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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 SPECIAL NOZZLES

I - EFFICIENCY WITH 0.45-INCH ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

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SUMMARY

An investigation was made of the first-stage turbine of a Mark 25 torpedo power plant to determine the performance of the unit with two nozzle configurations and a special rotor having 0.45-inch blades instead of the standard length of 0.40 inch. Both nozzles had smaller passages than the nozzles of similar shape that were previously investigated. The performance of the nozzle-blade combinations is evaluated in terms of brake, rotor, and blade efficiency as functions of blade-jet speed ratio for three pressure ratios.

Over the range of speeds and pressure ratios investigated, the efficiency with the nozzle having rectangular passages (J) was higher than that with a nozzle having circular passages (K). The difference in blade efficiencies varied from less than 0.010 at the lower blade-jet speed ratios for the three pressure ratios investigated to 0.030 at a pressure ratio of 8 and a blade-jet speed ratio of 0.295. The efficiencies with these two nozzles were generally lower than those obtained with nozzles previously reported in combination with the 0.45-inch blades.

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 from a Mark 25 aerial torpedo with a view towards possible application of similar high-pressure turbines to rocket-motor accessory drive. The research program consists of the determination of the effects of (1) nozzle design, (2) clearance, and (3) blade design on over-all performance. Reference 1 presents the efficiency of the two-stage turbine with various nozzles. The effect of nozzle-rotor axial clearance on the performance of the two-stage turbine is reported in reference 2. The effect of blade length, blade inlet angle, and shroud condition was investigated with the turbine modified to operate as a single-stage unit (reference 3). An evaluation of the relative output of each of the counterrotating stages is presented in reference 4.

A continuation of the single-stage-turbine studies with two additional nozzles, arbitrarily designated J and K, is presented herein. Both nozzles had smaller passage cross-sectional areas than those of similar design that were previously investigated (reference 1). The rotor has special blades 0.45 inch long as compared with the standard blade length of 0.40 inch. Hence, the ratio of blade area to nozzle area was increased from that of the preceding investigations.

Both nozzles were investigated at pressure ratios of 8, 15, and 20, and over a speed range from approximately 6000 to 18,000 rpm. Inlet conditions were maintained at 1000° F and 95 pounds per square inch gage. Measured turbine output was corrected for mechanical losses and disk and blade windage to determine the rotor and blade efficiencies by the method given in reference 4.

APPARATUS AND METHODS

Nozzles. - Nozzle J (fig. 1) has nine rectangular ports fabricated by a refined casting technique that permits small dimensional tolerances. This nozzle has smaller passages than nozzle H (reference 1) but the design and fabrication are similar. The throat dimensions are approximately 0.215 by 0.099 inch, and the cross-sectional dimensions at the outlet plane are approximately 0.203 by 0.116 inch. The geometric nozzle 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°. These passages have an intangency angle of 9° and an inlet angle to the turbine rotor of 12° measured with a plane normal to the axis of rotation.

Nozzle K (fig. 2) has eight ports fabricated by drilling and reaming. The circular passages have a throat diameter of 0.156 inch and an outlet-plane diameter of 0.168 inch, making the measured expansion ratio approximately 1.16. The passages were equally spaced over a section of the rotor periphery to also form an arc of gas admission of approximately 90°. The angle of intangency is 6° and the inlet-air angle to the turbine rotor is 12°.

Characteristics of nozzles J and K and the nozzles previously investigated (references 1 and 3) are presented in the following table:

Nozzle	Number of ports	Port-inlet configuration	Cross-sectional shape	Total measured throat area (sq in.)	Measured expansion ratio
A	9	Rounded	Rectangular	0.183	1.47
E	9	Rounded	Circular	.193	1.00
H	9	Sharp-edged	Rectangular	.226	1.12
I	9	Sharp-edged	Rectangular	.217	1.20
J	9	Sharp-edged	Rectangular	.191	1.11
K	8	Sharp-edged	Circular	.153	1.16

Apparatus. - The standard Mark 25 aerial-torpedo power plant is a two-stage counterrotating impulse turbine. For this investigation, the unit was modified to operate as a single-stage turbine by the procedure outlined in reference 4. A schematic drawing of the nozzle and the turbine-wheel assembly is shown in figure 3. A special 0.45-inch blade described in reference 3 was used in this investigation. The inlet-air angle and the outlet angle are the same as those of the standard first-stage rotor. The ratio of blade-passage area to nozzle-throat area with the 0.45-inch blades was approximately 1.13 times as great as that of the standard blades.

