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RESEARCH MEMORANDUM

for the

Bureau of Ordnance, Navy Department

INVESTIGATION OF SINGLE-STAGE MODIFIED TURBINE OF MARK 25 TORPEDO POWER PLANT

By Jack W. Hoyt

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

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SUMMARY

Efficiency investigations have been made on a single-stage modification of the turbine of a Mark 25 aerial torpedo to determine the performance of the unit with five different turbine nozzles. The output of the turbine blades was computed by analyzing the windage and mechanical-friction losses of the unit.

The turbine was found to be most efficient with a cast nozzle having sharp-edged inlets to the nine nozzle ports. An analysis of the effectiveness of the first and second stages of the standard Mark 25 torpedo turbine indicates that the first-stage turbine contributes nearly all the brake power produced at blade-jet speed ratios above 0.26.

INTRODUCTION

As part of a program of ordnance development, the two-stage turbine of a Mark 25 aerial-torpedo power plant was investigated at the NACA Cleveland laboratory at request of the Bureau of Ordnance, Navy Department. The performance of the standard two-stage turbine is presented in reference 1.

A single-stage modification of the Mark 25 turbine was made by removing the second-stage turbine wheel and was investigated to aid in the analysis of the standard two-stage turbine. The analysis of the single-stage turbine may also provide data useful in developing a high-pressure turbine for powering rocket fuel pumps or other accessories.

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The performance of the single-stage unit was investigated under steady-state conditions with five different turbine nozzles and the effect of the nozzle designs on over-all turbine efficiency was compared. The five turbine nozzles were studied to determine the effect of pressure ratio and blade-jet speed ratio on single-stage-turbine efficiency. These investigations covered a range of pressure ratios from 8 to 20 and turbine speeds from 6000 to 18,000 rpm with an inlet-gas temperature of 1000° F and pressure of 95 pounds per square inch gage. The true output of the nozzle-blade combinations was determined by evaluating the power losses of the turbine due to windage and mechanical friction.

TURBINE MODIFICATIONS AND SETUP

The standard Mark 25 torpedo power plant is a two-stage, counterrotating impulse turbine with partial gas admission, integral speed reduction, and power-equalizing gearing. The unit was converted to a single-stage turbine by: (1) replacing the rear turbine-wheel pinion gear with a blank spacer, (2) replacing the rear turbine wheel with a disk of the same diameter as the blade-root diameter of the standard rear wheel, (3) fastening sheet-metal guide vanes to the disk (fig. 1) in order to direct the gases axially into the exhaust, and (4) pinning the disk to the turbine casing to prevent rotation. All turbine clearances were thus unchanged, yet only the forward turbine wheel was operative. The rest of the reduction-gear train remained unchanged in order to maintain the counterrotation at the output shafts and thus utilize the combining gearbox and all other equipment described in reference 1.

The turbine was operated with five different nozzle designs, which are described in detail in reference 1. Nozzle A has rounded inlets to the nine rectangular converging-diverging nozzle ports. Nozzle E has nine reamed ports with rounded inlets. The ports are cylindrical with no area divergence in the nozzle, necessary gas expansion taking place in the clearance space between the nozzle and the forward turbine blades. Nozzle F is similar to nozzle E, but only three ports are active. Nozzle G is the same as nozzle E, except that a shroud projects 0.216 inch axially from the nozzle-outlet face to guide the combustion gases to a more favorable flow profile. Nozzle H has nine rectangular ports with sharp-edged inlets to the throats cast by a different technique from that used for nozzle A. The gas mass flow through nozzle H is about 20 percent greater than that through nozzle A. The nine-port nozzles (A, E, G, and H) have 90° nozzle-arc gas admission. The three-port nozzle (F) has 30° nozzle-arc gas admission.

The axial nozzle-turbine clearances were set to give a running clearance of 0.030 inch when the parts reach operating temperature. Radial nozzle settings, as well as the proper allowances for thermal changes in axial clearances, were made to conform with the recommendations of reference 1.

PROCEDURE

The studies to evaluate the performance of the single-stage modification of the Mark 25 torpedo turbine consisted of (1) efficiency runs with the different turbine nozzles, and (2) motoring runs to evaluate the windage and mechanical losses of the unit. The brake efficiency of the turbine power plant and the combining gear was obtained from the power output with various nozzles at several pressure ratios and turbine speeds over the operating range of the unit. With the inlet-gas conditions maintained at 1000° F and 95 pounds per square inch gage, the turbine speed was varied from 6000 to 18,000 rpm at pressure ratios of 8, 10, 15, and 20. Owing to air-flow limitations, the maximum pressure ratio obtained with nozzle H was 19. The output obtained during these runs represents the output of the turbine wheel with the windage loss and the gear and bearing friction in the power plant subtracted.

The rotation losses of the unit due to gears, bearings, and turbine disk were obtained by motoring the unit with a disk installed instead of the forward turbine wheel. The disk was 10.075 inches in diameter, or exactly the same diameter as the root diameter of the turbine blades. The power required to motor this disk at speeds from 6000 to 18,000 rpm and at various air densities in the turbine case represents the total power absorbed through mechanical losses in the gears and the bearings and windage of the turbine disk. The motoring runs were repeated with a standard forward wheel having a turbine-shroud-band diameter of 11.000 inches. The power then required represents all the losses of the disk unit plus the air-pumping effect of the turbine blades. All motoring runs were made without air flow through the turbine, the nozzle-box inlet being blocked.

CALCULATIONS

The isentropic enthalpy drop available for an expansion from the inlet-gas total temperature and pressure to the outlet-gas static pressure was computed from the air tables of reference 2 and corrected for the effect of the fuel input. The blade-jet speed ratio is the ratio of the blade speed at the pitch diameter of the wheel to the ideal nozzle-jet velocity corresponding to an isentropic expansion from the inlet-gas total temperature and pressure to the outlet-gas static pressure. Pressure ratio is defined as the ratio of the inlet-gas total pressure to the outlet-gas static pressure.

The brake, wheel, and blade efficiencies were computed by the method developed in reference 1. Brake efficiency is the ratio of the brake power calculated from the torque and the speed at the dynamometer shaft to the isentropic power available; wheel efficiency is the ratio of the brake power plus the mechanical losses in the gears and bearings to the isentropic power; and blade efficiency is the ratio of the brake power plus the mechanical losses and the disk and blade windage losses to the isentropic power. If the high residual velocity leaving the turbine wheel can be recovered, the turbine can be credited with this velocity and the efficiency computed on the basis of the outlet-gas total pressure at the measuring station 2 inches behind the outlet straightening vanes. The total-pressure brake efficiency is thus the ratio of the brake power to the isentropic power based on the inlet-gas total temperature and pressure and the outlet-gas total pressure. The ratio of the total-pressure brake efficiency to the brake efficiency is defined herein as the efficiency ratio.

Charts of the windage and mechanical losses of the single-stage unit prepared from motoring studies of a disk and the complete wheel are based upon the analysis and the calculation procedure described in reference 1 for the two-stage turbine. The power required to motor the unit with the disk installed instead of the turbine wheel represents the total power absorbed through mechanical losses in the gears and bearings plus windage of the disk. The losses are presented in figure 2(a) and table I. Curves of constant disk speed have been extrapolated to zero air density to separate the mechanical losses from the power losses due to the disk windage. The windage and mechanical losses obtained by motoring the turbine unit are presented in figure 2(b) and table II. Slight differences shown in figures 2(a) and 2(b) in mechanical losses in the units are indicative of the differences to be expected in different turbine assemblies.

When the nine-port nozzles with 90° nozzle-arc gas admission (nozzles A, E, G, and H) are used, 90° of the blade periphery, or one-fourth of the turbine blades, are active and hence are not subject to windage loss. The windage losses of the unit with these nozzles are composed of the total disk windage plus three-fourths of the windage due to the turbine blades. Accordingly, figure 3(a) was prepared from the total disk windage loss plus three-fourths of the additional windage loss due to the turbine blades. This chart can be used to find directly the windage and mechanical losses of the unit with a nine-port nozzle if the gas density in the turbine case is known.

In nozzle F, which has three ports with 30° nozzle-arc gas admission, 30° of the blade periphery, or one-twelfth of the turbine blades, are active and thus have no windage losses. Figure 3(b) was prepared by using the total disk windage loss plus eleven-twelfths of the additional windage loss due to the blades.

RESULTS

Turbine efficiency. - The individual performances of the single-stage turbine with nozzles A, E, F, G, and H at inlet-gas conditions of 1000° F and 95 pounds per square inch gage at pressure ratios of 8 to 20 are shown in figures 4 to 8 and tables III to VII, respectively. The highest brake efficiency of 0.513 was obtained with nozzle H at a blade-jet speed ratio of approximately 0.295 at a pressure ratio of 8 (fig. 8(a)). At these conditions the wheel efficiency was 0.542 and the blade efficiency 0.569. The peak brake efficiency, which would be at a higher blade-jet speed ratio, could not be determined for the nine-port nozzles because of the 18,000-rpm speed limitation of the turbine.

In reference 1, the two-stage turbine using nozzle H was shown to be considerably more efficient than with the other nozzles, perhaps because the greater gas mass flow through nozzle H filled the turbine flow area more completely and hence extracted more work from the reaction blades of the second-stage wheel, or because of lower losses in the nozzle passage due to the smoother port surfaces of this nozzle. Nozzles A, E, and H give the highest efficiencies in the single-stage turbine; however the brake efficiencies with all three fall within two efficiency points of each other at each blade-jet speed ratio over the range of pressure ratios, as do also the wheel efficiencies and the blade efficiencies with the three nozzles. No one of these three nozzles can therefore be considered definitely most efficient in a single-stage application. Because the windage losses of the single-stage turbine with nozzle A are a much greater proportion of the total turbine work output than the windage losses with nozzle H, the blade efficiency computed for nozzle A is slightly greater than the blade efficiency for nozzle H.

