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ANALYSIS OF INTERNAL FLOW OF J85-13 MULTISTAGE COMPRESSOR

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16. Abstract

Interstage data recorded on a J85-13 engine were used to analyze the internal flow of the compressor. Measured pressures and temperatures were used as input to a streamline analysis program to calculate the velocity diagrams at the inlet and outlet of each blade row. From the velocity diagrams and blade geometry, selected blade-element performance parameters were calculated. From the detailed analysis it is concluded that the compressor is probably hub critical (stall initiates at the hub) in the latter stages for the design speed conditions. As a result, the casing treatment over the blade tips has little or no effect on stall margin at design speed. Radial inlet distortion did not appear to change the flow in the stages that control stall because of the rapid attenuation of the distortion within the compressor.

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SUMMARY

Interstage data recorded on a J85-13 engine tested at Lewis Research Center were used to analyze the internal flow of the compressor. Data from six operating points obtained at 100 percent of design speed were selected for detailed analysis. Of these, four were taken with undistorted inlet flow and two with hub and tip radial distortion. Two of the undistorted flow points were taken with different casing treatment configurations. Measured pressures and temperatures were used as input to a streamline analysis program to calculate the velocity diagrams at the inlet and outlet of each blade row. From the velocity diagrams and blade geometry selected blade-element performance parameters were calculated. The detailed analysis revealed that the compressor is probably hub critical (stall initiates at the hub) in the latter stages for the design speed conditions. This results in the casing treatment over the blade tips having little or no effect on stall margin at design speed. Radial inlet distortion did not appear to change the flow in the stages that control stall because of the rapid attenuation of the distortion within the compressor.

INTRODUCTION

Casing treatment has been found to be beneficial in improving the stall margin of single-stage axial-flow compressors (refs. 1 to 4). To study the effectiveness of casing treatment on improving the stall margin of a multistage compressor, the compressor casing of a J85-13 turbojet engine was modified to accommodate various casing treatment configurations. Tests were conducted in altitude engine test facility for two casing treatment configurations (see refs. 5 and 6 for results). A solid-wall compressor casing was used as a reference. The compressor performance was obtained with distorted as well as undistorted inlet flow. Comparing performances with and without casing treatment showed that the casing treatment had little effect on overall performance. This was true for both the undistorted and the distorted inlet flow conditions.

To gain a better understanding of the internal flow conditions within the compressor and to determine why this compressor did not respond to casing treatment, a detailed flow analysis was conducted for selected data points using a streamline analysis program. Experimental data and design-point information were used as input to the streamline analysis program. Assuming design total-pressure losses and deviation angles for the stators permitted the calculation of the velocity diagrams at the leading and trailing edge of each blade row. The performance at six data points obtained at 100 percent of design speed was analyzed in detail. Four of the points were taken with undistorted inlet flow, and two with radial inlet distortion (hub and tip). Because the streamline analysis program is capable of analyzing only axisymmetric flow fields, circumferential distortion points were not processed. One of the points taken with undistorted inlet had circumferential groove casing treatment over the tips of rotors 1, 2, 3, 6, 7, and 8, and one had blade angle slots over rotors 6 to 8 (see ref. 5 for treatment description). All points analyzed were at near-stall weight flow with the exception of one undistorted inlet flow point with solid casing, which was near the design pressure ratio.

Results of this analysis are presented in comparison plots of inlet axial velocity, inlet relative flow angle, and D-factor (for selected points only) as a function of blade span for each of the rotor blade rows. For the stator blade rows the absolute flow angle is plotted as a function of blade span for the six points to reflect the relative difference in stator incidence angle between configurations. Trends are inferred from the calculated results, and comparisons are made with design values. Conclusions are drawn concerning the location of stall initiation (with and without radial distortion) and the effect of casing treatment on the compressor flow.

EXPERIMENTAL SETUP

The modification of the compressor casing to accommodate the casing treatment and the detailed design of the casing treatment, including photographs, are presented in reference 5. This reference also gives details of the instrumentation and the test procedure used. The more important features of this experimental setup are given hereafter.

Total pressure and temperature rakes were installed at the compressor inlet and outlet to obtain overall performance. Interstage performance was obtained from one total-temperature and one total-pressure rake located at the inlet to each stator. Each rake had elements located at approximately 10, 50, and 90 percent of blade span. The locations and description of the rakes is given in reference 5. An upstream measuring station is used to calculate inlet weight flow.

The engine was operated in an altitude test facility at Lewis. Inlet conditions were set to provide a Reynolds number index (inlet pressure/101.3 kPa (14.7 psia)) = 0.65

to 0.70 at the compressor face. The altitude chamber was maintained at a low pressure to insure a choked exhaust nozzle.

The mapping with casing treatment and distortion screens was accomplished at 80, 87, 94, and 100 percent of corrected design speed. Each speed line consisted of steady-state data points recorded between wide open nozzle and the stall point (see ref. 5). The analysis in this report uses data points obtained at the 100 percent of design speed.

ANALYTICAL PROCEDURE

To study the internal flow of the compressor, a streamline analysis program was used. The program assumes the flow to be axisymmetric and invicid. The radial momentum equation and continuity equation were solved by the streamline curvature method. Radial computing stations were selected at several axial locations upstream of the compressor, between blade rows, and downstream of the compressor. Inputs required at the rotating blade-row outlets are pressures and temperatures, and at the stationary blade-row outlets, pressures and flow angles at the appropriate radii. Other inputs to the program are the inlet weight flow, rotational speed, and flow passage geometry (ref. 7). These inputs will define the flow field requirements within the compressor. The program uses these inputs to calculate the flow distribution and the resulting streamline locations. The program calculates the stream static pressures and the velocity diagrams at the radial planes approximately at blade leading and trailing edges. A blade diffusion parameter (see ref. 7 for definition) was calculated for the rotors without casing treatment and without inlet distortion by using the velocities and blade geometry.

Inlet weight flow was calculated using measurements made at a station upstream of the compressor. The measured total pressures and temperatures obtained at the stator leading edges were used to define the radial profiles at the rotor outlet. To obtain the radial profile of total pressure, total temperature, and flow angle at the stator outlet (rotor inlet), stator design pressure losses were assumed along with design deviation angles. No attempt was made to adjust the design losses and deviation angles for off-design operation of the blade elements. The temperature profile was translated to the stator outlet along design streamlines using the same radial profile.

The rake measurements were faired axially through the machine to smooth out the data. Radial profiles were obtained by fairing curves through the three measurements to obtain five input points. The five radial points give a better definition of the profile needed to provide adequate input to the streamline analysis program.

PERFORMANCE DATA

Overall Performance Data

The overall performance map for the compressor with undistorted inlet flow and solid wall casing is presented in figure 1 with pressure ratio and efficiency plotted against corrected weight flow for 80, 87, 94, and 100 percent of corrected speed. This performance map is considered as a baseline in comparing performance measured with casing treatment and distorted inlet flows. The stall line in the top plot of figure 1 is determined using the turbine-exit temperature to establish the weight flow (ref. 5). The symbols plotted in figure 1 represent the data points at 100 percent of design speed selected for analysis in this report. The symbols at part speed show where the same near-stall points would be at lower operating speeds. Table I of reference 5 indicates that stall initiates in stages 6 or 7 for the undistorted inlet and in stages 5, 6, or 7 for the distorted inlet at 100 percent of design speed. The details of the distortion performance are presented in reference 6.

