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THE EFFECT OF INLET TEMPERATURE AND PRESSURE ON THE EFFICIENCY OF A SINGLE-STAGE IMPULSE TURBINE HAVING A 13.2-INCH PITCH-LINE DIAMETER WHEEL

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THE EFFECT OF INLET TEMPERATURE AND PRESSURE ON THE EFFICIENCY OF A SINGLE-STAGE IMPULSE TURBINE HAVING A 13.2-INCH PITCH-LINE DIAMETER WHEEL

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SUMMARY

Efficiency tests have been conducted on a single-stage impulse turbine having a 13.2-inch pitch-line diameter wheel and a cast nozzle diaphragm over a range of turbine speeds from 3000 to 17,000 rpm, pressure ratios from 1.5 to 5.0, inlet total temperatures from 1200° to 2000° R, and inlet total pressures from 18 to 59 inches of mercury absolute. The effect of inlet temperature and pressure on turbine efficiency for constant pressure ratio and blade-to-jet speed ratio is correlated against a factor derived from the equation for Reynolds number. The degree of correlation indicates that the change in turbine efficiency with inlet temperature and pressure for constant pressure ratio and blade-to-jet speed ratio is principally a Reynolds number effect.

INTRODUCTION

An analysis was presented in reference 1 showing that the Reynolds number of the flow through a turbine may be represented as a function of the ratio of the nozzle-box inlet total pressure to the 1.1 power of the inlet total temperature, the pressure ratio across the turbine, and the blade-to-jet speed ratio. Because the turbine efficiency is generally presented as a function of blade-to-jet speed ratio and the pressure ratio, the only new variable introduced by consideration of the Reynolds number is the ratio of the nozzle-box inlet total pressure to the 1.1 power of the inlet total temperature. This ratio, or Reynolds number factor, was used in reference 1 to correlate the effect of inlet total temperature and pressure on the efficiency of an exhaust-gas turbine having an 11.0-inch pitch-line diameter wheel. In order to further substantiate this correlation, efficiency tests, the results of which are presented

in this report, were made at the Cleveland laboratory of the NACA from January to April 1945 on a single-stage impulse turbine having a 13.2-inch pitch-line diameter wheel. These tests covered a range of turbine speeds from 3000 to 17,000 rpm, pressure ratios from 1.5 to 5.0, inlet total temperatures from 1200° to 2000° R, and inlet total pressures from 18 to 59 inches of mercury absolute.

APPARATUS AND METHOD

The turbine tested was a single-stage impulse type with a symmetrical nozzle box having a single radial inlet. The cast diaphragm had 44 airfoil-shaped blades with a nozzle angle of 24° and an angle between the turbine axis and the center line of the nozzle flow passage of 16°. The nozzle area was 19.8 square inches. The wheel had 144 buckets with a 13.2-inch pitch-line diameter, a bucket height of $1\frac{29}{64}$ inches, and a width of 0.6 inch. The buckets were welded to the wheel disk. Bucket-to-nozzle clearance was set at 0.12 to 0.13 inch. A high-speed eddy-current dynamometer was used to absorb turbine power. A photograph of the test setup showing the turbine mounting and the dynamometer is shown in figure 1.

Turbine speed was measured with a chronometric tachometer. The rest of the instrumentation and the hot-gas producer are described in reference 1.

The method suggested by the A.S.M.E. for estimating the accuracy of measurement of air flow utilizing their orifice data gives a probable error of ±1.17 percent. Turbine shaft torque was measured to the nearest 0.23 foot-pound. Turbine speed was accurate to ±10 rpm. All pressure readings were taken to 0.05 inch of mercury.

At each of three test conditions the speed was varied from 3000 to 17,000 rpm. The following table shows the approximate test conditions:

Pressure ratio p_i/p_d	Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i ($^\circ$R)
1.5, 2.0, 3.0, 4.0, 5.0	26.5	1200
		1400
		1600
1.5, 2.0, 3.0	18.3	1800
	26.5	1800
		2000
	34.6	1800
	42.8	1200
		1800
1.5, 2.0	59.1	1200

The results were calculated as in references 1, 2, and 3.

SYMBOLS

g acceleration due to gravity, 32.2 (ft)/(sec)^2, or dimensional constant, 32.2 (lb)/(slug)

M_t mass flow of air plus fuel, (slugs)/(sec)

N turbine speed, (rpm)

p_d static pressure of turbine discharge at plenum chamber, (in. Hg absolute)

p_i total pressure at nozzle-box inlet, (in. Hg absolute)

R_b gas constant for combustion products, (ft-lb)/(lb)($^\circ$F)

T_i total temperature at nozzle-box inlet, ($^\circ$R)

u blade pitch-line speed, (fps)

v theoretical jet speed, (fps)

W_t weight flow of air plus fuel, (lb)/(sec)

η turbine efficiency defined as ratio of shaft power to theoretical power computed from total temperature and pressure at turbine inlet and static pressure at turbine discharge

η' turbine efficiency defined as ratio of shaft power to difference between theoretical power and kinetic power where kinetic power corresponds to average axial component of velocity at turbine discharge

Theoretical power is computed from total temperature and pressure at turbine inlet and static pressure at turbine exit. Average axial component of turbine leaving velocity is computed by continuity equation using mass flow of gas and turbine-bucket annulus area.

RESULTS AND DISCUSSION

The test data and the results of the effect of inlet temperature and pressure on the efficiency of the turbine are presented in table I. Figure 2 gives the fuel-air ratio for various inlet total temperatures.

Typical curves of the turbine efficiency η plotted against the blade-to-jet speed ratio for various pressure ratios and inlet total temperatures and pressures are shown in figure 3. Maximum turbine efficiency occurred at a blade-to-jet speed ratio of approximately 0.43.

Figure 4 is a cross plot of figure 3 showing the variation of turbine efficiency with pressure ratio, inlet total temperature, and inlet total pressure for a blade-to-jet speed ratio of 0.4. Additional data taken from table I are included. The turbine efficiency reaches a maximum at a pressure ratio of approximately 2.4, decreases with an increase in inlet total temperature, and increases with an increase in inlet total pressure. The slope of the curves of efficiency plotted against inlet temperature and inlet pressure on logarithmic paper with constant blade-to-jet speed ratio of 0.4 was -0.0722 and 0.0645, respectively, and the ratio of their absolute values is equal to 1.12.

The variation of turbine efficiency with the Reynolds number factor $p_i/T_i^{1.1}$ for various blade-to-jet speed ratios and pressure ratios is shown in figures 5 and 6, which were obtained from cross plots of curves similar to figure 3 for all the data shown in table I. The curves for pressure ratios of 1.5 and 2.0 are separated from those for 3.0, 4.0, and 5.0 because overlap of the points would obscure the results. The extension of the curves for pressure ratios of 3.0, 4.0, and 5.0 was limited by the power-absorption capacity of the dynamometer. Good correlation is obtained with a maximum scatter of ±1 percent in efficiency. This degree of correlation is sufficient to

indicate that the variation of turbine efficiency with inlet total temperature and pressure is principally a Reynolds number effect.

The gas-flow factor $(M_t/p_i)\sqrt{g\,R_b\,T_i}$ is plotted against the speed factor $N\sqrt{519}/T_i$ in figure 7 for various pressure ratios. The gas-flow data are correlated on this plot with an accuracy of ± 1.7 percent.

Figure 8 is a cross plot of figure 7 showing the variation of gas-flow factor with pressure ratio. The gas-flow factor becomes constant with respect to the speed factor and the pressure ratio at a pressure ratio of approximately 2.4. No apparent significance is attached to the fact that this is the same value of pressure ratio at which maximum turbine efficiency occurs.

A plot of the efficiency ratio η'/η against blade-to-jet speed ratio is shown in figure 9. The data are correlated over a range of inlet total temperatures from 1200° to 2000° R and inlet total pressures from 18.3 to 59.1 inches of mercury absolute with an accuracy of ± 0.5 percent. The ratio η'/η increases with pressure ratio and decreases with blade-to-jet speed ratio. The values of η' range from 7 to 31 percent higher than the corresponding values of η.

