NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

# WARTIME REPORT

ORIGINALLY ISSUED

September 1945 as
Advance Restricted Report E5H10

## 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

By Ernest R. Chanes and L. Robert Carman

Aircraft Engine Research Laboratory
Cleveland, Ohio

NACA

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

# 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

By Ernest R. Chanes and L. Robert Carman

## 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 $p_1/p_d$ | Inlet total pressure $p_1$ (in. Hg absolute) | Inlet total temperature $T_1$ (°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)

$p_1$ total pressure at nozzle-box inlet, (in. Hg absolute)

$R_b$ gas constant for combustion products, (ft-lb)/(lb)(°F)

$T_1$ total temperature at nozzle-box inlet, (°R)

$u$ blade pitch-line speed, (fps)

$v$ theoretical jet speed, (fps)

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

$\eta$ 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

$\eta'$ 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 $\eta$ 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 $(M_t/p_1)\sqrt{g R_b T_1}$ is plotted against the speed factor $N\sqrt{519/T_1}$ 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 $\eta'/\eta$ 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 $\eta'/\eta$ increases with pressure ratio and decreases with blade-to-jet speed ratio. The values of $\eta'$ range from 7 to 31 percent higher than the corresponding values of $\eta$.

## 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.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

## REFERENCES

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2. Gabriel, David S., and Carman, L. Robert: Efficiency Tests of a Single-Stage Impulse Turbine Having an 11.0-Inch Pitch-Line Diameter Wheel with Air as the Driving Fluid. NACA ACR No. E5C30, 1945.

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 $p_1$ (in. Hg absolute) | Inlet total temperature $T_1$ (°R) | Pressure ratio $p_1/p_d$ | Turbine speed N (rpm) | Blade-to-jet speed ratio u/v | Turbine shaft power (hp) | Turbine efficiency | | Gas flow $W_t$ (lb/sec) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 |

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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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | 213.7 | .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 |

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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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | 221.7 | .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 | 39.4 | .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 | .066 | 88.8 | .167 | .219 | 2.96 |
| 26.4 | | 5.05 | 6,020 | .133 | 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 | .200 | 216.3 | .408 | .510 | 2.95 |

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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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | 1800 | 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 | .413 | 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 | 9,970 | .276 | 144.3 | .534 | .582 | 2.73 |
| 26.6 | | 2.02 | 10,430 | .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 | | 3.05 | 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 | 3,050 | .069 | 90.3 | .181 | .220 | 2.74 |
| 26.4 | | 4.02 | 5,050 | .135 | 160.6 | .322 | .385 | 2.74 |
| 26.3 | | 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 |

National Advisory Committee for Aeronautics

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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | .438 | .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 | .654 | 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 | .567 | .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 | .542 | .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 | .438 | .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 | .586 | .640 | 2.56 |
| 26.4 | | 2.01 | 16,970 | .490 | 167.1 | .582 | .632 | 2.55 |
| 26.6 | | 3.01 | 3,010 | .071 | 93.1 | .187 | .216 | 2.63 |
| 26.5 | | 3.03 | 6,020 | .141 | 152.9 | .342 | .391 | 2.63 |
| 26.5 | | 3.01 | 7,470 | .176 | 176.6 | .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 | .665 | 2.61 |
| 26.4 | | 2.98 | 16,920 | .400 | 261.8 | .600 | .672 | 2.61 |

National Advisory Committee
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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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | .165 | 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 |

National Advisory Committee
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TABLE I. - SUMMARY OF DATA AND RESULTS - Continued

| Inlet total pressure $p_1$ (in. Hg absolute) | Inlet total temperature $T_1$ (°R) | Pressure ratio $p_1/p_d$ | Turbine speed N (rpm) | Blade-to-jet speed ratio u/v | Turbine shaft power (hp) | Turbine efficiency | | Gas flow $W_t$ (lb/sec) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 34.6 | 1300 | 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 | 226.7 | .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 |

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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) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | .218 | 231.1 | .493 | .556 | 5.16 |
| 42.8 | | 2.98 | 9,050 | .264 | 311.8 | .550 | .617 | 5.15 |
| 42.8 | | 2.96 | 10,560 | .308 | 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 | .068 | 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 |