Pressure and Temperature Profiles

Figure 2 shows the pressure and temperature profiles used in the streamline analysis program. The symbols used for the plots match the symbols in figure 1 and indicate which points are represented by the profiles. The profiles show the data at the inlet of stator 1 to 8. Note the single symbol on the stator 8 curves. The stator 8 profiles are generated mathematically to fair through the pressure level at the midspan radius. This was necessary because the outlet rakes did not cover the actual flow path (see ref. 5). The midpassage measurement was translated upstream allowing for the outlet guide vane (OGV) and stator 8 losses to obtain a pressure at stator 8 midstream. The ratio of this pressure to the stator 7 midstream pressure is used to calculate the hub and tip portions of the stator 8 profiles by using the stator 7 measurements. A similar procedure is used for the temperature profiles.

The resulting profiles are shown in figure 2 and were used as input to the streamline analysis program. By comparing the near-stall undistorted inlet profiles (figs. 2(c) and (d)) with the other near-stall points, the changes in profile due to casing treatment or distortion can be seen. What appears to be a relatively small change in pressure and temperature profiles can result in a significant change in the calculated velocity diagrams.

RESULTS AND DISCUSSION

Solid Casing and Undistorted Inlet

Figures 3 to 5 show radial plots of inlet axial velocity, inlet relative flow angle (measured from the axis of rotation), and D-factor for the rotors, and figure 6 shows similar plots of inlet absolute flow angle for the stator vanes. The symbols are at the radii of the equal flow streamlines calculated by the analysis program. Each plot shows the design profile (ref. 7), a calculated profile near design pressure ratio, and a calculated profile near the stall line for 100 percent of design speed.

The shape of the axial velocity profile agrees with the design velocity profile for the first stage of the machine except for a slight velocity shift due to a small decrease in flow. As the flow moves through the compressor, the axial velocity at the hub decreases and by rotor 5 the inlet axial velocity profile is quite different from design. The difference between the design distribution and the distribution calculated from experimental measurements occurs mainly in the tip and hub regions. This suggests that the rotor tip and hub losses may be somewhat larger than those considered in the blading design. The incidence angle is reflected by the velocity, and for rotors 6 and 7 the incidence is 10° to 12° above design in the hub as can be seen by referring to the relative flow angle figures (fig. 4). The D-factors (fig. 5) do not show a consistent high value in the rotor hub for the stages that control stall. Thus the rotor hub incidence angle is probably the stall controlling parameter for this compressor. The plots of stator inlet flow angle (fig. 6) show that stators 6 and 7 have flow angles within 4° or 5° of design over the span and are less likely to cause a problem at near-stall flow.

Casing Treatment and Undistorted Inlet

The symbols in figure 1 show that the flow range, at 100 percent of design speed, did not increase with casing treatment and, at part speed (87 and 94%), was reduced. The use of treatment degrades efficiency by about 2 points for the slotted configuration and about 1 point for the circumferential groove configuration at part speed. For points analyzed with casing treatment, the inlet axial velocity and relative flow angle are plotted in figures 7 and 8. The figures have a near-stall point taken with an untreated casing plotted to show the change in profile resulting from the casing treatment.

The axial velocity profiles are very similar for the 3 points plotted. Rotor 6 and 7 velocities match closely the untreated case at the hub and show a small effect in the tip region. This effect amounts to a small change in incidence angle in the tip, and moves the slotted treatment point closer to design incidence. The profiles do not show any effect in the blade hub region. The blade hub continues to have a very high relative flow angle and would have an incidence angle as far above design as the untreated casing points. The hub very likely is controlling stall and would prevent the casing treatment from being effective in improving the compressor performance.

Solid Casing and Distorted Inlet

There is the possibility that, although casing treatment did not improve the undistorted operating range, it might reduce the performance degradation due to inlet distortion. Therefore, the compressor was tested with a tip radial and hub radial inlet-flow distortion with and without casing treatment. However, as indicated in reference 5, the overall performance with inlet distorted flow showed no significant change when casing treatment was applied. To understand why, two operating conditions with inlet radial distortion (hub and tip) were analyzed at 100 percent of design speed. Both operating conditions were for a solid casing to isolate the effects of radial distortion.

Figures 9 and 10 show the inlet axial velocity and relative flow angle plotted against radius. The points plotted are hub and tip radial distortions and undistorted inlet near stall, and undistorted inlet at design pressure ratio. The curves for the undistorted flow show how the flow change as the compressor moves to the stall line and gives an indication of the effect of the distortion on the flow. The streamline analysis calculations produce well-defined radial distortions in axial velocity at the inlet to rotor 1. As the flow progresses through the machine, the distortion is increasingly attenuated. The rotors that affect stall appear to be 5 to 7 (ref. 5). At these locations the distorted profile is almost entirely attenuated, and the hub incidence angle is as high as it is in the undistorted case. Thus the tip distortion was not of sufficient magnitude to move the location of stall away from the hub region of rotors 5 to 7. Tip casing treatment would therefore not be expected to improve stall margin for this magnitude of distortion.

SUMMARY OF RESULTS

Using performance data obtained on a General Electric J85-13 engine tested at Lewis, an analysis of the compressor internal flow was performed. Data recorded for the compressor performance were used in a streamline analysis program for undistorted inlet, casing treatment, and radial distorted inlet conditions at 100 percent of design speed. The following results were obtained:

1. The compressor rotor hub had low velocities and high incidence angles, indicating a condition in which stall would be initiated in the blade hub region.

2. Casing treatment was not effective in improving stall margin because stall was more likely initiated in the hub region.

3. Hub and tip inlet radial distortion had attenuated sufficiently before the flow reached the stall controlling rear stages such that these rotors still had high incidence angles (10° to 12° over design) in the hub region.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 16, 1976,
505-04.

REFERENCES

1. Bailey, Everett E.; and Voit, Charles H.: Some Observations of Effects of Porous Casing on Operating Range of a Single Axial-Flow Compressor Rotor. NASA TM X-2120, 1970.
2. Moore, Royce D.; Kovich, George; and Blade, Robert J.: Effects of Casing Treatment on Overall and Blade Element Performance of a Compressor Rotor. NASA TN D-6538, 1971.
3. Tesch, W. A.: Task 4 Stage Data and Performance Report for Casing Treatment Investigations. Evaluation of Range and Distortion Tolerance for High Mach Number Transonic Fan Stages, Vol. 1. (GE-R71-AEG-149-Vol.-1, General Electric Co.; NAS3-11157) NASA CR-72862, and Vol. 2. (GE-R71-AEG-149-Vol. 2, General Electric Co.; NAS3-11157) NASA CR-72867, 1971.
4. Bailey, Everett E.: Effects of Grooved Casing Treatment on the Flow Range Capability of a Single-Stage Axial Flow Compressor. NASA TM X-2459, 1972.
5. Wenzel, Leon M.; Moss, John E. Jr.; and Mehalic, Charles M.: Effect of Casing Treatment on the Performance of a Multistage Compressor. NASA TM X-3175, 1975.
6. Milner, Edward J.; and Wenzel, Leon M.: Performance of a J85-13 Compressor with Clean and Distorted Inlet Flow. NASA TM X-3304, 1975.
7. Dumont, L. B.; and Haywood, V. M.: J85 E7-4 Eight Stage Compressor Aerodynamic Design. Rept. R595E63, General Electric Co., 1959.

