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RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE OF COMPRESSOR, COMBUSTOR, AND TURBINE COMPONENTS OF XT38-A-2 TURBOPROP ENGINE

By Frederick W. Schulze and William R. Prince

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
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ALTITUDE PERFORMANCE OF COMPRESSOR, COMBUSTOR, AND TURBINE COMPONENTS OF XT38-A-2 TURBOPROP ENGINE

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SUMMARY

Performance characteristics of the compressor, combustor, and turbine operating as integral components of the XT38-A-2 turboprop engine were determined in the NACA Lewis altitude wind tunnel over a range of altitudes and flight Mach numbers corresponding to a range of compressor-inlet Reynolds number indices from 0.18 to 1.04. The engine, equipped with a standard-area exhaust nozzle, was run over a wide range of power settings with independent control of propeller and fuel flow.

The performance of the compressor and turbine is presented in conventional component maps, while combustor performance is shown as a function of various combustion parameters. Near the design flight condition of the engine (altitude, 15,000 ft; flight Mach number, 0.347) and at rated engine conditions, corrected air flow was 29.35 pounds per second, compressor pressure ratio was 6.8, compressor efficiency was 0.80, combustion efficiency was 0.99, and over-all expansion efficiency was 0.825. Up to the design flight condition, there were no Reynolds number effects on component performance at rated engine conditions. Decrease in the efficiency of the components with increase in altitude beyond 15,000 feet was appreciable and could result in serious loss in horsepower output.

INTRODUCTION

An investigation was conducted in the NACA Lewis altitude wind tunnel to determine the over-all performance, component performance, and operational characteristics of an XT38-A-2 turboprop engine. The over-all performance and operational characteristics are reported in reference 1. The performance of the components (compressor, combustor, turbine) is reported herein.

The over-all performance was investigated over a wide range of simulated flight conditions. Data were chosen for presentation in this report to demonstrate the effect of the maximum variation of Reynolds

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numbers on component performance. The simulated flight conditions ranged from altitudes of 5000 to 45,000 feet at an average flight Mach number of 0.30. The engine, equipped with a standard-area exhaust nozzle, was run over a wide range of power settings by means of independent control of propeller pitch and fuel flow. The performance characteristics of the compressor and turbine components are presented in the form of conventional component performance maps. Data from these maps were used to show the effect of altitude on component performance. Combustor performance is presented as a function of various combustion parameters. A tabulation of component performance data for the range of flight conditions is also included.

APPARATUS AND INSTRUMENTATION

As shown by the views of the installation in figures 1(a) and (b), the engine was mounted on a thin wing section spanning the 20-foot-diameter test section of the wind tunnel. The length of the engine from the foremost end of the propeller shaft to the exhaust-nozzle outlet is 157 inches; the maximum diameter of the engine mount is $37\frac{1}{2}$ inches; and the specially fitted three-blade variable-pitch propeller is 13 feet in diameter. The net dry weight of the engine, including power section, gearbox, control, torquemeter, and flight frame, but without propeller, is approximately 1660 pounds. The nominal military static sea-level rating is 2520 shaft horsepower and 603 pounds of jet thrust at the rated engine speed of 14,300 rpm and turbine-inlet temperature of 2060° R. For a 100-percent-normal continuous operating condition, the turbine-inlet temperature is 1960° R. The engine was designed for operation at an altitude of 15,000 feet and a flight Mach number of 0.347.

The 19-stage axial-flow compressor (fig. 1(c)) has a rated speed of 14,300 rpm, a rotor tip diameter of 14.72 inches, a relative tip inlet Mach number of 0.755, and a hub-tip radius ratio at the first rotor of 0.498. The eight cylindrical direct-flow combustors, which utilize duplex fuel nozzles and two spark plugs, comprise a total flow area of 1.12 square feet. The four-stage turbine has a design inlet temperature of 2060° R, a nozzle flow area of 0.21 square foot, a first-stage tip diameter of 16.41 inches, and a fourth-stage tip diameter of 18.10 inches. A cross-sectional view of the engine, showing the location of these components and the instrumentation used, is given in figure 1(d). Details of the instrumentation stations are shown in the diagrams of figure 1(e).

The engine speed was measured by a stroboscopic tachometer. Engine torque was determined from an electronically measured torsional deflection of a given portion of the shaft between the power section and the reduction gearbox. The torque measurement is believed to be accurate within 20 foot-pounds.

PROCEDURE

The performance characteristics were obtained for each of the engine components operating as an integral part of the engine. Flight conditions were simulated on the basis of the compressor-inlet total pressure and temperature to eliminate the effect of inlet duct losses on engine performance. Actual engine speed was varied between about 94 and 104 percent of rated speed. At each engine speed, the turbine-inlet temperature was varied over a wide range. Tunnel-test-section velocity was set to give the desired ram pressure ratio based on compressor-inlet total pressure and free-stream static pressure. Because of the large heat load imparted by the tunnel fan, adequate refrigeration was not available to give engine-inlet temperatures of NACA standard values for each flight condition. As a result, engine-inlet temperatures were as much as 40° F higher than the desired values. Fuel used during the investigation was clear gasoline having a lower heating value of 18,925 Btu per pound and a hydrogen-carbon ratio of 0.182. Symbols and methods used to compute the component performance are presented in appendixes A and B, respectively.

RESULTS AND DISCUSSION

Inasmuch as some deterioration in performance occurred during the course of the investigation, the time at which various parts of the data were obtained is significant. Accordingly, the engine operating time at each flight condition investigated is presented in the following table:

Engine time, hr	Turbine	Altitude, ft	Flight Mach number, M
0-20	A	Propeller vibration study	
20-25	A	25,000	0.291
33-40	A	35,000	0.301
60-82	A	5,000	0.300
83	Turbine assembly change		
91-96	B	45,000	0.294
96-105	B	15,000	0.303

A propeller vibration study was made during the first 20 hours of engine operation. At the completion of the vibration study, the compressor blading was found to be slightly nicked. The nicks were honed out; and, during the next 85 hours of engine operation, steady-state data were taken with an interruption for a change in turbine assembly at an engine time of 83 hours. The component performance data are presented in table I.

Compressor Deterioration

During the initial phases of the program, a deterioration of the compressor performance was observed. As shown in figure 2, this deterioration took place during the first 20 hours of engine operation, after which there appeared to be little additional deterioration. The principal effect of the deterioration was a reduction in air flow; little variation of compressor efficiency with time was observed. The air-flow reduction was probably caused by a combination of nicked blades and dirt accumulations on the blades and passage walls, which resulted in changed aerodynamic characteristics. The air-flow reduction was reflected in reduced pressure ratio at constant corrected turbine-inlet temperature. The reduction in compressor performance during the first 20 hours of operation is in agreement with the over-all engine performance deterioration discussed in reference 1. Subsequent compressor performance results and discussion will involve only data obtained after 20 hours of engine operation.

Effect of Turbine Change

On disassembly of the engine for periodic inspection, damage of the turbine labyrinth seal necessitated a change of turbine section. Although there appeared to be no discernible deterioration of turbine performance with time, changing turbine sections had a slight effect on performance, as shown in figure 3. Turbine B exhibited expansion efficiencies $1\frac{1}{2}$ percent higher than those of turbine A. Expansion pressure ratio and gas flow remained unchanged. Because the turbine-outlet total-pressure measurements were unreliable, the pressure ratio presented here and in the performance maps was calculated by using the turbine-inlet total pressure P_4 and the test-section static pressure p_0 (complete expansion). An adiabatic efficiency which was calculated from this pressure ratio is designated expansion efficiency for both the turbine and exhaust-nozzle sections. The change in turbine performance shown in figure 3 resulted in improved engine performance (ref. 1). Because of this change in turbine performance, the turbine used in producing the over-all turbine operating map for each altitude and in showing the effects of altitude on turbine performance is identified in each case.

Compressor Performance

Conventional compressor performance maps are shown in figures 4(a) to (e) for each flight condition reported. Compressor stall and surge lines were not determined. At an altitude of 15,000 feet and a Mach number of 0.30, a condition near the aerodynamic design flight condition (fig. 4(b)), the compressor efficiency was 0.80 at rated engine speed and turbine-inlet temperature, while the compressor pressure ratio was 6.8 and the corrected air flow was 29.35 pounds per second.

The variation of compressor performance with altitude (Reynolds number index) is shown for several speeds and pressure ratios in figure 5. Compressor efficiencies at a corrected engine speed of 14,400 rpm exhibited a maximum drop of 4 points and corrected air flow decreased approximately 0.4 pound per second as compressor-inlet Reynolds number index was reduced from 0.86 to 0.3. For higher corrected engine speeds, variation in Reynolds number index had a smaller effect on compressor performance.

Combustor Performance

Performance of the combustor is presented in figures 6 and 7. Typical combustor plots showing the effect of altitude on efficiency and total-pressure loss ratio are shown in figure 6. The total-pressure loss through the combustor (fig. 6(a)) was from 4 to 6 percent of combustor-inlet total pressure over the range of temperature ratios shown, the lower loss accompanying the higher temperature ratio. No discernible effect of pressure level or altitude was present. Failure of combustion efficiency to correlate for all altitudes on the basis of the conventional parameter $W_{a,1}T_4$ is illustrated in figure 6(b). The lack of generalization, especially at the higher altitudes, indicates a primary effect of fuel-air ratio (or turbine-inlet temperature) on efficiency. Accordingly, the effect of fuel-air ratio on efficiency is presented in figure 7 for the altitudes investigated. Because there was no observed effect of engine speed on combustion efficiency, the curve for each altitude represents the average efficiency over the entire operable range of engine speeds. In addition to normal decrease in efficiency with increased altitude, there was an appreciable reduction in efficiency as fuel-air ratio was decreased, the variation becoming more pronounced at high altitudes. For example, decreasing fuel-air ratio from 0.017 to 0.009 (corresponding to a decrease in corrected turbine-inlet temperature from approx. 2400° to 1600° R) resulted in a decrease in efficiency of 0.025 at an altitude of 5000 feet, as compared with a decrease of 0.075 at an altitude of 45,000 feet. The maximum combustion efficiency was 0.99 at a fuel-air ratio of 0.017.

Turbine Performance

Conventional turbine performance maps are shown in figures 8(a) to (e). Because the absolute values of expansion efficiency are not the same as absolute values of turbine efficiency, the expansion efficiency is presented only to show the trend of the turbine performance with altitude. The accuracy of the torque measurement permits accuracies of expansion efficiency within 0.015 at the 35,000-foot altitude and within 0.030 at the 45,000-foot altitude. With turbine A, the region of maximum expansion efficiency occurred at corrected turbine speeds between 7000 and 7800 rpm, while with turbine B the best operating region shifted to

8200 rpm and above. Corrected turbine speed for rated engine conditions is about 7200 rpm. Expansion efficiency had a maximum value of 0.825 at an altitude of 5000 feet (fig. 8(a)). At a given altitude, expansion efficiency varied only about 0.015 to 0.03 over the entire operating region.

Variation of the performance of turbines A and B with turbine-inlet Reynolds number index is given in figure 9 for several speeds and pressure ratios. Corrected turbine gas flow decreased only slightly as Reynolds number index was decreased from 1.15 to 0.23. The efficiency of turbine A decreased from about 0.82 to 0.76 as Reynolds number index decreased from 1.15 to 0.43, while the efficiency of turbine B decreased from about 0.815 to 0.77 as Reynolds number index decreased from 0.89 to 0.24. These reductions in expansion efficiency with Reynolds number index are greater than observed for other turbines but do not seem unreasonable in view of the geometry of the turbine (first-stage nozzle chord dimension of approx. 0.90 in.), which results in turbine operation in an absolute Reynolds number region much below that of larger turbine engines. However, some question as to the actual magnitude of the effect of Reynolds number on the turbine performance admittedly exists because of the torquemeter inaccuracy previously mentioned and of the inability to separate the turbine performance from the exhaust-nozzle performance.

Effect of Altitude on Integrated Component Performance

The effect of altitude on the performance of the compressor, combustor, and turbine for 100-percent-normal engine power (engine speed, 14,300 rpm; turbine-inlet temperature, 1960° R) is shown in figure 10. The reduction of ambient-air temperature with an increase in altitude from sea level to 45,000 feet results in an increase in corrected engine speed at a flight Mach number of 0.30 from approximately 99 to 114 percent of rated and an increase in corrected turbine-inlet temperature from 98 to 130 percent of rated. These variations combine the effects of corrected engine speed, pressure ratio, and Reynolds number on component performance. For the stated altitude variation, corrected air flow increased about $2\frac{1}{2}$ pounds per second as a result of the corrected-speed increase. Expansion efficiency decreased 4 percentage points as altitude increased from sea level to 35,000 feet, while compressor efficiency decreased 9 percentage points. The loss of compressor and turbine efficiency (especially compressor) in a turboprop engine would result in a serious loss in shaft horsepower, as is shown in reference 1. Although an increase in altitude was previously shown to have an effect on combustion efficiency, this effect was offset by increased fuel-air-ratio operation with altitude, which had a beneficial effect on efficiency. As a result, combustion efficiency at an altitude of 45,000 feet was only 3 percentage points less than the sea-level value.

CONCLUDING REMARKS

At altitudes below design flight condition of the XT38-A-2 turboprop engine (altitude, 15,000 ft; flight Mach number, 0.347), there were no Reynolds number effects on component performance at rated engine conditions. Above 15,000 feet, decreases in the efficiency of the components would result in serious loss in over-all engine output. Near the design point and at rated engine conditions, compressor efficiency was 0.80, pressure ratio was 6.8, and corrected air flow was 29.35 pounds per second. Operation at reduced compressor-inlet Reynolds number index resulted in the usual decrease in efficiency and corrected air flow for operation near rated corrected speed, but had a less pronounced effect on compressor performance as corrected engine speed was raised.

Combustion efficiency, which reached a maximum of 0.99, did not generalize with the conventional parameter $W_{a,1}T_4$ because of a primary effect of fuel-air ratio. The increase of combustion efficiency with fuel-air ratio was most pronounced at high altitudes. A 4- to 6-percent loss in total pressure occurred in the combustor regardless of altitude. At rated engine conditions, the original turbine had a maximum value of expansion efficiency of 0.825 at an altitude of 5000 feet and a flight Mach number of 0.30. Operation at reduced turbine-inlet Reynolds number index resulted in decreases in efficiency at all regions of operation.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
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APPENDIX A

SYMBOLS

The following symbols are used in this report:

A	cross-sectional area, sq ft
f	fuel-air ratio
g	acceleration due to gravity, 32.2 ft/sec^2
h	enthalpy, Btu/lb
J	mechanical equivalent of heat, 778 ft-lb/Btu
M	Mach number
N	engine speed, rpm
P	total pressure, lb/sq ft abs
p	static pressure, lb/sq ft abs
Q	torque measured by torquemeter, ft-lb
R	gas constant, 53.4 ft-lb/(lb)($^{\circ}$R)
T	total temperature, $^{\circ}$R
TMhp	torquemeter-measured horsepower
W_a	air flow, lb/sec
$W_{a,B}$	air leakage from burner-dome rings and cross-over tubes, lb/sec
$W_{a,ctl}$	air leakage from compressor and turbine bearing labyrinth, lb/sec
W_f	fuel flow, lb/hr
W_g	gas flow, lb/sec
β	specific-heat correction, $\frac{1.4}{\gamma}\frac{\left(\frac{\gamma+1}{2}\right)^{\frac{\gamma}{\gamma-1}}}{\left(\frac{1.4+1}{2}\right)^{\frac{1.4}{1.4-1}}}$

γ ratio of specific heats

δ pressure-correction factor, P/2116 lb/sq ft abs

η efficiency

θ temperature-correction factor, $\frac{\left(\frac{\gamma}{\gamma+1}\right)T}{\left(\frac{1.4}{1.4+1}\right)519^{\circ}\ R}$; at compressor-inlet conditions where $\gamma = 1.4$, $\theta = T/519^{\circ}$ R

π relative pressure function in ref. 2

φ viscosity-correction factor, ratio of absolute viscosity of air to absolute viscosity of air at NACA standard sea-level temperature

Subscripts:

a air

b combustor

c compressor

g gas

i isentropic

t turbine and exhaust nozzle

0 tunnel test section

1 cowl inlet

2 compressor inlet

3 compressor outlet, combustor inlet

4 combustor outlet, turbine inlet

6 exhaust nozzle

The data are generalized by the following parameters:

$\Delta h_t/\theta_4$	corrected turbine enthalpy drop, Btu/lb
$N/\sqrt{\theta_2}$	corrected engine speed, rpm
$N/\sqrt{\theta_4}$	corrected turbine speed, rpm
T_4/θ_2	corrected turbine-inlet total temperature, $^{\circ}R$
$W_{a,1}T_4$	combustor flow parameter, (lb)($^{\circ}R$)/sec
$\frac{W_{a,1}\sqrt{\theta_2}}{\delta_2}$	corrected compressor air flow, lb/sec
$\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\beta_4$	corrected turbine gas flow, lb/sec
$\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\frac{N}{60\sqrt{\theta_4}}\beta_4$	turbine weight-flow parameter, lb-rev/sec^2

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APPENDIX B

METHODS OF CALCULATION

Air flow. - Air flow was determined from pressure and temperature measurements at the cowl inlet by use of the equation

$$W_{a,1} = p_1 A_1 \sqrt{\frac{2g}{RT_1}\left(\frac{\gamma}{\gamma - 1}\right)\left(\frac{P_1}{p_1}\right)^{\frac{\gamma_1 - 1}{\gamma_1}}\left[\left(\frac{P_1}{p_1}\right)^{\frac{\gamma_1 - 1}{\gamma_1}} - 1\right]}$$

The leakage from the compressor and turbine bearing labyrinth $W_{a,ctl}$ was measured and found to be approximately 1 percent of $W_{a,1}$. Leakage from the burner-dome rings and cross-over tubes $W_{a,B}$ was assumed to be 1/4 of 1 percent of $W_{a,1}$. The gas flow through the turbine was

$$W_{g,4} = W_{a,1} - W_{a,ctl} - 0.0025\ W_{a,1} + \frac{W_f}{3600}$$

Torquemeter horsepower. - The torque, measured by the torquemeter, along with the measured engine speed, was used to calculate torquemeter horsepower as follows:

$$TMhp = \frac{2\pi NQ}{33,000}$$

where $\pi = 3.1416$.

