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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

INVESTIGATION OF PERFORMANCE OF AXIAL-FLOW COMPRESSOR OF XT-46 TURBINE-PROPELLER ENGINE

II - PERFORMANCE OF REVISED COMPRESSOR AT DESIGN EQUIVALENT SPEED

By John W. R. Creagh

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The compressor from the XT-46 turbine-propeller engine was revised by removing the last two rows of stator blades and by eliminating the interstage leakage paths described in a previous report.

With the revised compressor, the flow choking point shifted upstream into the last rotor-blade row but the maximum weight flow was not increased over that of the original compressor. The flow range of the revised compressor was reduced to about two-thirds that obtained with the original compressor. The later stages of the compressor did not produce the design static-pressure increase probably because of excessive boundary-layer build-up in this region. Measurements obtained in the ninth-stage stator showed that the performance up to this station was promising but that the last three stages of the compressor were limiting the useful operating range of the preceding stages. Some modificiations in flow-passage geometry and blade settings are believed to be necessary, however, before any major improvements in over-all compressor performance can be obtained.

INTRODUCTION

At the request of the Bureau of Aeronautics, Department of the Navy, an investigation of the performance characteristics of the compressor from the XT-46 turbine-propeller engine has been conducted. This compressor is of considerable interest because it is designed to obtain the unusually high pressure ratio of 9.0 in 12 stages, which is equivalent to a stage pressure ratio of 1.2. The original compressor

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performance over a range of speeds is presented in reference 1, where it is shown that the compressor was unable to produce design values of pressure ratio and efficiency at the design weight flow.

It is shown in reference 1 that two factors contributing to the inability of the compressor to meet the design requirements were large pressure losses through the last two stator-blade rows (twelfth and thirteenth) and interstage circulatory flows. The compressor was therefore modified to eliminate these two factors and the performance of this revised compressor was investigated over a range of air flows at design equivalent speed. Instrumentation was installed to obtain the compressor performance at the ninth-stage stator row and at the discharge of the twelfth-stage rotor. The investigation was limited by a compressor-component failure.

APPARATUS AND PROCEDURE

Compressor modifications. - The twelfth and thirteenth stator-blade rows were removed and a steel ring, machined to the contour of the passage wall, was installed in their place. Interstage circulatory flows were eliminated by applying a suitable covering material over the stator-blade bases where leakage was possible and by plugging air communication spaces between the annular diffuser discharge region and the area around the outside of the stator shell. Except for these changes, the compressor configuration was the same as that described in reference 1.

Instrumentation. - A total-pressure probe was installed in the ninth stator-blade row by removing a stator blade and positioning the probe in the center of the resultant area at a location corresponding to the stator-blade leading edge. A temperature probe was installed in a similar manner at a different circumferential location. These probes were set at an angle corresponding to the mean flow angle and were insensitive to variations in air-flow angle of $\pm 20^{\circ}$. This instrumentation was installed to obtain additional information on the compressor at this intermediate station inasmuch as in reference 1 it is shown that the static-pressure increase up to this blade row approximated the design value.

Two total-pressure probes were installed approximately 1/2 inch downstream of the twelfth rotor row to measure the total pressure at the rotor discharge. These probes were installed in the center of the annular area and set at an angle equivalent to that at which the twelfth-row stator blades had been installed. The angular sensitivity of these probes was similar to that of the probes in the ninth stator row. The compressor-inlet instrumentation, the location of the blade-row static-pressure taps, and the compressor-discharge-temperature measuring instruments were the same as described in reference 1. Because the removal of the twelfth and thirteenth stator-blade rows permitted a large magnitude of rotational velocity in the annular diffuser, it was necessary to aline the compressor-discharge temperature instruments to include this velocity component.

Procedure. - The compressor was operated at the design equivalent speed of 11,450 rpm using refrigerated air at approximately -55° F. The design inlet total pressure of 9.0 inches of mercury absolute was maintained during all tests. A complete range of flows from the maximum obtainable to the surge point was investigated. Operation of the revised compressor was terminated by failure of the rear compressor bearing housing after approximately 10 hours of running at design speed.