The apparatus and the instrumentation are the same as those described in reference 1. The precision of the observed measurements is estimated to be within the following limits:

Air flow, percent	±1.50
Torque, foot-pounds	±0.15
Dynamometer speed, rpm	±5
Inlet-gas pressure, percent	±0.50
Inlet-gas temperature, percent	±0.25
Pressure, inches mercury	±0.05

Procedure. - The modified single-stage turbine was operated with constant inlet-gas conditions of 1000° F and 95 pounds per square inch gage. Runs were made for both nozzles at pressure ratios of 8, 15 (design), and 20. The turbine speed for each run was varied from approximately 6000 to the design speed of 18,000 rpm. Nozzle J was run with a nozzle-rotor clearance of 0.030 inch. Because of inherent difficulties in setup, however, nozzle K was necessarily operated at a corresponding clearance of 0.040 inch. The performance effect of clearance within these limits was reported as negligible in reference 2.

Calculations. - Pressure ratio, blade-jet speed ratio, and brake, rotor, and blade efficiencies were calculated according to the procedure described in reference 1. For convenience, brief definitions of the three efficiencies are as follows:

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

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

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

The methods of evaluating windage and mechanical power losses necessary in the determination of rotor and blade efficiencies, and the quantitative values of these losses at various speeds are reported in reference 3; the losses were corrected to the density calculated from the observed pressure and temperature of the gases in the turbine casing.

RESULTS AND DISCUSSION

The performance data of the single-stage modified turbine with 0.45-inch rotor blades and nozzles J and K are summarized in tables I and II. The blade, rotor, and brake efficiencies are presented in figures 4, 5, and 6, respectively, for the two nozzle-rotor configurations. In all cases, the efficiencies increased continuously with blade-jet speed ratio. Maximum possible efficiency was not obtained at any pressure ratio because of design-speed limitations. Increasing the pressure ratio caused a decrease in the maximum obtained efficiencies and the efficiency at any specific blade-jet speed ratio.

Nozzle J showed higher efficiencies than nozzle K over the range of pressure ratios and blade-jet speed ratios investigated. At any pressure ratio, the unit operated with nozzle J became progressively more efficient than with nozzle K as the blade-jet speed ratio was increased. A maximum difference in brake efficiency of 0.051 occurred at a pressure ratio of 8 (fig. 6(a)). The corresponding difference at the design pressure ratio of 15 was 0.030 (fig. 6(b)). When the brake efficiency was corrected for mechanical and windage losses, that is, rotor or blade efficiency, this difference in maximum efficiency with the two nozzles was decreased.

The maximum blade efficiency of 0.545 occurred with nozzle J at a blade-jet speed ratio of 0.295 and a pressure ratio of 8 (fig. 4(a)). The corresponding maximum blade efficiency with nozzle K was 0.515, which is a decrease of 0.030. The maximum difference in efficiency of 0.030 as effected by the two nozzles occurred at this speed and pressure ratio, the minimum difference being less than 0.01 at the lower blade-jet speed ratios for the three pressure ratios investigated.

In figure 7, the blade efficiencies with nozzles J and K are compared with those obtained with nozzles A, E, H, and I (reference 3). Nozzles J and K with the decreased passage area generally showed lower efficiencies than the other nozzles, except E.

SUMMARY OF RESULTS

A single-stage turbine with 0.45-inch rotor blades from a Mark 25 torpedo power plant was investigated with nozzle designs J and K with the following results:

1. The blade efficiency with nozzle J was higher than that with nozzle K over the range of pressure ratios and speeds investigated.

2. The difference in blade efficiency with the two nozzles varied from less than 0.010 at the lower blade-jet speed ratios for the three pressure ratios to 0.030 at a pressure ratio of 8 and a blade-jet speed ratio of 0.295.

