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RESEARCH MEMORANDUM

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

V - EFFECT ON OVER-ALL PERFORMANCE CHARACTERISTICS OF A 20-PERCENT REDUCTION IN SOLIDITY OF THE FOURTEENTH THROUGH SIXTEENTH STAGE ROTORS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

In order to evaluate the effects of a solidity reduction in the exit stages of a multistage compressor, the solidity in the fourteenth through sixteenth rotors of a 16-stage compressor was decreased from 1.28 to 1.02 at the mean radius. The solidity reduction was achieved by decreasing the number of blades in each row from 170 to 136, a total decrease of 102 blades.

Comparison of the over-all performance of the compressor having reduced solidity with that of the compressor with the original solidity indicated that the decrease in exit stage rotor solidity resulted in slightly improved performance. The peak efficiency was increased by 2 to 3 points at 50, 65, and 80 percent of equivalent design speed. The changes in peak efficiency at other speeds were within the accuracy of measurement. The maximum weight flow was increased slightly (1 to 3 lb/sec) at all speeds except at 75 percent of equivalent design speed at which the weight flow was decreased about $1\frac{1}{2}$ pounds per second. The surge limit line was practically the same for both compressor configurations for speeds at which surge points were determined.

INTRODUCTION

The cost and weight of axial-flow compressors used in aircraft engines can be reduced by decreasing the number of blades required to obtain the prescribed design performance. The attainment of higher stage-pressure ratios than those currently in use will result in fewer stages for a given over-all pressure ratio and, hence, in the desired savings in weight and cost. With any given stage-pressure ratio, further reductions in weight and cost, however, can be obtained by the use of the lowest solidity required for the flow geometry to be used.

Two-dimensional cascade research (reference 1) and single-stage compressor research (reference 2) have indicated that in the intermediate range of solidities (1.0 to 1.5) small changes in peak efficiency with some reduction in maximum pressure ratio are obtained with decreases in solidity. At the high flow, or low angle of attack, end of the performance curves single-stage data have indicated that the performance is improved with the lower solidities.

At speeds below design the exit stages of a multistage compressor operate at high volume flows and low angles of attack. Therefore, it may be anticipated that a reduction in the solidity in the exit stages will improve the performance of these stages at part speed and will allow higher weight flows to be passed through the compressor. The higher weight flow will decrease the high angles of attack in the inlet stages at low speeds, and higher over-all compressor efficiencies might be anticipated.

In order to evaluate the effects of a solidity reduction in the exit stages of a multistage compressor and to determine if cascade and single-stage data could be qualitatively applied to multistage performance, the solidity at the mean radius of the fourteenth through sixteenth rotor rows of a 16-stage axial-flow compressor was decreased by 20 percent from 1.28 to 1.02.

From previous investigations of this compressor, a decrease in stator-blade angle (measured with respect to the compressor axis) of 3° in the twelfth through fifteenth stages resulted in improved performance over the entire speed range below design speed with no change in design-speed performance (reference 3). This compressor configuration was, therefore, chosen as that in which the effects of the solidity reduction were evaluated.

The over-all performance of the compressor with the reduced solidity was obtained over the flow range from maximum flow to surge at equivalent speeds from 50 to 100 percent of design. The runs were made at the NACA Lewis laboratory on a 15,000-horsepower test installation similar to that described in reference 4.

RESULTS AND DISCUSSION

The over-all performance of a 16-stage axial-flow compressor with a solidity at the mean radius in the fourteenth through sixteenth stage rotors of 1.02 is presented in figure 1. The performance of the same compressor with the original solidity of 1.28 (reference 3) in the exit rotor rows is shown for comparison.

