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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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ORIGINALLY ISSUED

October 1945 as
Advance Restricted Report E5J03

PERFORMANCE COMPARISON OF TWO DEEP INDUCERS AS SEPARATE COMPONENTS AND IN COMBINATION WITH AN IMPELLER

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PERFORMANCE COMPARISON OF TWO DEEP INDUCERS AS SEPARATE COMPONENTS AND IN COMBINATION WITH AN IMPELLER

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SUMMARY

Two deep inducers were tested as separate components and in combination with an impeller as a part of an investigation to correlate design requirements of inducers and impellers. The inducers were designed to impart solid-body, or wheel, rotation to the entering air at constant angular acceleration along the axial depth. The axial depths were 3.00 inches and 2.12 inches. The design load coefficients were 0.24 cubic foot per revolution for the 3.00-inch inducer and 0.35 cubic foot per revolution for the 2.12-inch inducer. The impeller had straight radial blades and a ratio of discharge to inlet areas of 0.715 with uniform change of area along the passage. The inlet diameters of the 24-blade impeller and inducers were 8 inches and the impeller diameter was 12 inches.

Both the inducers, when tested as separate components at a speed corresponding to an impeller tip speed of 1000 feet per second, had a peak adiabatic efficiency of approximately 82 percent. The peak efficiency in each case occurred very near the design load coefficient. The tangential velocity distribution at the discharge from the 3.00-inch inducer approached solid-body rotation more closely than that of the 2.12-inch inducer.

The efficiency curves for the two inducer-impeller combinations at a tip speed of 800 feet per second were practically the same; each was flat with a peak efficiency at the impeller discharge of 88 percent. At tip speeds of 1000 and 1200 feet per second the 2.12-inch inducer-impeller combination operated in a higher load-coefficient range and reached a higher efficiency than the 3.00-inch inducer-impeller combination. The relation between efficiency of the inducer and efficiency of the inducer-impeller unit is indefinite; however,

a comparison indicates that the flow capacity of the inducer as a separate component is reflected in the flow capacity of the inducer-impeller unit.

INTRODUCTION

The performance of a centrifugal supercharger is dependent upon the effectiveness with which each component part functions and by the degree of matching of characteristics of the components. The inducer, the component that imparts angular velocity of the impeller to the entering air, is one of the important centrifugal-supercharger components.

As part of a program to investigate the requirements and the design criterions of inducers and the relations between inducers and impellers, a family of single-stage deep inducers was designed and constructed for tests as separate components and in combination with impellers. Three inducers of this family of design were tested as separate supercharger components and the results are reported in reference 1. The present report covers the results of tests, made at the NACA Cleveland laboratory, of two more of this family of constant angular-acceleration inducers as separate components and in combination with an impeller. The inducers as separate components were rated on adiabatic efficiency and on their ability to impart angular velocity to the air; the performance of each in combination with the same impeller was obtained.

APPARATUS

Inducers. - The inducers were single-stage deep inducers designed to impart solid-body, or wheel, rotation to the entering air at constant angular acceleration along the axial depth. The design of this type of inducer is described in reference 1. Both of the inducers used in these tests had 24 blades, a constant outside diameter of 8 inches, and a constant hub diameter of 3 inches. One inducer had an axial depth of 3.00 inches and a design load coefficient of 0.24 cubic foot per revolution. The other inducer had the same blade curvature but an axial depth of 2.12 inches, making the design load coefficient 0.35 cubic foot per revolution.

Comparative design data for the two inducers, at a tip speed of 1000 feet per second of the impeller with which they were combined are:

		Design conditions		
Axial depth (in.)	Blade entrance edge	Load coefficient (cu ft/revolution)	Lift coefficient (rms diam.)	Acceleration of air (radians/sec^2)
3.00	Rounded	0.24	0.574	2.00×10^6
2.12	---do---	.35	.729	4.13

The inducers used for testing as separate components were aluminum castings and those used for the tests with the impeller were machined from an aluminum forging. The inducers used for the two types of test were the same except for slight dimensional inaccuracies of the castings. The 2.12-inch inducer was, in each case, obtained by cutting back the entrance of the 3.00-inch inducer.

Inducer-impeller units. - The inducer-impeller units consisted of each inducer assembled in turn with the same radial-bladed impeller.

The impeller was 12 inches in diameter with an 8-inch inlet diameter and a 3-inch hub. The 24-blade impeller was modeled, in rear-shroud profile, after an existing impeller of good performance characteristics and the passage area was made to converge, by selection of front-shroud profile, at a constant rate along the mean-flow path so that the ratio of discharge passage area to impeller-inlet passage area was 0.715. The inducer-impeller unit with the 3.00-inch and with the 2.12-inch inducers is shown in figure 1.

Test setup. - The inducers were tested as separate components in the inducer test rig described in reference 1. The inducer-impeller units were tested with a vaneless diffuser in a variable-component supercharger test rig. (See fig. 2.) The vaneless diffuser was 34 inches in diameter and was similar in design to diffusers that in previous tests had shown good pressure conversion over a wide range of operating conditions. The variable-component supercharger test rig was the same as described in reference 2 except that a flat-plate front collector cover was used for simplification of instrument installation. The test rig was driven by a 1000-horsepower aircraft engine in conjunction with a speed-increasing gear.

Instrumentation. - Instrumentation for the tests of the inducers as separate components is described in reference 1. Temperature and pressure measurements for the variable-component supercharger were made according to the standards in references 2 and 3 wherever applicable. Location of the measuring stations are shown in figure 3. All air temperatures were measured with iron-constantan thermocouples and a direct-reading potentiometer. Each thermocouple and the potentiometer were calibrated in the installation against a Bureau of Standards thermocouple. Total-pressure measurements in the inlet and outlet ducts were obtained with steel total-pressure tubes of 0.093-inch outside diameter and 0.067-inch bore. Static wall taps of 0.020-inch bore were also used in the inlet and outlet ducts.

A directional total- and static-pressure survey tube of 3/16-inch outside diameter of the type described in reference 4 was used for taking surveys of total and static pressure across the diffuser passage at a radial position of 3/8 inch from the impeller tip (fig. 2). Static wall taps of 0.020-inch bore were used in both the front and the rear diffuser walls at a radial position of 3/8 inch from the impeller tip.

Air-flow and pressure regulation was provided by throttle valves of the butterfly type in both the inlet and the discharge ducts. A large orifice tank with a thin-plate orifice at the entrance to measure the quantity of air flow (reference 5) was attached to the inlet duct.

The desired constant speed was maintained with a speed strip and a stroboscopic light operated on 60-cycle current. An electric counter and a stop watch were used to check the speed.

TESTS

Both inducers were tested as separate components at the speed corresponding to a tip speed of 1000 feet per second of the impeller, according to the procedure given in reference 1. Tests of the inducer-impeller units were conducted according to the procedure given in references 2 and 3. For each constant tip speed the volume flow was varied in a number of steps from wide-open throttle to pulsation. No tests were made in or below the pulsation range because it was desired to explore as widely as possible the operating range free of pulsation before subjecting the inducer-impeller unit to possible mechanical failure. A constant outlet total pressure of 10 inches of mercury above atmospheric pressure was maintained for all throttle settings, except at wide-open throttle.

