NACA

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

III - EFFICIENCY WITH STANDARD ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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

III - EFFICIENCY WITH STANDARD ROTOR BLADES

By Harold J. Schum and Warren J. Whitney

SUMMARY

    A Mark 25 torpedo power plant modified to operate as a single-
stage turbine was investigated to determine the performance with
two nozzle designs and a standard first-stage rotor having
0.40-inch blades with a 17° inlet-air angle. Both nozzles had
smaller port cross-sectional areas than those nozzles of similar
design, which were previously investigated. The performance of
the two nozzles was compared on the basis of blade, rotor, and
brake efficiencies as a function of blade-jet speed ratio for pres-
sure ratios of 8, 15 (design), and 20.

    At pressure ratios of 15 and 20, the blade efficiency obtained
with the nozzle having circular passages (K) was higher than that
obtained with the nozzle having rectangular passages (J). At a
pressure ratio of 8, the efficiencies obtained with the two nozzles
were comparable for blade-jet speed ratios of less than 0.260. For
blade-jet speed ratios exceeding this value, nozzle K yielded
slightly higher efficiencies. The maximum blade efficiency of
0.569 was obtained with nozzle K at a pressure ratio of 8 and a
blade-jet speed ratio of 0.295. At design speed and pressure ratio,
nozzle K yielded a maximum blade efficiency of 0.534, an increase
of 0.031 over that obtained with nozzle J.

    When the blade efficiencies of the two nozzles were compared
with those of four other nozzles previously investigated, the maxi-
mum difference for the six nozzles with this rotor was 0.050. From
this comparison, no specific effect of nozzles size or shape on
over-all performance was discernible.

INTRODUCTION

The NACA Lewis laboratory is conducting an investigation of the gas turbine from a Mark 25 aerial-torpedo power plant at the request of the Bureau of Ordnance, Department of the Navy. The over-all objective of this program is to extend the knowledge of high-pressure turbines toward future application to rocket-engine accessory drive. The program consists in determining the effect of (1) nozzle design, (2) axial nozzle-rotor clearance, and (3) blade design on performance. Results of investigations with various nozzles and blade designs are reported in references 1 to 4.

The present report is a continuation of the single-stage investigation with two nozzles (arbitrarily designated J and K) that have different physical dimensions from those previously investigated in combination with a standard first-stage rotor having 0.40-inch blades with an inlet-air angle of 17°. The performance with 0.45-inch blades and 20°-inlet-angle blades is given in references 5 and 6, respectively.

Both nozzle-rotor combinations were operated at pressure ratios of 8, 15 (design), and 20 for a speed range from 6000 to 18,000 rpm. Inlet conditions were maintained at a temperature of 1000° F and a pressure of 95 pounds per square inch gage. The turbine-shaft-power output was corrected for mechanical, disk, and blade-windage losses to determine the wheel and blade efficiencies by the procedure given in reference 2.

APPARATUS AND METHODS

The Mark 25 torpedo power plant is an impulse turbine composed of two counterrotating stages operating at the same speed. The turbine nozzles were designed to effect a gas-admission arc of approximately 90°. For this investigation, the power plant was modified to operate as a single-stage turbine; the experimental apparatus and instrumentation are the same as those described in reference 2 with the exception of the nozzles. Nozzles J and K are described in reference 5 and are shown in figures 1 and 2, respectively. Both nozzles have smaller cross-sectional port areas than similar nozzles that were previously investigated. Characteristics of all the nozzles used with the standard first-stage rotor 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

The operational procedure and the calculations of performance parameters were the same as those outlined in references 1 and 2. Nozzle J was operated with 0.030-inch nozzle-rotor clearance; nozzle K with 0.040-inch clearance. Reference 3 indicates that in this range of axial running clearance, performance would not be affected by a 0.010-inch change in clearance.