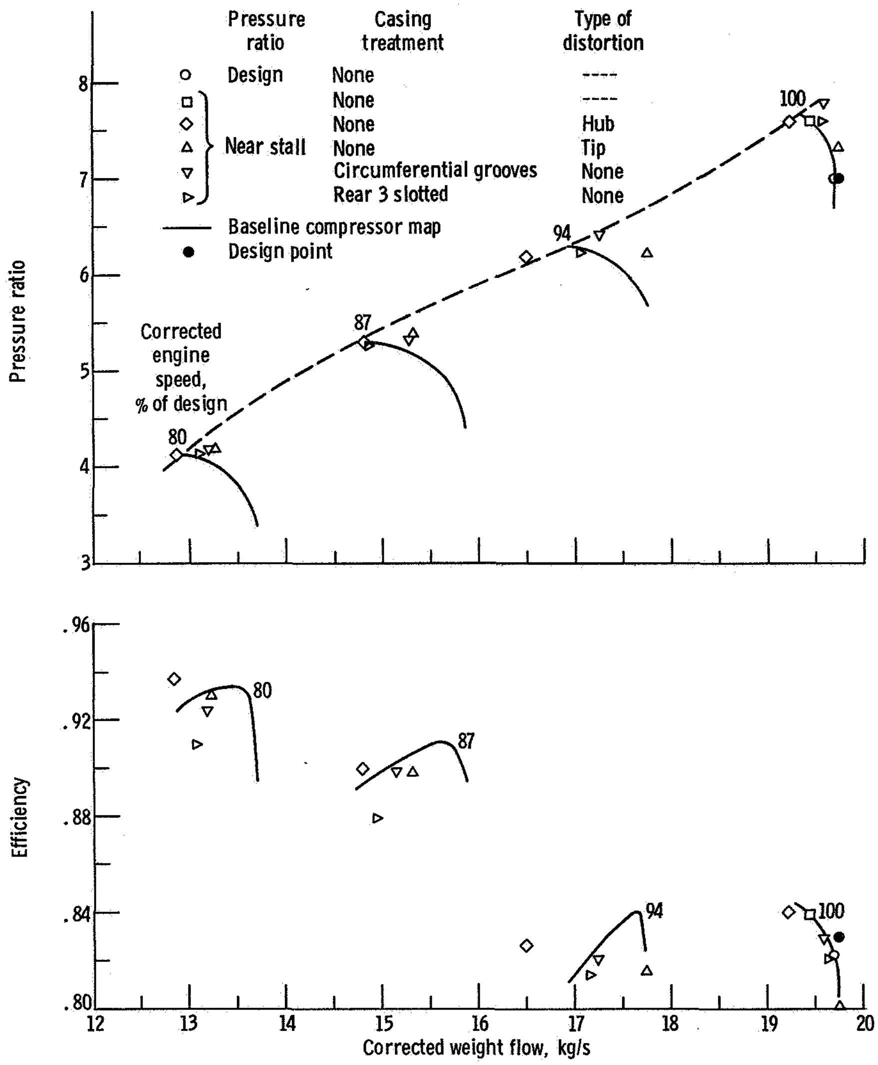


Figure 1. - Overall performance maps.