Temperatures. - The arithmetic averages of the indicated temperatures at the cowl inlet and compressor outlet were accepted as the total temperatures at those stations. A standard thermocouple recovery factor of 0.85 was applied, however, to the average of the indicated temperatures at the exhaust nozzle. This latter total temperature was taken as the turbine-outlet temperature. Because thermocouples could not be relied on at the turbine inlet, use of the torquemeter horsepower was required in calculating the turbine-inlet temperature. The turbine enthalpy drop equals the sum of the compressor enthalpy rise and the enthalpy rise equivalent to the power output, as follows:

$$W_{g,4}(h_4 - h_6) = W_{a,1}(h_3 - h_1) + \frac{550}{J}\ (TMhp)$$

Then the turbine-inlet temperature can be determined from the known value of h_4 and enthalpy charts.

Efficiencies. - Compressor efficiency was calculated with the aid of gas tables (ref. 2) giving enthalpy and relative pressure function π as a function of temperature. The isentropic enthalpy rise was determined, since

$$\pi_3 = \frac{P_3}{P_2} \pi_1$$

from which $h_{3,i}$ was found, and 3245

$$\eta_c = \frac{h_{3,i} - h_1}{h_3 - h_1}$$

Combustor efficiency was calculated from known values of inlet and outlet temperatures of the combustor:

$$\eta_b = \frac{(1+f)h_{g,4} - h_{a,3}}{18,925f}$$

where $f = \frac{W_f/3600}{W_{a,1}}$ and 18,925 Btu per pound is the lower heating value of the fuel.

Expansion efficiency of the turbine and exhaust-nozzle section was determined by the equation

$$\eta_t = \frac{1 - \frac{T_6}{T_4}}{1 - \left(\frac{p_0}{P_4}\right)^{\frac{\gamma_t - 1}{\gamma_t}}}$$

where γ_t is based on the average turbine temperature and the fuel-air ratio.

Reynolds number index. - The ratio of the Reynolds number to the sea-level Reynolds number for a given compressor or turbine Mach number is herein defined as the Reynolds number index:

$$\text{Reynolds number index} = \frac{\delta}{\varphi\sqrt{\theta}}$$

REFERENCES

1. Essig, R. H., and Schulze, F. W.: Altitude Performance and Operational Characteristics of an XT38-A-2 Turboprop Engine. NACA RM E53L18a, 1954.

2. Amorosi, A.: Gas Turbine Gas Charts. Res. Memo. No. 6-44 (Navships 250-330-6), Res. Branch, Bur. Ships, Navy Dept., Dec. 1944.

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TABLE I. - COMPONENT PERFORMANCE DATA

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Run	Tunnel static pressure, p_0, lb/sq ft abs	Flight Mach number, M	Engine speed, N, rpm	Engine air flow, $W_{a,1}$, lb/sec	Engine-inlet temperature, T_1, °R	Turbine-inlet gas temperature, T_4, °R	Exhaust-gas temperature, T_8, °R	Engine-inlet Reynolds number index, $\frac{\delta_2}{\varphi_2\sqrt{\theta_2}}$	Corrected engine speed, $N/\sqrt{\theta_2}$, rpm	Corrected air flow, $\frac{W_{a,1}\sqrt{\theta_2}}{\delta_2}$ lb/sec	Corrected turbine-inlet temperature, T_4/θ_2, °R	Compressor total-pressure ratio, P_3/P_2
Altitude, 5000 feet												
1	1758	0.292	14,310	28.96	451	1870	1272	1.060	15,355	30.61	2152	7.159
2	1757	.287		29.02	449	2000	1358	1.065	15,383	30.59	2312	7.397
3	1762	.295		29.27	446	1730	1174	1.070	15,440	30.67	2013	7.018
4	1761	.292		29.29	445	1543	1049	1.075	15,455	30.70	1799	6.700
5	1767	.292		29.43	446	1306	900	1.070	15,440	30.81	1520	6.173
6	1761	.295	14,310	29.22	448	1420	969	1.065	15,398	30.71	1645	6.396
7	1754	.295		27.90	470	2007	1371	1.000	15,040	30.16	2216	7.162
8	1763	.303		28.53	464	1515	913	1.025	15,140	30.58	1471	6.015
9	1766	.290		28.14	466	1503	1031	1.010	15,068	30.18	1667	6.351
10	1765	.295		28.11	473	1655	1131	1.000	14,983	30.33	1816	6.584
11	1754	.295	14,894	25.39	539	1670	1163	.838	14,617	29.40	1609	6.101
12	1753	.302		25.57	542	1520	1071	.835	14,575	29.61	1456	5.886
13	1755	.287		25.58	541	1470	1040	.830	14,587	29.65	1411	5.818
14	1758	.299	14,602	25.02	542	1983	1380	.837	14,290	28.95	1880	6.422
15	1757	.298		25.02	542	1870	1300	.837	14,290	28.95	1791	6.254
16	1759	.302	14,602	25.10	540	1773	1230	.838	14,316	28.94	1705	6.202
17	1754	.303		25.09	539	1690	1180	.840	14,330	28.95	1628	6.022
18	1758	.299	14,310	24.98	540	2023	1406	.838	14,030	28.83	1946	6.483
19	1756	.290		24.76	541	1450	1037	.830	14,015	28.75	1392	5.692
20	1765	.295		25.23	536	1583	1119	.842	14,081	28.94	1544	5.852
21	1762	.299	14,310	24.43	540	1690	1186	.839	14,030	28.14	1625	5.909
22	1765	.303		24.73	544	1813	1268	.851	13,977	28.49	1730	6.091
23	1761	.295		24.62	541	1950	1355	.825	14,015	28.44	1871	6.276
24	1754	.295	14,018	24.05	545	2038	1443	.823	13,680	27.95	1955	6.188
25	1759	.299	14,018	24.26	536	1428	1021	.845	13,784	27.92	1384	5.436
26	1757	.295	14,018	23.91	541	1573	1121	.832	13,729	27.64	1510	5.562
27	1762	.299		23.84	540	1673	1184	.840	13,743	27.46	1609	5.665
28	1757	.302		24.13	537	1793	1257	.842	13,781	27.75	1734	5.885
29	1759	.302		23.95	541	1910	1338	.835	13,729	27.61	1833	6.017
30	1757	.306	13,726	23.10	541	2033	1433	.835	13,000	26.63	1951	5.975
31	1759	.308	13,726	23.53	539	1407	1010	.841	13,443	27.01	1355	5.143
32	1757	.305		23.36	540	1533	1093	.837	13,471	26.93	1474	5.342
33	1756	.306		23.18	542	1700	1202	.833	13,457	26.77	1626	5.560
34	1759	.306		23.07	543	1870	1321	.832	13,432	26.62	1786	5.755
35	1760	.308	13,434	22.18	544	2047	1456	.832	13,420	25.57	1951	5.727
36	1760	.306	13,434	22.30	543	1900	1345	.833	13,121	25.71	1815	5.872
37	1759	.306		22.32	542	1753	1250	.834	13,147	25.73	1679	5.982
38	1759	.308		22.60	542	1535	1111	.835	13,147	26.04	1470	5.156
39	1762	.308		23.02	540	1393	1006	.841	13,171	26.38	1339	4.938
40	1758	.312	13,142	21.26	544	2055	1472	.832	12,836	24.49	1989	5.524
41	1755	.311		21.36	544	1747	1256	.830	12,836	24.67	1685	5.144
42	1758	.311		21.69	542	1570	1136	.835	12,861	24.97	1504	4.974
43	1755	.311		21.84	540	1373	1004	.838	12,886	25.14	1320	4.711
Altitude, 15,000 feet												
1	1187	0.303	14,894	19.39	475	1380	948	0.680	15,564	31.04	1508	6.309
2	1184	.302		19.37	474	1470	1001	.670	15,579	31.07	1609	6.531
3	1186	.295		19.46	475	1580	1074	.670	15,564	31.25	1726	6.744
4	1182	.299		19.44	475	1650	1113	.670	15,564	31.28	1803	6.859
5	1186	.297		19.44	476	1797	1216	.670	15,549	31.24	1959	7.118
6	1191	.297	14,602	19.29	475	1335	915	.680	15,258	30.84	1456	6.142
7	1185	.306		19.27	475	1523	1036	.680	15,259	30.87	1664	6.535
8	1187	.302		19.25	476	1620	1098	.680	15,244	30.86	1768	6.728
9	1185	.299		19.28	473	1747	1173	.670	15,288	30.89	1917	6.958
10	1187	.303		19.31	473	1857	1261	.670	15,286	30.84	2037	7.159
11	1183	.311	14,602	19.08	476	1997	1356	.660	15,244	30.72	2177	7.337
12	1179	.308	14,310	18.89	475	1577	945	.670	14,954	30.39	1604	6.215
13	1183	.303		19.05	473	1443	989	.670	14,983	30.52	1563	6.348
14	1190	.299		19.25	471	1775	1209	.680	15,026	30.65	1958	6.872
15	1189	.297		19.22	472	1903	1302	.680	15,011	30.68	2092	7.175
16	1190	.302	14,310	18.95	475	1983	1356	.675	14,954	30.28	2177	7.257
17	1195	.299		19.28	472	1593	1083	.680	15,011	30.58	1752	6.581
18	1186	.302	14,018	18.72	473	1307	901	.672	14,677	29.93	1434	5.928
19	1187	.302		18.74	473	1455	989	.673	14,677	29.95	1596	6.249
20	1188	.299		18.74	474	1680	1145	.671	14,663	29.98	1839	6.645
21	1192	.302	14,018	18.74	475	1790	1228	.672	14,649	29.92	1952	6.765
22	1187	.299		18.69	475	1937	1327	.668	14,649	29.94	2116	7.007
23	1187	.302		18.68	476	2020	1385	.667	14,635	29.94	2202	7.151
24	1179	.306	13,728	18.14	478	2003	1390	.660	14,302	29.28	2175	6.975
25	1190	.306		18.52	475	1340	925	.672	14,344	29.52	1464	5.803
26	1189	.303	13,728	18.34	477	1503	1036	.667	14,316	29.36	1635	6.178
27	1190	.303		18.50	475	1603	1099	.671	14,344	29.54	1751	6.382
28	1187	.303		18.34	476	1763	1210	.667	14,330	29.38	1922	6.635
29	1189	.302		18.44	477	1850	1274	.666	14,316	29.54	2013	6.741
30	1194	.306	13,434	18.04	477	1240	865	.670	14,012	28.72	1349	5.541
31	1187	.306	13,434	18.20	476	1360	945	.665	13,998	29.17	1477	5.771
32	1184	.306		17.82	478	1530	1056	.662	13,998	28.64	1661	6.099
33	1188	.299		17.96	477	1703	1173	.665	14,012	28.83	1853	6.407
34	1188	.302		17.97	477	1863	1291	.665	14,012	28.82	2027	6.662
35	1189	.302		18.11	476	2037	1409	.668	14,025	28.98	2221	6.892
36	1186	.306	13,142	17.48	477	1223	864	.670	13,707	28.06	1331	5.327
37	1190	.306		17.08	483	2037	1425	.659	13,628	27.37	2189	6.569
38	1183	.306		17.19	478	1943	1354	.668	13,694	27.66	2110	6.508
39	1193	.302		17.54	476	1813	1265	.672	13,720	27.98	1977	6.382
40	1188	.303		17.45	480	1600	1116	.662	13,668	28.01	1730	6.029
41	1184	.312		17.43	480	1410	985	.662	13,666	27.99	1524	5.667

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FOR XT38-A-2 TURBOPROP ENGINE

