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RESEARCH MEMORANDUM

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EFFECT OF VARIOUS BLADE MODIFICATIONS ON PERFORMANCE OF A

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16-STAGE HIGH-PRESSURE-RATIO AXIAL-FLOW COMPRESSOR

I - EFFECT ON OVER-ALL PERFORMANCE CHARACTERISTICS

OF DECREASING TWELFTH THROUGH FIFTEENTH

STAGE STATOR-BLADE ANGLES 3°

By Arthur A. Medeiros, James E. Hatch, and James F. Dugan, Jr.

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

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SUMMARY

The stator-blade angles in the twelfth through fifteenth stages of a 16-stage high-pressure-ratio axial-flow compressor were decreased 3° to increase the work output of the exit stages, particularly at low speeds, where they are normally turbining. This modified compressor was run at 30 to 100 percent of equivalent design speed. The over-all performance of the modified compressor was compared with that of the same compressor with the original blade angles.

The modification of the compressor resulted in an increase in peak efficiency of from 1 point at 30 percent of equivalent design speed to $4\frac{1}{2}$ points at 85 percent of equivalent design speed. The peak efficiency at design speed was 80 percent for both configurations. The surge pressure ratio was increased at all speeds at which the surge points were determined. Increases in equivalent weight flow partially compensated for this effect, however. When plotted against inlet equivalent weight flow, the surge line is therefore only slightly higher for the modified compressor.

Calculations to determine the matching characteristics of the compressors with a two-stage turbine indicated that the equilibrium operating line lies in the surge region at intermediate engine speeds for both compressor-turbine combinations. The maximum deficiency between the operating line and the surge line, as measured in terms of the compressor flow parameter, is 45 percent less for the engine with the modified compressor. Compressor air bleed is therefore a more practical means of shifting the operating line out of the surge region for the engine with the modified compressor.

INTRODUCTION

As the speed of a multistage axial-flow compressor is decreased below design, the angles of attack in the exit stages decrease below those for which they were designed until at some speed the exit stages are turbinizing over the entire flow range of the compressor. This condition results in a limiting of the weight flow which can be passed through the compressor and therefore forces the inlet stages to operate at angles of attack higher than those for which they were designed. These deviations from design angle of attack result in low part-speed efficiency and pressure ratio, which lead to engine starting and acceleration problems. If the exit blade rows are reset so that, at design speed, they operate at angles of attack higher than those for maximum efficiency, the drop in efficiency and pressure ratio with decreasing speed may be less severe, although the design-speed efficiency may be decreased. Some such compromise may be necessary, however, particularly for high-pressure-ratio compressors, in order to obtain good starting and accelerating characteristics for the engine in which the compressor is to be used.

In order to determine the effect of changes in angle of attack on compressor performance over the entire operating range, the stator-blade angles (measured with respect to the axis of the compressor) in the twelfth through fifteenth stages of a 16-stage high-pressure-ratio axial-flow compressor were decreased ^{unimproved} 3°. The compressor used for this investigation was the original [^]compressor design for the J35-A-23 turbojet engine.

Over-all performance runs of the modified compressor were made at speeds from 30 to 100 percent of equivalent design speed over a flow range at each speed from maximum weight flow to surge. The performance of the compressor with original blade angles was obtained for comparison.

The effect of the compressor modifications on the compressor-turbine matching characteristics was determined by using the methods of reference 1 to obtain a comparison of the surge line and the equilibrium operating line of an engine consisting of the modified compressor and a two-stage turbine, and of an engine consisting of the compressor with original blade angles and the same turbine. The performance characteristics of this turbine are reported in reference 2.

APPARATUS AND INSTRUMENTATION

The setup used in these tests is similar to that reported in reference 3, with the exception of the drive equipment. A 15,000 horsepower

motor with a gearbox having a step-up ratio of 2.101 provided 12,100 horsepower at the compressor design speed of 6100 rpm. This increase made it possible to run the compressor at higher inlet pressures than were possible in reference 3, in which 6100 horsepower was available.