Tests of the 3.00-inch inducer-impeller unit were made at impeller tip speeds of 800, 1000, and 1200 feet per second with the directional survey tube installed in the diffuser passage. The tests were being repeated without the survey tube when the partial failure of an inducer blade occurred, and only the test at 1000 feet per second was completed.

The 2.12-inch inducer-impeller unit was tested without the survey tube installed at impeller tip speeds of 700, 800, 900, 1000, and 1200 feet per second. Tests at higher speeds were prevented by failure of the impeller shaft.

RESULTS AND DISCUSSION

Inducers as Separate Components

The 3.00-inch inducer. - The tangential discharge velocities produced by the 3.00-inch inducer are shown in figure 4 for an impeller tip speed of 1000 feet per second. The load coefficient Q_1/n and the blade angle of attack α is shown for each test condition; the tangential velocity required for wheel rotation is represented by a solid line. The inducer produced tangential velocities approaching those of wheel rotation as design flow conditions were approached. Velocities definitely lower than those required for wheel rotation were evident near the wall. This characteristic was common to all the inducers of the constant angular-acceleration family (reference 1).

Excess temperature rise, adiabatic efficiency, and slip factor at an impeller tip speed of 1000 feet per second, computed according to procedure given in reference 1, are shown in figure 5. A maximum adiabatic efficiency of approximately 82 percent was reached at a load coefficient of 0.25. The slip factor, which was below 1.0 at high flows and above 1.0 for low flows, is similar to that of the 2-inch, 24-blade inducer described in reference 1.

The 2.12-inch inducer. - A tangential-velocity plot for an impeller tip speed of 1000 feet per second is shown in figure 6 for the 2.12-inch inducer. The velocities near the design flow did not approach wheel rotation so closely as those of the 3.00-inch inducer because of an increased departure from wheel rotation near the wall.

As shown in figure 7, a peak adiabatic efficiency of approximately 82 percent was reached at a load coefficient of 0.33. A slip factor of 0.97 was reached at the corresponding flow and increased to 0.99 at a load coefficient of 0.23.

For both the 3.00-inch and the 2.12-inch inducers peak efficiency occurred very near their respective design load coefficients.

Inducer-Impeller Units

Over-all performance of inducer-impeller units. - The over-all adiabatic efficiencies for the 2.12-inch inducer-impeller unit at impeller tip speeds of 800, 1000, and 1200 feet per second and for the 3.00-inch inducer-impeller unit at an impeller tip speed of 1000 feet per second are shown in figure 8. At a tip speed of 1000 feet per second the presence of the survey tube caused a drop of 4 to 20 points in adiabatic efficiency of the unit with the 3.00-inch inducer. It is therefore apparent that the over-all results with the survey tube in place are of no value in defining the characteristics of the inducer-impeller combinations and are not shown except for the condition for which data were obtained both with and without the survey tube in place. A diffuser lamp-black pattern (fig. 9) shows the disturbed flow in the diffuser channel caused by the survey tube at peak efficiency and at a tip speed of 800 feet per second.

Performance computed at the impeller discharge. - The performance characteristics of the 3.00-inch and the 2.12-inch inducer-impeller combinations were compared on the basis of efficiency computed at the impeller discharge. The ratings computed from measurements in the discharge duct do not furnish proper comparison because most of the tests with the 3.00-inch inducer-impeller unit were made with the survey tube in place. The comparative performance of the 3.00-inch inducer unit and the 2.12-inch inducer unit, based on impeller-discharge ratings, was computed from arithmetic averages of total-pressure surveys for the unit with the 3.00-inch inducer and static wall-tap pressure measurements for the unit with the 2.12-inch inducer. Static pressures could not be used for the 3.00-inch inducer-impeller unit because the static wall taps were located in the wake of the survey tube. (See fig. 9.) Inasmuch as tests of the 3.00-inch inducer-impeller unit both with and without the survey tube were made at a tip speed of 1000 feet per second, this test served as a correlation for the performance comparison. The correlation is shown in figure 10 and the comparative performance in figure 11.

The total pressure at a point in the diffuser 0.375 inch from the impeller discharge (6.375-in. radius) may be determined from the computed dynamic pressure and the measured static pressure. The calculations are made on the assumptions that there is no change in total temperature of the air from the impeller tip through the insulated system to the measuring station in the discharge duct, that the friction loss in the short flow length is negligible, and that the velocity profile is uniform across the diffuser passage. The velocity and the density of the air may be found from the measured static pressure, the continuity of flow, and the foregoing stated assumptions.

Comparison of the efficiencies of the 3.00-inch inducer-impeller and the 2.12-inch inducer-impeller units (fig. 11) shows that at a tip speed of 800 feet per second the adiabatic-efficiency values were practically the same; each was flat with a peak efficiency of 88 percent. At tip speeds of 1000 and 1200 feet per second the 2.12-inch inducer-impeller unit operates in a higher load-coefficient range and maintains a higher adiabatic efficiency. The maximum load-coefficient difference between the two at the higher tip speeds reflects the change in inducer design load coefficient.

Comparison of Inducer Performance as a Separate and as an Integral Impeller Component

Figure 12 shows the efficiency of the 3.00-inch and 2.12-inch inducers as separate components, of the inducer-impeller units, and of the complete installation of inducer-impeller unit and diffuser in the variable-component supercharger at a tip speed of 1000 feet per second.

The 3.00-inch inducer, which had discharge characteristics more nearly approaching solid-body rotation, had approximately the same peak adiabatic efficiency as a separate component as the 2.12-inch inducer. The peak adiabatic efficiency in each case occurred near the design load coefficient. The maximum efficiency of the inducer-impeller unit with the 2.12-inch inducer was 87.2 percent and with the 3.00-inch inducer was 82.8 percent; both peak efficiencies were near the load coefficients for peak efficiencies of the inducers as separate components. In the over-all rating of the units with the diffuser in the variable component supercharger, however, the unit with the 3.00-inch inducer had an efficiency of about 1 point higher than the unit with the 2.12-inch inducer. Although the higher flow may have an influence on other variables, it is probable that the better rotational characteristics obtained with the 3.00-inch inducer would produce a more uniform flow in the impeller and result in lower mixing losses in the diffuser.

The relation between efficiency of the inducer and efficiency of the inducer-impeller unit is indefinite; however, a comparison indicates that the flow capacity of the inducer as a separate component is reflected in the flow capacity of the inducer-impeller unit.

CONCLUSION

The flow capacity of an inducer as a separate component is reflected in the flow capacity of an inducer-impeller unit.