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

Air flow, percent . . . . ±1.50
Torque, foot-pound . . . . ±0.15
Dynamometer speed, rpm . . . . ±5
Inlet-gas temperature, percent . . . . ±0.25
Inlet-gas pressure, percent . . . . ±0.50
Pressure, inch mercury absolute . . . . ±0.05

RESULTS AND DISCUSSION

Efficiency data for the modified single-stage Mark 25 turbine with nozzles J and K in combination with standard rotor blades is given in tables I and II and figures 3 to 5. Because of the design-speed limitation of 18,000 rpm, attainment of an optimum blade-jet speed ratio was impossible. Efficiency increased continuously with rotative speed for both nozzle J and K at all pressure ratios investigated. At any given blade-jet speed ratio, the efficiency decreased as pressure ratio was increased.

Brake efficiency and rotor efficiency are presented as functions of blade-jet speed ratio in figures 3 and 4, respectively. At pressure ratios of 15 and 20, brake and rotor efficiencies for nozzle K were higher than those obtained for nozzle J for all speeds investigated. At a pressure ratio of 8, nozzle J had a higher brake

efficiency than nozzle K although the blade efficiency (fig. 5) of
nozzle J was lower at blade-jet speed ratios above 0.250 and within
0.010 below this value. Because of the larger weight flow passed
by nozzle J, the mechanical losses are a smaller percentage of the
total power output for nozzle J than for nozzle K and the brake
efficiency for nozzle J is less affected when these losses are
charged to the turbine. Although the rotor efficiencies with noz-
zle K were greater than those with nozzle J at pressure ratios of
15 and 20, the rotor efficiencies with the two nozzles at a pres-
sure ratio of 8 were found to be substantially equal, the maximum
difference being less than 0.010 (fig. 4(a)). The rotor efficiency
with nozzle J decreased a greater amount than with nozzle K for an
increase in pressure ratio. A corresponding effect was also
noticeable, although to a lesser degree, when these two nozzles were
investigated in combination with 20°-inlet rotor blades (refer-
ence 6).

Blade efficiency (fig. 5) is considered a better criterion of
performance of various nozzle-blade combinations because the effects
of mechanical and windage losses are eliminated. The maximum blade
efficiency of 0.569 was obtained with nozzle K at a pressure ratio
of 8 and a blade-jet speed ratio of 0.295, which was 0.014 higher
than the efficiency with nozzle J at the same conditions. For
blade-jet speed ratios below 0.260 at this pressure ratio, however,
the efficiencies with the two nozzles were comparable. At pressure
ratios of 15 and 20, the blade efficiencies with nozzle K were
higher than those with nozzle J over the speed range investigated.
The blade efficiency of nozzle K at the design pressure ratio of
15 and a blade-jet speed ratio of 0.268 (corresponding to the design
speed) was 0.534, which is an increase of 0.031 over that obtained
with nozzle J at corresponding operating conditions. The trends
of the blade-efficiency curves are similar to those of the brake-
and rotor-efficiency curves in that the efficiencies of the two
nozzles are comparable at a pressure ratio of 8 and the curves
diverge as the pressure ratio is increased. This effect was also
observed when the two nozzles were run in combination with the
rotor having 20°-inlet-angle blades (reference 6).

The blade efficiencies with nozzles J and K are compared with
those for the other nozzles previously investigated (A, E, H, and I)
in combination with the standard blades (fig. 6). At a pressure
ratio of 8, the blade efficiencies with nozzles J and K were lower
than with the other nozzles, with the exception of nozzle E. At a
pressure ratio of 15 and the maximum blade-jet speed ratio, noz-
zle K yielded an efficiency that was higher than that of the other
nozzles. At lower speeds, the efficiencies with nozzles K and I

were comparable (within 0.01) and are higher than the efficiencies
with other nozzles. The blade efficiency yielded with nozzle J
was generally low at a pressure ratio of 15, again with the excep-
tion of nozzle E. At a pressure ratio of 20, nozzle K was found to
have the highest blade efficiency, whereas nozzle J was found to
have the lowest efficiency of all the nozzles investigated. The
maximum difference in blade efficiency with the six nozzles in
combination with the standard first-stage rotor was 0.050.