CONCLUDING REMARKS

Tests on a single-stage impulse turbine having a 13.2-inch pitch-line diameter wheel check the results of similar tests on a turbine with an 11.0-inch pitch-line diameter in showing that for a constant blade-to-jet speed ratio and pressure ratio the effect of turbine inlet total temperature and inlet total pressure on the turbine efficiency is correlated by use of the ratio of inlet total pressure to the 1.1 power of inlet total temperature. Because this ratio was derived from the Reynolds number, the correlation obtained is further evidence that the effect of inlet total temperature and pressure on turbine efficiency is a Reynolds number effect.

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REFERENCES

1. Gabriel, David S., Carman, L. Robert, and Trautwein, Elmer E.: The Effect of Inlet Pressure and Temperature on the Efficiency of a Single-Stage Impulse Turbine Having an 11.0-Inch Pitch-Line Diameter Wheel. NACA ACR No. E5E19, 1945.

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3. Pinkel, Benjamin, and Turner, L. Richard: Thermodynamic Data for the Computation of the Performance of Exhaust-Gas Turbines. NACA ARR No. 4B25, 1944.

TABLE I. - SUMMARY OF DATA AND RESULTS

Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i (°R)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
18.3	1800	1.51	3,070	0.113	30.2	0.270	0.291	1.63
18.3		1.50	6,160	.229	49.8	.451	.485	1.63
18.3		1.50	7,610	.282	54.9	.497	.534	1.62
18.4		1.51	9,070	.334	57.4	.517	.554	1.61
18.3		1.50	10,570	.394	59.5	.553	.593	1.60
18.3		1.51	12,000	.444	59.1	.541	.580	1.60
18.3		1.50	13,290	.493	57.2	.531	.569	1.58
18.3		1.50	14,920	.555	49.8	.467	.500	1.57
18.3		2.01	2,960	.086	44.2	.224	.246	1.76
18.3		2.00	6,120	.177	79.6	.403	.441	1.76
18.3		2.01	7,700	.222	91.7	.464	.506	1.76
18.3		2.00	9,140	.265	99.6	.508	.552	1.75
18.4		2.01	10,500	.303	106.1	.539	.587	1.75
18.4		2.02	12,000	.346	111.8	.565	.613	1.75
18.3		2.00	13,410	.389	112.0	.576	.626	1.75
18.3		2.01	14,910	.431	112.7	.577	.626	1.74
18.3		2.00	16,900	.489	109.9	.567	.614	1.73
18.4		3.00	2,920	.069	55.8	.184	.212	1.80
18.3		3.02	6,050	.142	103.7	.341	.388	1.80
18.4		3.00	7,610	.180	124.4	.412	.466	1.80
18.4		3.01	9,110	.214	138.5	.456	.515	1.80
18.3		3.01	10,550	.248	150.2	.495	.558	1.80
18.4		3.01	11,950	.281	160.2	.528	.593	1.80
18.3		3.00	13,600	.321	167.4	.553	.620	1.80
18.3		3.00	15,700	.370	179.4	.594	.666	1.79
18.3		3.02	16,970	.399	176.0	.579	.650	1.79
26.4	1200	1.50	2,970	0.136	42.7	0.326	0.352	2.93
26.4		1.50	6,040	.276	70.6	.543	.585	2.91
26.6		1.51	7,500	.341	76.5	.580	.622	2.90
26.4		1.50	8,900	.408	76.7	.598	.643	2.88
26.4		1.50	10,530	.483	76.8	.603	.646	2.86
26.3		1.50	12,060	.551	69.9	.550	.591	2.83
26.4		1.50	13,480	.615	58.1	.461	.493	2.80
26.4		1.49	14,980	.688	57.9	.469	.502	2.78
26.6		2.00	3,080	.110	64.6	.279	.307	3.17

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i ($^\circ$R)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
26.5	1200	2.00	5,970	0.214	109.6	0.473	0.516	3.17
26.5		2.02	7,560	.269	126.9	.542	.592	3.17
26.7		2.01	9,080	.324	134.8	.581	.631	3.16
26.6		2.01	10,520	.375	138.7	.595	.648	3.16
26.7		2.02	12,040	.428	142.9	.611	.665	3.16
26.6		2.01	13,550	.483	139.4	.602	.654	3.14
26.6		2.02	14,920	.531	136.4	.589	.640	3.13
26.6		2.02	17,020	.606	124.2	.541	.588	3.10
26.6		3.05	3,060	.089	83.7	.234	.269	3.19
26.7		3.04	6,090	.176	149.4	.417	.472	3.19
26.6		3.02	7,540	.218	171.7	.480	.541	3.19
26.4		3.02	9,140	.265	189.6	.533	.599	3.20
26.6		3.02	10,500	.305	201.2	.566	.633	3.19
26.5		3.04	11,980	.346	211.7	.591	.661	3.20
26.6		3.04	13,470	.389	216.7	.604	.676	3.20
26.7		3.04	14,940	.432	216.6	.604	.674	3.19
26.6		3.07	16,950	.488	214.6	.597	.667	3.18
26.5		4.03	3,030	.080	90.8	.211	.257	3.19
26.5		4.03	6,050	.159	160.6	.372	.443	3.19
26.5		4.01	7,500	.198	186.6	.434	.513	3.19
26.5		3.99	9,000	.238	209.6	.489	.573	3.19
26.5		4.02	10,560	.278	227.4	.528	.616	3.19
26.5		4.06	12,060	.317	240.6	.555	.646	3.19
26.5		4.05	13,540	.356	251.1	.580	.675	3.19
26.4		4.01	14,990	.395	254.3	.592	.687	3.18
26.4		5.00	2,990	.074	89.1	.185	.240	3.16
26.5		4.97	5,960	.148	156.6	.327	.410	3.16
26.5		5.04	7,540	.187	189.6	.390	.487	3.18
26.5		4.99	8,980	.223	212.3	.439	.543	3.19
26.5		5.01	11,980	.261	245.4	.476	.584	3.18
26.5		5.05	13,530	.335	255.7	.525	.642	3.19
26.5		5.02	15,030	.373	261.6	.539	.656	3.19
26.5	1400	1.50	2,980	0.126	42.4	0.298	0.322	2.72
26.4		1.50	6,050	.256	70.2	.497	.536	2.70
26.4		1.50	7,540	.319	77.5	.551	.593	2.69
26.4		1.50	9,030	.382	81.0	.578	.622	2.68

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i ($^{\circ}R$)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
26.3	1400	1.50	10,570	0.447	80.8	0.579	0.623	2.67
26.4		1.50	12,060	.510	76.9	.557	.597	2.64
26.4		1.50	13,640	.577	71.9	.527	.566	2.61
26.5		1.50	14,960	.632	62.4	.462	.495	2.59
26.5		1.50	17,030	.720	49.4	.368	.395	2.56
26.5		2.01	3,000	.099	63.0	.249	.273	2.92
26.5		2.00	6,000	.198	111.3	.440	.481	2.93
26.5		2.01	7,480	.246	128.2	.505	.551	2.92
26.6		2.02	9,020	.295	140.3	.549	.597	2.91
26.5		2.01	10,470	.343	147.2	.581	.632	2.91
26.6		2.01	11,960	.394	150.3	.600	.651	2.89
26.4		2.00	13,450	.443	148.9	.600	.651	2.88
26.5		2.00	15,000	.494	149.0	.600	.651	2.87
26.4		2.00	17,000	.561	140.4	.570	.618	2.87
26.5		3.03	2,980	.080	81.4	.212	.243	2.93
26.5		3.03	5,990	.160	148.5	.386	.438	2.94
26.6		3.03	7,500	.200	174.7	.452	.511	2.95
26.6		3.06	8,950	.238	194.4	.500	.562	2.95
26.5		3.03	10,490	.280	209.3	.544	.610	2.93
26.5		3.03	12,010	.321	219.6	.567	.636	2.95
26.5		3.03	13,450	.360	224.7	.580	.650	2.95
26.5		3.02	14,990	.401	231.8	.599	.671	2.95
26.6		3.04	17,020	.455	230.4	.597	.667	2.94
26.5		4.00	3,000	.073	89.4	.193	.234	2.94
26.5		4.02	5,960	.145	160.3	.345	.412	2.93
26.5		4.00	7,510	.183	189.5	.408	.483	2.93
26.5		4.04	9,000	.218	212.8	.456	.537	2.93
26.6		4.00	10,500	.256	230.6	.496	.581	2.94
26.6		4.01	11,990	.292	244.5	.525	.599	2.94
26.5		4.03	13,470	.327	256.8	.549	.640	2.95
26.6		4.04	14,990	.364	264.8	.565	.657	2.95
26.6		4.02	17,060	.415	269.9	.578	.671	2.94
26.6		5.06	2,970	.068	88.6	.167	.219	2.96
26.4		5.03	6,020	.138	163.0	.308	.392	2.96
26.4		4.96	7,500	.172	191.8	.366	.459	2.95
26.6		5.09	9,020	.206	216.3	.408	.510	2.95

