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 Haróld J. Schum and Warren J. Whitney

Lewis Flight Propulsion Laboratory
Cleveland, Ohio
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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PERFORMANCE OF SINGLE-STAGE TURBINE OF MARK 25 TORPEDO POWER PLANT WITH TWO SPECIAL NOZZLES

III - EFFICIENCY WITH STANDARD ROTOR BLADES

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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 pressure 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 maximum 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:
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-
kle 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-
kle 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 exception 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 highest 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 comparable 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 nozzle 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
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Warren J. Whitney
Aeronautical Research Scientist.

Approved: Robert O. Bullock
Robert O. Bullock, Aeronautical Research Scientist.

Oscar W. Schey
Aeronautical Research Scientist.

REFERENCES


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]

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<th>Pressure ratio</th>
<th>Air weight flow (lb/hr)</th>
<th>Fuel-air ratio</th>
<th>Horsepower available from isentropic expansion</th>
<th>Turbine speed (rpm)</th>
<th>Brake horsepower</th>
<th>Blade-jet speed ratio</th>
<th>Gas density in turbine case (lb/cu ft)</th>
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### 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]

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Figure 1. - Nozzle-box assembly showing outlet face of cast nozzle J.
Angle of intangency $\alpha$, 90°.

Figure 2. - Nozzle-box assembly showing outlet face of reamed nozzle K.
Angle of intangency $\alpha$, 60°.
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.
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.
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.
Figure 6. - Variation of blade efficiency with blade-jet speed ratio for single-stage modified Mark 25 torpedo turbine with nozzles J, A, E, H, and I and standard rotor blades. (Data for nozzles A, E, H, and I from reference 3.)