Nozzle I, which passed a comparatively large weight flow, and
nozzle K, which passed the smallest weight flow, yielded the high-
est efficiencies at pressure ratios of 15 and 20. A comparison of
the performance with the six nozzles (fig. 6) indicates that there
is no apparent trend in performance with nozzle size and shape.
Owing to the complexity of the flow in the small passages, it is
doubtful if such a trend could be found with such simple concepts.
It is felt that undeterminable losses resulting from shock in the
supersonic air stream would obscure the trends of nozzle and
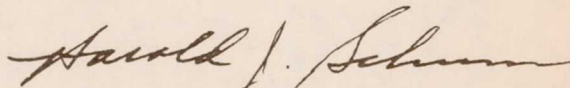blade characteristics.

SUMMARY OF RESULTS

A Mark 25 single-stage turbine was investigated with nozzle
designs J and K in combination with a standard rotor with the
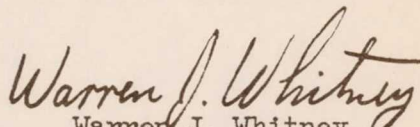following results:

1. The blade efficiency obtained with nozzle K was higher than
that obtained with nozzle J at pressure ratios of 15 and 20. At a
pressure ratio of 8, the efficiencies of the two nozzles were com-
parable at blade-jet speed ratios of less than 0.260; for blade-jet
speed ratios exceeding this value, nozzle K had slightly higher
efficiencies.

2. The maximum blade efficiency of 0.569 was obtained with noz-
zle K at a pressure ratio of 8 and a blade-jet speed ratio of 0.295.

3. At the design speed and pressure ratio, nozzle K yielded a
blade efficiency of 0.534, an increase of 0.031 over that obtained
with nozzle J.

4. The maximum difference in blade efficiency with the six
nozzles at any blade-jet speed ratio was 0.050.

5. A comparison of the results obtained with the six nozzles has indicated that there is no apparent trend in performance with nozzle size or shape.

Lewis Flight Propulsion Laboratory,
    National Advisory Committee for Aeronautics,
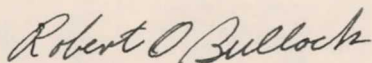   Cleveland, Ohio, May 19, 1949.

Harold J. Schum,
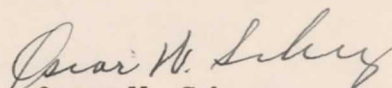Aeronautical Research
Scientist.

Warren J. Whitney,
Aeronautical Research
Scientist.

Approved: Robert O. Bullock,
Aeronautical Research
Scientist.

Oscar W. Schey,
Aeronautical Research
Scientist.

rl

REFERENCES

1. Hoyt, Jack W., and Kottas, Harry: Investigation of Turbine of Mark 25 Torpedo Power Plant with Five Nozzle Designs. NACA RM SE7I03, Bur. Ord., 1947.

2. Hoyt, Jack W.: Investigation of Single-Stage Modified Turbine of Mark 25 Torpedo Power Plant. NACA RM SE7L15, Bur. Ord., 1948.

3. 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.

4. Schum, Harold J., and Hoyt, Jack W.: Effect of First-Stage Blade Design on Performance of Mark 25 Torpedo Power Plant. NACA RM SE9G20, Bur. Ord., 1949.

5. Schum, Harold J., and Whitney, Warren J.: Performance of Single-Stage Turbine of Mark 25 Torpedo Power Plant with Two Special Nozzles. I - Efficiency with 0.45-Inch Rotor Blades. NACA RM SE9G20a, Bur. Ord., 1949.

6. Schum, Harold J., and Whitney, Warren J.: Performance of Single-Stage Turbine of Mark 25 Torpedo Power Plant with Two Special Nozzles. II - Efficiency with 20°-Inlet Rotor Blades. NACA RM SE9H09, Bur. Ord., 1949.

TABLE I – EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE J AND STANDARD 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

NACA

TABLE II - EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED TURBINE WITH NOZZLE K AND STANDARD 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

