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RESEARCH MEMORANDUM

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

IV - EFFECT ON OVER-ALL PERFORMANCE CHARACTERISTICS OF DECREASING TWELFTH THROUGH FIFTEENTH STAGE STATOR-BLADE ANGLES 3° AND INCREASING STATOR ANGLES IN THE INLET STAGES

By James E. Hatch and Arthur A. Medeiros

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Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON

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SUMMARY

The performance of a 16-stage axial-flow compressor, in which two modifications of unloaded inlet stages were combined with loaded exit stages, has been determined. In the first modification the exit stages were loaded by decreasing the twelfth through fifteenth stage stator angles 3° as compared with the blade angles in the original compressor, and the inlet stages were unloaded by increasing the blade angles the following amounts: guide vanes and first-stage stator, 6°; second- and third-stage stators, 4°; and fourth-stage stators, 3°. The over-all performance of this configuration was compared with that of the compressor with the original blade angles. The peak efficiency was increased at all speeds below design and the weight flow was higher at speeds below 80 percent of design, the same at 80 percent of design, and lower at speeds above 80 percent of design. The maximum reduction in weight flow occurred at design speed. The surge limit line was higher at speeds between 75 and 90 percent of design when presented on a pressure ratio against weight flow basis.

The second configuration was the same as the first with the exception that the second-, third-, and fourth-stage stator blade angles were the same as in the compressor with the original blade angles. A comparison of the performance of this configuration with that of the compressor with the original blade angles showed the same general trends of changes in performance as the first configuration.

Comparisons were made of compressor configurations to show the effects upon the performance of decreased loading in the inlet stages. Below 75 percent of design speed, decreased loading results in increased

weight flow and peak efficiency; above 80 percent of design speed, decreased loading in the inlet stages results in decreased weight flow and small changes in peak efficiencies. Between 75 and 90 percent of design the changes in surge weight flow and pressure ratio were such that the surge limit line was raised with decreased loading in the inlet stages when presented as pressure ratio against weight flow.

INTRODUCTION

Performance of the original compressor (reported in reference 1) indicates rather low part-speed efficiency and an undesirable change in slope of the surge line. The reason for this poor part-speed performance is that the latter stages receive the air at conditions such that operation is at the choke point. Thus, at partial speed the weight flow is limited by the exit stages, and the inlet stages are always forced to operate in a region of relatively low efficiency in the stall region. If this compressor is to be altered in order to reduce these problems at part speed without complete redesign, two possible methods are immediately recognized:

(1) Changes in the geometry of the exit stages such that the choke weight flow is higher (increased loading)

(2) Changes in the geometry of the inlet stages such that operation is at a more favorable angle of attack with better part-speed efficiencies

The first configuration investigated (reference 1) in this series showed that increasing the loading of the last four stages by decreasing stator blade angles (measured from the axial direction) resulted in increased part-speed efficiency and weight flow with no sacrifice of design-speed performance as compared with the compressor with the original blade angles. However, the surge-line shape was not altered appreciably by this change. Decreasing stator angles in the exit stages increases the angle of attack in these stages at low speed with resultant increased pressure ratio and higher weight flow causing decreased angle of attack in the inlet stages; both the decreased angle of attack in the inlet stages and increased angle of attack in the exit stages are in the direction of shifting the design match point in these stages to a lower percentage of design speed with resultant improvement in low-speed efficiency.

In order to determine the effect of directly decreasing the loading in the inlet stages, the guide vane and the first four stage stator-blade angles were increased a large amount in the third compressor configuration (reference 2). Over-all performance for this configuration showed appreciably improved part-speed efficiency and higher weight flow at

75 percent of design speed and below. However, the design-speed efficiency was decreased 4.5 points and design-speed weight flow was decreased appreciably. This reduction in efficiency and weight flow was anticipated because the stages affected would reach design angle at a speed below design speed with resultant low angles on the inlet stages at design speed. These low angles cause a reduction in the weight flow since design energy addition is not attained.

The effect of the loaded exits was combined with the effect of inlets that were unloaded a more moderate amount than the amount of the configuration in reference 2. This configuration was anticipated to result in better part-speed efficiencies than for the compressor with the original blade angles and less sacrifice in design-speed weight flow and efficiency than was found with the highly unloaded inlet stages. Possibly no combination of changing stator-blade angles alone will give the desired improvement in part-speed performance without sacrifice in design-speed performance, but these investigations give valuable information as to magnitudes and trends of performance changes and are not necessarily aimed at developing a compressor to fit a definite application. Presented herein are the results of the investigation of two modifications; one in which the guide-vane angles and the stator-blade angles of the first four stages were increased and the angles in the twelfth through fifteenth stage stators were decreased, and the other in which only the guide-vane and first-stage stator angles were increased and the exit-stator angles were decreased the same amount. The investigations were conducted at the NACA Lewis laboratory and the test equipment was similar to that described in reference 3 except that a 15,000-horsepower motor was used.