When the solidity of the exit-stage rotor rows is decreased by a decrease in the number of blades in each row from 170 to 136, a slightly improved performance over most of the investigated speed range resulted. The peak efficiency was increased by 2 to 3 points at equivalent speeds of 50, 65, and 80 percent of design. The changes in efficiency at other speeds were within the limits of the accuracy of measurement. The maximum weight flow was slightly increased (1 to 3 lb/sec) at all speeds except at 75 percent of equivalent design speed, at which the weight flow was decreased about $1\frac{1}{2}$ pounds per second. The surge limit was practically the same for both compressor configurations over the range of speeds at which the surge points were determined. The surge point at design speed was not determined for either configuration.

The stator blade-row solidities in the exit stages were not changed, because stator blade rings with decreased solidity were not available at the time of this investigation. The same trends in changes in performance would, probably be obtained with a corresponding decrease in stator solidity.

As previously mentioned, the trends of changes in performance presented could have been anticipated from the single-stage compressor tests reported in reference 1. Two-dimensional cascade research of NACA 65-series blower blades (reference 1) also indicates the changes to be anticipated by the solidity decrease made in this multistage compressor. The blades in this compressor were 65-series thickness distributions on a circular-arc camber line. In order to correlate the camber of the blades used in the compressor with the camber of the NACA 65-series blower blades, the ratio of the maximum height from the chord line to the mean camber line, was assumed to be the same for equivalent cambers. On this basis, the average camber of the rotor blades in the stages in which the solidity was decreased corresponds to the NACA 65-12 blade section. Figure 2 presents the cascade performance of the NACA 65-(12)10 blade section reported in reference 1. The change in turning angle with a solidity decrease from 1.25 to 1.0 (approximately the reduction made in the multistage compressor) is less than $1/2^{\circ}$ at the lower angles of attack that would be encountered in the exit stages at part speed. The higher choking weight flow for the lower solidity is indicated by the fact that the negative-stall high-drag region occurs at a lower angle of attack.

The effects that may be expected at speeds above design with the solidity of 1.02 are shown in figure 2. As the solidity is decreased the positive stall angle of attack also decreases. At surge flow at design speed and at speeds above design, the exit stages will operate at or near the stall angle of attack. It may be anticipated, therefore, that the surge pressure ratio at these speeds will be decreased.

A further corresponding percentage decrease in solidity is shown in figure 2 for the two-dimensional cascade data. The turning angle is decreased by 2 to 3° with a decrease in solidity from 1.00 to 0.75. Decreasing the solidity in the multistage compressor over this range, therefore, would not be expected to improve the over-all performance, because the decrease in area would be compensated by the decrease in turning angle. The high-speed performance would also be detrimentally affected so that engine operation at speeds above design may be difficult because of the lower surge limit.

SUMMARY OF RESULTS

A 20-percent reduction in solidity (from 1.28 to 1.02 at the mean radius) in the fourteenth through sixteenth stage rotors of a 16-stage compressor was made by reducing the number of blades in each blade row from 170 to 136. A total reduction of 102 rotor blades in the last three stages resulted in the following performance changes, which can qualitatively be predicted from NACA two-dimensional cascade and single-stage compressor research:

1. The peak efficiency at 50, 65, and 80 percent of equivalent design speed was increased by 2 to 3 points. The efficiencies at other speeds were essentially unaffected.

2. The maximum weight flow was slightly increased at all speeds except at 75 percent design speed, at which there was a small decrease.

3. The surge limit line was practically the same for both compressor configurations at speeds for which the surge point was determined.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, April 21, 1952