The difference in the general trends of the curves of brake efficiency and blade efficiency can be ascribed to the approximately cubic increase of windage losses with speed. The turbine is therefore penalized by the use of partial-admission nozzles, as shown by the three-port nozzle F for which the brake efficiency drops off sharply with increased blade-jet speed ratio but the blade efficiency increases with increased speed. The windage and mechanical losses for the turbine with nozzle F are a large proportion of the total turbine output and give a high computed value of blade efficiency, although the brake efficiency is poor.

The reamed nozzles (nozzles E, F, G) generally showed lower efficiencies than the cast nozzles (nozzles A and H). The addition of a shroud (nozzle G) to guide the nozzle jets markedly decreased efficiency, presumably because of increased shock and eddy losses.

The total-pressure brake efficiencies are given in tables III, IV, VI, and VII for nozzles A, E, G, and H, respectively. The efficiency ratio, or ratio of the total-pressure brake efficiency to the brake efficiency, for nozzle H is shown in figure 9. The efficiency ratio becomes greater with increased pressure ratio but falls off with increased turbine speed because a greater proportion of the gas velocity is converted into power output.

Analysis of stage output. - The power outputs under the same inlet-gas conditions with nozzle H for the single-stage turbine and the standard two-stage turbine (reference 1) are compared in figure 10. At a pressure ratio of 8 (fig. 10(a)), the brake-horsepower curves intersect at a blade-jet speed ratio of about 0.262, which indicates that the additional power output of the second stage is completely absorbed at that point by the additional windage and mechanical losses of the second-stage turbine. The percentage of single-stage brake horsepower, brake horsepower plus mechanical losses, and brake horsepower plus mechanical losses and windage contributed by the second-stage turbine for a pressure ratio of 8 is shown in figure 11(a). At blade-jet speed ratios above 0.262, the mechanical losses and the windage incurred by the second wheel exceed the additional power output of the second stage.

With higher pressure ratios, the second stage contributes somewhat higher percentage outputs. Figure 10(b) compares the single-stage and two-stage power outputs with nozzle H at a pressure ratio of 19. The brake efficiencies do not intersect owing to the limit of the blade-jet speed ratio imposed by the 18,000-rpm speed limitation of the turbine; however, extension of these curves would place their intersection at approximately a blade-jet speed ratio of 0.28. Figure 11(b) shows the percentage output contributed by the second stage at a pressure ratio of 19. At the highest blade-jet speed ratio obtained (0.261), the second stage contributes only about 9 percent additional brake output.

A similar analysis for the single-stage and two-stage turbines with nozzle A is shown in figures 12 and 13. The percentage of additional power contributed by the second stage is considerably less than when nozzle H is used. Inasmuch as the efficiencies of the single-stage turbine with nozzles A and H are almost the same, nozzle H in the two-stage turbine is utilizing the second stage much more effectively than nozzle A. The gas mass flow of nozzle H is about 20 percent greater than that of nozzle A, which apparently causes a greater amount of power to be produced in the reaction blading of the second stage because of increased gas velocities.

Careful consideration should be given to the problem of whether a single-stage or two-stage turbine should be used for power plants of the Mark 25 type at blade-jet speed ratios above 0.26 with the type of nozzle available for these investigations. For operation at lower blade-jet speed ratios, where maximum power extraction is necessary, and for applications where the gyroscopic effect of a single-stage turbine is undesirable, the two-stage unit may be justified.

SUMMARY OF RESULTS

From windage and efficiency runs of a single-stage modification of the Mark 25 torpedo turbine with five different nozzles at inlet-gas conditions of 1000° F and 95 pounds per square inch gage, the following results were obtained:

1. The single-stage turbine had the greatest brake efficiency with a cast, sharp-edged-inlet nozzle, designated nozzle H. A cast, rounded-edged-inlet, diverging nozzle and a reamed nozzle showed only slightly less over-all efficiency.

2. The highest brake efficiency of the turbine obtained with nozzle H at a pressure ratio of 8 and a blade-jet speed ratio of 0.295 was 0.513. If the turbine is credited with the work necessary to drive the gears and bearings, the wheel efficiency at the foregoing conditions would be 0.542. If the turbine is also credited with the work necessary to overcome windage losses, the blade efficiency would be 0.569.

3. An analysis of the stage effectiveness of the first and second stages of the standard Mark 25 torpedo turbine indicates

that the first stage contributes nearly all the brake power produced at blade-jet speed ratios above 0.26 with the nozzles used.

4. Windage and mechanical-loss charts that were prepared gave the operating loss of the single-stage turbine for various turbine-casing pressures, speeds, and active nozzle arcs of 30° and 90°.

Flight Propulsion Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, December 1, 1947.

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TABLE I - SUMMARY OF DATA FOR WINDAGE AND MECHANICAL LOSSES OF SINGLE-STAGE MODIFIED MARK 25 TURBINE DISK UNIT

Turbine speed (rpm)	Air temperature in turbine case (°F) (a)	Pressure in turbine case (in. Hg absolute)	Horsepower to drive turbine
6,069	122	29.33	0.38
	133	24.33	.40
	133	19.34	.40
	133	14.33	.40
	132	9.33	.40
8,092	135	29.33	0.69
	140	24.33	.69
	145	19.25	.69
	142	14.33	.67
	143	9.33	.64
10,115	153	29.33	1.20
	158	24.36	1.20
	160	19.26	1.17
	158	14.33	1.15
	156	9.33	1.13
12,138	175	29.33	1.68
	170	24.33	1.68
	173	19.33	1.64
	174	14.33	1.60
	168	9.33	1.52
14,161	199	29.38	2.33
	198	24.33	2.24
	198	19.36	2.19
	195	14.33	2.10
	190	9.33	2.01
16,184	218	29.46	3.09
	198	24.17	3.04
	205	19.15	2.93
	206	14.14	2.83
	201	9.10	2.72
18,207	245	29.43	3.96
	234	24.19	3.84
	236	19.13	3.66
	235	14.10	3.48
	222	9.18	3.30

[a]Average of values from three thermocouples.

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TABLE II - SUMMARY OF DATA FOR WINDAGE AND MECHANICAL LOSSES OF SINGLE-STAGE MODIFIED MARK 25 TURBINE UNIT (DISK AND BLADES)

Turbine speed (rpm)	Air temperature in turbine case (°F) (a)	Pressure in turbine case (in. Hg absolute)	Horsepower to drive turbine
6,069	119	29.39	0.52
	158	24.39	.44
	154	19.33	.44
	151	14.42	.44
	148	9.39	.42
8,092	139	29.40	0.93
	162	23.78	.88
	162	19.30	.85
	162	14.33	.83
	160	9.66	.77
10,115	169	29.40	1.57
	192	24.66	1.47
	195	19.57	1.37
	194	14.38	1.27
	188	9.46	1.17
12,138	204	29.45	2.40
	215	24.42	2.12
	222	19.40	1.92
	223	14.42	1.72
	218	9.54	1.48
14,161	285	29.53	3.27
	288	24.58	2.89
	287	19.57	2.52
	279	14.55	2.24
	265	9.56	2.01
16,184	329	29.53	4.38
	316	24.45	3.90
	324	19.43	3.41
	319	14.45	2.99
	304	9.54	2.56
18,207	390	29.53	5.46
	380	24.53	4.92
	382	19.46	4.32
	376	14.43	3.72
	351	9.50	3.18

[a]Average of values from three thermocouples.

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TABLE III - SUMMARY OF EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED

MARK 25 POWER PLANT WITH NOZZLE A

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

Pressure ratio	Air mass 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)	Total brake cienc
8	956.2	0.0138	61.19	6,089	15.95	0.0987	0.0324	0.
	958.1		61.30	8,122	20.18	.1316	.0335	.
	957.0		61.23	10,125	23.69	.1641	.0339	.
	957.0		61.23	12,168	26.79	.1972	.0342	.
	957.0		61.23	14,171	29.19	.2297	.0342	.
	957.0		61.23	16,214	30.62	.2628	.0340	.
	957.0		61.23	18,207	31.32	.2951	.0339	.
10	956.2	0.0138	65.93	6,079	16.53	0.0949	0.0260	0.
	956.2		65.93	8,102	20.93	.1265	.0265	.
	956.2		65.93	10,115	24.57	.1580	.0268	.
	957.0		65.99	12,178	27.61	.1902	.0270	.
	957.0		65.99	14,141	29.68	.2208	.0270	.
	957.0		65.99	16,164	31.21	.2524	.0270	.
	957.0		65.99	18,197	32.20	.2842	.0270	.
15	957.0	0.0138	73.91	6,069	16.62	0.0896	0.0168	0.
	957.0		73.91	8,143	21.23	.1202	.0176	.
	957.0		73.91	10,125	24.86	.1495	.0178	.
	957.0		73.91	12,158	28.13	.1795	.0181	.
	957.9		73.98	14,171	30.40	.2092	.0182	.
	957.9		73.98	16,184	32.16	.2389	.0183	.
	957.9		73.98	18,227	33.64	.2691	.0185	.
20	957.9	0.0138	79.09	6,069	16.50	0.0867	0.0133	0.
				8,102	21.15	.1157	.0138	.
				10,115	25.20	.1445	.0140	.
				12,168	28.67	.1738	.0141	.
				14,171	31.85	.2024	.0145	.
				16,184	33.97	.2311	.0146	.
				18,207	35.88	.2600	.0148	.

