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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

PERFORMANCE OF THE MODIFIED V-1710-93 ENGINE-STAGE SUPERCHARGER WITH A CONSTANT-AREA VANELESS DIFFUSER

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

As part of an investigation to increase the power output of the V-1710-93 engine at altitude, the engine-stage supercharger was combined with a constant-area vaneless diffuser designed to improve the performance of the engine-stage supercharger at the rated engine operating point. The performance of the modified supercharger was investigated in a variable-component supercharger test rig and compared with that of the standard supercharger with an 8-vaned diffuser. A separate evaluation of the component efficiencies and a study of the flow characteristics of the modified supercharger were made possible by internal diffuser instrumentation.

At the volume flow required by the engine for rated operating conditions, the modified supercharger increased the over-all adiabatic efficiency 0.05 and the over-all pressure coefficient 0.035. Furthermore, the capacity of the engine-stage supercharger was increased by replacing the standard 8-vaned diffuser with the vaneless diffuser. The peak over-all adiabatic efficiency for the modified supercharger, however, was 0.05 to 0.07 lower than that of the standard unit over the range of tip speeds investigated. The improved performance of the modified supercharger at rated engine operating conditions resulted from a shift of the point of peak adiabatic efficiency and pressure coefficient of the standard supercharger to a higher volume flow.

The energy loss through the vaneless diffuser was found to be small. Because of the restricted diffuser diameter, however, diffusion was inadequate, which resulted in a relatively small static-pressure rise through the diffuser, high diffuser-exit velocities, and excessive collector-case losses.

INTRODUCTION

An investigation to improve the altitude performance of the V-1710-93 engine was conducted at the NACA Cleveland laboratory. Full-scale tests of the engine (reference 1) and component tests of the engine-stage supercharger (reference 2) indicated that the volume flow of charge air required at rated engine conditions was greater than the volume flow at which peak supercharger adiabatic efficiency and pressure ratio occurred. Because the performance beyond the point of peak conditions rapidly decreased as the volume flow increased, the engine-stage supercharger usually operated at less than peak efficiency when in use with the V-1710-93 engine. In order to increase the supercharger performance at the high volume flows required for the engine, the standard 8-vaned diffuser was replaced by a constant-area vaneless diffuser of the same outer diameter. The outer diameters of both diffusers were the same in order that the vaneless diffuser could be directly substituted for the 8-vaned diffuser in the standard supercharger installation. The modified supercharger was tested in a variable-component supercharger test rig and internal-pressure measurements were made in addition to the usual over-all measurements in order to ascertain the performance of the supercharger components and the flow characteristics through the modified unit.

The adiabatic efficiencies for the impeller, for the impeller and vaneless-diffuser combination, and for the complete modified supercharger including the collector are presented. The over-all performance of the modified supercharger is compared with that of the standard unit. The effect of internal instrumentation on over-all performance and the flow characteristics through the impellor and diffuser are discussed.

APPARATUS AND INSTRUMENTATION

A drawing of the V-1710-93 engine-stage impeller with the constant-area vaneless diffuser is shown in figure 1. The impeller and standard 8-vaned diffuser are described in reference 2. The modified supercharger was provided with an axial inlet having a circular cross section 5.54 inches in diameter. The vaneless diffuser was machined from an aluminum-alloy casting and had an outer diameter of 14.5 inches. The diffuser was designed to provide a constant passage area equal to the impeller-exit area at all radii.

The impeller was driven by a 1000-horsepower constant-speed induction motor with a variable-speed magnetic clutch. Two gear boxes with an over-all step-up gear ratio of 21.03:1 were used to obtain high rotational speeds. The speed was measured with an automatic counter and frequently checked with a stroboscope.

The air flow and pressure ratio were regulated by motor-driven butterfly throttle valves in the inlet and outlet ducts. Low over-all pressure ratios (of the order of unity) were obtained by an evacuated exhaust system. The weight flow through the unit was measured with a flat-plate orifice at the inlet to the depression tank and the over-all pressure and temperature measurements were made according to the recommendations in reference 3. Air pressures were indicated by mercury and alcohol manometers and the temperatures were measured with shielded iron-constantan thermocouples. The collector case and ducting were insulated to minimize heat transfer.

Static pressure was measured along the impeller front shroud and throughout the diffuser by a series of wall static-pressure taps. A two-holed cylindrical yaw tube was used to survey the total pressure at the impeller exit; the tube was rotated to read maximum pressure at each survey station. A fixed five-tube shielded total-pressure rake was used to measure the total pressure at the diffuser exit. (See fig. 1.) Calibration of the rake showed that it would measure true total pressure within 0.5 percent of the dynamic pressure up to an angle of 44° to the direction of flow. The diffuser-passage width at a station one-fourth inch beyond the impeller exit and at the diffuser exit was divided into five equal parts and the total pressure was measured at the center of these parts.

PROCEDURE AND CALCULATIONS

The performance of the modified supercharger was investigated in a variable-component supercharger test rig at constant actual impeller tip speeds of 900, 1000, 1100, and 1200 feet per second, the same actual tip speeds at which the supercharger had been run (reference 2). These actual tip speeds correspond approximately to the equivalent tip speeds of 878, 972, 1068, and 1169 feet per second (reference 4). Because internal diffuser instrumentation was used during this investigation, an additional run at an equivalent tip speed of 1169 feet per second was made with the diffuser instruments removed to determine their effect on supercharger performance.