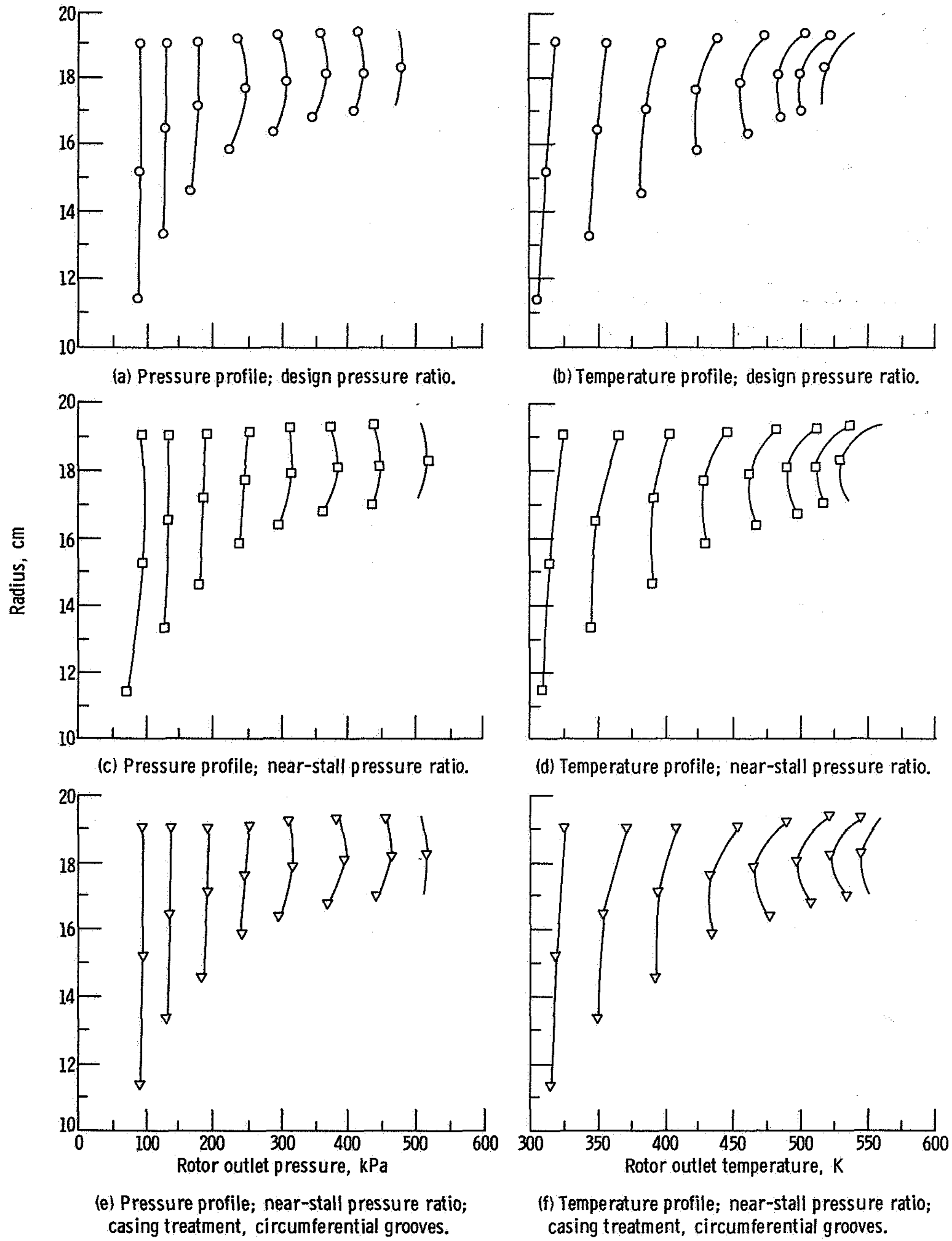
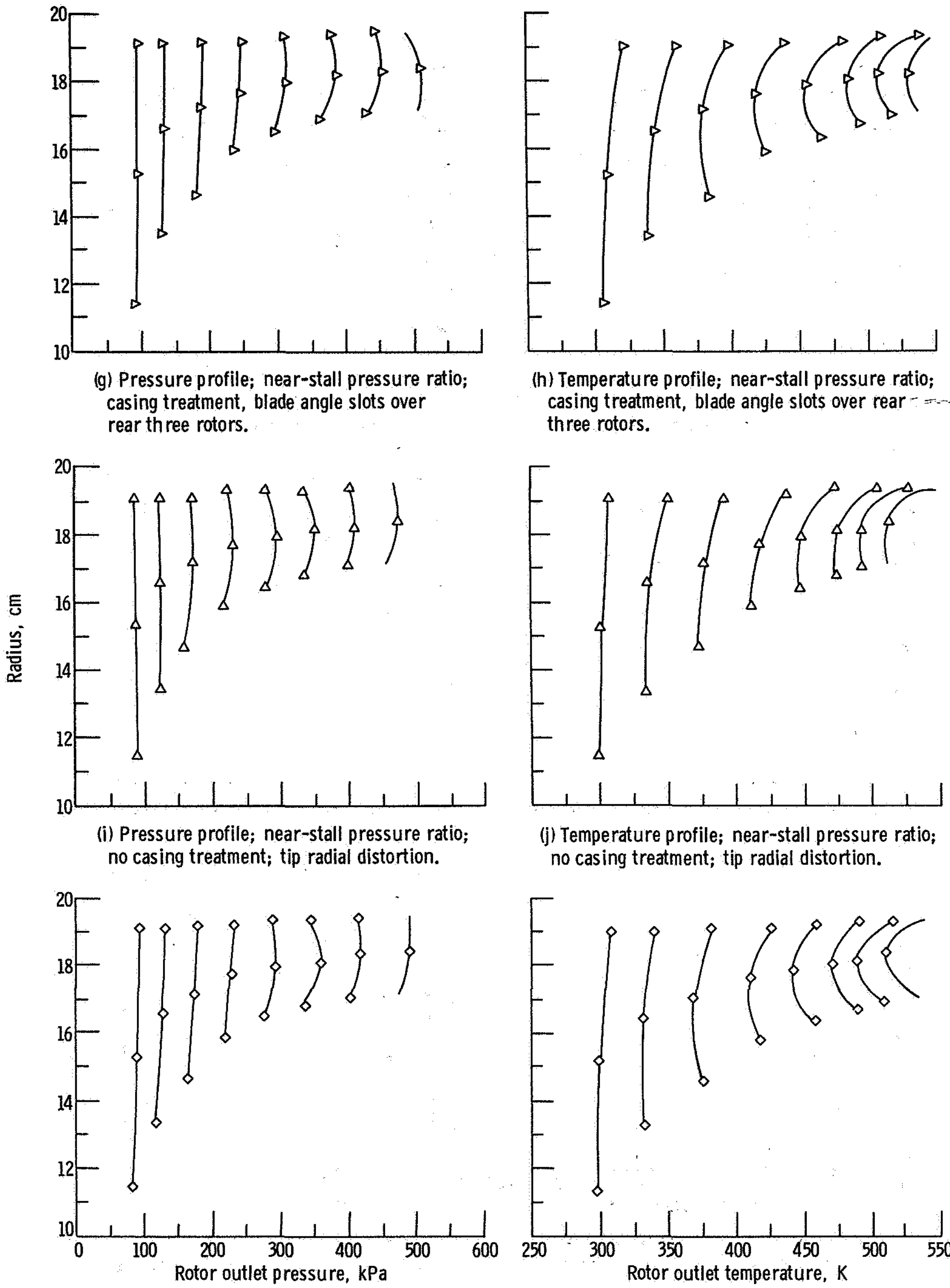


Figure 2. - Pressure and temperature profiles for J85-13 engine running at 100 percent of design speed.



(g) Pressure profile; near-stall pressure ratio; casing treatment, blade angle slots over rear three rotors.

(h) Temperature profile; near-stall pressure ratio; casing treatment, blade angle slots over rear three rotors.

(i) Pressure profile; near-stall pressure ratio; no casing treatment; tip radial distortion.

(j) Temperature profile; near-stall pressure ratio; no casing treatment; tip radial distortion.

(k) Pressure profile; near-stall pressure ratio; no casing treatment; hub radial distortion.

(ℓ) Temperature profile; near-stall pressure ratio; no casing treatment; hub radial distortion.

Figure 2. - Concluded.

