1260	378
91	45,000	1.206	.528	301	7692	8307	445	852	1927	2179	750
92	45,000	1.209	.530	301	7500	8093	446	829	1858	2040	713
93	45,000	1.198	.515	303	6993	7559	444	778	1686	1745	648
94	45,000	1.204	.525	304	6459	6995	443	731	1511	1510	578
95	45,000	1.205	.525	303	5944	6437	443	691	1275	1315	502
96	45,000	1.203	.520	296	5024	5441	443	620	872	1080	388
97	50,000	1.027	.190	225	7500	8123	443	843	1239	2145	469
98	50,000	1.025	.185	236	6993	7573	443	790	1159	1858	446
99	50,000	1.025	.185	238	6459	7008	441	740	1031	1610	404
100	50,000	1.025	.185	239	5944	6455	440	702	901	1458	365
Exhaust-nozzle outlet area, 302 square inches											
1	5,000	1.036	0.220	1740	7895	8077	496	869	8573	1817	3066
2	5,000	1.033	.215	1746	7692	7861	497	853	8301	1733	2993
3	5,000	1.036	.220	1753	7500	7658	498	841	8105	1652	2935
4	5,000	1.033	.215	1747	6993	7133	499	808	7456	1516	2742
5	5,000	1.030	.206	1745	6459	6575	501	770	6581	1389	2495
6	5,000	1.030	.206	1745	5944	6051	501	734	5612	1290	2306
7	5,000	1.030	.206	1754	5024	5114	501	668	4096	1170	2087
8	5,000	1.029	.198	1746	4091	4173	499	612	2975	1155	1906
9	5,000	1.028	.196	1745	3147	3213	498	562	2355	1162	1827
10	5,000	1.029	.198	1748	2046	2091	497	525	1982	1119	1779
11	15,000	1.035	.220	1186	7895	8227	478	857	6033	1860	2163
12	15,000	1.034	.215	1186	7692	8015	478	837	5775	1720	2070
13	15,000	1.034	.215	1190	7500	7830	476	821	5651	1673	2029
14	15,000	1.033	.210	1191	6993	7301	476	787	5257	1500	1917
15	15,000	1.030	.205	1189	6459	6750	475	751	4688	1370	1765
16	15,000	1.029	.198	1190	5944	6217	474	712	4041	1260	1612
17	15,000	1.028	.197	1188	5024	5250	475	646	2913	1132	1410
18	15,000	1.029	.198	1186	4091	4300	470	580	2103	1092	1300
19	15,000	1.030	.205	1183	3147	3301	472	535	1623	1118	1238
20	15,000	1.029	.198	1188	2046	2142	473	---	----	----	1206
21	25,000	1.031	.203	785	7895	8400	458	848	4079	1900	1467
22	25,000	1.032	.203	781	7692	8169	460	825	3872	1763	1397
23	25,000	1.031	.203	781	7500	7980	458	806	3770	1668	1357
24	25,000	1.029	.200	781	6993	7441	458	767	3502	1497	1278
25	25,000	1.029	.200	781	6459	6918	452	727	3196	1361	1192
26	25,000	1.028	.198	781	5944	6378	451	---	2776	----	1089
27	25,000	1.029	.200	781	5024	5391	451	621	1999	1092	943
28	25,000	1.028	.198	781	4091	4349	459	569	1411	1102	866
29	25,000	1.032	.203	783	3147	3336	462	523	1080	1110	823
30	25,000	1.031	.203	774	2046	2167	463	488	891	1086	788
31	25,000	1.402	.712	776	7895	8266	473	852	5333	1828	1895
32	25,000	1.398	.710	781	7692	8046	474	833	5109	1697	1661
33	25,000	1.405	.720	778	7500	7823	477	821	4943	1630	1752
34	25,000	1.408	.720	781	6993	7287	478	787	4588	1440	1618
35	25,000	1.405	.720	780	6459	6724	479	749	4006	1267	1415
36	25,000	1.406	.720	781	5944	6182	480	708	3348	1101	1216
37	25,000	1.411	.720	776	5024	5230	479	636	2322	775	987
38	25,000	1.393	.707	778	4091	4255	480	575	1547	760	871
39	25,000	1.824	.969	774	7895	8116	491	863	6692	1797	2369
40	25,000	1.829	.970	767	7692	7900	492	848	6424	1701	2267
41	25,000	1.813	.963	781	7500	7703	492	835	6283	1620	2218
42	25,000	1.827	.969	781	6993	7175	493	798	5793	1430	2036
43	25,000	1.832	.971	779	6459	6614	495	758	4968	1231	1749
44	25,000	1.817	.964	781	5944	6093	494	713	4053	1038	1405
45	35,000	1.030	.200	494	7895	8424	456	861	2607	1992	940
46	35,000	1.032	.203	494	7692	8207	456	833	2507	1842	909

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FOR J47 TURBOJET ENGINE - Continued

Turbine-outlet total temperature T_6 (°R)	Fuel flow W_f (lb/hr)	Engine-inlet air flow W_a (lb/sec)	Compressor leakage air flow W_y (lb/sec)	Aft turbine cooling-air flow W_z (lb/sec)	Turbine gas flow $W_{g,4}$ (lb/sec)	Turbine pressure ratio P_4/P_6	Turbine temperature ratio T_4/T_6	Corrected turbine speed $N/\sqrt{\theta_4}$ (rpm)	Corrected turbine gas flow $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4(\gamma_4/1.4)}$ (lb/sec)	Adiabatic turbine efficiency η_t	Run
Exhaust-nozzle outlet area, 280 square inches											
1598	1690	28.66	0.51	0.15	28.47	2.608	1.198	4024	39.47	0.789	74
1586	1300	28.26	.48	.15	28.01	2.608	1.209	3992	39.66	.800	75
1215	1000	24.25	.50	.12	25.91	2.606	1.212	3919	38.26	.795	76
1051	760	24.32	.28	.11	24.14	2.560	1.214	3852	38.96	.799	77
876	430	18.82	.23	.08	18.63	2.233	1.184	3591	39.10	.784	78
1782	2295	33.74	.68	.18	33.52	2.596	1.192	3987	40.06	.789	79
1724	2165	33.83	.69	.17	33.57	2.603	1.195	3988	40.02	.794	80
1579	1950	34.14	.59	.17	33.92	2.609	1.205	4037	40.20	.810	81
1373	1550	33.76	.58	.15	33.46	2.646	1.205	4015	39.64	.781	82
1197	1175	32.19	.55	.14	31.83	2.634	1.211	3946	39.61	.783	83
998	820	29.09	.36	.12	28.84	2.630	1.232	3921	39.25	.827	84
849	544	26.10	.30	.11	25.84	2.567	1.216	3905	39.31	.777	85
1793	1030	14.72	.39	.08	14.54	2.601	1.188	3829	38.90	.774	86
1510	788	14.43	.40	.07	14.18	2.586	1.199	3853	38.31	.792	87
1516	615	13.78	.38	.06	13.51	2.592	1.204	3786	38.69	.787	88
1176	474	12.42	.39	.05	12.11	2.434	1.203	3672	38.09	.816	89
1076	326	9.81	.40	.04	9.46	2.122	1.171	3277	39.57	.807	90
1830	1225	17.28	.38	.09	17.15	2.569	1.191	3885	39.93	.795	91
1710	1093	17.77	.38	.09	17.60	2.606	1.193	3906	41.03	.780	92
1456	847	16.67	.31	.08	16.52	2.602	1.198	3917	39.04	.781	93
1253	655	16.18	.27	.07	16.02	2.614	1.205	3870	39.12	.776	94
1087	497	14.87	.18	.07	14.76	2.540	1.210	3801	39.66	.794	95
915	271	11.35	.14	.05	11.23	2.247	1.180	3521	39.78	.771	96
1812	773	10.97	.19	.06	10.93	2.642	1.184	3817	39.28	.750	97
1554	637	11.00	.20	.05	10.93	2.599	1.196	3807	38.89	.780	98
1546	493	10.34	.18	.05	10.25	2.552	1.196	3760	37.98	.774	99
1221	416	9.62	.19	.04	9.51	2.469	1.194	3622	38.23	.780	100
Exhaust-nozzle outlet area, 302 square inches											
1485	4320	81.86	1.66	0.43	80.97	2.796	1.224	4341	38.45	0.811	1
1415	3910	81.82	1.56	.42	80.93	2.773	1.225	4324	38.72	.813	2
1351	3600	81.83	1.51	.40	80.92	2.762	1.223	4310	38.64	.804	3
1236	3000	78.55	1.38	.37	77.63	2.719	1.226	4183	38.53	.814	4
1138	2400	72.30	1.21	.33	71.43	2.658	1.220	4023	38.28	.806	5
1071	1850	64.11	1.01	.29	63.32	2.434	1.204	3832	38.25	.808	6
1013	1230	49.38	.61	.23	48.88	1.963	1.155	3391	38.41	.808	7
1052	999	36.38	.28	.16	36.22	1.561	1.098	2780	38.94	.791	8
1101	768	25.40	.22	.10	25.29	1.289	1.055	2131	34.44	.802	9
1097	502	15.06	.11	.06	15.03	1.114	1.020	1410	23.88	.690	10
1522	3160	56.71	1.15	.31	56.13	2.789	1.222	4293	38.37	.812	11
1415	2760	56.66	1.06	.30	56.07	2.789	1.216	4338	38.41	.781	12
1357	2570	56.30	1.00	.29	55.72	2.785	1.233	4285	38.43	.829	13
1220	2120	55.33	.96	.26	54.70	2.742	1.230	4204	38.26	.813	14
1115	1710	51.61	.79	.23	51.07	2.656	1.229	4051	38.17	.823	15
1034	1320	46.65	.68	.20	46.14	2.507	1.218	3876	38.25	.824	16
969	890	35.04	.41	.15	34.73	2.066	1.168	3446	37.75	.808	17
990	728	25.43	.28	.10	25.25	1.618	1.103	2852	37.27	.766	18
1059	585	18.37	.23	.05	18.25	1.311	1.056	2171	35.37	.754	19
1061	396	11.60	0	0	11.71	-----	-----	----	-----	----	20
1555	2200	37.77	.76	.21	37.41	2.781	1.222	4253	38.27	.820	21
1440	1940	37.39	.70	.20	37.03	2.772	1.224	4290	38.33	.816	22
1356	1760	37.31	.65	.19	36.96	2.779	1.230	4234	38.18	.821	23
1220	1450	36.54	.60	.18	36.16	2.740	1.227	4208	37.93	.810	24
1107	1190	35.26	.51	.16	34.92	2.681	1.229	4061	38.12	.819	25
1015	940	31.91	----	.14	31.63	2.549	-----	----	-----	----	26
935	660	24.49	.24	.11	24.32	2.120	1.168	3504	37.79	.777	27
993	513	16.93	.15	.07	16.85	1.629	1.110	2842	37.28	.802	28
1050	425	12.32	.11	.04	12.29	1.312	1.057	2180	35.68	.769	29
1065	341	7.67	.08	0	7.68	1.131	1.020	1432	26.72	.600	30
1491	2700	51.04	1.06	.28	50.45	2.815	1.228	4328	38.67	.816	31
1380	2400	50.60	----	.27	50.00	3.076	1.230	4365	38.45	.758	32
1314	2160	50.64	.93	.26	50.05	2.822	1.240	4337	38.90	.836	33
1159	1750	49.93	.84	.23	49.35	2.835	1.242	4283	38.69	.820	34
1012	1260	46.36	----	.21	45.80	2.831	1.252	4200	38.40	.829	35
876	830	42.12	.56	.18	41.61	2.753	1.257	4128	38.71	.845	36
721	386	32.38	.32	.14	32.03	2.352	1.075	4125	35.78	.326	37
662	236	23.54	.16	.09	23.36	1.776	1.148	3391	38.78	.863	38
1453	3300	65.43	1.44	.34	64.57	2.825	1.237	4362	39.04	.840	39
1379	2930	64.49	1.35	.33	63.62	2.834	1.234	4360	38.93	.818	40
1308	2680	65.10	1.30	.32	64.22	2.853	1.238	4348	39.14	.827	41
1152	2120	63.48	1.15	.28	62.64	2.845	1.241	4297	38.74	.813	42
981	1430	58.85	.93	.24	58.08	2.840	1.255	4257	38.68	.850	43
819	820	52.31	.71	.21	51.62	2.884	1.267	4243	38.48	.833	44
1642	1462	23.65	.37	.13	23.56	2.773	1.213	4159	38.65	.799	45
1509	1292	23.70	.48	.13	23.45	2.758	1.221	4204	38.39	.814	46