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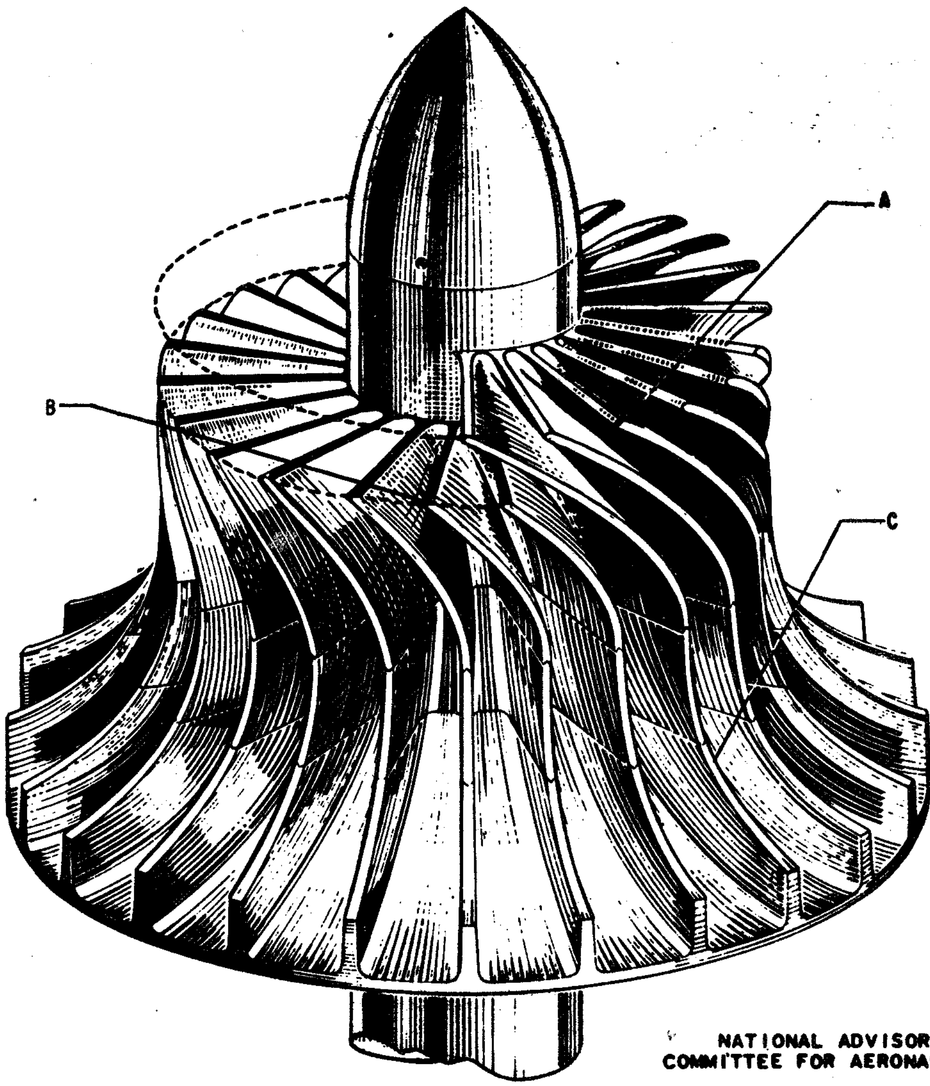
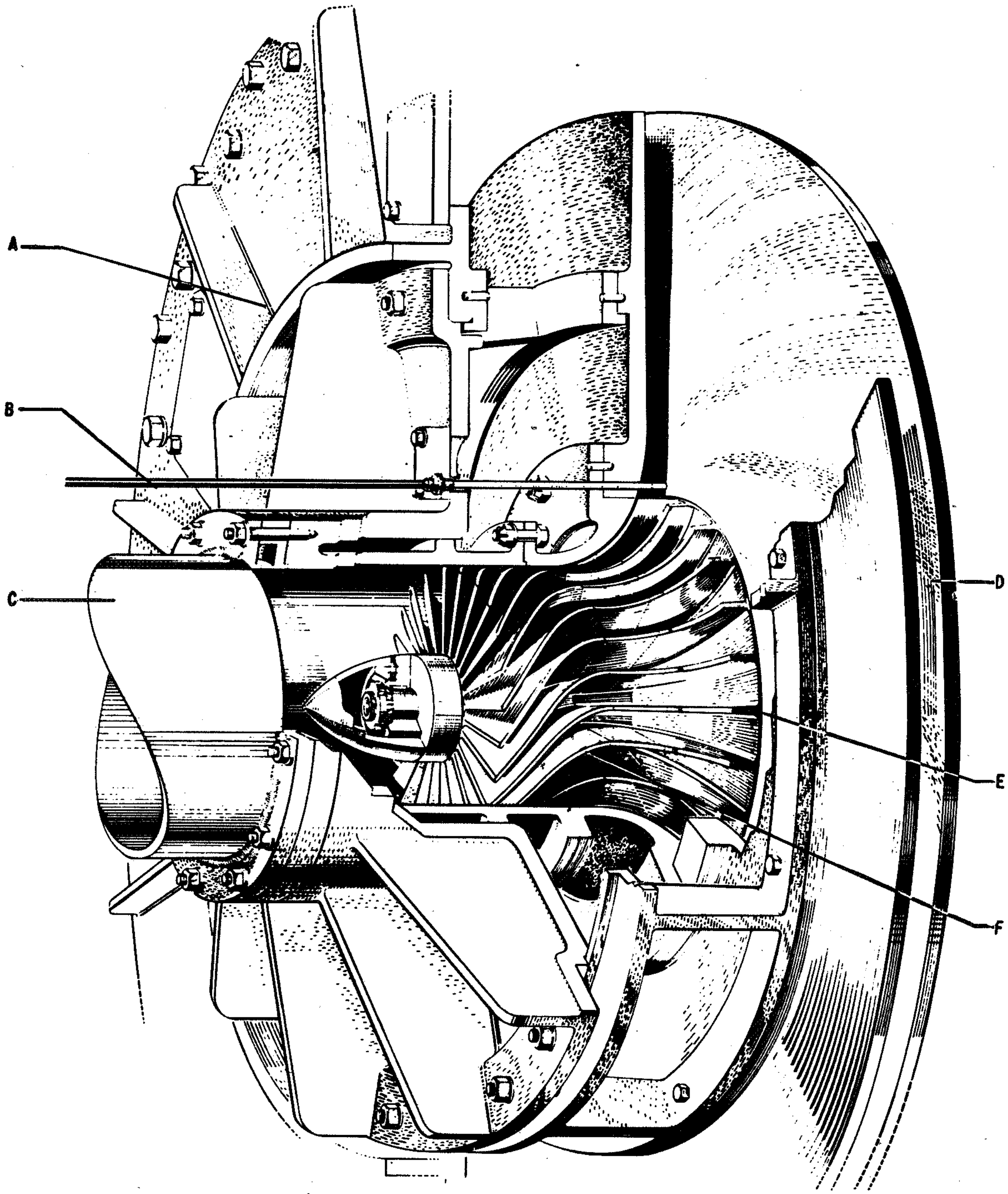


A 3.00-inch machined deep inducer
B 3.00-inch inducer cut back to an axial depth of 2.12-inches.
C Impeller

Figure 1. - Inducer-impeller unit with 3.00-inch and 2.12-inch inducers.



A Collector cover plate
B Survey tube
C Inlet pipe
D Vaneless diffuser
E Impeller
F 3.00-inch inducer

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Figure 2. - Assembly of 3.00-inch inducer, impeller, and vaneless diffuser in variable-component supercharger test rig.