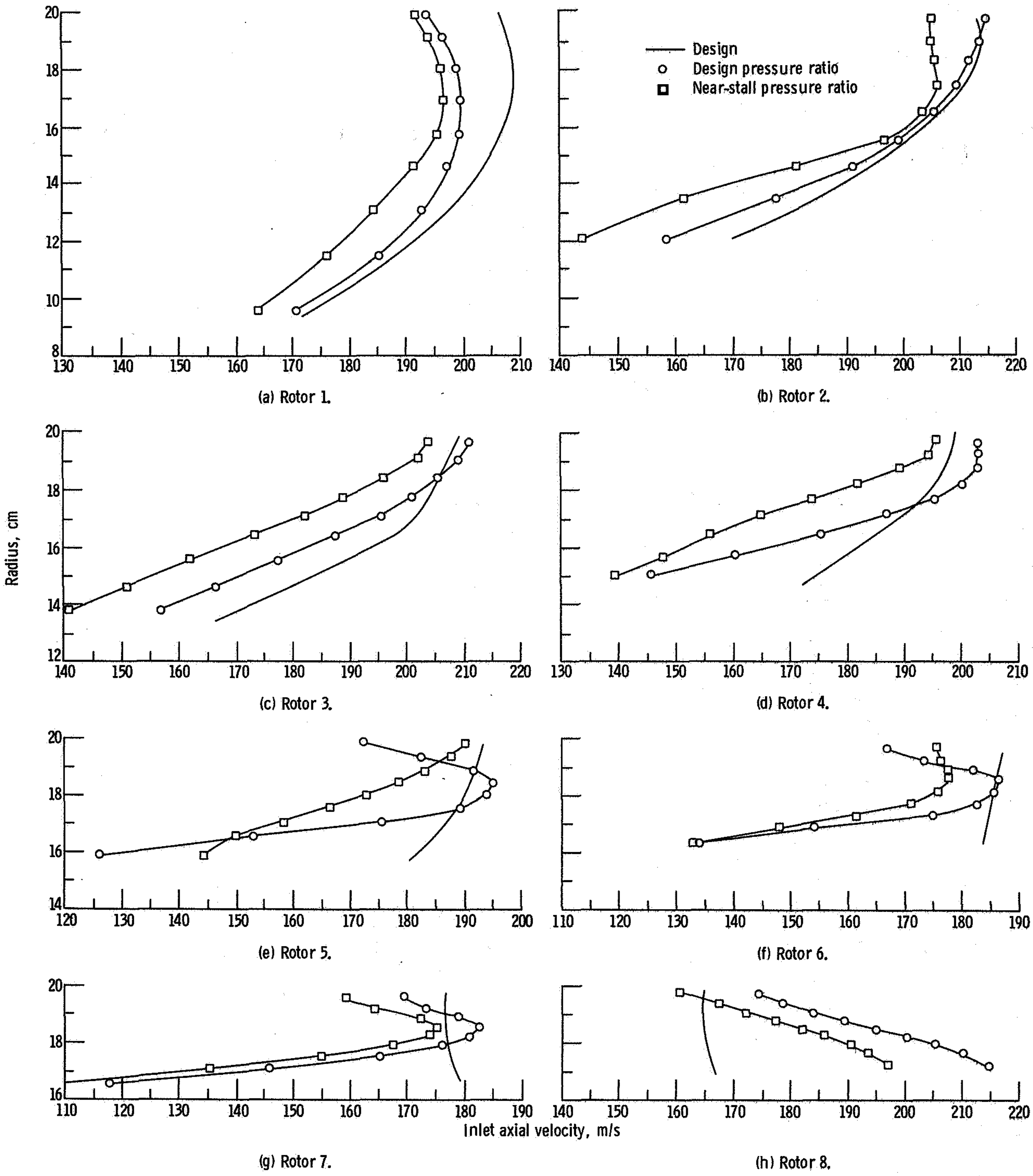


Figure 3. - Rotor inlet axial velocity profile for J85-13 engine at 100 percent of design speed without casing treatment.

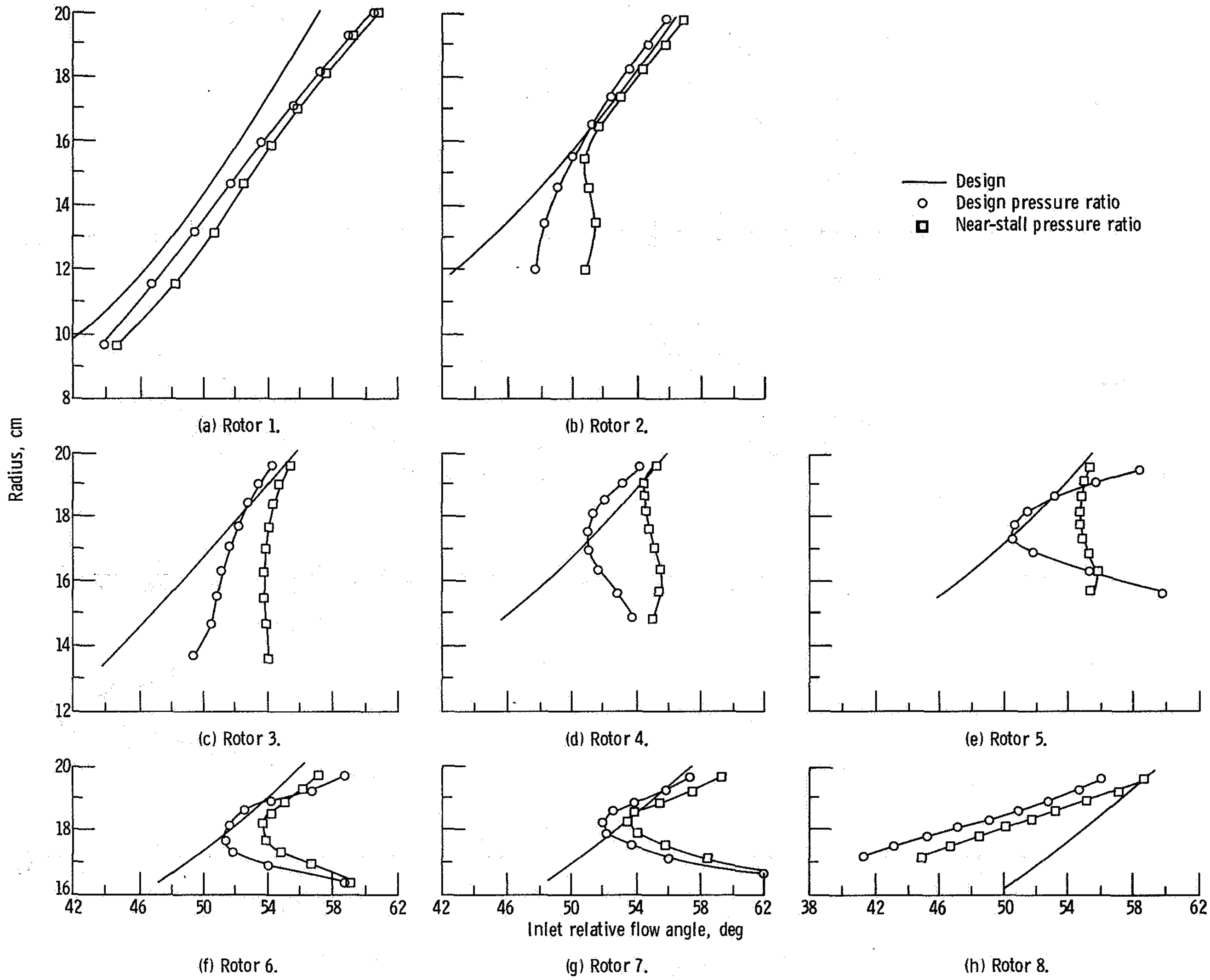


Figure 4. - Rotor inlet relative flow angle profile for J85-13 engine at 100 percent of design speed without casing treatment.