RATING METHODS

In reference 1, the over-all compressor performance was determined both according to the method outlined in reference 2 for calculating total pressure and from total pressures determined by rakes installed in the annular diffuser in a location corresponding approximately to the entrance section of the combustors. In the present investigation, however, because the last two stator-blade rows had been removed, the rotational component of the compressor-discharge air velocity could not be neglected and the method of reference 2 was not believed applicable. Also, owing to the presence of the rear compressor bearing supporting struts in the air-flow passage of the annular diffuser, appreciable losses in total pressure were found to occur between the twelfth rotor row and the simulated combustor entrance. Consequently, the total-pressure values obtained from the rakes were not regarded as representative of the true compressor performance and are not included in this report. The over-all total-pressure ratio of the revised compressor was determined from measurements obtained at the twelfth-rotor discharge by means of the two probes installed at this location.

RESULTS AND DISCUSSION

Over-all performance. - The over-all performance characteristics of the compressor are presented in figure 1. A peak pressure ratio of 7.75 was obtained at a corrected weight flow of 25.2 pounds per second and an adiabatic efficiency of 0.70. The peak adiabatic efficiency of 0.78 was obtained at the maximum corrected weight flow of 30.1 pounds per second and a pressure ratio of 6.45. These values of pressure ratio and efficiency are probably optimistic inasmuch as they represent mean-radius conditions and neglect the high-loss regions at the hub and the tip. Revision of the compressor produced practically no change in the maximum weight flow at design speed but the operating flow range was reduced to about two-thirds of that obtained with the original compressor (reference 1). This reduction in flow range may be attributed to the removal of the interstage leakage paths and air-communication spaces previously described. Although no direct comparisons can be made between the over-all performance of the original and revised compressors because the performance data were obtained at different compressor-discharge stations, the relative magnitudes of the data on the two compressors indicate that no appreciable improvement was obtained by the revision.

Blade-row static pressure. - The blade-row static-pressure variation through the compressor is shown in figure 2 for four corrected weight flows. The static pressures are expressed as ratios to the compressor-inlet total pressure, and the design variation of this ordinate is also shown. It can be seen from the figure that the experimental static-pressure ratios exceed the design values for the blade rows up to and including the ninth rotor row. Downstream of this point, the performance varied considerably with corrected weight flow, the two higher weight-flow curves falling away from the design curve more rapidly than the lower weight-flow curves. A considerable increase in static pressure was obtained across the last rotor row at the lower weight flows. Removal of the last two stator-blade rows where large losses were obtained on the original compressor resulted in displacement of this high-pressure-loss region upstream into the last rotor row of the revised compressor.

In figure 3, the ratio of the experimental accumulated static pressure at any blade row to the experimental inlet total pressure is expressed as a fraction of the corresponding design ratio. The blade rows from the fifth rotor to the eighth rotor inclusive are evidently more heavily loaded than the others, because static-pressure increases from 8 to 24 percent higher than design are obtained in this region. For all the weight flows shown, the performance downstream of the ninth rotor row became increasingly worse and at the maximum weight flow only 35 percent of the over-all design static-pressure ratio was obtained. At the lower weight flows, between 85 to 88 percent of the design static-pressure ratio was obtained. From the third stator row to the eleventh stator row, the curves of figure 3 exhibit the same trend with weight flow as the over-all total-pressure curve of figure 1; namely, the pressure decreased with increased weight flow up to a point and then increased as the weight flow increased. This orientation of the curves for these blade rows may be caused by the apparent stalling in the second rotor-blade row for all weight flows except the maximum value.

Performance limitation factors. - The variation of Mach number at the compressor discharge with corrected weight flow is shown in figure 4. The Mach numbers were determined from total pressures measured by the two probes at the twelfth-rotor discharge and static pressures measured with an outer-wall pressure tap installed immediately downstream of the twelfth rotor. The Mach numbers shown include both the rotational and the axial velocity components and the curve shows that supersonic velocities existed at this station for corrected weight flow values higher than 28 pounds per second. At the maximum-weight-flow point, the Mach numbers obtained were approximately twice the design values for this flow.