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TABLE I.- SUMMARY OF DATA AND RESULTS - Concluded

| Inlet total pressure $p_1$ (in. Hg absolute) | Inlet total temperature $T_1$ (°R) | Pressure ratio $p_1/p_2$ | Turbine speed N (rpm) | Blade-to-jet speed ratio u/v | Turbine shaft power (hp) | Turbine efficiency | | Gas flow $W_t$ (lb/sec) |
|---|---|---|---|---|---|---|---|---|
| | | | | | | $\eta$ | $\eta'$ | |
| 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 | 293.6 | .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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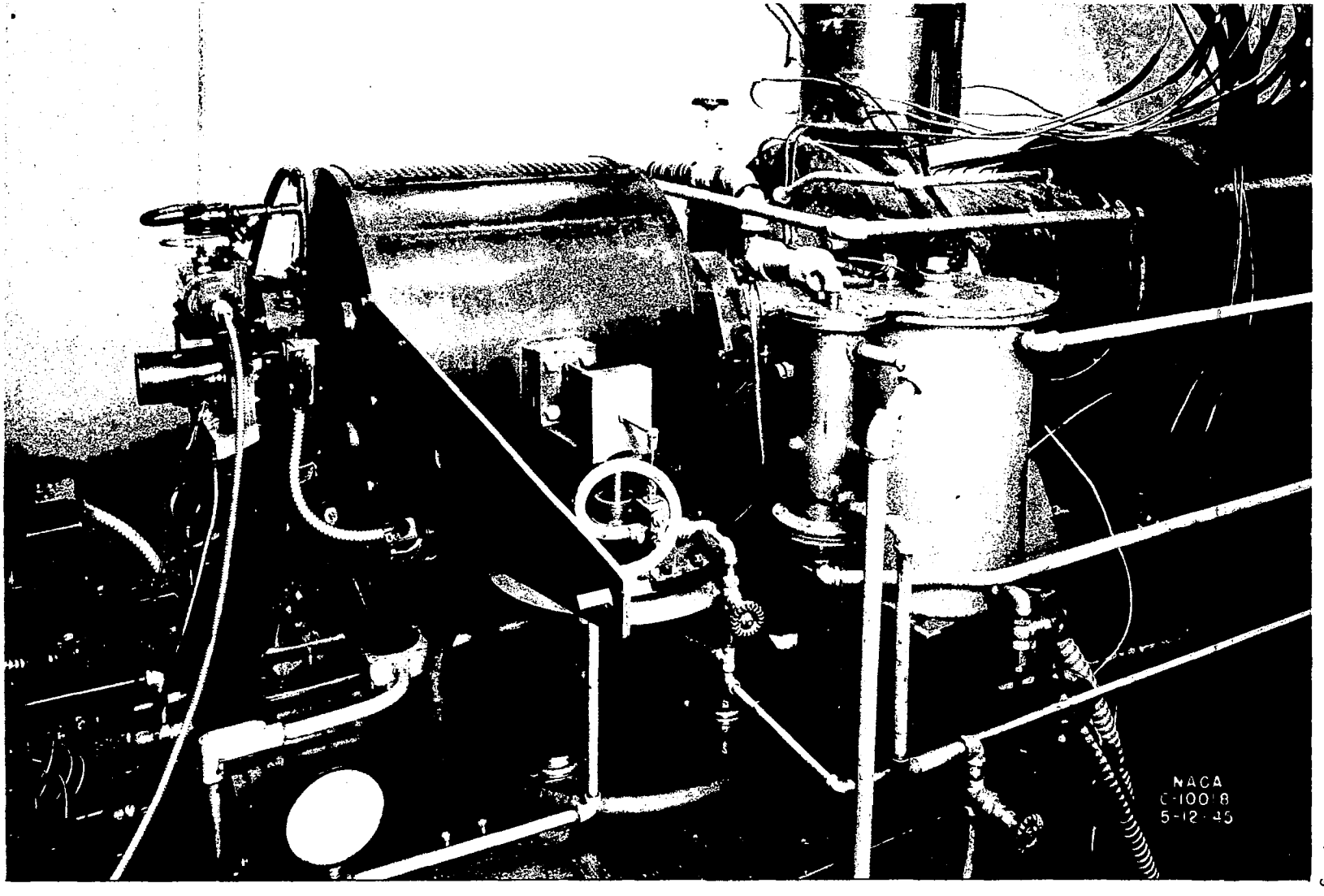


Figure 1. - Apparatus for testing efficiency of the exhaust-gas turbine.