3. The blade efficiency with nozzles J and K was found to be somewhat lower than that with nozzles A, H, I and comparable to that with nozzle E.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, May 4, 1949.

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2. Hoyt, Jack W., and Kottas, Harry: Effect of Turbine Axial Nozzle-Wheel Clearance on Performance of Mark 25 Torpedo Power Plant. NACA RM SE8B04, Bur. Ord., 1948.

3. Schum, Harold J., and Hoyt, Jack W.: Effect of Variation in First Wheel Blade Shape upon Performance of Mark 25 Torpedo Power Plant. NACA RM SE9G20, Bur. Ord., 1949.

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TABLE I - EFFICIENCY DATA FOR SINGLE-STAGE TURBINE WITH NOZZLE J AND 0.45-INCH 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 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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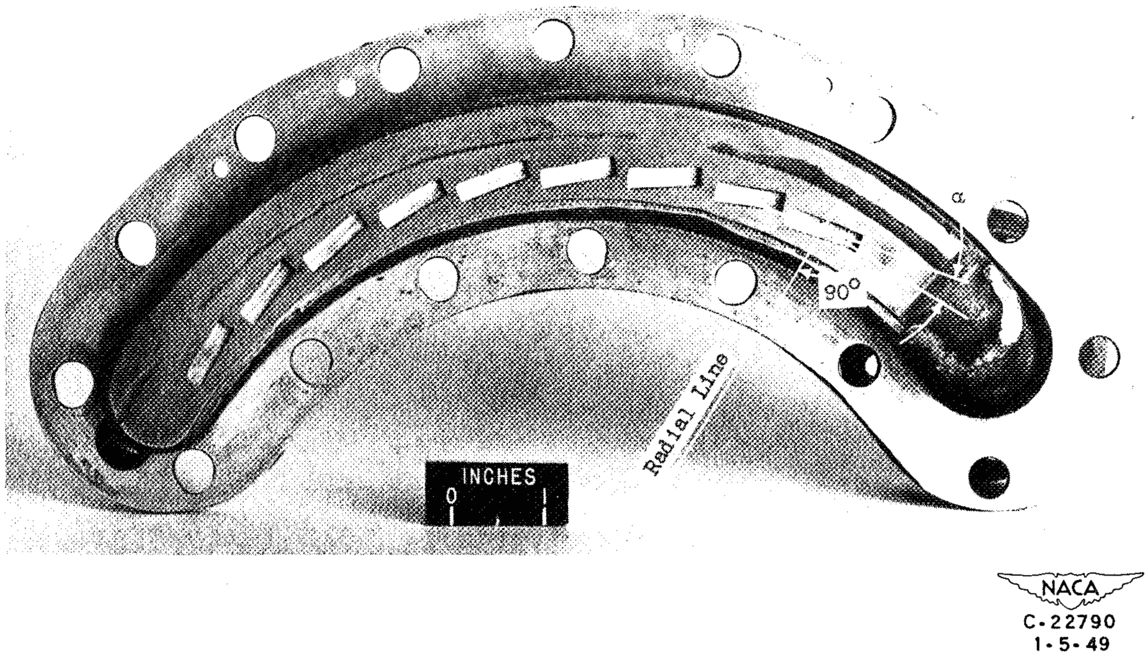


Figure 1. - Nozzle-box assembly showing outlet face of cast nozzle J. Angle of intangency α, 9°.

