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NACA

RESEARCH MEMORANDUM

PERFORMANCE OF MIXED-FLOW IMPELLER, MODEL MFI-1B, WITH DIFFUSER VANES AT EQUIVALENT IMPELLER SPEEDS FROM 1100 TO 1700 FEET PER SECOND

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

An investigation was made of the performance characteristics of a mixed-flow impeller, model MFI-1B, in combination with a vaned diffuser. The experimental results indicated that the peak pressure ratio and maximum efficiency were not being obtained at overdesign speeds because of premature surge. An increase in the inlet angle at the leading edge of the vanes from 61° (as designed) to 66° improved the pressure ratio and efficiency at overdesign speeds with little or no effect at underdesign speeds. The peak pressure ratio and maximum efficiency at an equivalent speed of 1700 feet per second with a vane inlet angle of 66° were 5.39 and 0.733, respectively. An analysis of the data indicates that a pressure ratio of 6.0 and an efficiency of 0.72 can be obtained at an equivalent impeller speed of 1800 feet per second with a vane inlet angle of 69°.

INTRODUCTION

Two mixed-flow impellers, models MFI-1 and MFI-2, have been designed and tested at the NACA Lewis laboratory in order to develop a reliable aerodynamic design procedure for centrifugal compressors (refs. 1 to 4). The over-all performance characteristics of the two impellers, when tested with a vaneless diffuser, indicated good range, high efficiency, and high pressure ratio per stage for this type compressor over a range of equivalent impeller speed from 700 to 1600 feet per second. However, it was recognized that the over-all performance characteristics of an impeller in combination with a vaned diffuser would be of more practical value to the designer. Therefore, the more efficient of the two impellers, the MFI-1 (configuration B, ref. 4), was selected for testing with a vaned diffuser. A vaned diffuser, incorporating 24 vanes, was designed by the method of reference 5 and is shown in figures 1 and 2. The vanes were designed for an equivalent impeller speed of 1400 feet per second (design speed for the impeller) with a resulting inlet angle (fig. 1) at the leading edge of the vanes of 61°.

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Three overdesign speeds, 1500, 1600, and 1700 feet per second, were investigated with the vaned diffuser to enable the designer interested in high pressure ratio per stage to extrapolate the performance curves to a pressure ratio of 6.0 with a higher degree of accuracy. At the overdesign speeds, it was indicated that the maximum efficiency and peak pressure ratio were not being obtained because of premature surge. To alleviate this condition, the inlet angle at the leading edge of the vanes was increased from 61° to 66°.

This report presents the performance characteristics of the MFI-1B impeller with a vaned diffuser consisting of 24 vanes having an inlet angle of 66°. In addition, portions of the performance curves for the impeller with the vaned diffuser as designed (inlet angle of 61°) are presented to indicate the change in performance obtained by increasing the inlet angle of the vanes and to enable the designer to extrapolate the results to obtain the performance at additional settings of the inlet angle.

SYMBOLS

The following symbols are used in this report:

U actual impeller speed based on 7.00-in. radius, ft/sec

W actual air weight flow, lb/sec

β angle between camber line of vane and a conic element through leading edge of vane (fig. 1)

δ ratio of inlet total pressure to NACA standard sea-level pressure, 29.92 in. Hg abs

η_{ad} adiabatic temperature-rise efficiency

θ ratio of inlet total temperature to NACA standard sea-level temperature, 518.4° R

APPARATUS, INSTRUMENTATION, AND PROCEDURE

Apparatus

The impeller used in this investigation was of the mixed-flow type with 21 complete blades and 21 splitter blades and is identified as configuration B of model MFI-1 (ref. 4). In order to smooth out several damaged blades at the inlet, the leading edges of this impeller were swept backward from the hub to a point on the shroud 0.25 inch in the axial direction from the original leading edge as shown in figure 1.

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For the purposes of this investigation, a new diffuser was fabricated (fig. 1) incorporating a 2.40-inch vaneless section followed by a 3.50-inch vaned section composed of 24 vanes which were designed by the method presented in reference 5 for a diverging annulus. The divergence is continued for an additional 0.5 inch, at which point the passage becomes a constant-area duct for the remaining 6.0 inches. A schematic diagram and photograph of the impeller and vaned diffuser are shown in figures 1 and 2, respectively. The vanes were cast from a 0.90-0.10 tin-zinc alloy having a melting point of 390° F and were attached to the lower diffuser wall. A brass strip embedded in the casting for a distance of 2.0 inches from the leading edge (fig. 2) enabled the inlet section of the vanes to be bent a small amount in order to make changes in the inlet angle β.

The remainder of the experimental setup is the same as that described in reference 2.

Instrumentation

The instrumentation is the same as that in reference 2 with the exception that unshielded-type total-pressure probes were used for the outlet instrumentation. The outlet measuring station is located at a 13.0-inch radius (0.882 in. upstream from the end of the passage). The outlet instrumentation consisted of eight static-pressure taps, 12 total-pressure rakes, four thermocouple rakes, and eight thermocouple probes distributed throughout the 24 passages in such a manner as to give a minimum blockage effect. The outlet instrumentation gave the equivalent of four passages instrumented as shown in figure 1.

Procedure

This investigation was carried out at a constant inlet air pressure of 14 inches of mercury absolute. Ambient air at 75° F was used at an equivalent impeller speed of 1100 feet per second. For speeds from 1300 to 1700 feet per second, an inlet air temperature of -60° F was used because of the low melting point of the tin-zinc alloy used in the construction of the vanes and because of impeller stress considerations at speeds above 1400 feet per second.

The test and computation procedures are the same as those used in reference 2.