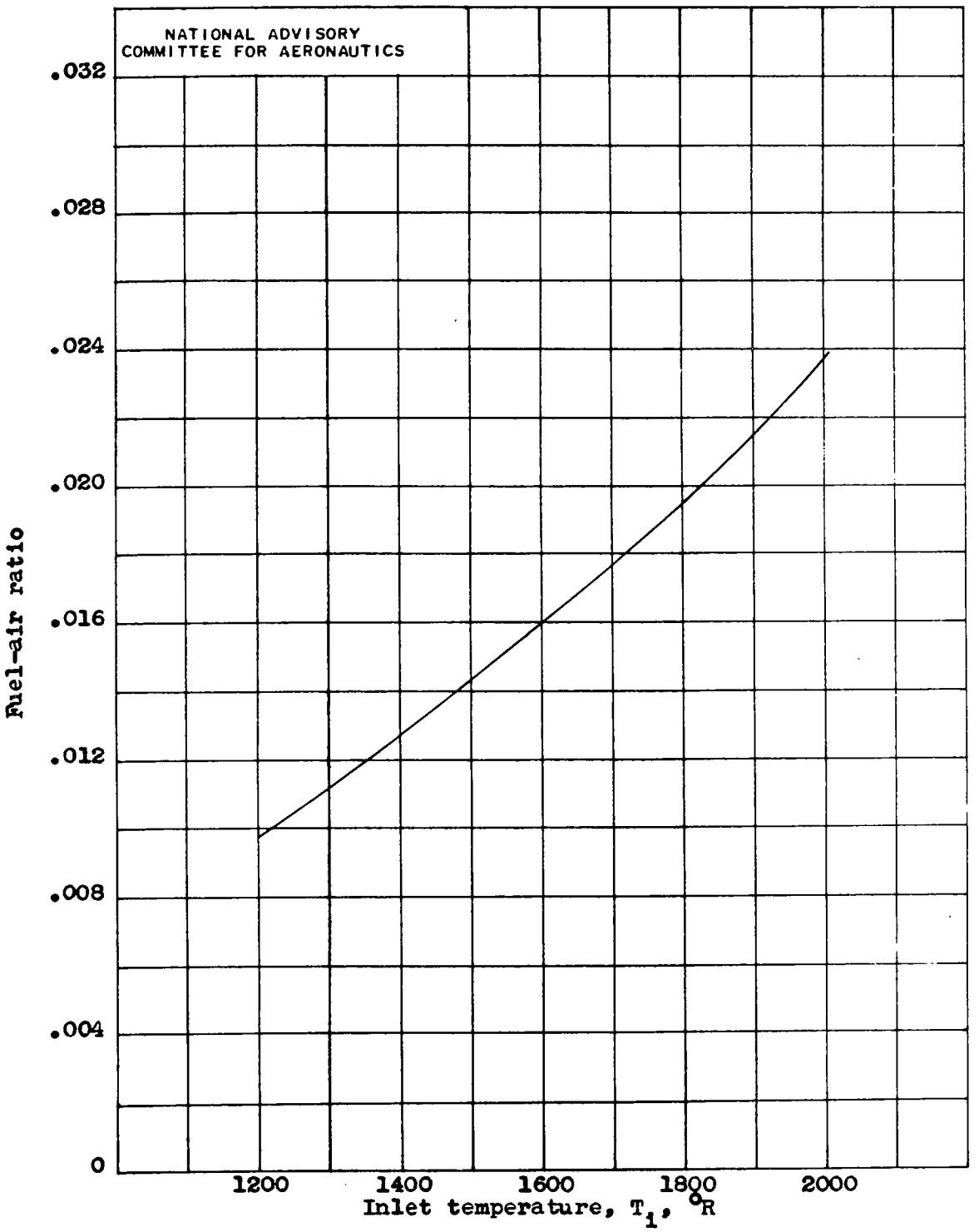


Figure 2. - Variation of fuel-air ratio with temperature.

