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RESEARCH MEMORANDUM

EFFECT OF VARIOUS BLADE MODIFICATIONS ON PERFORMANCE OF A 16-STAGE AXIAL-FLOW COMPRESSOR

III – EFFECT ON OVER-ALL PERFORMANCE CHARACTERISTICS OF INCREASING STATOR-BLADE ANGLES IN INLET STAGES

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

The inlet stages of a 16-stage compressor were unloaded by increasing the stator-blade angles by the following amounts: guide vanes 9°, first, second, and third stage stators 10°, and fourth stage stators 5°. The performance of this modified compressor was compared with that of the same compressor with original blade angles. The peak efficiency of the modified compressor was higher at all speeds up to 90 percent of equivalent design speed. The maximum efficiency of the modified compressor occurred at 85 percent of equivalent design speed and was 82 percent. This was $1\frac{1}{2}$ points higher than the maximum efficiency of the compressor with original blade angles, which occurred at an equivalent speed of 90 percent of design, and 3 points higher than the peak efficiency of the compressor with original blade angles at the same speed. The increases in peak efficiency attained by this modification were from 10.5 to 7 points at equivalent speeds from 30 to 80 percent of design. The peak efficiency was decreased about 1/2 point at 90 percent of equivalent design speed and $4\frac{1}{2}$ points at 100 percent of equivalent design speed.

The surge pressure ratio was increased at all speeds up to 90 percent of equivalent design speed and decreased at 90 and 100 percent of equivalent design speed. The weight flow was increased at equivalent speeds up to and including 75 percent of design and was decreased at higher speeds. The maximum reduction in weight flow was 13.5 percent at design speed. The changes in surge pressure ratio and flow were such that the surge line was about the same for both configurations at speeds up to 75 percent of equivalent design speed, whereas at higher speeds, the surge line for the modified compressor occurred at a higher pressure ratio for a given weight flow.

INTRODUCTION

All the blade rows of a multistage axial-flow compressor are usually set to operate at the angle of attack for maximum efficiency at design speed so that optimum performance is attained at design conditions. At speeds below design, the decreased energy addition leads to high volume flows and low angles of attack in the exit stages. The high volume flows in the exit stages limit the weight flow which can be passed through the compressor and force the inlet stages to operate at angles of attack higher than those for which they were designed. The deviations with speed from the angles of attack for maximum efficiency in both the inlet and exit stages are therefore large and result in low over-all efficiencies at low speeds. This mismatching of the stages naturally becomes more severe as the number of stages and over-all pressure ratio are increased. A peak efficiency of 50 percent at 30 percent of design speed is reported in reference 1 for a 16-stage compressor, although the design-speed peak efficiency is 80 percent.

If the blade rows of a compressor were set to operate at angles of attack for maximum efficiency at some speed below design, the deviation with speed from these optimum angles would be decreased and better part-speed performance could be anticipated. Some loss in design-speed performance may be incurred. Some such compromise may be necessary, however, particularly in high over-all pressure ratio compressors, to obtain a compressor with part-speed characteristics that will allow a good acceleration margin for the engine in which the compressor is to be used.

The method for achieving such a compressor design would be to set the inlet stages to operate at angles of attack lower than those for maximum efficiency and increase the blade camber of these stages so that design pressure ratio is attained at design speed and flow. Conversely, the blades in the exit stages would have a decreased camber and increased angle of attack. Because the middle stages tend to operate at a constant angle of attack at all speeds, these stages could be set to operate at the angle of attack for maximum efficiency. These stages could also be highly loaded because of the small range of angle of attack at which they operate, and the number of stages required for a given over-all pressure ratio would thereby be decreased.

Changing rotor-blade angles and blade cambers was not a feasible method of altering the stage operating point in this investigation because of fabrication and assembly difficulties. Therefore, the stage operational point was varied by resetting the stator blades upstream of the stage in which the changes were required. The effect on over-all performance of both increasing and decreasing stator-blade angles in the exit stages 3° from the original settings is presented in references 2 and 3. Some improvements in part-speed efficiency and surge characteristics were reported when the angles of attack in the exit stages were increased by decreasing the stator-blade angles 3°. The performance at design speed was unchanged by this modification. Comparison of the three configurations indicated that optimum performance obtainable in this compressor with stator-blade resetting in the exit stages was approached with the stator-blade angles decreased 3°.

In this investigation also conducted at the NACA Lewis laboratory and reported herein, the loading in the inlet stages was decreased by increasing the setting angles of the inlet guide vanes and stator blades in the first four stages. The blade angles were arbitrarily changed by a relatively large amount to obtain a large effect on over-all performance and thereby to determine if an intermediate change might be advantageous. The inlet-blade angles were increased by the following amounts: guide vanes 9°, first, second, and third stage stators 10°, and fourth stage stators 5°. In order to determine the effect on performance of changes in the inlet stages independently of other blade angle changes, the blades in the fifth to sixteenth stages were set at the original angles.