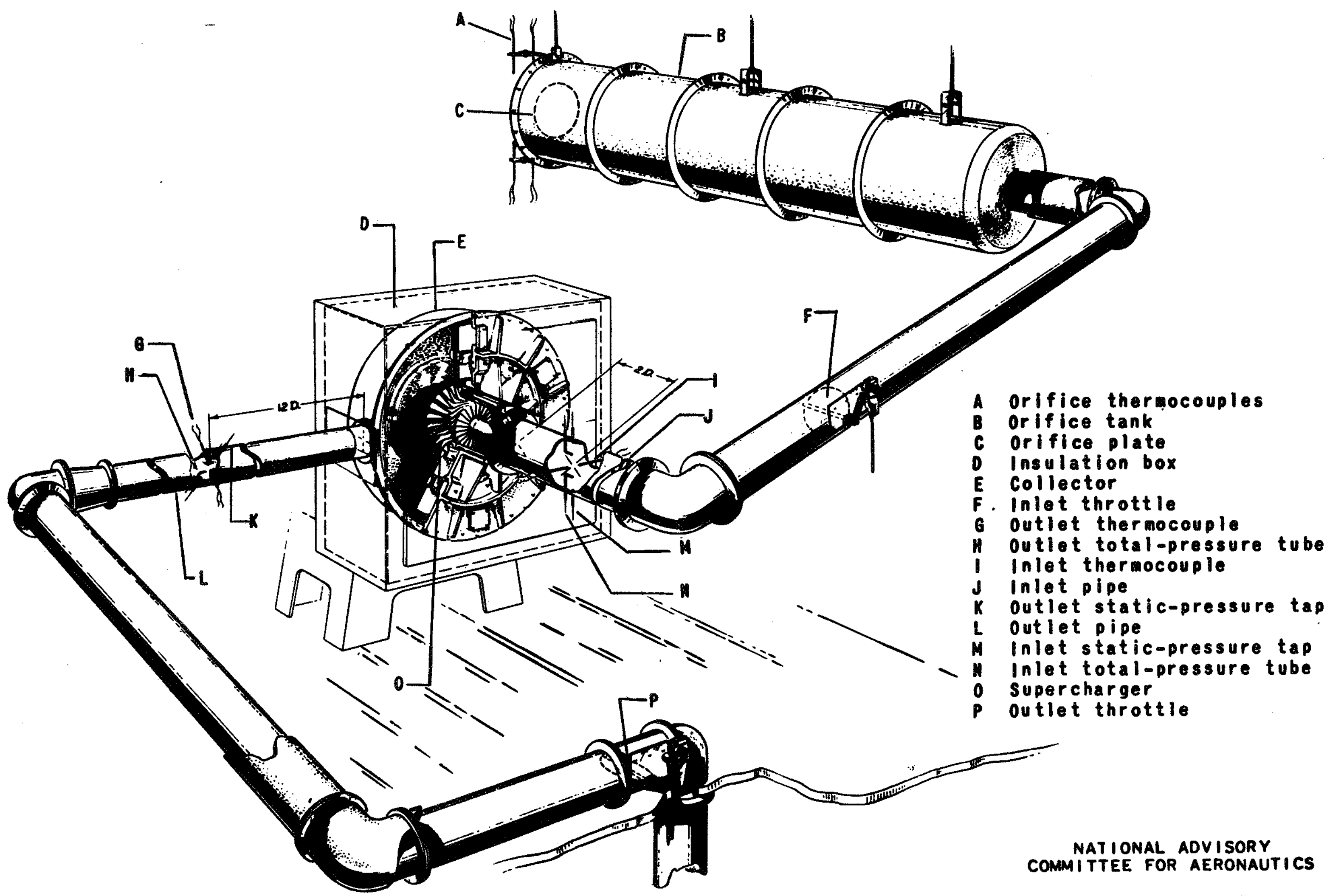

Figure 3. - Variable-component-supercharger test installation showing location of instruments.

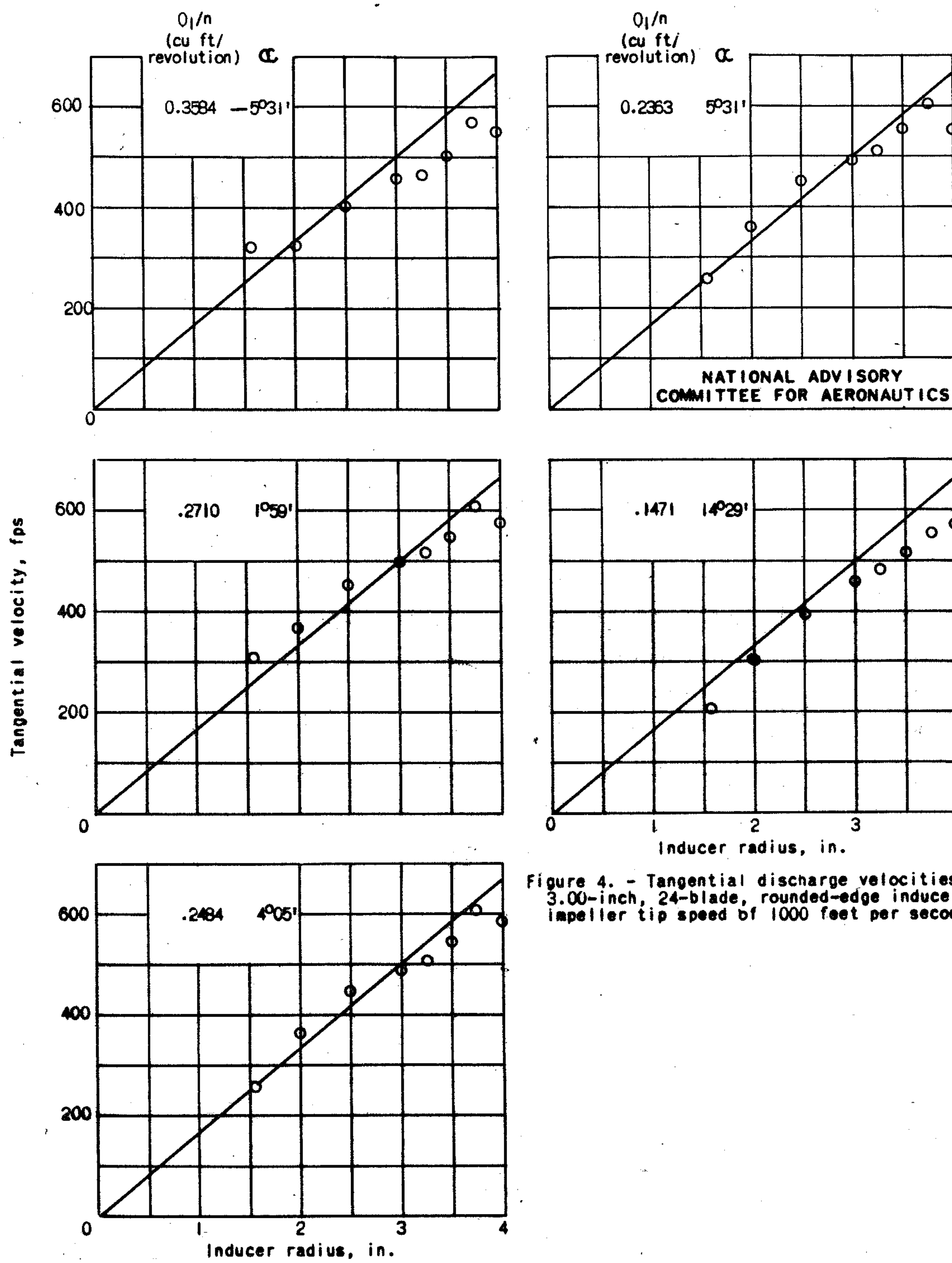

Figure 4. - Tangential discharge velocities for 3.00-inch, 24-blade, rounded-edge inducer at impeller tip speed of 1000 feet per second.

