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RESEARCH MEMORANDUM

for the

Bureau of Ordnance, Department of the Navy

PERFORMANCE OF SINGLE-STAGE TURBINE OF MARK 25 TORPEDO POWER PLANT WITH TWO NOZZLES AND THREE ROTOR-BLADE DESIGNS

By Harold J. Schum and Warren J. Whitney

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

A single-stage modification of the turbine from a Mark 25 torpedo power plant was investigated to determine the performance with two nozzles and three rotor-blade designs. The performance was evaluated in terms of brake, rotor, and blade efficiencies at pressure ratios of 8, 15 (design), and 20. The blade efficiencies with the two nozzles are compared with those obtained with four other nozzles previously investigated with the same three rotor-blade designs.

Blade efficiency with the cast nozzle of rectangular cross section (J) was higher than that with the circular reamed nozzle (K) at all speeds and pressure ratios with a rotor having a 0.45-inch 17°-inlet-angle blades. The efficiencies for both these nozzles were generally low compared with those of the four other nozzles previously investigated in combination with this rotor. At pressure ratios of 15 and 20, the blade efficiencies with nozzle K and the two rotors with 0.40-inch blades having different inlet angles were higher than with the four other nozzles, but the efficiency with nozzle J was generally low.

Increasing the blade inlet angle from 17° to 20° had little effect on turbine performance, whereas changing the blade length from 0.40 to 0.45 inch had a marked effect. Although a slight correlation of efficiency with nozzle size was noted for the rotor with 0.45-inch 17°-inlet-angle blades, no such effect was discernible for the two rotors with 0.40-inch blades. Losses in the supersonic air stream resulting from the complex flow path in the small air passages are probably a large percentage of the total losses, and apparently the effects of changing nozzle size and shape within the limits investigated are of secondary importance.

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INTRODUCTION

At the request of the Bureau of Ordnance, Department of the Navy, the NACA Lewis laboratory is conducting an investigation of the gas-turbine power plant from a Mark 25 aerial torpedo. The turbine has two velocity stages, which are geared to operate at equal but opposite rotative speeds in order to eliminate gyroscopic effect.

The investigation was conducted to augment knowledge of small high-pressure turbines for possible application to aircraft propulsion where high energy extraction and low volume flow are required. The research program includes the determination of the effect on over-all performance of (1) nozzle design, (2) axial nozzle-rotor clearance, and (3) blade design. The performance of the two-stage turbine with five nozzle designs and with various axial nozzle-rotor clearances is presented in references 1 and 2, respectively. The unit was modified to operate as a single-stage turbine and the performance of the single stage with various nozzle designs was determined; these results and an analysis of the relative power output of each stage are included in reference 3. The performance of the modified single-stage turbine with various blade designs and nozzles is given in reference 4.

The single-stage investigations with two additional nozzles, designated J and K, operated in combination with three blade designs is presented in references 5 to 7. Nozzle J has ports of rectangular cross section and nozzle K has circular reamed ports. Both nozzles are similar in design to the nozzles previously investigated but have smaller port cross-sectional areas. Each nozzle was operated with standard 0.40-inch 17°-inlet-angle blades, 0.45-inch 17°-inlet-angle blades, and 0.40-inch 20°-inlet-angle blades.

Turbine performance with each nozzle-rotor combination was determined and is presented herein for constant inlet conditions of temperature and pressure of 1000° F and 95 pounds per square inch gage, respectively. Each nozzle-rotor combination was operated at pressure ratios of 8, 15 (design), and 20 over a range of speeds from approximately 6000 rpm to the design speed of 18,000 rpm. Indicated brake power output was corrected for mechanical losses to determine rotor efficiency and for mechanical and windage losses to determine blade efficiency by the methods given in reference 3.

APPARATUS AND METHODS

Nozzles. - Nozzle J (fig. 1), which has nine rectangular ports, was fabricated by a refined casting technique that permitted small dimensional tolerances. Nozzle J has smaller passages than those of nozzle H described in reference 1, although the design and fabrication are similar. The average throat dimensions of nozzle J are 0.215 inch by 0.099 inch, and the cross-sectional dimensions at the outlet plane are approximately 0.203 by 0.116 inch. The geometric area expansion ratio is therefore approximately 1.11. The nine ports have sharp-edged inlets and are equally spaced to subtend an arc of gas admission of approximately 90°. The ports have an intangency angle α (fig. 1) of 9° and an inlet angle to the rotor of 12° measured from a plane normal to the axis of rotor rotation.

Nozzle K (fig. 2) has eight drilled and reamed ports, which have a nominal throat diameter of 0.156 inch and an outlet-plane diameter of 0.168 inch, making the measured area expansion ratio approximately 1.16. The ports are equally spaced over a section of the rotor periphery to form an arc of gas admission of approximately 90°. The angle of intangency α for nozzle K is 6°; the air inlet angle to the turbine rotor is 12°.

Nozzles J and K are compared with the four nozzles previously investigated in the following table:

Nozzle	Number of ports	Port-inlet configuration	Port cross-sectional shape	Total measured throat area (sq in.)	Measured expansion ratio	Height of passage at throat section (in.)
A	9	Rounded	Rectangular	0.183	1.47	0.210
E	9	Rounded	Circular	.193	1.00	.165
H	9	Sharp-edged	Rectangular	.226	1.12	.257
I	9	Sharp-edged	Rectangular	.217	1.20	.254
J	9	Sharp-edged	Rectangular	.191	1.11	.215
K	8	Sharp-edged	Circular	.153	1.16	.156

Apparatus. - The standard Mark 25 torpedo power plant is an impulse turbine consisting of two counterrotating velocity stages. For this investigation, the unit was modified to operate as a single-stage turbine by the procedure described in reference 3. The apparatus and the instrumentation used in this investigation are the same as those in reference 3. An over-all view of the setup and a cross-sectional view of the turbine are shown in figures 3 and 4, respectively.

The standard rotor has blades 0.40 inch long with an inlet angle of 17°. In order to determine the effect of increased effective flow area of the rotor on performance, the blade length was increased to 0.45 inch for one special rotor. Another special rotor having 0.40-inch 20°-inlet-angle blades was investigated to ascertain the effect of increasing the blade inlet angle.

Precision. - The precision of the observed measurements is estimated to be within the following limits:

Air flow, percent	±1.5
Torque, foot-pound	±0.15
Dynamometer speed, rpm	±5
Inlet-gas temperature, percent	±0.25
Inlet-gas pressure, percent	±0.5
Pressure, inch mercury absolute	±0.05

Procedure. - The turbine was operated with constant inlet-gas conditions of temperature and pressure of 1000° F and 95 pounds per square inch gage, respectively. Runs were made for nozzles J and K in combination with the three rotors at pressure ratios of 8, 15 (design), and 20. Turbine speed was varied from approximately 6000 to 18,000 (design) rpm for each run. Nozzle J was operated with 0.030-inch nozzle-rotor clearance; nozzle K was operated with 0.040-inch clearance. The effect of clearance on performance within this range was reported as negligible in reference 2.

Calculations. - The methods of calculating brake, rotor, and blade efficiencies, blade-jet speed ratio, and pressure ratio are described in reference 1.