APPARATUS AND PROCEDURE

The test installation used for these runs is similar to that described in reference 1 except that a 15,000-horsepower-drive motor was used. The average inlet Reynolds number, relative to the first rotor, was approximately 350,000 for the runs reported herein and in references 2 and 3. Over-all performance data were obtained at equivalent speeds of 30 to 100 percent of design over a flow range at each speed from maximum to surge.

DISCUSSION OF RESULTS

The over-all performance of a 16-stage axial-flow compressor is presented in figure 1 with inlet stage blade angles increased the following amounts: guide vanes 9°, first, second, and third stage stators 10°, and fourth stage stators 5°. The performance of the same compressor with original blade angles (reference 2) is presented for comparison.

The speed at which the maximum efficiency occurs was decreased by the modification from 90 to 85 percent of equivalent design speed. The maximum efficiency of the modified compressor is 82 percent. This efficiency is $1\frac{1}{2}$ points higher than the maximum efficiency of the compressor with original blade angles, and 3 points higher than the peak efficiency of the compressor with original blade angles at the same speed. At speeds below 85 percent of design speed, the increases in peak efficiency with the modified compressor are large, namely, 10.5, 7.5, 7.5, 10.5, and 7 points at speeds of 30, 50, 65, 75, and 80 percent of equivalent design speed, respectively. At equivalent speeds higher than 85 percent of design, the peak efficiencies were decreased. The peak efficiency was decreased about 1/2 point at 90 percent of equivalent design speed and $4\frac{1}{2}$ points at 100 percent of equivalent design speed.

At speeds up to and including 75 percent of equivalent design speed, the weight flow was increased by the modification. This increase indicates that in the compressor with original blade angles, the inlet stages, at these speeds, were operating at angles of attack greater than those required for maximum pressure ratio; decreasing the angle of attack by resetting the stator blades therefore increases the pressure ratio in these stages and allows more weight flow to be passed through the choked, or negatively stalled, exit stages. At higher speeds, the decreased angles of attack in the inlet stages of the modified compressor resulted in a lower pressure ratio for these stages. The decreased pressure ratio in the inlet stages will not permit the same weight flow to be passed through the exit stages and, therefore, the weight flow at equivalent speeds of 80 to 100 percent of design was lower for the modified compressor. The maximum reduction in weight flow was 13.5 percent at 100 percent of equivalent design speed.

At equivalent speeds up to and including 75 percent of design, the surge pressure ratio and weight flow were both increased such that the surge line of these speeds is about the same for both compressor configurations. At 80 and 85 percent of equivalent design speed, the surge pressure ratio was increased while the weight flow was decreased; a large shift of the surge line, at these speeds, to a higher pressure ratio for a given weight flow resulted. The surge pressure ratio and weight flow were both decreased at equivalent speeds of 90 and 100 percent of design. Because the weight flow decrease predominated, a shift of the surge line to a higher pressure ratio for a given weight flow still occurred at these speeds.

If, in addition to resetting the inlet stages to operate at angles of attack for maximum efficiency at some speed below design, the blade cambers were increased so that design pressure ratio at design speed was still attained, the reduction in weight flow at design speed would not be incurred, and the penalty in efficiency might not be so severe. In addition, the improvement in performance at the intermediate speeds might be greater because of the increased available pressure ratio in the inlet stages with the greater camber.

SUMMARY OF RESULTS

The stator-blade angles in the inlet stages of a 16-stage axial-flow compressor were increased by the following amounts: guide vanes 9°, first, second, and third stage stators 10°, and fourth stage stators 5°, and produced the following results when compared with the same compressor with original blade angles:

1. The maximum efficiency of the modified compressor occurred at 85 percent of equivalent design speed and was 82 percent. This efficiency was $1\frac{1}{2}$ points higher than the maximum efficiency of the compressor with original blade angles, which occurred at 90 percent of equivalent design speed, and was 3 points higher than the peak efficiency of the compressor with original blade angles at the same speed.

2. At speeds below 85 percent of equivalent design speed, the peak efficiencies were increased 10.5, 7.5, 7.5, 10.5, and 7 points at speeds of 30, 50, 65, 75, and 80 percent of equivalent design speed, respectively.

3. At equivalent speeds of 90 and 100 percent of design, the peak efficiencies were decreased by the modification. The peak efficiency was 1/2 point lower at 90 percent of equivalent design speed and $4\frac{1}{2}$ points lower at 100 percent of equivalent design speed.

4. The weight flow was increased at equivalent speeds up to and including 75 percent of design and was decreased at higher speeds. The maximum decrease in weight flow was 13.5 percent at 100 percent of equivalent design speed.