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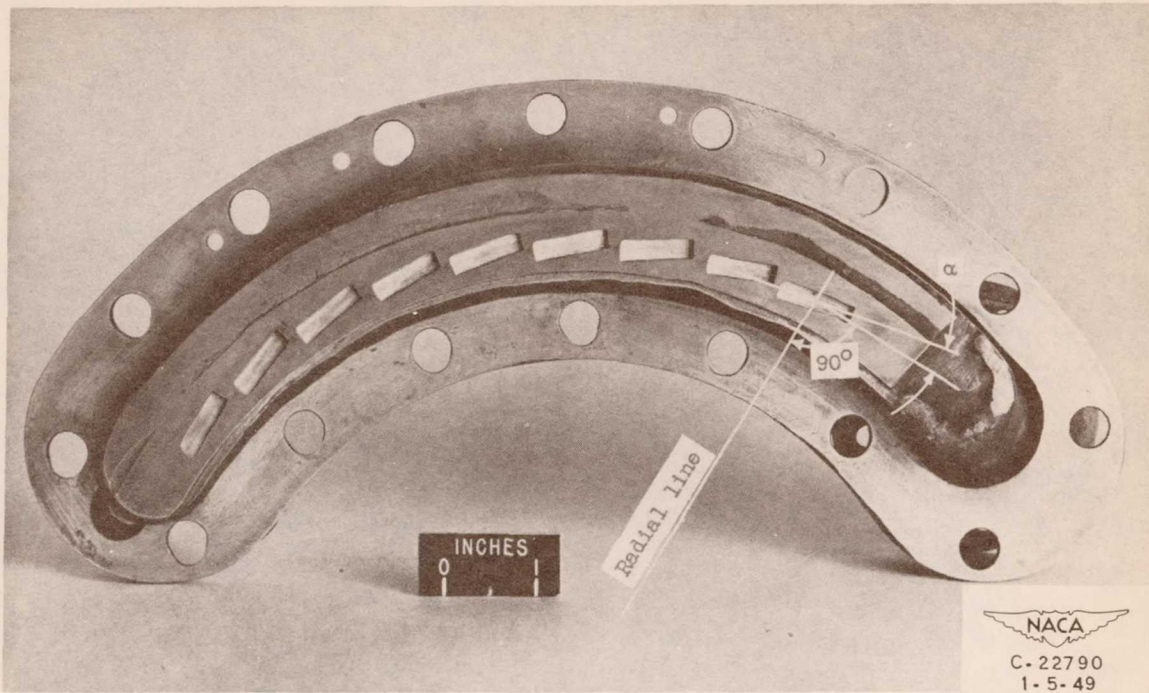
Figure 1. - Nozzle-box assembly showing outlet face of cast nozzle J.
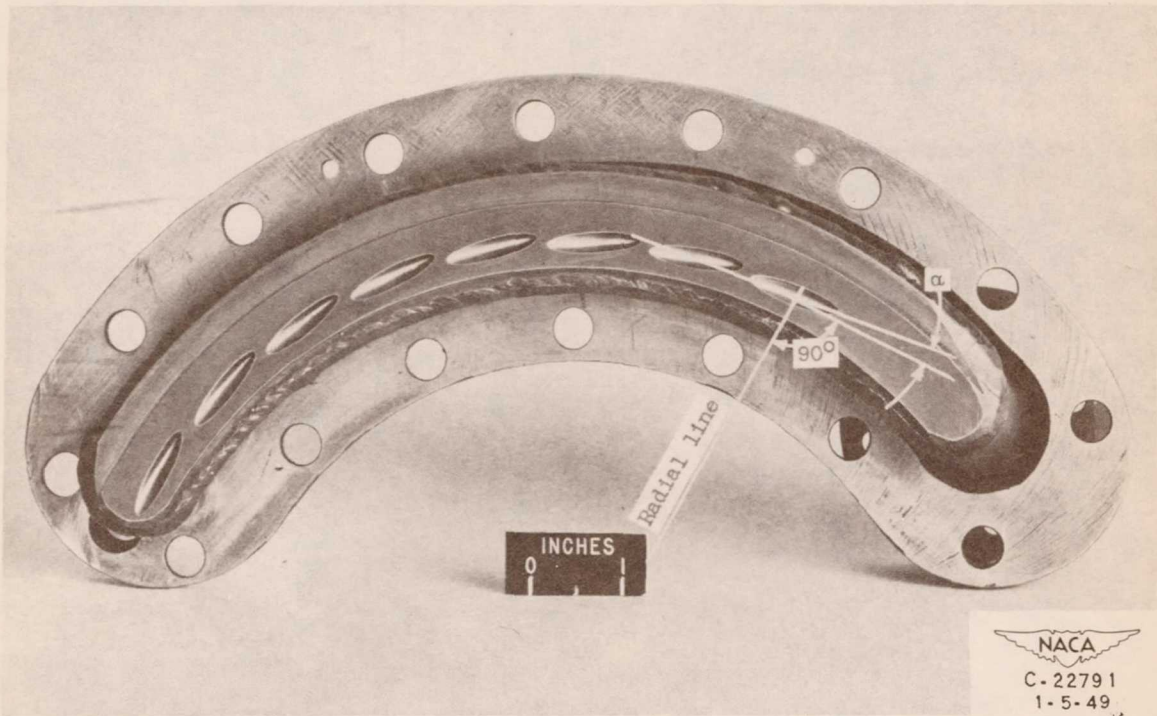Angle of intangency α, 9°.