The high Mach numbers at the compressor discharge could be caused by stalling of a blade row or rows or by insufficient flow-passage area in some of the preceding stages resulting from a combination of wall boundary-layer build-up and wakes from the blades. The possibility of blade-row stalling was investigated. The curves of figure 5 show the variation of the static-pressure ratios across several blade rows with corrected weight flow. The blade rows shown were selected after a study of figure 3 and represent the performance upstream and downstream of the ninth stator where the initial deterioration in static-pressure performance has been shown to occur. It can be seen from figure 5 that no evidence of severe blade-row stalling existed because no abrupt decrease in pressure ratio was obtained over the range of corrected weight flows shown. The eighth stator-blade row appeared to be operating on the low-weight-flow side of the peak-pressure point. Evidently, however, the poor performance in the later blade rows was the result of boundary-layer build-up and blade wakes, which become increasingly damaging after the ninth stator row.

Performance at ninth-stage stator. - The variation with corrected weight flow of the Mach number, total-pressure ratio, and adiabatic efficiency determined from measurements in the ninth-stage stator are shown in figure 6. Because the measurements were taken in the center of the flow passage, the values obtained are somewhat optimistic owing to neglect of flow conditions near the hub and the tip where the performance may be expected to be poorer. The peak adiabatic efficiency of 0.85 was obtained at the peak total-pressure ratio of 5.6 and a corrected weight flow of 30.1 pounds per second. This peak-pressure-ratio value was approximately 10 percent higher than the design total-pressure ratio and, combined with the efficiency value at this point, indicates that up to the ninth stage the performance of the compressor was quite good. This statement is further substantiated by an examination of the Mach number curve where it can be seen that the experimental and design values were of the same magnitude.

From the shapes of the efficiency and total-pressure curves it would appear that the first nine stages of the compressor are operating in at least part of the corrected-weight-flow region where surge might be expected to occur. The stages downstream of the ninth stage evidently do not allow the preceding stages to operate over a range of weight flows corresponding to a normal operating curve in which an increase in corrected weight flow is accompanied by a decrease in pressure ratio. The last three stages seem to be choking off the high flow region of the preceding stages and it may be concluded that these last stages are not adequately matched to the rest of the compressor. Probably the best return in improved compressor performance will be obtained by concentrating on improvements in the design of the last few stages where the wall boundary layer and blade wakes occupy an appreciable percentage of the geometric area.

CONCLUDING REMARKS

The compressor of the XT-46 turbine-propeller engine was modified by removing the twelfth and thirteenth stator-blade rows and the interstage circulatory flows. As a result, the flow choking point of the compressor was shifted upstream into the twelfth rotor row but no increase in maximum weight flow was obtained as compared with the original compressor. The flow range of the revised compressor was reduced to about two-thirds that obtained on the original compressor. Data obtained at the ninth-stage stator showed that the performance up to this station was promising but that the last three stages were limiting the useful operating range of the preceding stages.

The progressively deteriorating static-pressure performance of the later stages with attendant high discharge air velocities continued to be present and may be attributed to insufficient aerodynamic flow area in these stages. Evidently the design contraction of the geometric flow area in the latter stages was too rapid. A compressor designed to produce the high stage pressure ratios of this unit apparently requires exceedingly careful consideration of the effects of passage-wall boundary-layer and blade wakes. It is possible that high-pressure-ratio compressors of small diameter will be difficult to design because of boundary-layer problems especially where the boundary layer constitutes an appreciable part of the geometric area.

No marked improvement in the over-all performance of this compressor is believed possible unless a major change in flow-passage geometry and blade settings is made.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, October 3, 1950.

John W. R. Creagh
John W. R. Creagh,
Aeronautical Research
Scientist.

Approved: Irving A. Johnsen
Irving A. Johnsen,
Aeronautical Research
Scientist.

Oscar W. Schey
Oscar W. Schey,
Aeronautical Research
Scientist.

mch

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1. Creagh, John W. R., and Sandercock, Donald M.: Investigation of Performance of Axial-Flow Compressor of XT-46 Turbine-Propeller Engine. I - Preliminary Investigation at 50-, 70-, and 100-Percent Design Equivalent Speed. NACA RM SE50E22, Bur. Aero., 1950.

2. NACA Subcommittee on Compressors: Standard Procedures for Rating and Testing Multistage Axial-Flow Compressors. NACA TN 1138, 1946.