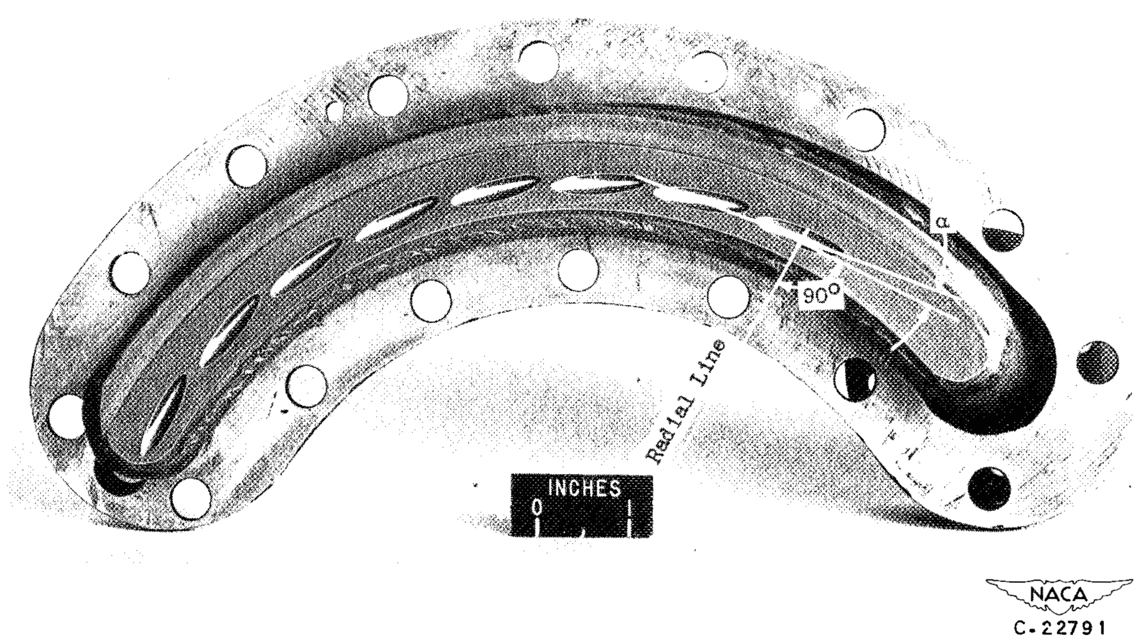


Figure 2. - Nozzle-box assembly showing outlet face of reamed nozzle K. Angle of intangency α, 6°.