The three efficiencies are defined as follows:

$$\text{brake efficiency} = \frac{\text{brake power}}{\text{available isentropic power}}$$

$$\text{rotor efficiency} = \frac{\text{brake power + mechanical losses}}{\text{available isentropic power}}$$

$$\text{blade efficiency} = \frac{\text{brake power + mechanical losses + windage losses}}{\text{available isentropic power}}$$

The windage losses were based on the gas density in the turbine casing. The methods of evaluating the windage and mechanical losses for various speeds and gas densities are described in reference 4.

RESULTS AND DISCUSSION

Efficiency data for the single-stage modified turbine with nozzles J and K and the three blade designs are summarized in tables I to VI. The blade efficiencies obtained with the three rotors and nozzles J and K are presented as functions of blade-jet speed ratio in figures 5 and 6, respectively. Blade efficiency was considered a better criterion of performance than either brake or rotor efficiencies because the effects of mechanical friction and windage are eliminated. The brake and rotor efficiencies are given in the tables and follow the same trends as the blade efficiencies. The blade efficiencies with nozzles J and K are compared with those obtained with four other nozzles, A, E, H, and I previously investigated (reference 4) with the same three turbine rotors (figs. 7 to 9). For all the nozzle-rotor combinations, efficiency increased with blade-jet speed ratio, and the speed limitation of 18,000 rpm prevented attaining a peak efficiency. Efficiency for all combinations decreased with increasing pressure ratio.

The effect of rotor-blade design on turbine performance with nozzles J and K (figs. 5 and 6, respectively) indicates that increasing the blade inlet angle from 17° to 20° had only a small effect on performance; the blade efficiency was usually lower for the increased inlet angle. Increasing the blade length from 0.40 inch to 0.45 inch, however, had a more marked effect on the efficiency. When operated with nozzle J, the blade efficiencies for the 0.45-inch rotor blades were higher than those obtained with the other two rotor blades at pressure ratios of 15 and 20 (fig. 5). At a pressure ratio of 8, blade efficiencies with the three rotor configurations were very nearly the same. The efficiency with nozzle K (fig. 6) and the 0.45-inch rotor blades was considerably lower than the efficiencies with the other two rotors at all pressure ratios investigated. An increase in effective flow area through the turbine blading apparently improves the turbine performance with nozzle J at the higher pressure ratios (fig. 5). With nozzle K (fig. 6), however, the reverse occurs. It is possible that the nozzle with the smaller flow area (K) is better matched with a rotor having a smaller flow area, and that nozzle J with a larger flow area is more suitably matched with the rotor having the greater flow area.

The blade efficiencies of nozzles J and K are compared in figure 7 with the efficiencies of four nozzles (A, E, H, and I) previously investigated in combination with the 0.45-inch rotor blades. Blade efficiencies with nozzles J and K were lower than those obtained with any of the other nozzles except nozzle E. From figure 7, a slight correlation of nozzle size and efficiency apparently exists; that is, the nozzles with the larger flow areas have the higher blade efficiencies. Efficiency also seems somewhat dependent on nozzle-passage height because the nozzles with the greatest height have the highest blade efficiencies with the 0.45-inch rotor blades.

The same trend is not evidenced in figures 8 and 9 for the 20°-inlet-angle blades and the standard blades with the same six nozzles. With the standard rotor blades at pressure ratios of 15 and 20 (fig. 9), nozzle K, which has the smallest measured throat area and circular ports, and nozzle I, which is surpassed in area only by nozzle H and has rectangular ports, yielded the highest efficiencies. At a pressure ratio of 8, the highest efficiency with this rotor occurred with nozzles I and A, which had the smallest area with the exception of K. The efficiency with nozzle J and the standard rotor blades was generally low compared with the other nozzles.

The efficiencies of nozzles A and K were higher than those of the other nozzles in combination with the 20°-inlet-angle rotor blades for pressure ratios of 15 and 20 (fig. 8). At a pressure ratio of 8, the highest efficiency was obtained with nozzle I. The efficiency with nozzle J was again low compared with the other nozzles. For the two 0.40-inch rotors, no effect of nozzle size or shape on turbine performance can be ascertained. No such trend can be definitely based on such simple concepts because of the complexity of the flow in the small passages. The losses inherent in all nozzle-rotor combinations because of the small flow area, jet defection, and the inability of the blade passages to swallow the shock (reference 4) are probably such a large percentage of the total losses that the effect of changing nozzle size and shape within the limits investigated is of secondary significance.

SUMMARY OF RESULTS

A single-stage modification of the turbine from a Mark 25 torpedo power plant in combination with two nozzles and three rotor-blade designs has been investigated with the following results:

1. Blade efficiency with nozzle J was higher than that of nozzle K when operated with the 0.45-inch 17°-inlet-angle rotor blades at all speeds and pressure ratios investigated.

2. With the 0.45-inch 17°-inlet-angle rotor blades, nozzles J and K yielded low turbine efficiencies compared with those obtained with other nozzles previously investigated.

3. When the turbine was operated with the two rotors with 0.40-inch blades and different inlet angles at pressure ratios of 15 and 20, nozzle K had a high efficiency compared with the other nozzles, whereas the efficiency with nozzle J was generally low.

4. A slight trend with nozzle size and efficiency was noted with the 0.45-inch 17°-inlet-angle rotor blades; the nozzles with the larger flow areas have higher efficiencies. No such trend was noted for the 0.40-inch 20°-inlet-angle rotor or the 0.40-inch 17°-inlet-angle rotor blades.

5. The effect of increasing the inlet angle from 17° to 20° on blade efficiency was small compared with the effect of increasing the blade length from 0.40 to 0.45 inch.

6. Losses in the supersonic air stream resulting from a complex flow pattern in the small air passages are probably of such magnitude that the effects of changing nozzle size and shape are of secondary importance.

Lewis Flight Propulsion Laboratory,
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TABLE I - EFFICIENCY DATA FOR SINGLE-STAGE TURBINE WITH NOZZLE J AND 0.45-INCH 17°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	933.5	0.0138	59.73	6,069	14.72	0.0984	0.0353	0.246	0.252	0.254
	933.9	.0138	59.76	8,132	18.76	.1318	.0361	.314	.324	.327
	993.9	.0138	59.76	10,155	22.29	.1646	.0363	.373	.388	.394
	934.8	.0137	59.82	12,158	24.88	.1970	.0358	.416	.436	.445
	934.8	.0137	59.82	14,222	27.18	.2305	.0353	.454	.480	.494
	934.8	.0138	59.82	16,164	28.28	.2620	.0347	.473	.503	.526
	933.9	.0138	59.76	18,187	28.47	.2948	.0341	.476	.512	.545
15	934.8	0.0139	72.22	6,069	15.92	0.0896	0.0182	0.220	0.225	0.226
	934.8	.0138	72.21	8,092	20.43	.1195	.0191	.283	.291	.293
	934.8	.0138	72.20	10,176	24.51	.1503	.0192	.340	.352	.355
	934.8	.0137	72.20	12,138	27.68	.1792	.0191	.383	.400	.404
	934.8	.0137	72.20	14,161	30.19	.2091	.0191	.418	.439	.445
	934.8	.0137	72.20	16,184	32.21	.2389	.0191	.446	.471	.481
	934.8	.0137	72.19	18,207	33.12	.2688	.0189	.459	.488	.503
20	936.1	0.0139	77.31	6,089	16.39	0.0870	0.0143	0.212	0.216	0.217
	936.1	.0138	77.30	8,112	20.99	.1158	.0143	.272	.279	.281
	936.9	.0138	77.37	10,155	25.07	.1450	.0147	.324	.336	.338
	936.1	.0138	77.30	12,138	28.32	.1733	.0146	.366	.382	.384
	936.9	.0138	77.37	14,201	30.98	.2028	.0145	.400	.420	.423
	936.1	.0138	77.30	16,184	33.49	.2311	.0144	.433	.457	.463
	936.1	.0138	77.29	18,227	34.60	.2603	.0146	.448	.475	.485