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

(a)   Pressure ratio, 8.

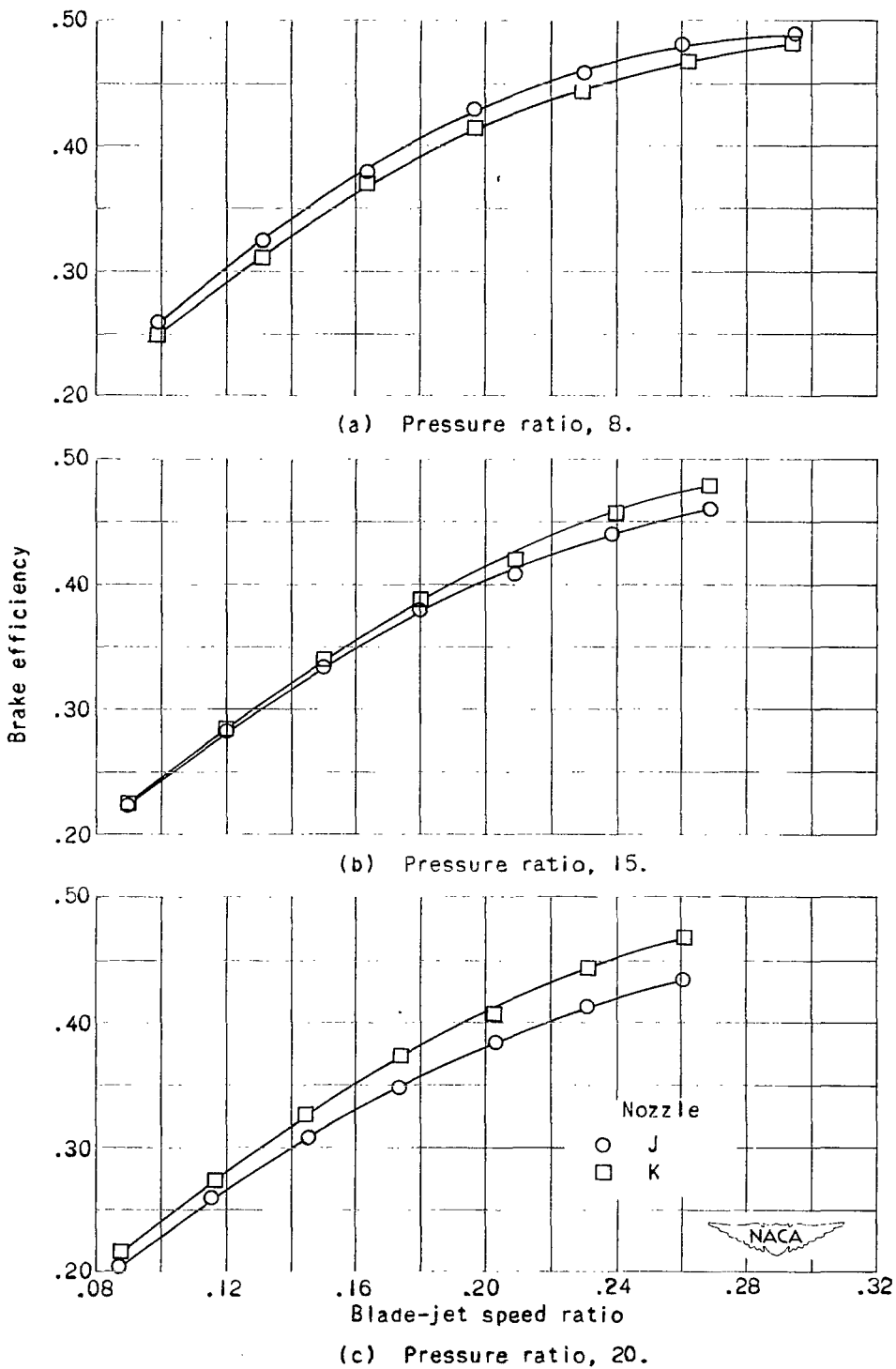(b)   Pressure ratio, 15.