SUMMARY OF COMPRESSOR MODIFICATIONS

The following table summarizes the compressor configurations investigated up to the present time. For ease in discussion, each configuration is designated by a letter and the stator-blade angle modifications, as measured from the axial direction, are shown. References to reports presenting the performance of previous compressor modifications are also shown.

Configuration	Deviation of stage stator-blade angles from original (Measured from the axial direction) (deg)									Reference
		Stage								
	Guide vanes	1st	2nd	3rd	4th	12th	13th	14th	15th	
A	0	0	0	0	0	0	0	0	0	1
B	0	0	0	0	0	-3	-3	-3	-3	1
C	0	0	0	0	0	3	3	3	3	4
D	9	10	10	10	5	0	0	0	0	2
E	6	6	4	4	3	-3	-3	-3	-3	This report
F	6	6	0	0	0	-3	-3	-3	-3	This report

RESULTS AND DISCUSSION

The over-all performances of configurations A and E are compared in figure 1. This figure, therefore, compares the performance of the compressor having loaded exit and unloaded inlet stages with the performance of the compressor with the original blade angles. At all speeds below design, configuration E gave higher peak efficiency than configuration A. The weight flow for configuration E was higher than for configuration A at speeds below 80 percent of design and lower at speeds above 80 percent of design whereas the weight flow at 80 percent 2553
was approximately the same. The maximum reduction in weight flow of approximately 10 percent occurred at design speed. However, changes in surge pressure ratio and weight flow were such that the surge limit line for configuration E was higher than for configuration A at speeds between 75 and 90 percent of design when presented on the pressure ratio against weight flow basis.

The performance of configuration F is compared with configuration A in figure 2. The performance of the compressor having loaded exit stages and unloading in only the first two stages is compared with that of the compressor having the original blade angles. The general trends of changes in performance of configuration F from the performance of the compressor having the original blade angles presented in figure 2 are similar to the trends in figure 1.

In order to illustrate better the effect upon the over-all performance of increasing only the inlet guide vane and first-stage stator-blade angles (configuration F) as compared with configuration E in which the inlet guide vane and stator-blade angles of the first four stages were increased, the performances of configurations E and F are directly compared in figure 3. The performance of configuration B (increased loading in last four stages with the original inlet blade angles) is also presented on figure 3, because this configuration represented the best previous modification and the comparison would tend to isolate the effect upon performance of unloading the inlet stages. A comparison of the curves shows that at speeds below 75 percent of design the weight flow and peak efficiency increase with decrease in the amount of inlet loading. Above 80 percent of design speed the weight flow is decreased with decreased loading with the maximum decrease of approximately 10 percent occurring at design speed. Configurations E and F produced practically identical weight flow at design speed. This reduction of weight flow is anticipated since it was realized that stator-blade angle resetting in the inlet stage would not be adequate to obtain the desired stage matching at design speed and maintain design weight flow. This could possibly be accomplished with recambering in the inlet stages. The changes in peak efficiency with decrease in inlet loading were small at speeds above 80 percent. The trends of changes in peak efficiency and weight flow with decrease in inlet loading at 75 and 80 percent of design speed are not well defined as would be expected since this is the cross-over region. The changes in surge pressure ratio and weight flow between 75 and 90 percent of design speed were such that the surge limit line was progressively higher with decreased inlet loading when presented on a pressure ratio against weight flow basis. However, in this region the changes of surge pressure ratio and weight flow were of such magnitude that the inflection in the surge limit line occurs between 80 and 85 percent of design speed for configuration B as compared with 75 percent of design speed for configurations E and F.

The preceding results indicate that the major changes in compressor performance are brought about by changes in the first stage of the compressor. A preliminary analysis has indicated that the point on the surge limit line where the inflection occurs corresponds to the occurrence of stall angle of attack at the tip of the first rotor. It will be noted from figure 3 that speeds below the inflection point, which represent higher than stall angle of attack on the inlet stage, show a marked decrease in peak efficiency whereas speeds above this point show relatively constant peak efficiencies of a higher value.