DISCUSSION OF RESULTS

Performance of compressor with original blade angles. - After completion of the runs reported in reference 3, the tip clearances in the first four rows of rotor blades had to be increased to prevent the blade tips from rubbing on the casing. Also, the first stage rotor blades were replaced. Surge points on this original compressor were then rerun. A failure of this compressor occurred during these runs, but a replacement compressor was obtained and the over-all performance rerun with blade angles set the same as those of the original compressor. This performance is presented in figure 1 where over-all total-pressure ratio and adiabatic temperature-rise efficiency are shown as functions of equivalent weight flow at equivalent speeds of 30 to 100 percent of design. These data are based on the measured discharge total pressure, which was obtained by the method described in reference 3. The surge points obtained on the original compressor with the increased clearances are shown for comparison. Good agreement with the replacement compressor was obtained with the exception of 90 percent equivalent design speed, where the original compressor indicated a higher pressure ratio than that attainable with the replacement compressor. The surge point at design speed was not determined for the replacement compressor; however, the maximum pressure ratio obtained (about 9.6) allows considerable margin over the design pressure ratio of 8.75.

Performance of compressor with reset blade angles. - In figure 2, a comparison is presented of the over-all performance of the compressor with original blade angles (from fig. 1) and the same compressor with the stator-blade angles in the twelfth through fifteenth stages decreased 3° . The peak efficiency has been increased at all speeds except design by this modification. The increases range from 1 point at 30 percent of equivalent design speed to $4\frac{1}{2}$ points at 85 percent of equivalent design speed. The peak efficiency at design speed was 80 percent for both configurations. The maximum efficiency of the compressor with reset stator blades occurred at 85 percent equivalent design speed and is 83.5 percent at an equivalent weight flow of 120.5 pounds per second and an over-all total-pressure ratio of 5.95.

The surge pressure ratio was increased at all speeds over the range tested. However, at speeds up to 75 percent of equivalent design speed, the surge weight flow has also been increased, so that on a plot of

inlet equivalent weight flow against pressure ratio, both configurations have about the same surge line. At speeds above 75 percent of equivalent design speed, the increase in surge pressure ratio with little or no change in surge weight flow results in a slightly higher surge limit for the compressor with reset stator blades. A more valid comparison of the effect of the compressor modifications on the surge line will be obtained on the basis of compressor-turbine matching characteristics.

Compressor-turbine matching. - The methods of reference 1 were used to obtain the equilibrium operating line of an engine consisting of the modified compressor and the turbine reported in reference 2 in order that the changes in compressor performance on the compressor-turbine matching characteristics could be evaluated. The equilibrium operating line and surge limit of an engine consisting of the compressor with original blade angles and the same turbine ~~which has been presented in~~ ~~reference 2~~ is shown for comparison in figure 3. The operating line lies in the surge region at speeds of about 65 to 83 percent equivalent design speed for both engine configurations. However, the deficiency between the surge line and the equilibrium operating line, as measured in terms of the compressor flow parameter, has been decreased about 45 percent by the compressor modification. This result would make compressor air bleed a more practical means of shifting the operating line out of the surge region for the engine with the modified compressor. The improvement in matching characteristics is a result of the fact that the surge line for the modified compressor occurs at lower values of the compressor flow parameter at all speeds. In fact, the equilibrium operating line has been shifted toward the surge region at speeds up to 80 percent equivalent design speed because of the increased weight flow handled by the compressor, which is only partially compensated by the increase in compressor efficiency.

SUMMARY OF RESULTS

Decreasing the stator-blade angles 3° in the twelfth through fifteenth stages of a 16-stage high-pressure-ratio axial-flow compressor produced the following results:

1. The performance at design speed was approximately the same as that of the standard compressor over the entire flow range covered by the tests.

2. The peak efficiency was higher for the modified compressor at all speeds except design where it was the same (80 percent) for both configurations. The increase in peak efficiency ranged from 1 point at 30 percent of equivalent design speed to $4\frac{1}{2}$ points at 85 percent of design speed.

3. The surge pressure was higher for the modified compressor at all speeds. However, at speeds up to 75 percent equivalent design speed the surge weight flow was also increased, so that on the basis of inlet equivalent weight flow, both configurations had about the same surge line. Above this speed, the increase in surge pressure ratio with little or no change in surge weight flow resulted in a slightly higher surge limit for the modified compressor.