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure P_i (in. Hg absolute)	Inlet total temperature T_i ($^\circ$R)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
26.5	1400	5.04	10,520	0.241	237.7	0.449	0.557	2.95
26.5		5.03	12,010	.275	255.4	.483	.594	2.96
26.6		5.05	13,500	.309	267.0	.504	.618	2.95
26.5		5.03	15,020	.344	277.2	.526	.643	2.95
26.5		5.06	16,940	.387	285.9	.539	.660	2.95
26.5	1600	1.50	2,970	0.117	42.3	0.277	0.299	2.54
26.5		1.50	5,970	.235	71.9	.473	.510	2.52
26.4		1.50	7,500	.296	79.8	.528	.569	2.52
26.4		1.50	9,030	.358	84.1	.561	.603	2.51
26.4		1.49	10,500	.416	84.9	.573	.616	2.49
26.5		1.50	11,960	.473	82.0	.552	.592	2.48
26.5		1.50	13,430	.531	80.3	.547	.586	2.45
26.5		1.50	15,030	.593	71.4	.487	.522	2.43
26.4		1.49	16,970	.673	61.2	.425	.456	2.42
26.4		2.03	2,950	.090	63.5	.232	.255	2.72
26.3		2.01	6,030	.185	114.0	.423	.463	2.71
26.4		2.02	7,540	.231	131.9	.489	.533	2.70
26.4		2.00	8,970	.276	144.3	.534	.582	2.73
26.6		2.02	10,480	.320	153.8	.560	.610	2.73
26.4		2.02	11,920	.365	160.3	.590	.642	2.71
26.3		2.01	13,470	.413	162.2	.601	.654	2.71
26.4		2.01	15,010	.460	160.9	.598	.649	2.70
26.3		2.02	17,050	.521	155.9	.578	.628	2.69
26.3		3.05	3,010	.075	83.0	.201	.232	2.74
26.4		3.02	6,000	.150	150.3	.362	.413	2.77
26.5		3.04	7,510	.187	178.9	.430	.487	2.75
26.4		3.02	9,040	.226	198.7	.481	.543	2.76
26.6		3.03	10,480	.262	216.4	.520	.585	2.77
26.5		3.05	12,000	.299	229.9	.554	.622	2.75
26.5		3.06	13,460	.335	237.9	.570	.640	2.76
26.5		3.03	14,980	.374	243.7	.586	.657	2.76
26.6		3.05	17,020	.424	245.3	.589	.661	2.75
26.5		4.02	3,030	.069	90.3	.181	.220	2.74
26.4		4.02	5,950	.135	160.6	.322	.385	2.74
26.6		4.03	7,470	.169	189.8	.379	.451	2.74
26.4		4.02	8,980	.204	214.7	.428	.507	2.75
26.5		4.03	10,530	.239	237.0	.474	.557	2.74
26.5		4.03	11,960	.271	252.3	.505	.592	2.74
26.5		4.03	13,500	.306	263.4	.527	.617	2.74

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure P_i (in. Hg absolute)	Inlet total temperature T_i (°R)	Pressure ratio P_i/P_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
26.4	1600	4.04	14,930	0.338	271.7	0.543	0.633	2.74
26.5		5.02	3,020	.064	91.2	.162	.212	2.74
26.5		5.02	6,010	.128	164.8	.293	.373	2.74
26.5		5.00	7,490	.160	195.5	.348	.438	2.74
26.5		5.04	8,950	.191	221.1	.392	.490	2.74
26.5		5.06	10,490	.224	244.4	.432	.537	2.74
26.5		5.05	11,990	.256	264.5	.468	.579	2.74
26.4		5.04	13,440	.287	277.6	.492	.605	2.74
26.5		5.06	14,910	.318	283.0	.502	.615	2.73
26.6		5.11	16,910	.360	292.8	.517	.634	2.73
26.4	1800	1.50	2,990	0.111	43.3	0.269	0.292	2.39
26.4		1.50	6,040	.225	73.8	.459	.495	2.38
26.4		1.50	7,510	.279	82.5	.514	.553	2.36
26.4		1.50	9,000	.335	87.8	.553	.595	2.35
26.4		1.50	10,450	.390	88.2	.560	.603	2.34
26.4		1.50	11,930	.443	88.1	.556	.597	2.34
26.3		1.49	13,450	.504	83.9	.544	.584	2.31
26.3		1.50	14,960	.559	80.2	.521	.559	2.30
26.4		1.50	16,930	.630	67.0	.435	.467	2.28
26.5		2.01	2,970	.086	63.9	.220	.243	2.59
26.4		2.01	6,000	.173	114.5	.393	.432	2.59
26.5		2.01	7,510	.217	135.2	.466	.510	2.59
26.5		2.01	9,010	.260	148.9	.514	.562	2.58
26.6		2.01	10,490	.303	159.5	.550	.599	2.58
26.5		2.00	11,980	.347	164.1	.573	.623	2.57
26.5		2.01	13,460	.389	168.0	.581	.633	2.57
26.4		1.99	15,000	.436	167.5	.580	.640	2.56
26.4		2.01	16,970	.490	167.1	.582	.632	2.55
26.6		3.01	3,010	.071	83.1	.187	.216	2.63
26.5		3.03	6,020	.141	152.9	.342	.391	2.63
26.5		3.01	7,470	.176	178.6	.402	.458	2.63
26.5		2.99	9,080	.214	205.9	.465	.527	2.63
26.6		3.02	10,570	.249	223.9	.504	.568	2.63
26.5		3.00	12,100	.285	241.4	.548	.616	2.61
26.5		3.00	13,640	.322	253.0	.573	.644	2.62
26.4		3.01	15,070	.355	261.0	.591	.663	2.61
26.4		2.98	16,920	.400	261.8	.600	.672	2.61

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i ($^\circ$R)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
26.5	2000	1.50	3,000	0.106	43.5	0.254	0.276	2.28
26.4		1.50	6,030	.213	75.3	.441	.476	2.27
26.4		1.50	7,510	.266	84.5	.500	.538	2.25
26.4		1.50	8,990	.318	90.1	.536	.577	2.25
26.4		1.50	10,470	.370	92.9	.555	.598	2.24
26.4		1.50	12,020	.426	91.9	.553	.594	2.23
26.4		1.50	13,500	.477	92.6	.558	.599	2.21
26.4		1.50	14,930	.527	86.6	.523	.561	2.20
26.4		1.50	16,990	.600	76.2	.466	.500	2.17
26.5		2.01	3,000	.082	65.1	.212	.234	2.45
26.5		2.01	5,970	.163	117.0	.381	.418	2.45
26.5		2.01	7,490	.205	137.6	.448	.490	2.45
26.5		2.01	8,990	.246	150.9	.490	.536	2.45
26.4		2.00	10,490	.288	163.1	.537	.585	2.44
26.6		2.02	12,020	.328	171.1	.557	.606	2.44
26.4		2.00	13,700	.376	177.0	.582	.634	2.44
26.5		2.01	14,960	.409	177.5	.582	.634	2.43
26.5		2.00	16,960	.465	174.4	.579	.626	2.42
26.5		3.02	2,990	.067	83.1	.178	.206	2.48
26.5		3.01	6,020	.135	154.1	.331	.378	2.48
26.5		3.02	7,490	.167	182.3	.390	.443	2.48
26.5		3.02	8,990	.200	205.5	.439	.498	2.48
26.5		3.02	10,510	.234	227.3	.486	.549	2.48
26.4		3.00	12,000	.268	241.6	.519	.585	2.48
26.5		3.02	13,510	.301	254.1	.544	.612	2.48
26.5		3.04	15,050	.335	263.3	.561	.632	2.48
26.6		3.02	17,000	.379	267.4	.572	.642	2.48
34.6	1800	1.50	3,080	0.115	58.8	0.275	0.298	3.16
34.6		1.50	6,080	.226	99.9	.471	.508	3.14
34.6		1.50	7,560	.281	111.0	.526	.567	3.11
34.5		1.50	9,080	.338	118.1	.559	.602	3.12
34.5		1.50	10,470	.390	121.5	.581	.625	3.09
34.5		1.50	11,960	.446	122.0	.589	.633	3.07
34.5		1.50	13,570	.505	118.1	.571	.613	3.05
34.5		1.49	15,020	.562	110.9	.548	.589	3.02
34.5		1.50	16,830	.629	96.2	.479	.514	2.99