Compressor efficiency, η_c	Fuel-air ratio, f	Combustor total-pressure loss ratio, $\frac{P_3 - P_4}{P_3}$	Combustor efficiency, η_b	Corrected turbine speed, $N/\sqrt{\theta_4}$, rpm	Corrected turbine gas flow, $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\beta_4$, lb/sec	Expansion pressure ratio, P_4/p_0	Turbine weight-flow parameter, $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\frac{N}{60\sqrt{\theta_4}}\beta_4$, $\frac{\text{lb-rev}}{\text{sec}^2}$	Corrected turbine enthalpy drop, $\Delta h_t/\theta_4$, Btu/lb	Expansion efficiency, η_t	Run
Altitude, 5000 feet										
0.7468	0.0141	0.0477	0.9897	7636	9.354	7.237	1190	46.68	0.8171	1
.7491	.0160	.0455	.9983	7392	9.391	7.500	1157	47.21	.8187	2
.7400	.0122	.0562	.9784	7932	9.301	7.030	1230	46.07	.8193	3
.7310	.0096	.0533	.9643	8383	9.134	6.735	1276	44.94	.8181	4
.7147	.0062	.0612	.9631	9086	9.143	6.150	1385	41.94	.8044	5
.7256	.0078	.0587	.9613	8726	9.151	6.412	1331	43.51	.8175	6
.7692	.0159	.0392	.9957	7376	9.292	7.310	1143	46.78	.8163	7
.7308	.0061	.0561	.9624	9057	9.062	6.050	1368	41.27	.7968	8
.7488	.0087	.0485	.9669	8488	9.066	6.408	1283	43.98	.8149	9
.7575	.0107	.0447	.9798	8098	9.167	6.680	1237	45.18	.8183	10
.7526	.0096	.0527	.9720	8396	9.062	6.135	1268	43.20	.8157	11
.7575	.0076	.0560	.9504	8787	9.002	5.918	1318	41.41	.7947	12
.7547	.0070	.0579	.9323	8929	8.974	5.825	1335	40.98	.7878	13
.7745	.0141	.0444	.9770	7609	9.158	6.530	1161	45.04	.8258	14
.7712	.0127	.0462	.9761	7792	9.189	6.345	1193	44.41	.8216	15
.7709	.0113	.0598	.9706	7992	9.129	6.212	1216	44.05	.8261	16
.7841	.0102	.0508	.9604	8185	9.098	6.095	1241	43.03	.8152	17
.8044	.0152	.0422	.9862	7350	9.193	6.610	1126	44.83	.8197	18
.7706	.0068	.0568	.9612	8636	8.991	5.590	1294	40.06	.7773	19
.7757	.0088	.0529	.9781	8248	9.107	5.890	1252	41.87	.8074	20
.7773	.0103	.0505	.9665	8017	8.998	5.968	1202	42.69	.8128	21
.7928	.0121	.0469	.9708	7748	9.114	6.190	1177	43.40	.8146	22
.7910	.0140	.0444	.9881	7480	9.101	6.373	1135	44.54	.8268	23
.8005	.0156	.0430	.9860	7174	9.340	6.300	1118	43.75	.8104	24
.7720	.0068	.0570	.9503	8522	8.961	5.445	1273	39.56	.7853	25
.7750	.0088	.0532	.9559	8131	9.054	5.610	1227	41.39	.7963	26
.7808	.0103	.0502	.9614	7897	9.107	5.720	1199	41.89	.8101	27
.7801	.0119	.0481	.9786	7631	9.211	5.968	1171	42.99	.8219	28
.7879	.0136	.0451	.9814	7405	9.214	6.118	1137	43.79	.8244	29
.7941	.0157	.0424	.9814	7032	9.231	6.100	1082	43.84	.8236	30
.7639	.0064	.0583	.9784	6405	9.072	5.170	1271	38.62	.8008	31
.7724	.0082	.0543	.9743	9060	9.065	5.388	1218	40.36	.8062	32
.7834	.0107	.0506	.9689	7672	9.109	5.633	1165	41.85	.8196	33
.7862	.0132	.0457	.9747	7324	9.165	5.860	1119	42.98	.8206	34
.7921	.0162	.0418	.9717	6861	9.249	5.863	1056	43.02	.8218	35
.7874	.0158	.0450	.9779	7112	9.226	5.680	1094	42.04	.8255	36
.8421	.0116	.0489	.9744	7398	9.149	5.480	1128	41.22	.8188	37
.7768	.0086	.0528	.9493	7888	9.056	5.215	1191	39.99	.7903	38
.7640	.0063	.0575	.9855	8267	9.166	4.975	1263	37.86	.8006	39
.7938	.0165	.0413	.9716	6698	9.216	5.667	1029	42.09	.8202	40
.7801	.0117	.0430	.9705	7249	9.179	5.235	1109	40.45	.8200	41
.7765	.0091	.0518	.9705	7632	9.105	5.040	1158	39.11	.8056	42
.7597	.0063	.0570	.9654	8143	9.063	4.745	1233	36.87	.7920	43
Altitude, 15,000 feet										
0.7243	0.0065	0.0538	0.9658	9211	8.943	6.360	1373	43.30	0.8034	1
.7318	.0079	.0499	.9544	8929	8.916	6.610	1327	44.62	.8138	2
.7366	.0095	.0465	.9522	8624	8.995	6.830	1293	45.84	.8150	3
.7409	.0104	.0451	.9669	8443	9.044	6.968	1273	46.13	.8257	4
.7493	.0126	.0431	.9691	8103	9.091	7.240	1228	46.68	.8201	5
.7449	.0059	.0558	.9993	9172	8.980	6.165	1373	42.03	.8142	6
.7447	.0087	.0487	.9633	8605	9.008	6.632	1292	44.66	.8198	7
.7546	.0102	.0455	.9574	8354	9.036	6.840	1258	45.94	.8221	8
.7581	.0119	.0434	.9933	8054	9.092	7.080	1220	46.20	.8368	9
.7629	.0136	.0416	.9767	7817	9.106	7.310	1186	46.85	.8170	10
.7631	.0158	.0393	.9725	7546	9.154	7.480	1151	47.18	.8172	11
.7544	.0070	.0528	.9670	8855	8.877	6.280	1310	42.98	.8093	12
.7616	.0078	.0504	.9620	8657	8.937	6.430	1289	43.55	.8102	13
.7716	.0126	.0425	.9729	7833	9.097	7.100	1188	45.94	.8137	14
.7703	.0145	.0403	.9737	7571	9.122	7.320	1151	45.91	.8080	15
.7762	.0160	.0391	.9683	7403	9.123	7.425	1126	47.10	.8184	16
.7533	.0099	.0463	.9645	8252	9.084	6.675	1249	45.18	.8236	17
.7543	.0059	.0545	.9753	8900	8.935	5.972	1325	41.90	.8139	18
.7640	.0081	.0500	.9589	8445	8.960	6.320	1261	44.15	.8307	19
.7777	.0114	.0443	.9618	7880	9.049	6.760	1188	45.57	.8205	20
.7831	.0129	.0415	.9730	7843	9.130	6.890	1164	45.58	.8105	21
.7857	.0150	.0399	.9863	7351	9.211	7.157	1129	45.93	.8135	22
.7866	.0163	.0390	.9829	7203	9.218	7.320	1107	46.63	.8109	23
.8026	.0164	.0388	.9714	7083	9.183	7.152	1084	46.20	.7967	24
.7723	.0065	.0546	.9723	8606	8.951	5.955	1284	42.14	.8150	25
.7873	.0091	.0474	.9430	8140	8.980	6.272	1209	43.69	.8158	26
.7873	.0104	.0446	.9603	7893	9.014	6.508	1186	44.56	.8173	27
.7921	.0127	.0411	.9682	7538	9.069	6.780	1139	45.20	.8154	28
.7925	.0139	.0410	.9762	7364	9.209	6.880	1130	45.19	.8116	29
.7722	.0052	.0560	.9786	8746	8.896	5.580	1297	40.08	.8103	30
.7793	.0088	.0528	.9806	8365	9.084	5.833	1266	41.67	.8117	31
.7935	.0096	.0467	.9418	7902	8.943	6.205	1178	43.46	.8178	32
.8024	.0120	.0425	.9630	7501	9.046	6.528	1131	44.48	.8174	33
.8051	.0144	.0399	.9665	7180	9.137	6.805	1093	44.97	.8051	34
.8061	.0167	.0382	.9929	6879	9.193	7.060	1054	45.60	.8096	35
.7726	.0051	.0566	.9822	8618	8.992	5.360	1292	39.35	.8015	36
.8168	.0171	.0379	.9755	6729	9.145	6.741	1026	44.61	.8054	37
.8120	.0155	.0384	.9859	6894	9.141	6.677	1049	44.40	.8070	38
.8198	.0139	.0404	.9610	7119	9.116	6.520	1082	44.50	.8040	39
.8101	.0107	.0444	.9531	7562	9.027	6.148	1138	43.20	.8082	40
.7927	.0077	.0511	.9738	8043	9.023	5.755	1210	41.55	.8131	41

[redacted]

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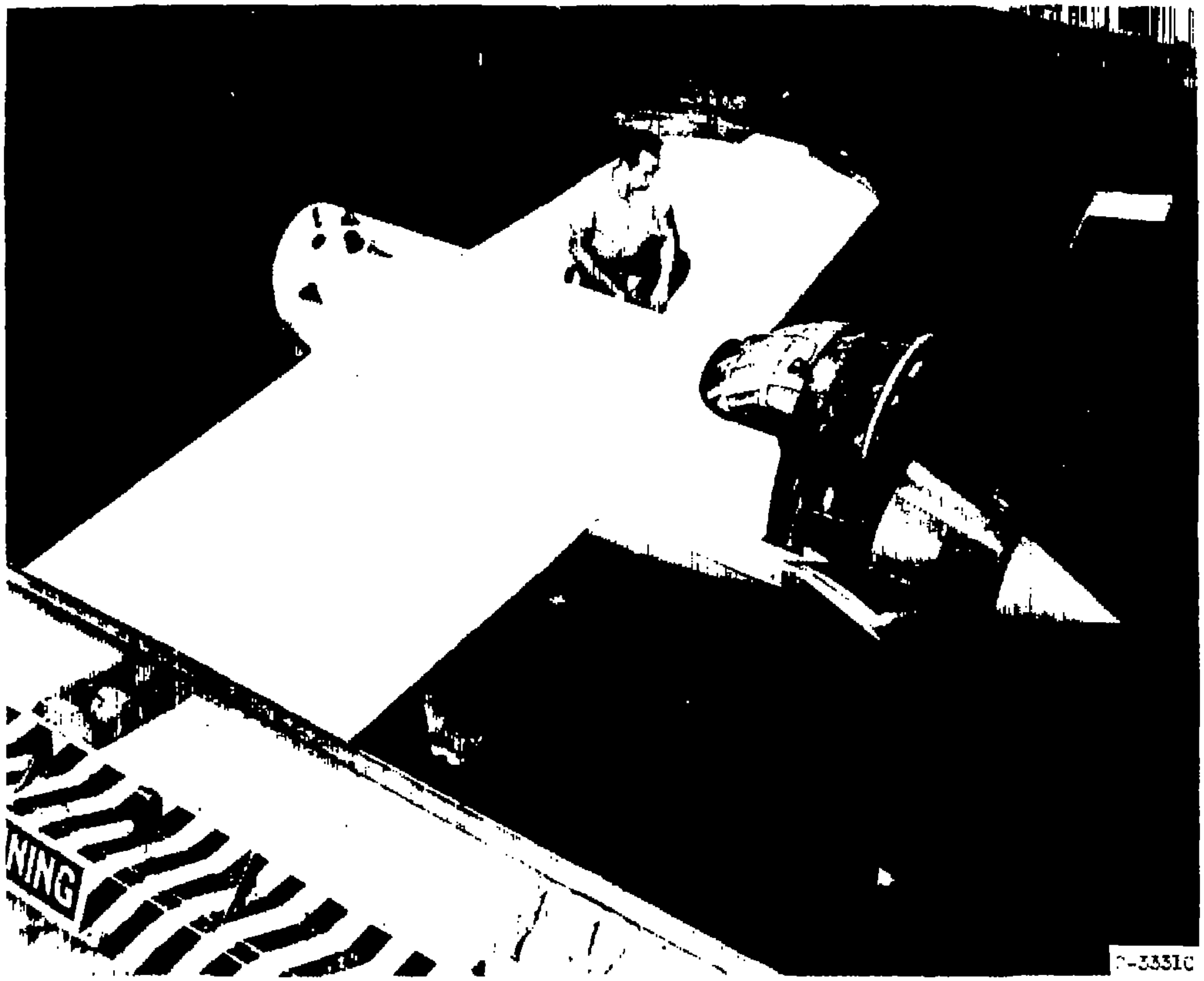
TABLE I. - Concluded. COMPONENT PERFORMANCE

Run	Tunnel static pressure, p_0, lb/sq ft abs	Flight Mach number, M	Engine speed, N, rpm	Engine air flow, $W_{a,1}$, lb/sec	Engine-inlet temperature, T_1, °R	Turbine-inlet gas temperature, T_4, °R	Exhaust-gas temperature, T_5, °R	Engine-inlet Reynolds number index, $\delta_2/\varphi_2\sqrt{\theta_2}$	Corrected engine speed, $N/\sqrt{\theta_2}$, rpm	Corrected air flow, $W_{a,1}\sqrt{\theta_2}/\delta_2$, lb/sec	Corrected turbine-inlet temperature, T_4/θ_2, °R	Compressor total-pressure ratio, P_3/P_2
Altitude, 25,000 feet												
1	778	0.273	14,894	13.29	441	1829	1247	0.468	16,160	31.66	2165	7.507
2	774	.280		13.18	442	1918	1310	.469	16,145	31.55	2252	7.610
3	763	.287		13.10	439	1472	1018	.471	16,190	31.56	1740	6.847
4	781	.280		13.29	440	1555	1069	.476	16,175	31.23	1834	6.962
5	773	.280		13.15	441	1670	1144	.472	16,160	31.43	1965	7.219
6	768	.287	14,894	13.11	441	1720	1174	.472	16,160	31.45	2024	7.328
7	771	.292	14,602	13.08	439	1894	1290	.478	15,872	31.12	2239	7.516
8	780	.287		13.13	440	1748	1180	.480	15,858	30.97	2062	7.241
9	771	.299		13.07	440	1620	1104	.478	15,858	31.06	1911	7.023
10	773	.295		13.36	430	1478	1012	.485	16,049	31.34	1784	6.837
11	770	.302	14,602	13.08	440	1404	969	.478	15,858	31.10	1656	6.562
12	775	.302	14,310	13.19	432	1975	1349	.489	15,612	31.01	2351	7.598
13	774	.292		13.10	436	1434	991	.492	15,684	30.80	1723	6.815
14	775	.302		13.19	436	1878	1081	.489	15,612	31.01	1879	6.887
15	776	.297		13.07	435	1755	1192	.490	15,627	30.89	2094	7.205
16	770	.290	14,310	12.80	441	1925	1317	.475	15,626	30.59	2266	7.462
17	774	.297	14,018	12.92	437	2010	1376	.487	15,260	30.48	2387	7.583
18	770	.290		13.05	433	1875	1282	.488	15,350	30.90	2247	7.418
19	773	.302		13.09	433	1788	1221	.491	15,350	30.74	2143	7.275
20	780	.287		13.14	433	1647	1124	.494	15,350	30.63	1974	7.004
21	778	.295	14,018	13.10	433	1518	1040	.490	15,350	30.73	1816	6.720
22	775	.297		13.08	434	1585	958	.487	15,336	30.71	1657	6.444
23	775	.287	13,726	12.87	431	1970	1357	.490	15,057	30.22	2572	7.507
24	773	.292		12.87	436	1870	1284	.485	14,975	29.96	2226	7.229
25	778	.297		12.70	436	1710	1170	.486	14,875	29.90	2036	6.975
26	771	.299	13,726	12.68	435	1657	1057	.485	14,989	29.95	1834	6.684
27	770	.303		13.89	435	1390	963	.485	14,989	29.94	1659	6.378
28	778	.295	13,434	12.53	441	1537	1059	.482	14,576	29.60	1809	6.581
29	773	.297		12.57	435	1695	1162	.486	14,670	29.61	2020	6.920
30	776	.295		12.56	439	1840	1266	.484	14,630	29.61	2181	7.085
31	777	.290		12.45	437	1395	970	.484	14,643	29.33	1654	6.269
Altitude, 35,000 feet												
1	488	0.303	14,894	8.42	435	1590	1100	0.310	16,264	31.42	1897	7.247
2	487	.305		8.42	435	1770	1218	.310	16,264	31.36	2112	7.585
3	484	.305		8.39	435	1860	1281	.309	16,264	31.50	2219	7.756
4	485	.290		8.39	433	1480	1042	.308	16,309	31.55	1774	7.035
5	488	.303		8.44	433	1545	1070	.311	16,309	31.37	1849	7.136
6	480	.306	14,602	8.25	436	1937	1357	.310	15,931	31.18	2306	7.775
7	479	.311		8.35	436	2030	1405	.310	15,931	31.63	2417	7.949
8	486	.306		8.40	436	1780	1234	.311	15,951	31.45	2119	7.510
9	485	.303		8.27	437	1693	1173	.309	15,916	31.06	2011	7.346
10	486	.295		8.36	436	1520	1058	.306	15,931	31.50	1810	7.025
11	485	.308	14,310	8.28	434	2083	1451	.311	15,655	30.96	2491	7.988
12	494	.292		8.27	444	1443	1016	.308	15,469	30.89	1687	6.856
13	487	.295		8.16	437	1443	1009	.310	15,598	30.65	1714	6.754
14	484	.303		8.14	437	1570	1089	.308	15,598	30.63	1865	6.981
15	482	.308		8.10	440	1667	1180	.302	15,541	30.65	1966	7.227
16	488	.303	14,310	8.32	434	1843	1272	.312	15,655	30.96	2204	7.540
17	480	.306		8.13	435	1953	1350	.310	15,627	30.78	2330	7.734
18	486	.308	14,018	8.20	434	2105	1467	.310	15,336	30.57	2515	7.921
19	487	.303		8.19	434	1957	1362	.310	15,336	30.53	2341	7.640
20	486	.295		8.17	434	1837	1274	.311	15,336	30.64	2197	7.460
21	487	.299	14,018	8.08	432	1627	1142	.311	15,564	30.15	1954	7.069
22	486	.303		8.13	440	1503	1044	.308	15,274	30.58	1775	6.722
23	486	.295	13,726	8.05	433	1480	1025	.309	14,989	30.22	1742	6.643
24	484	.299		7.90	437	1700	1181	.308	14,961	29.78	2019	7.035
25	491	.302		8.10	433	1935	1343	.311	14,989	30.00	2306	7.478
26	490	.302	13,726	8.09	433	2048	1426	.311	14,989	30.02	2444	7.653
27	487	.302	13,434	7.97	433	1899	1323	.308	14,710	29.88	2276	7.277
28	490	.287		7.96	435	1780	1241	.309	14,670	29.60	2124	7.086
29	489	.302		7.82	436	1671	1168	.309	14,656	29.11	1988	6.877
30	490	.306		7.85	436	1588	1113	.310	14,630	20.16	1882	6.718
31	493	.297		7.97	437	1455	1026	.310	14,643	29.53	1730	6.466
Altitude, 45,000 feet												
1	293	0.292	14,894	5.02	440	1940	1325	0.181	16,175	31.48	2288	7.936
2	300	.283		5.08	438	1477	1009	.186	16,220	31.10	1750	7.076
3	298	.283		5.06	440	1548	1049	.182	16,175	31.23	1820	7.190
4	299	.283		5.07	439	1640	1114	.185	16,190	31.22	1939	7.402
5	296	.287		5.04	439	1735	1178	.184	16,190	31.43	2049	7.568
6	296	.299	14,884	5.17	440	1850	1259	.183	16,175	31.98	2182	7.759
7	294	.286	14,602	5.03	440	1493	1019	.180	15,858	31.51	1761	7.019
8	293	.302		4.94	436	1600	1088	.180	15,931	30.71	1905	7.253
9	293	.285		5.02	439	1775	1217	.180	15,872	31.52	2099	7.503
10	298	.276		4.93	441	1847	1263	.180	15,843	30.63	2174	8.025
11	293	.292	14,602	5.02	440	1947	1338	.180	15,858	31.45	2296	7.743
12	295	.276		5.04	437	2047	1413	.180	15,916	31.46	2431	7.878
13	299	.285	14,310	4.98	435	1793	1228	.180	15,627	30.55	2139	7.570
14	318	.292		5.04	440	1980	1332	.180	15,541	31.37	2312	7.773
15	313	.292		5.03	440	2115	1462	.180	15,541	31.41	2492	8.087
16	313	.286	14,310	4.78	440	1863	1262	.180	15,541	30.04	2197	7.581
17	313	.276		4.78	439	1703	1168	.180	15,555	30.01	2013	7.300
18	314	.278		4.89	440	1603	1098	.180	15,541	30.84	1891	7.188
19	313	.278		5.00	440	1470	1011	.180	15,541	31.53	1734	6.906
20	295	.292	14,018	4.79	441	1640	1137	.182	15,210	29.85	1930	7.102
21	298	.299	14,018	4.95	438	1737	1193	.184	15,268	30.54	2058	7.321
22	298	.276		4.79	441	1843	1269	.182	15,210	29.95	2169	7.471
23	294	.308		4.93	441	1940	1338	.182	15,210	30.63	2283	7.681
24	295	.292		4.92	442	2057	1439	.183	15,198	30.69	2427	7.888
25	295	.276		4.93	436	1410	974	.184	15,294	30.74	1679	6.727