EXPERIMENTAL RESULTS

The over-all performance characteristics for the MFI-1B impeller with a vaned diffuser with the vane inlet angle β set at 66° are

presented in figure 3 for a range of speed from 1100 to 1700 feet per second. The over-all pressure ratio is plotted against weight flow for the range of speed, with contours of constant efficiency superimposed in figure 3(a). The adiabatic temperature-rise efficiency and Mach number at the outlet measuring station are plotted against weight flow for the range of speed in figure 3(b). The peak pressure ratio and maximum adiabatic efficiency at the design equivalent speed (1400 ft/sec) were 3.71 and 0.771, respectively. At an overdesign speed of 1700 feet per second, the peak pressure ratio was 5.39 and the maximum efficiency was 0.733. The average Mach number at the outlet measuring station for the 3336
maximum efficiency points for the range of speed was between 0.27 and 0.30 as shown in figure 3(b).

In figures 4 and 5, the performance of the impeller with vaned diffuser is compared at two settings of β, 61° (as designed) and 66°. The peak total-pressure ratio, maximum adiabatic efficiency, and maximum and minimum weight flow are plotted against equivalent speed in figures 4(a), (b), and (c), respectively. It is indicated in figure 4(a) that the increase in β to 66° caused no appreciable effect upon the pressure ratio at speeds of 1300, 1400, and 1500 feet per second. However, at speeds of 1600 and 1700 feet per second, there are substantial gains in pressure ratio with a 7-percent increase at 1700 feet per second. Figure 4(b) indicates a similar trend in the maximum efficiency with an increase of approximately 3 points in efficiency at 1700 feet per second. The weight-flow range shown in figure 4(c) indicates a gain in range at all speeds except 1300 feet per second as β is increased from 61° to 66°. Figure 5 shows a comparison of the over-all performance characteristics at the two settings of β for the overdesign speeds and summarizes the curves presented in figures 4(a) and (c).

Figure 6 gives an indication of the losses that might be expected from dumping the air at the end of the diffuser vanes into a collector by comparing the pressure ratio and efficiency based on measurements taken at the outlet measuring station with the pressure ratio and efficiency based on static-pressure measurements taken in the collector. Figure 6(a) indicates a 5- to 6-percent decrease in pressure ratio over the speed range, while figure 6(b) indicates losses of 3 to 4.5 points in efficiency with the greater losses occurring at the lower speeds.

DISCUSSION OF RESULTS

The experimental results obtained with the diffuser vanes as designed indicated that the peak total-pressure ratio and the maximum adiabatic efficiency at speeds above design speed (1400 ft/sec) were not being obtained because of premature surge, as shown by the surge line for $\beta = 61^{\circ}$ in figure 5. Therefore, the leading edges of the vanes were bent slightly to increase β to 66°. This change in β

caused little or no loss in maximum flow but increased the range by shifting the surge line, as shown in figure 5 for $\beta = 66^{\circ}$, thus producing a peak pressure ratio of 5.39 and a maximum efficiency of 0.733 at a speed of 1700 feet per second.

The performance at 1700 feet per second gave indications that a pressure ratio of 6.0 with an efficiency of 0.70 or more could be obtained by increasing the equivalent impeller speed. With the assumption that the pressure ratio will increase as the square of the speed, a speed of 1800 feet per second is necessary to obtain a pressure ratio of 6.0. However, figure 4(a) shows that a pressure ratio of 6.0 could not be obtained with vane inlet angles of either 61° or 66° for a speed of 1800 feet per second. In figure 4(c), zero range of weight flow is indicated for $\beta = 61^{\circ}$ and a very small range for $\beta = 66^{\circ}$ at 1800 feet per second. In figure 4(b), efficiencies below 0.70 are indicated for both angle settings.

A comparison of the over-all performance characteristics at 1600 feet per second (fig. 3(a)) with those of the impeller with a vaneless diffuser (ref. 4) indicated that, with the vaned diffuser, surge was caused by the vanes. Thus, it may be assumed that the vanes could be bent an additional 5° from $\beta = 66^{\circ}$ to $\beta = 71^{\circ}$ with an increase in performance resulting at overdesign speeds. Hypothetical performance curves, obtained by extrapolating the performance curves of figures 4 and 5 by direct proportion, were determined for the minimum value of β required to obtain a pressure ratio of 6.0. Only the minimum required angle is considered here in order to minimize any detrimental effects upon the compressor performance which may result at lower speeds. The inlet vane angle required was 69°, and the hypothetical curves of figures 4 and 5 for this angle indicate that a pressure ratio of 6.0 and an efficiency of 0.72 can be obtained at an equivalent impeller speed of 1800 feet per second.

SUMMARY OF RESULTS

An investigation was made of the performance characteristics of a mixed-flow impeller, model MFI-1B, in combination with a vaned diffuser. In order to improve the performance characteristics at speeds above design speed, the inlet angle of the vanes was increased from 61° (as designed) to 66°. The experimental data were analyzed to see if a pressure ratio of 6.0 could be obtained at a higher speed. The following results were obtained:

1. At a vane inlet angle of 66°, the peak pressure ratio and maximum adiabatic efficiency at a design equivalent speed of 1400 feet per second were 3.71 and 0.771, respectively. At an overdesign speed of 1700 feet per second, the peak pressure ratio was 5.39 and the maximum efficiency was 0.733.

2. Increasing the vane inlet angle from 61° to 66° had no appreciable effect upon the pressure ratio and efficiency at a design speed of 1400 feet per second and at lower speeds. However, there were gains of 7 percent in pressure ratio and 3 points in efficiency at 1700 feet per second. There were gains in weight-flow range at nearly all speeds.

3. Losses of 5 to 6 percent in pressure ratio and 3 to 4.5 points in efficiency may be expected by dumping the air into a collector at the end of the diffuser vanes.