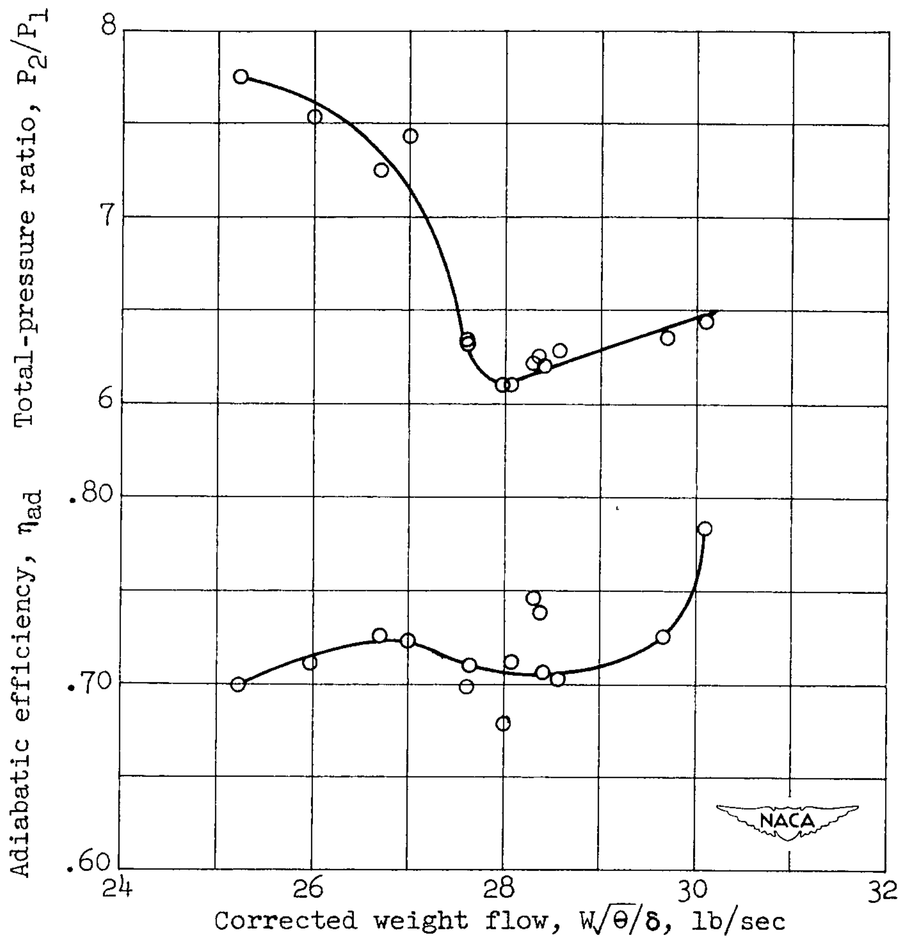

Figure 1. - Over-all performance characteristics of revised compressor of XT-46 turbine-propeller engine.