TABLE IV - SUMMARY OF EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED

MARK 25 POWER PLANT WITH NOZZLE E

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

Pressure ratio	Air mass 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)	Total-[illegible] brake [illegible]ciency
8	975.1	0.0138	62.40	6,079	15.45	0.0985	0.0325	0.2[illegible]
	975.4		62.42	8,112	19.46	.1315	.0330	.3[illegible]
	975.4		62.42	10,115	22.90	.1639	.0336	.3[illegible]
	975.4		62.42	12,148	25.90	.1969	.0336	.4[illegible]
	974.6		62.37	14,181	28.13	.2298	.0336	.4[illegible]
	974.6		62.37	16,184	29.65	.2623	.0334	.4[illegible]
	974.6		62.37	18,207	30.96	.2951	.0334	.5[illegible]
10	973.7	0.0138	67.15	6,079	15.69	0.0949	0.0256	0.2[illegible]
	973.7		67.15	8,112	19.89	.1267	.0261	.3[illegible]
	973.7		67.15	10,115	23.33	.1580	.0264	.3[illegible]
	973.3		67.13	12,148	26.42	.1897	.0263	.3[illegible]
	973.7		67.15	14,161	28.98	.2211	.0264	.4[illegible]
	974.6		67.21	16,184	30.77	.2527	.0264	.4[illegible]
	974.6		67.21	18,187	32.06	.2840	.0265	.4[illegible]
15	974.6	0.0138	75.27	6,069	16.20	0.0896	0.0169	0.2[illegible]
	974.6		75.27	8,122	20.74	.1199	.0174	.2[illegible]
	976.3		75.42	10,105	24.48	.1492	.0177	.3[illegible]
	974.6		75.27	12,138	27.84	.1792	.0179	.3[illegible]
	976.3		75.42	14,171	30.59	.2092	.0179	.4[illegible]
	974.6		75.27	16,204	32.79	.2392	.0181	.4[illegible]
	974.6		75.27	18,207	34.92	.2688	.0183	.4[illegible]
20	974.6	0.0138	80.48	6,059	16.43	0.0865	0.0135	0.2[illegible]
				8,112	21.04	.1158	.0137	.2[illegible]
				10,115	25.00	.1444	.0141	.3[illegible]
				12,138	28.60	.1733	.0141	.3[illegible]
				14,161	31.59	.2022	.0142	.4[illegible]
				16,194	34.05	.2313	.0144	.4[illegible]
				18,187	35.90	.2597	.0144	.4[illegible]

TABLE V - SUMMARY OF EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED

MARK 25 POWER PLANT WITH NOZZLE F

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

Pressure ratio	Air mass flow (lb/hr)	Fuel-air ratio	Horsepower available from isentropic expansion	Turbine speed (rpm)	Brake horsepower	Blade-jet speed ratio	Gas densit in turbin case (lb/cu ft
8	244.6	0.0209	15.82	6,120	4.66	0.0992	0.0352
		.0209	15.82	8,092	5.65	.1311	.0355
		.0209	15.82	10,125	6.37	.1641	.0353
		.0215	15.83	12,168	6.82	.1972	.0359
		.0215	15.83	14,151	6.95	.2293	.0357
		.0215	15.83	16,194	6.56	.2625	.0353
		.0215	15.83	18,227	5.95	.2954	.0346
10	244.6	0.0215	17.06	6,069	4.86	0.0948	0.0276
	244.8	.0214	17.07	8,082	5.94	.1262	.0282
	244.8	.0214	17.07	10,115	6.80	.1580	.0280
	244.8	.0214	17.07	12,087	7.29	.1888	.0282
	244.6	.0215	17.06	14,161	7.37	.2212	.0280
	244.6	.0215	17.06	16,194	7.15	.2529	.0280
	244.6	.0215	17.06	18,217	6.42	.2845	.0278
15	244.4	0.0215	19.10	6,069	4.56	0.0896	0.0188
	244.4		19.10	8,092	5.60	.1195	.0186
	244.1		19.08	10,115	6.50	.1493	.0186
	244.1		19.08	12,138	6.92	.1792	.0187
	244.1		19.08	14,161	7.23	.2091	.0186
	244.1		19.08	16,184	7.20	.2389	.0186
	244.1		19.08	18,207	6.78	.2688	.0187
20	244.1	0.0215	20.40	6,069	4.36	0.0867	0.0138
	244.1		20.40	8,092	5.36	.1156	.0140
	244.1		20.40	10,095	6.15	.1442	.0142
	243.9		20.39	12,138	6.60	.1733	.0142
	243.9		20.39	14,151	6.90	.2021	.0144
	243.9		20.39	16,184	6.99	.2311	.0144
	243.9		20.39	18,207	6.66	.2600	.0144

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TABLE VI - SUMMARY OF EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED

MARK 25 POWER PLANT WITH NOZZLE G

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

Pressure ratio	Air mass 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)	Total brake cienc
8	977.2	0.0138	62.53	6,109	14.58	0.0990	0.0313	0
	976.2		62.47	8,132	18.30	.1318	.0316	
	977.2		62.53	10,135	21.38	.1643	.0319	
	977.2		62.53	12,178	23.88	.1974	.0321	
	977.2		62.53	14,161	25.67	.2295	.0320	
	977.2		62.53	16,204	26.86	.2626	.0321	
	977.2		62.53	18,207	27.36	.2951	.0321	
10	976.3	0.0138	67.33	6,079	15.37	0.0949	0.0254	0
				8,102	19.30	.1265	.0256	
				10,135	22.44	.1583	.0260	
				12,148	25.02	.1897	.0261	
				14,171	26.76	.2213	.0260	
				16,184	27.95	.2527	.0261	
				18,187	28.89	.2840	.0261	
15	976.3	0.0138	75.41	6,069	15.72	0.0896	0.0172	0.
	976.3		75.41	8,102	20.00	.1196	.0174	.
	976.3		75.41	10,115	23.70	.1493	.0176	.
	977.2		75.48	12,168	26.67	.1796	.0177	.
	977.2		75.48	14,171	28.95	.2092	.0177	.
	977.2		75.48	16,224	30.58	.2395	.0180	.
	977.2		75.48	18,197	31.72	.2686	.0180	.
20	976.0	0.0138	80.59	6,069	15.78	0.0867	0.0140	0.
	975.1		80.52	8,102	20.08	.1157	.0139	.
	975.1		80.52	10,115	23.77	.1445	.0140	.
	975.1		80.52	12,178	26.97	.1739	.0143	.
	975.1		80.52	14,161	29.35	.2022	.0142	.
	975.1		80.52	16,214	31.31	.2315	.0143	.
	975.1		80.52	18,207	32.58	.2600	.0144	.

TABLE VII - SUMMARY OF EFFICIENCY DATA FOR SINGLE-STAGE MODIFIED

MARK 25 POWER PLANT WITH NOZZLE H

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

Pressure ratio	Air mass 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)	Total-p brake e ciency
8	1140	0.0142	72.99	6,069	19.56	0.0984	0.0314	0.2
	1140		72.99	8,102	24.78	.1313	.0323	.3
	1141		73.05	10,105	29.00	.1638	.0325	.4
	1140		72.99	12,168	32.48	.1972	.0326	.4
	1141		73.05	14,171	34.98	.2297	.0324	.4
	1140		72.99	16,184	36.53	.2623	.0323	.5
	1140		72.99	18,197	37.48	.2949	.0327	.5
10	1140	0.0142	78.66	6,059	19.81	0.0946	0.0249	0.2
	1139		78.59	8,072	25.03	.1261	.0253	.3
	1140		78.66	10,095	29.47	.1577	.0256	.3
	1140		78.66	12,158	33.26	.1898	.0259	.4
	1140		78.66	14,161	36.03	.2211	.0259	.4
	1140		78.66	16,194	38.32	.2529	.0261	.4
	1140		78.66	18,227	39.52	.2846	.0265	.5
15	1139	0.0142	88.03	6,079	19.53	0.0897	0.0178	0.2
	1139		88.03	8,122	24.87	.1199	.0181	.2
	1138		87.95	10,115	29.63	.1493	.0183	.3
	1138		87.95	12,178	33.51	.1798	.0186	.3
	1139		88.03	14,171	36.89	.2092	.0187	.4
	1139		88.03	16,194	39.65	.2391	.0189	.4
	1139		88.03	18,177	41.69	.2683	.0192	.4
19	1139	0.0142	93.06	6,059	19.65	0.0870	0.0151	0.2
	1140		93.15	8,092	25.07	.1162	.0153	.2
	1139		93.06	10,115	29.80	.1453	.0154	.3
	1139		93.06	12,138	33.96	.1743	.0156	.3
	1139		93.06	14,151	37.35	.2032	.0157	.4
	1139		93.06	16,204	40.32	.2327	.0160	.4
	1139		93.06	18,187	42.55	.2612	.0162	.4