For all runs, the air flow was varied from a maximum (at a pressure ratio near unity) to the surge point. The inlet static pressure was held constant at 22 ±0.1 inches of mercury absolute as in the tests of the standard unit (reference 2). Ambient air, varying from 72° to 91° F, was used throughout the investigation; the inlet-air temperature during each run, however, varied within ±0.5° F.

The calculations and the graphical presentation of results were made in accordance with the recommendations of references 3 and 4. The efficiencies from the inlet measuring station to the impeller and diffuser exits were calculated by the method given in reference 2.

RESULTS AND DISCUSSION

Comparison of Over-all Performance

An investigation of a full-scale V-1710-93 engine (reference 1) showed that when the engine was operated at the rated speed of 3000 rpm, the load coefficient of the engine-stage supercharger was approximately 0.11 for all simulated altitude conditions and auxiliary-stage supercharger impeller tip speeds. This operating point approximately corresponds to an equivalent volume flow of 2510 cubic feet per minute at an equivalent impeller tip speed of 972 feet per second.

A comparison between the performance of the superchargers with the vaneless diffuser and with the standard 8-vaned diffuser with internal instrumentation is presented in figure 2. At the operating point of the standard engine-stage supercharger for rated engine conditions, indicated in figure 2(a) for an equivalent tip speed of 972 feet per second, the adiabatic efficiency and the pressure coefficient for the modified supercharger are 0.05 and 0.035 higher, respectively, than those of the standard unit. Furthermore, the performance of the standard supercharger rapidly decreases with only a small increase in flow beyond 2510 cubic feet per minute; whereas an equivalent volume flow of 2510 cubic feet per minute for the modified unit falls approximately at the point of peak performance and on a much flatter portion of the curve. Performance in this region was therefore only slightly affected by small changes in volume flow. This improved performance of the engine-stage impeller when combined with the vaneless diffuser would effect an increase of the power output of the V-1710-93 engine at the rated operating point. Because the rapid fall in efficiency of the standard supercharger is not caused by the impeller, a similar significant improvement of the performance of the supercharger in the engine would result from the use of a suitably redesigned vaned diffuser.

The over-all performance of the superchargers is compared at high equivalent tip speeds with internal diffuser instrumentation in figures 2(b) and 2(c). The peak over-all adiabatic efficiency of the modified supercharger is lower than that of the standard supercharger, the difference increasing from 0.05 at an equivalent tip speed of 972 feet per second to 0.07 at 1169 feet per second. The peak pressure coefficients of the modified unit are likewise lower, the difference varying from 0.09 to 0.11 over the same range of tip speeds.

Removal of the internal diffuser instruments from the modified supercharger increases the peak over-all adiabatic efficiency and pressure coefficient approximately 0.02 at an equivalent tip speed of 1169 feet per second (figs. 2(c) and 3). According to the results of reference 2, the detrimental effects of such internal instruments are practically independent of tip speed.

The capacity of the modified supercharger was appreciably higher than that of the standard unit, the greatest difference occurring at the lowest equivalent tip speed. The standard supercharger operated at substantially lower flows before surging than did the modified unit, especially at the high tip speeds, possibly because of the occurrence of flow separation at higher volume flows in the vaneless diffuser than in the standard 8-vaned diffuser.

Component Performance of Modified Supercharger

Component efficiencies. - The component adiabatic efficiencies of the modified supercharger from the inlet-duct measuring station to the impeller exit and to the diffuser exit (fig. 4) were calculated from a mass-flow-weighted average of the measured total pressures. The maximum efficiency to the impeller exit (impeller efficiency) and the maximum efficiency to the diffuser exit (efficiency of the impeller-diffuser combination excluding collector losses) are approximately 0.84 and 0.82, respectively, at an equivalent tip speed of 878 feet per second. The maximum over-all efficiency, which includes collector-case losses, is 0.62 at the same equivalent tip speed. All three efficiencies decrease with increasing tip speed for the range of speeds run.

The relatively small drop in efficiency from the impeller exit to the diffuser exit followed by the large drop from the diffuser exit to the outlet-duct measuring station at all speeds (fig. 4) indicates a large energy loss through the collector case as compared with the loss through the diffuser. The large collector-case loss is indicative of the excessively high diffuser-exit velocities due to insufficient kinetic-energy transformation through the diffuser. For example, at an equivalent tip speed of 1169 feet per second, the diffuser-exit dynamic pressure was more than 12 inches of mercury or approximately 800 feet per second in velocity, most of which was dissipated in the collector case. The over-all performance of the supercharger investigated would thus be higher than the data indicate if operated in an actual supercharger installation because a suitable scroll would decrease the large momentum loss usually obtained when a variable-component supercharger test rig is used.

Impeller-exit and diffuser-exit total-pressure profiles. - The total-pressure distributions at the impeller and diffuser exits are given in figures 5 and 6, respectively. Several representative volume flows were chosen from close to maximum flow to surge for a range of equivalent tip speeds from 878 to 1169 feet per second. At 1169 feet per second, the curves represent conditions for only a small flow range and are consequently closer together than at the other speeds. The impeller-exit total-pressure profiles (fig. 5) are highly asymmetrical and peak near the diffuser front shroud, indicating a concentration of air flow at the front of the diffuser channel. Such asymmetry causes diffuser mixing losses that adversely affect the performance of the compressor. The profiles of the total pressure at the diffuser exit (fig. 6) are noticeably more symmetrical and show less variation across the passage than those at the impeller exit, which indicates fairly uniform flow leaving the diffuser.