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TABLE I - TURBINE PERFORMANCE DATA

Run	Altitude (ft)	Ram-pressure ratio P_1/p_0	Flight Mach number M_0	Tunnel static pressure p_0 (lb/sq ft abs.)	Engine speed N (rpm)	Corrected engine speed $N/\sqrt{\theta_1}$ (rpm)	Compressor-inlet total temperature T_1 (°R)	Compressor-outlet total temperature T_3 (°R)	Turbine-inlet total pressure P_4 (lb/sq ft abs.)	Turbine-inlet total temperature T_4 (°R)	Turbine-outlet total pressure P_5 (lb/sq ft abs.)
Exhaust-nozzle outlet area, 302 square inches											
47	35,000	1.030	0.200	494	7500	7995	457	813	2408	1740	864
48	35,000	1.028	.198	495	6993	7455	457	774	2241	1560	826
49	35,000	1.028	.198	496	6459	6885	457	739	2021	1418	758
50	35,000	1.030	.200	495	5944	6342	456	699	1737	1272	689
51	35,000	1.028	.198	496	5024	5356	457	632	1246	1143	596
52	35,000	1.030	.200	494	4091	4361	457	568	878	1132	545
53	35,000	1.028	.198	496	3147	3355	457	526	687	1160	529
54	35,000	1.032	.203	498	2046	2177	458	489	590	1155	519
55	45,000	1.032	.210	310	7895	8574	440	859	1673	2050	602
56	45,000	1.026	.185	308	7692	8361	439	831	1596	1930	570
57	45,000	1.034	.215	293	7500	8168	438	805	1492	1778	530
58	45,000	1.033	.210	306	6993	7594	440	769	1420	1590	515
59	45,000	1.032	.210	308	6459	7002	442	735	1296	1450	475
60	45,000	1.023	.180	311	5944	6443	442	695	1116	1320	434
61	45,000	1.030	.205	304	5024	5446	442	629	781	1170	361
Exhaust-nozzle outlet area, 342 square inches											
1	5,000	1.034	0.215	1752	7895	8084	495	855	8137	1632	2686
2	5,000	1.032	.210	1745	7692	7869	496	839	7897	1564	2648
3	5,000	1.030	.210	1747	7500	7673	496	---	----	----	2603
4	5,000	1.030	.210	1753	6993	7140	498	795	7166	1372	2493
5	5,000	1.027	.195	1753	6459	6601	497	764	6564	1282	2307
6	5,000	1.030	.210	1741	5944	6075	497	727	5486	1206	2147
7	5,000	1.029	.200	1753	5024	5135	497	664	4042	1115	1982
8	5,000	1.029	.200	1744	4091	4177	498	606	2957	1108	1860
9	5,000	1.029	.200	1744	3147	3219	496	561	2327	1120	1806
10	5,000	1.029	.200	1742	2046	2095	495	519	1954	1075	1765
11	15,000	1.033	.210	1183	7895	8250	475	843	5656	1645	1824
12	15,000	1.033	.210	1187	7692	8023	477	828	5475	1578	1789
13	15,000	1.033	.210	1193	7500	7815	476	814	5360	1500	1769
14	15,000	1.030	.205	1190	6993	7336	472	776	5005	1363	1692
15	15,000	1.029	.200	1187	6459	6724	479	747	4461	1268	1585
16	15,000	1.028	.198	1188	5944	6188	479	712	3852	1190	1486
17	15,000	1.028	.198	1188	5024	5220	481	650	2822	1090	1348
18	15,000	1.029	.200	1190	4091	4259	479	590	2055	1080	1273
19	15,000	1.029	.200	1190	3147	3279	478	542	1618	1092	1232
20	15,000	1.029	.200	1186	2046	2134	477	502	1341	1070	1204
21	25,000	1.032	.210	781	7895	8361	463	835	3781	1636	1212
22	25,000	1.032	.210	781	7692	8146	463	820	3668	1587	1190
23	25,000	1.031	.210	778	7500	7943	463	801	3545	1493	1169
24	25,000	1.029	.200	781	6993	7413	462	766	3348	1382	1112
25	25,000	1.028	.200	781	6459	6853	461	731	3028	1271	1060
26	25,000	1.027	.195	780	5944	6313	460	697	2636	1175	996
27	25,000	1.027	.195	780	5024	5341	459	628	1926	1064	889
28	25,000	1.028	.200	781	4091	4349	459	566	1379	1052	857
29	25,000	1.028	.200	776	3147	3348	458	526	1062	1081	802
30	25,000	1.404	.713	778	7895	8290	471	835	4978	1597	1580
31	25,000	1.399	.710	780	7692	8054	473	822	4850	1520	1540
32	25,000	1.399	.710	781	7500	7868	472	805	4695	1438	1488
33	25,000	1.403	.712	785	6993	7343	471	769	4371	1282	1401
34	25,000	1.406	.719	781	6459	6775	472	731	3927	1142	1256
35	25,000	1.397	.709	778	5944	6255	472	695	3241	1015	1087
36	25,000	1.397	.709	774	5024	5270	472	624	2269	880	926
37	25,000	1.407	.719	778	4091	4279	474	566	1602	749	857
38	25,000	1.836	.970	781	7895	8148	487	848	6468	1594	2075
39	25,000	1.827	.970	780	7692	7938	487	833	6194	1513	1985
40	25,000	1.823	.965	778	7500	7725	489	819	5978	1432	1912
41	25,000	1.827	.970	780	6993	7189	491	784	5477	1279	1753
42	25,000	1.819	.965	781	6459	6627	493	746	4730	1116	1498
43	25,000	1.827	.970	784	5944	6099	493	706	3949	943	1280
44	35,000	1.030	.205	492	7895	8534	444	826	2448	1700	788
45	35,000	1.032	.210	493	7692	8300	446	809	2377	1602	769
46	35,000	1.030	.205	494	7500	8123	443	792	2325	1531	760
47	35,000	1.028	.200	494	6993	7587	441	753	2176	1399	721
48	35,000	1.026	.190	496	6459	7002	442	726	1993	1290	683
49	35,000	1.028	.200	493	5944	6437	443	683	1728	1164	632
50	35,000	1.028	.200	493	5024	5431	444	618	1259	1063	566
51	35,000	1.028	.200	494	4091	4414	446	571	908	1072	531
52	45,000	1.026	.190	312	7895	8574	440	830	1568	1762	502
53	45,000	1.026	.190	310	7692	8354	440	816	1515	1700	493
54	45,000	1.029	.200	310	7500	8145	440	796	1462	1585	472
55	45,000	1.026	.190	310	6993	7594	440	762	1363	1452	456
56	45,000	1.026	.190	310	6459	7014	440	731	1246	1346	420
57	45,000	1.026	.190	307	5944	6443	442	693	1085	1211	395
58	45,000	1.029	.200	306	5024	5441	443	627	750	1118	345