(c)   Pressure ratio, 20.

Figure 3. - Variation of brake efficiency with blade-jet speed
ratio for single-stage modified Mark 25 torpedo turbine with
nozzles J and K and standard rotor blades.

(a)   Pressure ratio, 8.

(b)   Pressure ratio, 15.

(c)   Pressure ratio, 20.

Nozzle

○   J
□   K
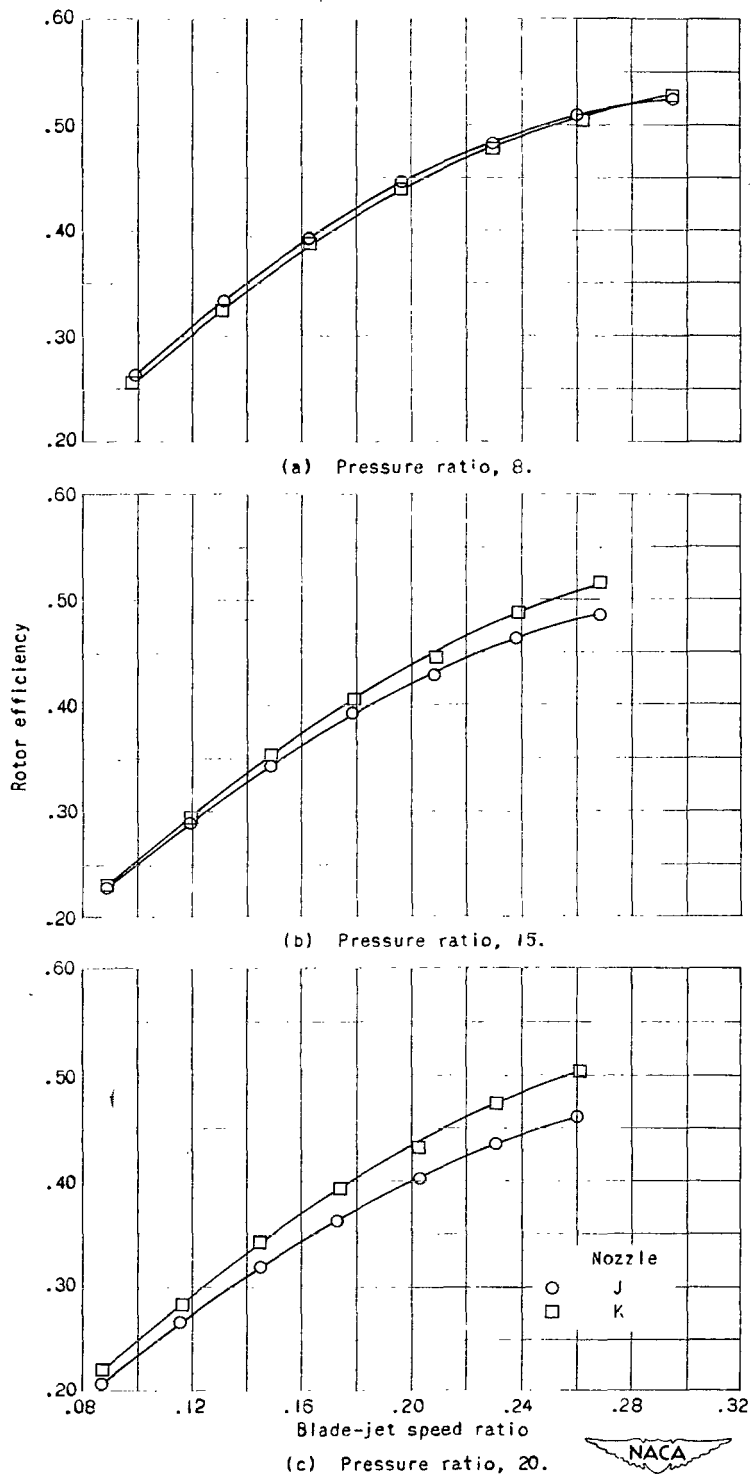