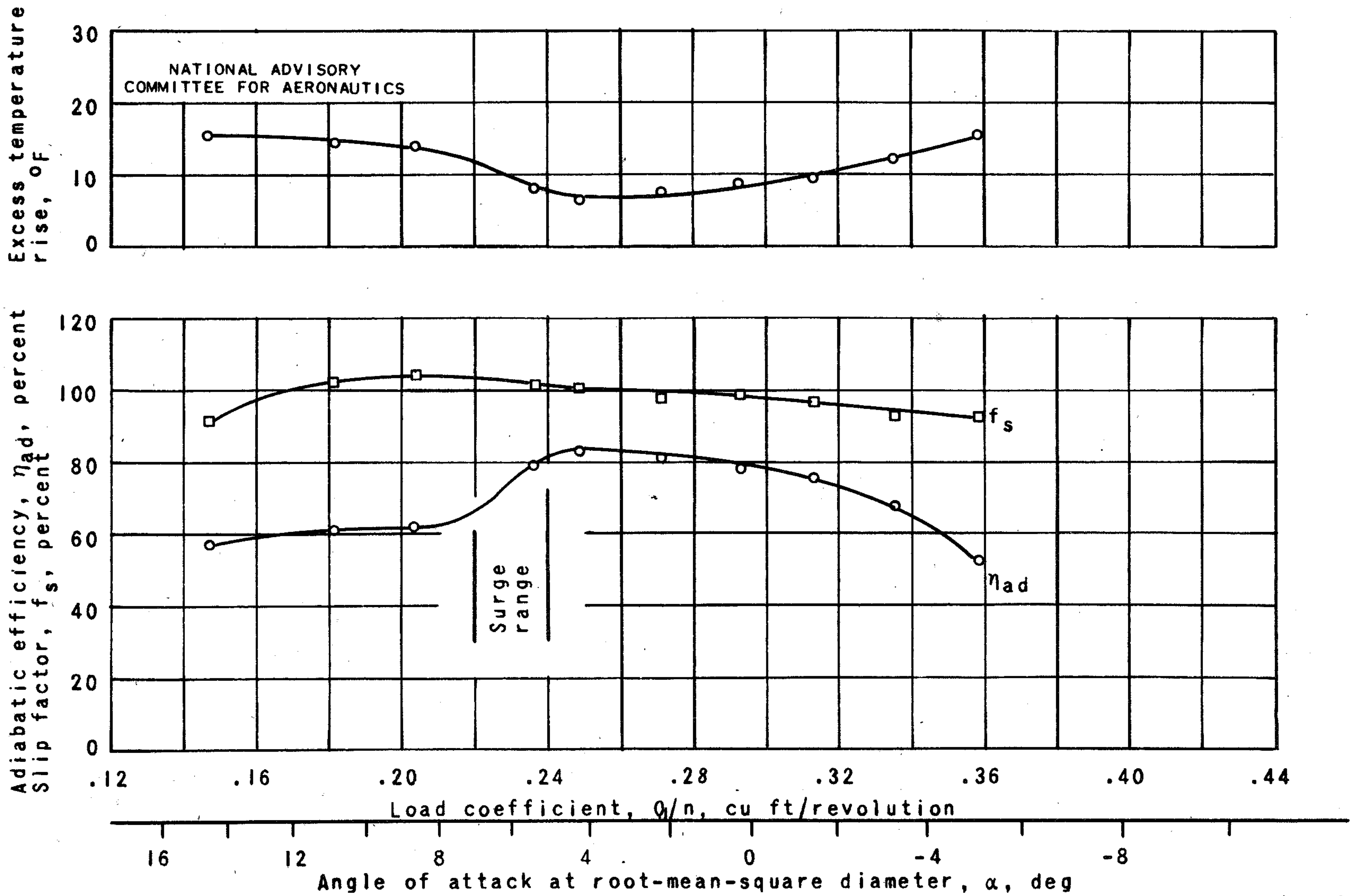

Figure 5. - Performance characteristics of 3.00-inch, 24-blade, rounded-edge inducer at impeller tip speed of 1000 feet per second.