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure P_i (in. Hg absolute)	Inlet total temperature T_i (°R)	Pressure ratio P_i/P_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
34.6	1800	2.00	3,020	0.087	85.0	0.224	0.247	3.40
34.7		2.00	6,000	.174	153.5	.404	.443	3.40
34.7		2.00	7,550	.219	179.2	.474	.518	3.40
34.7		2.00	9,040	.262	200.2	.528	.576	3.40
34.7		2.00	10,570	.306	214.6	.565	.616	3.40
34.6		2.00	12,000	.348	222.6	.590	.644	3.39
34.7		2.00	13,550	.393	228.7	.609	.663	3.37
34.6		1.99	15,140	.439	230.9	.615	.669	3.37
34.6		2.00	16,980	.492	229.9	.612	.665	3.38
34.7		3.01	2,960	.070	107.9	.187	.215	3.42
34.7		3.01	6,000	.141	202.0	.349	.399	3.43
34.6		2.98	7,520	.178	239.3	.417	.474	3.42
34.7		3.00	9,020	.213	270.4	.468	.530	3.43
34.7		3.01	10,510	.248	298.4	.516	.581	3.43
34.7		2.99	11,970	.283	314.6	.546	.614	3.43
34.7		3.00	13,480	.318	331.8	.575	.645	3.42
34.7		3.00	15,060	.355	344.2	.596	.669	3.42
34.7		3.01	16,930	.399	351.2	.610	.683	3.41
42.6	1200	1.49	3,010	0.139	70.1	0.336	0.364	4.74
42.7		1.49	6,020	.277	113.8	.549	.590	4.70
42.5		1.48	7,600	.353	124.3	.611	.658	4.69
42.8		1.49	9,080	.419	128.5	.626	.673	4.66
42.5		1.48	10,610	.492	125.9	.622	.667	4.64
42.7		1.49	12,090	.557	119.0	.584	.626	4.61
42.5		1.49	13,530	.624	103.5	.517	.554	4.54
42.6		1.49	15,090	.698	91.5	.461	.494	4.53
42.6		1.49	16,840	.779	68.1	.347	.373	4.47
42.8		1.99	2,960	.106	103.6	.275	.303	5.13
42.8		1.99	6,120	.219	188.8	.502	.548	5.13
42.8		1.99	7,500	.268	212.3	.564	.614	5.13
42.9		2.00	9,030	.322	229.4	.608	.660	5.13
42.8		1.99	10,620	.380	239.0	.640	.696	5.10
42.9		2.00	12,000	.428	243.7	.649	.704	5.10
42.7		1.99	13,560	.485	242.0	.649	.705	5.10
42.8		1.99	15,000	.536	237.3	.638	.691	5.07
42.8		2.00	16,910	.603	223.0	.600	.652	5.05

TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

Inlet total pressure P_i (in. Hg absolute)	Inlet total temperature T_i (°R)	Pressure ratio p_i/p_d	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
42.9	1200	2.99	2,990	0.087	133.5	0.234	0.268	5.16
42.8		3.00	6,030	.175	243.8	.427	.483	5.15
42.9		2.98	7,490	.219	281.1	.493	.556	5.16
42.8		2.98	9,050	.264	311.8	.550	.617	5.15
42.8		2.96	10,560	.309	335.1	.591	.660	5.16
42.9		2.99	11,940	.348	351.6	.618	.689	5.15
42.9		2.98	13,540	.395	358.2	.630	.701	5.15
42.8		2.98	14,870	.433	363.4	.639	.711	5.15
42.8		2.98	16,940	.493	364.8	.641	.713	5.15
42.7	1800	1.49	3,020	0.113	69.4	0.272	0.295	3.84
42.8		1.49	6,050	.227	119.7	.471	.507	3.83
42.8		1.49	7,500	.282	134.5	.533	.574	3.81
42.8		1.49	9,010	.338	143.4	.567	.609	3.79
42.6		1.48	10,470	.395	146.3	.588	.632	3.77
42.7		1.49	11,920	.448	143.5	.576	.619	3.75
42.6		1.49	13,560	.511	139.5	.565	.608	3.73
42.6		1.49	15,050	.567	129.6	.531	.569	3.69
42.9		2.00	3,030	.088	106.0	.229	.252	4.15
42.9		2.00	6,030	.175	190.3	.409	.448	4.17
42.7		1.99	7,410	.215	220.2	.476	.521	4.16
42.9		2.00	8,970	.260	244.4	.526	.574	4.15
42.8		2.00	10,540	.305	263.1	.567	.617	4.15
42.9		2.00	12,300	.356	280.0	.604	.657	4.15
42.7		2.00	13,660	.396	282.2	.612	.666	4.14
42.8		2.00	15,170	.439	288.0	.623	.676	4.14
42.7		2.00	16,970	.492	281.9	.614	.666	4.13
42.8		3.00	2,950	.070	134.3	.192	.220	4.16
42.9		2.99	6,000	.142	246.8	.353	.400	4.17
42.9		2.98	7,460	.176	291.2	.416	.470	4.17
42.8		3.00	8,980	.212	331.5	.472	.532	4.17
42.9		2.98	10,490	.248	357.8	.512	.575	4.18
42.9		2.99	12,110	.286	382.1	.545	.612	4.18
42.8		2.98	13,570	.321	402.0	.575	.642	4.17
42.9		2.99	15,000	.354	410.1	.586	.655	4.17

TABLE I.- SUMMARY OF DATA AND RESULTS - Concluded

Inlet total pressure p_i (in. Hg absolute)	Inlet total temperature T_i (°R)	Pressure ratio p_i/p_j	Turbine speed N (rpm)	Blade-to-jet speed ratio u/v	Turbine shaft power (hp)	Turbine efficiency		Gas flow W_t (lb/sec)
						η	η'	
59.1	1200	1.49	3,070	0.141	100.0	0.341	0.369	6.60
59.1		1.49	6,000	.276	165.6	.567	.611	6.59
59.2		1.50	7,440	.341	181.9	.619	.667	6.56
59.0		1.49	8,990	.413	187.4	.645	.696	6.54
58.9		1.49	10,460	.482	185.7	.647	.696	6.50
58.9		1.49	11,970	.551	176.7	.619	.665	6.47
59.0		1.49	13,480	.622	150.5	.539	.578	6.35
58.9		1.49	15,010	.694	135.9	.492	.528	6.31
59.0		1.49	16,990	.782	92.6	.333	.358	6.27
59.1		1.99	3,000	.107	144.0	.278	.306	7.06
59.1		1.99	6,020	.216	256.6	.498	.544	7.05
59.1		1.99	7,490	.268	295.6	.569	.620	7.04
59.2		1.99	9,000	.321	317.2	.614	.667	7.03
59.0		1.99	10,500	.376	332.3	.647	.703	7.03
59.3		1.99	12,100	.433	338.2	.657	.712	7.03
59.2		1.99	13,560	.485	336.1	.655	.710	7.00
59.1		1.99	15,060	.538	329.6	.642	.696	7.00
59.2		1.99	16,940	.605	305.3	.595	.647	6.98