FOR J47 TURBOJET ENGINE - Concluded

Turbine-outlet total temperature T_6 (°R)	Fuel flow W_f (lb/hr)	Engine-inlet air flow W_a (lb/sec)	Compressor leakage air flow W_y (lb/sec)	Aft turbine cooling-air flow W_z (lb/sec)	Turbine gas flow $W_{g,4}$ (lb/sec)	Turbine pressure ratio P_4/P_6	Turbine temperature ratio T_4/T_6	Corrected turbine speed $N/\sqrt{\theta_4}$ (rpm)	Corrected turbine gas flow $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4(\gamma_4/1.4)}$ (lb/sec)	Adiabatic turbine efficiency η_t	Run
Exhaust-nozzle outlet area, 302 square inches											
1415	1171	23.43	0.45	0.12	23.19	2.787	1.230	4208	38.33	0.823	47
1271	968	23.01	.15	.11	23.02	2.713	1.227	4128	38.54	.819	48
1154	794	21.59	.36	.10	21.35	2.668	1.229	3987	37.70	.825	49
1047	647	20.15	.27	.09	19.97	2.521	1.215	3859	38.70	.809	50
978	450	15.14	.06	.07	15.14	2.091	1.169	3430	38.65	.797	51
1022	346	10.46	.08	.05	10.43	1.611	1.108	2806	37.60	.809	52
1095	361	7.10	.06	.03	7.11	1.299	1.059	2137	33.23	.833	53
1125	351	7.15	.09	.01	7.15	1.137	1.027	1391	38.78	.769	54
1690	983	15.01	.35	.09	14.84	2.779	1.213	4105	38.54	.806	55
1588	881	14.97	.31	.09	14.81	2.800	1.215	4115	39.04	.795	56
1460	762	14.40	.29	.08	14.24	2.815	1.218	4165	38.41	.785	57
1299	646	14.71	.27	.08	14.54	2.757	1.224	4092	38.84	.803	58
1185	544	14.34	.23	.07	14.19	2.729	1.224	3944	39.53	.798	59
1085	450	12.76	.17	.06	12.66	2.571	1.217	3794	38.97	.804	60
992	291	9.10	.12	.04	9.02	2.164	1.179	3394	37.20	.814	61
Exhaust-nozzle outlet area, 342 square inches											
1308	3450	82.17	1.50	0.43	81.20	3.029	1.248	4562	38.35	0.808	1
1252	3200	81.30	1.42	.42	80.35	2.982	1.249	4534	38.22	.816	2
1201	2950	80.99	1.38	.40	80.03	-----	-----	----	-----	----	3
1100	2470	78.42	1.27	.37	77.41	2.874	1.247	4380	37.88	.815	4
1036	1990	72.30	.63	.33	71.89	2.759	1.237	4175	38.16	.812	5
986	1575	64.61	.93	.29	63.83	2.555	1.223	3956	38.07	.818	6
957	1100	49.49	.59	.23	48.98	2.039	1.165	3469	38.02	.809	7
1006	910	36.37	.37	.16	36.09	1.590	1.101	2834	38.18	.782	8
1060	763	23.97	.11	.10	23.97	1.288	1.057	2169	32.41	.813	9
1048	450	15.05	0	.06	15.12	1.107	1.026	1438	23.84	.927	10
1313	2490	56.55	1.04	.51	55.89	3.101	1.253	4545	38.14	.807	11
1252	2260	56.24	.96	.50	55.61	3.060	1.260	4516	38.37	.827	12
1196	2090	56.05	.93	.29	55.41	3.030	1.254	4508	38.01	.811	13
1082	1740	55.37	.84	.26	54.75	2.958	1.260	4394	38.19	.830	14
1016	1420	50.93	.75	.23	50.34	2.815	1.248	4198	37.90	.822	15
965	1100	45.43	.62	.20	44.92	2.592	1.233	3980	37.90	.834	16
927	813	34.87	.36	.15	34.59	2.093	1.176	3507	38.01	.821	17
975	674	24.56	.22	.10	24.43	1.614	1.108	2869	36.72	.799	18
1035	560	18.37	.09	.05	18.39	1.313	1.055	2196	35.29	.736	19
1049	376	11.56	0	0	11.66	1.114	1.020	1441	26.72	.686	20
1311	1681	37.53	.67	.21	37.12	3.119	1.248	4556	37.79	.791	21
1265	1556	37.28	.62	.20	36.89	3.083	1.254	4503	38.11	.812	22
1206	1417	37.01	.38	.19	36.83	3.032	1.238	4518	38.12	.769	23
1100	1204	36.37	.54	.18	35.98	3.011	1.256	4368	37.81	.810	24
1010	988	34.82	.47	.16	34.46	2.856	1.258	4193	38.66	.842	25
946	818	31.50	.40	.14	31.18	2.647	1.242	4003	38.16	.840	26
902	580	23.99	.24	.11	23.80	2.166	1.180	3548	37.84	.798	27
947	474	16.94	.13	.07	16.87	1.647	1.111	2904	37.22	.785	28
1019	401	11.80	0	.04	11.87	1.324	1.061	2207	34.53	.787	29
1268	2090	51.83	.91	.28	51.22	3.151	1.259	4610	39.12	.810	30
1207	1925	50.99	.86	.27	50.39	3.150	1.259	4596	38.50	.804	31
1133	1720	51.43	.81	.26	50.84	3.156	1.269	4591	38.84	.818	32
1003	1360	50.49	.73	.24	49.90	3.120	1.278	4522	38.58	.831	33
891	970	47.18	.61	.21	46.63	3.127	1.282	4409	37.73	.822	34
795	700	41.99	.49	.19	41.50	2.982	1.277	4289	38.23	.832	35
733	450	32.18	.29	.14	31.88	2.450	1.200	3881	38.96	.755	36
658	251	24.31	.07	.10	24.21	1.869	1.138	3415	38.52	.751	37
1265	2625	66.93	1.31	.35	66.00	3.117	1.260	4614	38.74	.819	38
1190	2375	65.99	1.21	.33	65.11	3.120	1.271	4605	38.82	.839	39
1127	2125	65.18	1.15	.32	64.30	3.127	1.271	4601	38.57	.827	40
1000	1660	63.24	1.01	.28	62.41	3.124	1.279	4526	38.44	.832	41
872	1070	58.44	.83	.24	57.67	3.158	1.280	4456	38.25	.811	42
735	628	53.07	.62	.21	52.41	3.085	1.283	4441	38.13	.819	43
1361	1153	23.86	.42	.13	23.63	3.107	1.249	4477	37.95	.801	44
1274	1052	24.06	.39	.13	23.83	3.091	1.257	4484	38.15	.819	45
1229	979	24.15	.37	.12	23.93	3.059	1.246	4467	38.24	.789	46
1110	827	23.51	.32	.11	23.31	3.018	1.260	4342	37.93	.821	47
1021	697	22.70	.29	.10	22.50	2.918	1.263	4165	38.27	.841	48
937	565	20.57	.23	.09	20.41	2.734	1.242	4023	37.94	.817	49
898	396	15.95	.15	.07	15.84	2.224	1.184	3547	38.49	.791	50
952	346	11.16	.08	.05	11.13	1.710	1.126	2880	37.71	.829	51
1411	778	15.01	.27	.09	14.87	3.123	1.249	4406	37.99	.803	52
1364	723	14.99	.26	.09	14.84	3.073	1.246	4361	38.51	.802	53
1266	655	15.04	.24	.08	14.90	3.098	1.252	4396	38.59	.801	54
1163	560	14.74	.21	.08	14.61	2.989	1.248	4267	38.70	.805	55
1075	483	13.85	.19	.07	13.72	2.966	1.252	4085	38.20	.808	56
978	401	12.20	.13	.06	12.12	2.746	1.238	3950	36.64	.809	57
946	281	9.92	.12	.04	9.84	2.174	1.182	3466	41.26	.810	58

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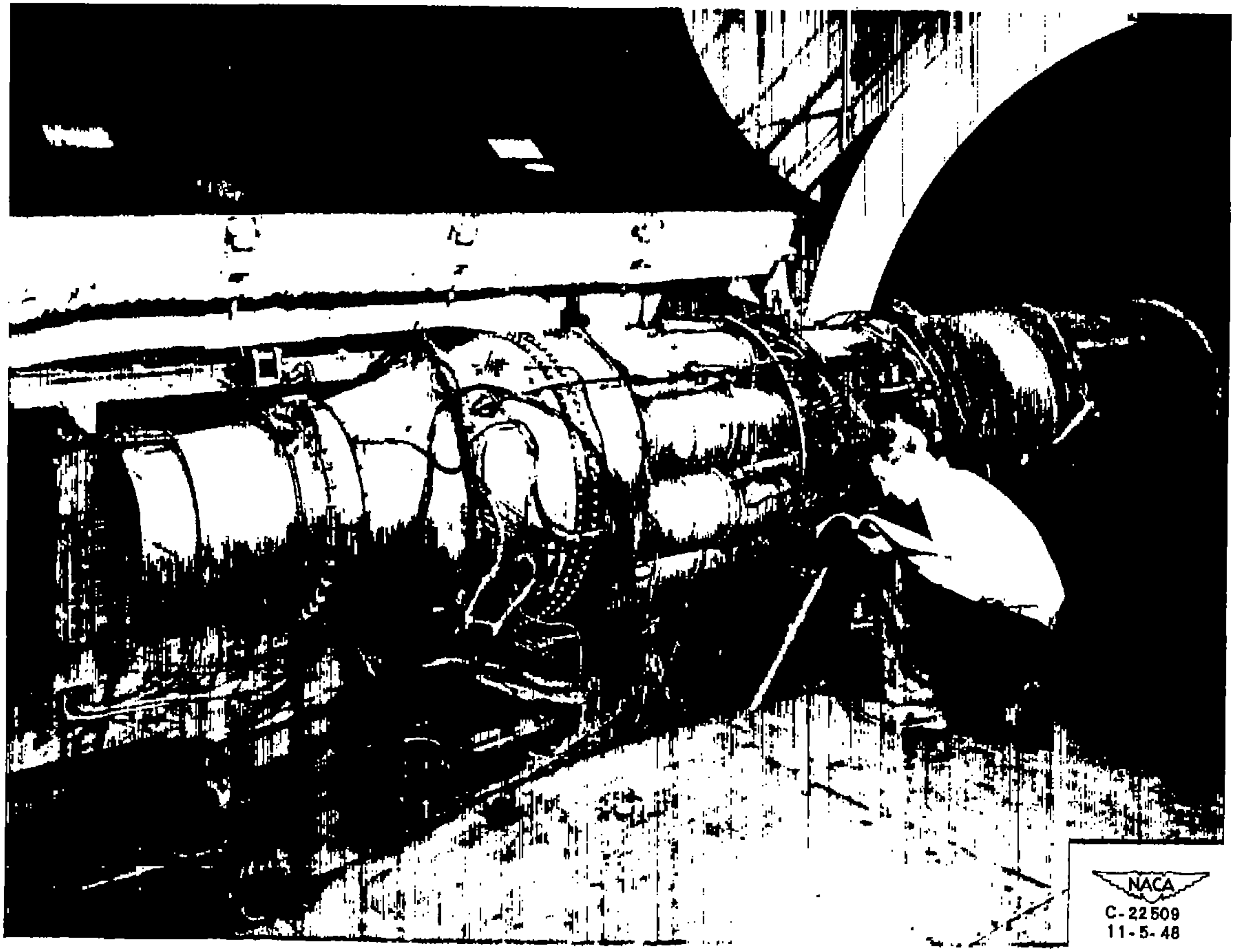
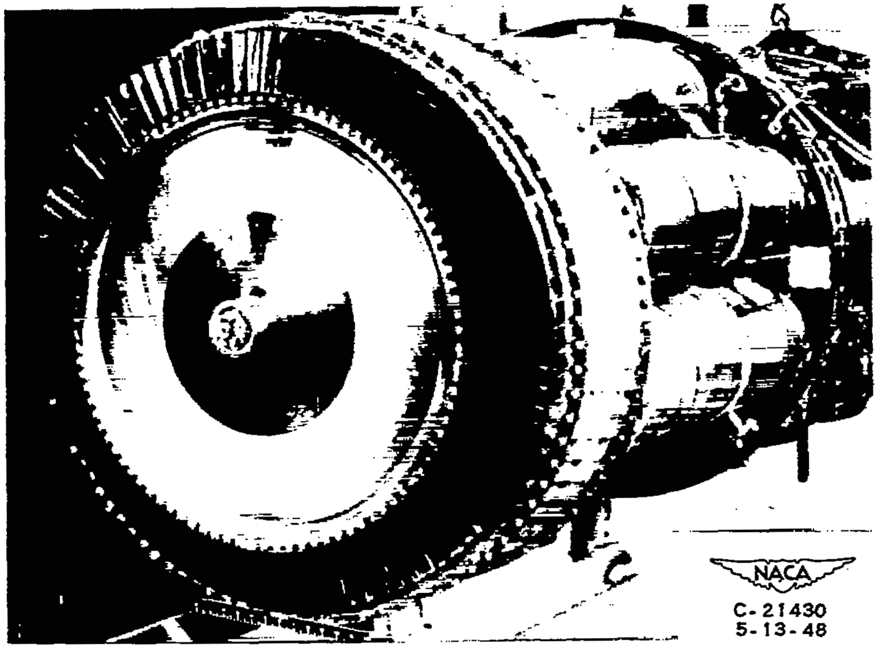
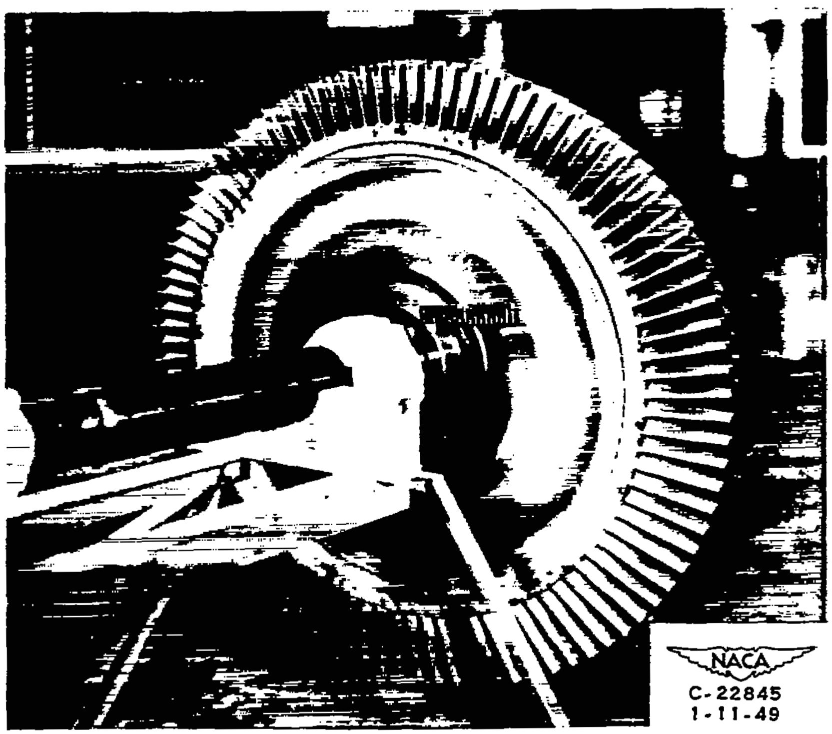