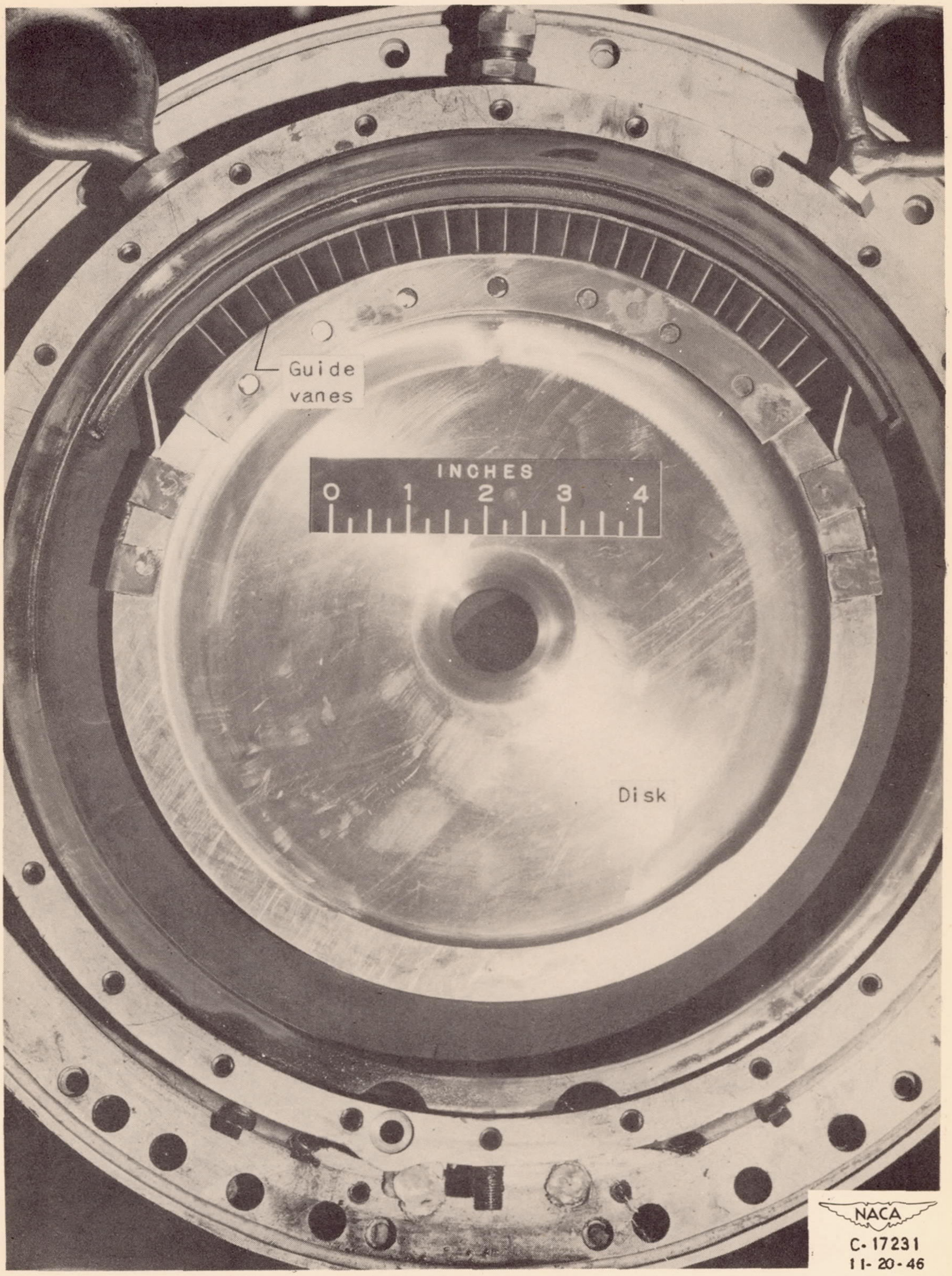
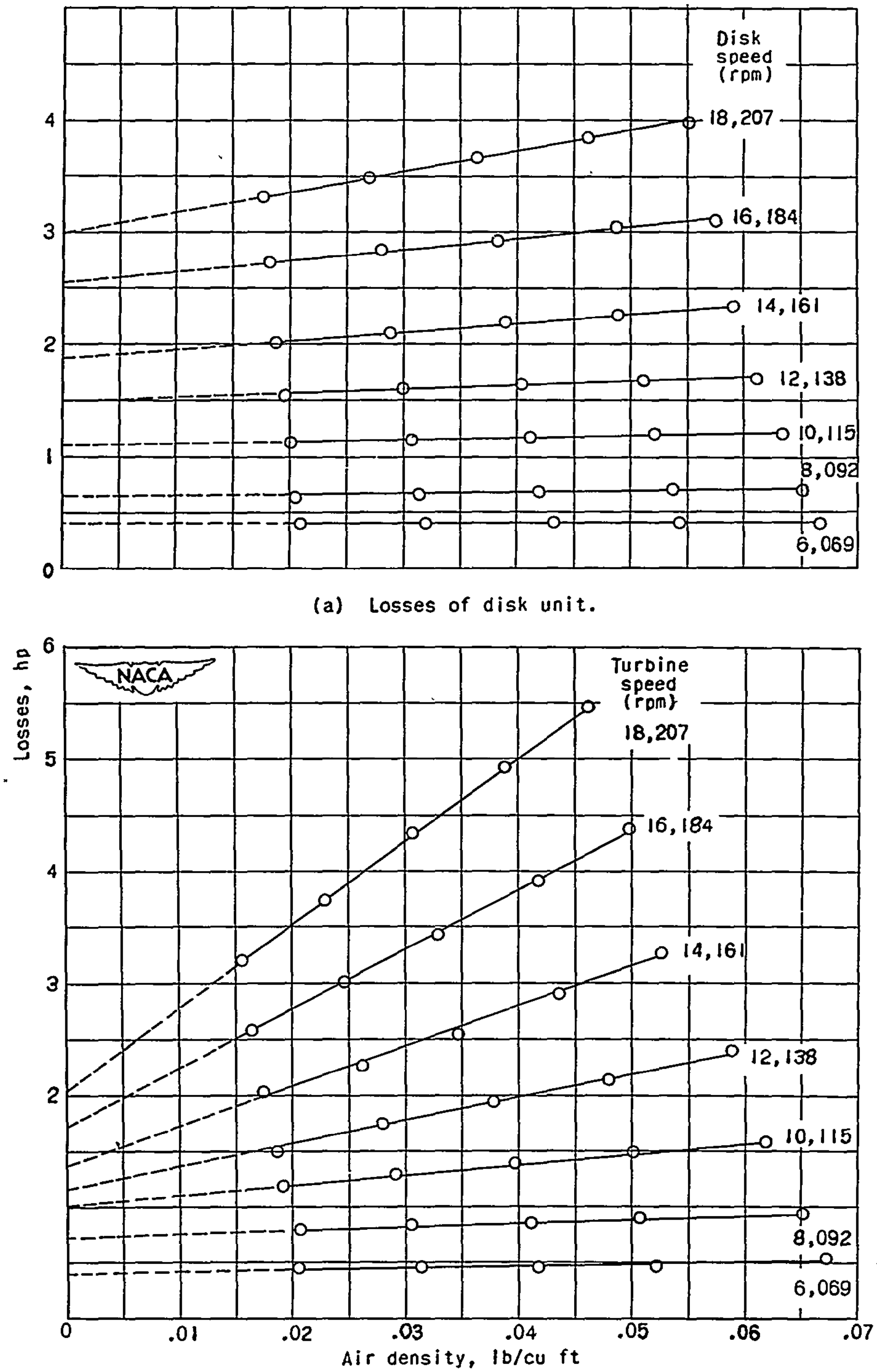


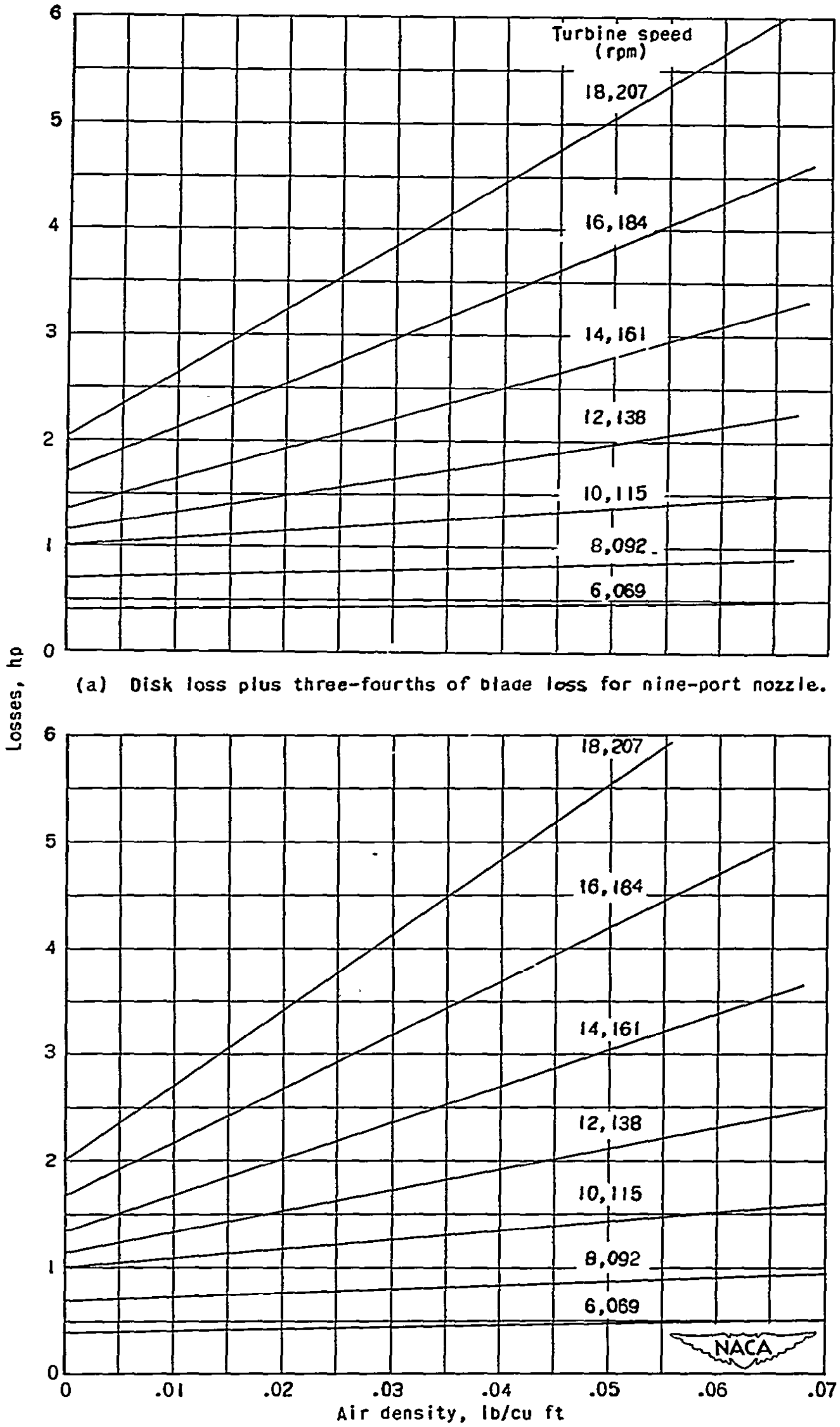
Figure 1. - Front of single-stage modified Mark 25 turbine with front cover and wheel removed showing stationary guide vanes.



(a) Losses of disk unit.

(b) Losses of turbine unit.