4. An analysis of the experimental data for vane inlet angles of 61° and 66° indicated that a pressure ratio of 6.0 and an efficiency of 0.72 can be obtained at a speed of 1800 feet per second with a vane inlet angle of 69°. 3336

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Lewis Flight Propulsion Laboratory
Cleveland, Ohio, April 22, 1954

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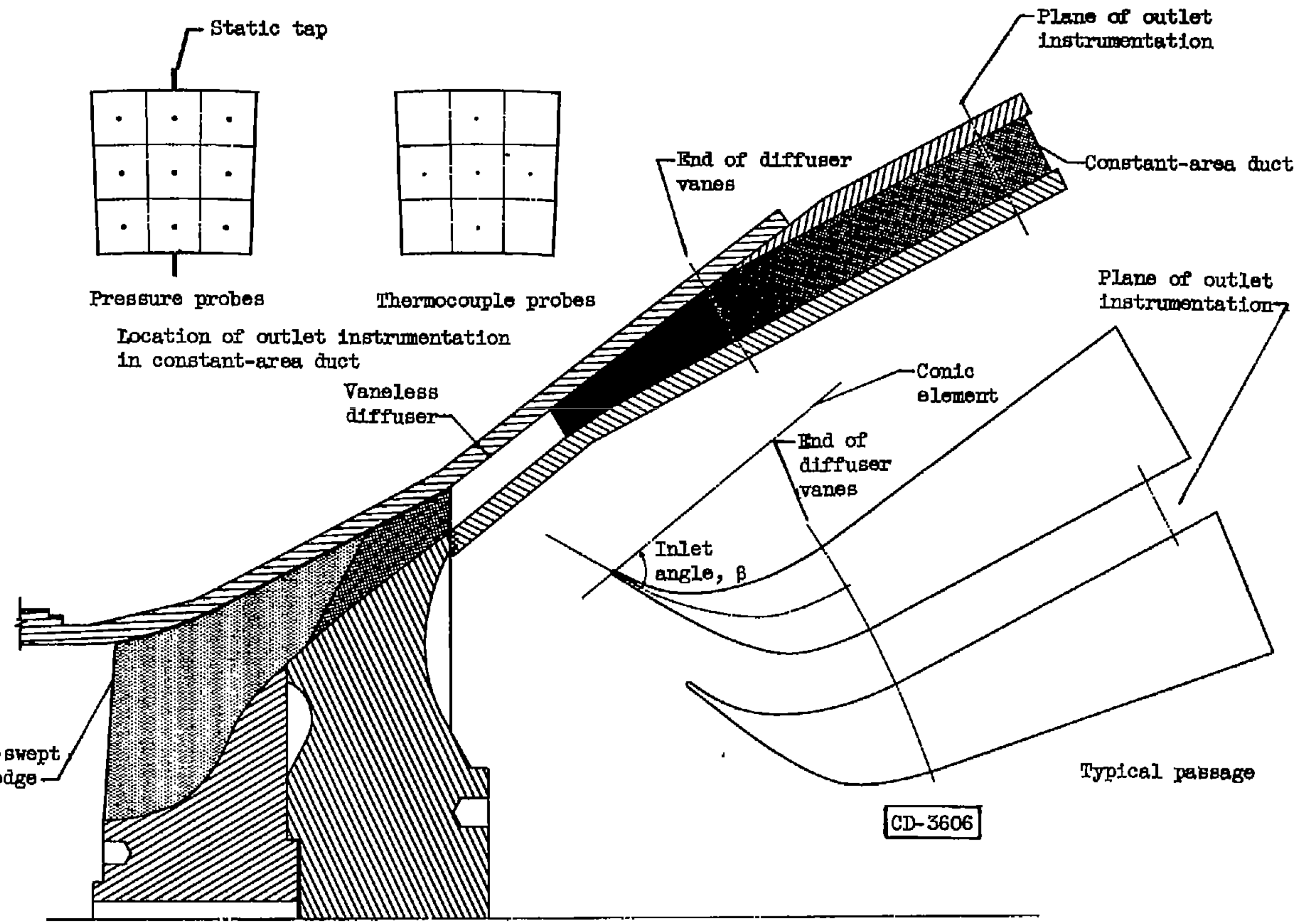
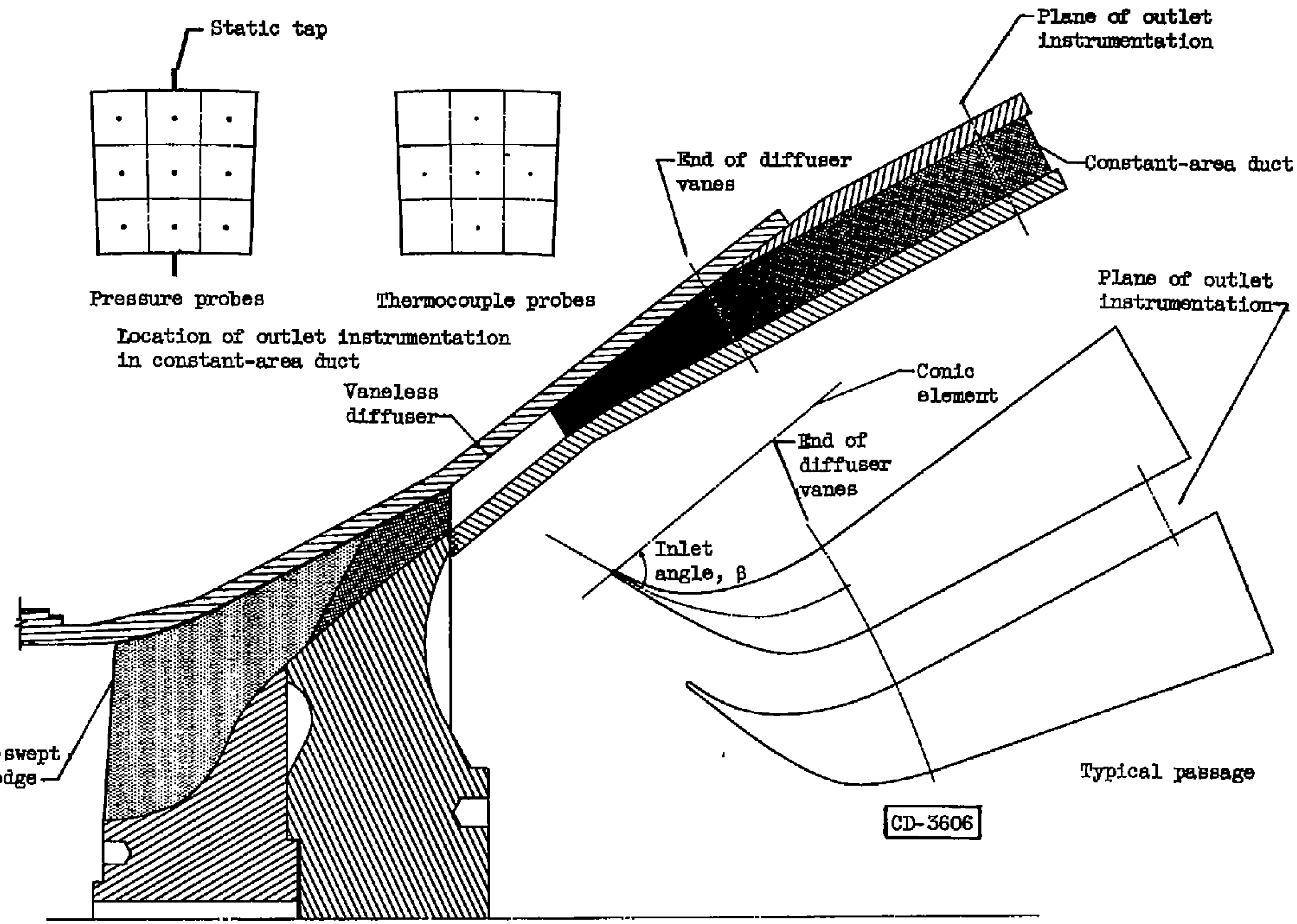