Figure 1. - Installation of J47 turbojet engine in altitude wind tunnel.



(a) Rear view of turbine installed in engine with tail pipe and shroud removed.



(b) Inlet side of turbine rotor.

Figure 2. - Turbine used in investigation.

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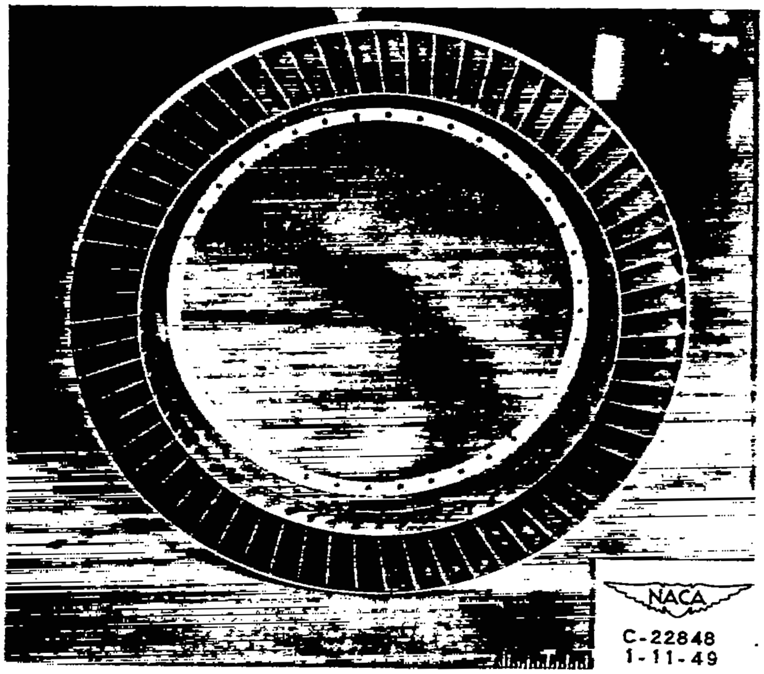
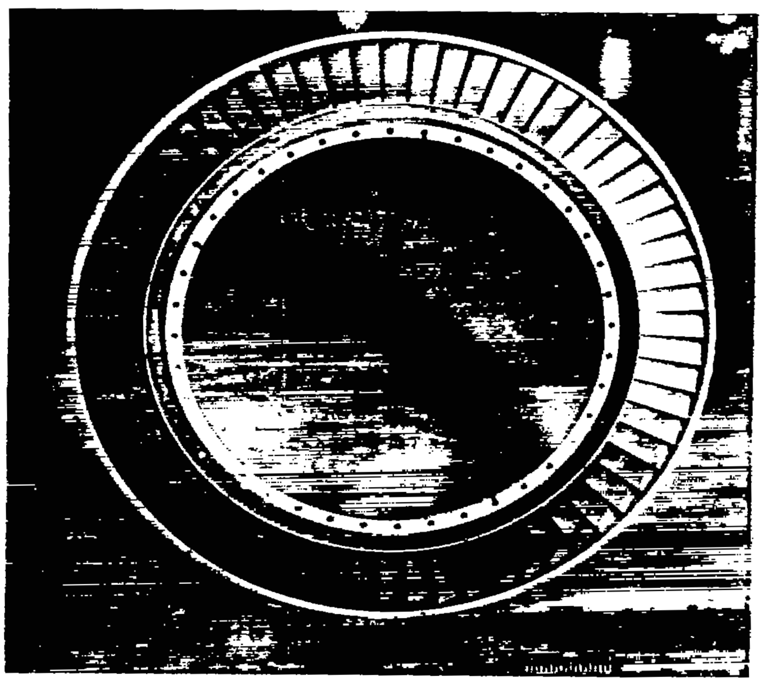


(c) Inlet side of turbine stator.



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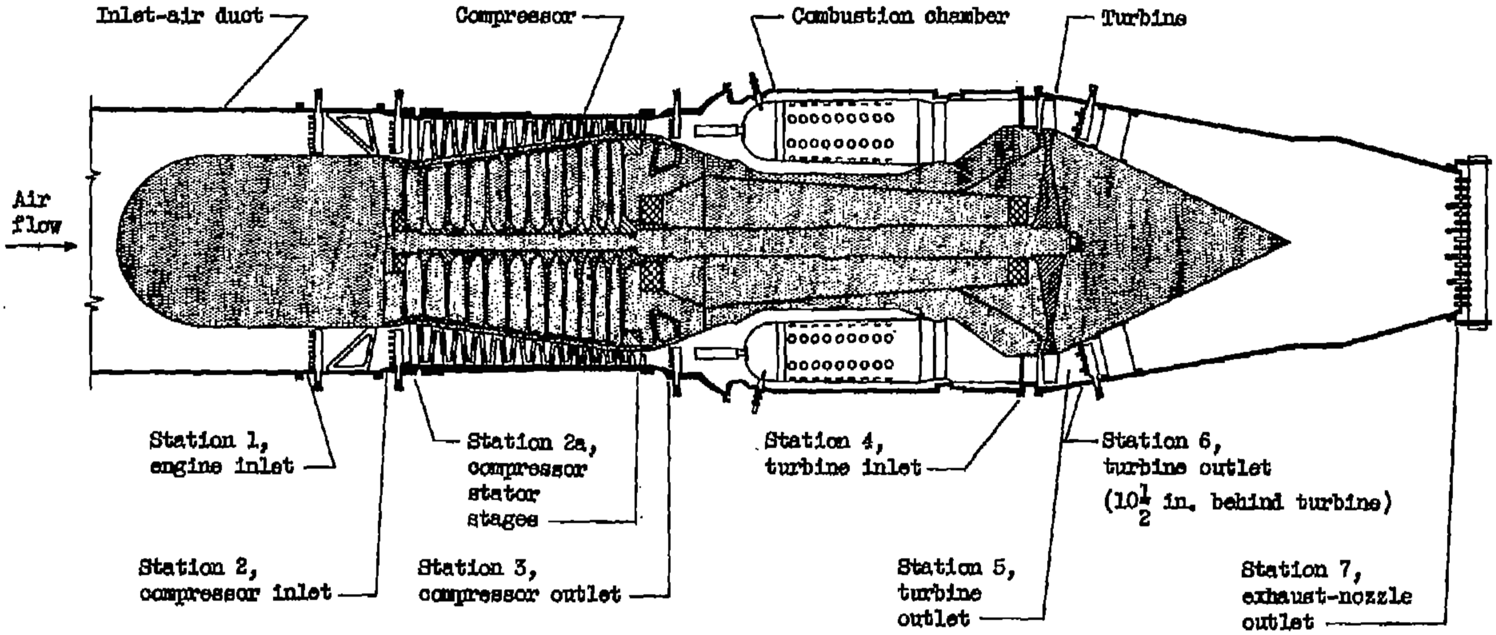
(d) Outlet side of turbine stator.

Figure 2. - Concluded. Turbine used in investigation.



Station	Total-pressure tubes	Static-pressure tubes	Wall static-pressure orifices	Thermo-couples
1	40	4	0	8
2	24	0	4	0
2a	0	0	13	0
3	20	0	4	6
4	5	0	0	0
5	0	0	0	8
6	30	0	2	24
7	18	5	4	14

Figure 3. - Cross section of turbojet-engine installation showing stations at which instrumentation was installed.