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TABLE II - EFFICIENCY DATA FOR SINGLE-STAGE TURBINE WITH NOZZLE K AND 0.45-INCH 17°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	723.4	0.0142	46.32	6,069	10.88	0.0984	0.0346	0.235	0.242	0.245
	723.4	.0142	46.32	8,112	13.69	.1315	.0359	.296	.309	.313
	723.4	.0142	46.32	10,135	16.17	.1643	.0370	.349	.369	.377
	723.4	.0141	46.31	12,138	17.92	.1968	.0371	.387	.413	.425
	723.4	.0141	46.31	14,141	19.11	.2293	.0364	.413	.445	.465
	723.4	.0141	46.31	16,184	19.73	.2624	.0361	.426	.465	.496
	724.1	.0142	46.36	18,268	19.69	.2962	.0355	.425	.471	.515
15	722.8	0.0143	55.87	6,109	12.06	0.0902	0.0193	0.220	0.222	0.223
	722.2	.0142	55.82	8,112	15.37	.1197	.0206	.275	.287	.289
	722.2	.0143	55.83	10,095	18.26	.1490	.0206	.327	.343	.348
	722.2	.0142	55.82	12,138	20.88	.1791	.0207	.374	.396	.401
	722.2	.0142	55.82	14,201	22.65	.2096	.0207	.406	.433	.441
	722.2	.0142	55.82	16,184	23.79	.2389	.0201	.426	.459	.472
	722.2	.0142	55.82	18,187	23.97	.2684	.0200	.429	.467	.488
20	722.8	0.0141	59.71	6,069	12.18	0.0867	0.0153	0.204	0.209	0.211
	723.4	.0141	59.76	8,072	15.45	.1152	.0155	.259	.269	.272
	723.4	.0141	59.76	10,135	18.50	.1447	.0155	.310	.325	.328
	723.4	.0141	59.76	12,118	20.81	.1730	.0157	.348	.368	.372
	723.4	.0141	59.76	14,141	22.65	.2019	.0158	.379	.404	.410
	723.4	.0142	59.77	16,184	24.16	.2310	.0154	.404	.435	.447
	722.8	.0141	59.77	18,177	25.10	.2595	.0157	.420	.455	.470

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TABLE III - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE J AND 0.40-INCH 20°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	935.0	0.0136	59.81	6,029	14.92	0.0977	0.0323	0.249	0.255	0.257
	934.2	.0136	59.76	8,112	18.87	.1315	.0328	.316	.326	.329
	934.2	.0136	59.76	10,135	22.21	.1643	.0331	.372	.387	.393
	934.2	.0136	59.76	12,138	24.80	.1967	.0330	.415	.435	.443
	934.2	.0136	59.76	14,181	26.82	.2298	.0327	.449	.474	.487
	933.3	.0135	59.70	16,204	28.36	.2626	.0324	.475	.505	.527
	933.3	.0135	59.70	18,247	29.10	.2957	.0320	.487	.523	.554
15	930.7	0.0137	71.88	6,069	15.52	0.0896	0.0168	0.216	0.220	0.222
	930.7	.0137	71.88	8,112	19.73	.1198	.0170	.275	.283	.285
	930.7	.0137	71.88	10,095	23.15	.1491	.0168	.322	.335	.338
	930.7	.0137	71.88	12,158	26.24	.1795	.0166	.365	.382	.385
	930.7	.0137	71.88	14,181	28.65	.2094	.0167	.399	.420	.424
	929.9	.0136	71.81	16,184	30.56	.2389	.0165	.426	.451	.459
	930.7	.0136	71.87	18,207	31.98	.2688	.0165	.445	.474	.487
20	930.7	0.0138	76.86	6,089	15.55	0.0870	0.0139	0.202	0.207	0.208
	930.7	.0138	76.86	8,092	19.52	.1156	.0142	.254	.262	.264
	930.7	.0138	76.86	10,115	23.17	.1445	.0139	.302	.313	.316
	930.7	.0138	76.86	12,138	26.36	.1733	.0136	.343	.359	.361
	930.7	.0137	76.85	14,161	28.93	.2022	.0137	.376	.396	.399
	930.7	.0137	76.85	16,194	31.22	.2313	.0136	.406	.430	.436
	930.7	.0137	76.84	18,207	32.70	.2600	.0136	.426	.453	.463

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TABLE IV - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE K AND 0.40-INCH 20°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	724.8	0.0142	46.41	6,049	11.44	0.0980	0.0329	0.247	0.253	0.256
	724.8	.0142	46.41	8,092	14.40	.1311	.0330	.310	.323	.328
	724.8	.0141	46.40	10,115	17.13	.1639	.0342	.369	.389	.396
	724.8	.0142	46.41	12,158	19.43	.1970	.0349	.419	.445	.456
	724.1	.0141	46.35	14,201	20.78	.2301	.0354	.448	.481	.500
	724.1	.0141	46.35	16,184	21.92	.2623	.0349	.473	.512	.542
	723.4	.0141	46.31	18,247	22.31	.2957	.0347	.482	.528	.571
15	724.8	0.0142	56.02	6,089	12.44	0.0899	0.0180	0.222	0.228	0.230
	724.8	.0142	56.02	8,092	15.76	.1195	.0181	.281	.292	.295
	724.8	.0142	56.01	10,166	18.83	.1501	.0183	.336	.353	.357
	724.8	.0142	56.01	12,118	21.36	.1789	.0187	.381	.403	.407
	724.8	.0142	56.01	14,161	23.47	.2091	.0190	.419	.446	.453
	724.8	.0142	56.02	16,224	25.13	.2396	.0191	.449	.481	.493
	724.8	.0142	56.01	18,207	26.28	.2688	.0191	.469	.507	.526
20	723.4	0.0141	59.76	6,069	12.48	0.0867	0.0136	0.209	0.214	0.216
	722.8	.0141	59.71	8,092	15.92	.1156	.0138	.267	.277	.279
	722.8	.0141	59.71	10,115	19.00	.1445	.0140	.318	.333	.337
	722.8	.0141	59.71	12,138	21.68	.1733	.0140	.363	.383	.386
	722.8	.0141	59.71	14,201	23.91	.2028	.0142	.400	.426	.430
	722.8	.0141	59.71	16,184	25.87	.2311	.0143	.433	.464	.472
	722.8	.0141	59.71	18,227	27.15	.2603	.0143	.455	.490	.503