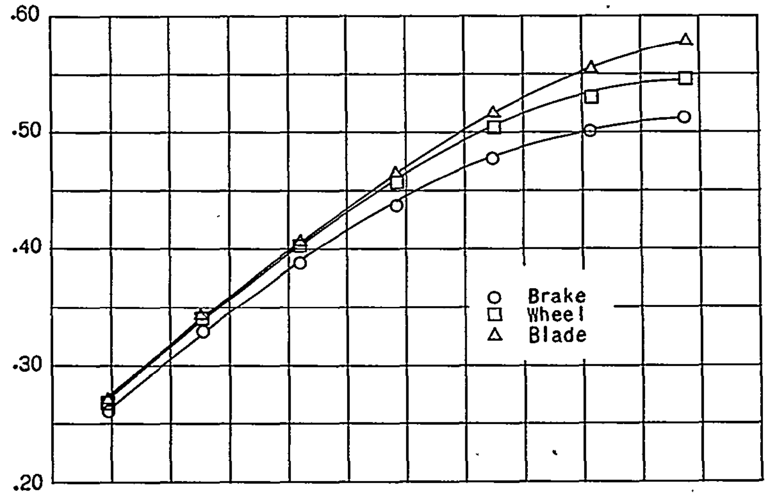
Figure 2. – Variation of windage and mechanical losses with air density and speed in single-stage modified Mark 25 turbine.



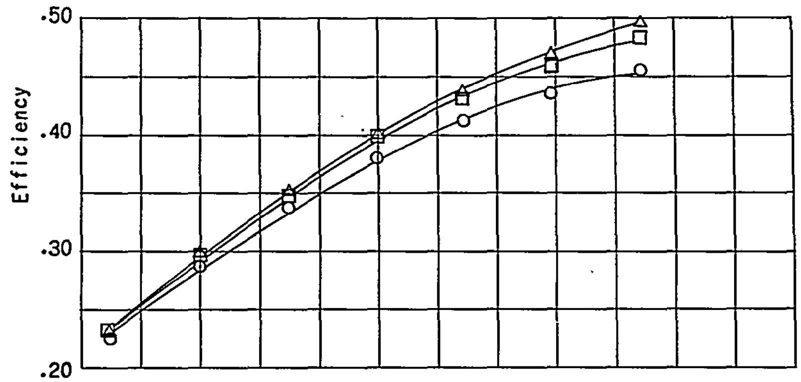
(a) Disk loss plus three-fourths of blade loss for nine-port nozzle.

(b) Disk loss plus eleven-twelfths of blade loss for three-port nozzle.

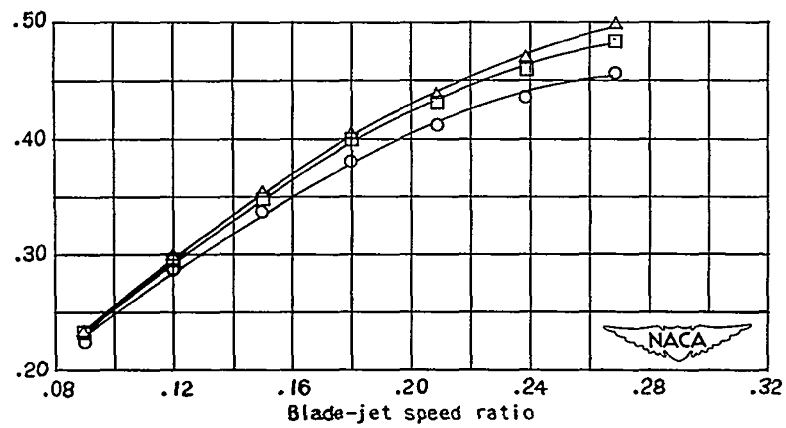
Figure 3. - Variation of calculated windage and mechanical losses with air density and turbine speed in single-stage modified Mark 25 turbine with partial gas admission. (Data from fig. 2.)



(a) Pressure ratio, 8.

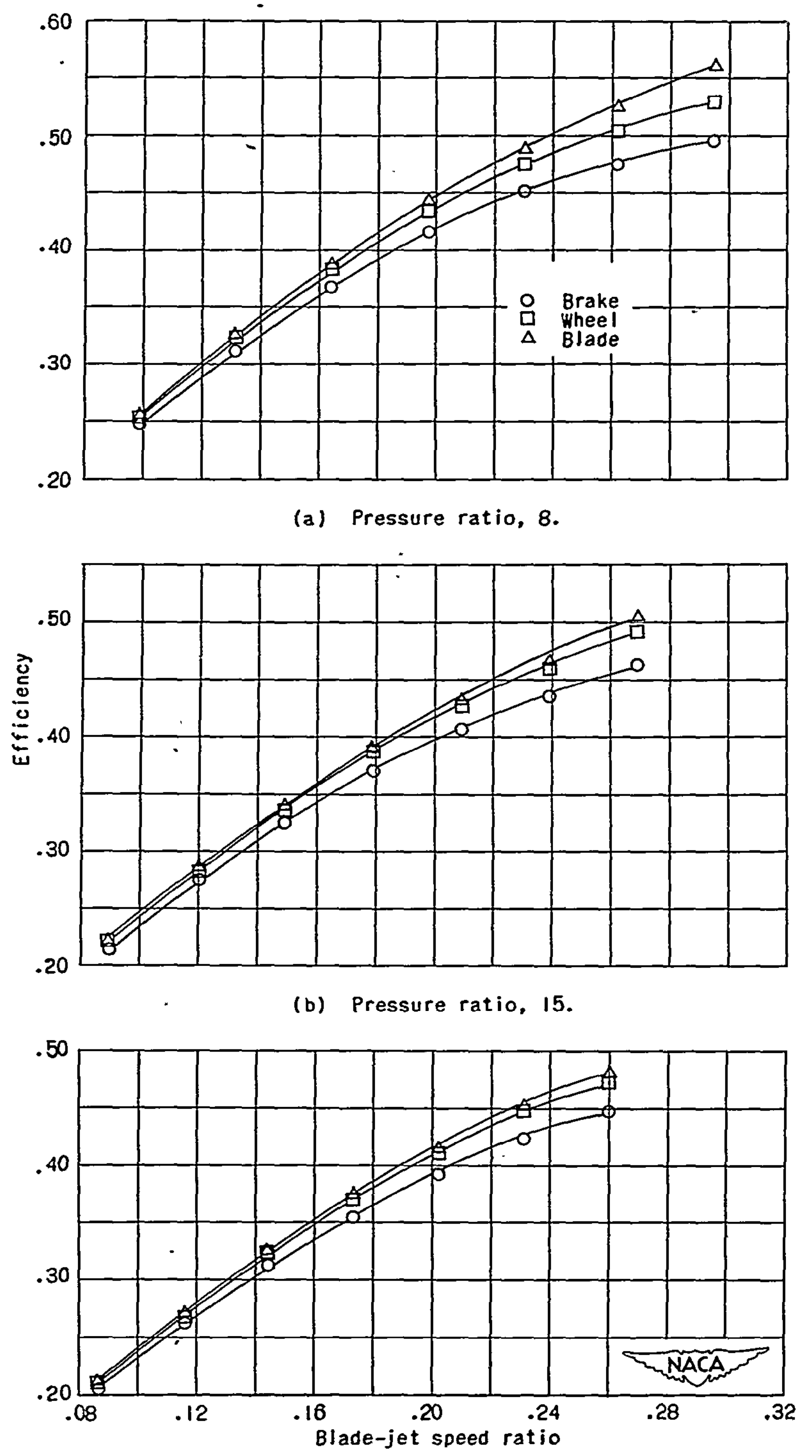


(b) Pressure ratio, 15.



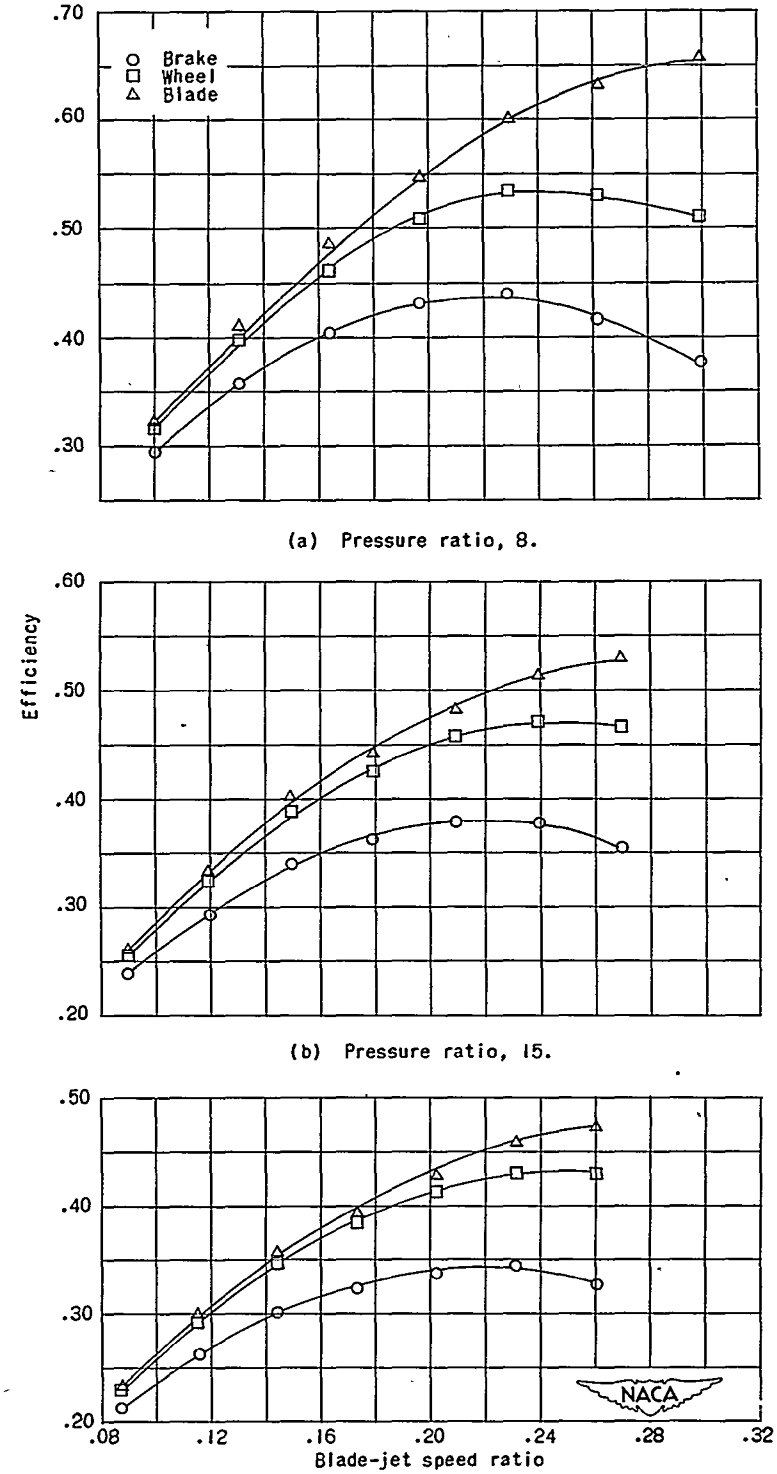
(c) Pressure ratio, 20.