[redacted]

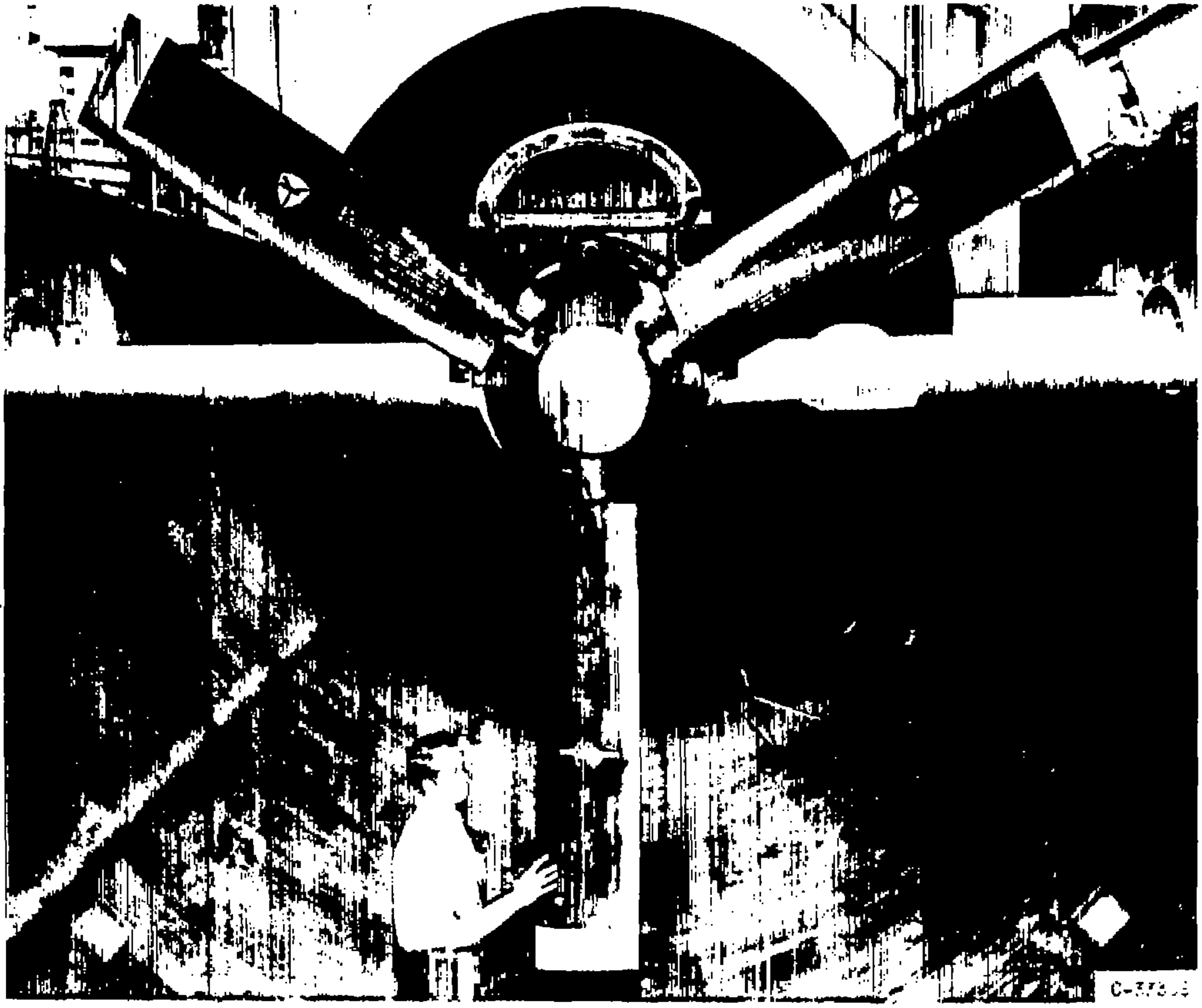
DATA FOR XT38-A-2 TURBOPROP ENGINE

Compressor efficiency, η_c	Fuel-air ratio, f	Combustor total-pressure loss ratio, $\frac{P_3 - P_4}{P_3}$	Combustor efficiency, η_b	Corrected turbine speed, $N/\sqrt{\theta_4}$, rpm	Corrected turbine gas flow, $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\beta_4$, lb/sec	Expansion pressure ratio, P_4/p_0	Turbine weight-flow parameter, $\frac{W_{g,4}\sqrt{\theta_4}}{\delta_4}\frac{N}{60\sqrt{\theta_4}}\beta_4$, $\frac{\text{lb-rev}}{\text{sec}^2}$	Corrected turbine enthalpy drop, $\Delta h_t/\theta_4$, Btu/lb	Expansion efficiency, η_t	Run
Altitude, 25,000 feet										
0.7052	0.0132	0.438	0.9875	8033	9.180	7.560	1226	45.36	0.7965	1
.7019	.0145	.0436	.9894	7851	9.179	7.690	1201	46.11	.7941	2
.6884	.0084	.0515	.9423	8924	8.984	6.875	1336	43.07	.7751	3
.6881	.0095	.0482	.9528	8690	8.977	6.995	1300	43.92	.7864	4
.6992	.0111	.0462	.9640	8396	9.028	7.270	1283	45.12	.7885	5
.7019	.0119	.0457	.9604	8274	9.025	7.400	1244	45.38	.7932	6
.7015	.0143	.0438	.9847	7742	9.190	7.630	1186	46.40	.7896	7
.6983	.0122	.0467	.9745	8050	9.068	7.310	1219	45.20	.8026	8
.6956	.0108	.0485	.9486	8354	9.037	7.110	1258	44.16	.8017	9
.6790	.0086	.0510	.9499	8733	9.043	6.895	1316	44.01	.7918	10
.6827	.0074	.0555	.9475	8953	9.033	6.800	1348	42.47	.7856	11
.7093	.0156	.0417	.9924	7438	9.278	7.750	1150	46.45	.7971	12
.6861	.0081	.0531	.9472	8683	9.043	6.645	1309	42.71	.7836	13
.6910	.0100	.0496	.9580	8291	9.159	6.948	1288	44.64	.7961	14
.7063	.0124	.0453	.9865	7878	9.115	7.315	1196	46.01	.8066	15
.7170	.0150	.0422	.9793	7528	9.143	7.580	1147	46.21	.7971	16
.7298	.0164	.0412	.9885	7222	9.210	7.740	1109	46.44	.7967	17
.7291	.0142	.0433	.9999	7468	9.258	7.520	1152	46.00	.7976	18
.7279	.0131	.0444	.9878	7643	9.155	7.400	1166	45.78	.7975	19
.7218	.0113	.0484	.9623	7956	9.097	7.085	1206	45.07	.8012	20
.7135	.0094	.0495	.9567	8285	9.099	6.780	1256	43.99	.7961	21
.7100	.0076	.0535	.9476	8653	9.066	6.485	1307	42.29	.7861	22
.7397	.0161	.0414	.9849	7142	9.187	7.620	1095	46.02	.7874	23
.7421	.0145	.0427	.9854	7324	9.160	7.340	1118	45.57	.7975	24
.7374	.0123	.0449	.9679	7651	9.036	7.080	1152	45.34	.8027	25
.7322	.0101	.0484	.9354	8055	8.965	6.765	1204	44.08	.8004	26
.7280	.0079	.0538	.9404	8457	8.941	6.435	1260	42.14	.7871	27
.7601	.0103	.0478	.9360	7884	8.965	6.655	1177	43.76	.7999	28
.7831	.0126	.0445	.9515	7526	8.968	7.030	1127	44.86	.7962	29
.7656	.0143	.0427	.9796	7226	9.126	7.205	1099	45.13	.7971	30
.7400	.0081	.0542	.9348	8267	8.910	6.290	1228	41.67	.7856	31
Altitude, 35,000 feet										
0.6792	0.0108	0.0464	0.8782	8599	8.816	7.365	1263	43.65	0.7640	1
.6851	.0132	.0444	.9159	8161	8.898	7.740	1210	45.05	.7701	2
.6845	.0144	.0445	.9317	7869	8.975	7.900	1192	45.22	.7705	3
.6727	.0091	.0517	.9012	8903	8.829	7.070	1310	41.79	.7370	4
.6721	.0099	.0510	.8929	8725	8.759	7.220	1274	43.22	.7621	5
.6977	.0155	.0430	.9484	7661	9.034	7.940	1153	45.42	.7708	6
.6989	.0166	.0415	.9699	7488	9.180	8.145	1146	45.49	.7655	7
.7005	.0132	.0447	.9391	7979	9.024	7.660	1200	44.19	.7815	8
.6970	.0122	.0466	.9100	8176	8.871	7.467	1209	43.90	.7638	9
.6906	.0098	.0516	.8826	8615	8.825	7.070	1281	42.48	.7604	10
.7108	.0160	.0428	.9520	7246	9.115	8.170	1101	45.78	.7564	11
.6999	.0086	.0525	.8823	8657	8.913	6.690	1286	41.38	.7510	12
.6927	.0089	.0527	.8597	8657	8.797	6.795	1269	41.74	.7526	13
.6969	.0107	.0489	.8835	8310	8.872	7.080	1229	43.18	.7700	14
.7097	.0126	.0480	.8584	8076	8.794	7.370	1184	41.71	.7301	15
.7089	.0143	.0431	.9445	7689	9.031	7.688	1157	44.77	.7738	16
.7095	.0158	.0417	.9508	7476	9.000	7.910	1121	45.33	.7693	17
.7281	.0183	.0401	.9844	7066	9.100	8.120	1072	46.22	.7568	18
.7264	.0181	.0401	.9560	7320	9.044	7.816	1103	44.70	.7621	19
.7259	.0144	.0419	.9449	7545	9.019	7.572	1134	44.35	.7691	20
.7166	.0119	.0462	.8668	8001	8.957	7.170	1194	42.68	.7458	21
.7154	.0094	.0528	.9206	8314	8.972	6.780	1243	42.93	.7739	22
.7244	.0094	.0499	.8814	8259	8.861	6.700	1220	41.26	.7567	23
.7336	.0128	.0442	.9127	7672	8.876	7.153	1135	43.74	.7729	24
.7377	.0160	.0399	.9488	7209	9.026	7.645	1084	44.68	.7701	25
.7381	.0174	.0396	.9730	7010	9.094	7.630	1062	44.85	.7650	26
.7465	.0153	.0405	.9708	7116	9.108	7.440	1080	44.05	.7692	27
.7455	.0141	.0417	.9248	7341	8.982	7.220	1099	43.81	.7688	28
.7389	.0126	.0438	.9054	7573	8.806	7.010	1111	43.20	.7671	29
.7400	.0115	.0461	.8863	7761	8.757	6.840	1133	42.38	.7632	30
.7339	.0094	.0499	.8870	8120	8.860	6.528	1180	41.10	.7568	31
Altitude, 45,000 feet										
0.6877	0.0166	0.0434	0.9327	7806	8.919	8.060	1160	46.44	0.7845	1
.6752	.0030	.0495	.8636	8909	8.618	7.108	1280	44.02	.7889	2
.6780	.0099	.0464	.8759	8725	8.658	7.243	1259	44.84	.7947	3
.6772	.0116	.0445	.8725	8472	8.678	7.475	1225	45.92	.7950	4
.6821	.0125	.0485	.9105	8247	8.860	7.560	1218	45.98	.7964	5
.6852	.0142	.0364	.9229	7990	8.964	7.955	1194	46.32	.7862	6
.6823	.0091	.0477	.8280	8686	8.795	7.070	1273	44.23	.7880	7
.6848	.0109	.0460	.8862	8406	8.640	7.367	1210	45.39	.7931	8
.6888	.0129	.0452	.9405	7988	9.020	7.580	1201	45.50	.7809	9
.7194	.0145	.0441	.9121	7836	8.371	8.030	1094	45.83	.7748	10
.6903	.0159	.0461	.9259	7641	9.198	7.840	1171	46.01	.7820	11
.6896	.0174	.0449	.9384	7478	9.308	7.930	1157	45.91	.7791	12
.7071	.0138	.0464	.9178	7790	8.715	7.630	1131	45.66	.7850	13
.7125	.0159	.0452	.9496	7465	9.161	7.875	1140	45.71	.7753	14
.7130	.0183	.0428	.9520	7198	9.152	8.220	1098	46.04	.7691	15
.7087	.0147	.0451	.9270	7648	8.742	7.660	1114	45.44	.7811	16
.6976	.0124	.0465	.9051	7990	8.646	7.350	1151	45.21	.7200	17
.7010	.0109	.0470	.8973	8229	8.755	7.205	1201	44.66	.7887	18
.7238	.0088	.0511	.9001	8579	8.897	6.910	1272	43.51	.7835	19
.7175	.0117	.0472	.9064	7974	8.710	7.165	1158	43.88	.7700	20
.7200	.0129	.0442	.9380	7753	8.863	7.445	1145	44.97	.7834	21
.7206	.0147	.0429	.9180	7533	8.771	7.535	1101	45.06	.7836	22
.7298	.0161	.0436	.9288	7347	8.953	7.855	1096	45.80	.7792	23
.7392	.0181	.0417	.9374	7127	9.032	8.020	1075	45.22	.7626	24
.7045	.0083	.0507	.8805	8599	8.719	6.733	1247	42.68	.7766	25



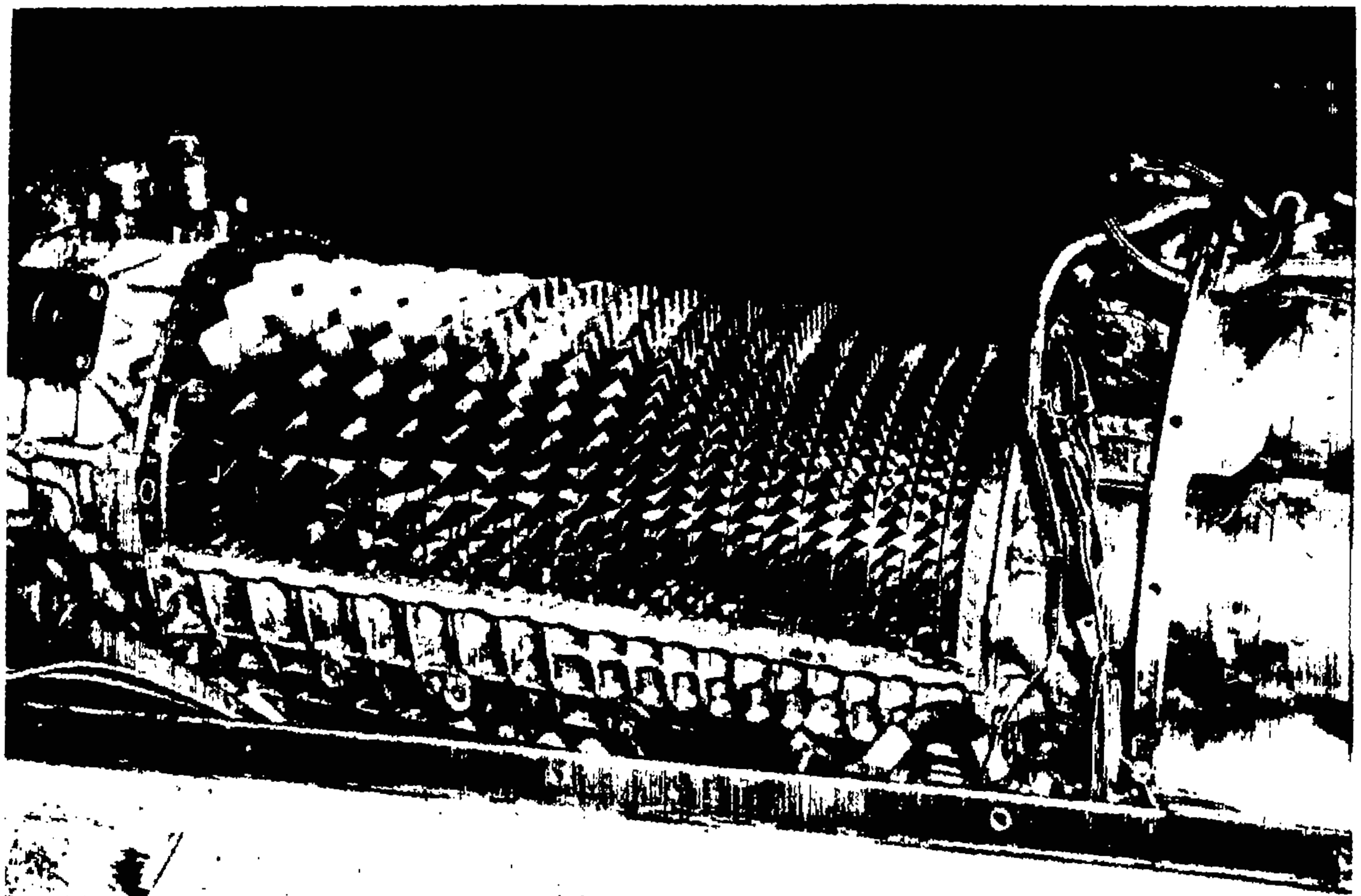
(a) Side view of engine installed in altitude wind tunnel.