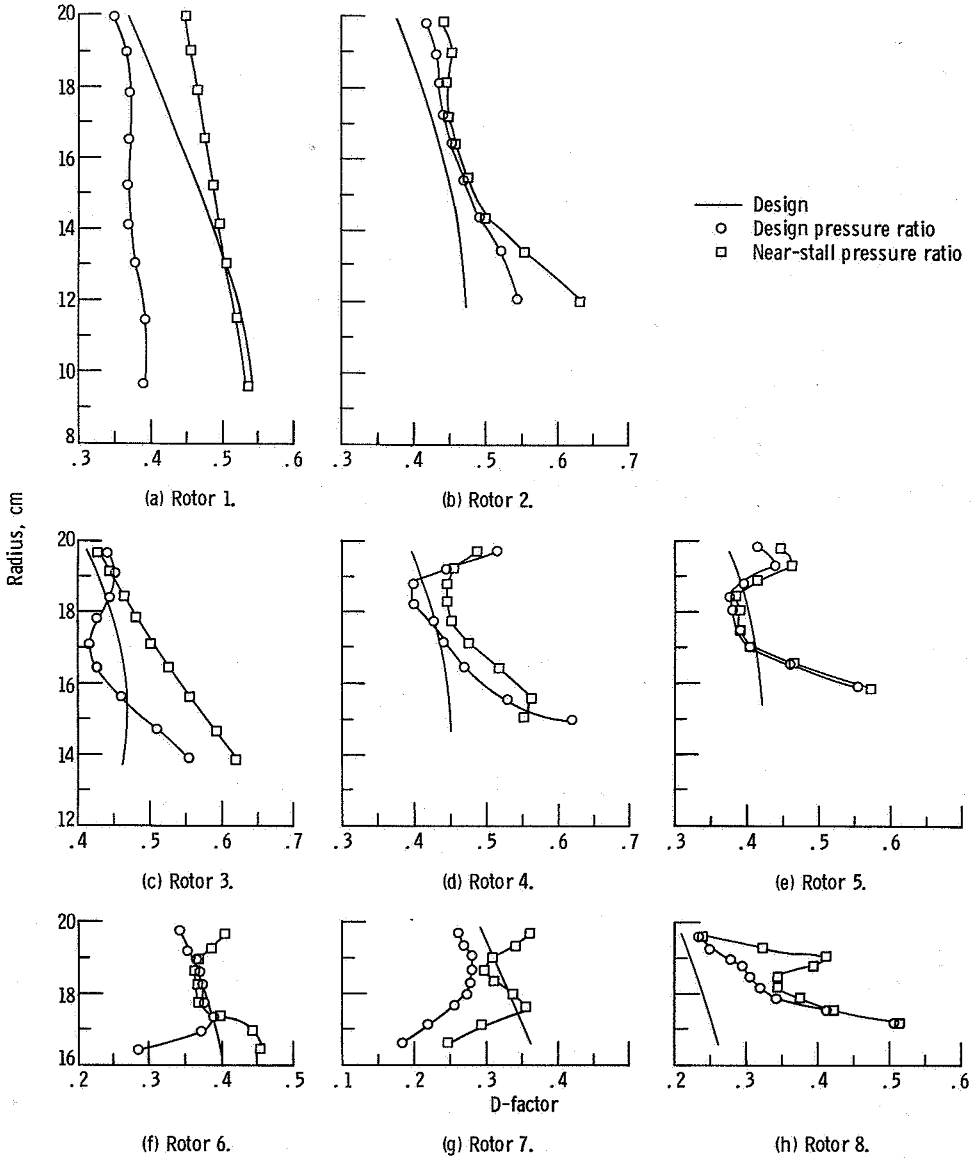


Figure 5. - Rotor D-factor profile for J85-13 engine at 100 percent of design speed without casing treatment.

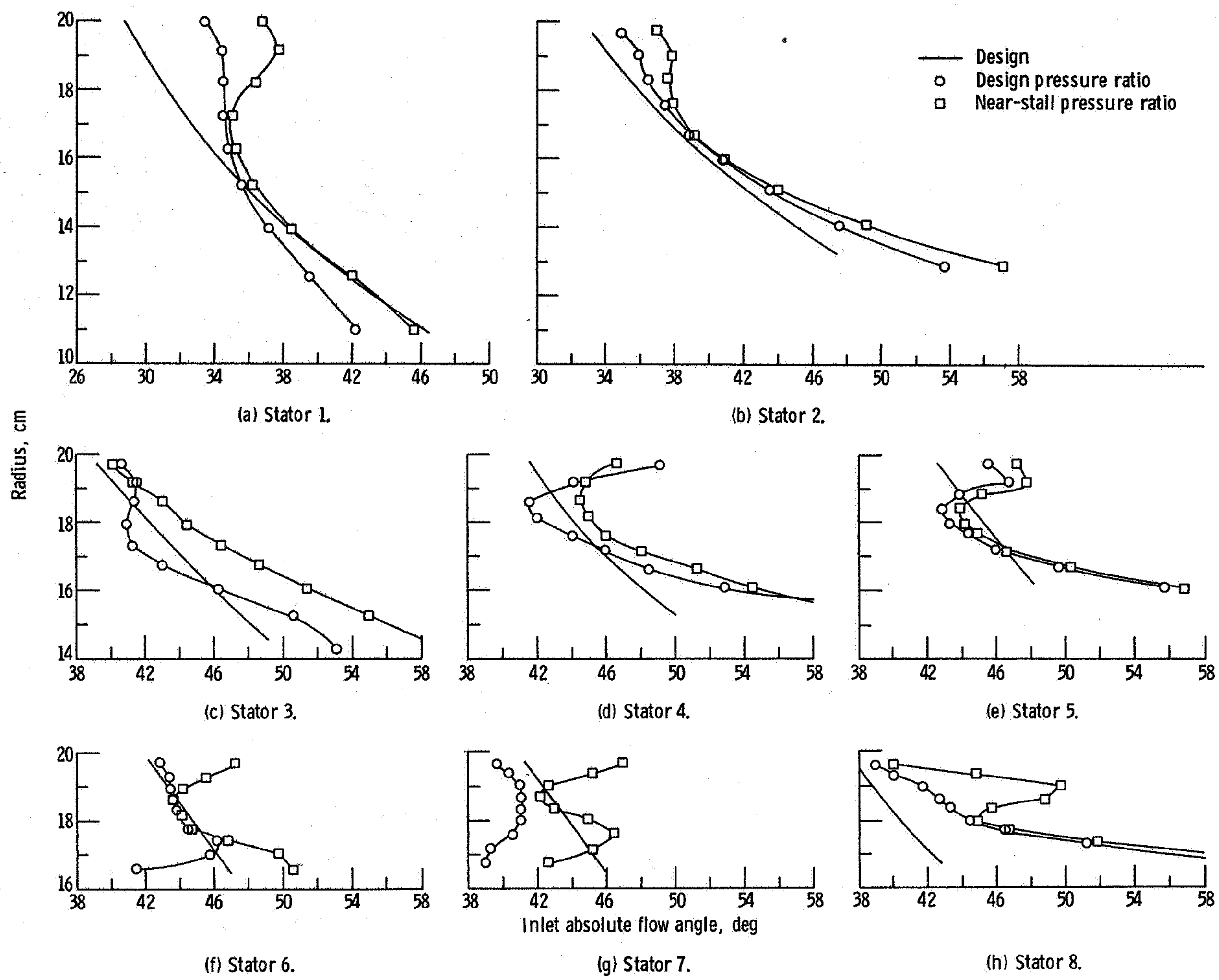


Figure 6. - Stator inlet absolute flow angle for J85-13 engine at 100 percent of design speed without casing treatment.