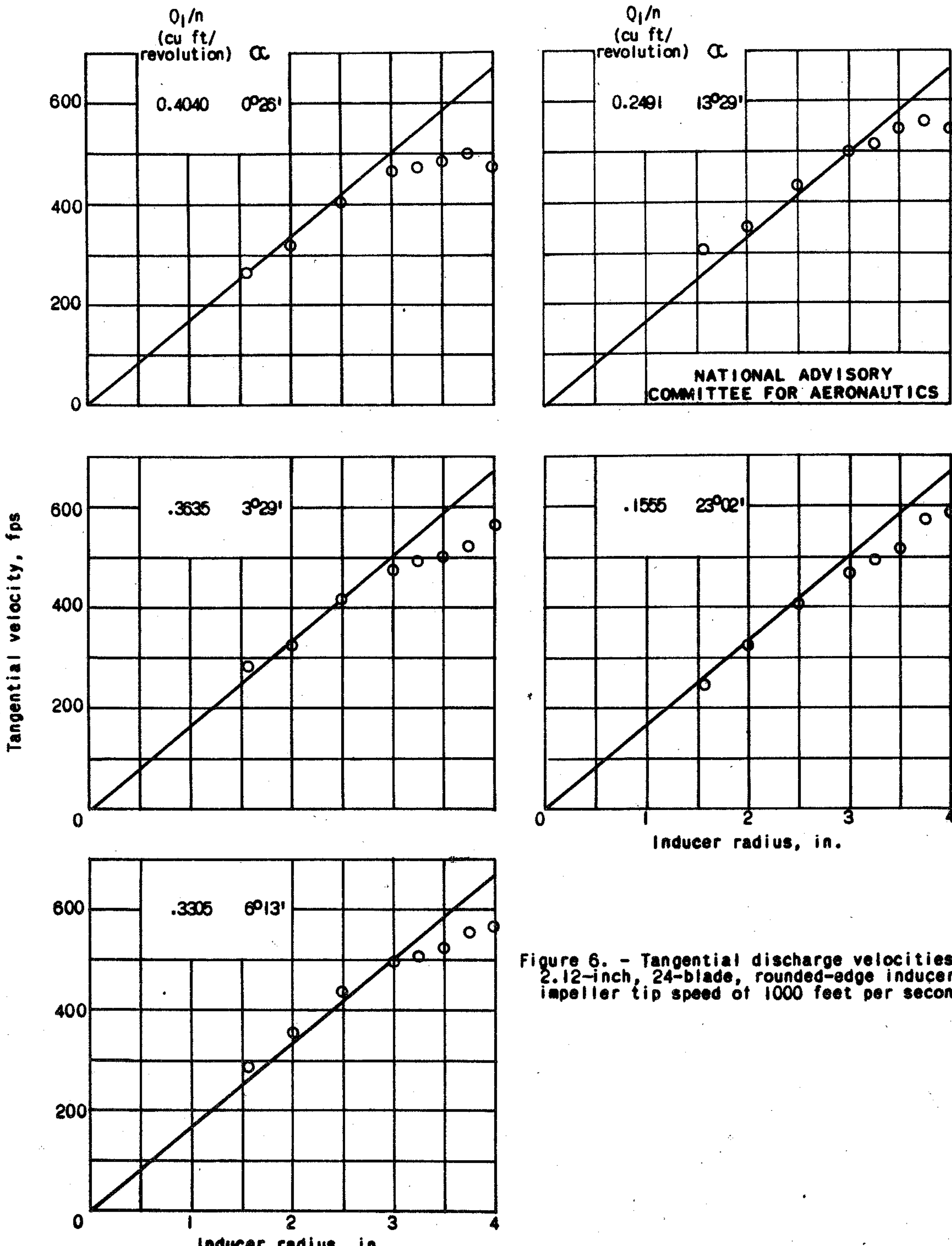

Figure 6. - Tangential discharge velocities for 2.12-inch, 24-blade, rounded-edge inducer at impeller tip speed of 1000 feet per second.

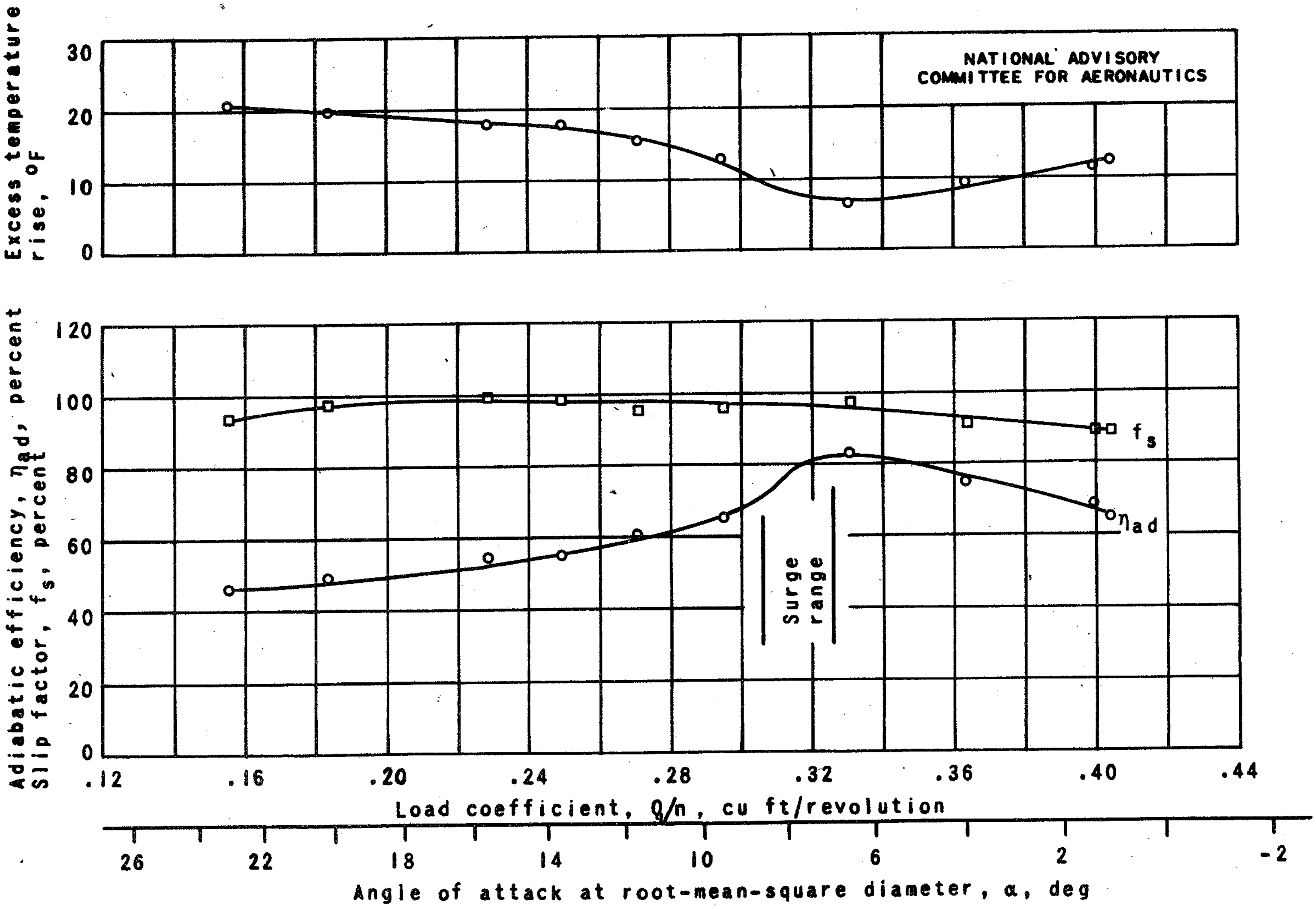

Figure 7. - Performance characteristics of 2.12-inch, 24-blade, rounded-edge inducer at impeller tip speed of 1000 feet per second.