Figure 4. – Variation of power-plant component efficiencies with blade-jet speed ratio in single-stage modified Mark 25 power plant with nozzle A. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.



(c) Pressure ratio, 20.

Figure 5. - Variation of power-plant component efficiencies with blade-jet speed ratio in single-stage modified Mark 25 power plant with nozzle E. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.

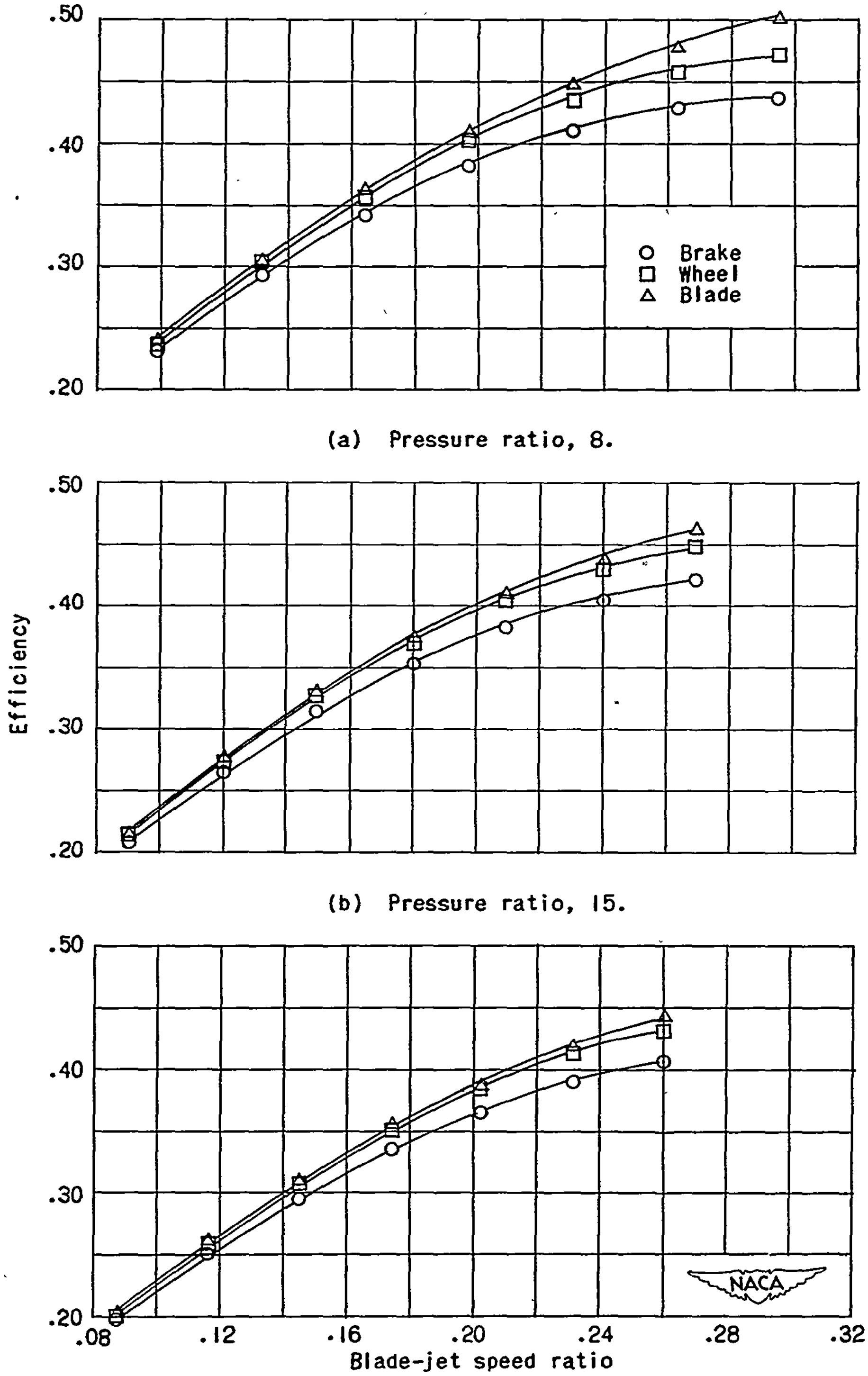


(a) Pressure ratio, 8.

(b) Pressure ratio, 15.

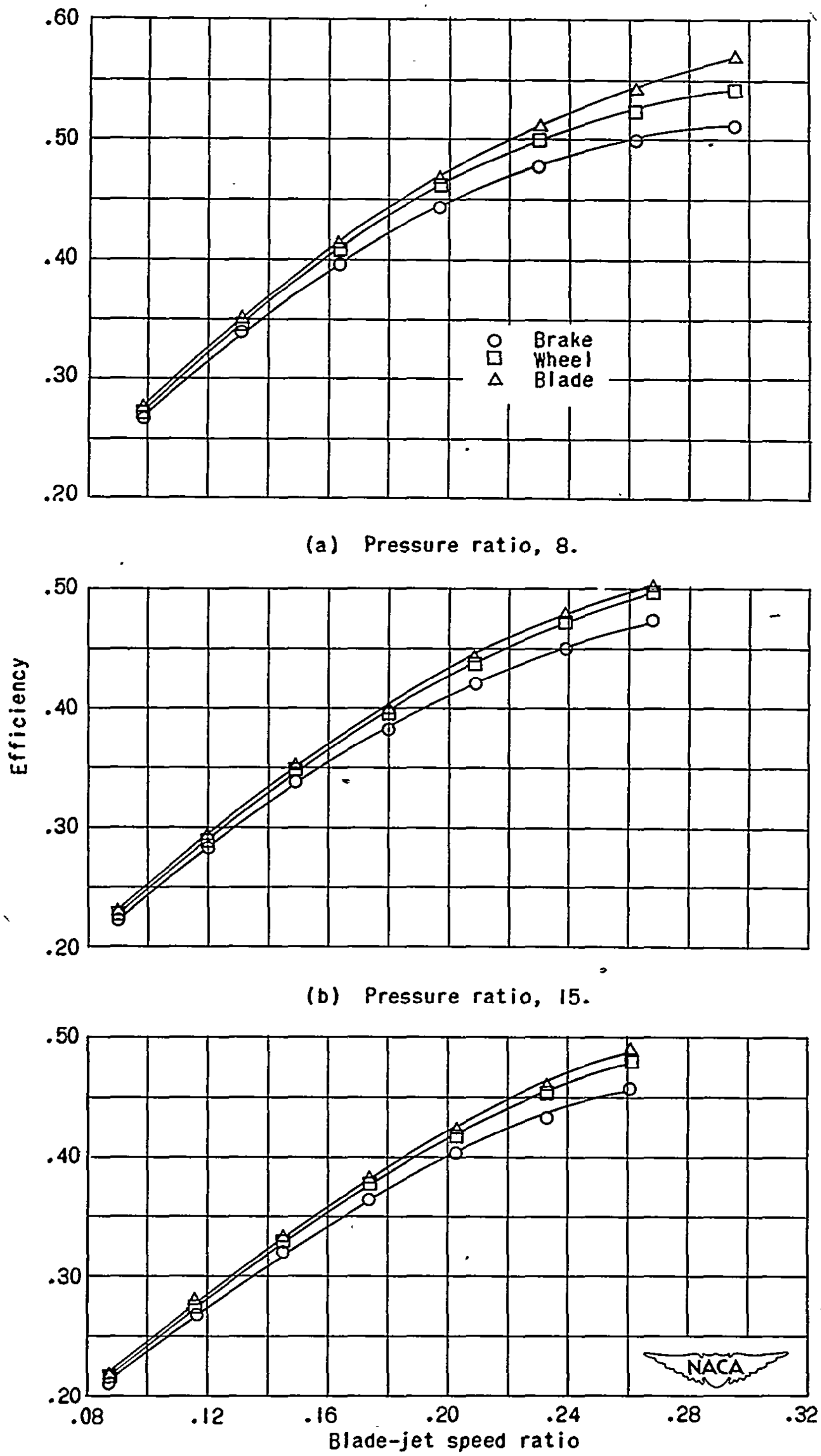
(c) Pressure ratio, 20.

Figure 6. - Variation of power-plant component efficiencies with blade-jet speed ratio in single-stage modified Mark 25 power plant with nozzle F. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.



(c) Pressure ratio, 20.

Figure 7. - Variation of power-plant component efficiencies with blade-jet speed ratio in single-stage modified Mark 25 power plant with nozzle G. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.



(c) Pressure ratio, 19.