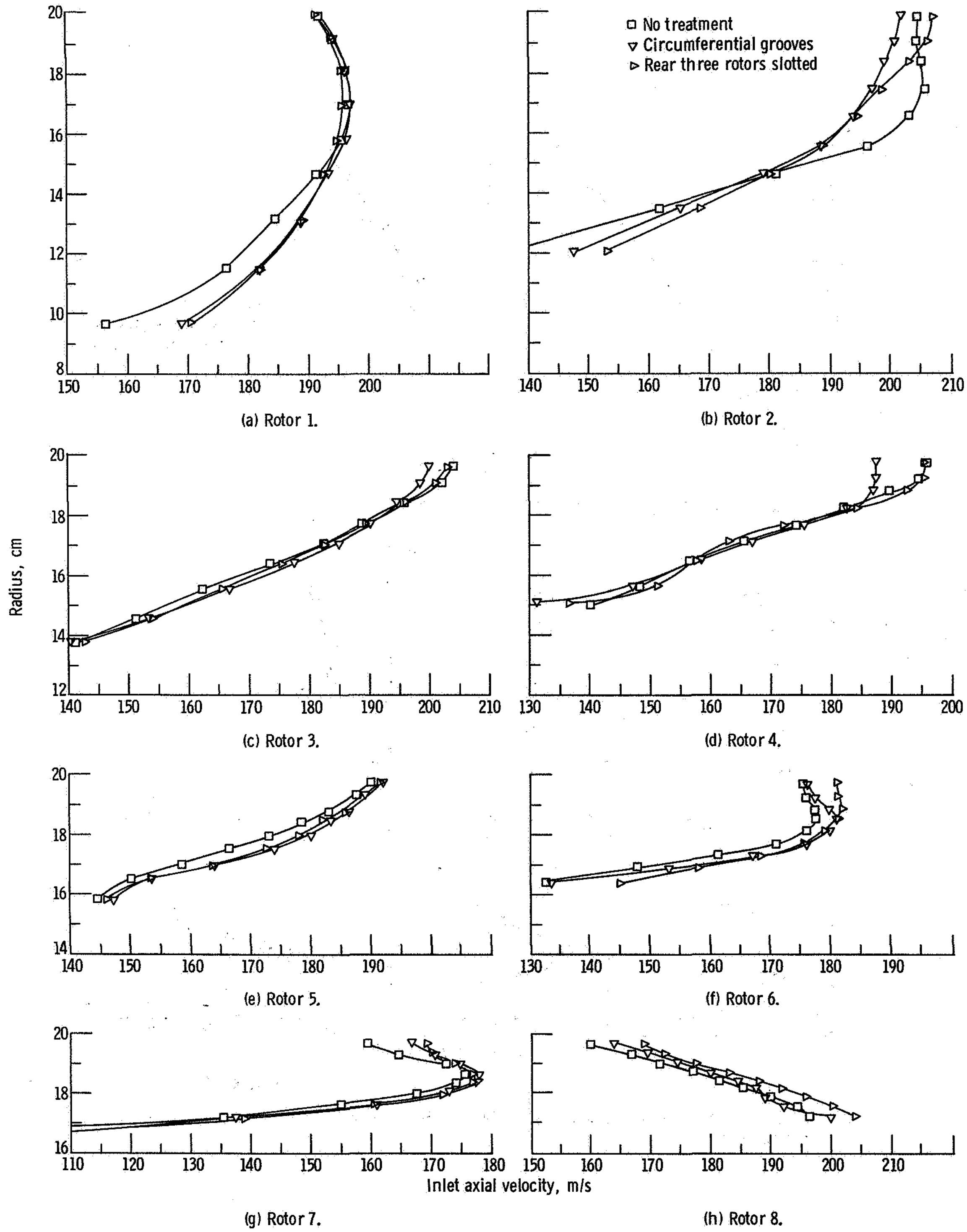


Figure 7. - Rotor inlet axial velocity profile for J85-13 engine at 100 percent of design speed with casing treatment.

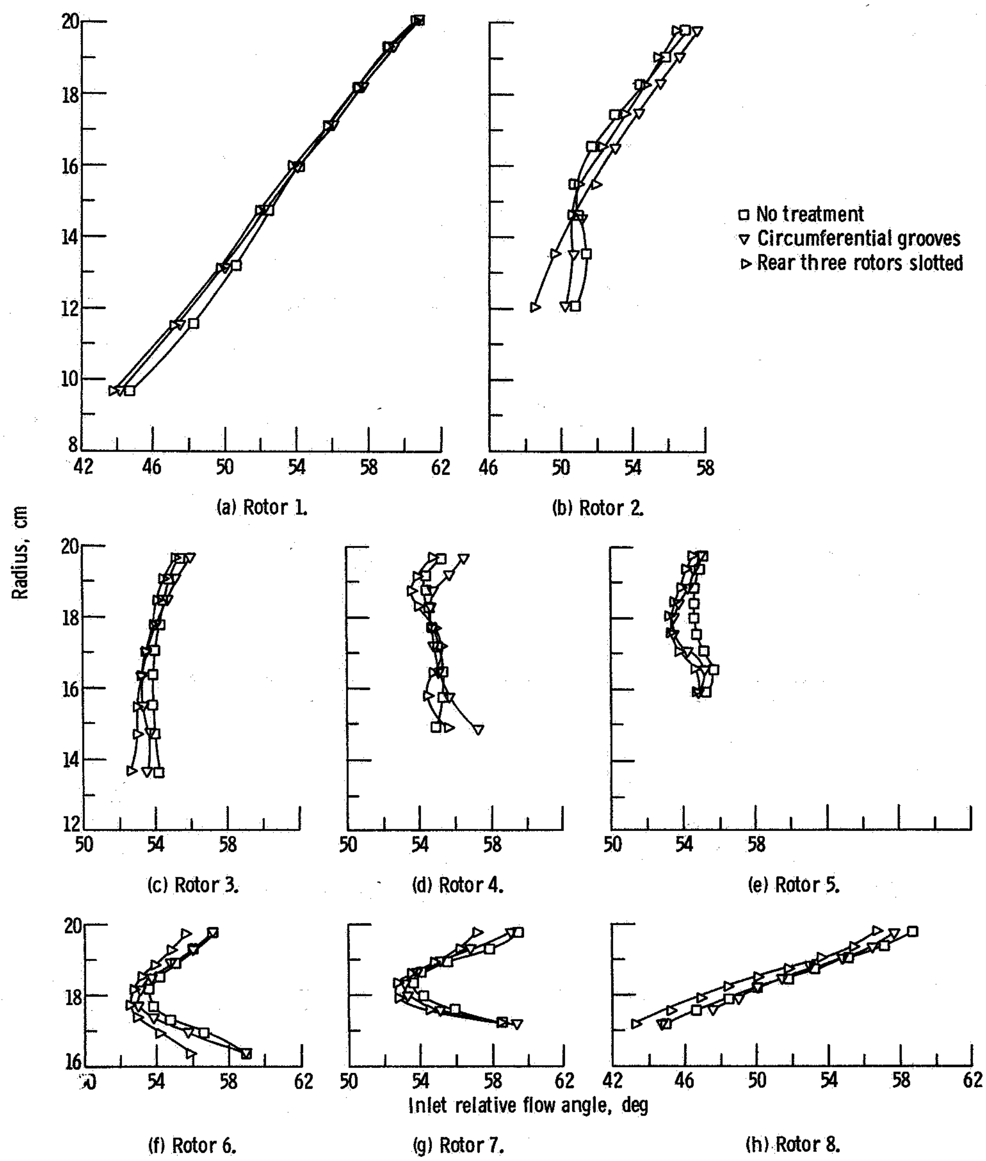


Figure 8. - Rotor inlet relative flow angle profile for J85-13 engine at 100 percent of design speed with casing treatment.