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TABLE V - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE J AND STANDARD 0.40-INCH 17°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	934.7	0.0137	59.80	6,130	15.39	0.0994	0.0320	0.257	0.263	0.265
	933.8	.0136	59.73	8,132	19.30	.1318	.0327	.323	.334	.337
	933.8	.0136	59.74	10,095	22.55	.1637	.0330	.378	.393	.398
	933.8	.0136	59.73	12,138	25.48	.1968	.0332	.427	.447	.455
	934.7	.0136	59.80	14,201	27.28	.2302	.0334	.456	.481	.495
	934.7	.0136	59.79	16,083	28.67	.2607	.0330	.480	.509	.531
	933.8	.0136	59.73	18,247	29.10	.2958	.0329	.487	.523	.555
15	933.8	0.0136	72.11	6,049	15.95	0.0893	0.0175	0.221	0.225	0.227
	933.8	.0136	72.11	8,112	20.26	.1197	.0175	.281	.289	.291
	933.8	.0136	72.11	10,115	23.90	.1493	.0177	.331	.344	.347
	933.8	.0136	72.11	12,138	27.20	.1791	.0179	.377	.394	.397
	933.8	.0136	72.11	14,141	29.36	.2087	.0180	.407	.428	.433
	933.8	.0136	72.10	16,144	31.65	.2383	.0180	.439	.464	.473
	933.8	.0136	72.10	18,207	33.12	.2687	.0180	.459	.489	.503
20	934.7	0.0137	77.17	6,089	15.81	0.0869	0.0133	0.205	0.209	0.210
	934.7	.0137	77.17	8,092	19.92	.1155	.0136	.258	.266	.268
	934.7	.0136	77.16	10,155	23.76	.1450	.0137	.308	.320	.322
	934.7	.0136	77.16	12,118	26.80	.1730	.0137	.347	.363	.365
	934.7	.0137	77.17	14,222	29.57	.2031	.0138	.383	.403	.406
	934.7	.0137	77.17	16,164	31.75	.2308	.0137	.411	.435	.441
	934.7	.0137	77.17	18,247	33.55	.2605	.0139	.435	.462	.472

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TABLE VI - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE K AND STANDARD 0.40-INCH 17°-INLET-ANGLE ROTOR BLADES

[Inlet temperature, 1000° F; inlet pressure, 95 lb/sq in. gage]

Pressure ratio	Air weight flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas density in turbine case (lb/cu ft)	Brake efficiency	Rotor efficiency	Blade efficiency
8	730.5	0.0141	46.76	6,069	11.62	0.0984	0.0325	0.249	0.255	0.258
	730.5	.0141	46.76	8,092	14.53	.1311	.0329	.311	.324	.328
	730.5	.0141	46.76	10,115	17.27	.1639	.0338	.369	.389	.396
	730.5	.0141	46.76	12,138	19.36	.1967	.0344	.414	.440	.451
	731.2	.0141	46.81	14,181	20.70	.2298	.0343	.442	.475	.492
	731.2	.0141	46.81	16,184	21.81	.2623	.0344	.466	.504	.533
	731.2	.0141	46.81	18,207	22.50	.2951	.0346	.481	.526	.569
15	726.5	0.0140	56.13	6,069	12.52	0.0896	0.0185	0.223	0.229	0.231
	726.5	.0141	56.14	8,092	15.95	.1195	.0183	.284	.295	.298
	726.5	.0141	56.14	10,075	18.99	.1487	.0185	.338	.354	.359
	726.5	.0140	56.13	12,168	21.65	.1797	.0186	.386	.407	.412
	726.5	.0139	56.12	14,161	23.52	.2091	.0188	.419	.446	.453
	726.5	.0140	56.13	16,164	25.57	.2387	.0188	.456	.488	.500
	726.5	.0140	56.13	18,167	26.82	.2682	.0188	.478	.515	.534
20	727.2	0.0141	60.08	6,109	12.97	0.0873	0.0139	0.216	0.221	0.223
	726.5	.0141	60.02	8,153	16.47	.1164	.0140	.274	.285	.287
	726.5	.0141	60.02	10,115	19.53	.1445	.0140	.325	.341	.344
	726.5	.0141	60.01	12,178	22.39	.1739	.0142	.373	.393	.396
	726.5	.0142	60.03	14,181	24.39	.2025	.0144	.406	.432	.436
	726.5	.0141	60.01	16,184	26.67	.2311	.0143	.444	.474	.483
	726.5	.0141	60.01	18,247	28.20	.2606	.0144	.470	.505	.518

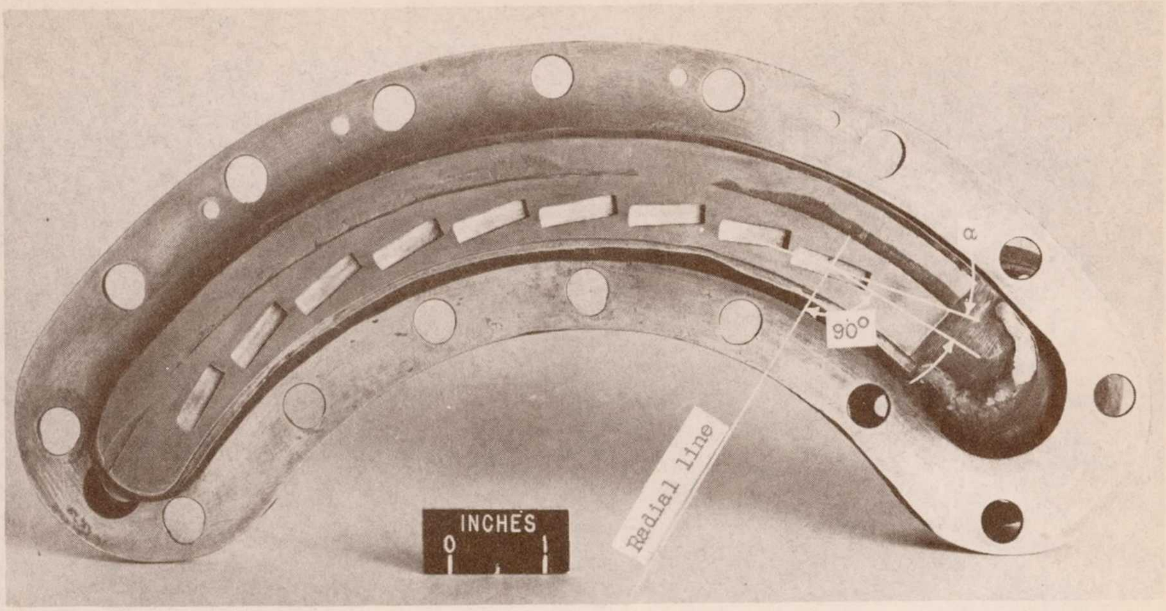

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Figure 1. - Nozzle-box assembly showing outlet face of cast nozzle J. Angle of intangency α, 9°.