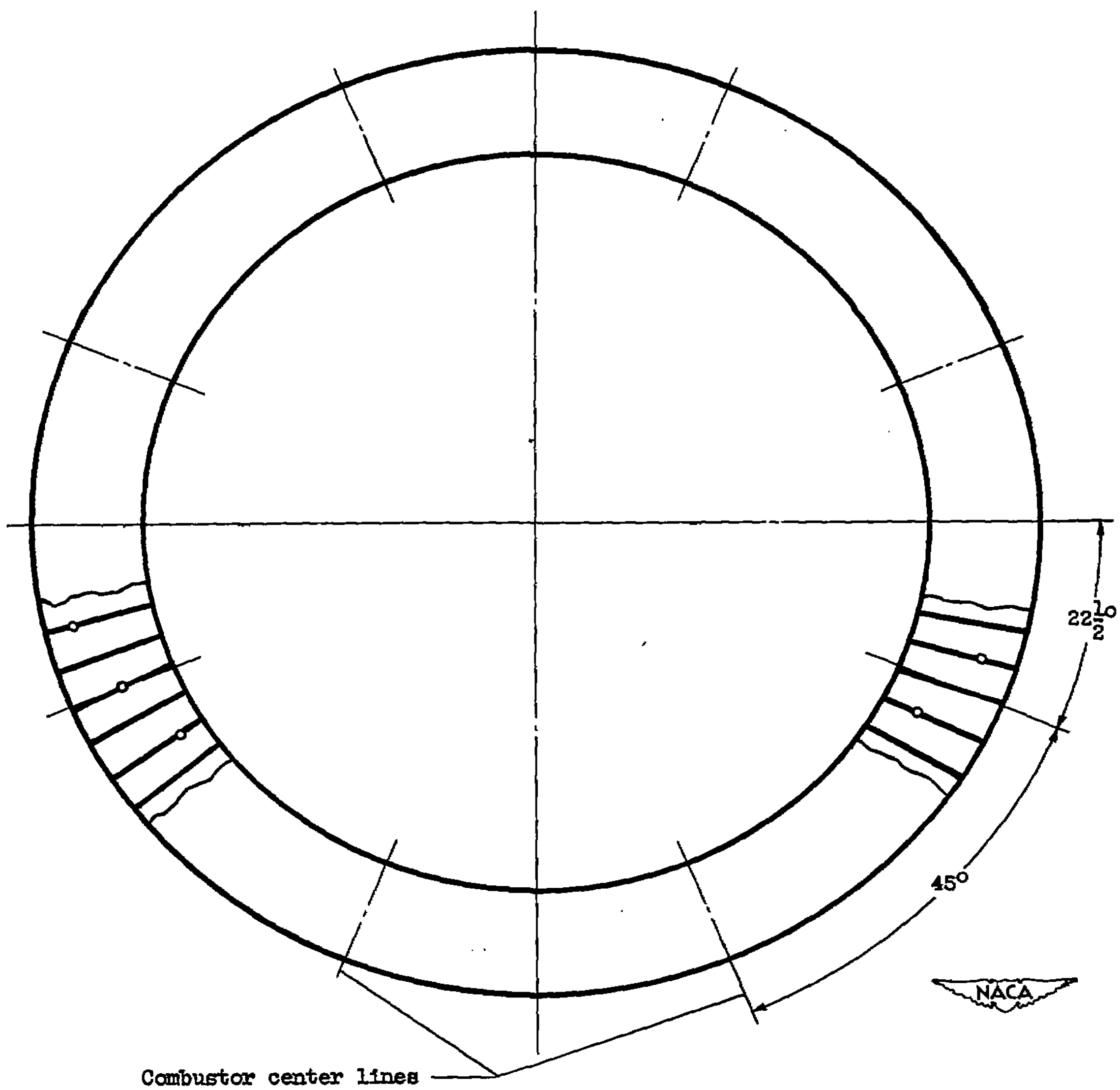


Figure 4. - Instrumentation at turbine inlet, station 4. Total-pressure holes located in leading edges of stator blades.

1221

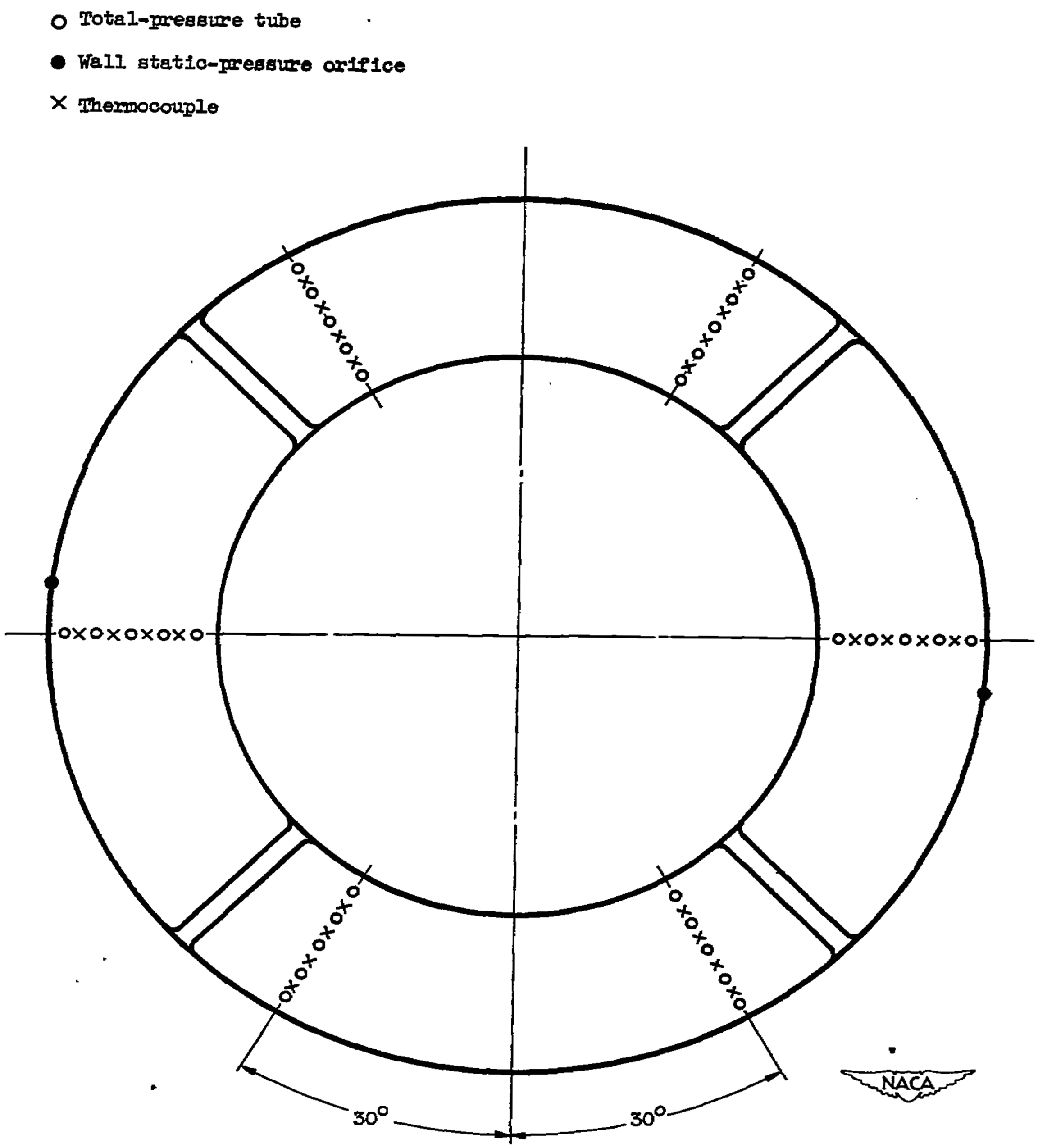
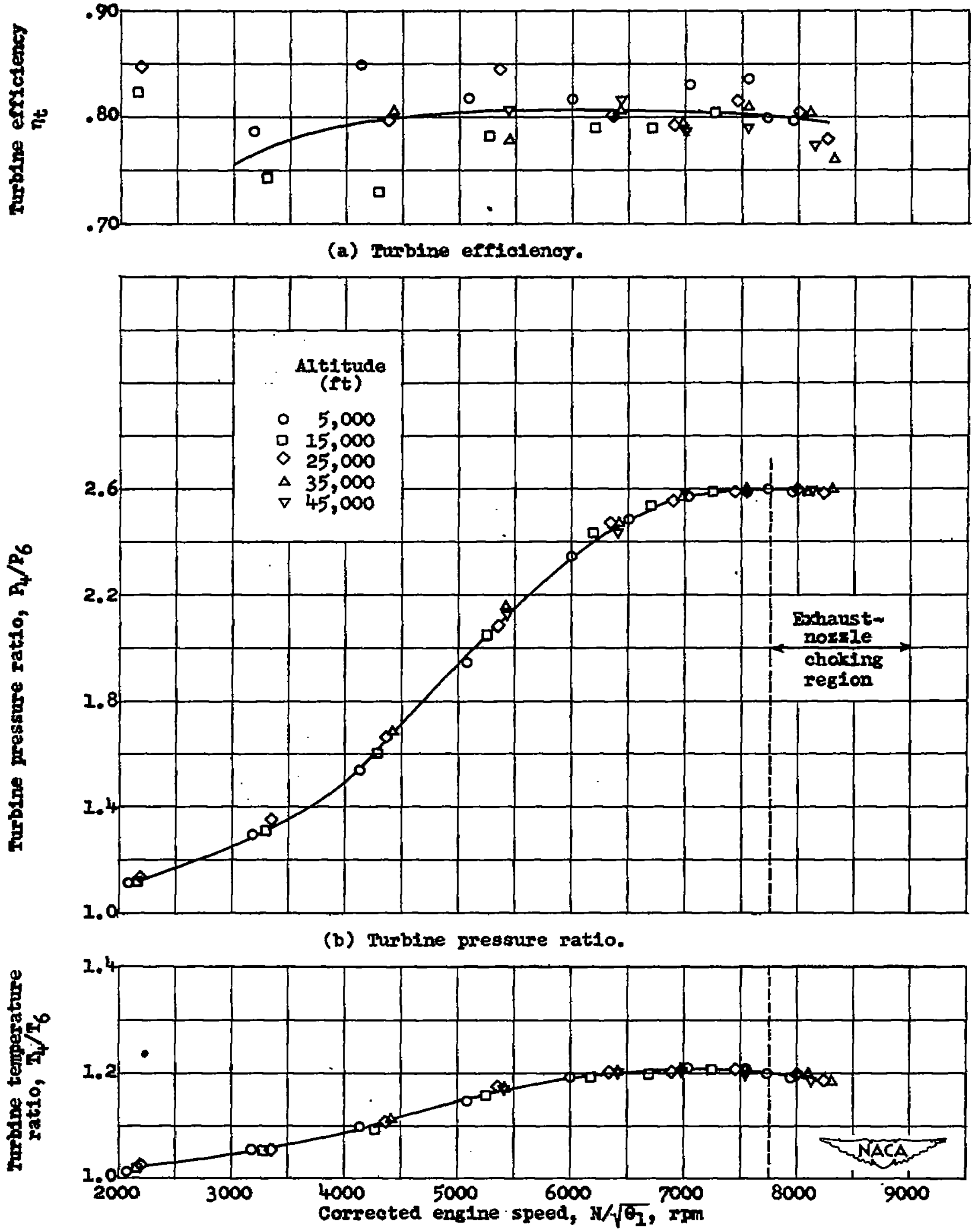