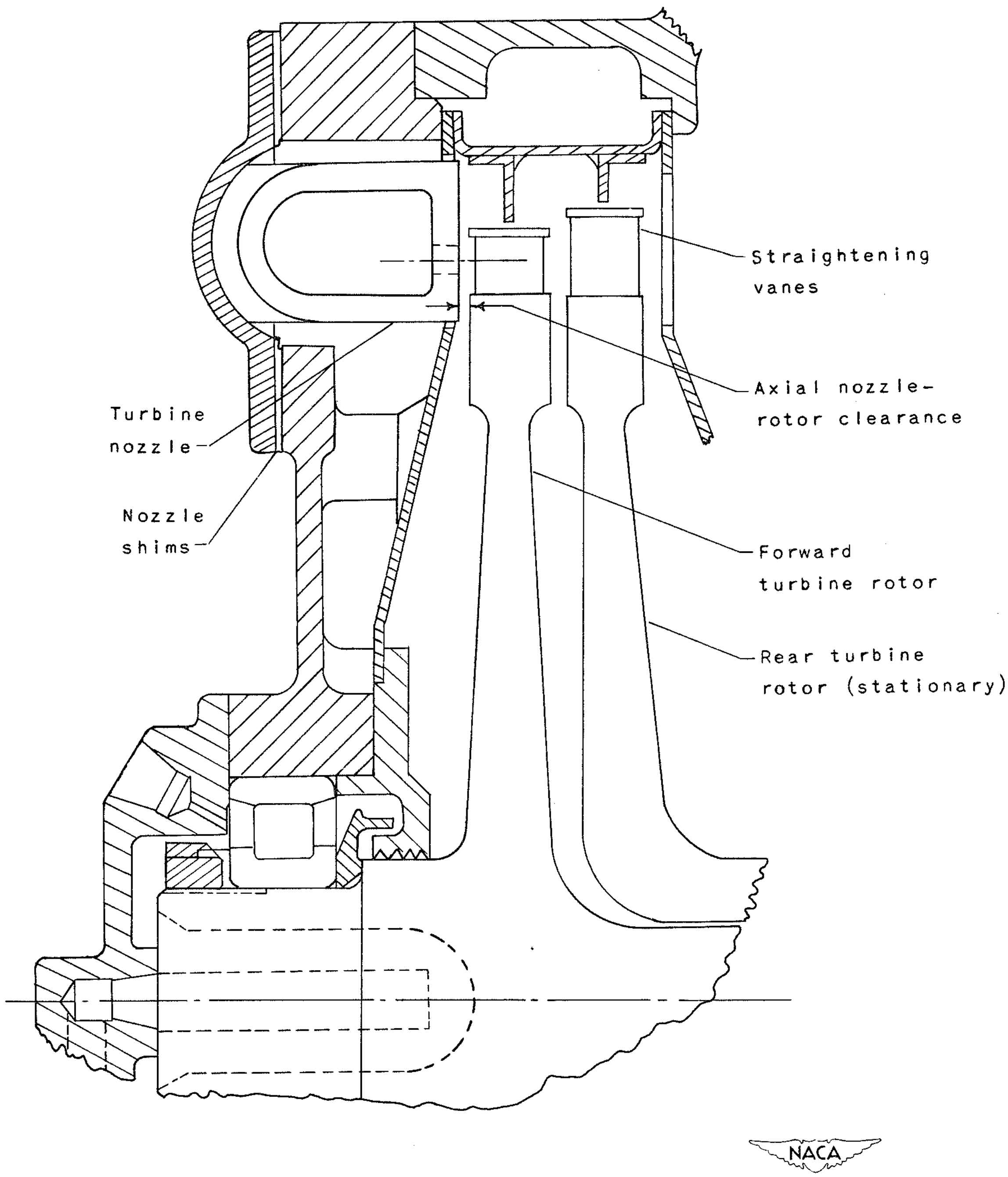
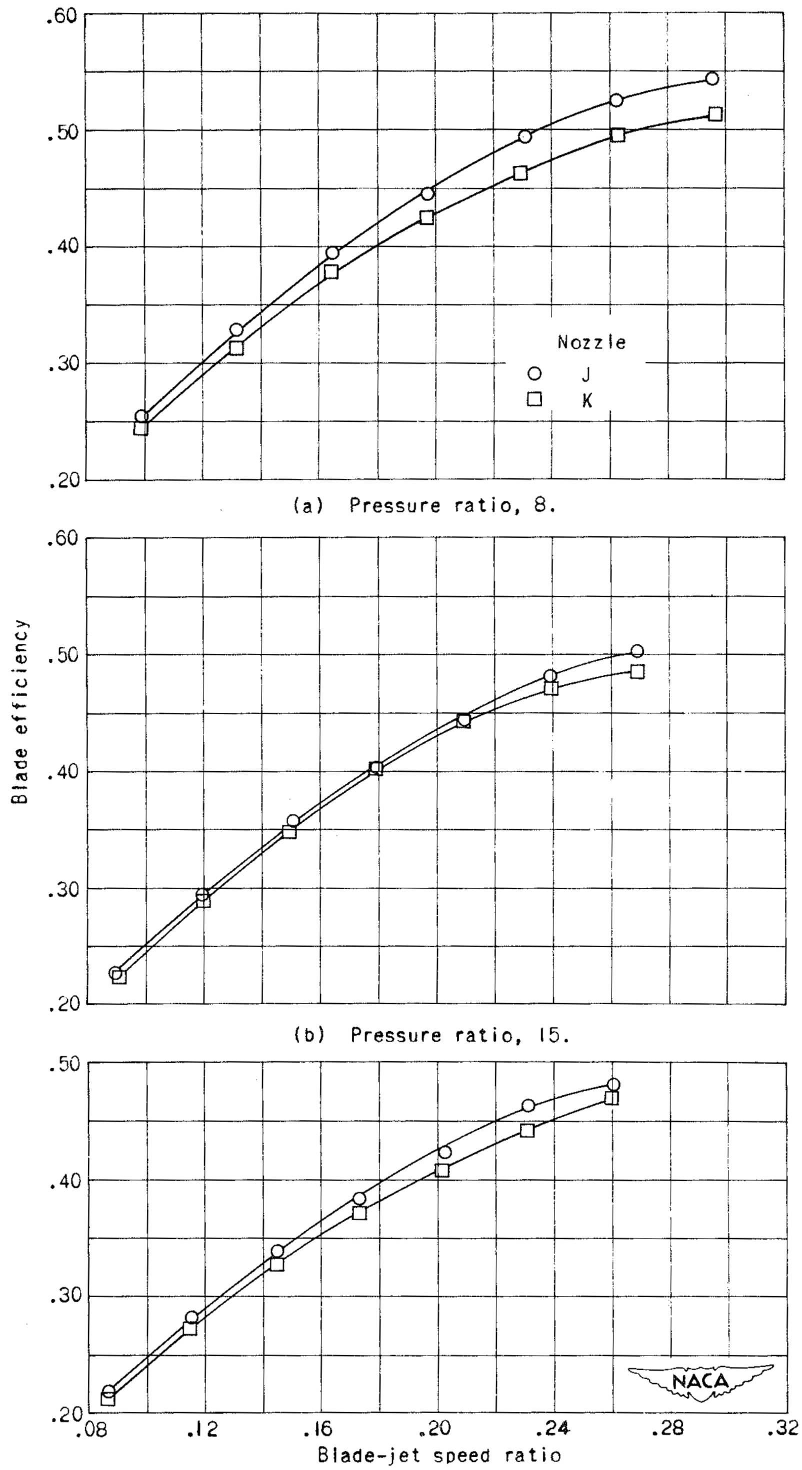