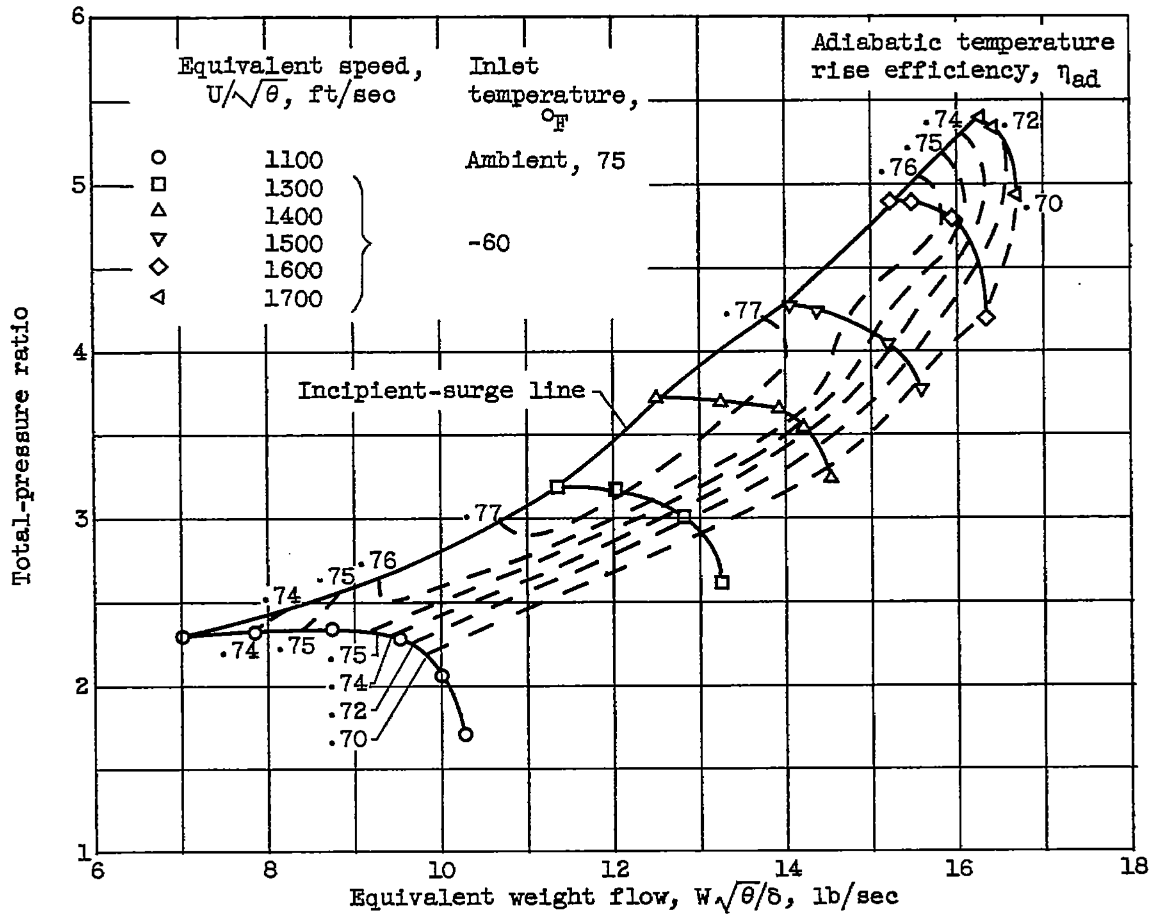
Cross-sectional view.

Figure 1. - Schematic diagram of MFI-1B impeller with vaned diffuser showing location of outlet instrumentation.