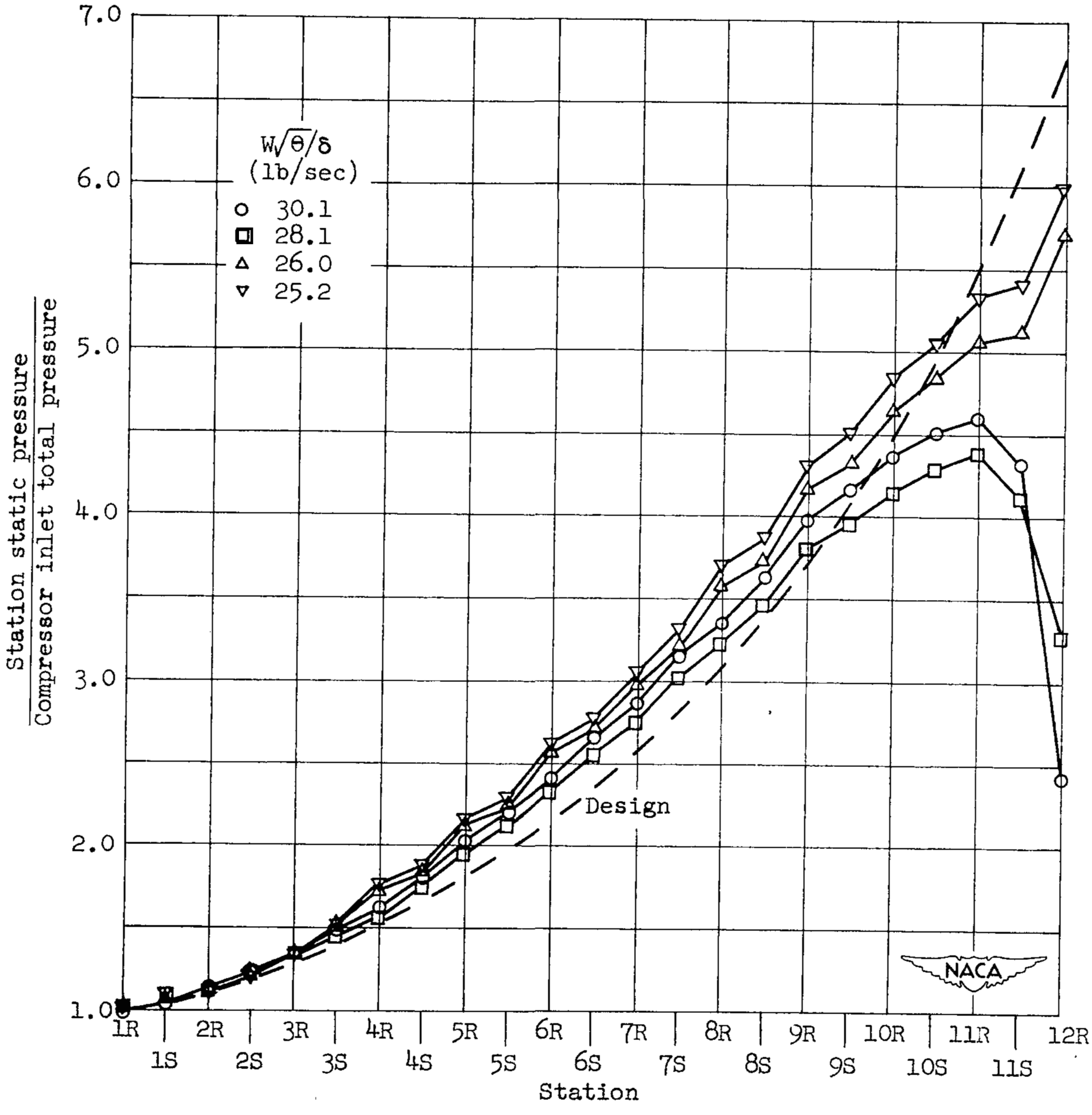

Figure 2. - Static-pressure distribution through revised compressor.