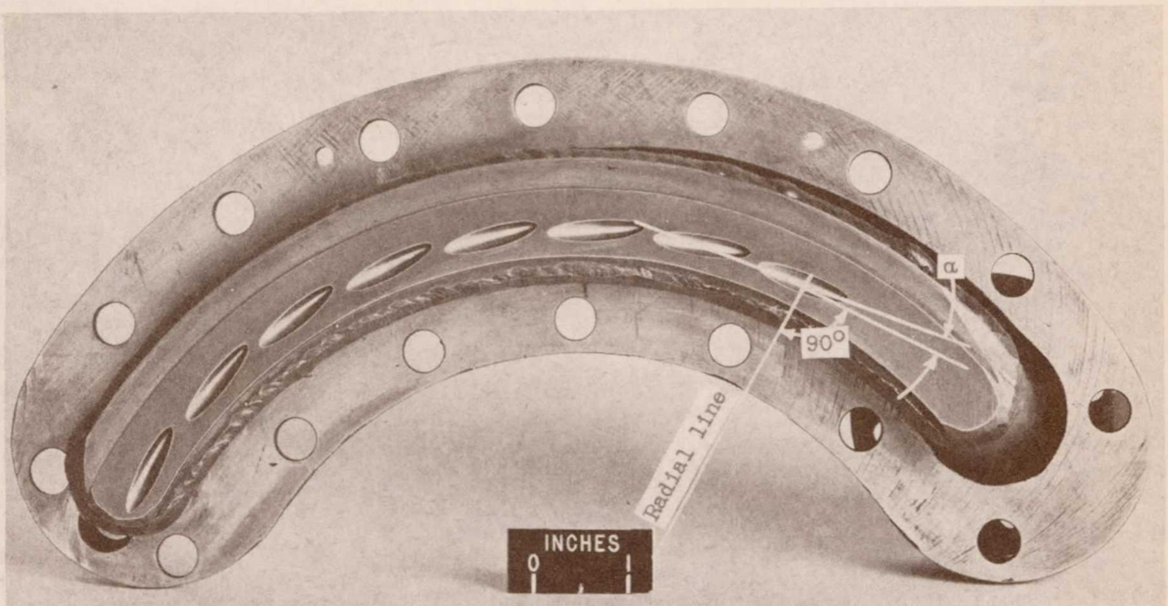

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Figure 2. - Nozzle-box assembly showing outlet face of reamed nozzle K. Angle of intangency α, 6°.

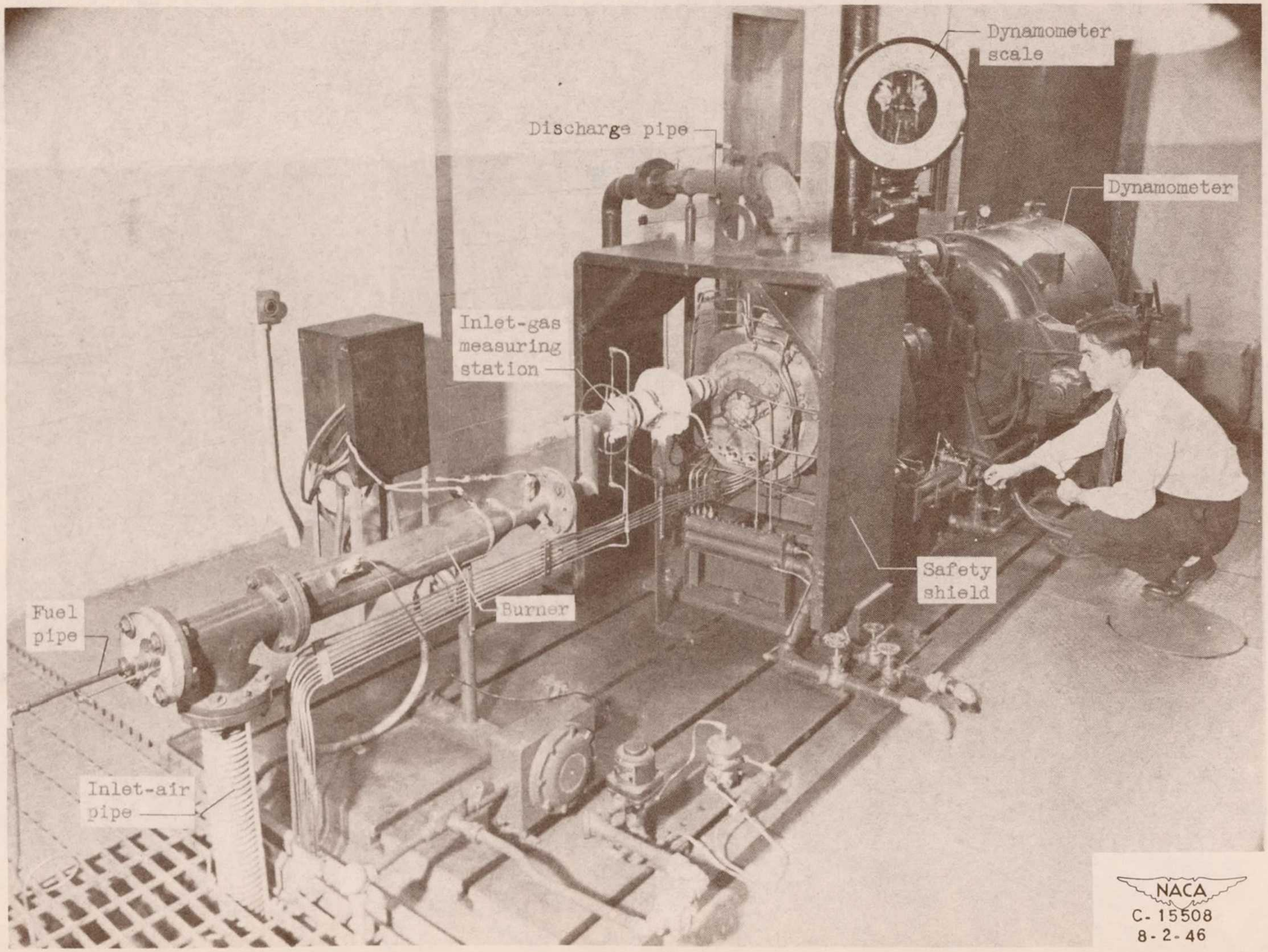


Figure 3. - Experimental setup for Mark 25 torpedo power plant.