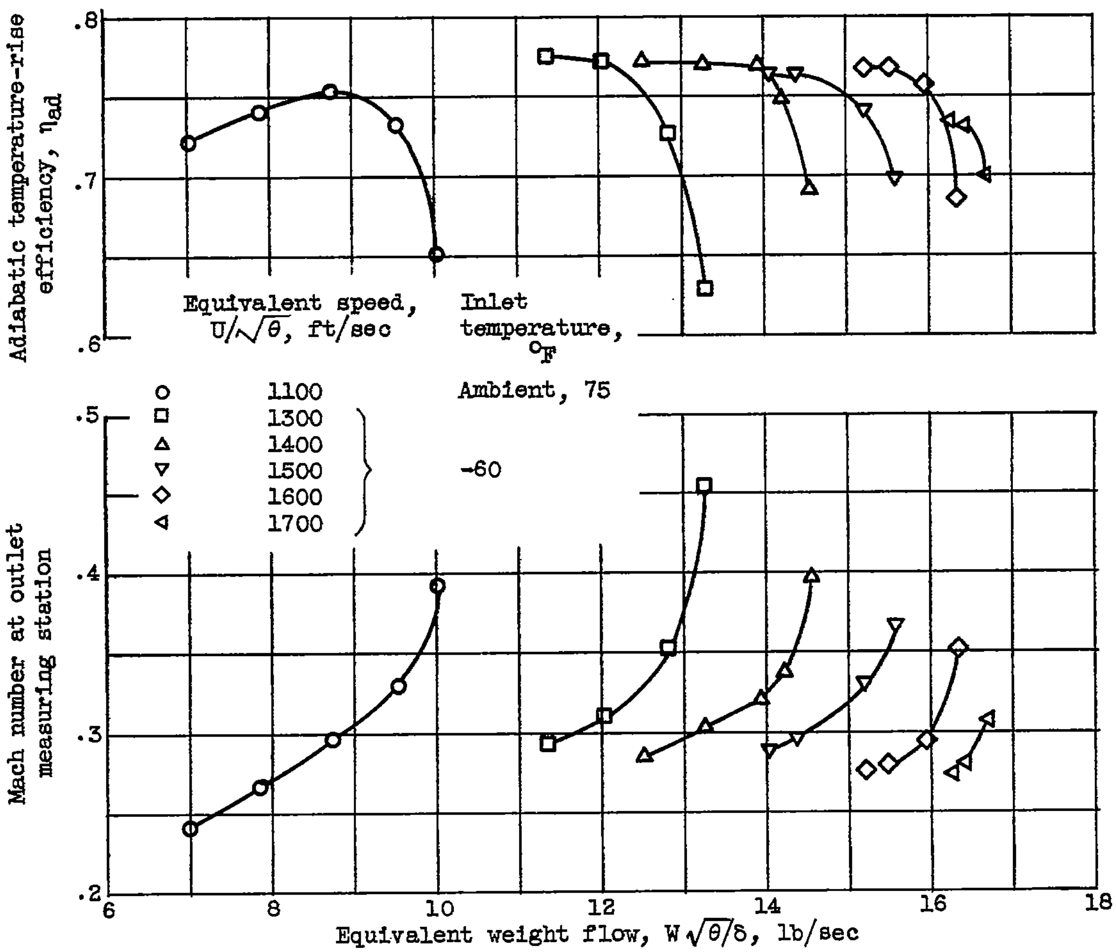
Cross-sectional view.

Figure 1. - Schematic diagram of MFI-1B impeller with vaned diffuser showing location of outlet instrumentation.



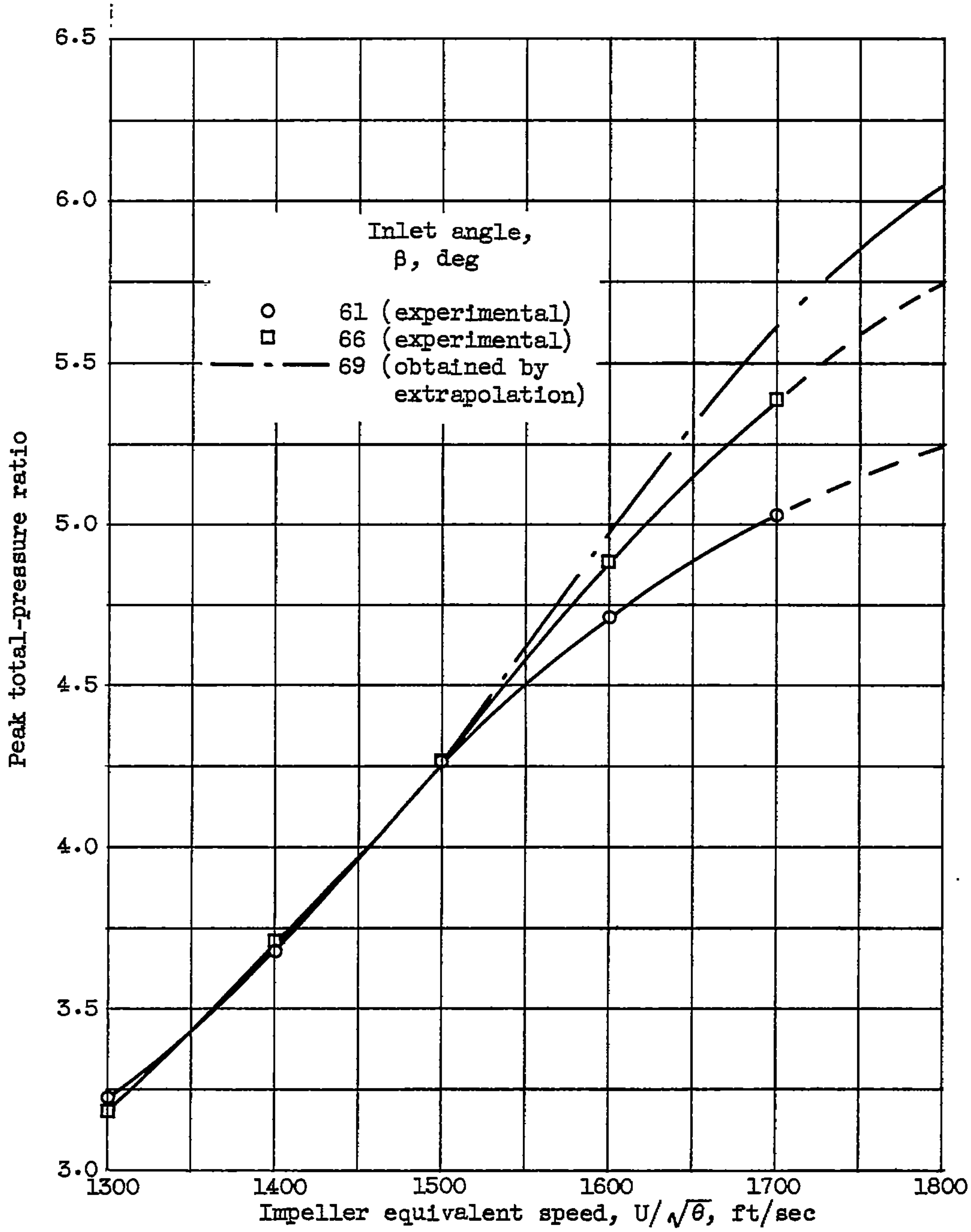
(a) Performance characteristics.