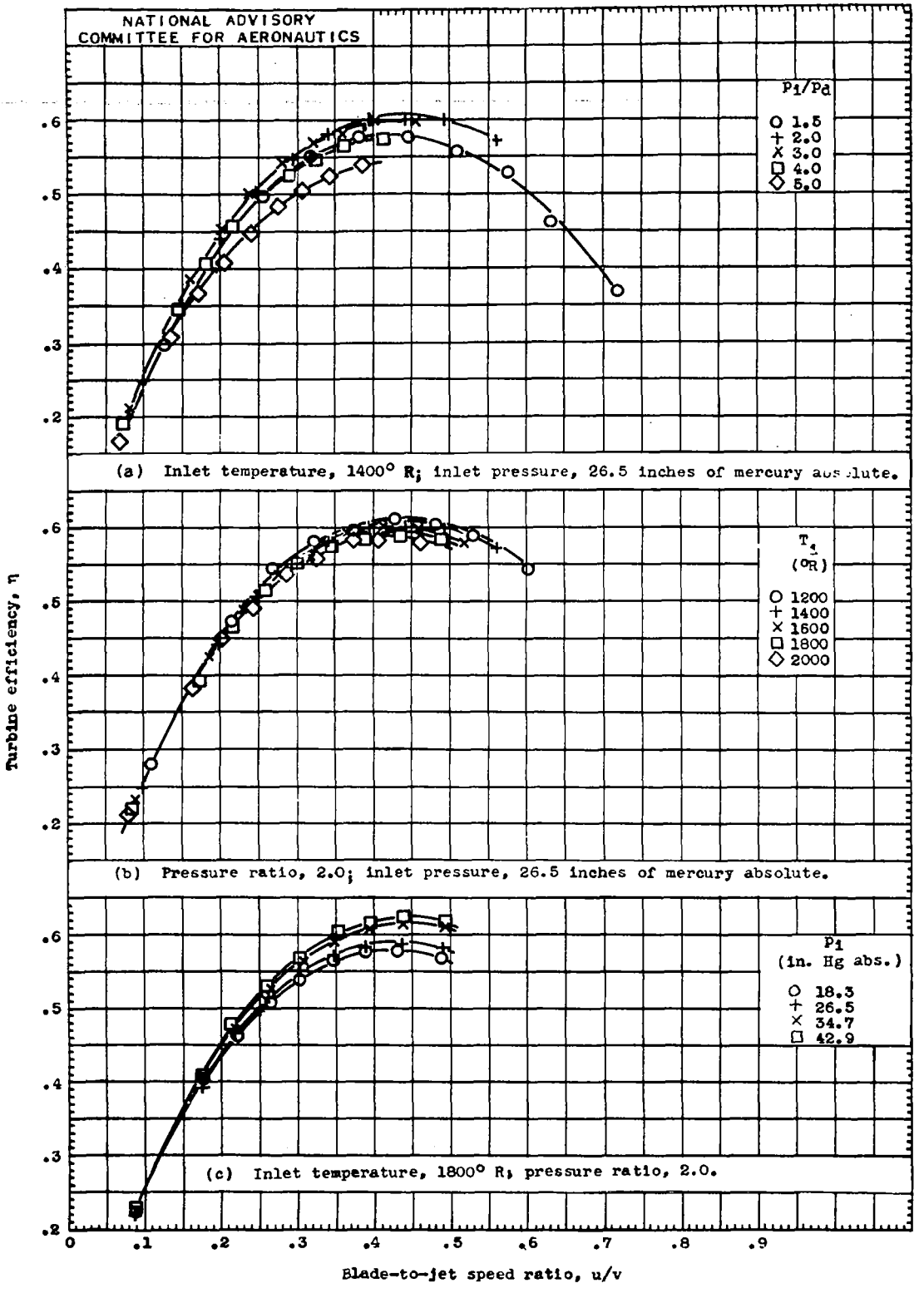


Figure 3.- Variation of turbine efficiency with blade-to-jet speed ratio for various pressure ratios, inlet total temperatures, and inlet total pressures.