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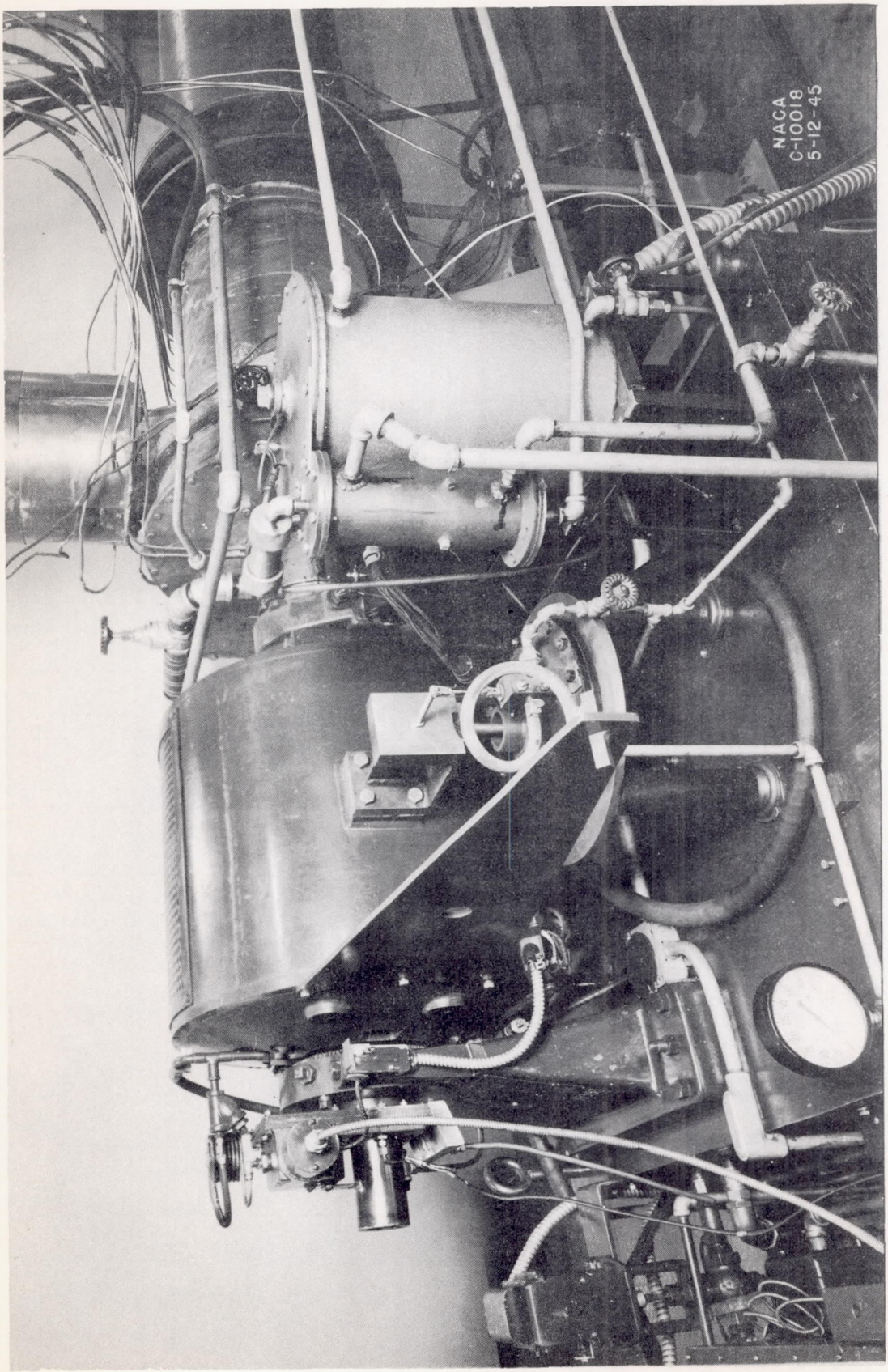

Figure 1. - Apparatus for testing efficiency of the exhaust-gas turbine.

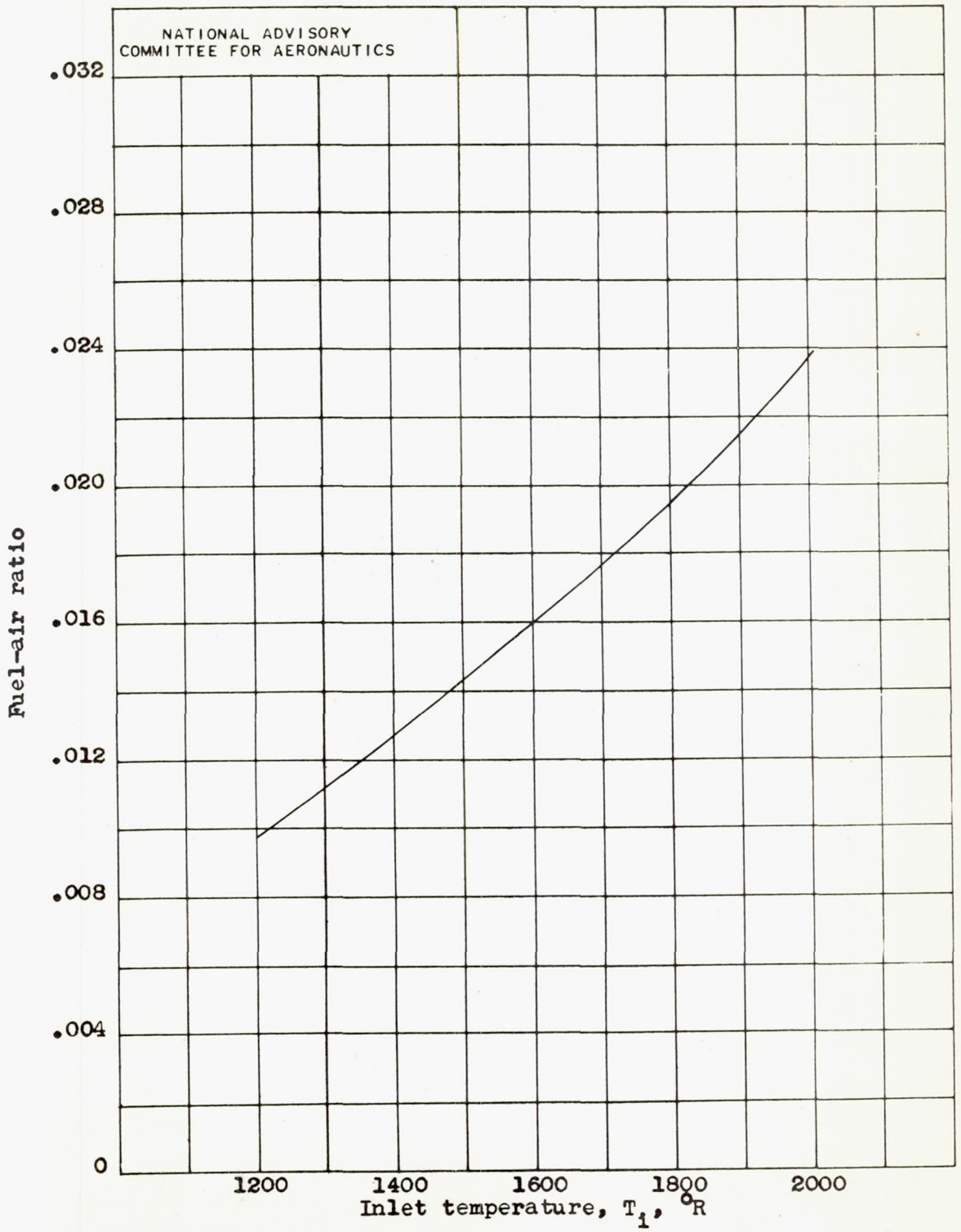

Figure 2. - Variation of fuel-air ratio with temperature.