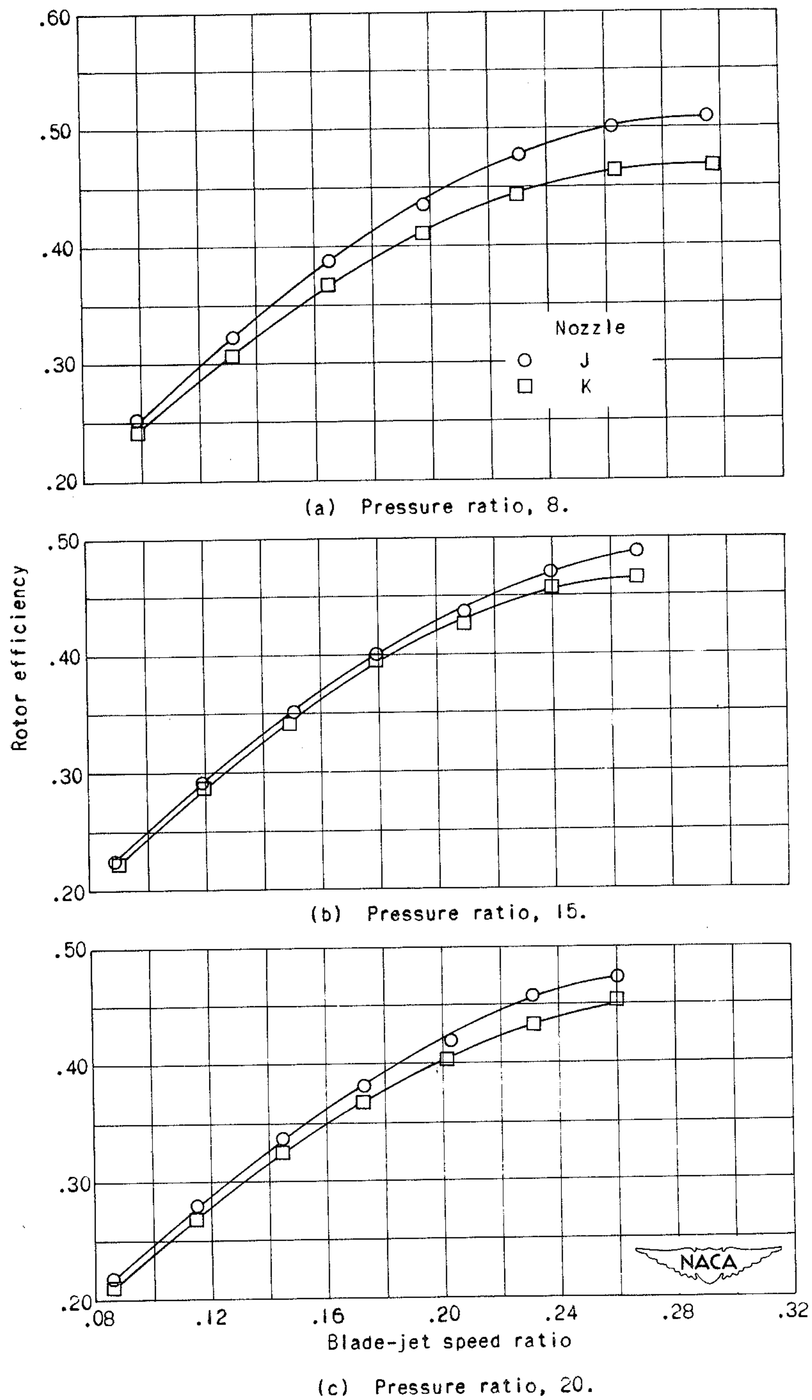