Figure 3. - Over-all performance characteristics of MFI-1B impeller with vaned diffuser. Angle at inlet to vanes, 66°; inlet-air pressure, 14 inches of mercury absolute.



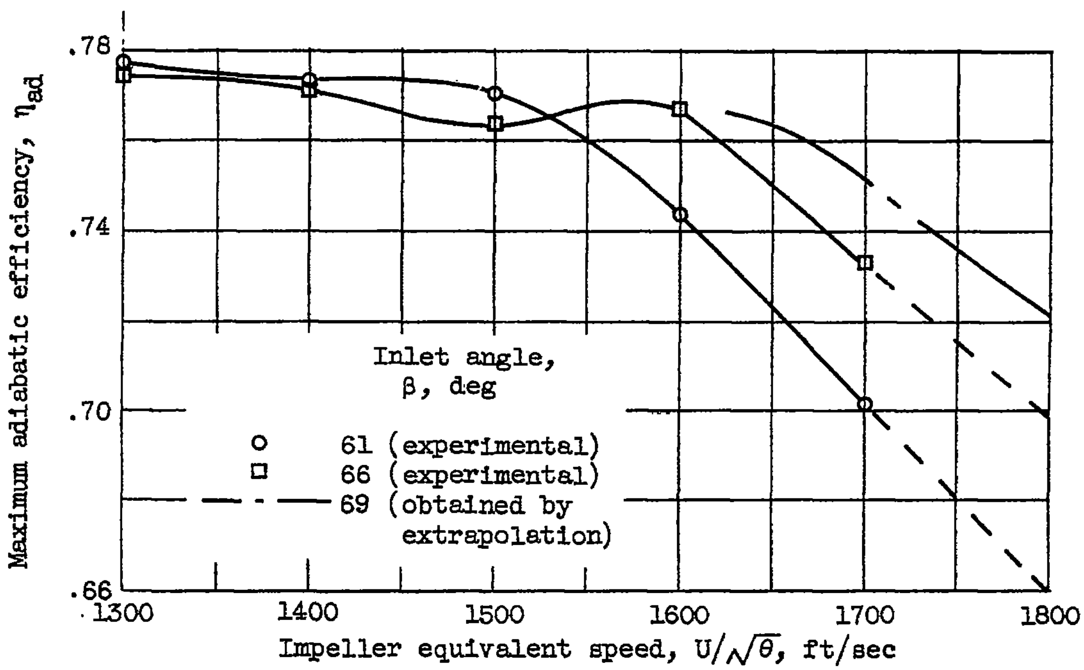
(b) Over-all efficiency and Mach number.

Figure 3. - Concluded. Over-all performance characteristics of MFI-1B impeller with vaned diffuser. Angle at inlet to vanes, 66°; inlet-air pressure, 14 inches of mercury absolute.



(a) Over-all pressure ratio.

Figure 4. - Comparison of performance of MFI-1B impeller with vaned diffuser with two settings of inlet angle at leading edges of vanes. (Curves are extended for impeller speeds greater than 1700 ft/sec.)



(b) Maximum efficiency.

Figure 4. - Continued. Comparison of performance of MFI-1B impeller with vaned diffuser with two settings of inlet angle at leading edges of vanes. (Curves are extended for impeller speeds greater than 1700 ft/sec.)

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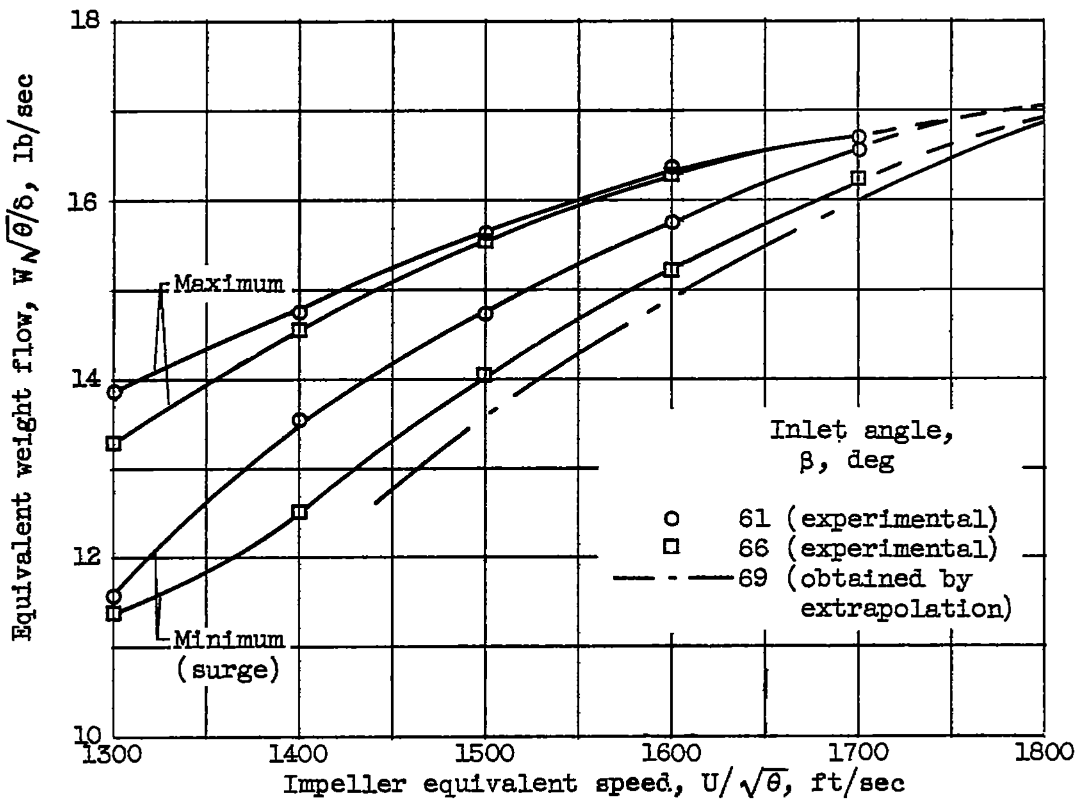