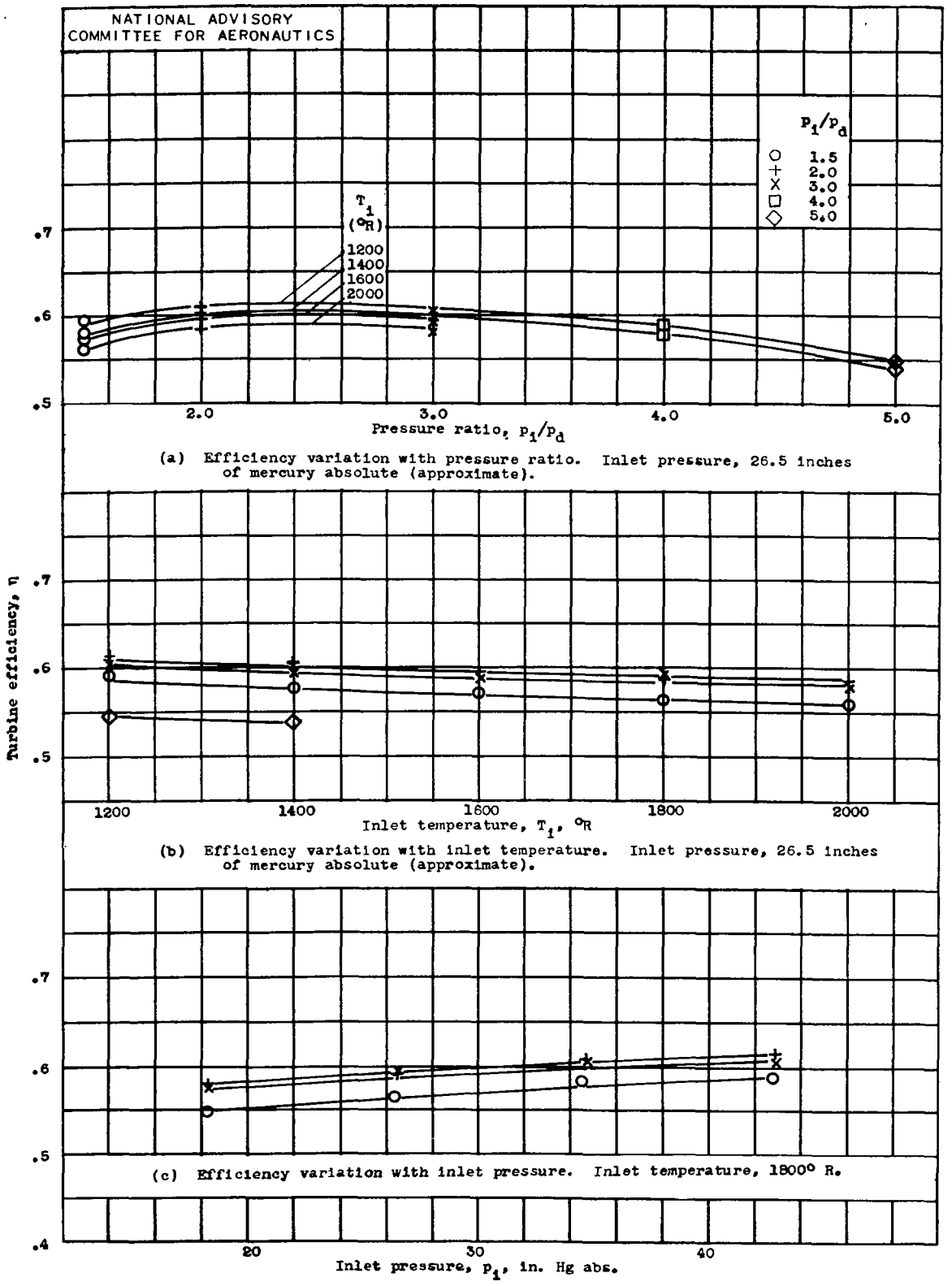


Figure 4. - Variation of turbine efficiency with pressure ratio, inlet total temperature, and inlet total pressure. Blade-to-jet speed ratio, 0.4.

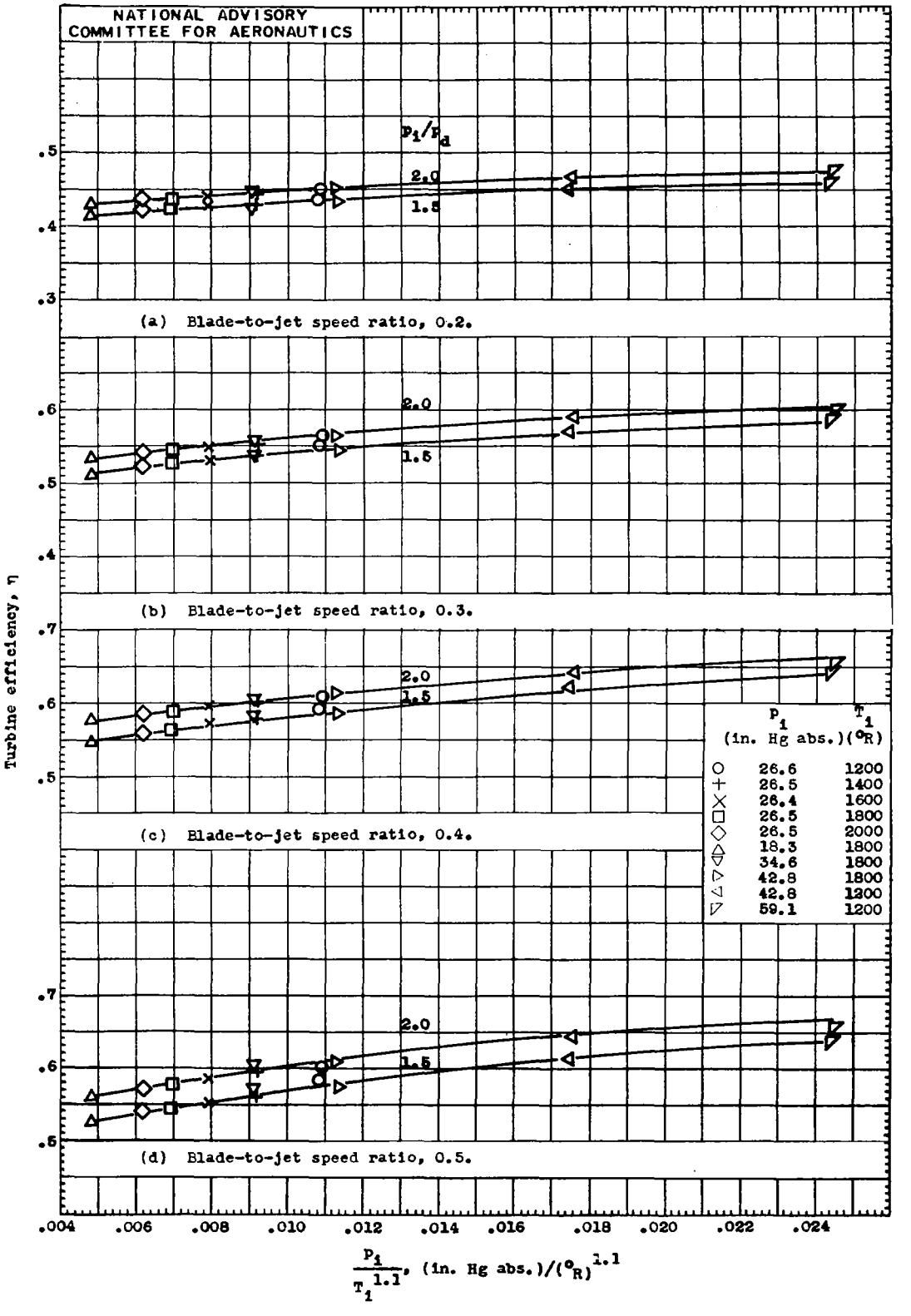


Figure 5. - Variation of turbine efficiency with Reynolds number factor for pressure ratios of 1.5 and 2.0.