4. Compressor-turbine matching characteristics indicated that the equilibrium operating line lies in the surge region at intermediate engine speeds with either compressor configuration and the two-stage turbine. The maximum deficiency between the operating line and the surge line, as measured in terms of the compressor flow parameter, is 45 percent less for the engine with the modified compressor. Compressor air bleed is therefore a more practical means of shifting the operating line out of the surge region for the engine with the modified compressor.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 20, 1951

REFERENCES

1. Dugan, James F., Jr., Rebeske, John J., Jr., and Finger, Harold B.: Matching Characteristics of J35-A-23 Compressor and Two-Stage Turbine. NACA RM E51H15, 1951. *B. 17*
2. Rebeske, John J., Jr., Berkey, William E., and Forrette, Robert E.: Over-All Performance of J35-A-23 Two-Stage Turbine. NACA RM E51E22, 1951. *cut 7*
3. Medeiros, Arthur A., Guentert, Donald C., and Hatch, James E.: Performance of J35-A-23 Compressor. I - Over-All Performance Characteristics at Equivalent Speeds from 20 to 100 Percent of Design. NACA RM E50J17, 1951. *cut 7*

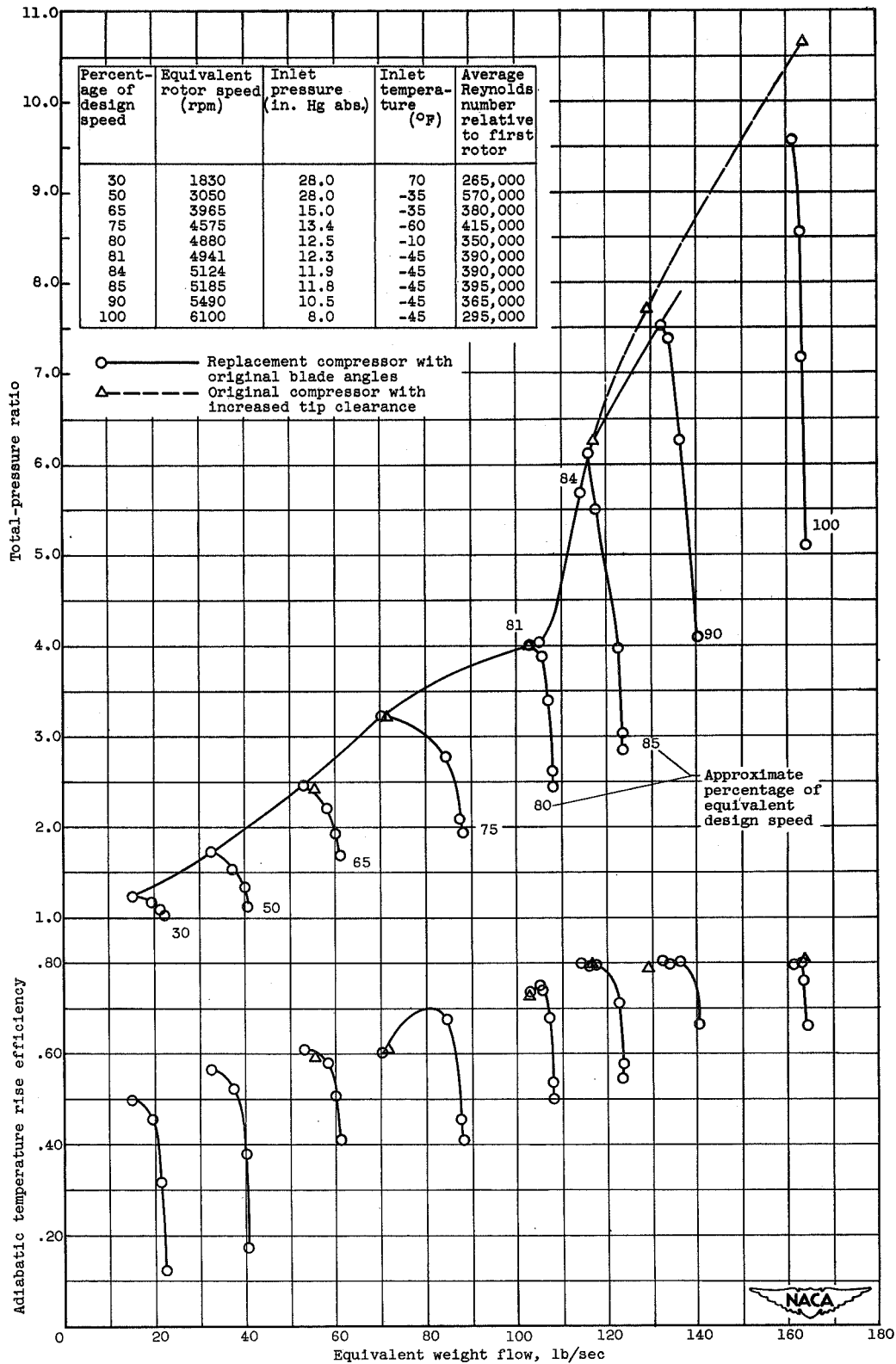


Figure 1. - Over-all performance of compressor with original blade angles.