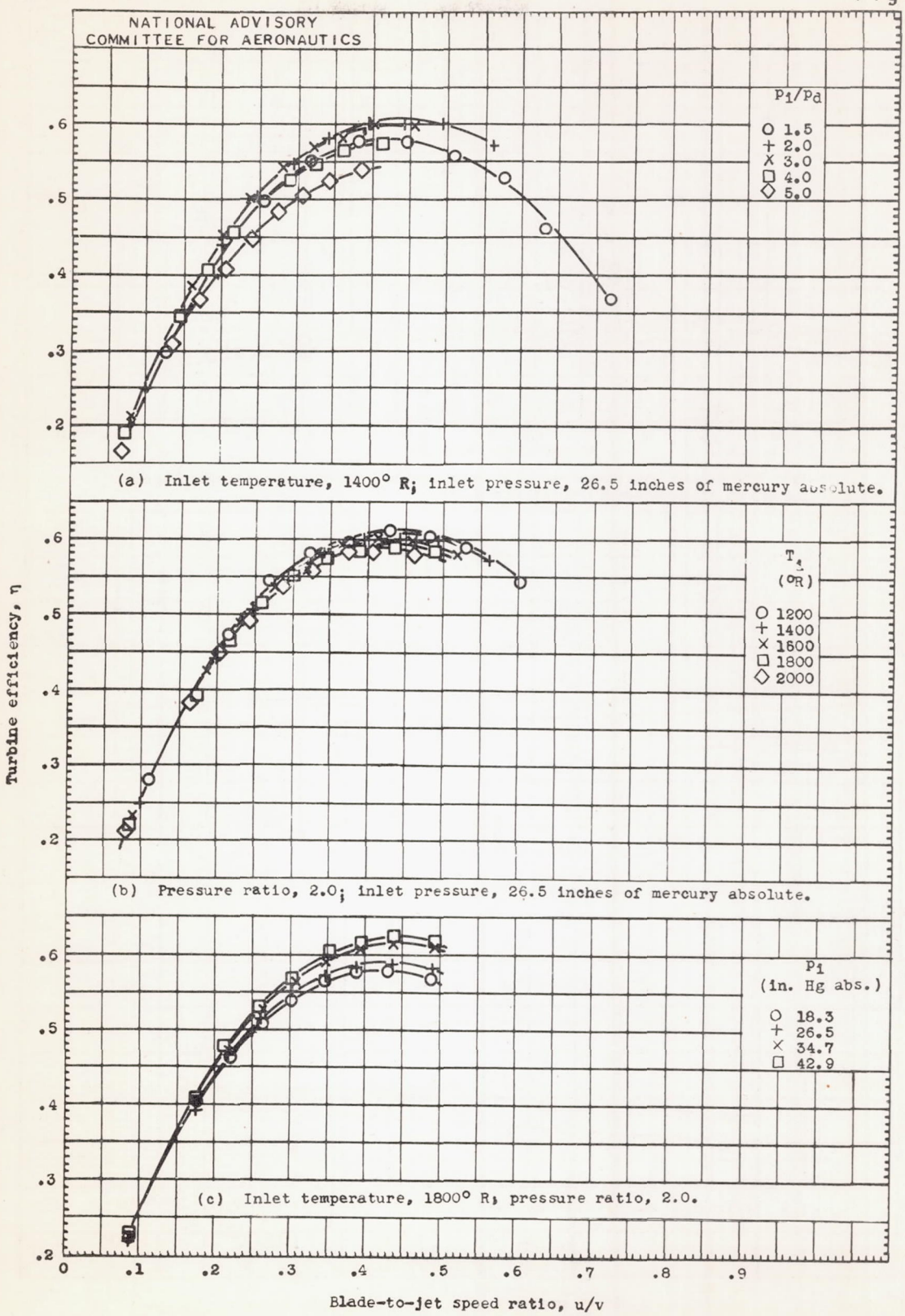

Figure 3.- Variation of turbine efficiency with blade-to-jet speed ratio for various pressure ratios, inlet total temperatures, and inlet total pressures.

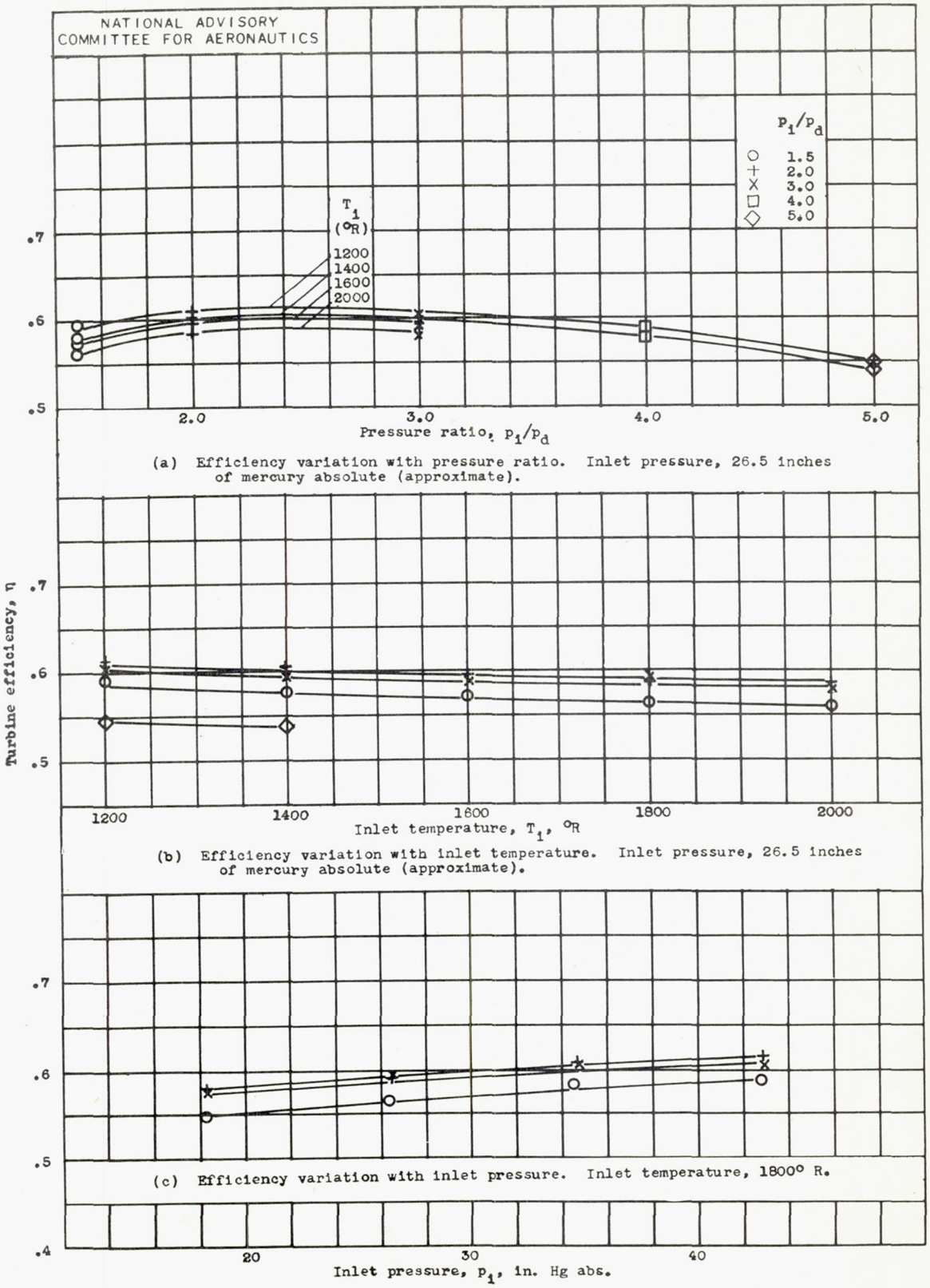

Figure 4. - Variation of turbine efficiency with pressure ratio, inlet total temperature, and inlet total pressure. Blade-to-jet speed ratio, 0.4.