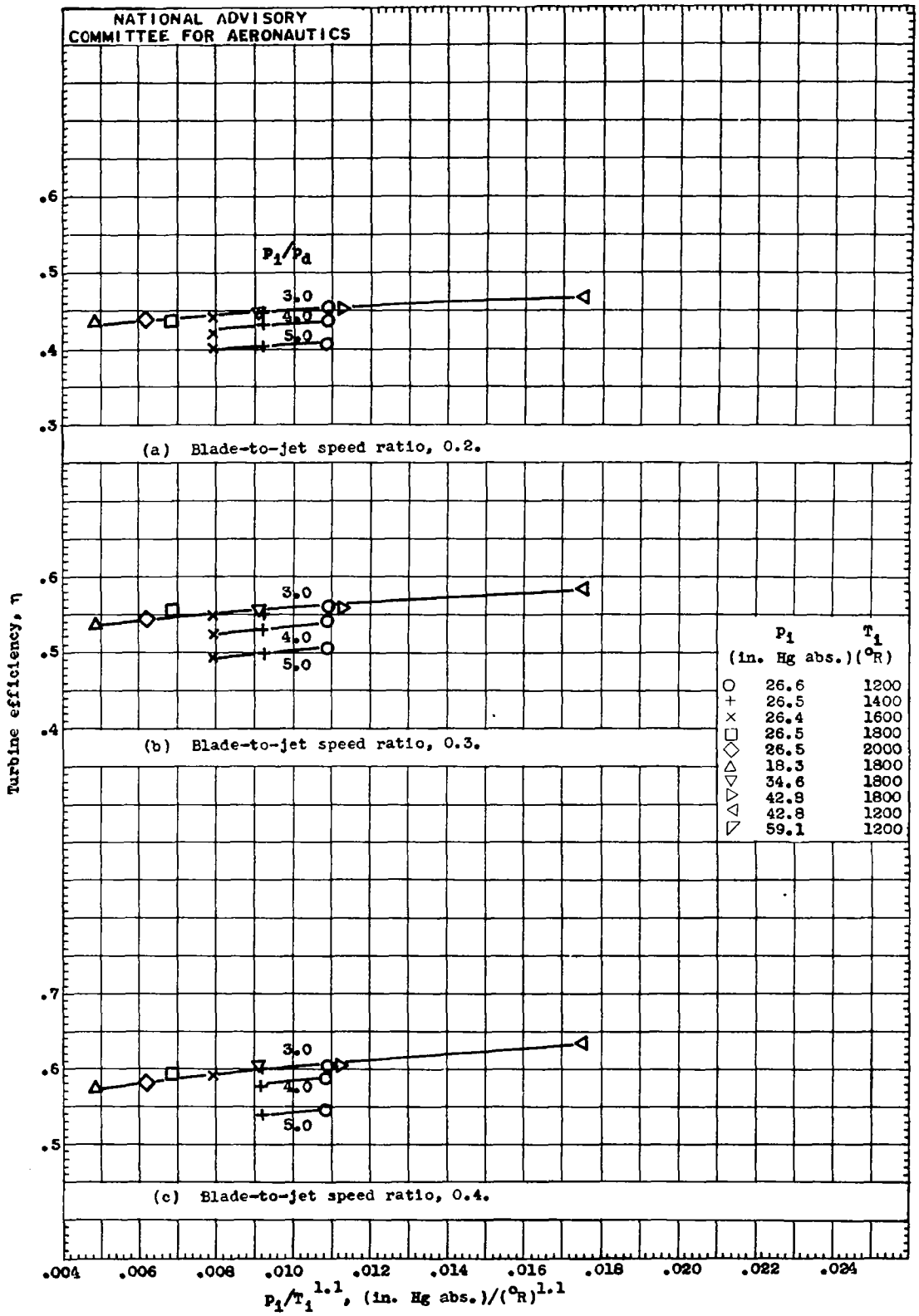


Figure 6. - Variation of turbine efficiency with Reynolds number factor for pressure ratios of 3.0, 4.0, and 5.0.