SUMMARY OF RESULTS

The results of the investigations of the performance of the compressor configurations reported herein may be summarized as follows:

1. Increasing inlet guide-vane angles and stator-blade angles of the first four stages and decreasing stator-blade angles in the twelfth through fifteenth stages by 3° resulted in the following performance compared with the compressor having the original blade angles:

(a) The peak efficiency was higher at all speeds below design; the weight flow was higher at speeds below 80 percent of design, lower at speeds above 80 percent of design, and essentially the same at 80 percent of design speed.

(b) The surge limit line was higher at speeds between 75 and 90 percent of design when presented on a pressure ratio against weight flow basis and the inflection point in the surge limit line occurred at approximately 75 percent of design speed.

2. Increasing inlet guide-vane and first-stage stator-blade angles and decreasing blade angles in the twelfth through fifteenth stage stators by 3° resulted in the same general trends of changes in performance as the compressor with the inlet guide-vane and first four stage stator-blade angles increased when compared with the performance of the compressor having the original blade angles.

3. Comparison of the effects of decreased loading in the inlet stages showed the following trends:

(a) The weight flow and peak efficiency increase with the decreased loading at speeds below 75 percent of design and above 80 percent of design speed the weight flow is decreased whereas the peak efficiency remains approximately unchanged.

(b) Decreased loading in the inlet stages resulted in a higher surge limit between 75 and 90 percent of design speed when presented on a pressure ratio against weight flow basis.

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Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 10, 1952

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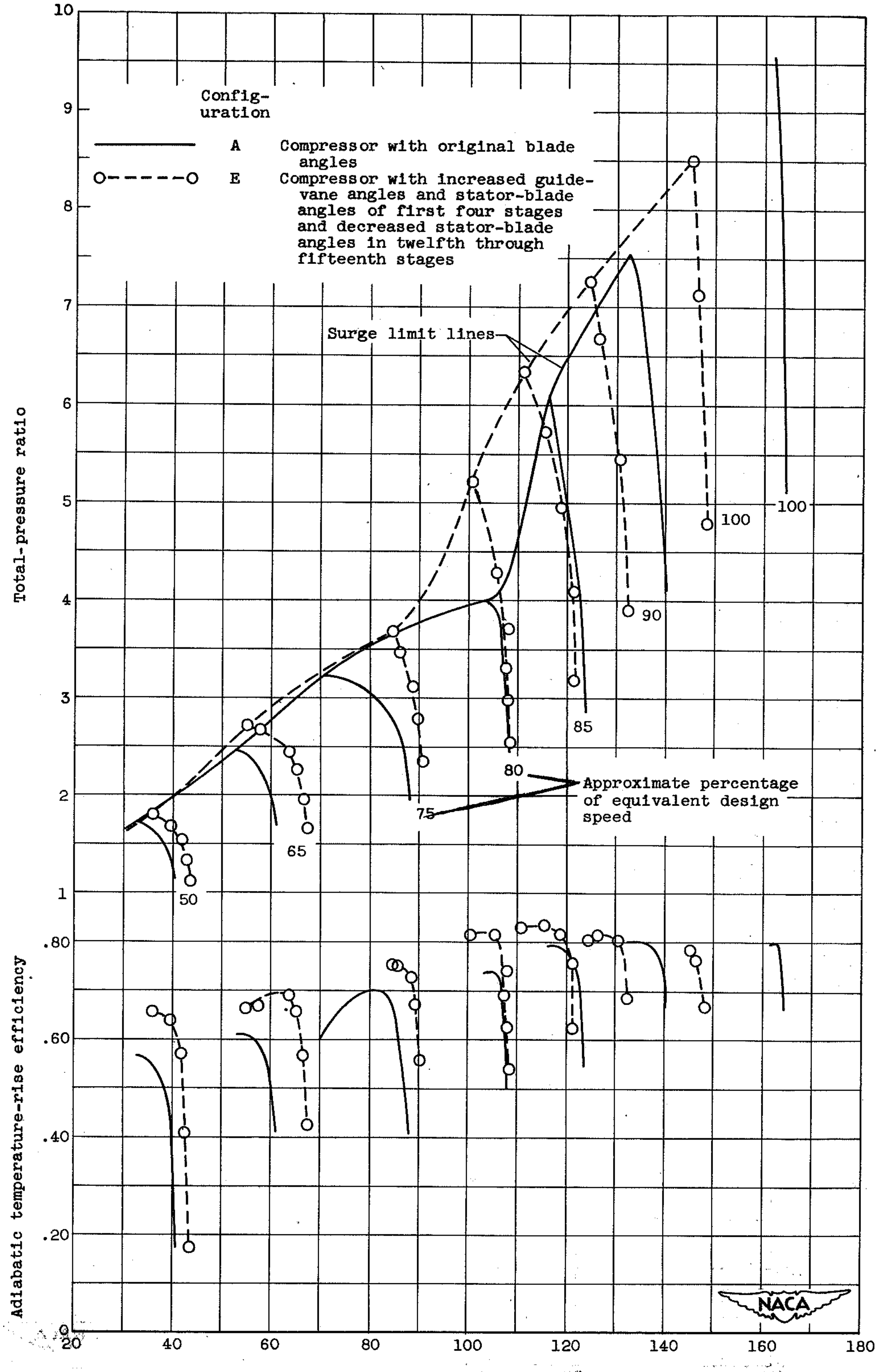