Static pressure through impeller and diffuser. - The static pressures measured at various points along the front shroud of the impeller and the diffuser are plotted in figure 7 against flow-path length. For each tip speed, although the static pressure at the inlet-duct measuring station was maintained at 22 ±0.1 inches of mercury absolute, the front-shroud static pressure at the impeller entrance decreases as the quantity of flow increases. At the diffuser exit, the static pressure increases from the point of maximum flow to the point of peak efficiency, then decreases with a further decrease in equivalent volume flow. The peak static pressures at the diffuser exit increase with speed.

On the average, approximately one-third of the over-all static-pressure rise from the inlet-duct station to the diffuser exit takes place through the diffuser. This relatively small diffuser static-pressure rise plus the excessively high diffuser-exit velocities, which give rise to large collector losses, explain the reduced peak efficiency of the modified supercharger as compared with that of the standard unit.

SUMMARY OF RESULTS

A V-1710-93 engine-stage impeller in combination with a constant-area vaneless diffuser was tested in a variable-component supercharger test rig. The over-all results were compared with those obtained from similar tests of the standard supercharger. The following results were obtained:

1. At the supercharger volume flow required for rated conditions of the V-1710-93 engine, the modified supercharger increased the adiabatic efficiency 0.05 and the pressure coefficient 0.035 over that of the standard unit. The improved performance of the modified supercharger at rated engine operating conditions resulted from a shift of the point of peak adiabatic efficiency and pressure coefficient of the standard supercharger to a higher volume flow.

2. The modified supercharger operated at higher capacity than the standard unit; the increase was largest at the lowest equivalent tip speed at which a comparison was available (972 ft/sec).

3. The peak adiabatic efficiency of the modified supercharger was 0.05 to 0.07 lower and the peak pressure coefficient 0.09 to 0.11 lower than that of the standard unit.

4. The impeller and vaneless-diffuser combination had a maximum efficiency, excluding collector-case losses, of 0.82 at an equivalent tip speed of 878 feet per second; the maximum impeller efficiency was 0.84 at the same equivalent tip speed. These component efficiencies are based on mass-flow-weighted averages of the impeller-exit and diffuser-exit total pressures.

5. A large axial total-pressure variation existed across the impeller exit, which led to mixing losses in the diffuser and impaired supercharger performance. The flow tended to concentrate in the forward part of the impeller-exit passage. The total-pressure gradient at the diffuser exit was fairly symmetrical, which indicates uniform flow leaving the diffuser.

6. Although the energy loss through the diffuser itself was low, the diffusion was inadequate as evidenced by the relatively small static-pressure rise through the diffuser and the high diffuser-exit velocities. These high velocities caused large momentum losses in the collector and detrimentally affected over-all performance.

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REFERENCES

1. Standahar, Raymond M., and Mizisin, John: Effect of Modifications to Induction System on the Altitude Performance of V-1710-93 Engine. I - Effect of Increased Supercharging, Interstage Carburetor, Aftercooling, and Internal-Coolant Injection. NACA MR No. E6E20, Army Air Forces, 1946.

2. Klein, Harold, and Douglas, John E.: Performance of the Engine-Stage Impeller and Diffuser of the Allison V-1710-93 Engine. NACA MR No. E6B15, Army Air Forces, 1946.

3. Ellerbrock, Herman H., Jr., and Goldstein, Arthur W.: Principles and Methods of Rating and Testing Centrifugal Superchargers. NACA ARR, Feb. 1942.

4. NACA Subcommittee on Supercharger Compressors: Standard Method of Graphical Presentation of Centrifugal Compressor Performance. NACA ARR No. E5F13a, 1945.