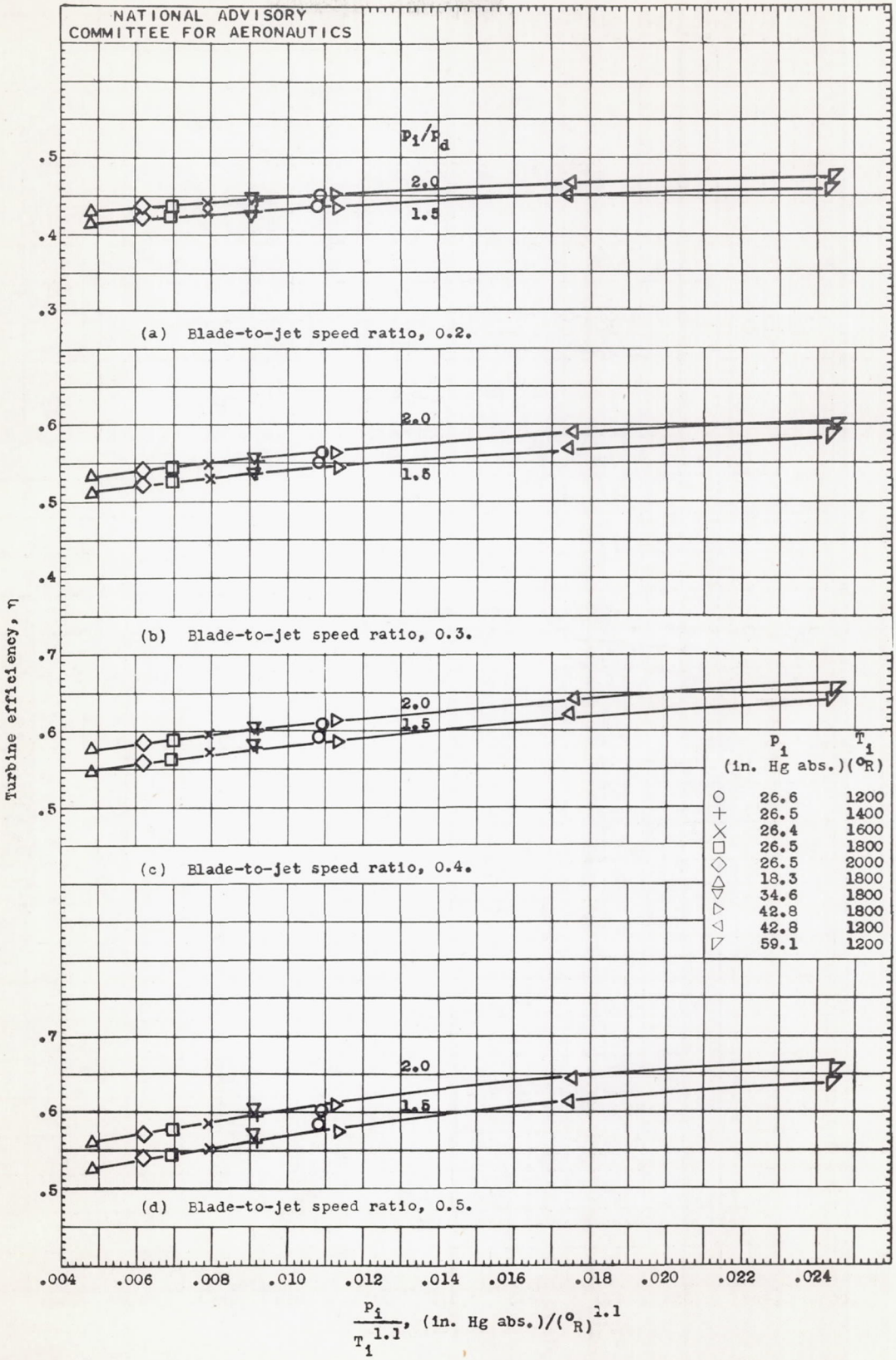

Figure 5. - Variation of turbine efficiency with Reynolds number factor for pressure ratios of 1.5 and 2.0.

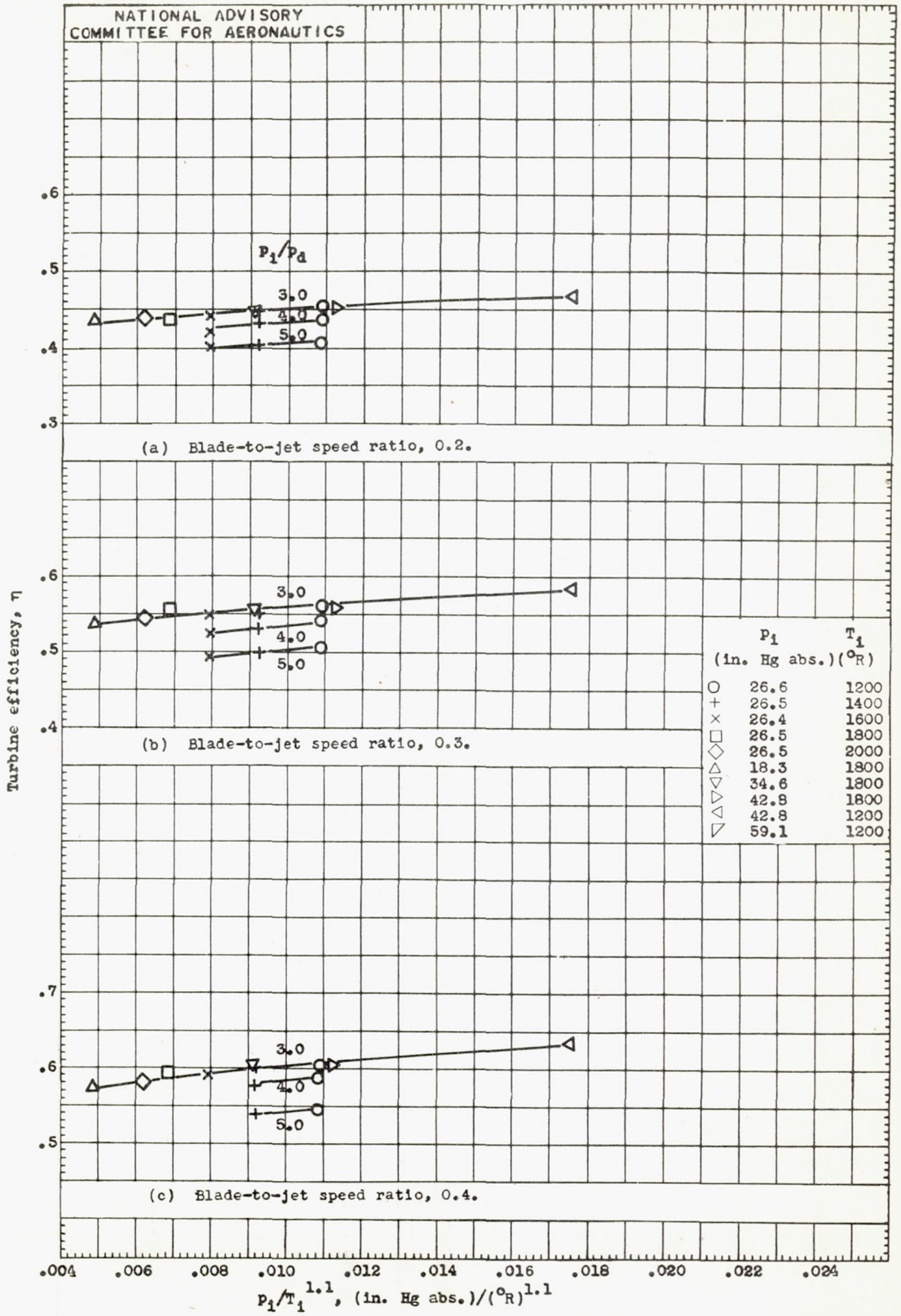

Figure 6. - Variation of turbine efficiency with Reynolds number factor for pressure ratios of 3.0, 4.0, and 5.0.