Figure 1. - Installation and instrumentation of XT38-A-2 turboprop engine.



(b) Front view of engine installation.

Figure 1. - Continued. Installation and instrumentation of XT38-A-2 turboprop engine.



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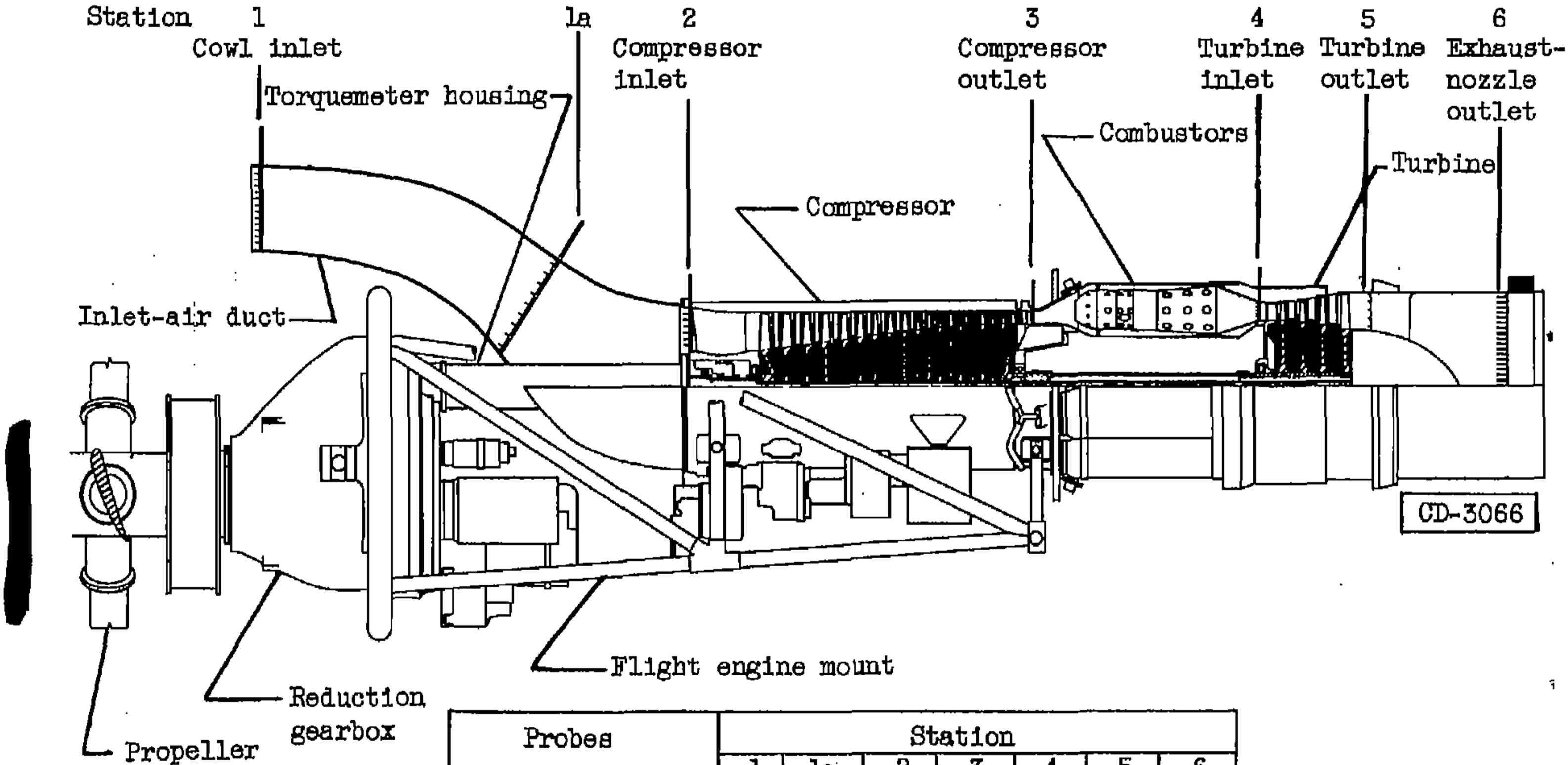
(c) Nineteen-stage axial-flow compressor.

Figure 1. - Continued. Installation and instrumentation of XT38-A-2 turboprop engine.

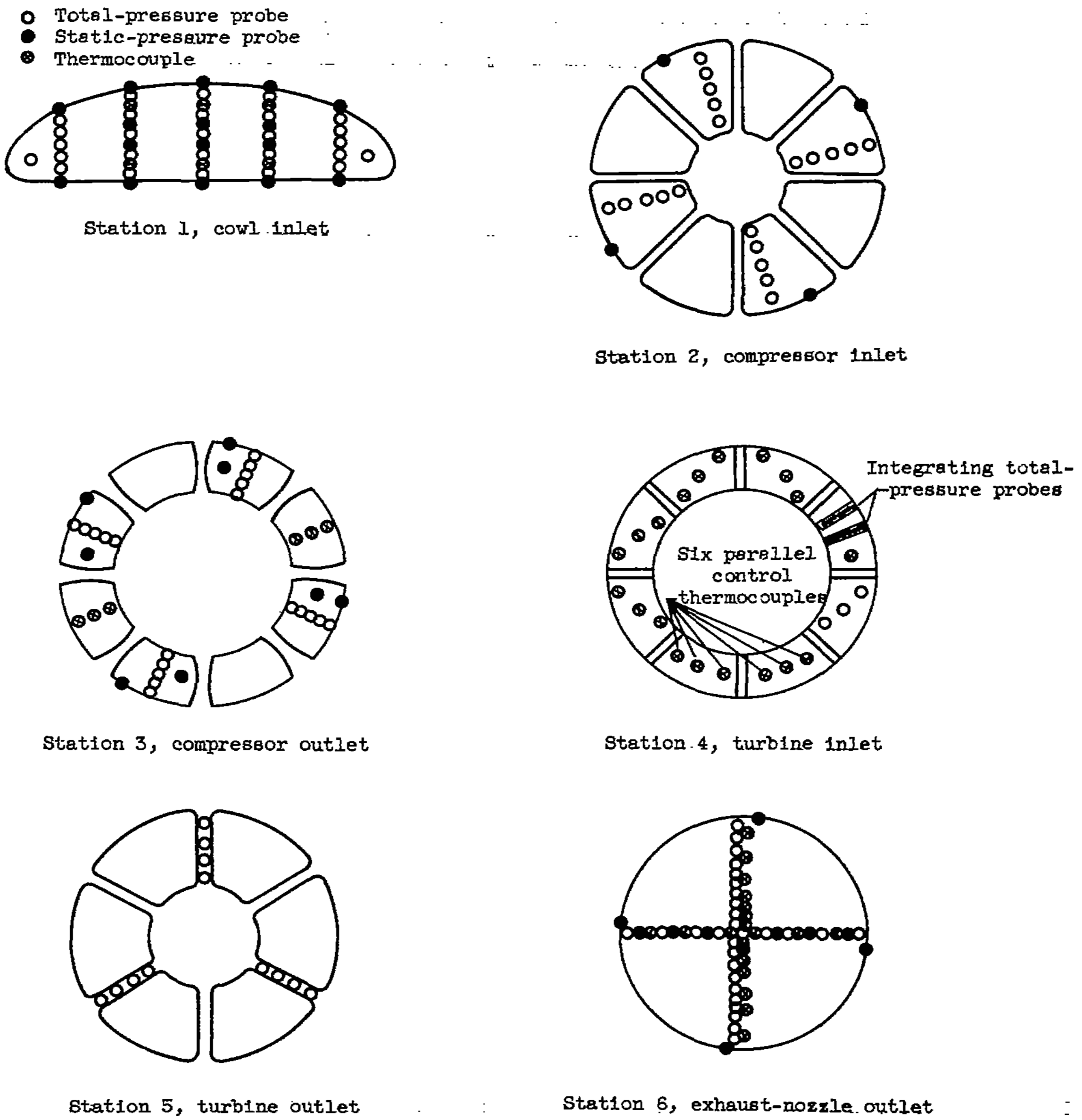


Probes	Station						
	1	1a	2	3	4	5	6
Thermocouple	6	0	0	6	19	0	20
Static pressure	16	20	4	8	0	0	10
Total pressure	27	27	20	20	5	12	29

(d) Engine cross section showing instrumentation stations.

Figure 1. - Continued. Installation and instrumentation of XT38-A-2 turboprop engine.

3245



(e) Schematic diagrams of instrumentation stations viewed from upstream.

Figure 1. - Concluded. Installation and instrumentation of XT38-A-2 turboprop engine.

3245

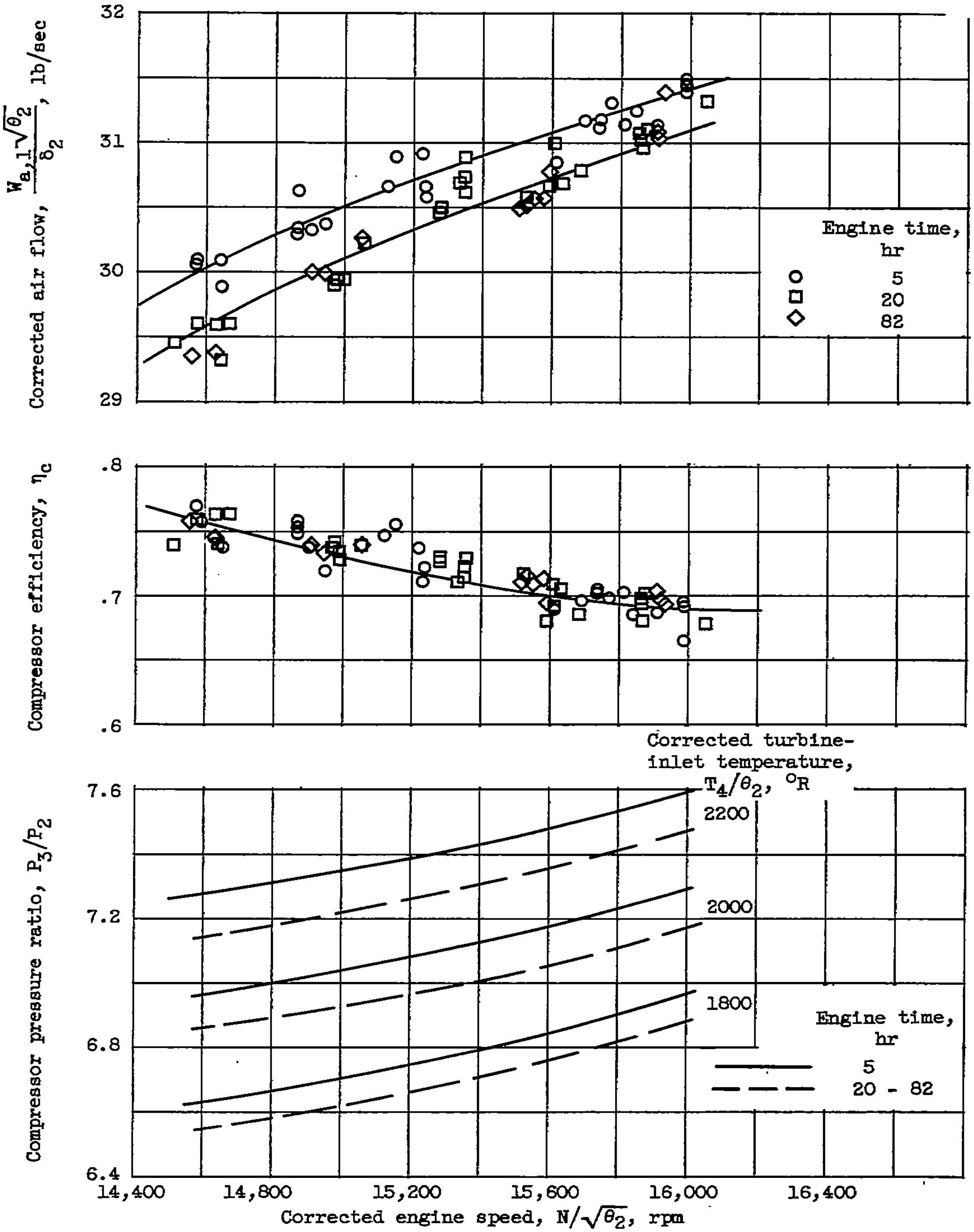


Figure 2. - Effect of engine operating time on compressor performance. Altitude, 25,000 feet; flight Mach number, 0.29.

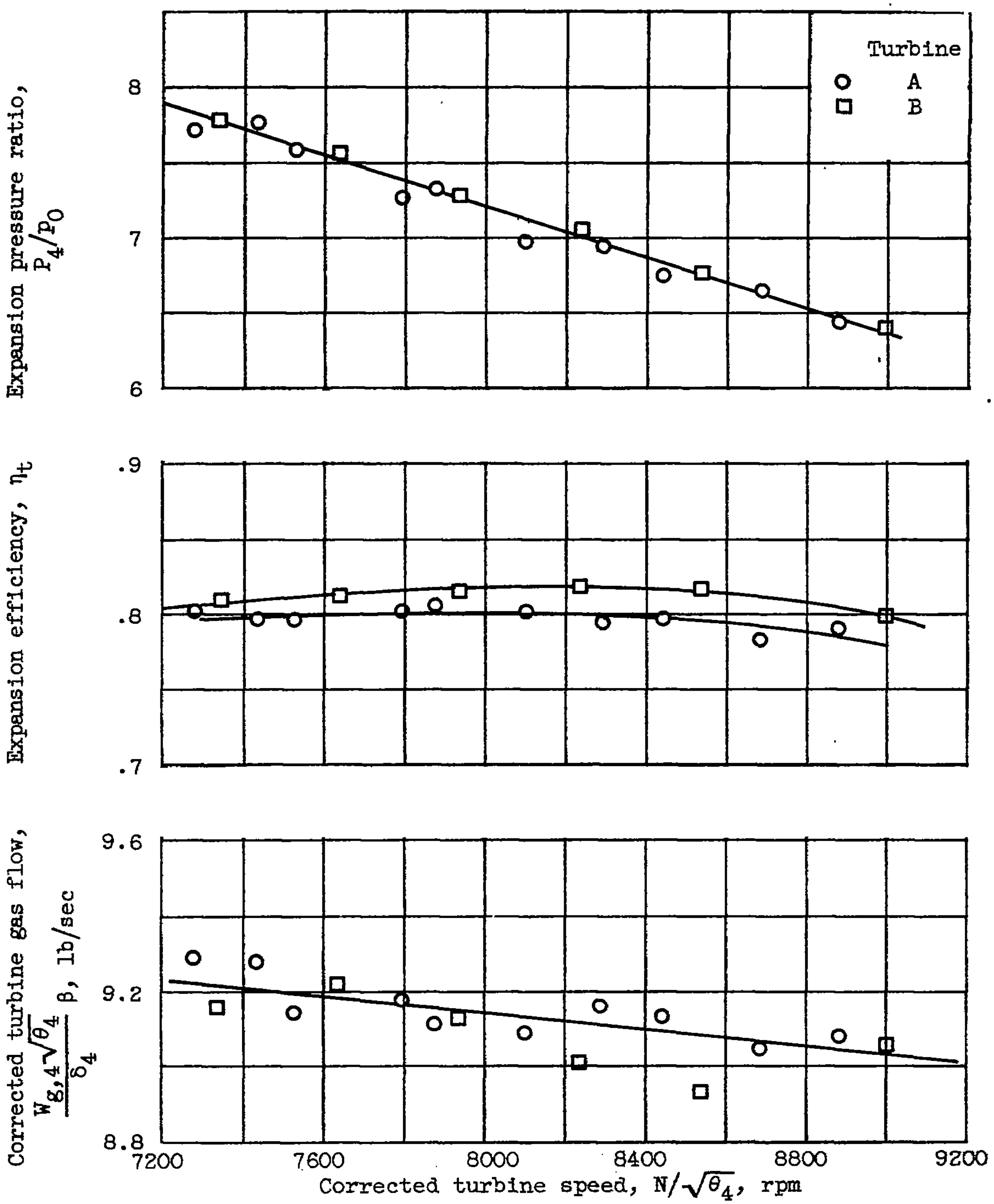


Figure 3. - Comparison of turbine performance for two similar turbines. Altitude, 25,000 feet; flight Mach number, 0.29; average corrected engine speed, 15,550 rpm.