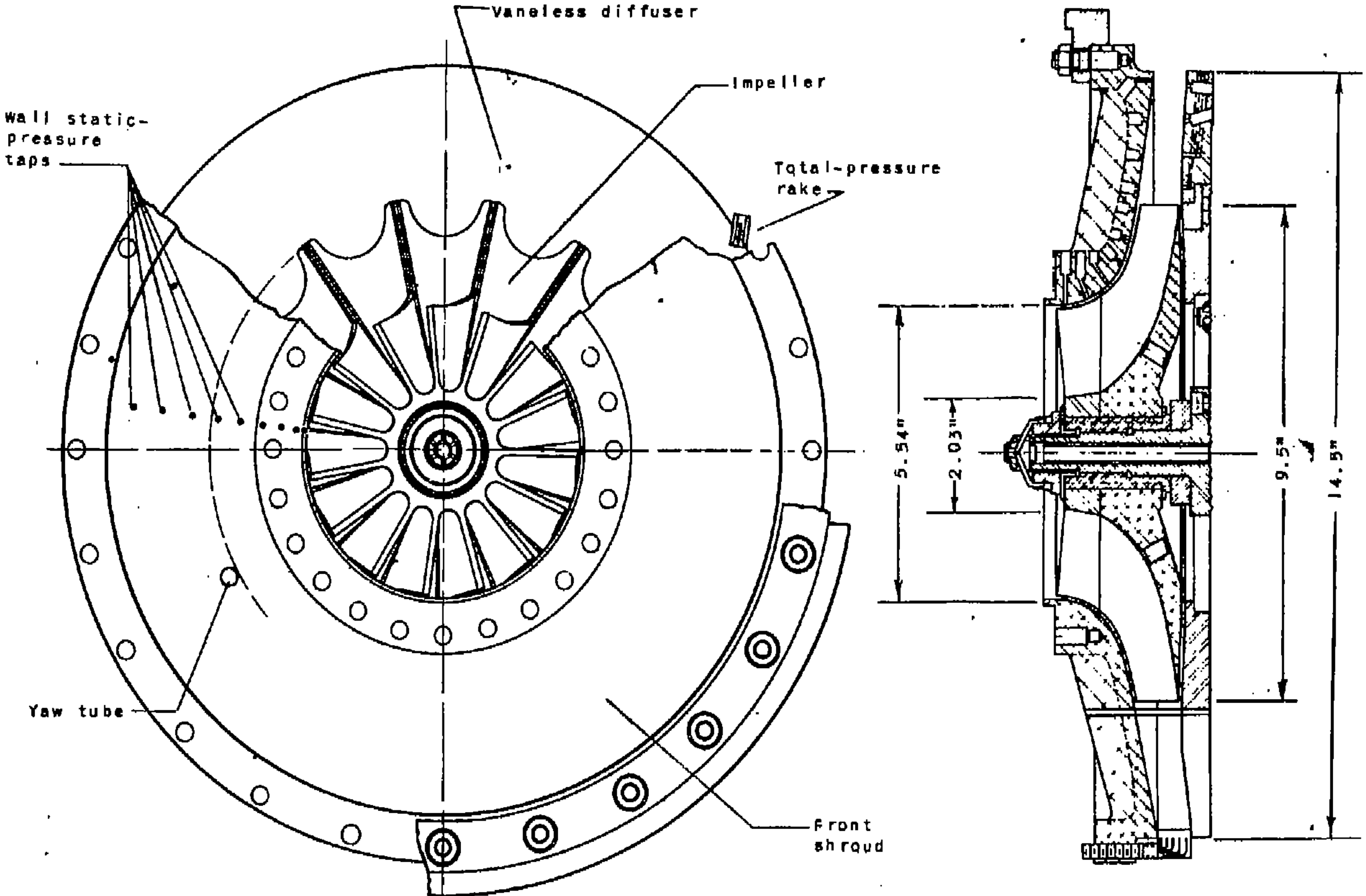
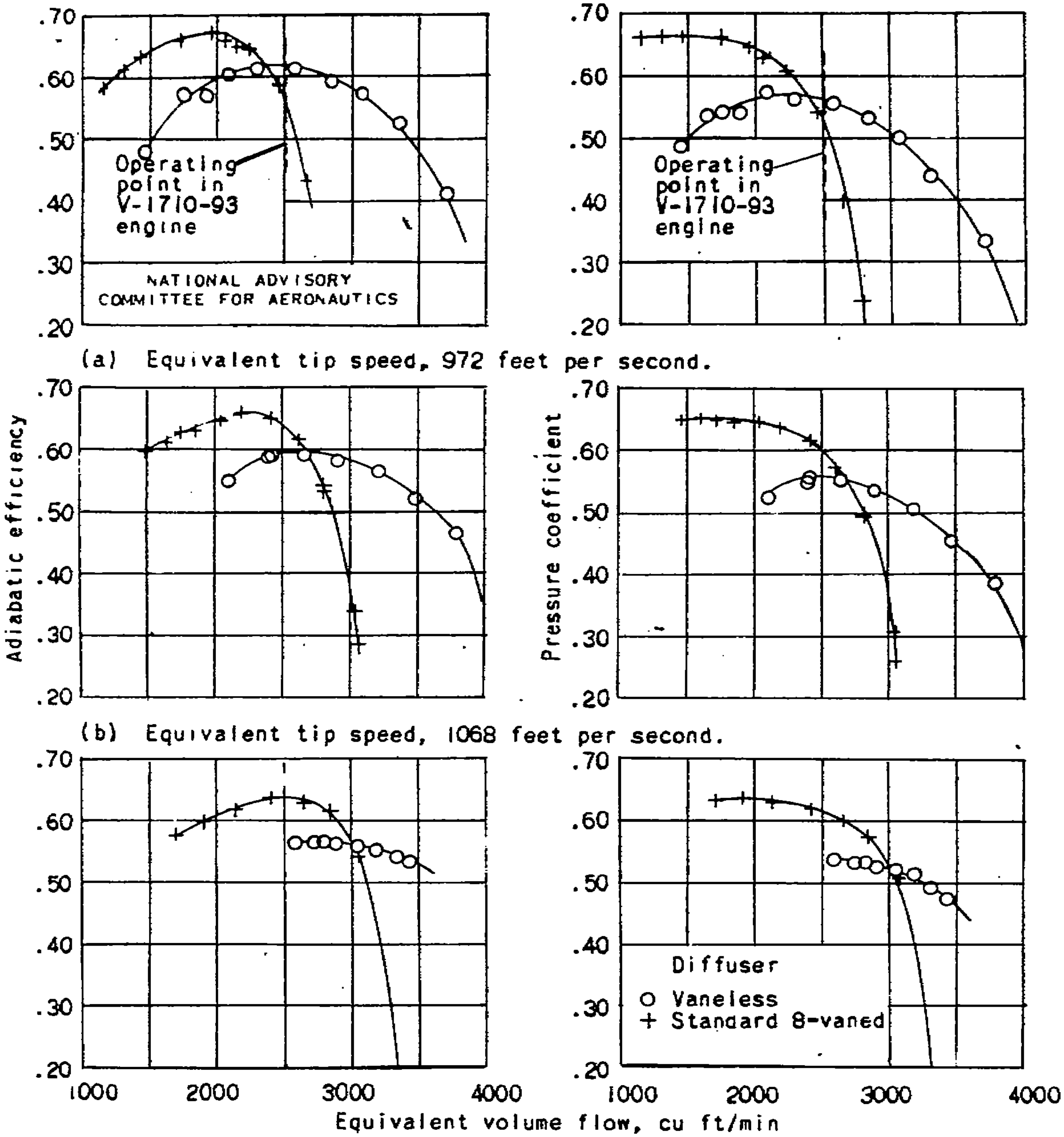