(c) Weight-flow range.

Figure 4. - Concluded. Comparison of performance of MFI-1B impeller with vaned diffuser with two settings of inlet angle at leading edges of vanes. (Curves are extended for impeller speeds greater than 1700 ft/sec.)

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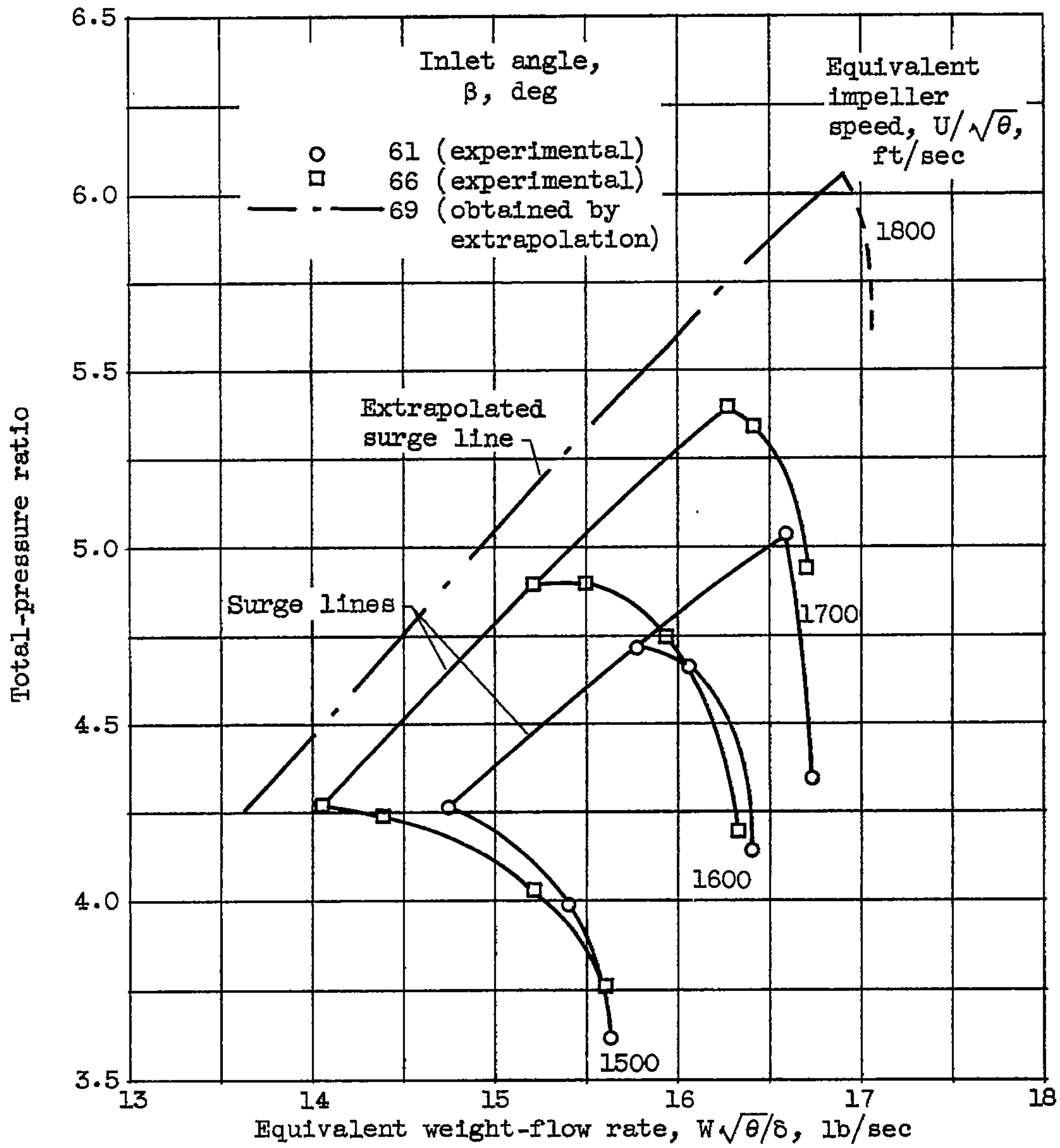

Figure 5. - Comparison of over-all performance characteristics of MFI-1B impeller with vaned diffuser at two settings of vane inlet angle. (Results are extrapolated to obtain performance curve at 1800 ft/sec with vane inlet angle of 69°.)