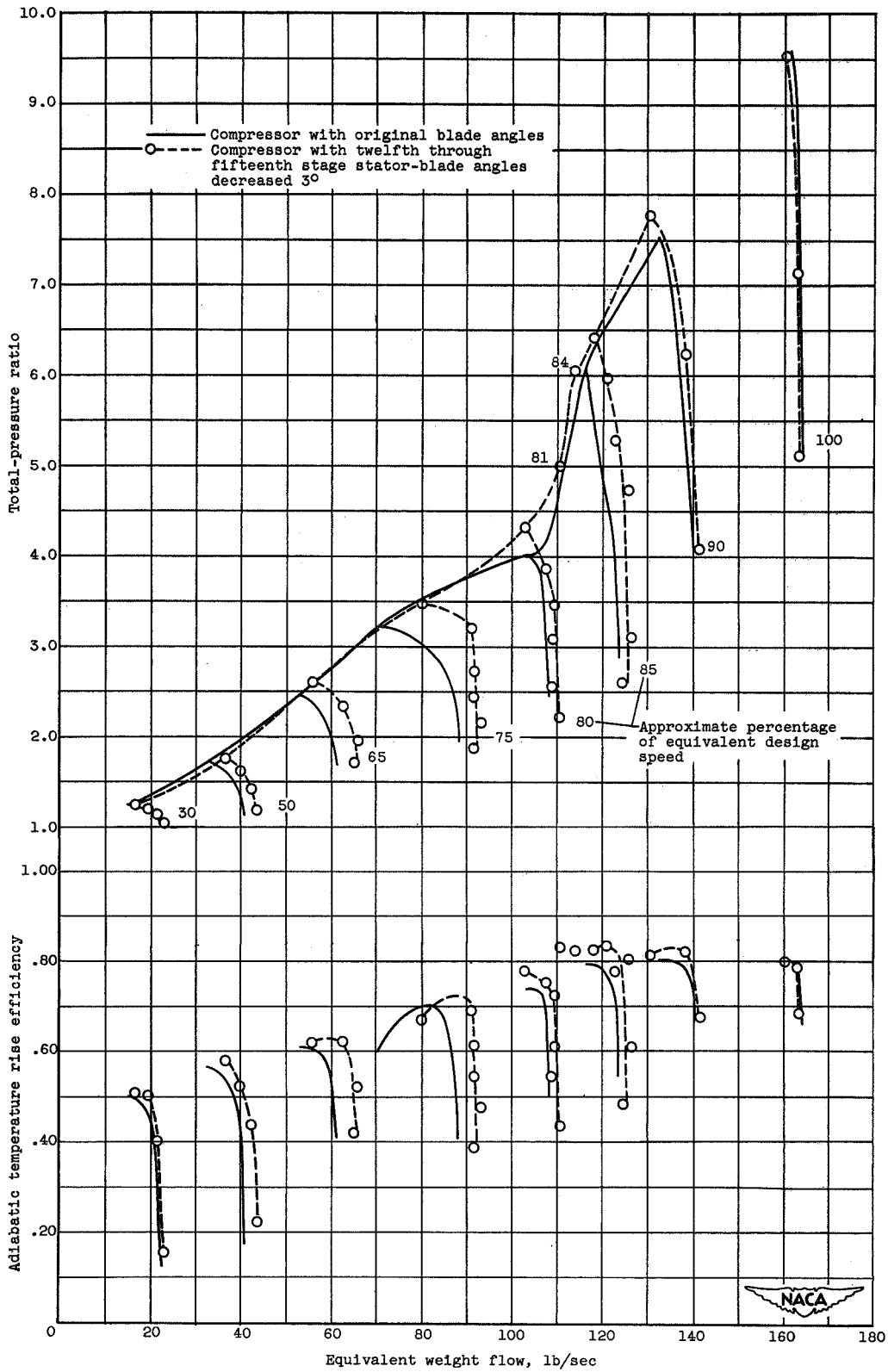


Figure 2. - Effect on over-all performance of decreasing twelfth through fifteenth stage stator-blade angles 3°.