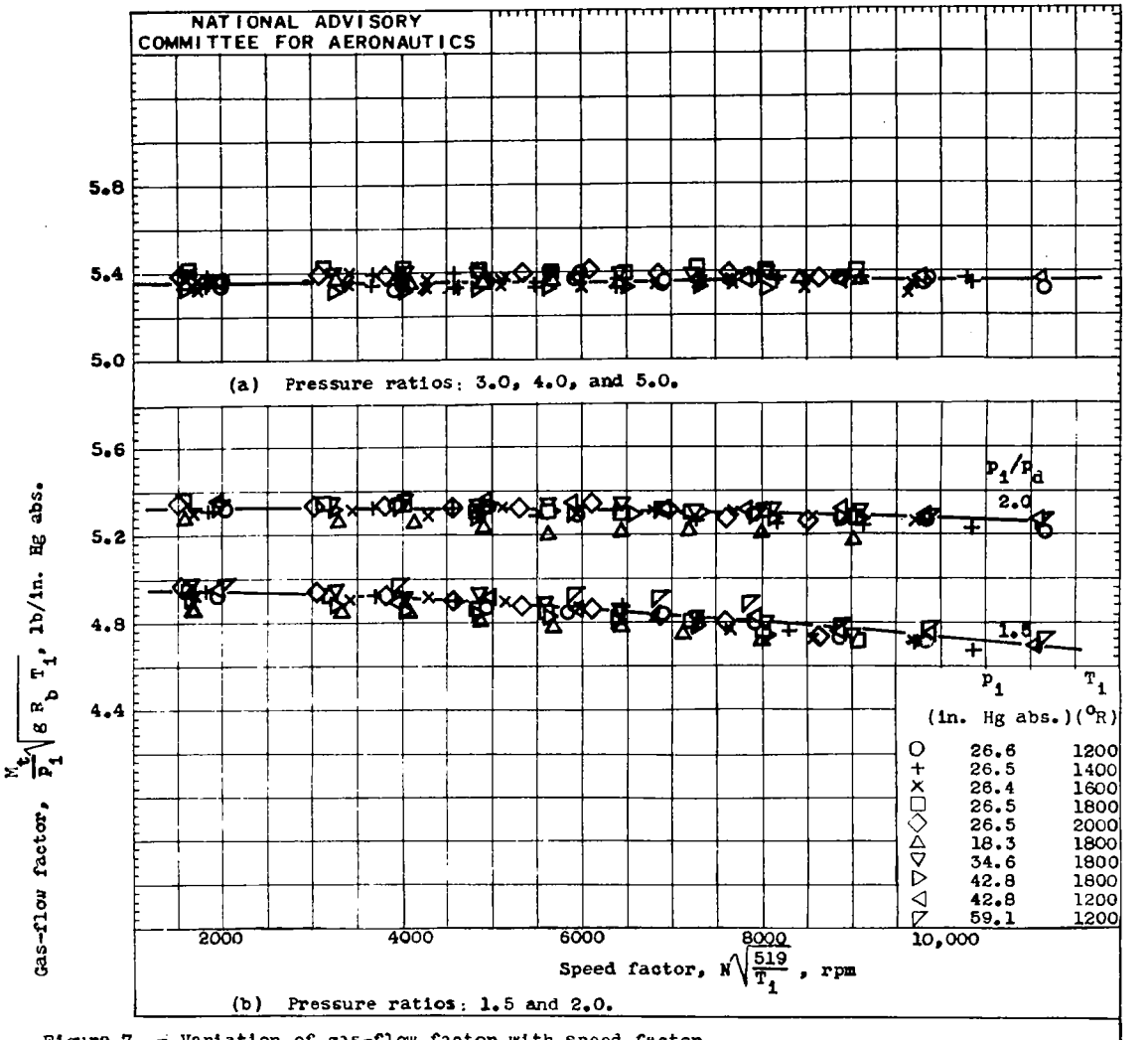


Figure 7. - Variation of gas-flow factor with speed factor.