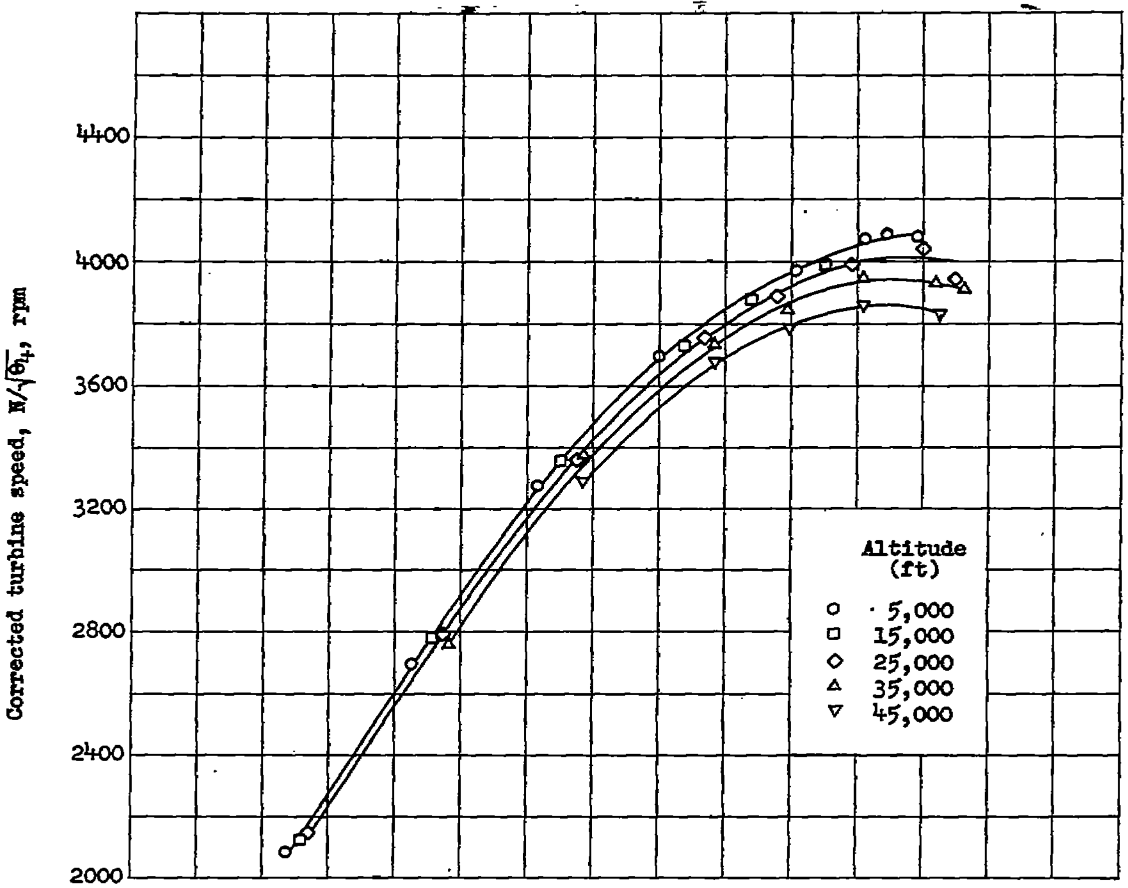
Figure 5. - Instrumentation at turbine outlet, station 6 ($10\frac{1}{2}$ in. downstream of turbine flange). View looking downstream.



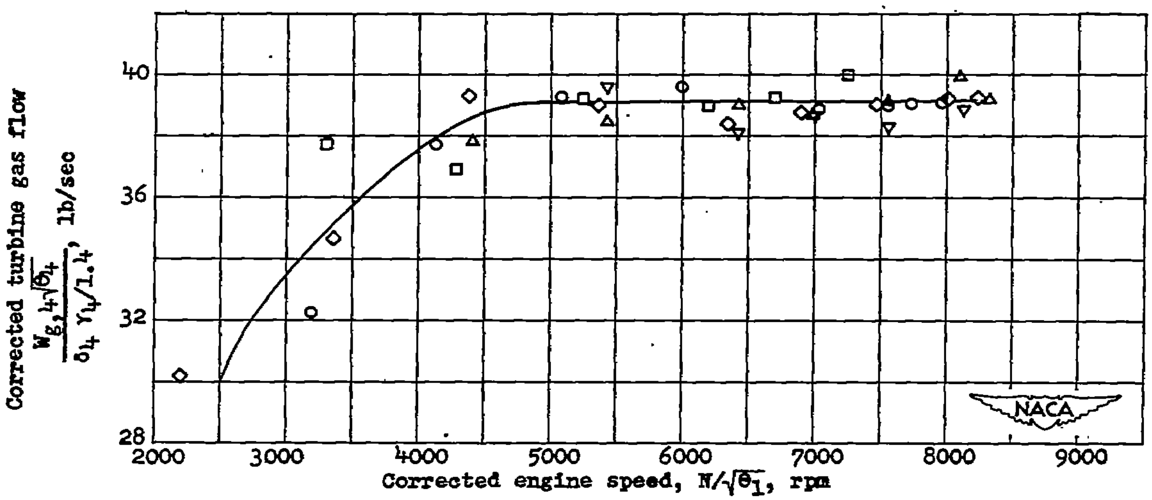
(c) Turbine temperature ratio.

Figure 6. - Effect of altitude on performance of turbine operating in engine. Flight Mach number, 0.21; exhaust-nozzle-outlet area, 280 square inches.

1211

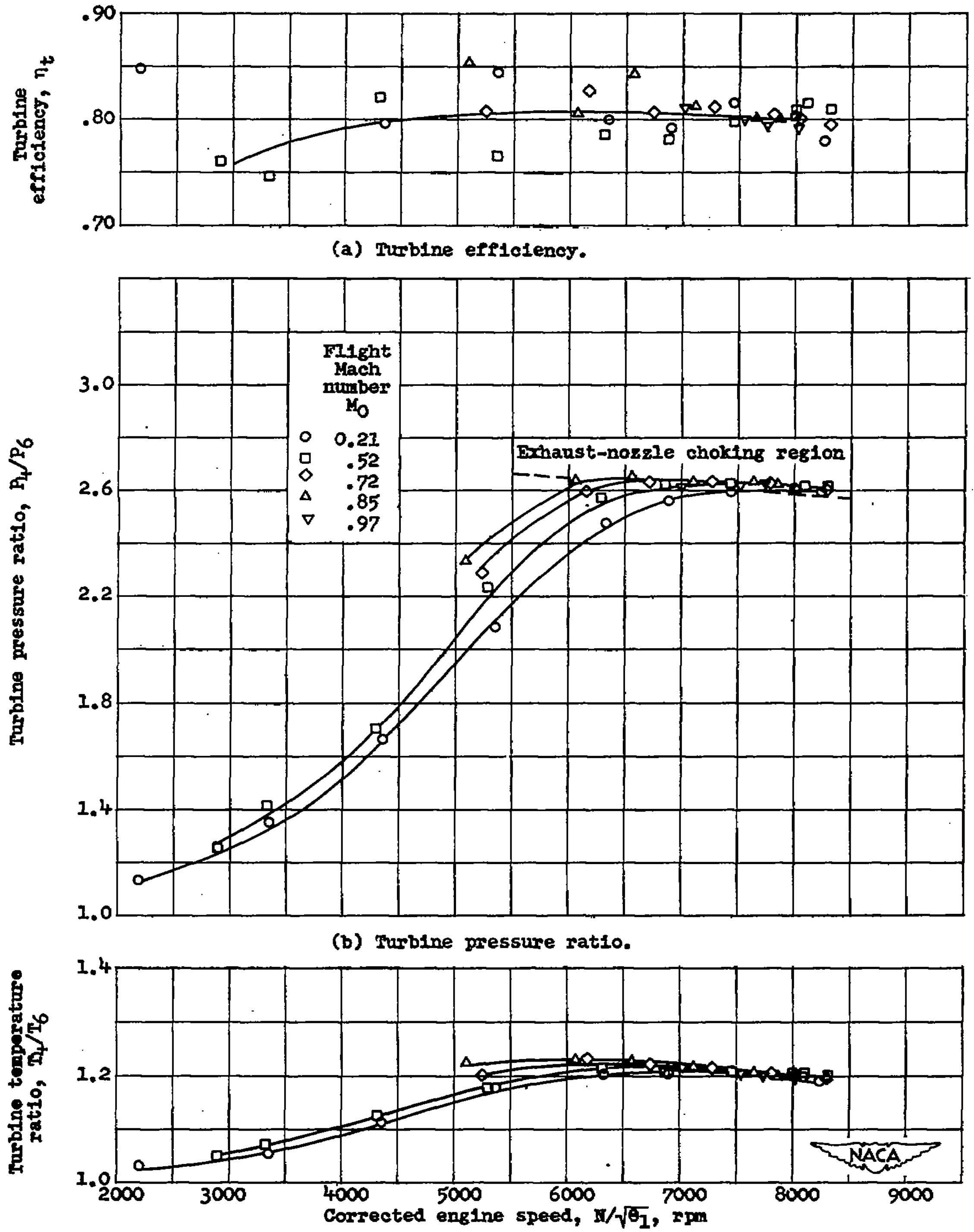


(d) Corrected turbine speed.



(e) Corrected turbine gas flow.

Figure 6. - Concluded. Effect of altitude on performance of turbine operating in engine. Flight Mach number, 0.21; exhaust-nozzle-outlet area, 280 square inches.



(a) Turbine efficiency.