Rotor efficiency

Blade-jet speed ratio

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

(a)   Pressure ratio, 8.

(b)   Pressure ratio, 15.

Blade efficiency

Nozzle
○   J
□   K

.08   .12   .16   .20   .24   .28   .32
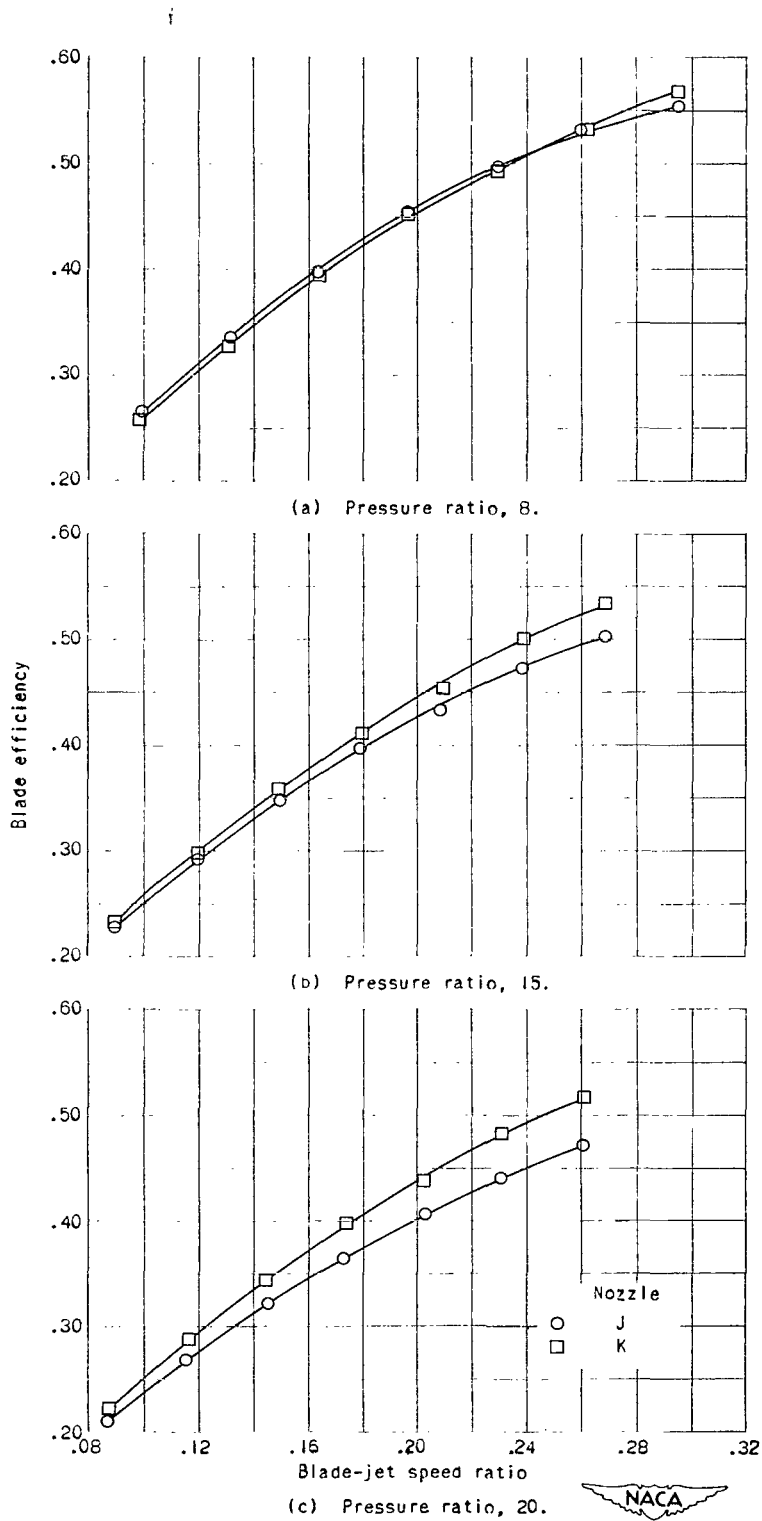Blade-jet speed ratio

(c)   Pressure ratio, 20.