Fig. 7

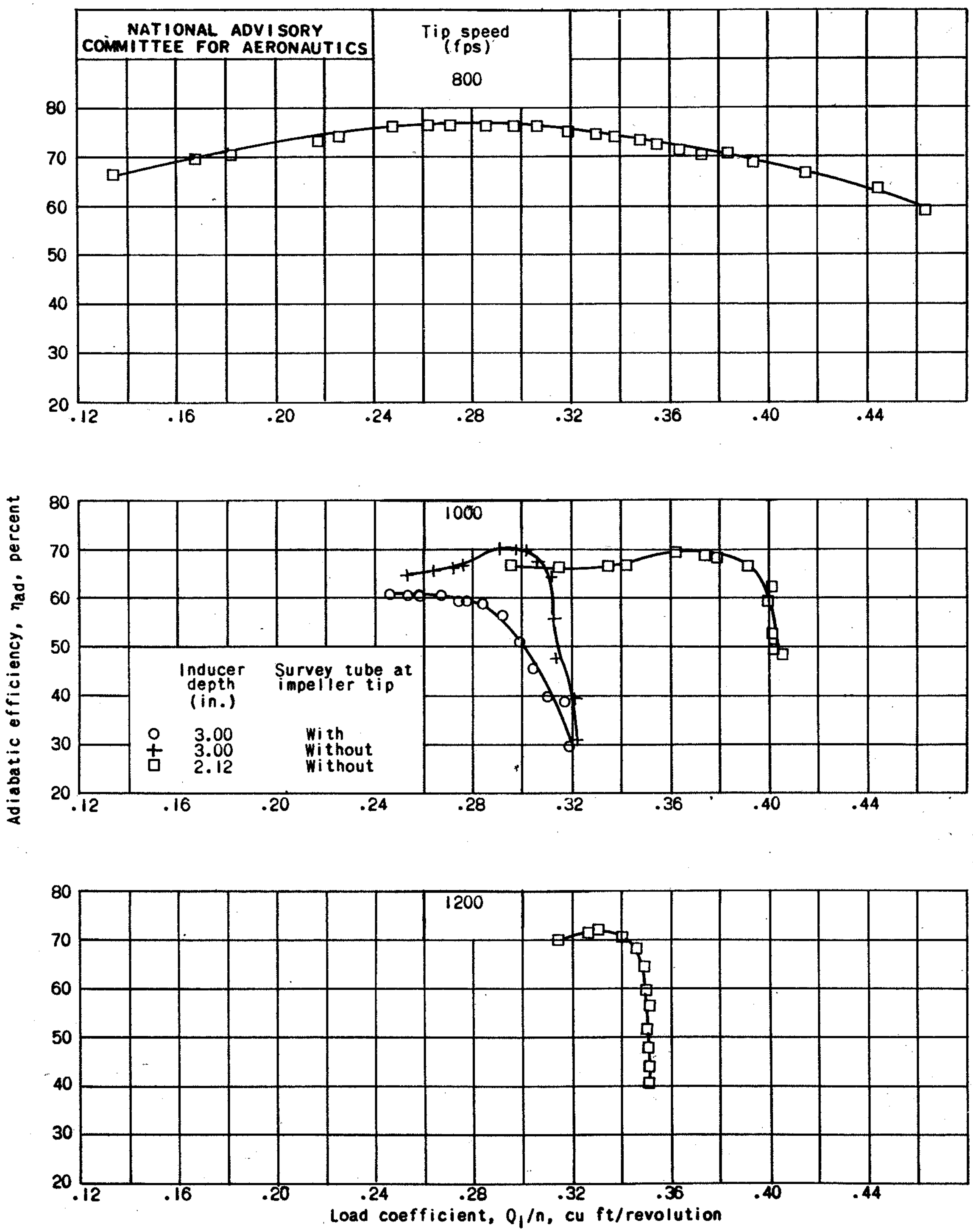

Figure 8. - Comparison of adiabatic efficiencies as determined in the discharge duct.

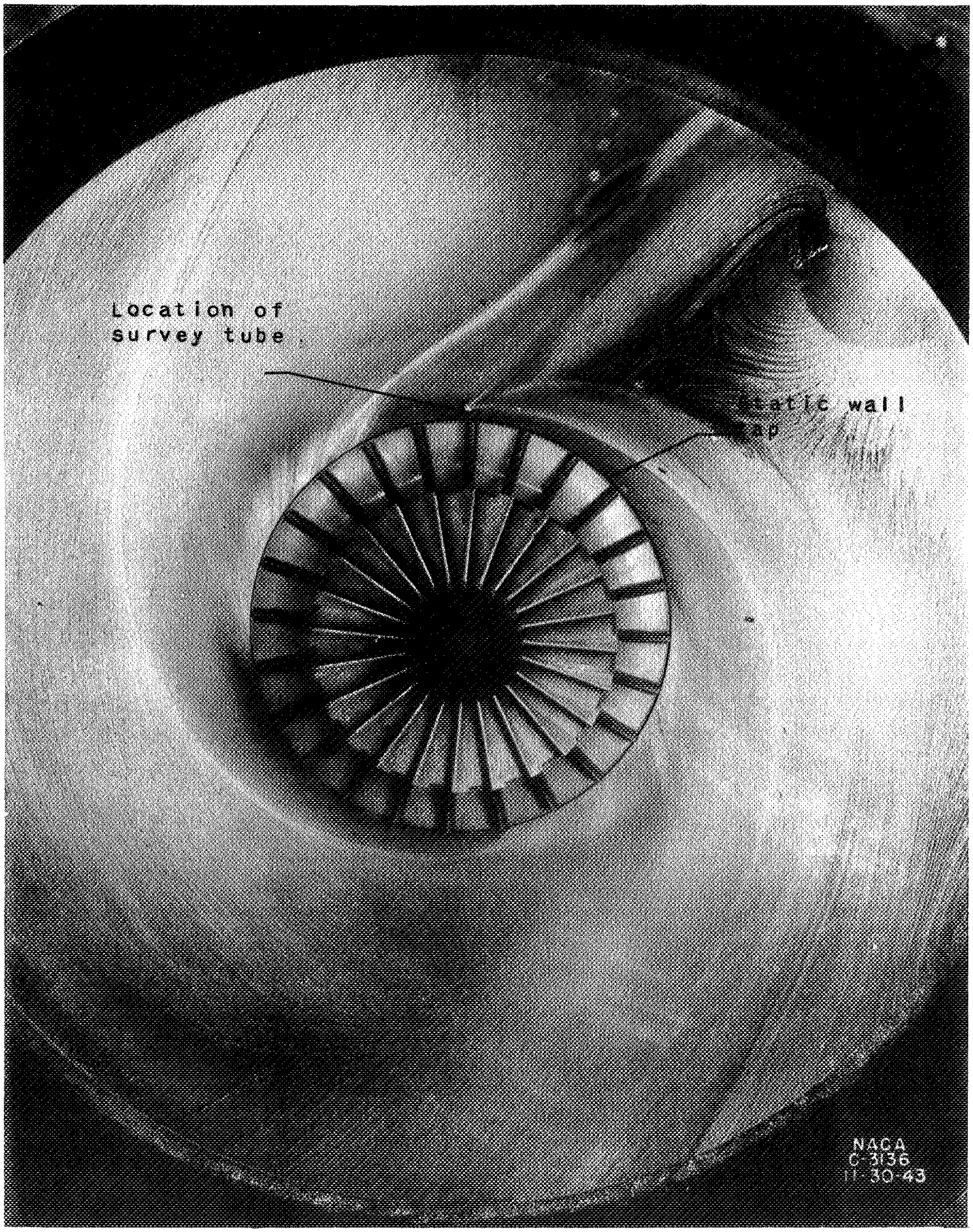

Figure 9. - Lampblack flow pattern showing disturbance of flow in diffuser channel resulting from survey tube at impeller discharge. Impeller tip speed, 800 feet per second; load coefficient, 0.26.