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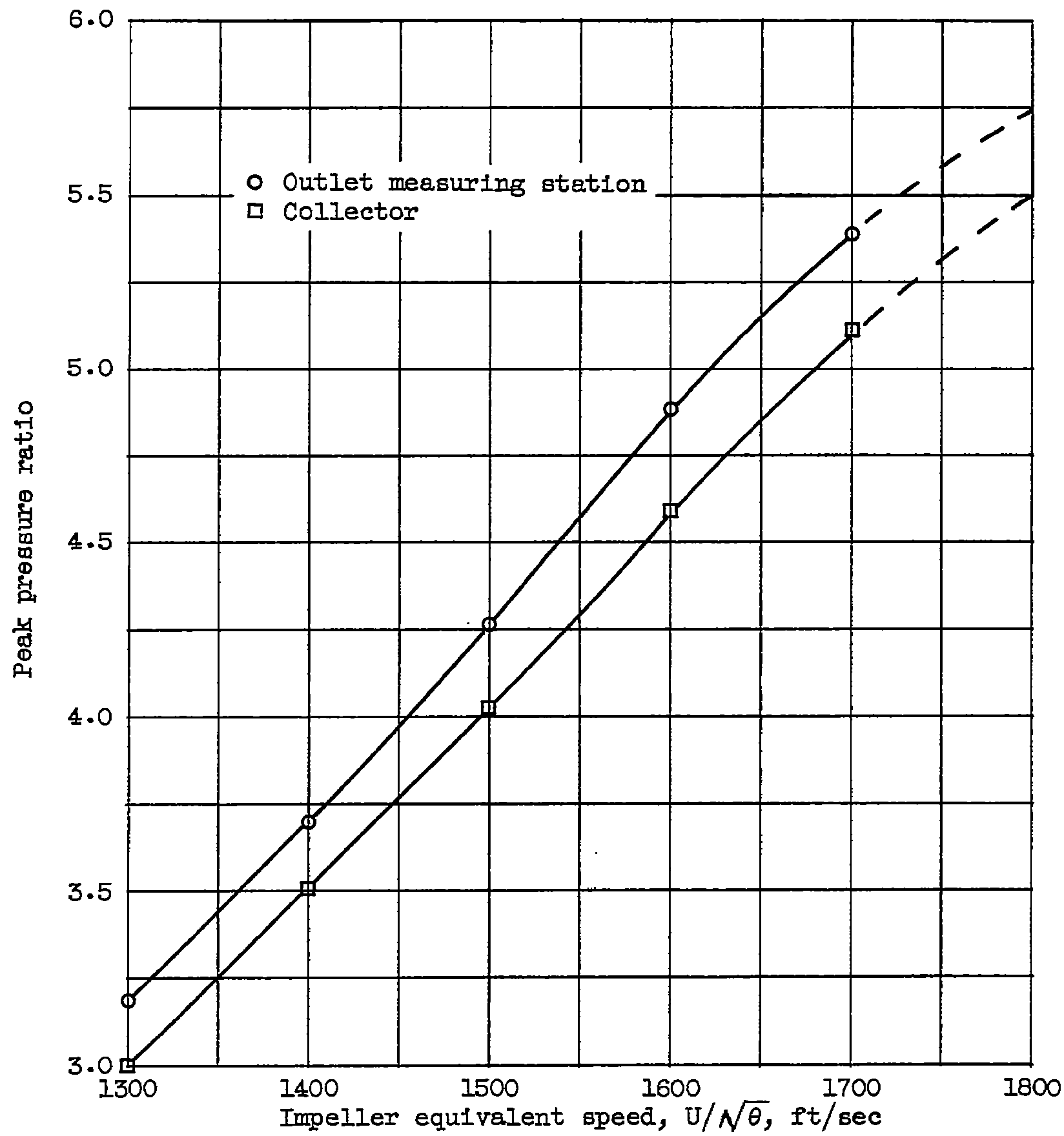

(a) Peak pressure ratio.

Figure 6. - Comparison of performance of MFI-1B impeller with vaned diffuser (vane inlet angle, 66°) based on measurements taken at the outlet measuring station and on static-pressure measurements taken in the collector.

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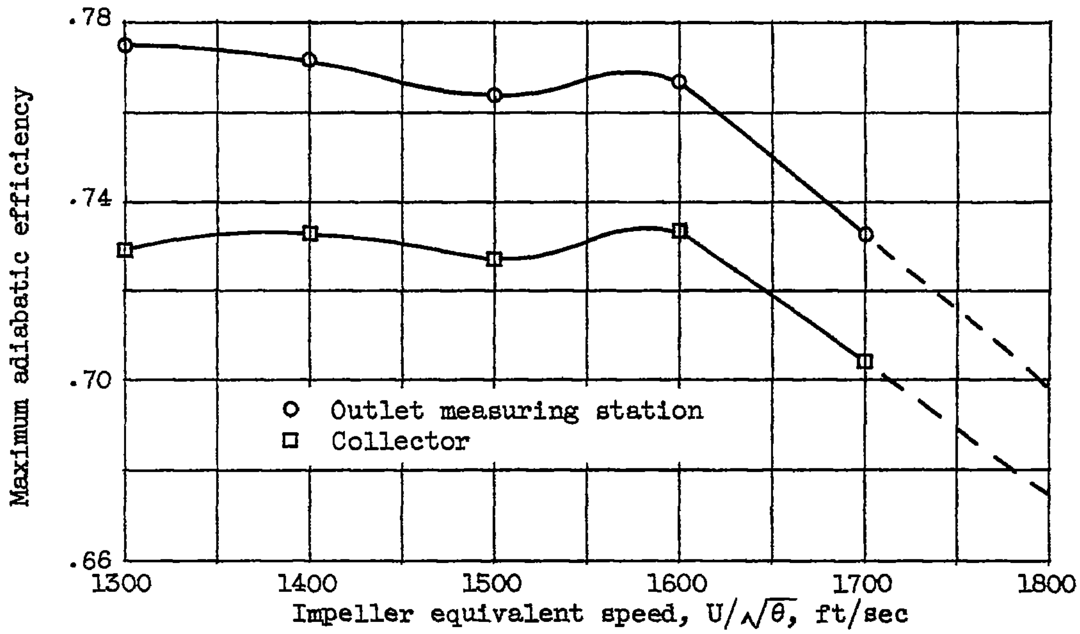

(b) Maximum adiabatic efficiency.

Figure 6. - Concluded. Comparison of performance of MFI-1B impeller with vaned diffuser (vane inlet angle, 66°) based on measurements taken at the outlet measuring station and on static-pressure measurements taken in the collector.