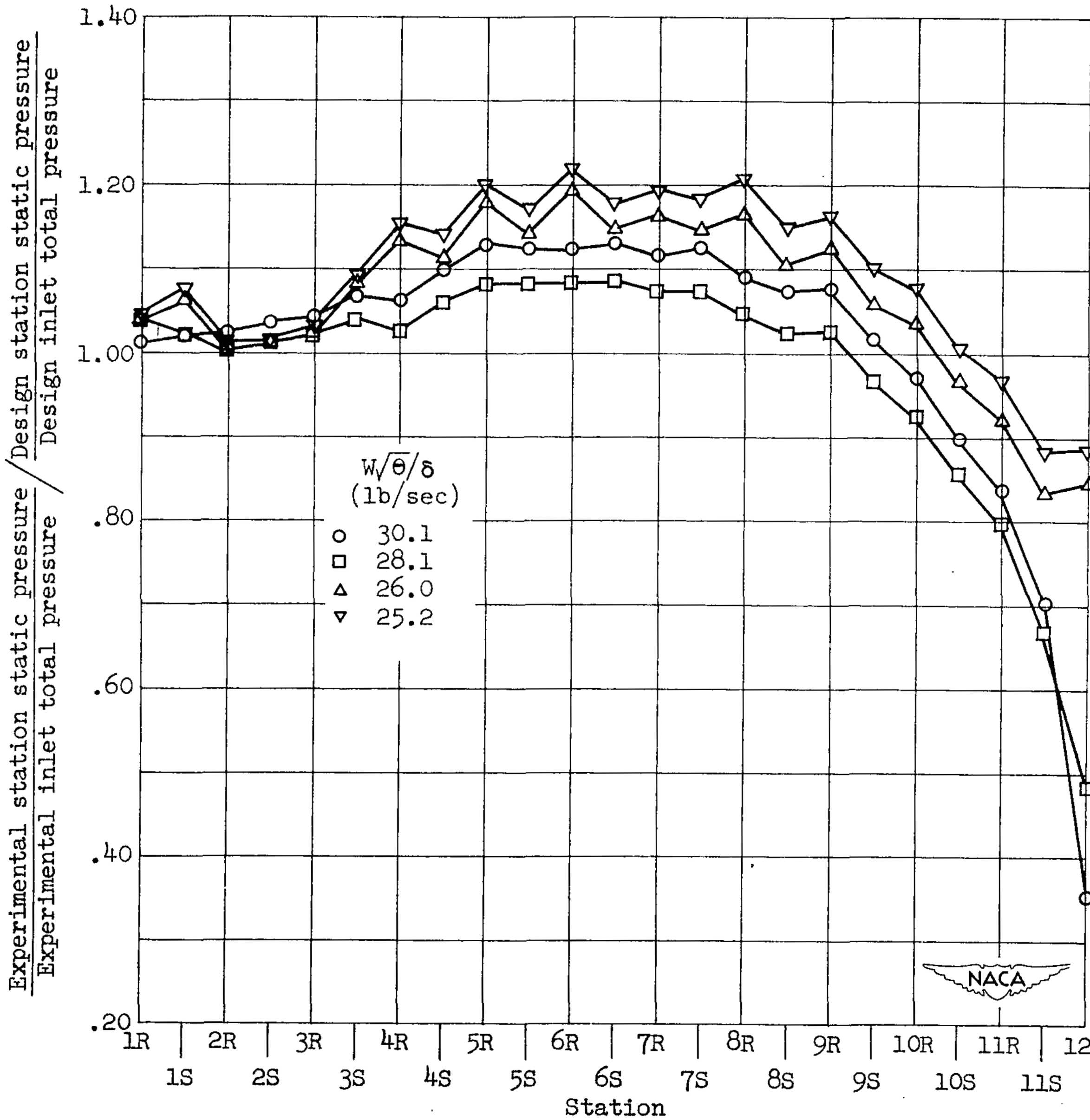

Figure 3. - Ratio of experimental to design pressure ratio through compressor.