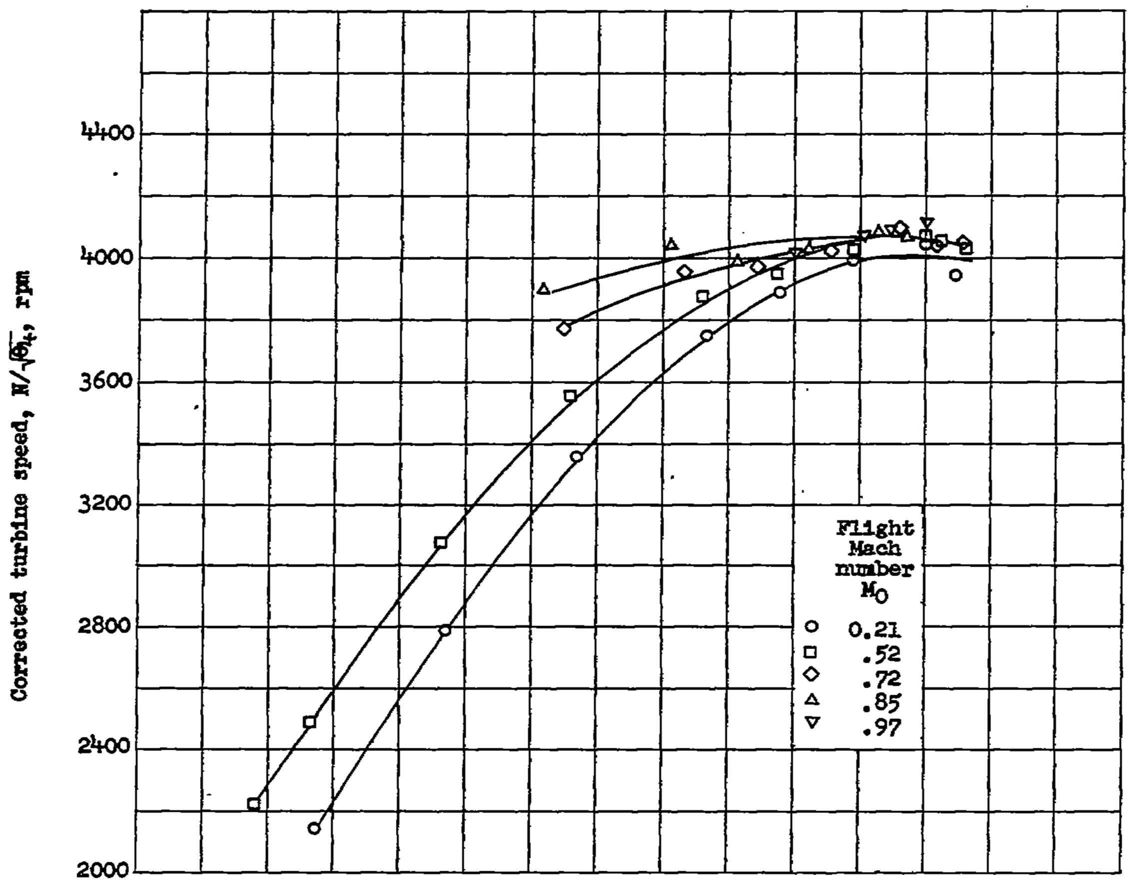
(b) Turbine pressure ratio.

(c) Turbine temperature ratio.

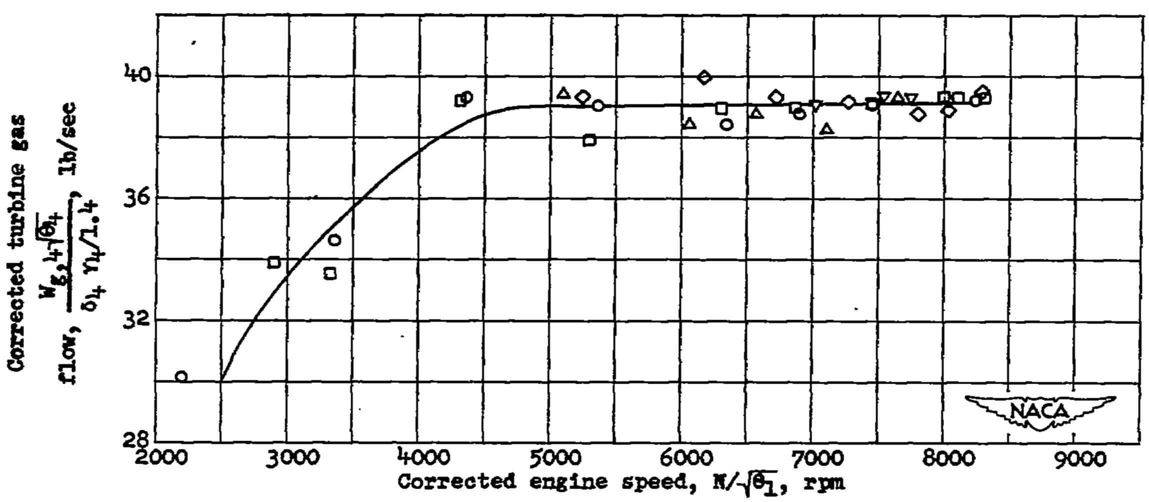
Figure 7. - Effect of flight Mach number on performance of turbine operating in engine. Altitude, 25,000 feet; exhaust-nozzle-outlet area, 280 square inches.

1211

1211

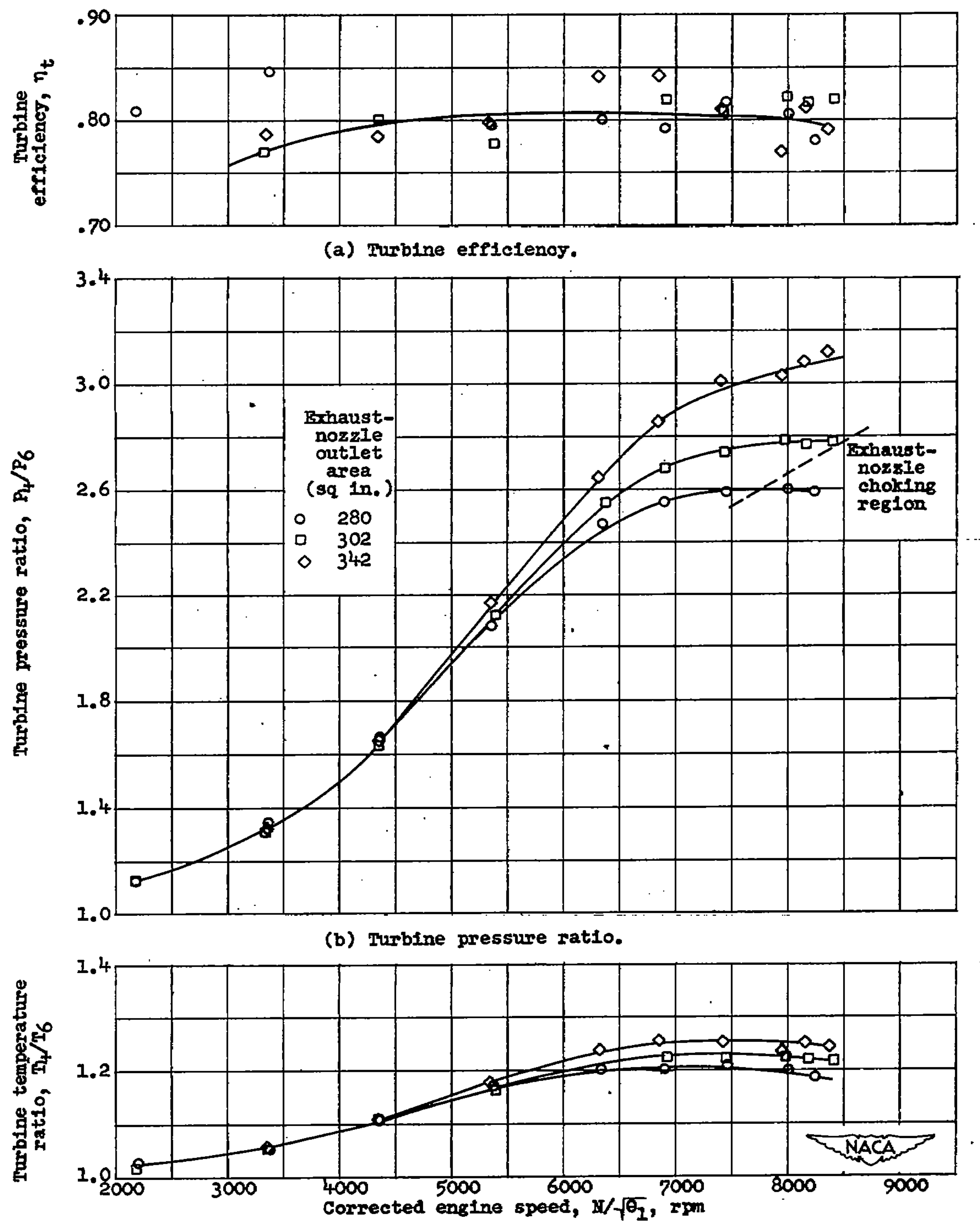


(d) Corrected turbine speed.



(e) Corrected turbine gas flow.

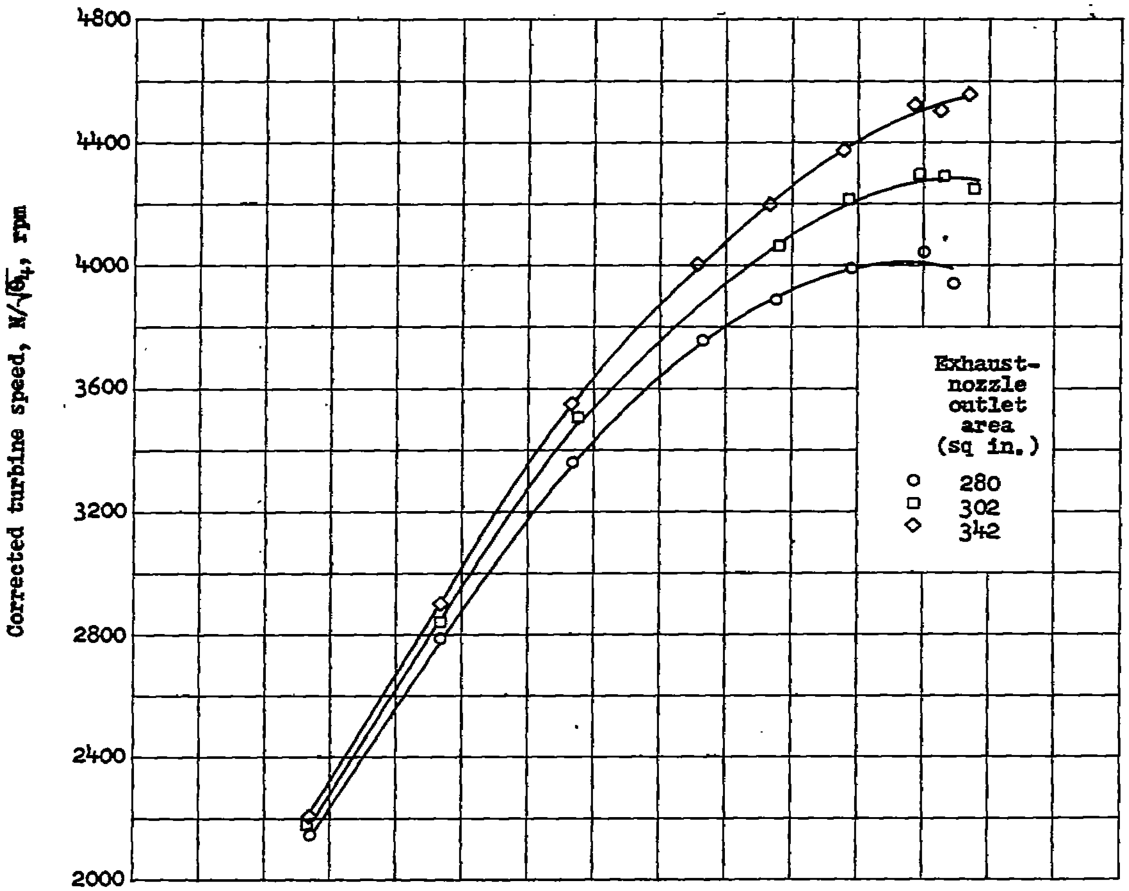
Figure 7. - Concluded. Effect of flight Mach number on performance of turbine operating in engine. Altitude, 25,000 feet; exhaust-nozzle-outlet area, 280 square inches.