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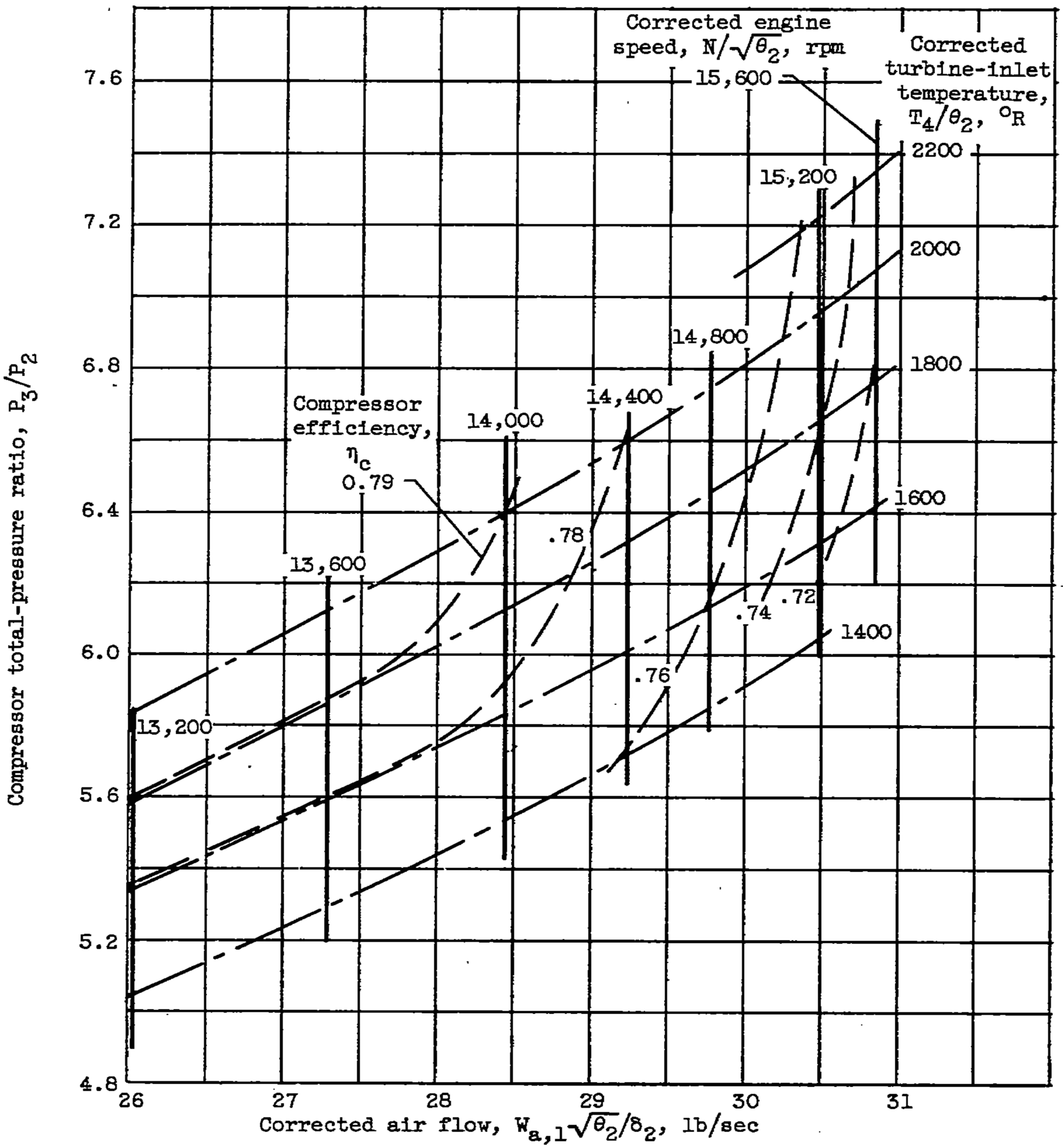
3245

3245

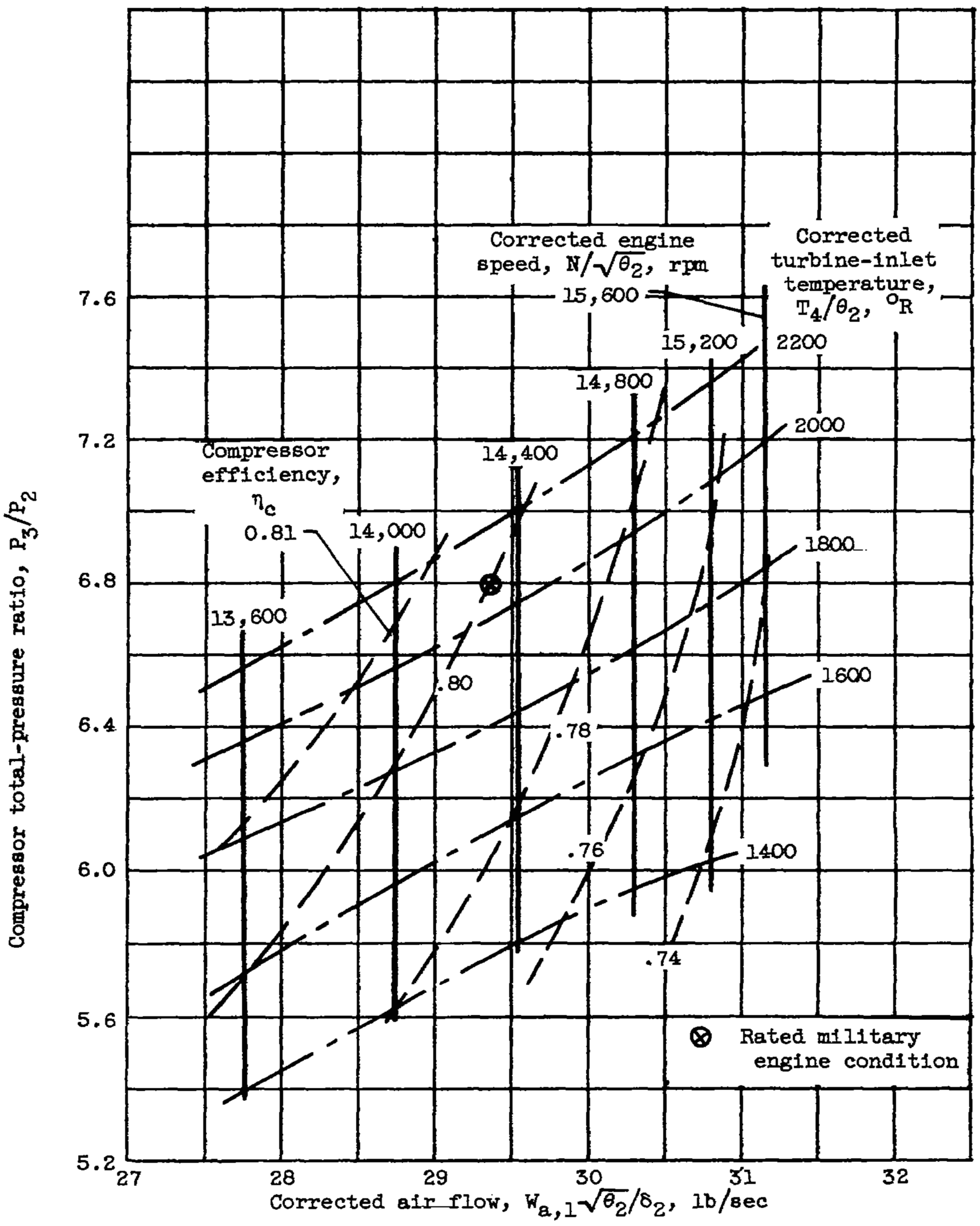
CP-4



(a) Altitude, 5000 feet. Compressor-inlet Reynolds number index, 0.864 up to 15,000 rpm; 1.038 above 15,000 rpm.

Figure 4. - Compressor performance maps. Flight Mach number, 0.30.

3245

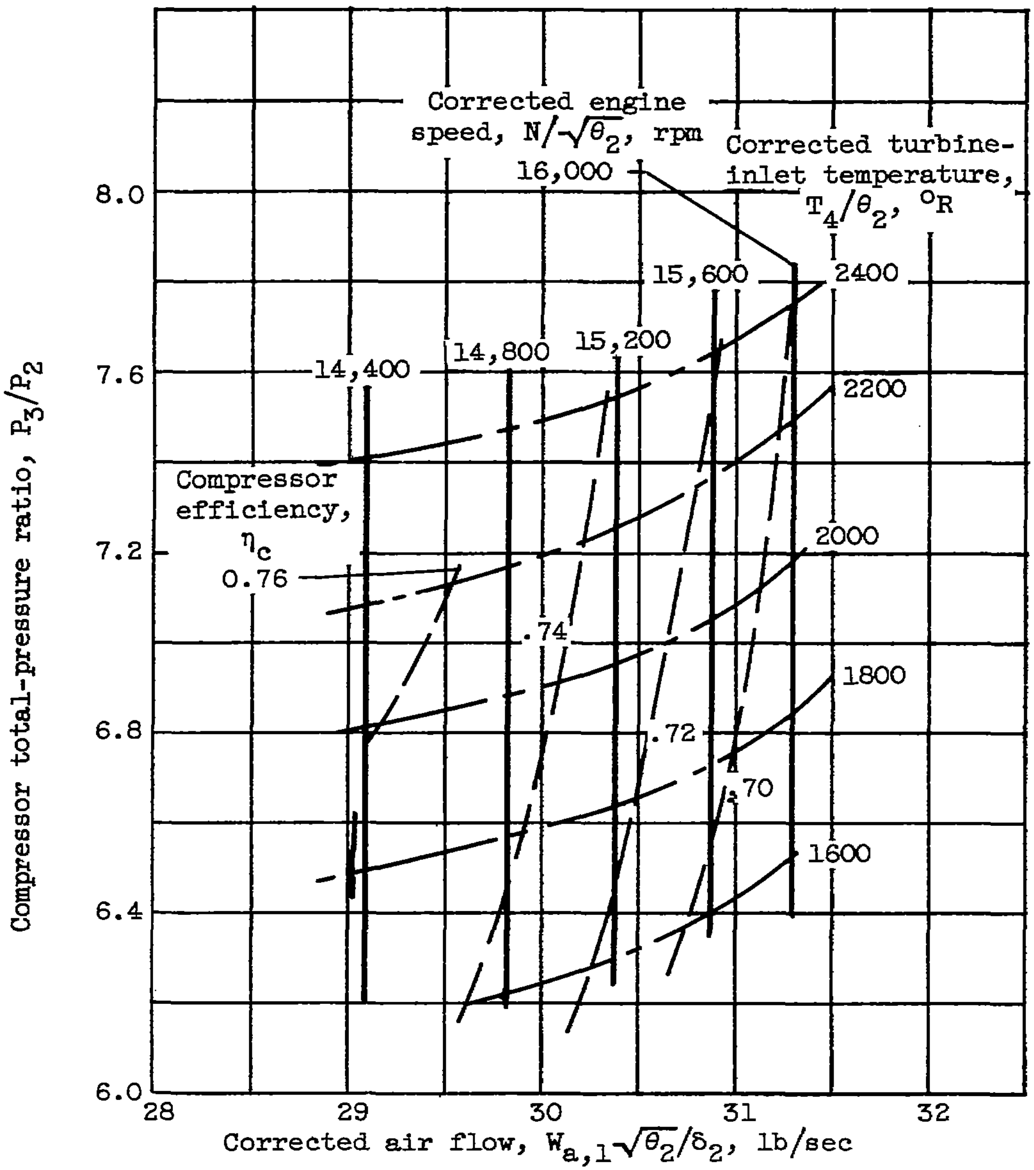


(b) Altitude, 15,000 feet. Compressor-inlet Reynolds number index, 0.670.

Figure 4. - Continued. Compressor performance maps. Flight Mach number, 0.30.

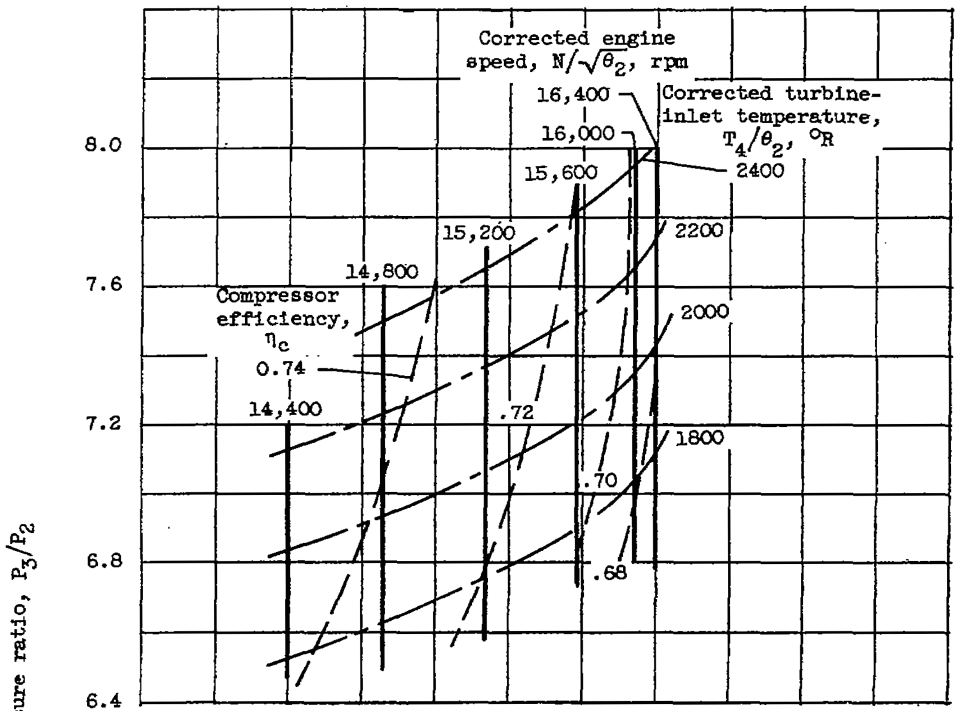
3245

CP-4 back

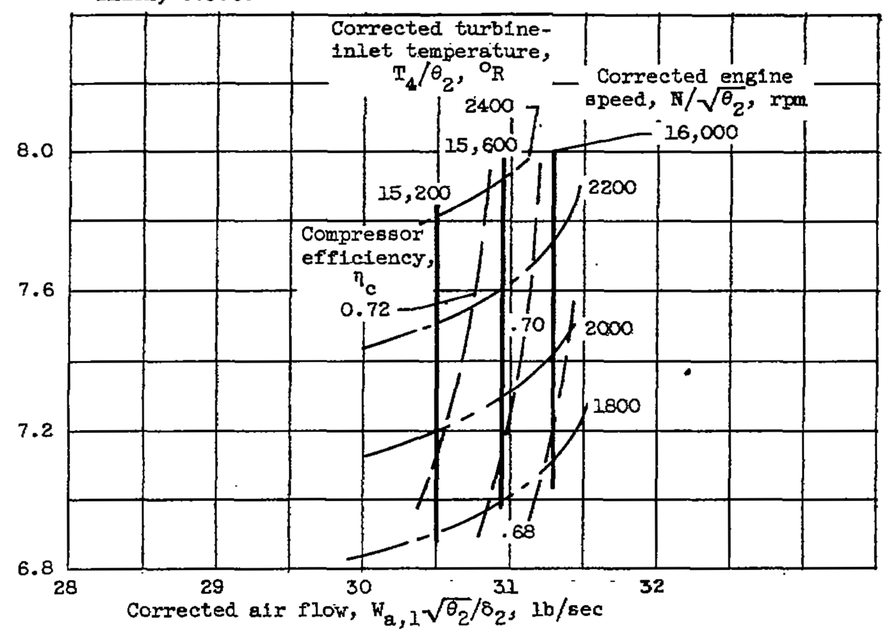


(c) Altitude, 25,000 feet. Compressor-inlet Reynolds number index, 0.482.

Figure 4. - Continued. Compressor performance maps. Flight Mach number, 0.30.



(d) Altitude, 35,000 feet. Compressor-inlet Reynolds number index, 0.306.



(e) Altitude, 45,000 feet. Compressor-inlet Reynolds number index, 0.182.

Figure 4. - Concluded. Compressor performance maps. Flight Mach number, 0.30.