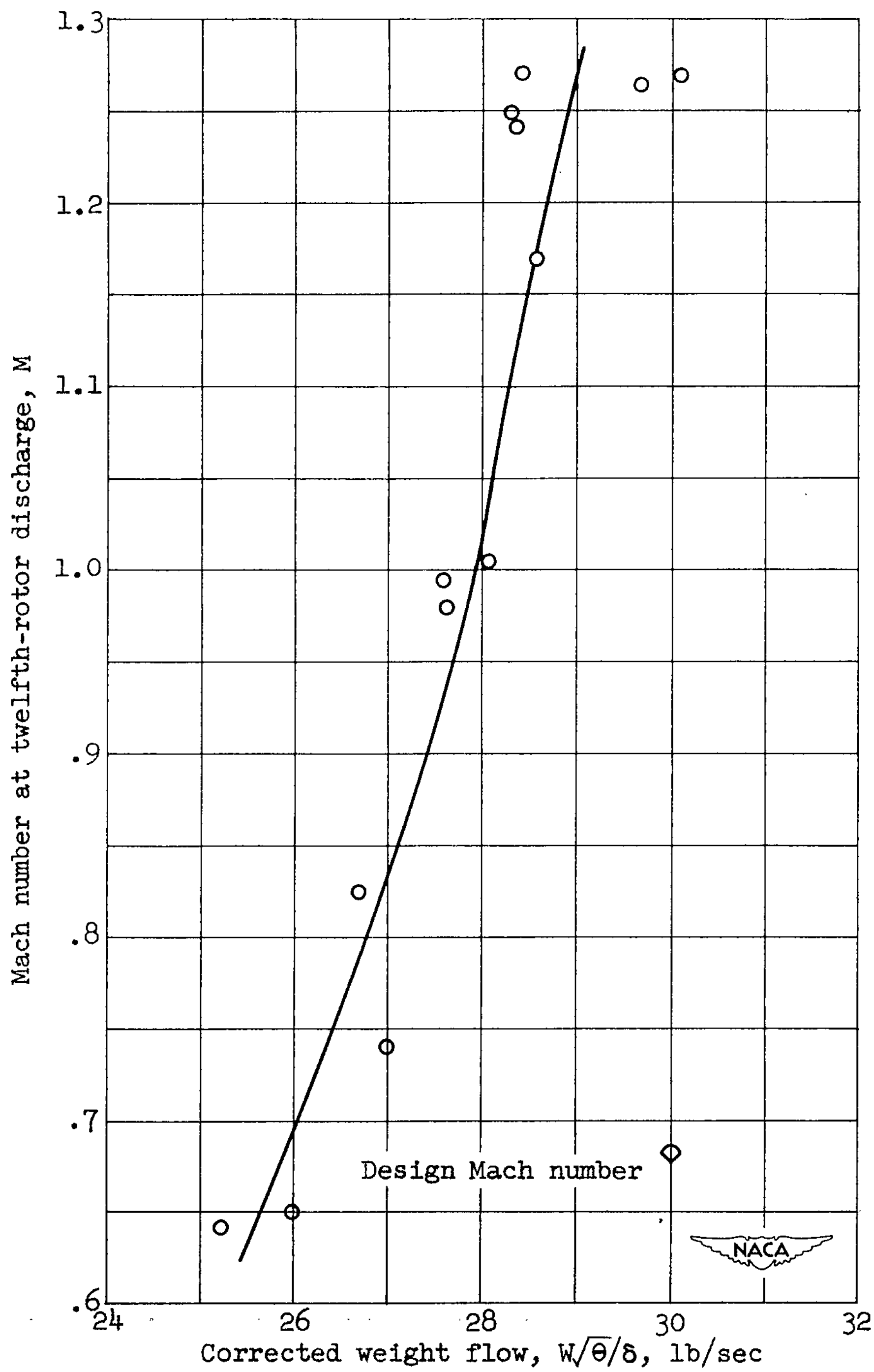

Figure 4. - Mach number variation at twelfth-rotor discharge.

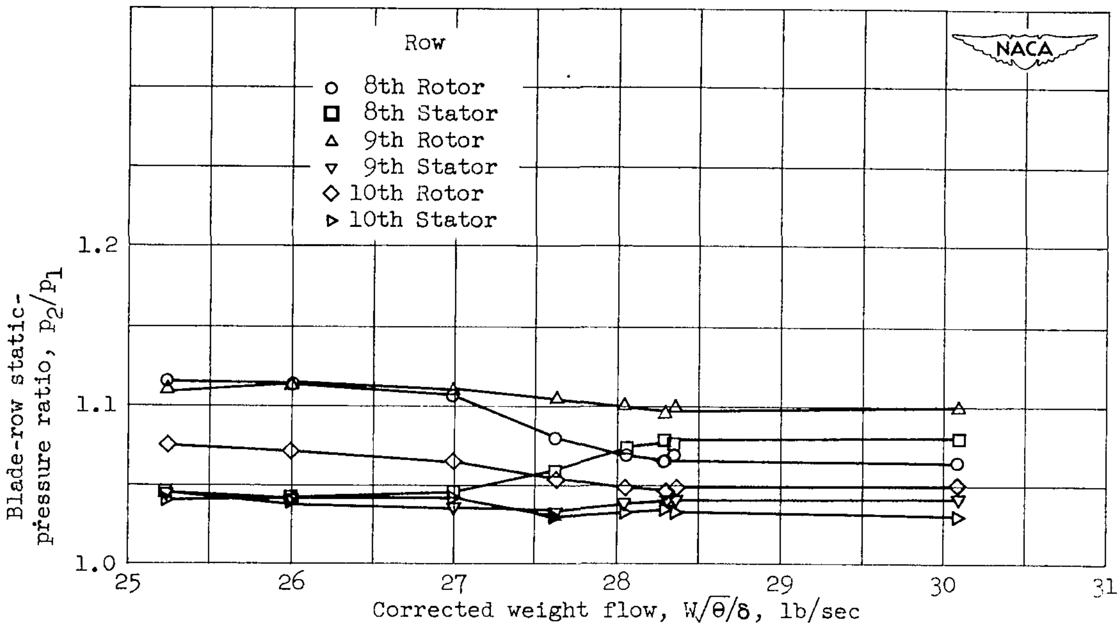

Figure 5. - Variation of static-pressure ratio with corrected weight flow for several blade rows.