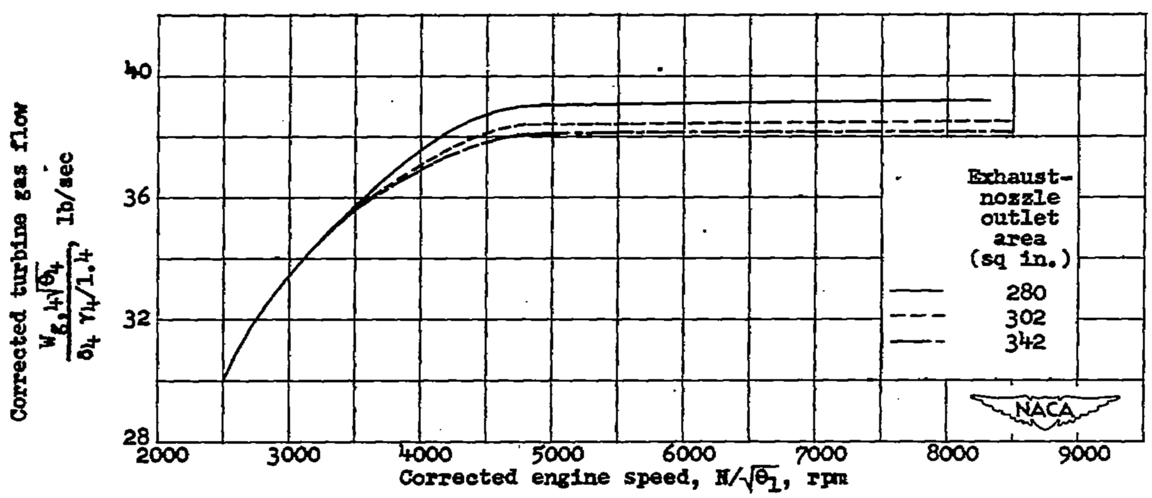
(c) Turbine temperature ratio.

Figure 8. - Effect of exhaust-nozzle-outlet area on performance of turbine operating in engine. Altitude, 25,000 feet; flight Mach number, 0.21.

1211



(d) Corrected turbine speed.



(e) Corrected turbine gas flow.

Figure 8. - Concluded. Effect of exhaust-nozzle-outlet area on performance of turbine operating in engine. Altitude, 25,000 feet; flight Mach number, 0.21.

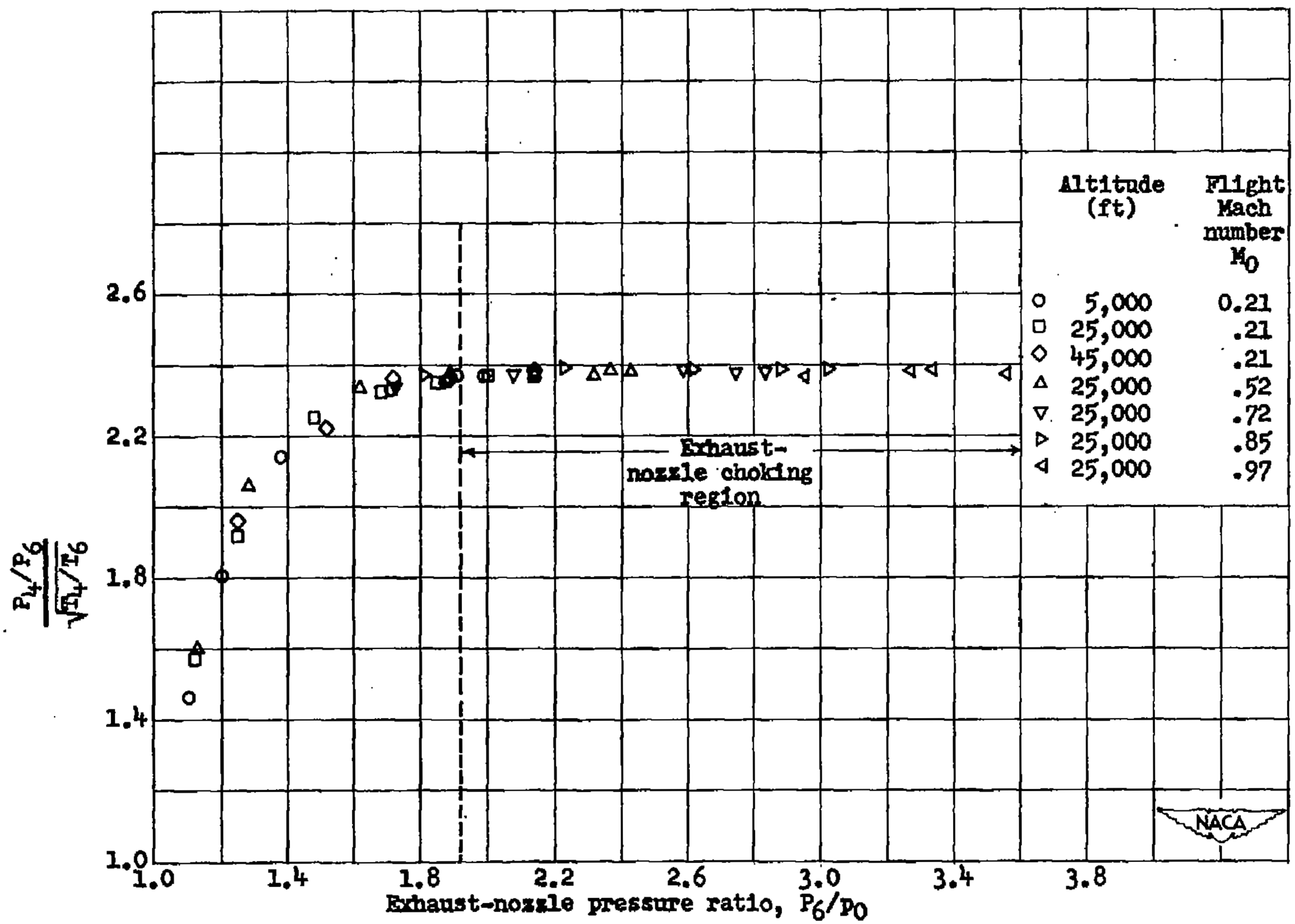


Figure 9. - Effect of exhaust-nozzle pressure ratio on relation between turbine pressure ratio and turbine temperature ratio. Exhaust-nozzle-outlet area, 280 square inches.

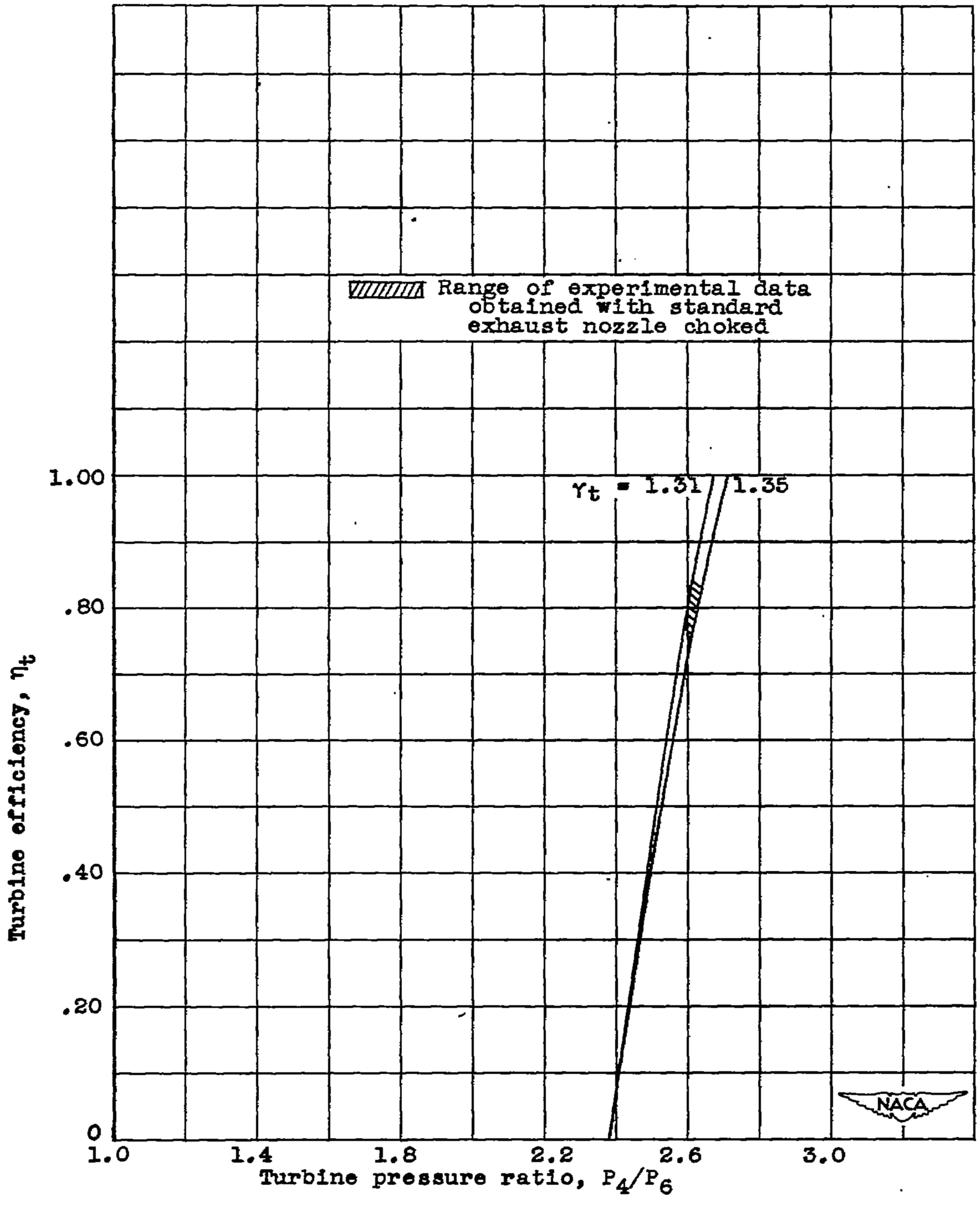


Figure 10. - Relation between turbine efficiency and turbine pressure ratio for condition of simultaneously choked turbine and exhaust nozzles. Calculated from equation (5) with C = 2.38.