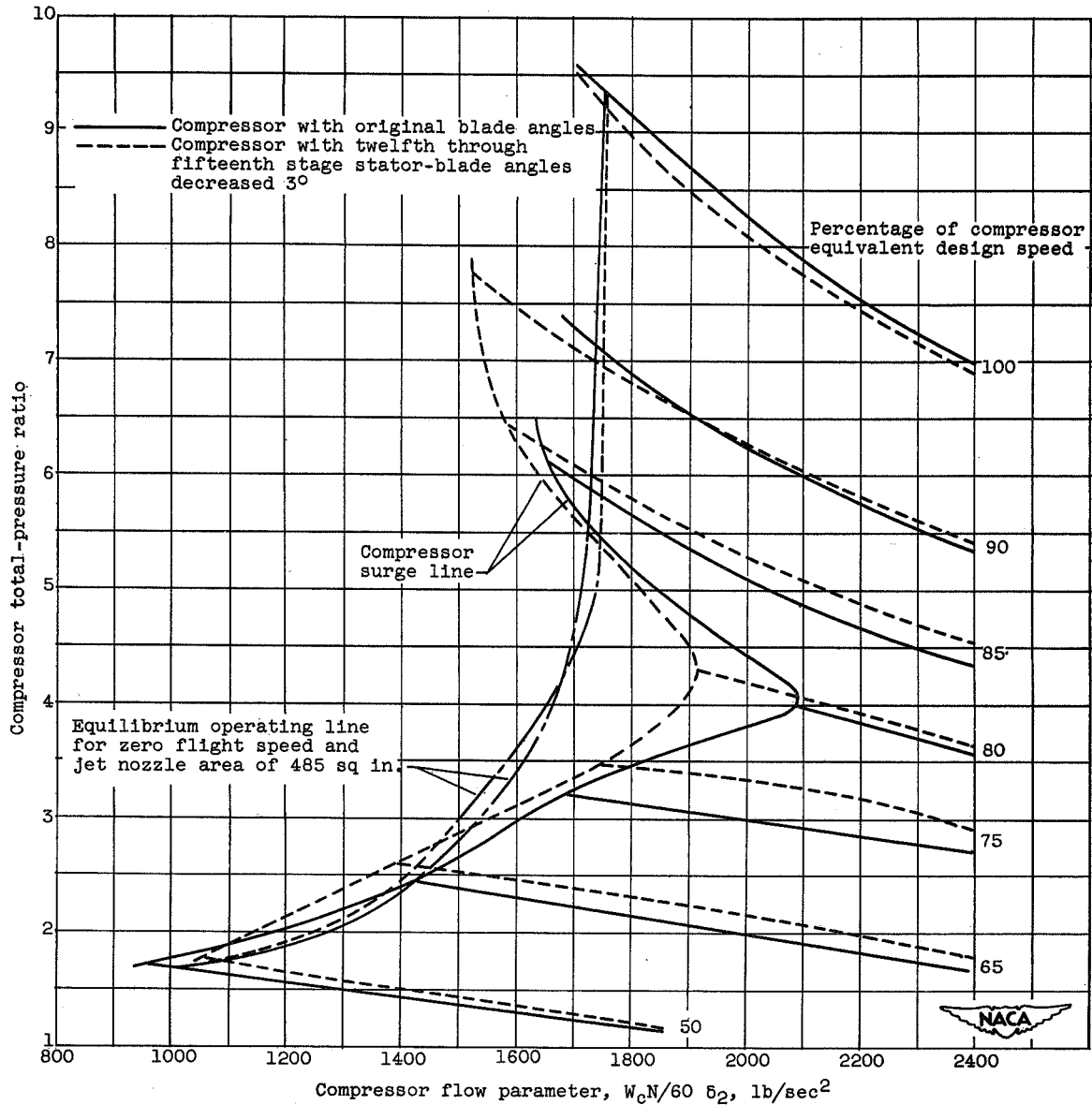


Figure 3. - Effect on matching characteristics of decreasing twelfth through fifteenth stage stator-blade angles 3°. Compressor weight flow, W_c , lb/sec; compressor speed, N , rpm; ratio of compressor outlet pressure to NACA standard sea-level pressure, δ_2 .

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Engines, Turbojet	3.1.3
Compressors - Axial Flow	3.6.1.1
Compressors - Matching	3.6.3
Turbines - Matching	3.7.4
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Abstract

The stator-blade angles in the twelfth to fifteenth stages of a 16-stage high-pressure-ratio axial-flow compressor were decreased 3° . The over-all performance of this compressor is compared with the performance of the same compressor with standard blade angles.

The matching characteristics of the modified compressor and a two-stage turbine were also obtained and compared with those of the compressor with the original blade angles and the same turbine.