Figure 8. - Variation of power-plant component efficiencies with blade-jet speed ratio in single-stage modified Mark 25 power plant with nozzle H. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.

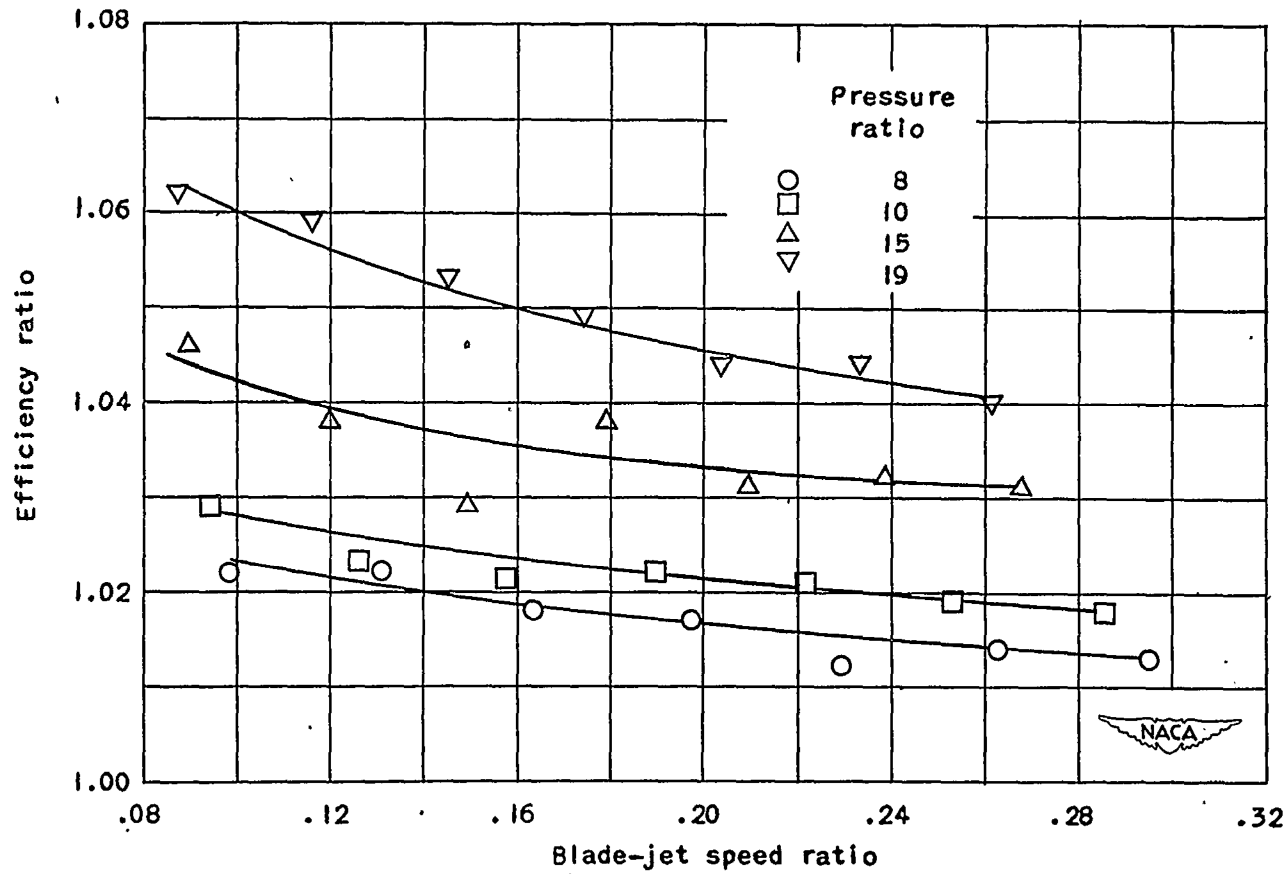
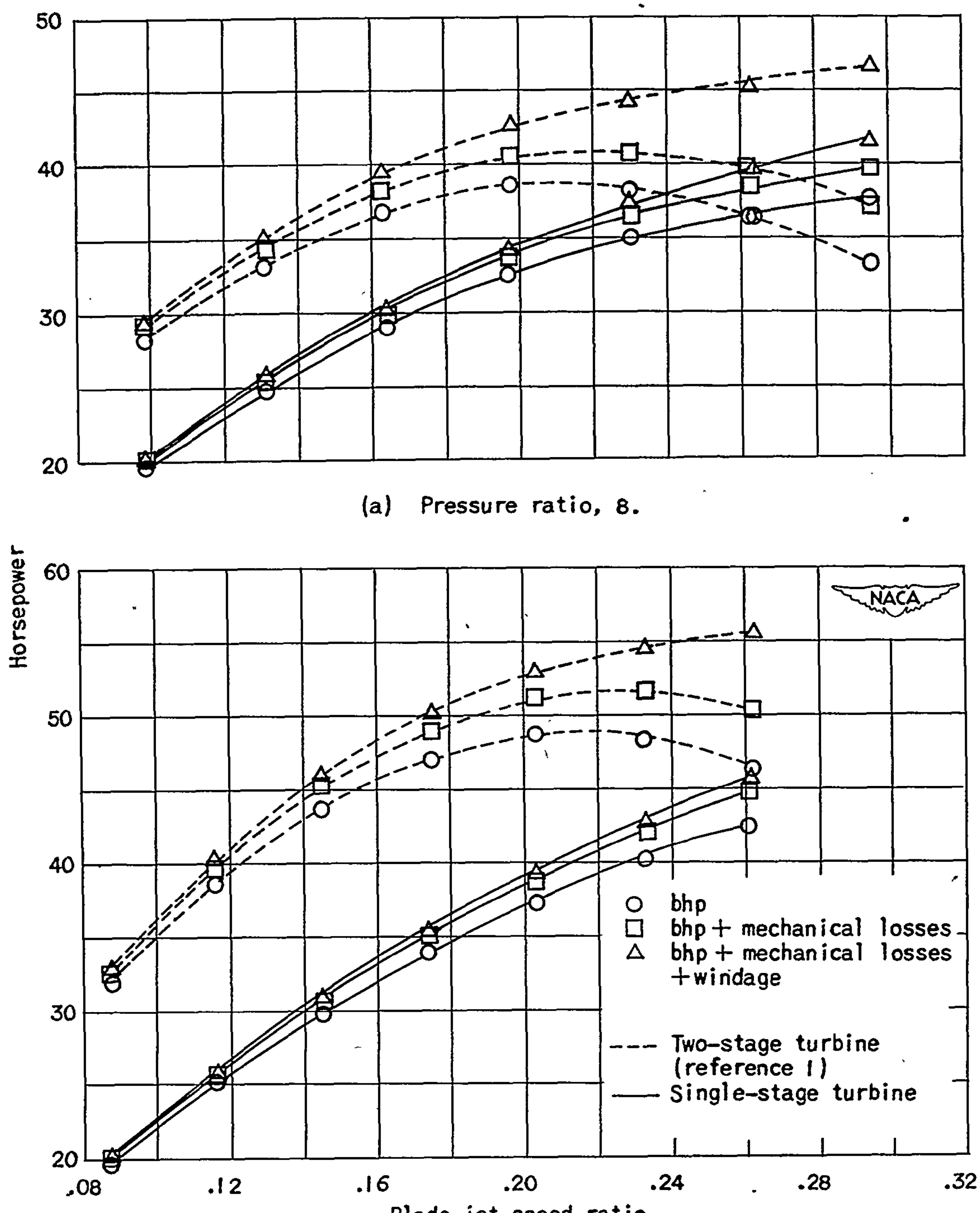


Figure 9. - Variation of efficiency ratio with blade-jet speed ratio for various pressure rati single-stage modified Mark 25 power plant with nozzle H. Inlet-gas temperature, 1000° F; in gas pressure, 95 pounds per square inch gage.



(a) Pressure ratio, 8.

(b) Pressure ratio, 19.

Figure 10. - Comparison of power output for single-stage modification and for standard two-stage Mark 25 power plant with nozzle H. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.