3245

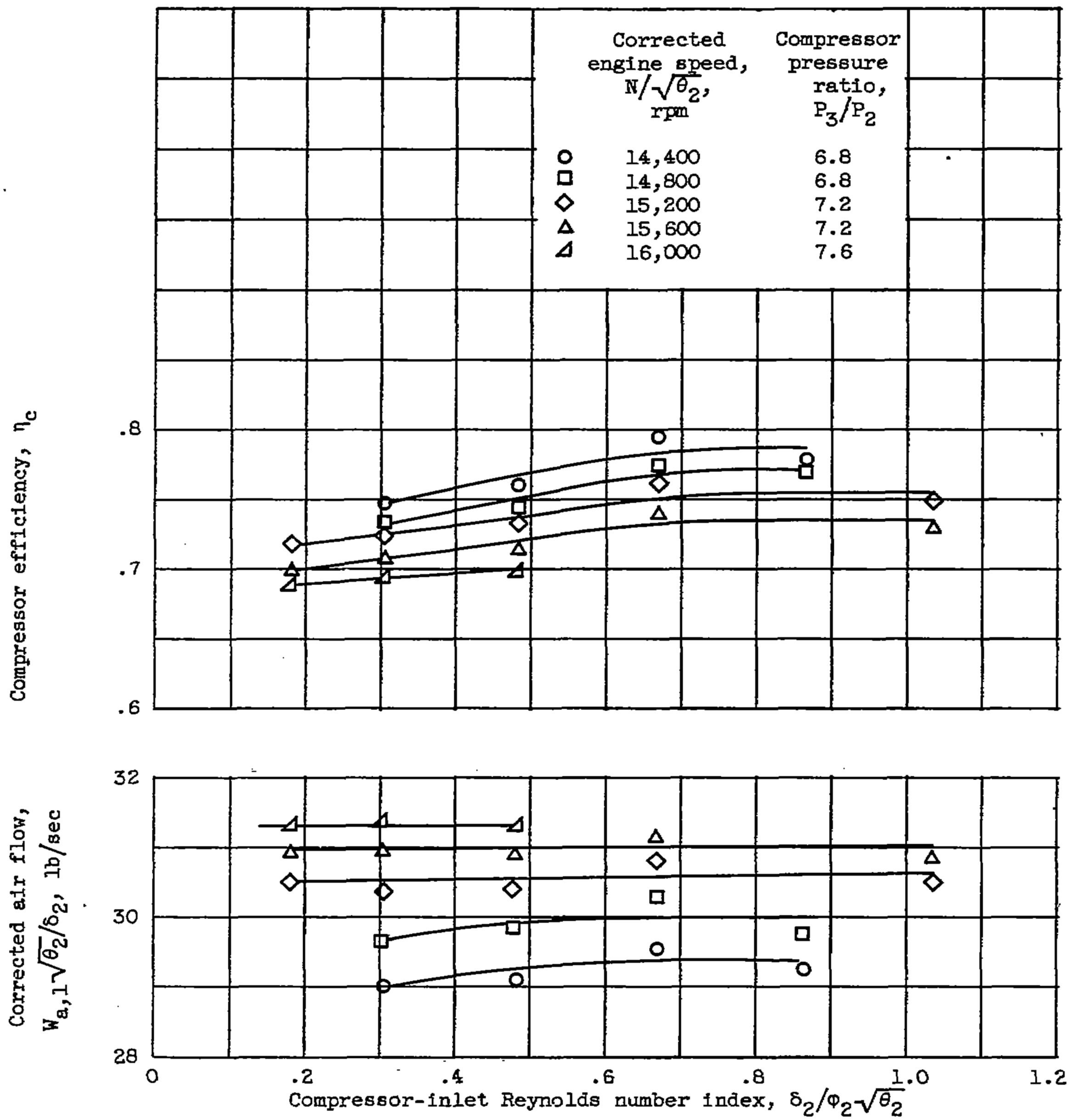
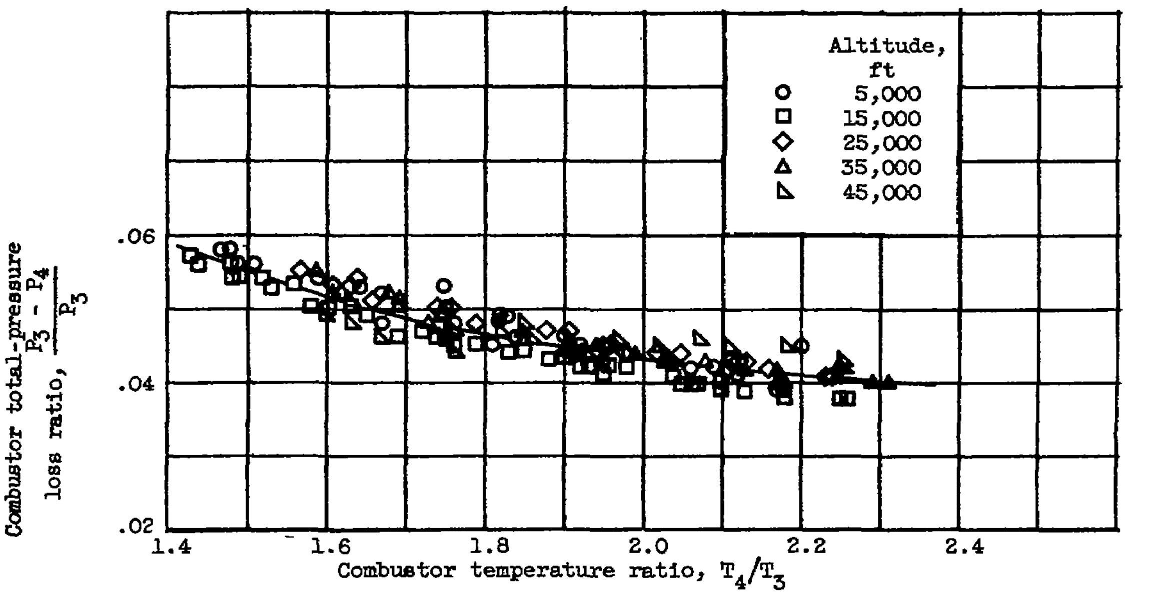
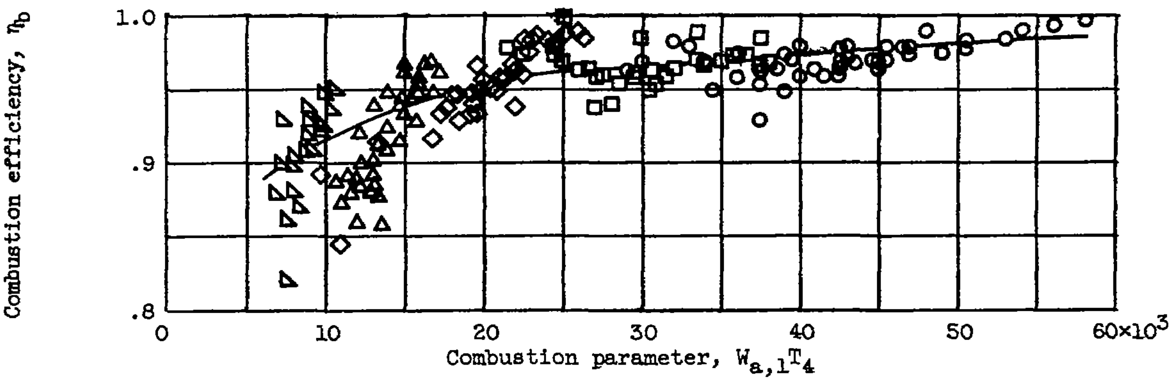


Figure 5. - Effect of Reynolds number index on compressor performance.

3245



(a) Variation of combustor total-pressure loss ratio with combustor temperature ratio.



(b) Variation of combustion efficiency with combustion parameter $W_{a,1}T_4$.

Figure 6. - Typical combustor plots showing effect of altitude. Flight Mach number, 0.30.

3245

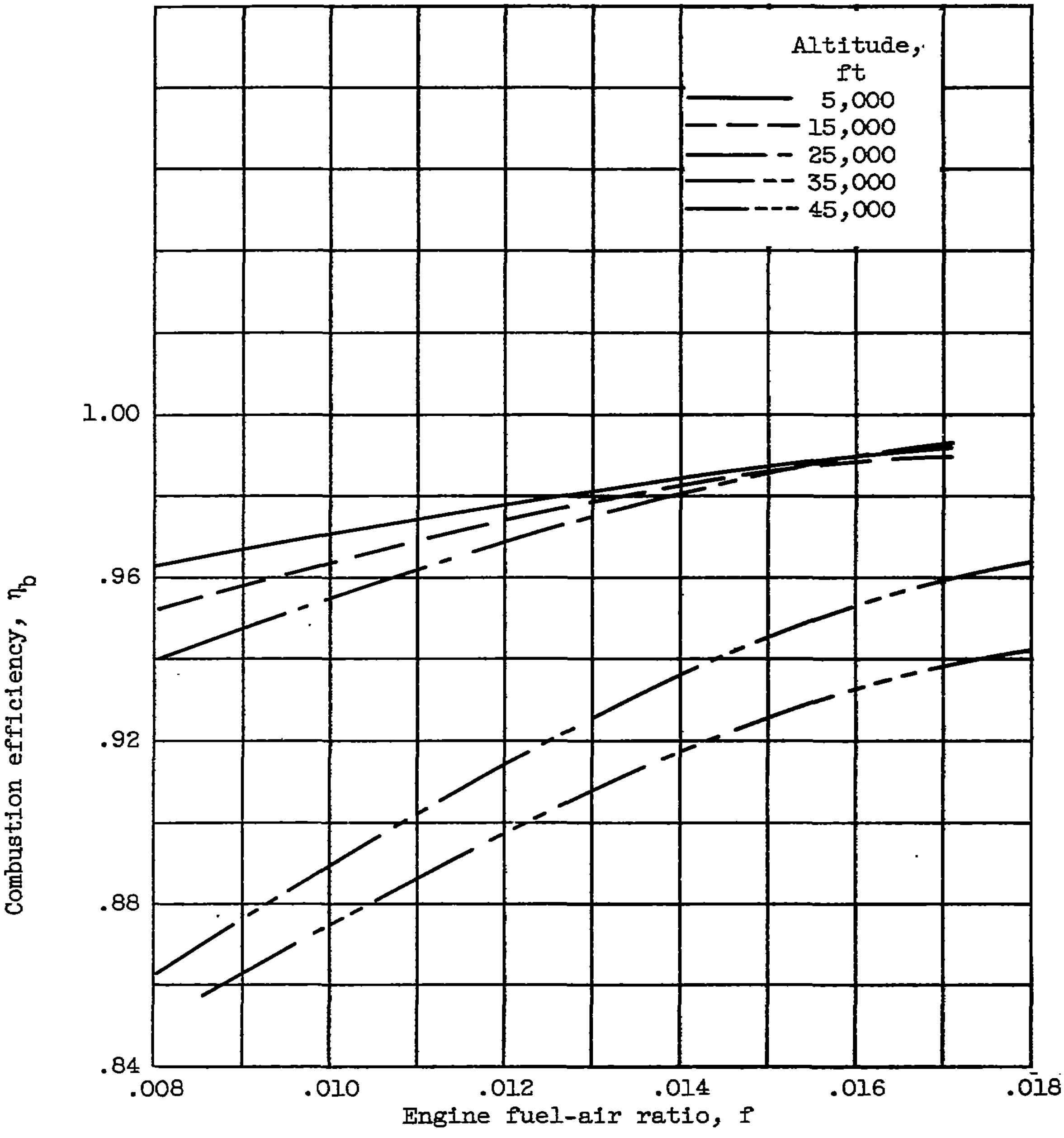
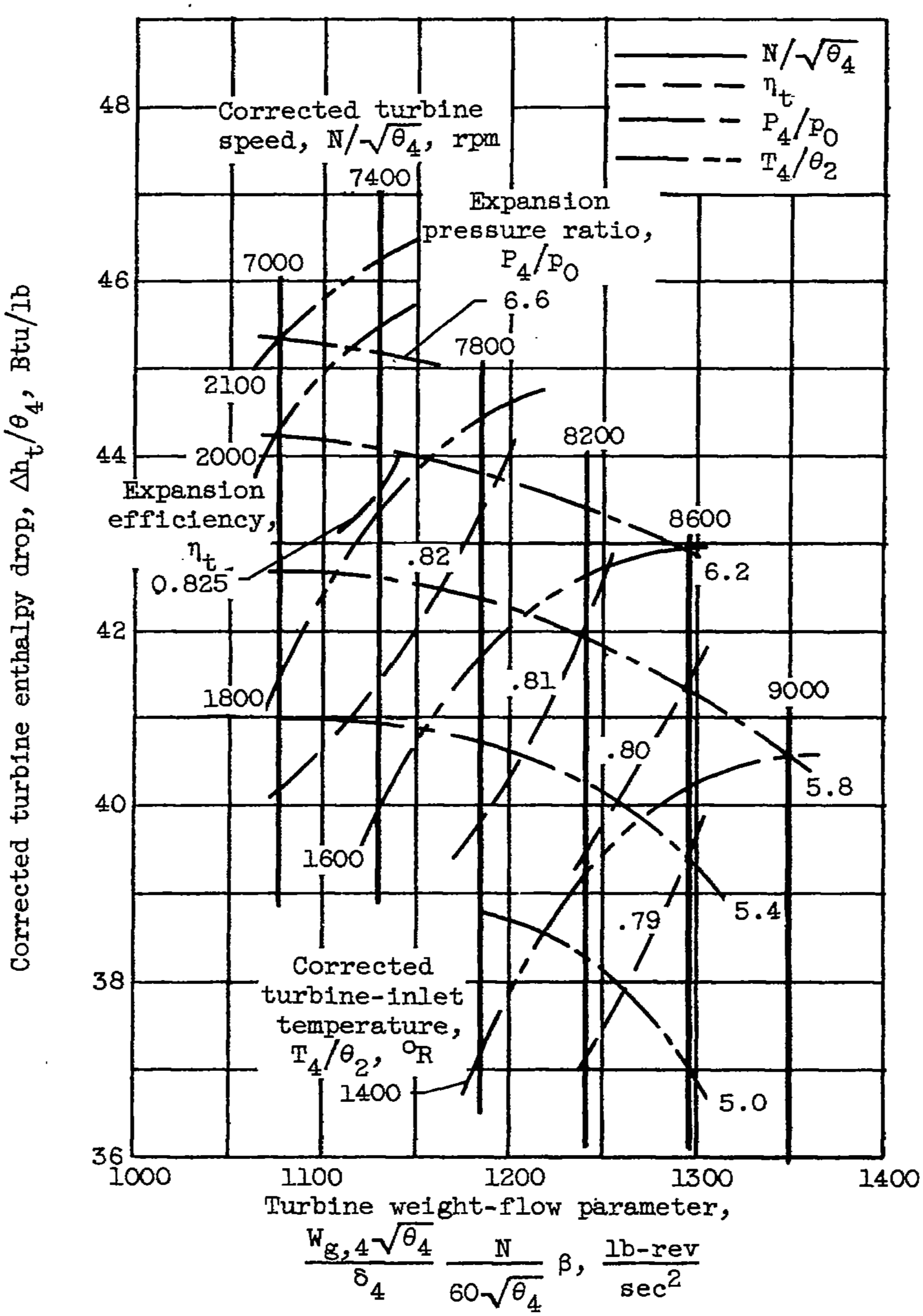


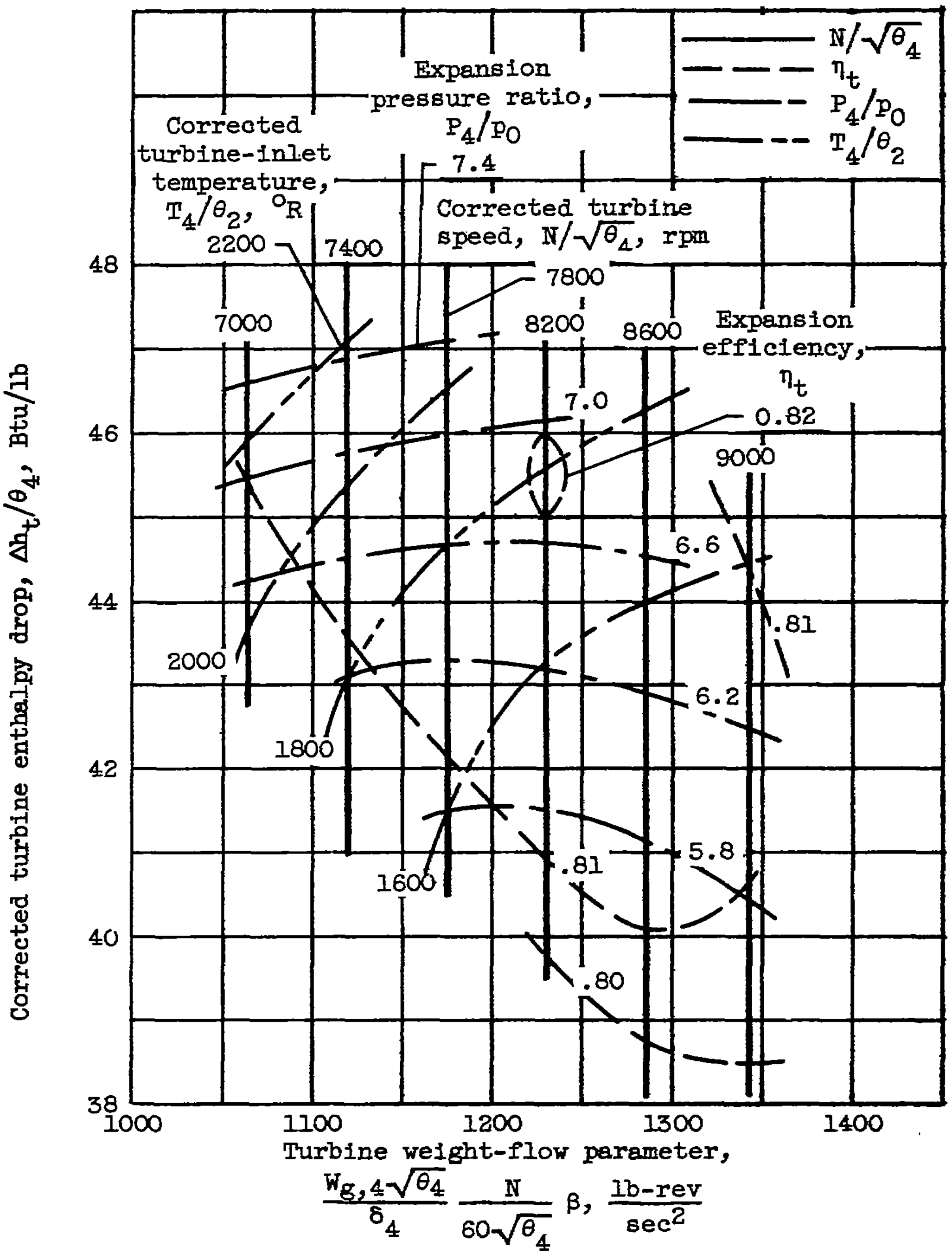
Figure 7. - Effect of fuel-air ratio on combustion efficiency for several altitudes. Flight Mach number, 0.30.