Figure 1. - Effect on over-all performance of increasing inlet guide-vane angles and stator-blade angles of first four stages and decreasing stator-blade angles in twelfth through fifteenth stages.

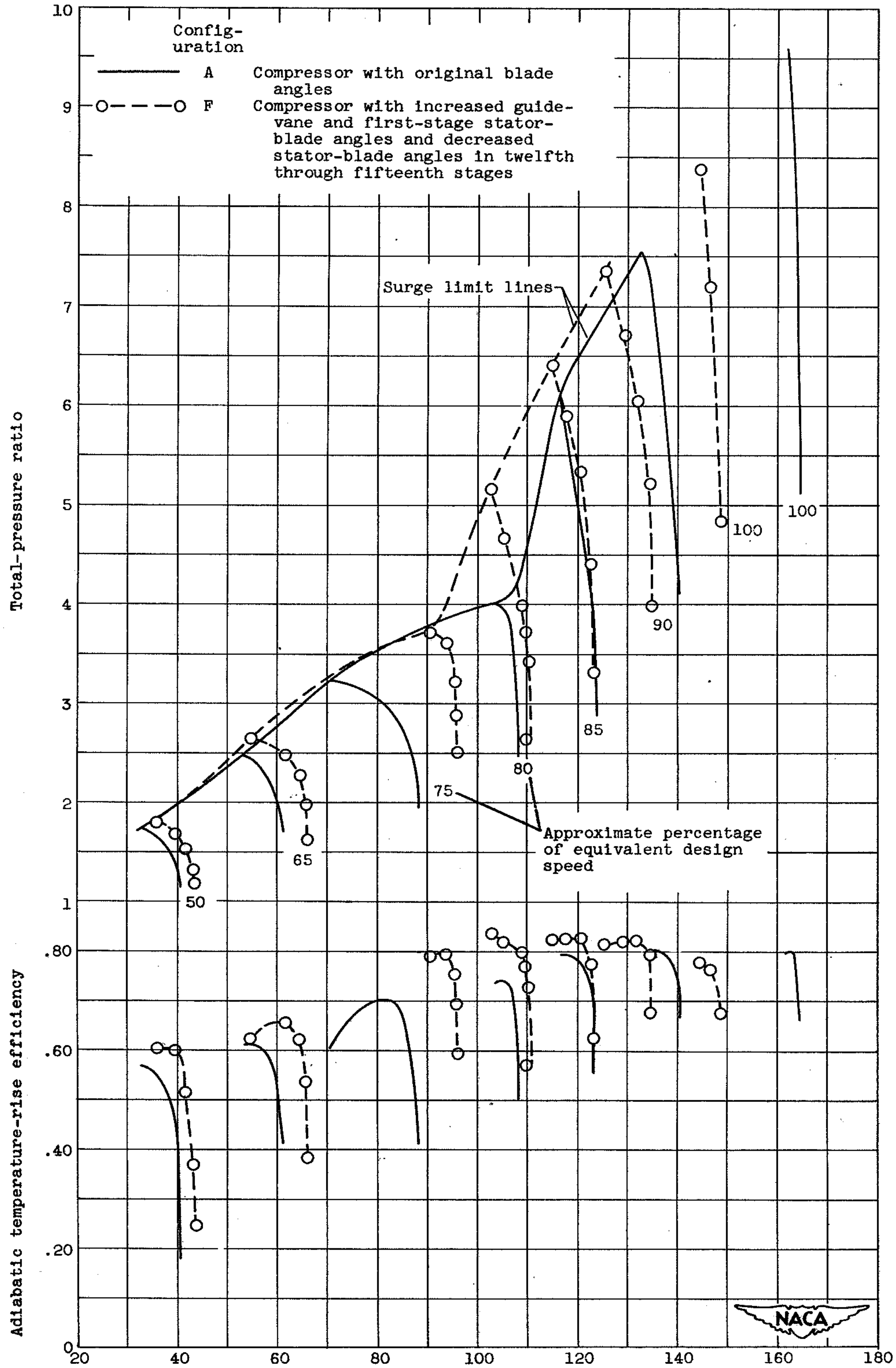

Figure 2. - Effect on over-all performance of increasing inlet guide-vane and first-stage stator-blade angles and decreasing stator-blade angles in twelfth through fifteenth stages.