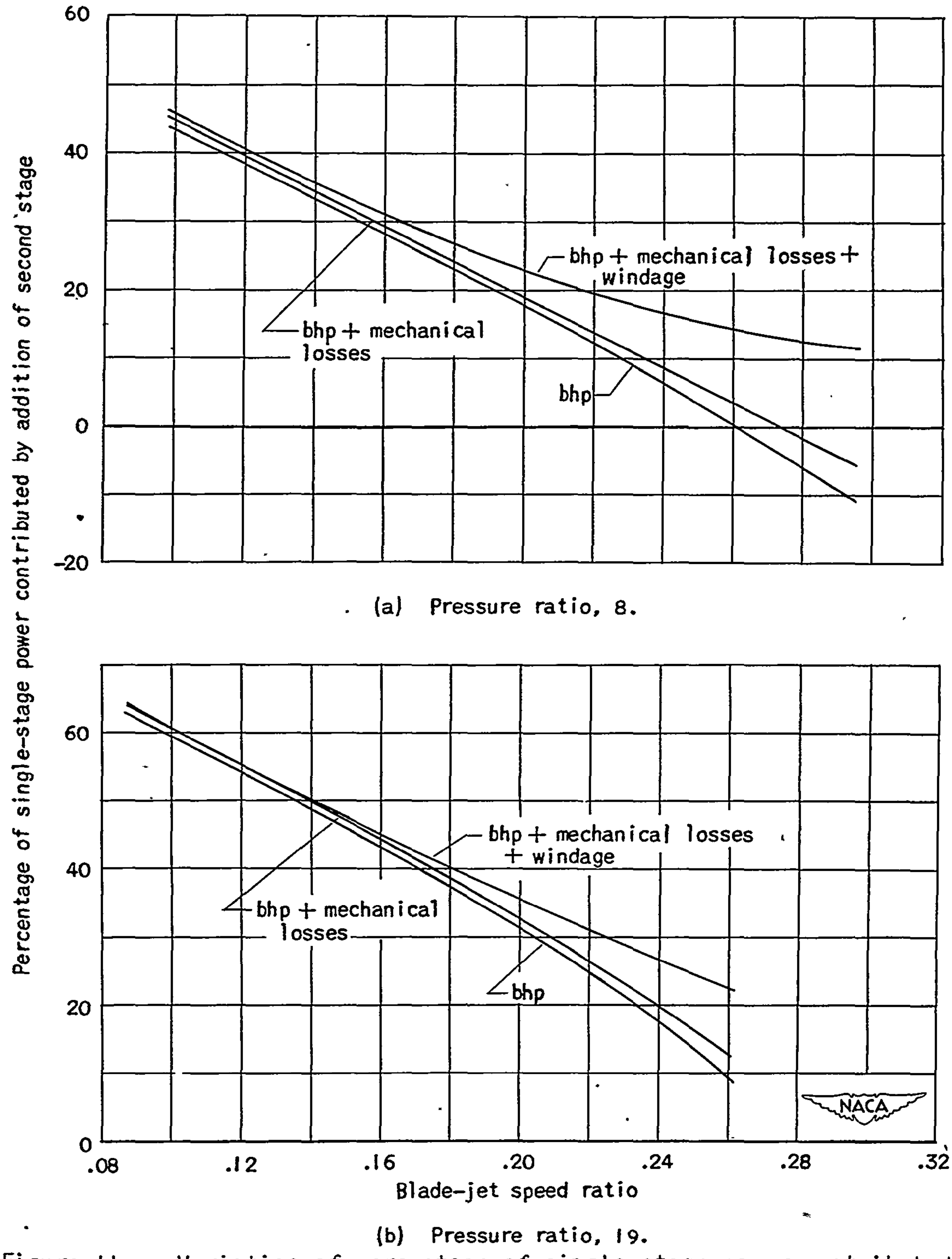


Figure 11. - Variation of percentage of single-stage power contributed by addition of second stage with blade-jet speed ratio in Mark 25 power plant with nozzle H. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage. (Data from fig. 10.)

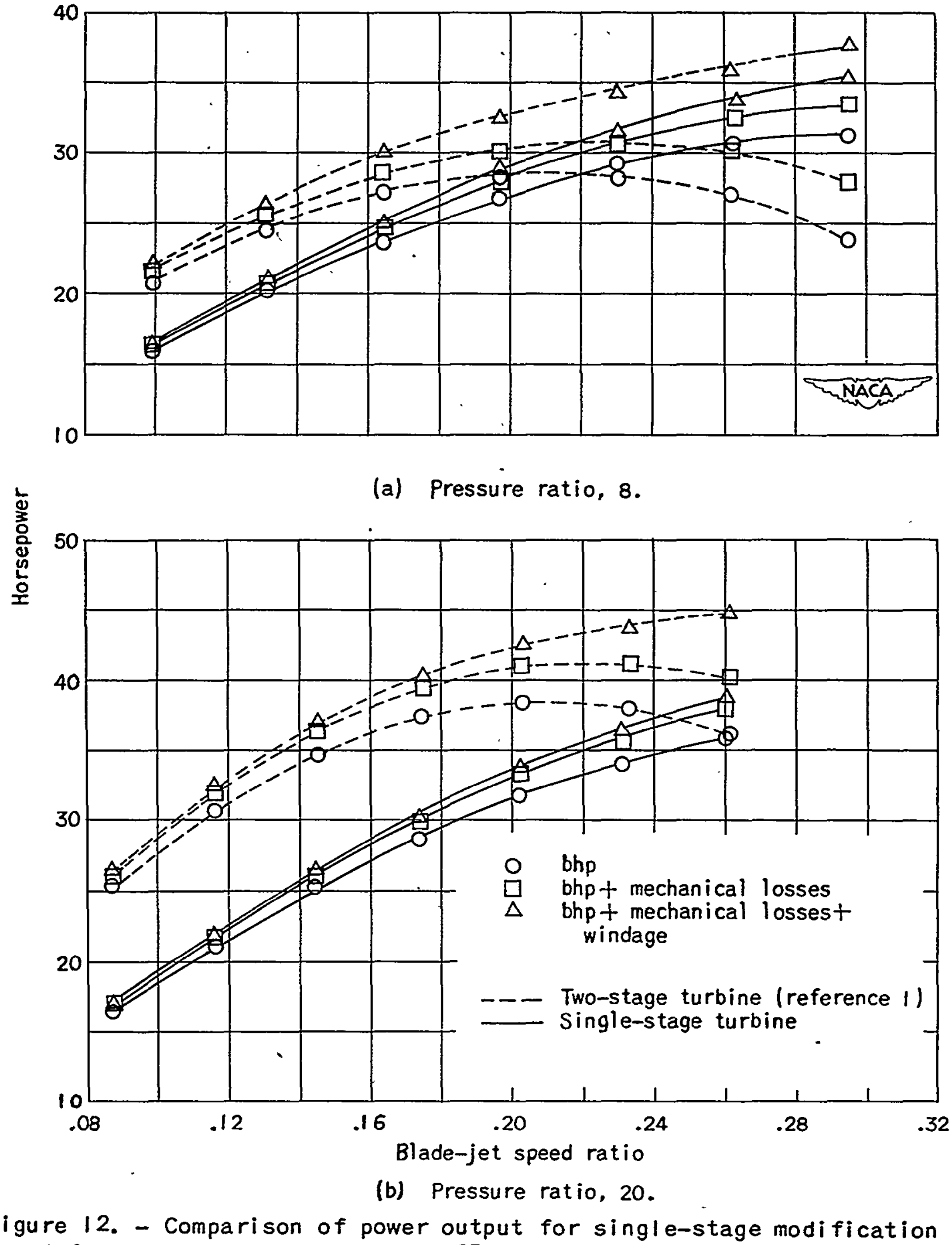


Figure 12. - Comparison of power output for single-stage modification and for standard two-stage Mark 25 power plant with nozzle A. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage.

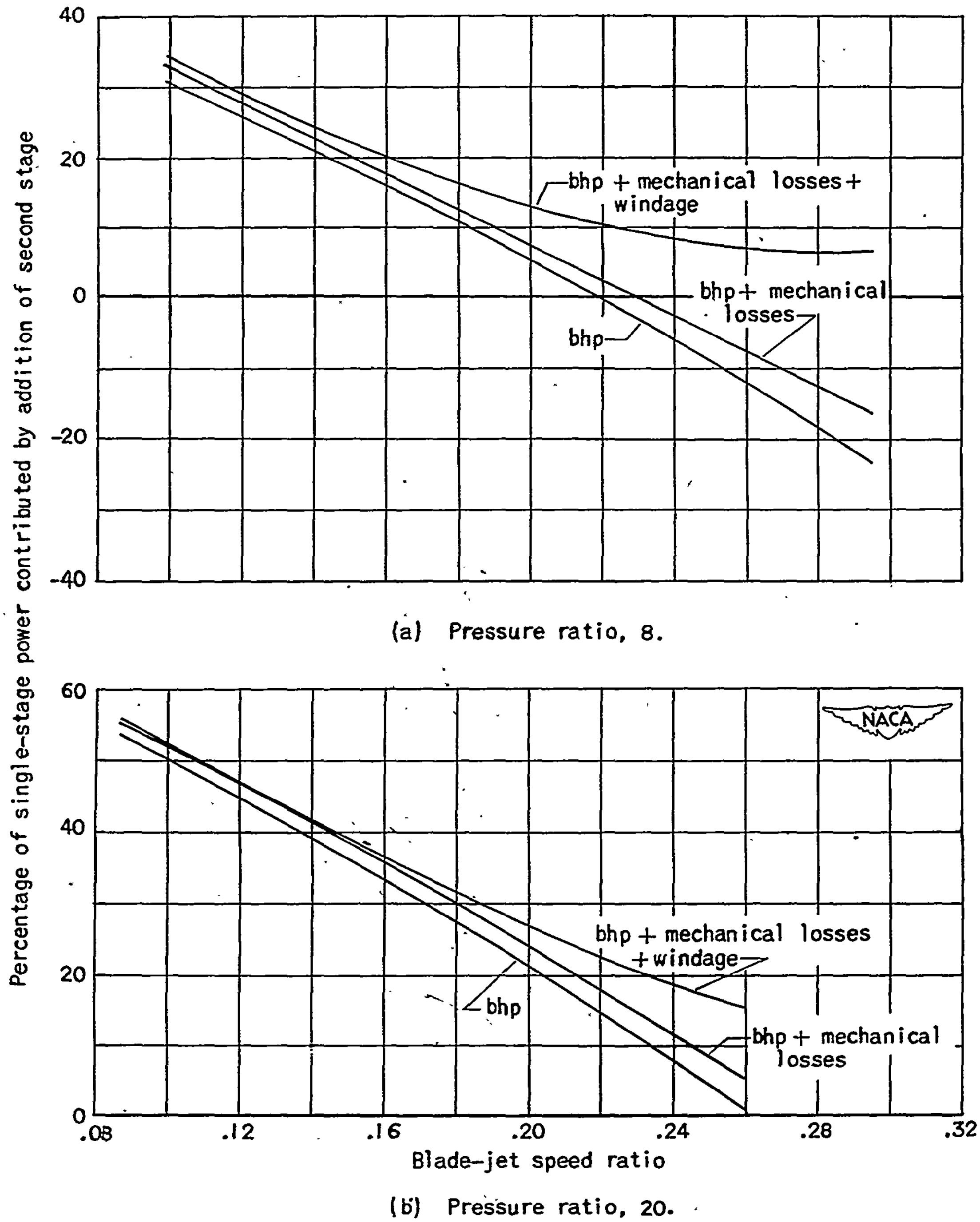


Figure 13. - Variation of percentage of single-stage power contributed by addition of the second stage with blade-jet speed ratio in Mark 25 power plant with nozzle A. Inlet-gas temperature, 1000° F; inlet-gas pressure, 95 pounds per square inch gage. (Data from fig. 12.)