5. The surge pressure ratio was increased at all speeds except 90 and 100 percent of equivalent design speed at which it was decreased. The changes in surge pressure ratio and weight flow were such that the surge line was about the same for both configurations at speeds up to 75 percent of equivalent design speed, whereas at higher speeds the surge line for the modified compressor occurred at a higher pressure ratio for a given weight flow.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, February 11, 1952

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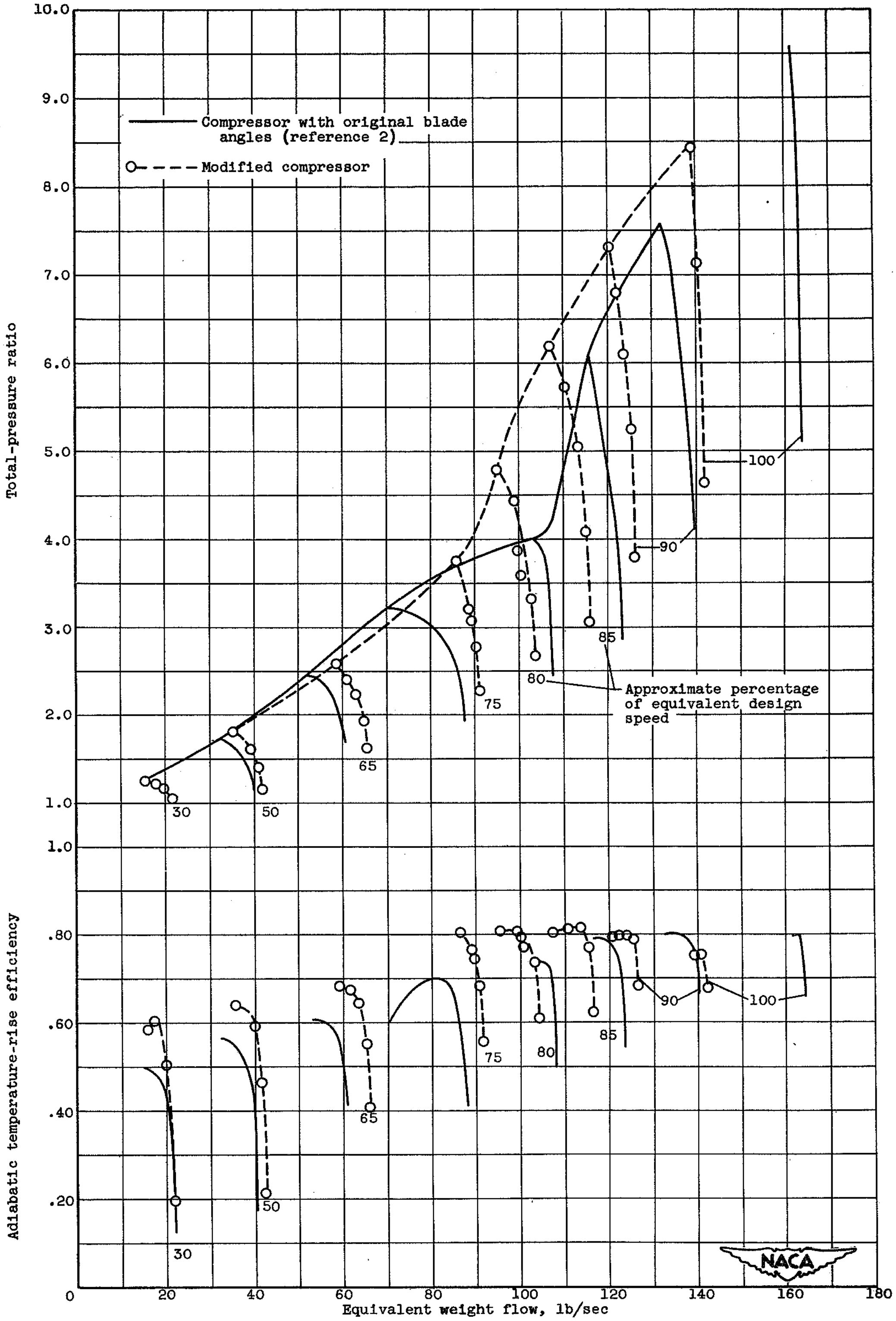

Figure 1. - Effect on over-all performance of increasing inlet guide vane and stator-blade angles in first four stages of 16-stage compressor.

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Compressors - Axial Flow 3.6.1.1

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Abstract

The stator-blade angles in the first four stages of a 16-stage axial-flow compressor were increased in order to decrease the angles of attack of these stages, and thereby to improve part-speed performance.

The performance of this modified compressor was compared with that of the same compressor with original blade angles.