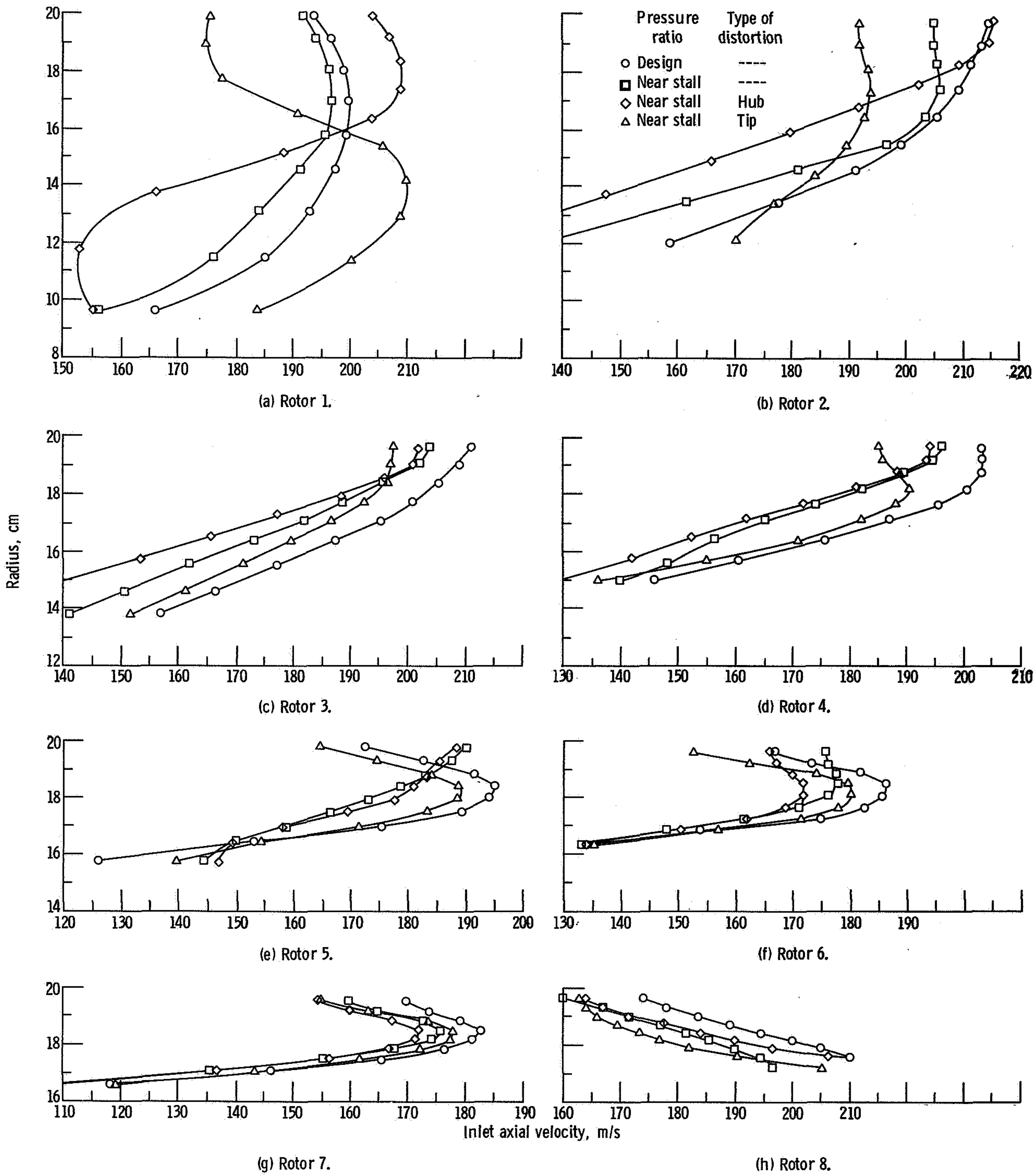


Figure 9. - Rotor inlet axial velocity profile for J85-13 engine at 100 percent of design speed; distortion compared with undistorted flow.

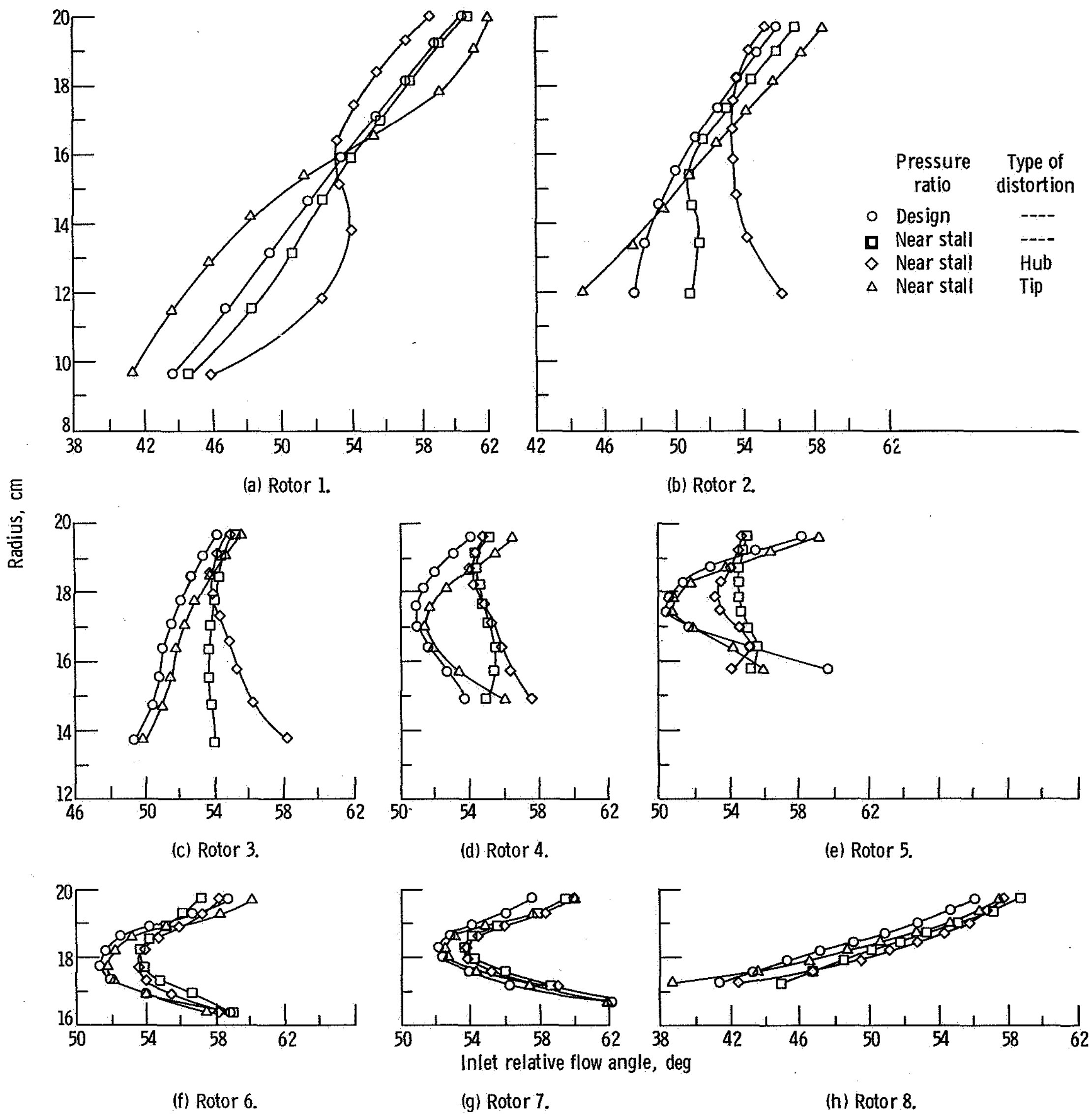


Figure 10. - Rotor inlet relative flow angle profile for J85-13 engine at 100 percent of design speed; distortion compared with undistorted flow.

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