Figure 1. - Drawing of V-1710-93 engine-stage impeller and constant-area vaneless diffuser showing instrumentation.



(c) Equivalent tip speed, 1169 feet per second.

Figure 2. - Over-all performance of V-1710-93 engine-stage supercharger with constant-area vaneless and standard 8-vaned diffusers with internal diffuser instrumentation.

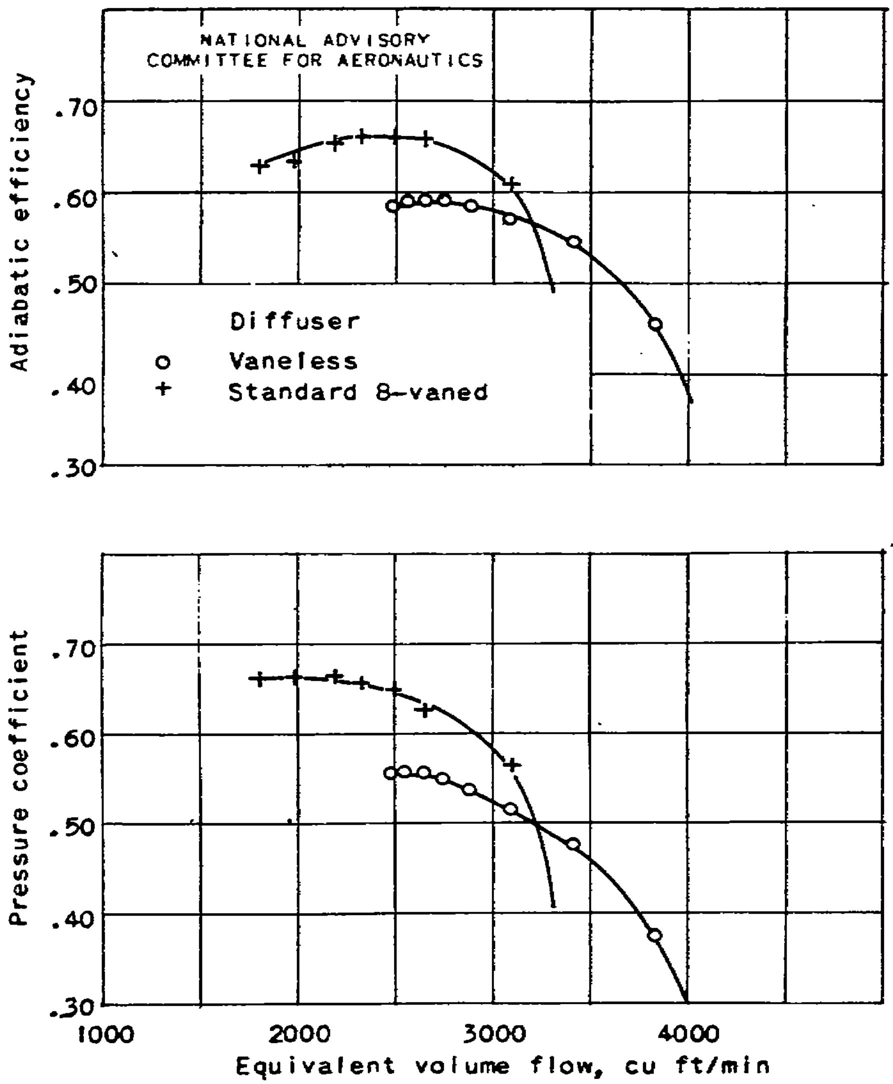


Figure 3. - Over-all performance of V-1710-93 engine-stage supercharger with constant-area vaneless and standard 8-vaned diffusers at 1169 feet per second with no internal diffuser instrumentation.