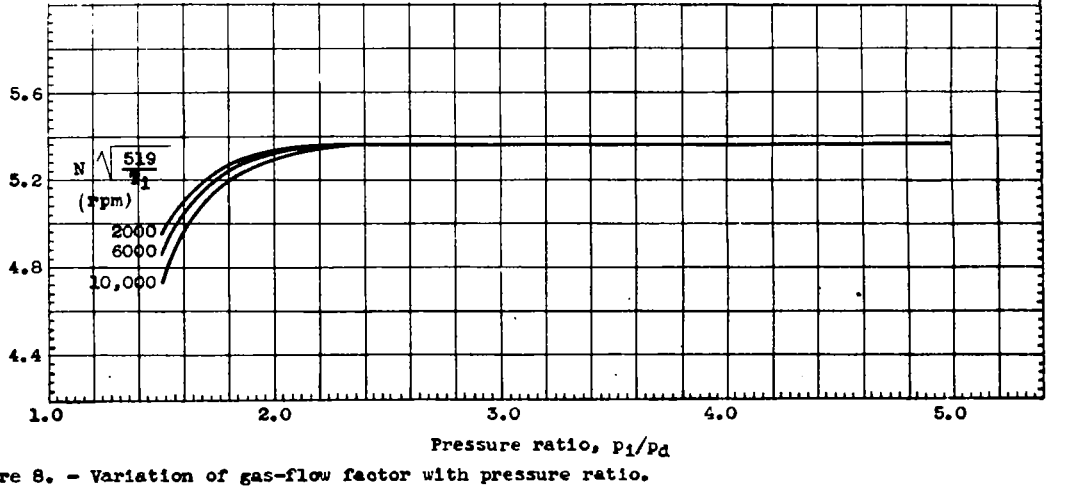


Figure 8. - Variation of gas-flow factor with pressure ratio.

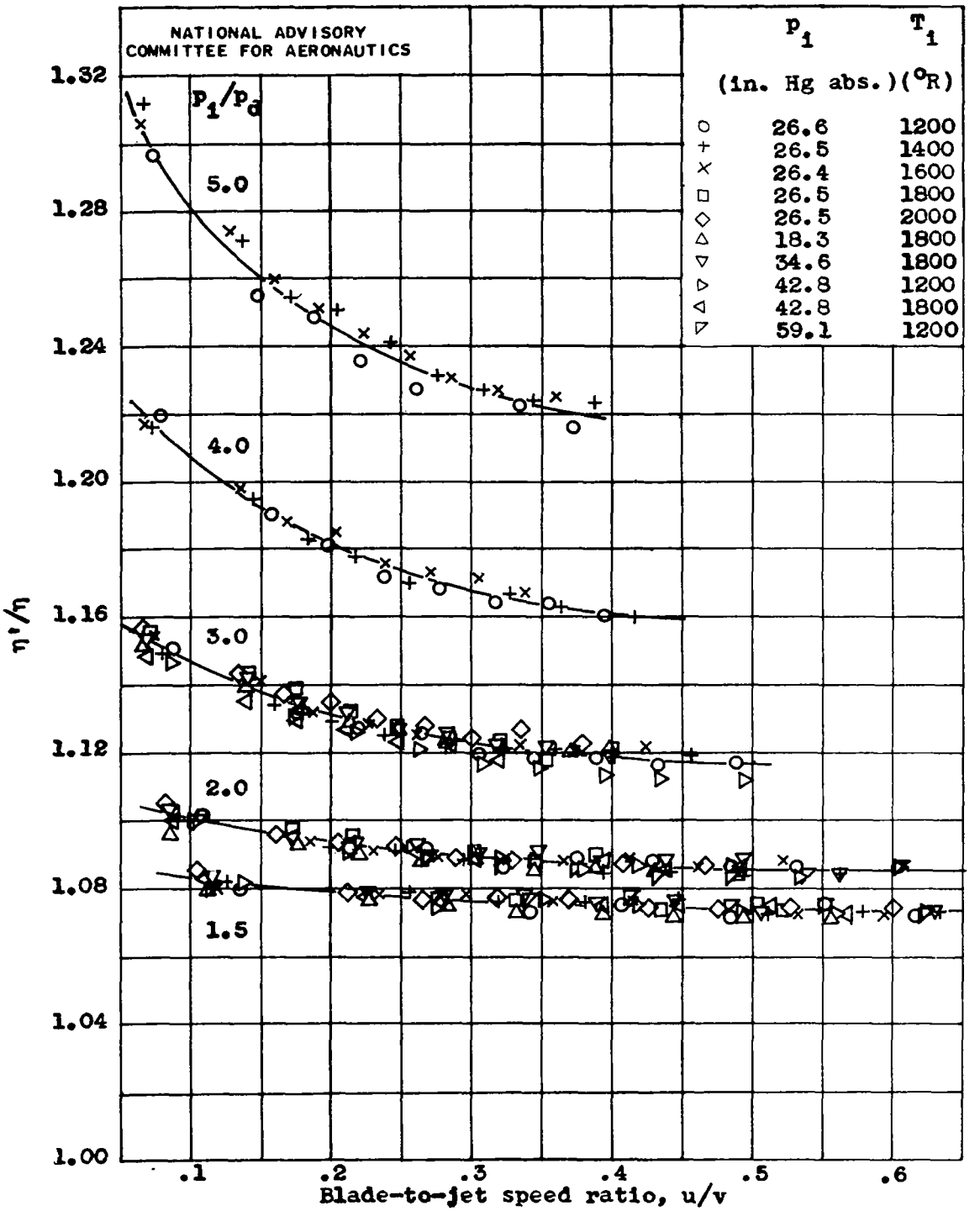


Figure 9. - Variation of the ratio $\eta'/\eta$ with the blade-to-jet speed ratio for various pressure ratios.

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