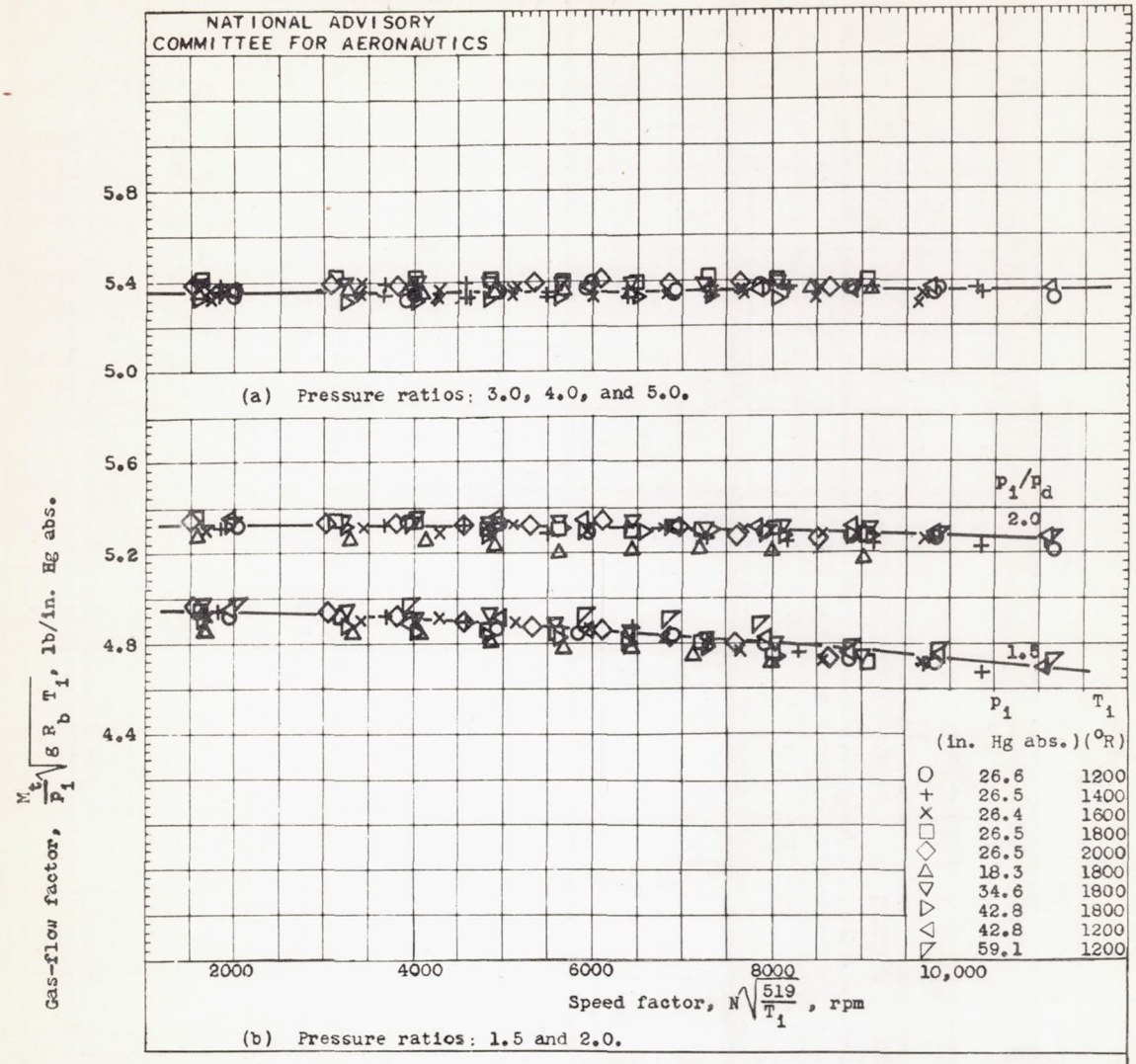

Figure 7. - Variation of gas-flow factor with speed factor.

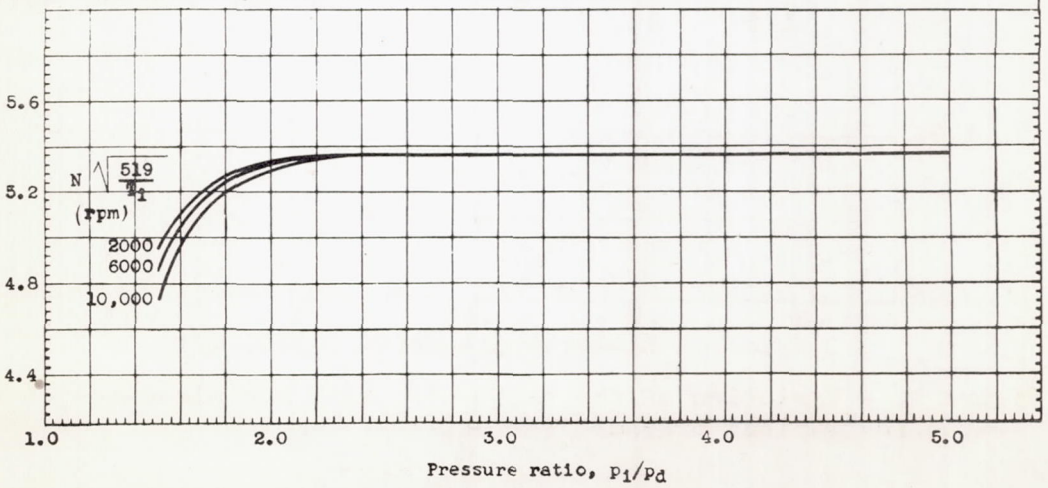

Figure 8. - Variation of gas-flow factor with pressure ratio.

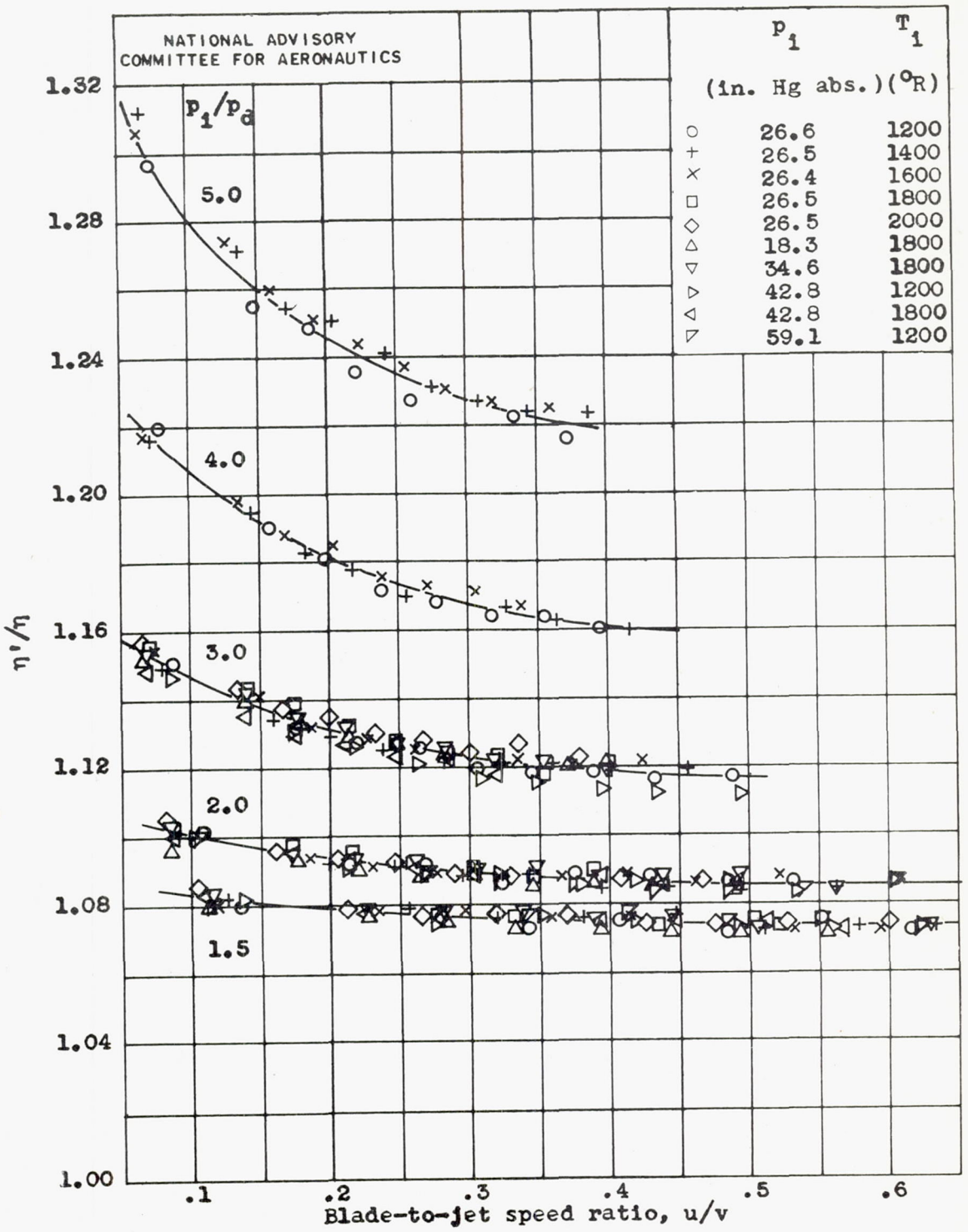

Figure 9. - Variation of the ratio η'/η with the blade-to-jet speed ratio for various pressure ratios.