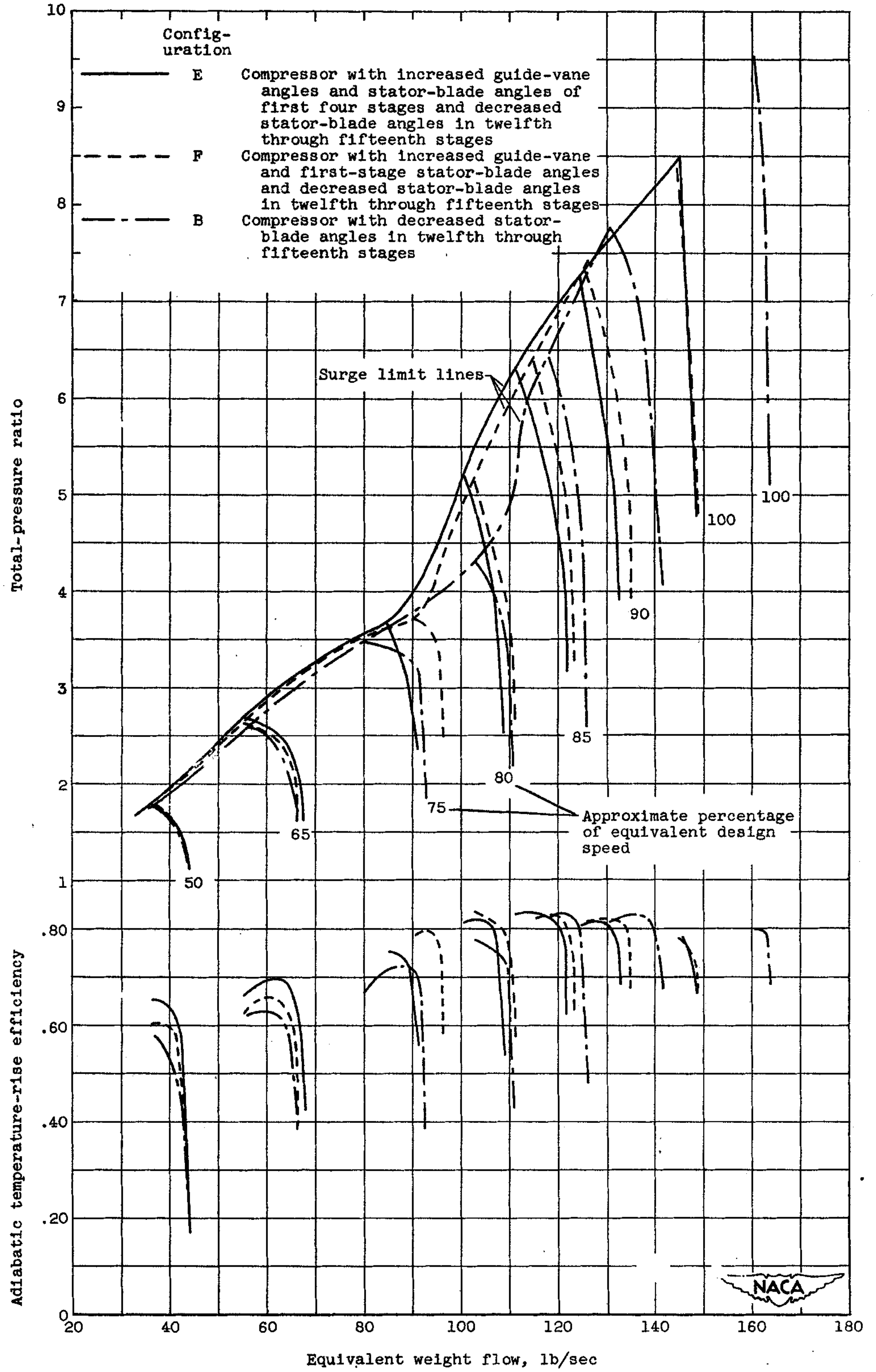

Figure 3. - Comparison of effect on over-all performance of varying amounts of unloading in inlet stages.

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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 two modifications of unloaded inlet stages were combined with loaded exit stages, has been determined. The over-all performance of the compressor with these modifications is compared with that of the compressor having original blade angles in the inlet stages.