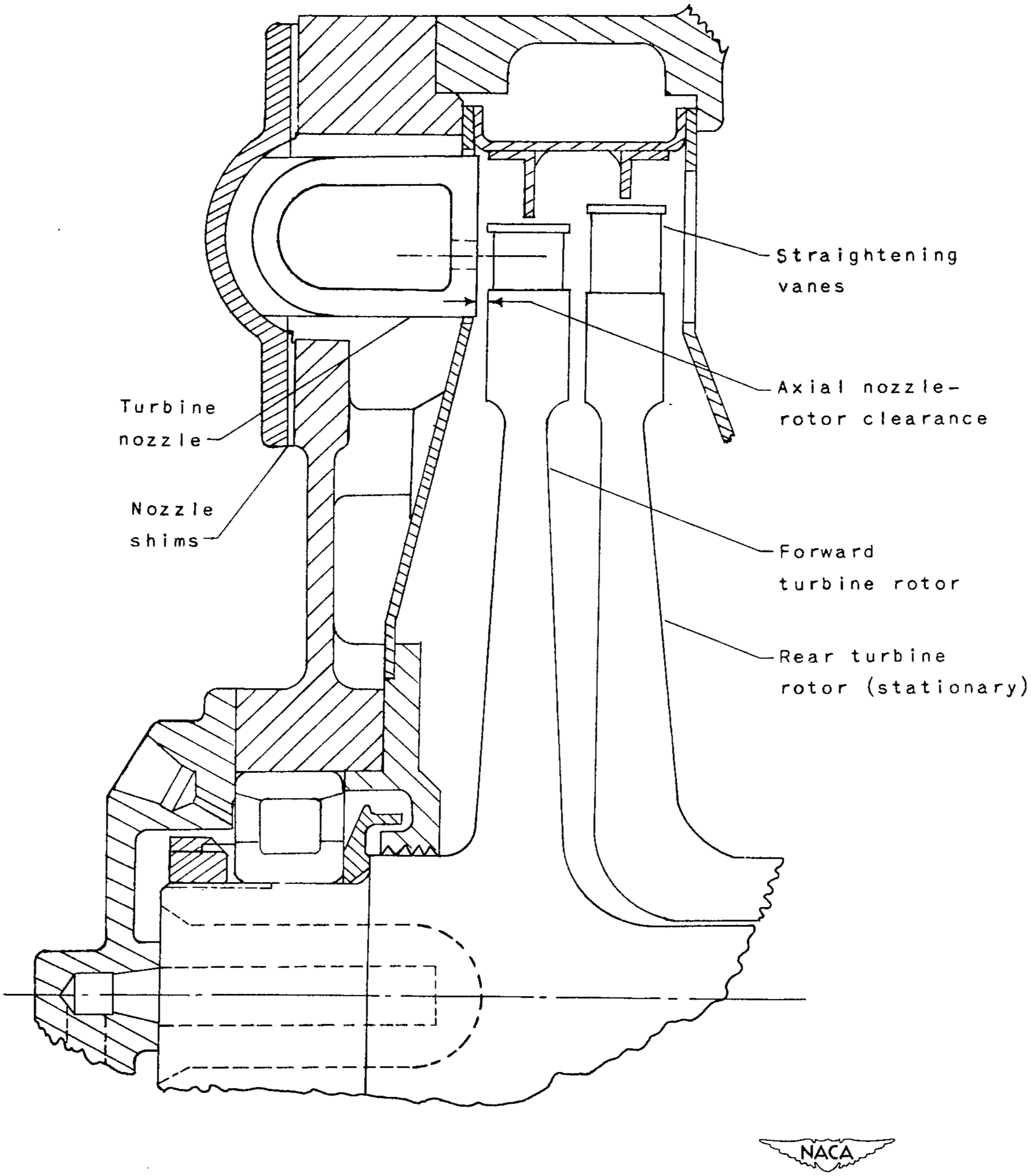


Figure 4. - Sketch of nozzle and rotor assembly for Mark 25 torpedo power plant.

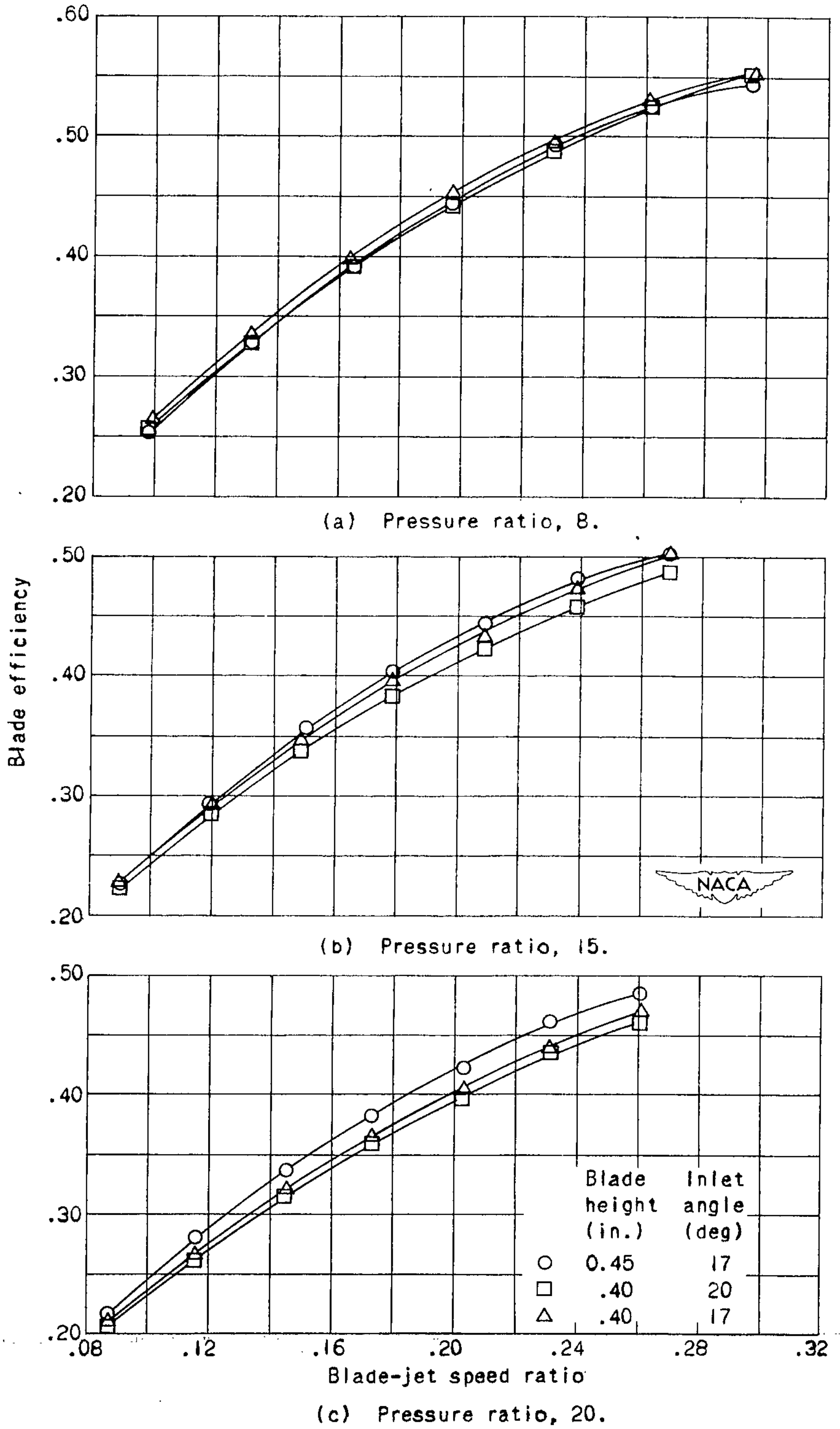


Figure 5. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzle J in combination with three rotor-blade designs.