Figure 3. - Sketch of nozzle and rotor assembly for Mark 25 torpedo power plant.



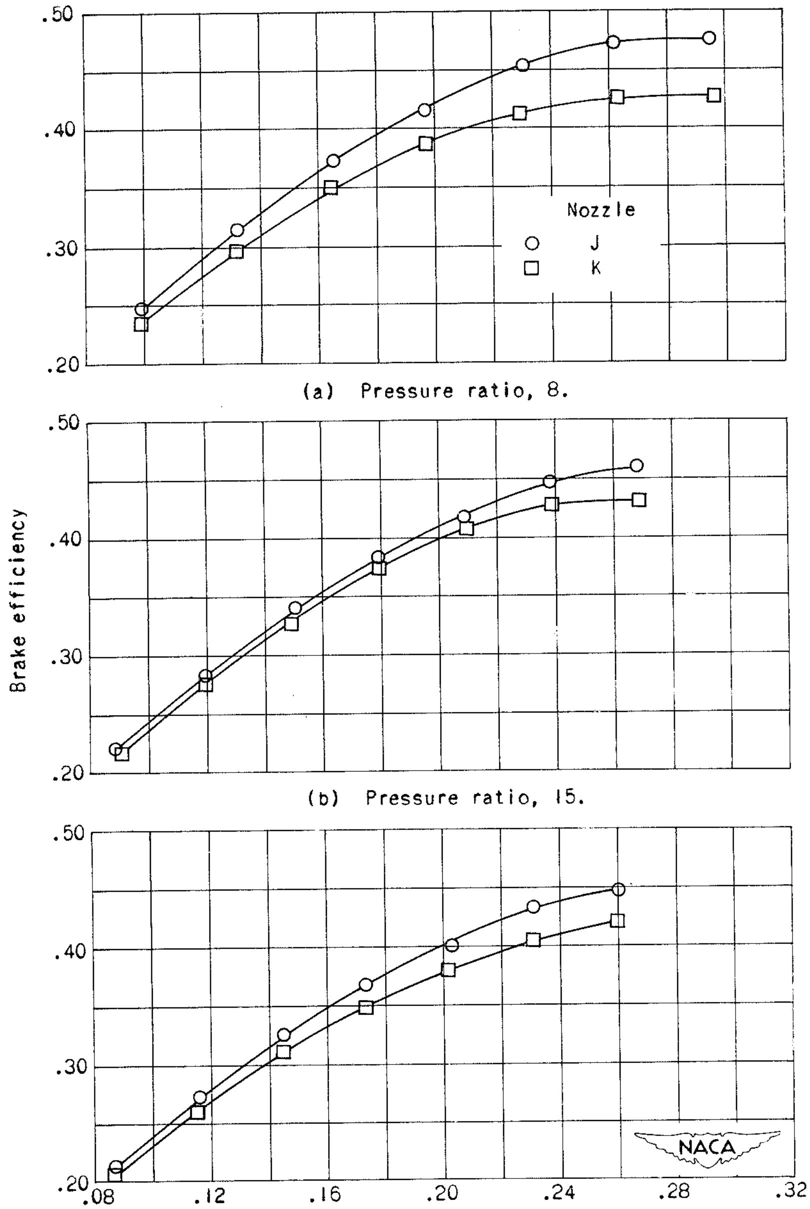
(c) Pressure ratio, 20.