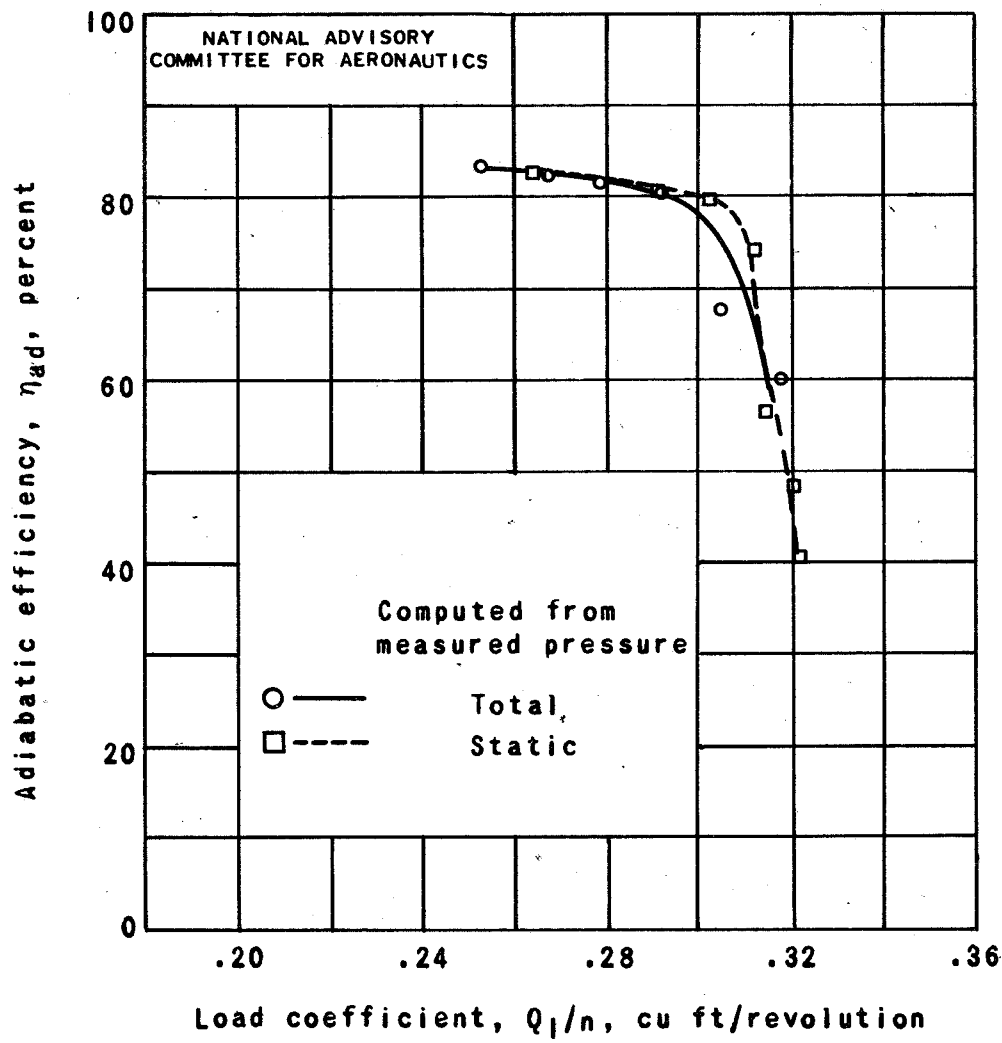

Figure 10. - Comparison of adiabatic efficiencies of 3.00-inch inducer-impeller unit as determined from measured static and total pressures at the impeller discharge at an impeller tip speed of 1000 feet per second.

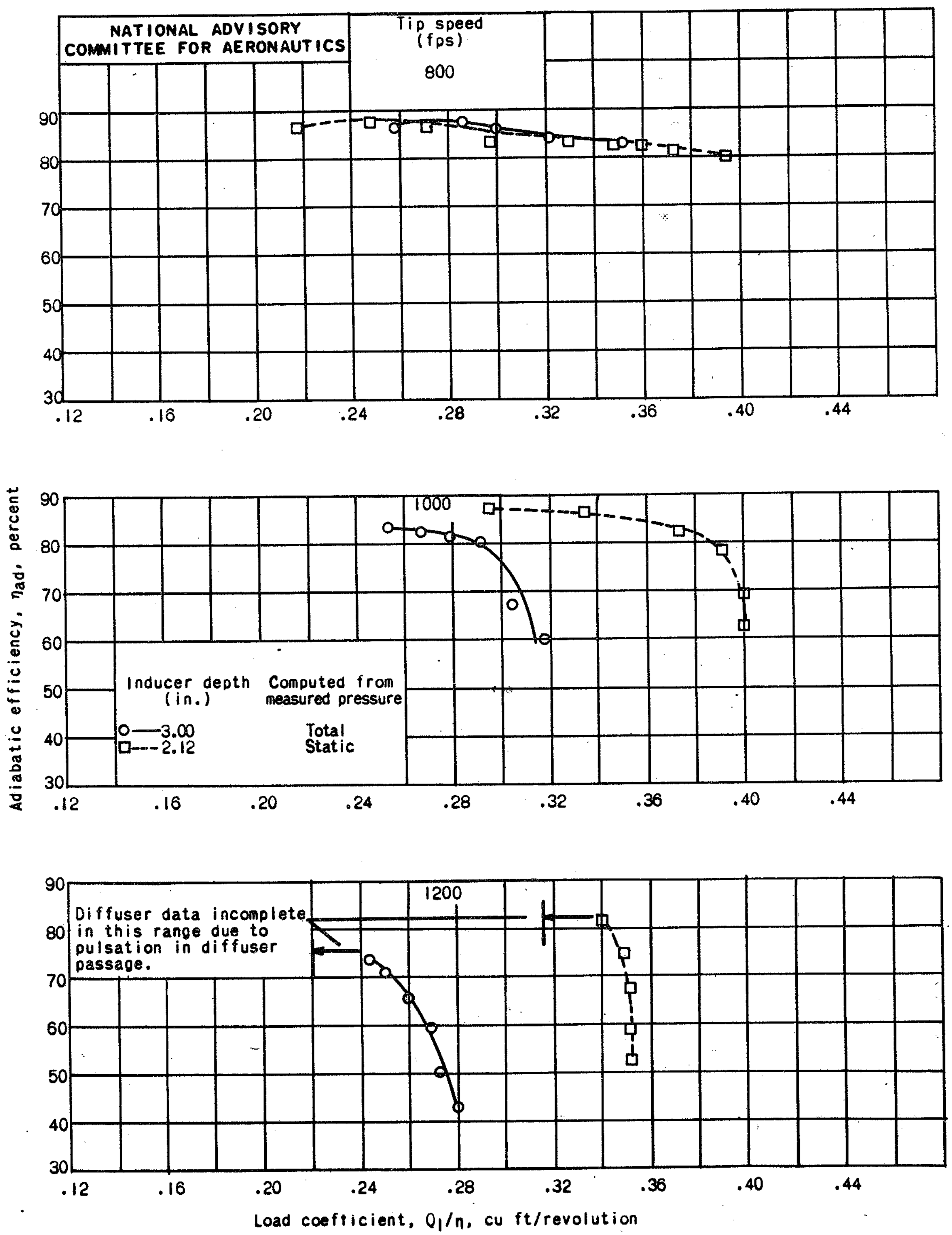

Figure 11. - Comparison of adiabatic efficiencies as determined at the impeller discharge.