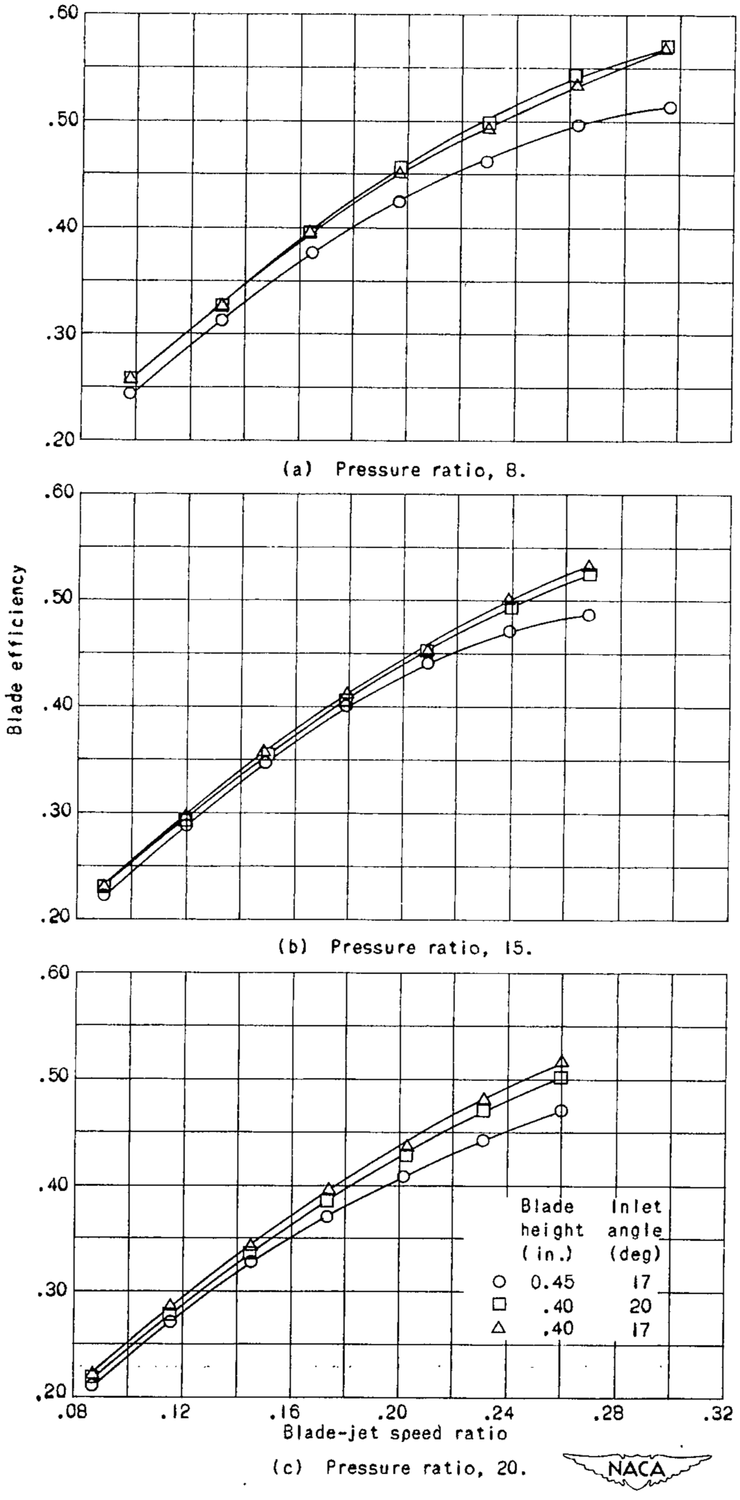
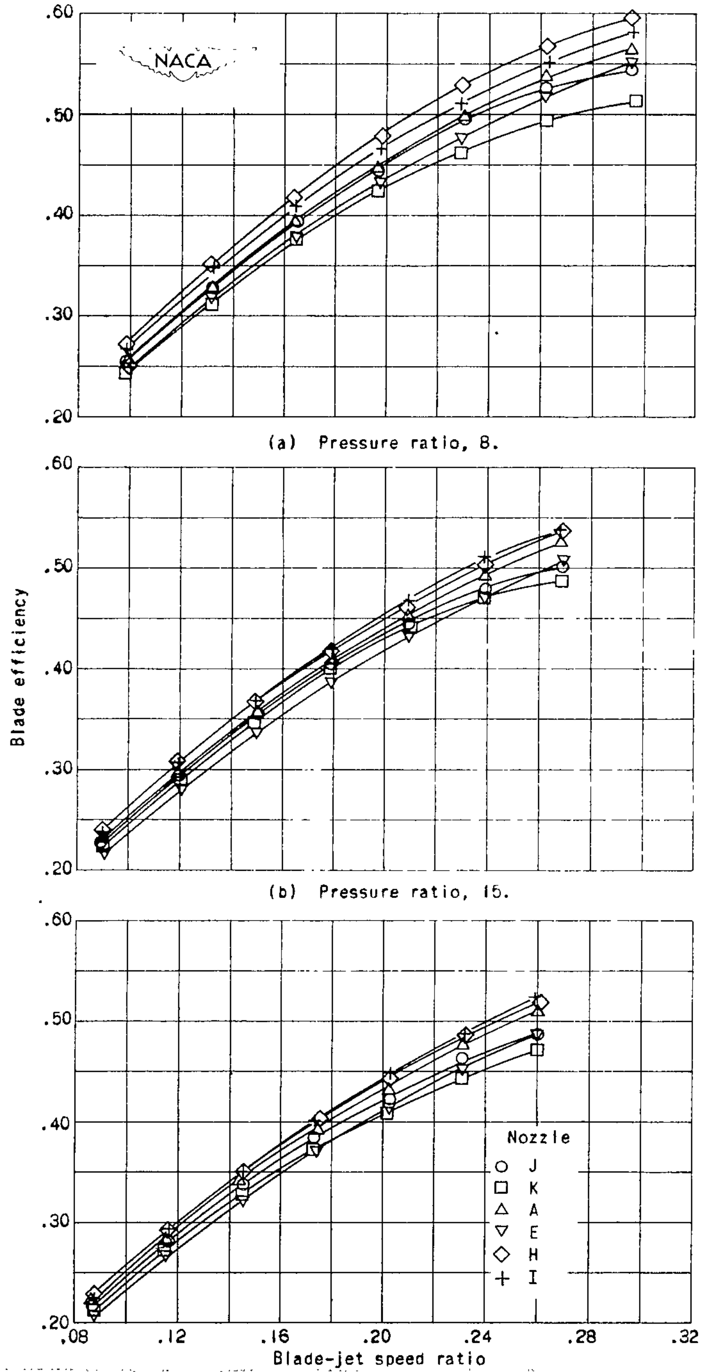
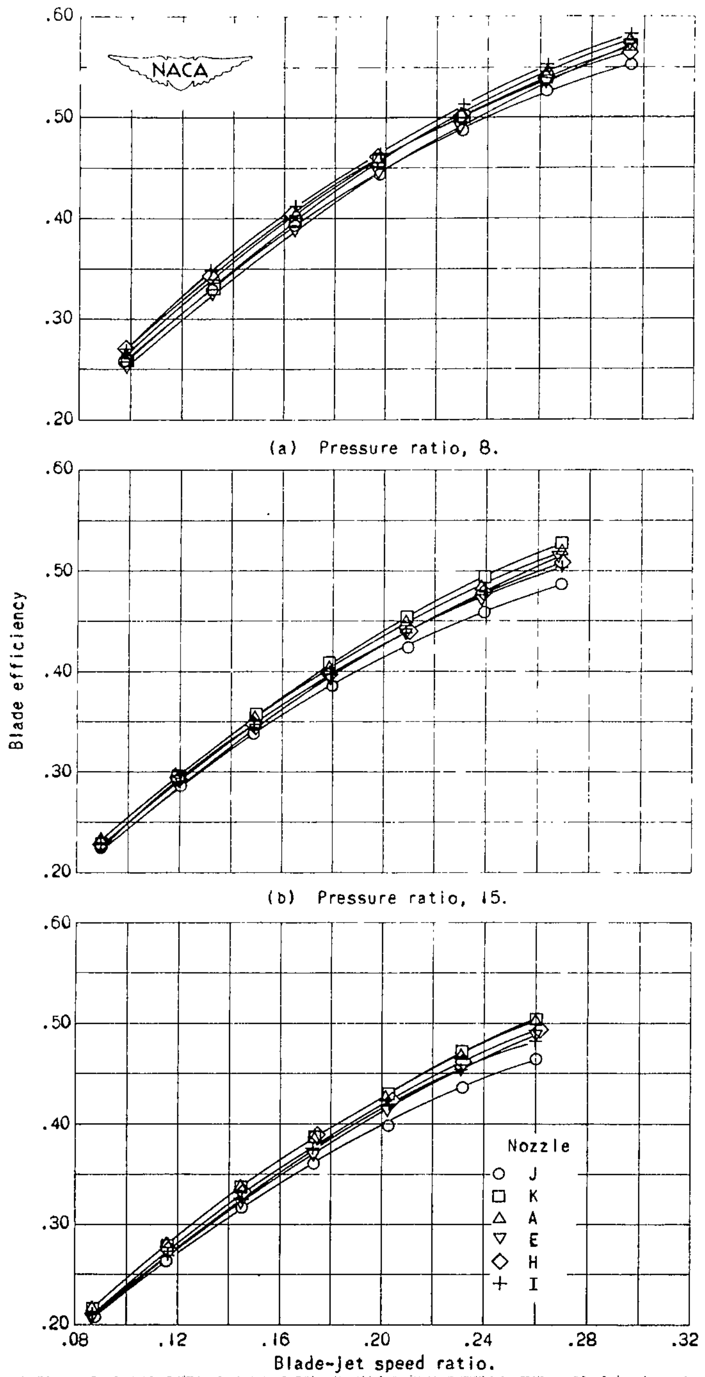