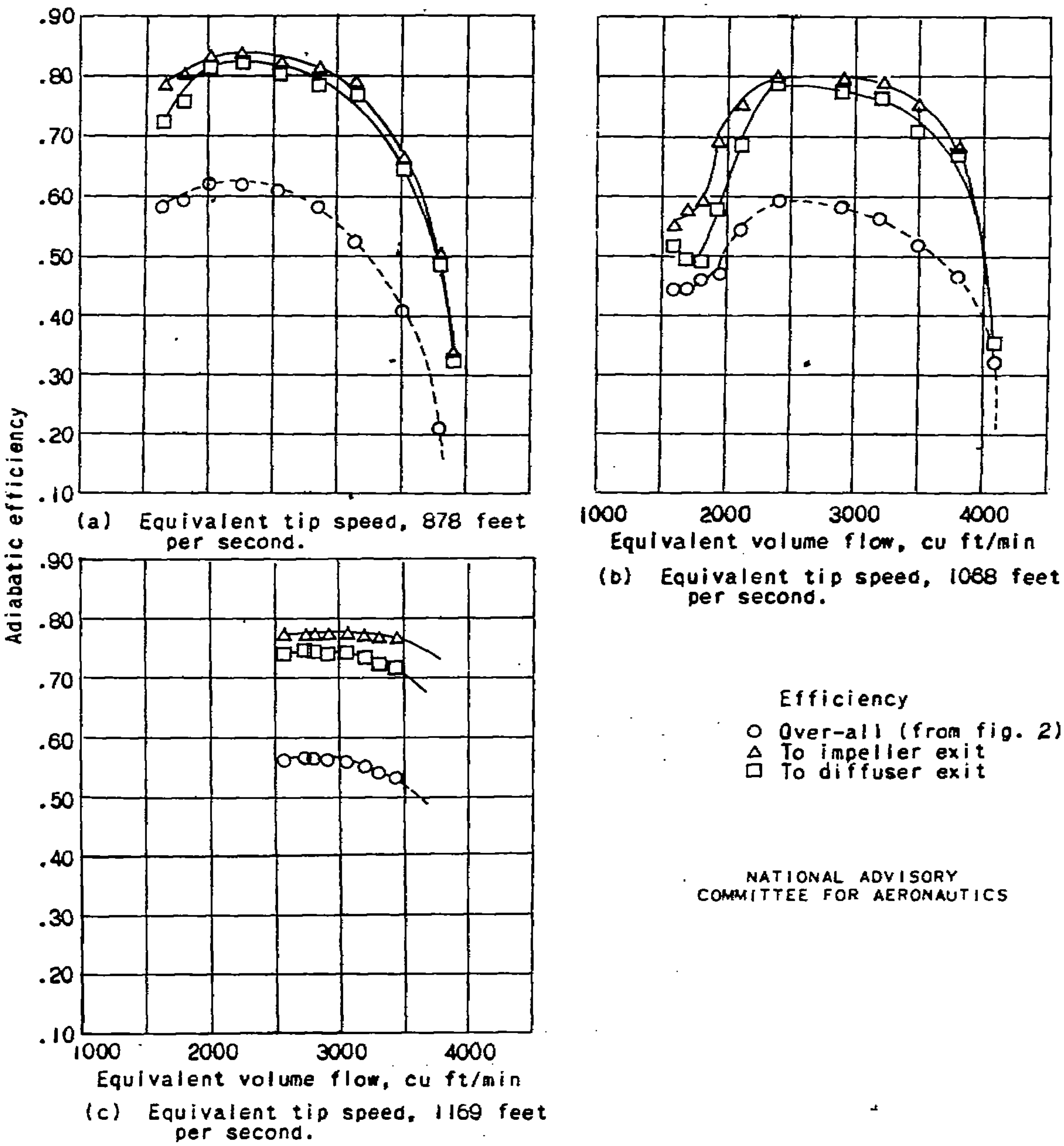


Figure 4. - Over-all and component efficiencies of V-1710-93 engine-stage impeller with constant-area vaneless diffuser.