(a) Altitude, 5000 feet; turbine A.

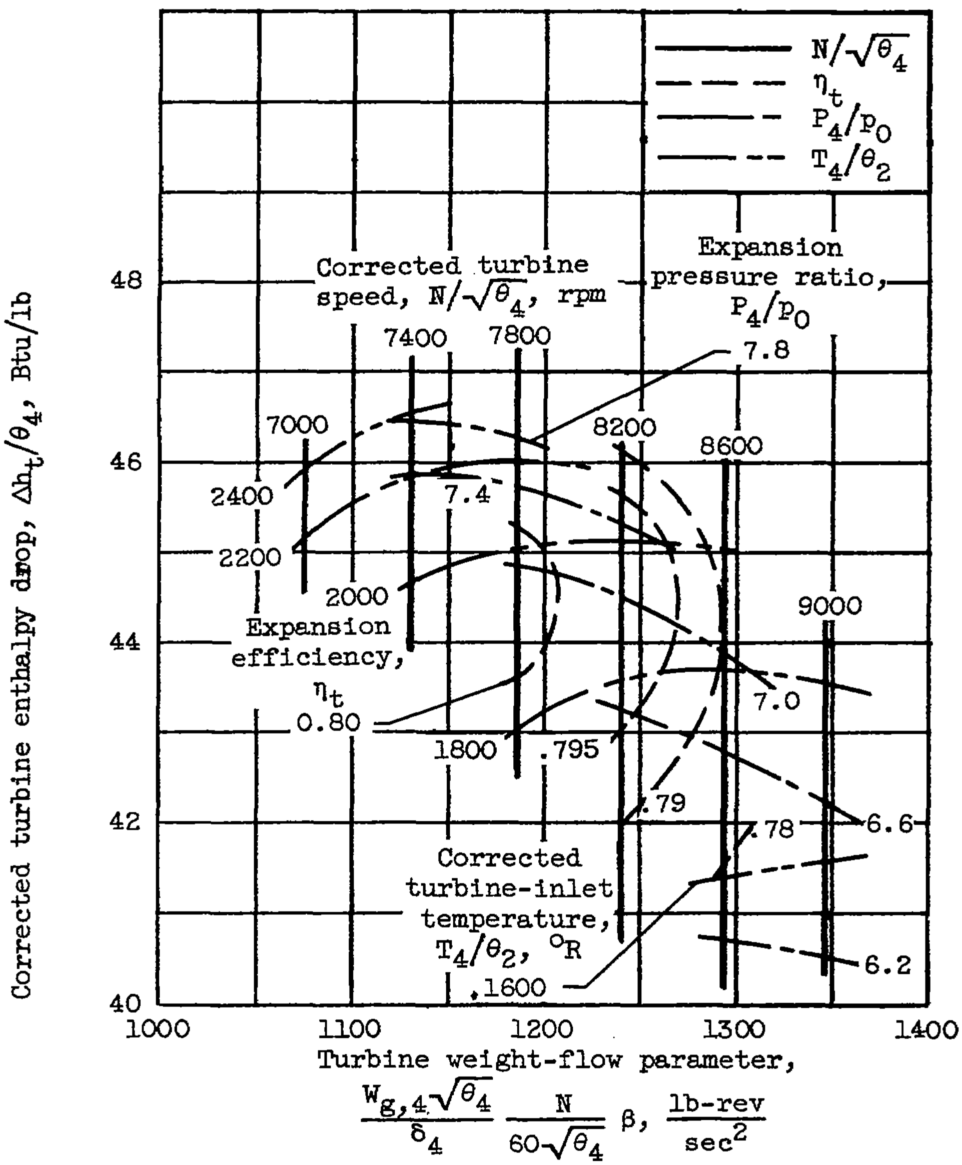
Figure 8. - Turbine performance maps. Flight Mach number, 0.30.

3245



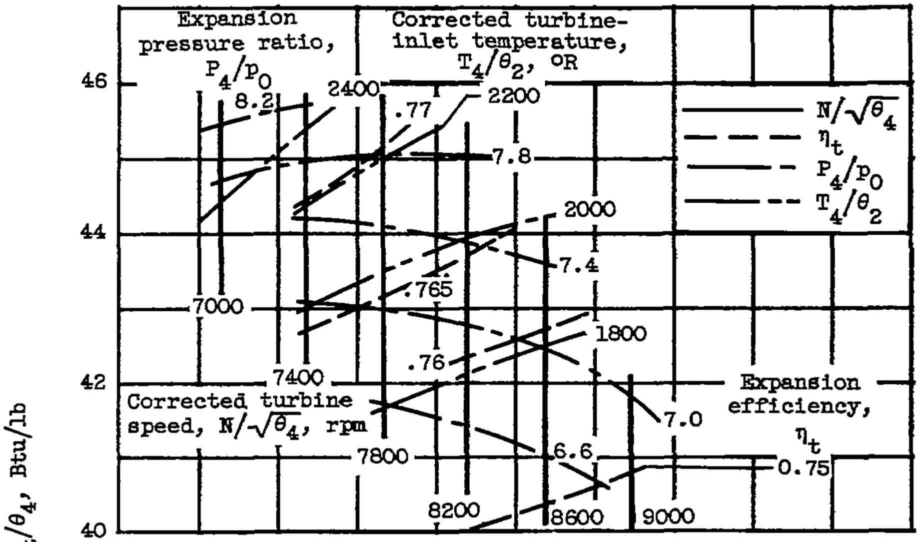
(b) Altitude, 15,000 feet; turbine B.

Figure 8. - Continued. Turbine performance maps. Flight Mach number, 0.30.

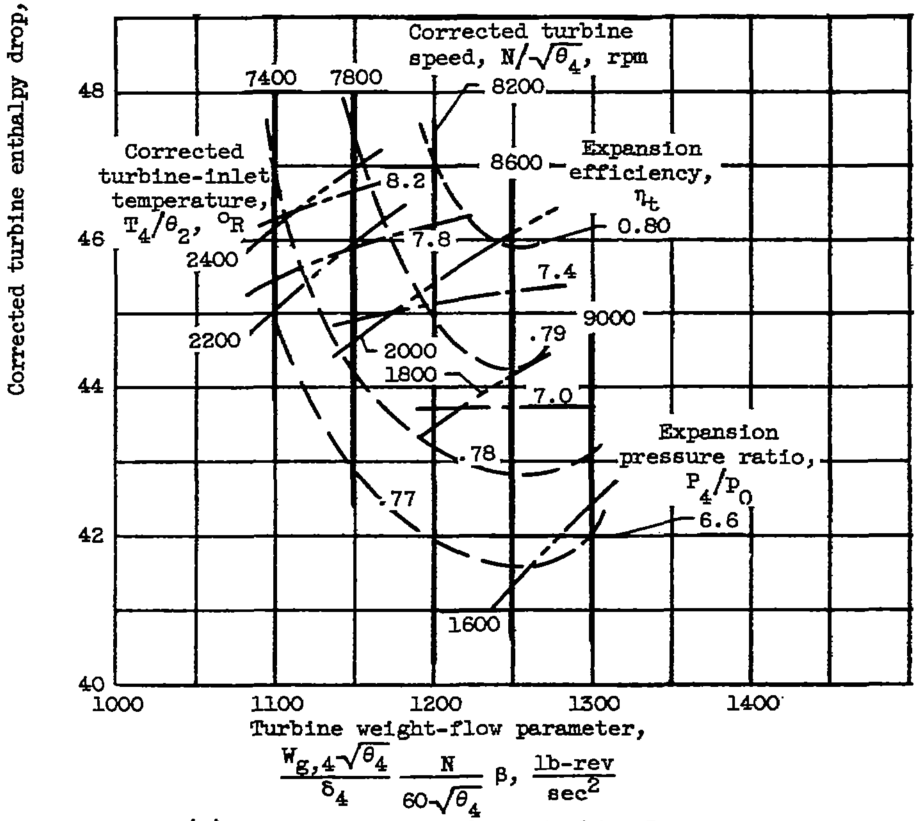


(c) Altitude, 25,000 feet; turbine A.

Figure 8. - Continued. Turbine performance maps. Flight Mach number, 0.30.



(d) Altitude, 35,000 feet; turbine A.



(e) Altitude, 45,000 feet; turbine B.

Figure 8. - Concluded. Turbine performance maps. Flight Mach number, 0.30.

[redacted]

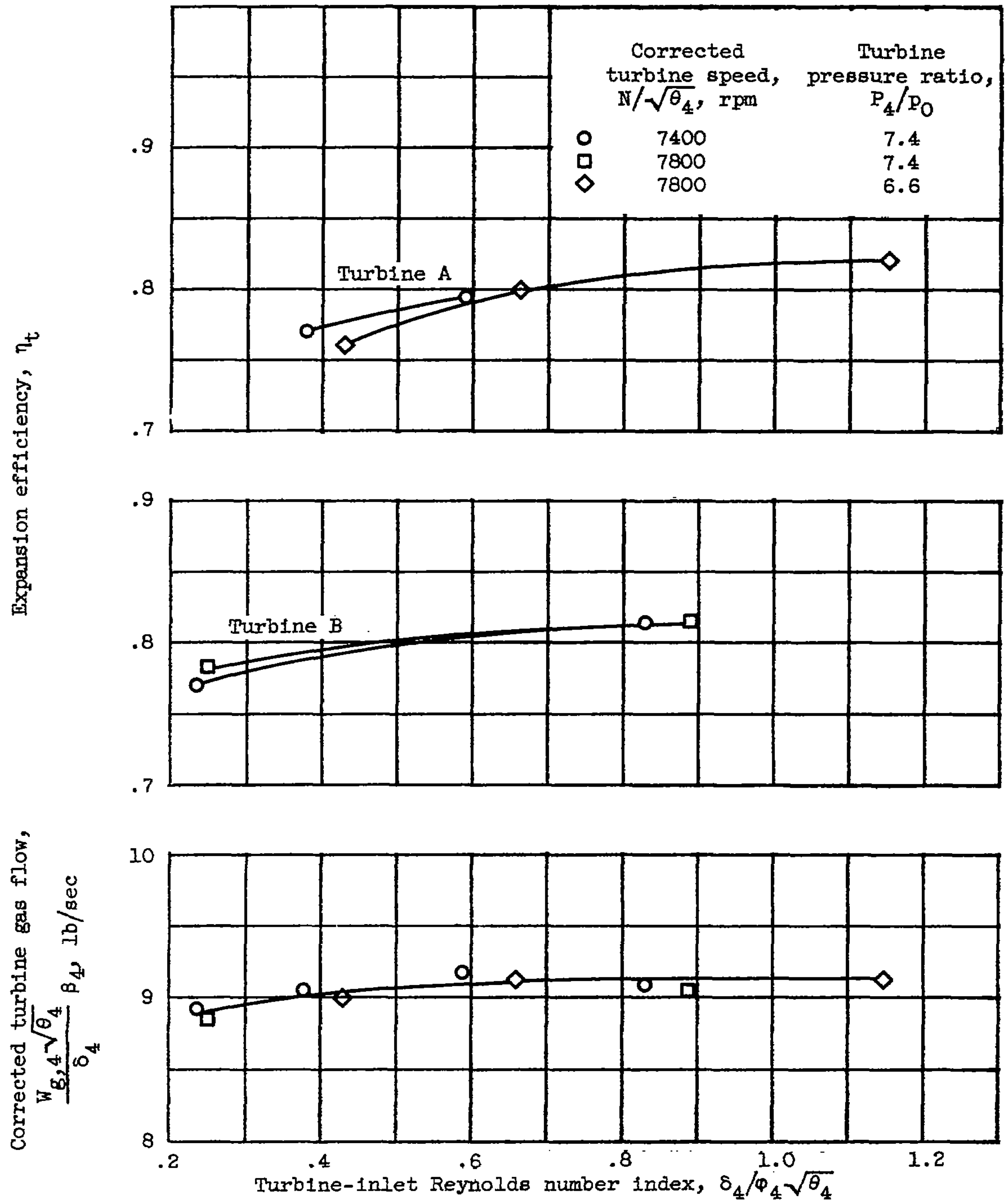


Figure 9. - Effect of Reynolds number index on turbine performance.

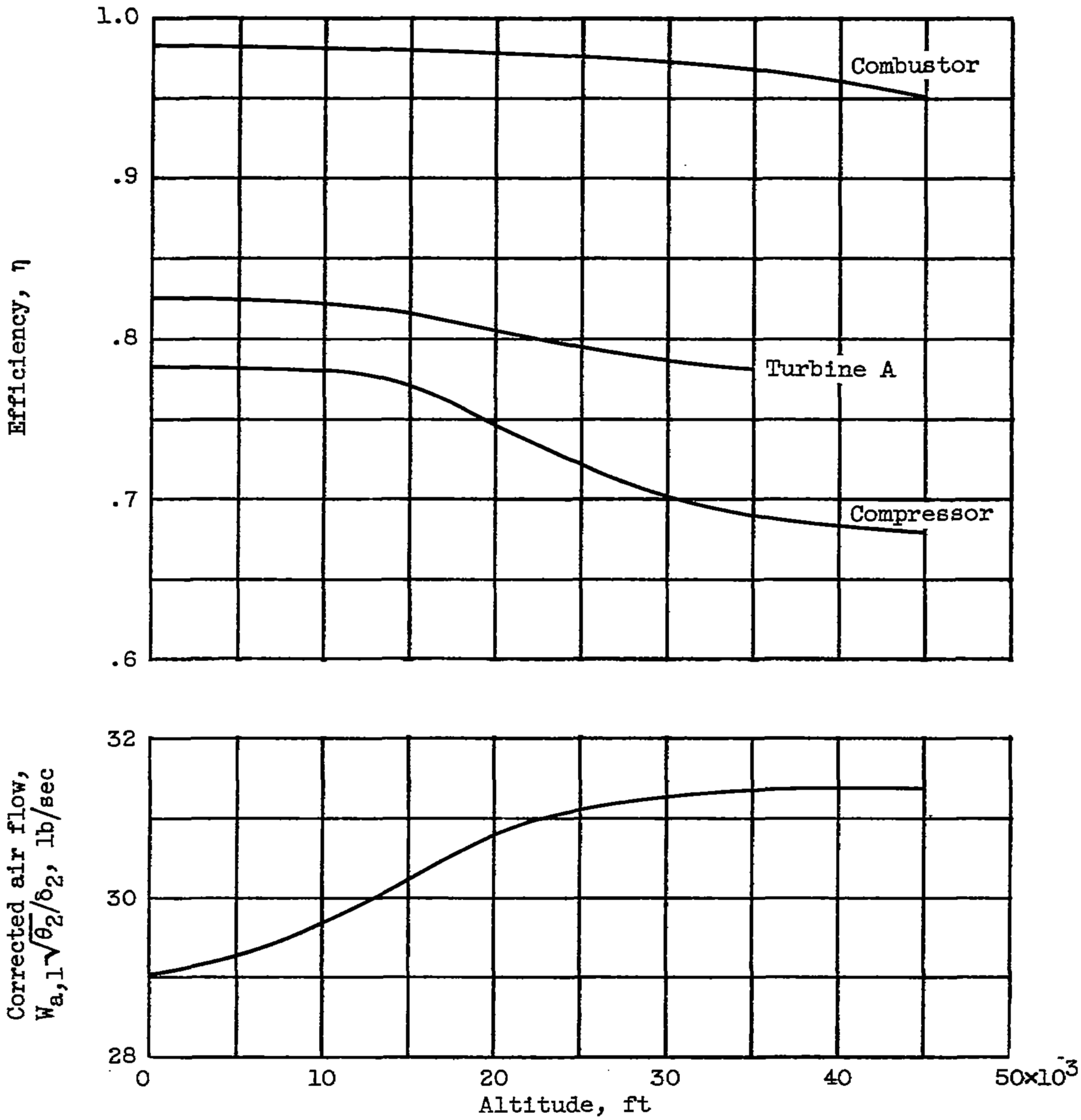


Figure 10. - Effect of altitude on compressor, combustor, and turbine performance. Flight Mach number, 0.30. Normal (continuous) power condition: engine speed, 14,300 rpm; turbine-inlet temperature, 1960° R.

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