Figure 6. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzle K in combination with three rotor-blade designs.



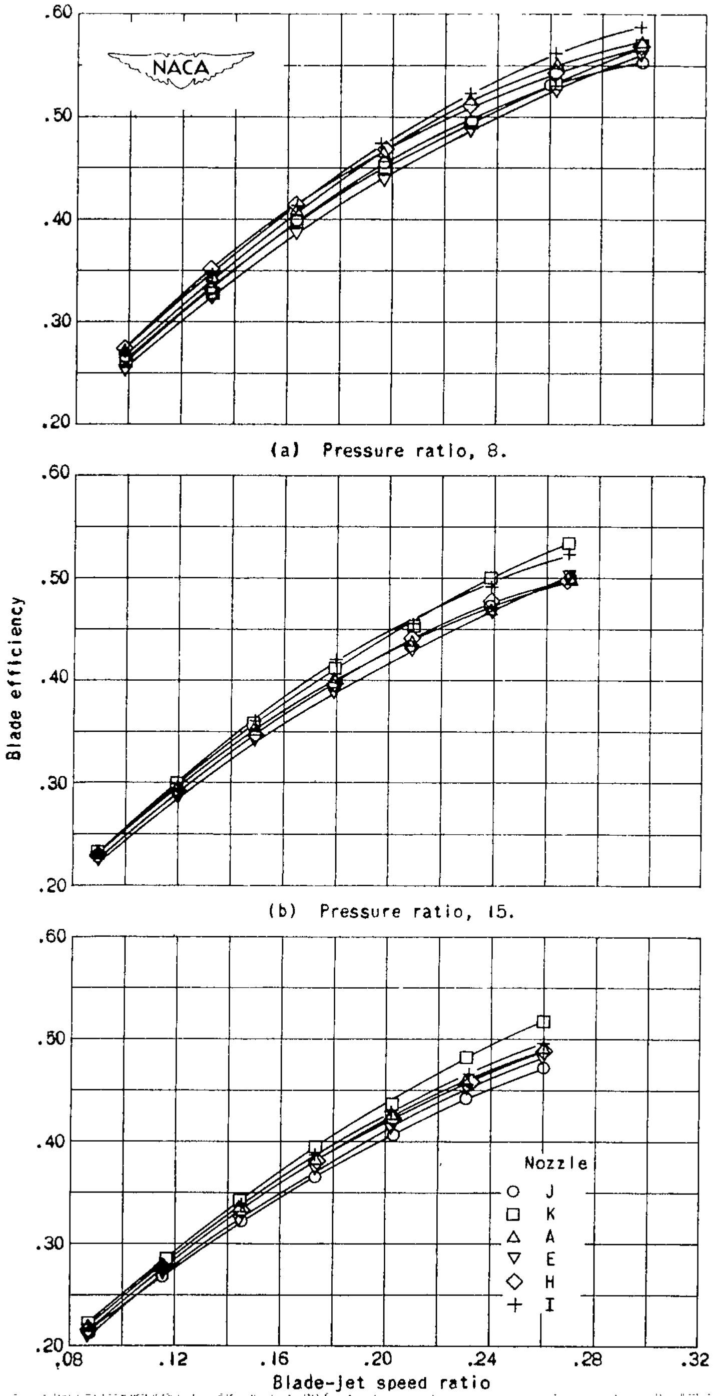
(c) Pressure ratio, 20. (Data for nozzle H were obtained at pressure ratio of 19.)

Figure 7. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J, K, A, E, H, and I in combination with 0.45-inch 17°-inlet-angle rotor blades. (Data for nozzles A, E, H, and I obtained from reference 4.)



(c) Pressure ratio, 20. (Data for nozzle H were obtained at pressure ratio of 19.)

Figure 8. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine for nozzles J, K, A, E, H, and I in combination with 0.40-inch 20°-inlet-angle rotor blades. (Data for nozzles A, E, H, and I obtained from reference 4.)



(c) Pressure ratio, 20. (Data for nozzle H were obtained at pressure ratio of 19.)

Figure 9. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J, K, A, E, H, and I in combination with 0.40-inch 17° inlet-angle (standard) rotor blades. (Data for nozzles A, E, H, and I obtained from references 3 and 4.)