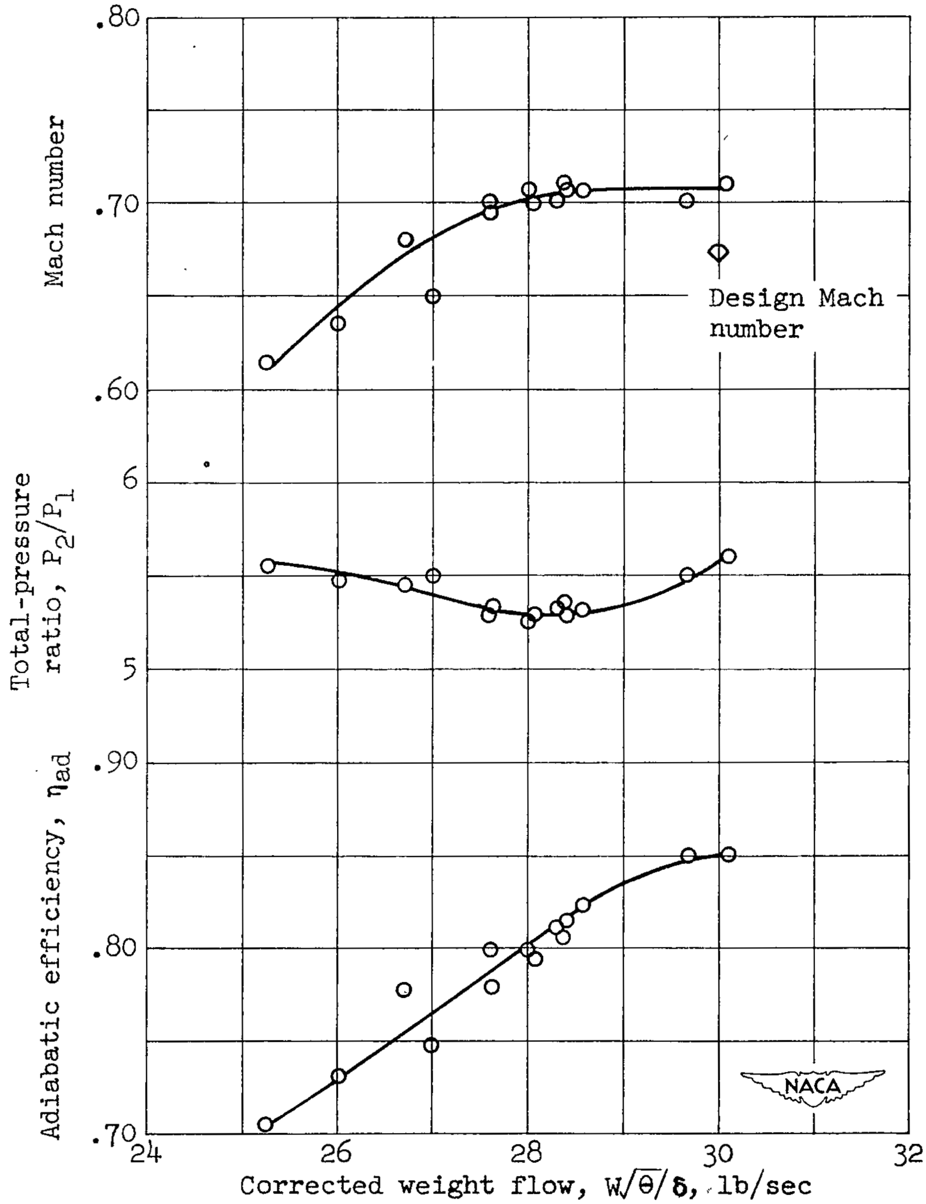

Figure 6. - Compressor performance characteristics at ninth-stage stator.