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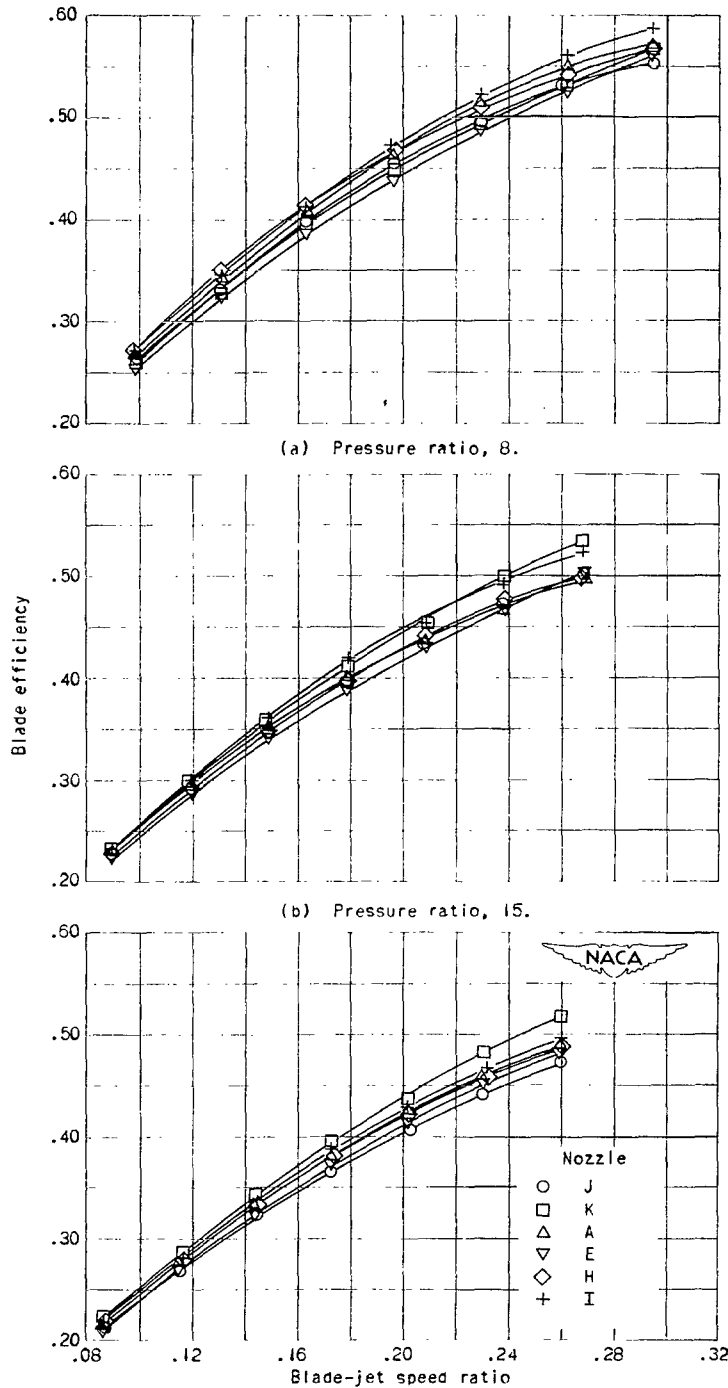nozzles J and K and standard rotor blades.

(a) Pressure ratio, 8.

(b) Pressure ratio, 15.

Nozzle

○	J
□	K
△	A
▽	E
◇	H
+	I

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

Figure 6. – 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 standard rotor blades.
(Data for nozzles A, E, H, and I from reference 3.)