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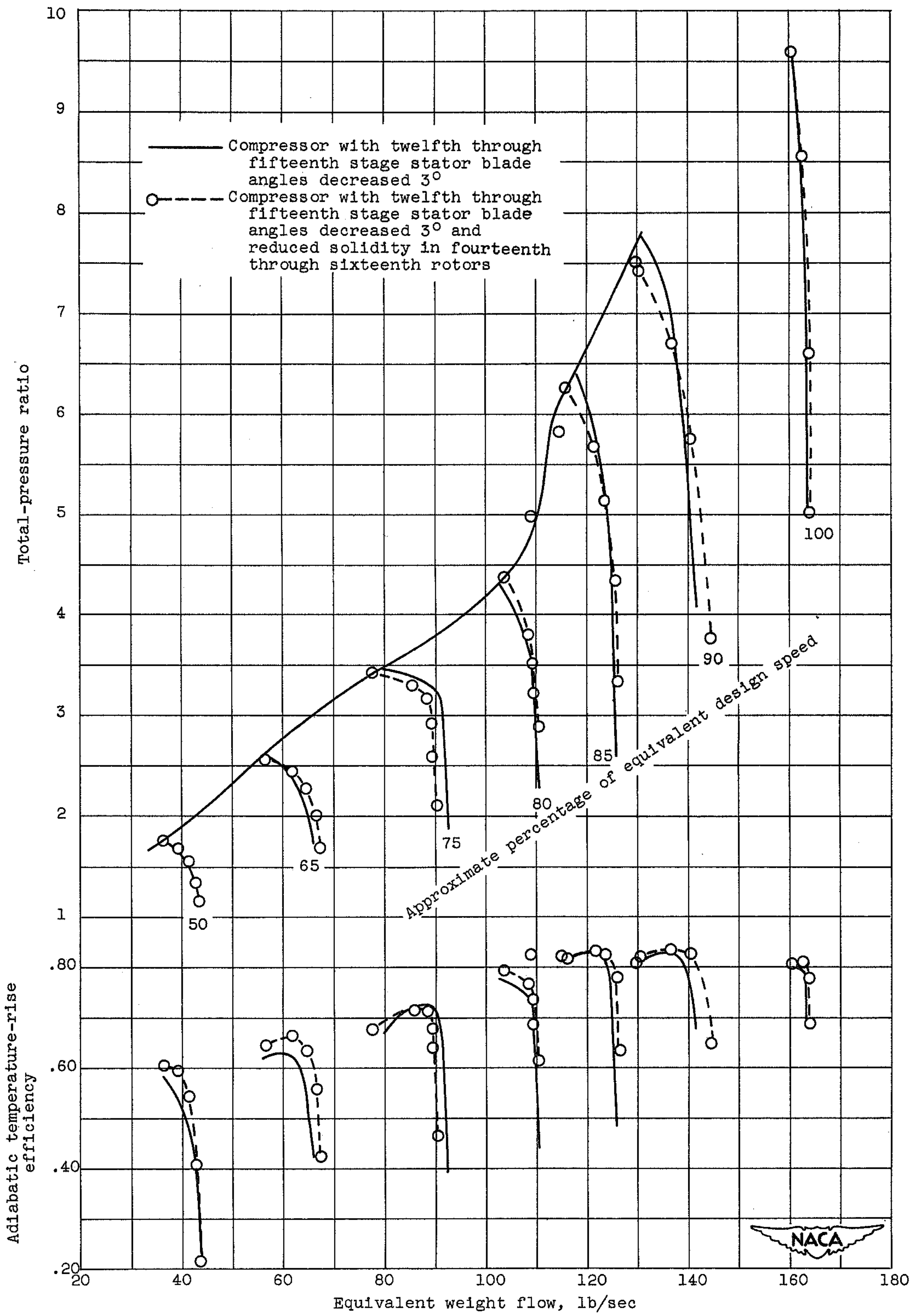

Figure 1. - Effect on over-all performance of a 20-percent reduction in solidity of fourteenth through sixteenth stage rotors.