Figure 4. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K and 0.45-inch rotor blades.



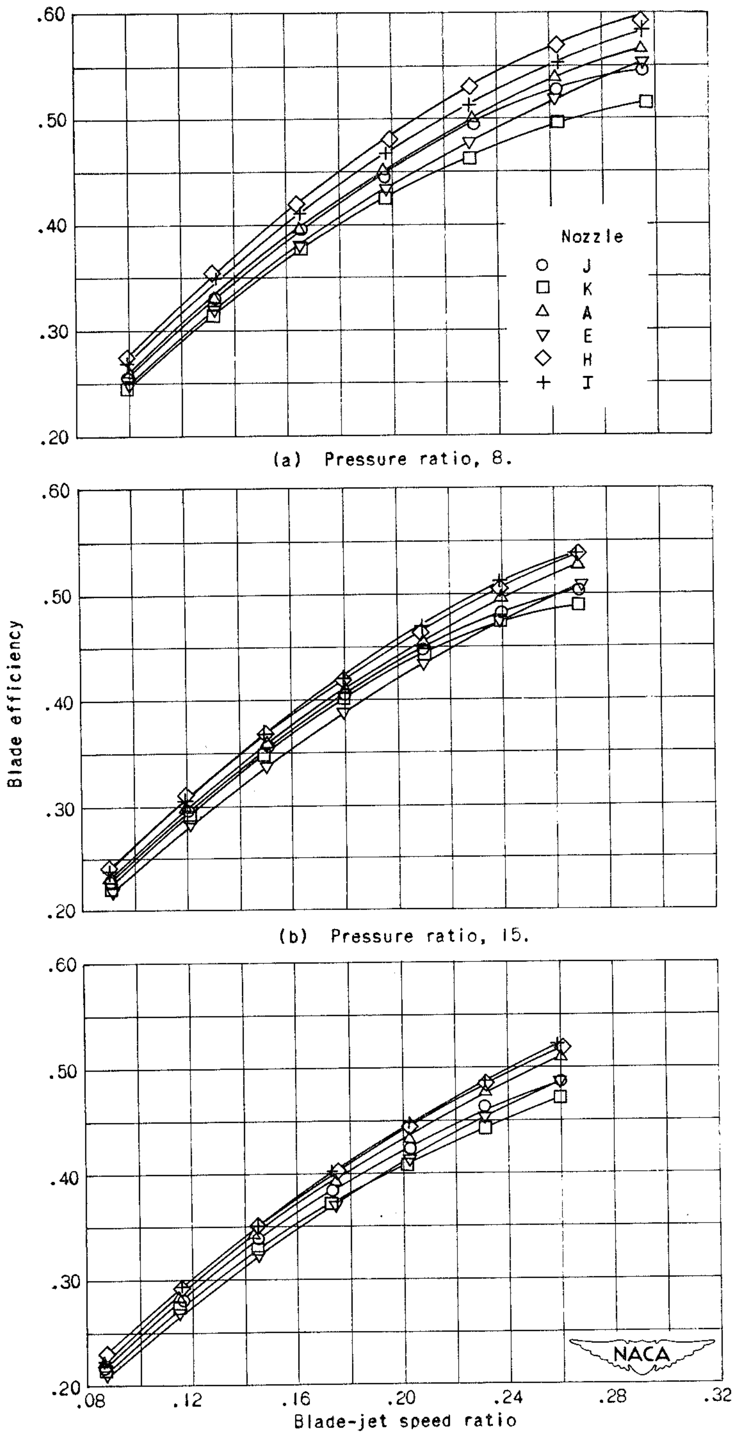
(c) Pressure ratio, 20.

Figure 5. - Variation of rotor efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K and 0.45-inch rotor blades.



(c) Pressure ratio, 20.

Figure 6. - Variation of brake efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J and K and 0.45-inch rotor blades.



(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 and 0.45-inch rotor blades. (Data for nozzles A, E, H, and I from reference 3.)