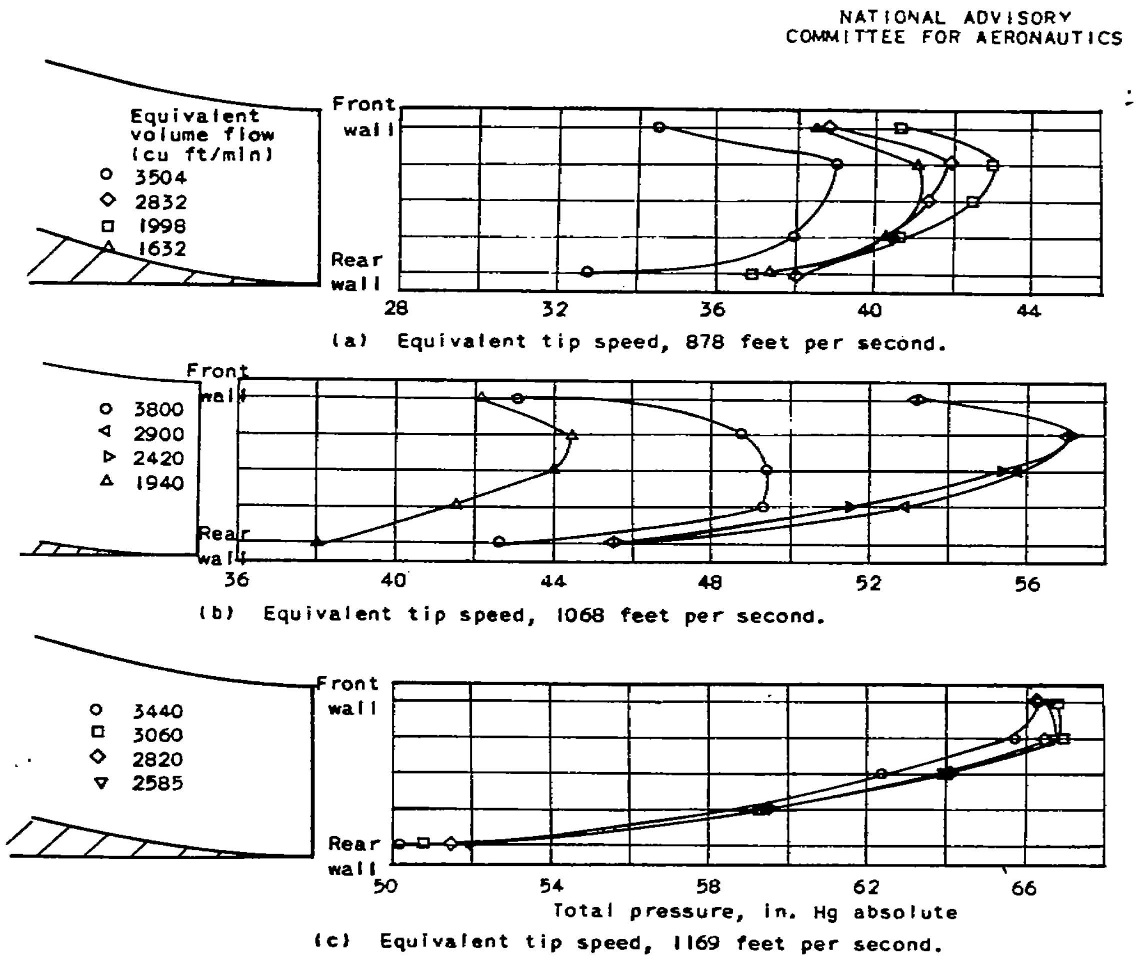


Figure 5. - Total-pressure profile across impeller exit for V-1710-93 engine-stage supercharger with constant-area vaneless diffuser.