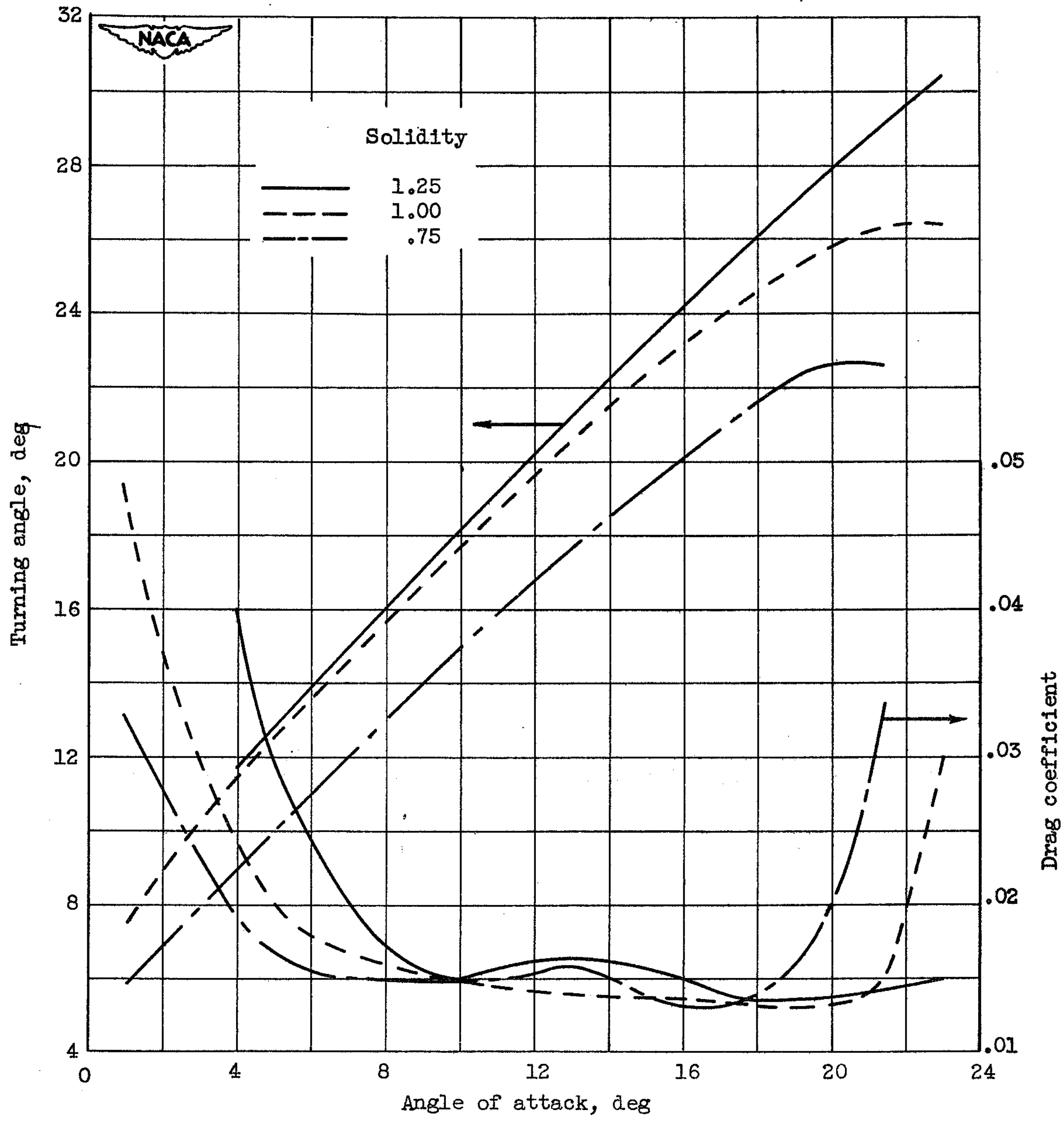

Figure 2. - Two-dimensional cascade results of blade section approximating average blade section in exit stages of test compressor. (Data from reference 1.) NACA 65-(12)10 blade section; inlet-air angle, 45°.

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Engines, Turbo-Jet 3.1.3

Compressors - Axial Flow 3.6.1.1

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Abstract

The performance of a 16-stage axial-flow compressor, in which the mean-radius solidity was reduced from 1.28 to 1.02 in the fourteenth through sixteenth stage rotors was determined. The performance of this modification was compared with that of the compressor with original rotors. The reduced solidity resulted in slightly improved performance.