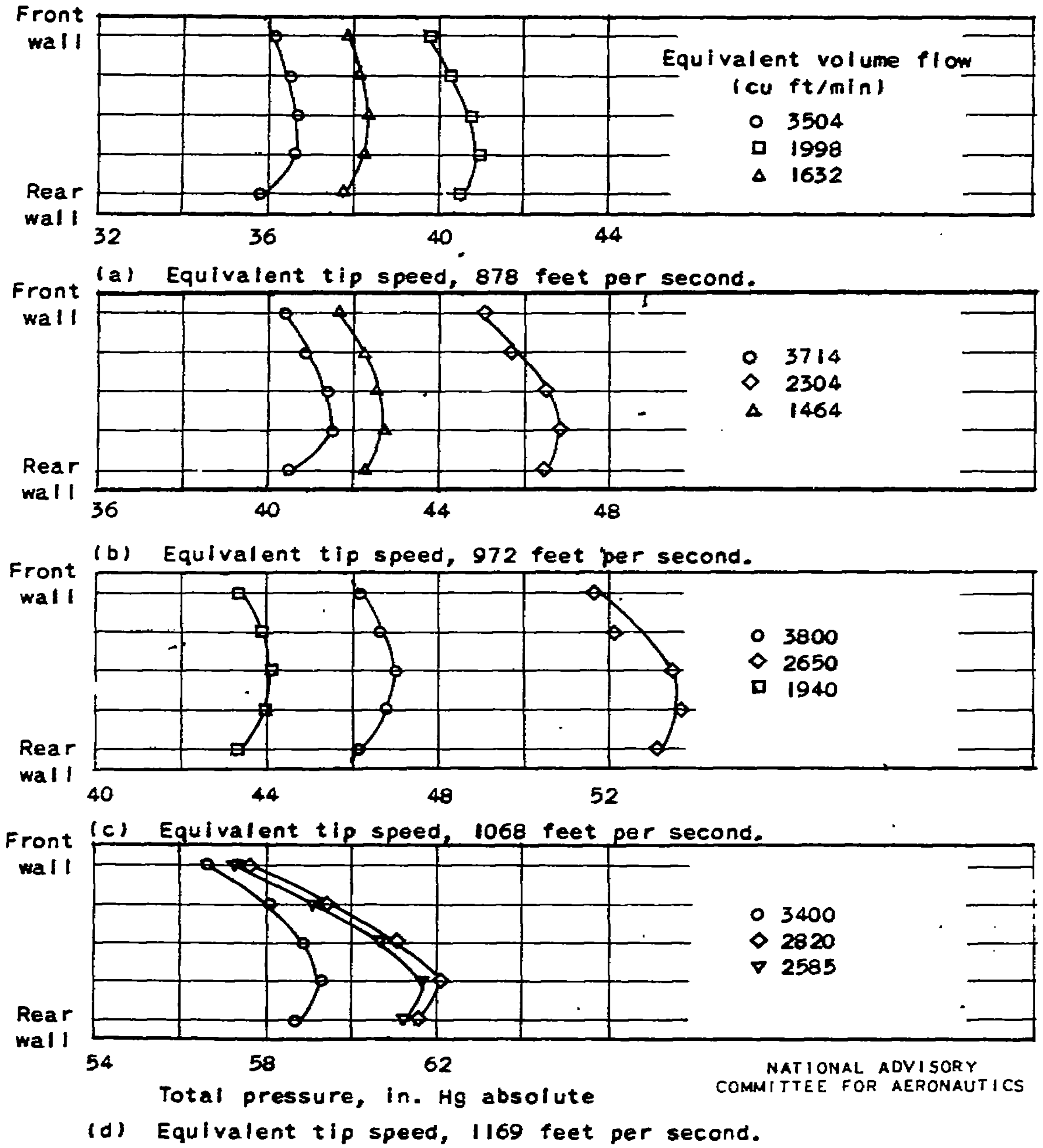
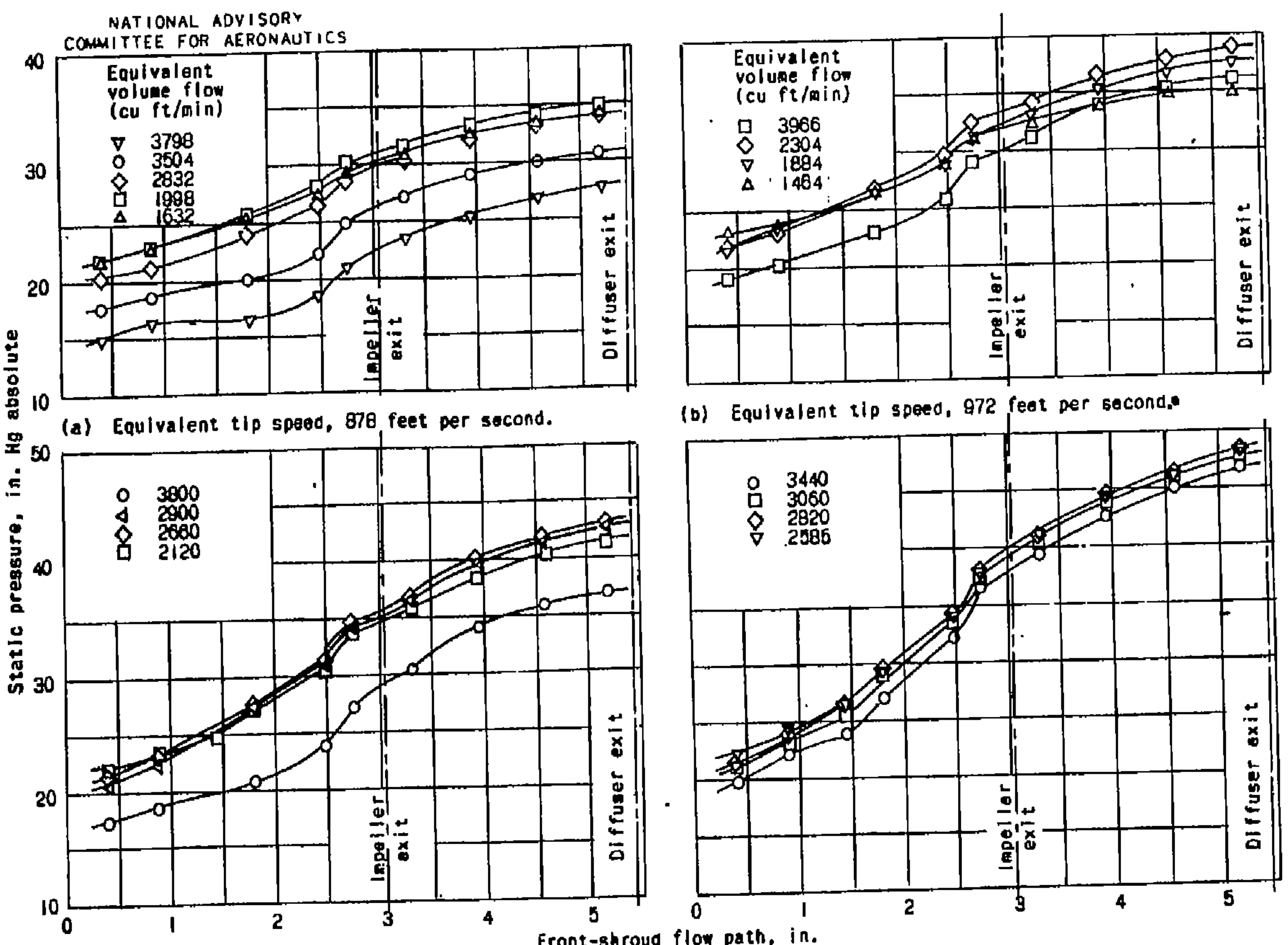


Figure 6. – Total-pressure profile across diffuser exit for V-1710-93 engine-stage supercharger with constant-area vaneless diffuser.



(a) Equivalent tip speed, 878 feet per second.

(b) Equivalent tip speed, 972 feet per second.

(c) Equivalent tip speed, 1068 feet per second.

(d) Equivalent tip speed, 1169 feet per second.

Figure 7. - Static-pressure rise along front shroud of impeller and vaneless diffuser for V-1710-93 engine-stage supercharger with constant-area vaneless diffuser.

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X Superchargers, Engine-stage
Superchargers - Performance
Superchargers - Efficiency
Diffusers, Vaneless
Engine - Allison V-1710-93
Pressure distribution - Engines