Three-Dimensional Flowfield Inside a Low-Speed Axial Flow Compressor Rotor

M. Pouagare,* K. N. S. Murthy,* and B. Lakshminarayana†
The Pennsylvania State University, University Park, Pennsylvania

Nomenclature

P, P_{OR}	= static pressure, relative total pressure
P_T, P_S	$= (P_{OR} - P_A)/(\frac{1}{2}\rho U_t^2)$, $(P - P_A)/(\frac{1}{2}\rho U_t^2)$
R	= radial distance normalized by the blade tip radius
S	= blade spacing
SS, PS	= suction and pressure side of the blade, respectively
U_t	= blade tip speed
W_R, W_θ, W_z	= radial, relative tangential, and axial velocity normalized by the blade tip speed U_t
Y	= tangential distance normalized by the local blade spacing ($Y = 0$ is the suction side)
Z	= axial distance measured from the leading edge normalized by the local blade chord
ρ	= density
$(\bar{\ })$	= passage averaged value

Abstract

THE velocity and pressure fields were measured across the entire rotor passage at six axial locations and five radial locations inside the passage of an axial flow compressor rotor. A rotating five-hole probe was used to measure the three components of velocity and the static pressure.

Contents

The objective of this investigation is to increase our understanding of the nature of the three-dimensional flowfield, and to give us a comprehensive set of data for computer code verification.

The measurements reported in this paper were performed using the axial flow compressor facility located in the Turbomachinery Laboratory of The Pennsylvania State University. The hub/annulus wall diameter ratio of the facility is 0.5 with the diameter of the annulus wall equal to 0.932 m. The operating conditions are as follows: flow coefficient based on tip speed, 0.56; stage loading coefficient based on the tip speed, 0.486; speed of the rotor, 1088 rpm.

A rotating five-hole probe similar (but much smaller in size) to that used in Ref. 1 was employed for all of the measurements reported in this paper. The probe head had a diamond shape with a diagonal distance of 1.67 mm. The pressures measured by the five holes were used to determine the velocity and pressure field by interpolation of the calibration curves.

Presented as Paper 82-1006 at the AIAA/ASME Third Joint Thermophysics, Fluids, Plasma, and Heat Transfer Conference, St. Louis, Mo., June 7-11, 1982; submitted June 17, 1982; synoptic received March 7, 1983. Full paper available from AIAA Library, 555 W. 57th Street, New York, N.Y. 10019. Price: Microfiche, $4.00; hard copy $8.00. **Remittance must accompany order.**

*Graduate Assistant. Member AIAA.

†Director of Computational Fluid Dynamics Studies and Professor of Aerospace Engineering. Fellow AIAA.

The measurements consist of tangential surveys across one rotor blade passage at six axial and five radial locations. These locations are listed in Table 1. In this paper only a small sample of the results are given, the complete set of data can be found in Ref. 2.

The circumferential variation of the axial, tangential, and radial velocity inside the passage at various axial locations at $R = 0.75$ is presented in Fig. 1. The axial velocity W_z varies almost linearly from the suction to the pressure side. The circumferential gradient is maximum at the leading-edge region, diminishing gradually as the flow moves towards the trailing edge. Similar trends can be seen at all radii with the circumferential gradient being larger at the lower radii than at the higher radii.

The relative tangential velocity W_θ is maximum in the leading-edge region, diminishing as the flow is turned by the blades. The maximum circumferential gradient occurs near the quarter-chord point, the location of the peak suction pressure. The profiles tend to become uniform beyond the midchord.

The radial velocity W_R is very small (less than 3% of U_t) at all locations. It should be remarked that the data were acquired only in the inviscid region. The radial velocity is likely to be much higher inside the blade boundary layer. The most probable reason for the existence of radial velocity in the passage (away from the blade surfaces) is the blockage due to the blade thickness. The blockage effect induces outward radial velocity, primarily in the leading-edge region where the maximum blade thickness exists. This can be seen clearly in the present set of data. The maximum radial velocity occurs at the location nearest to the leading edge ($Z = 0.17$), and it is outward. As the flow moves toward the trailing edge the blockage effect diminishes, and so does the radial velocity.

The static pressure P_S and the square of the relative total velocity W^2 are also shown in Fig. 1. It can be seen that the slope of P_S and the slope of W^2 are approximately equal and of opposite sign. This is exactly what the Bernoulli equation implies when it is differentiated in the tangential direction. This observation gives added confidence to the data. At all of the stations both P_S and W^2 profiles vary almost linearly in the tangential direction. It also can be seen that the pressure rise increases from the inlet to the exit and that the tangential pressure gradient (representing the local blade loading) generally decreases from the inlet to the exit.

The axial velocity profiles at the exit of the rotor are shown in Fig. 2. The axial velocity is uniform on either side of the wake. The defect at the center is substantially smaller at the tip than at the hub of the rotor. A most likely reason for this is

Table 1 Axial and radial measuring stations

R	Z					
0.583	−0.75	0.17	0.40	0.60	0.80	1.049
0.670	−0.75	0.17	0.40	0.60	0.80	1.061
0.750	−0.75	0.17	0.40	0.60	0.80	1.069
0.832	−0.75	0.20	0.42	0.63	0.83	1.077
0.918	−0.75	0.24	0.48	0.69	0.89	1.085

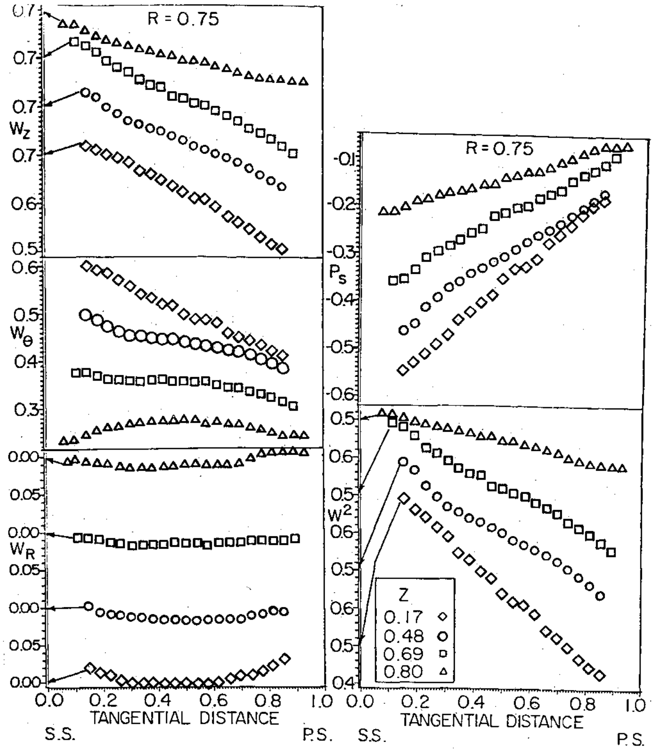

Fig. 1 **Blade-to-blade distribution of the axial, relative tangential, and radial velocities, static pressure, and the square of the relative total velocity at $R = 0.75$.**

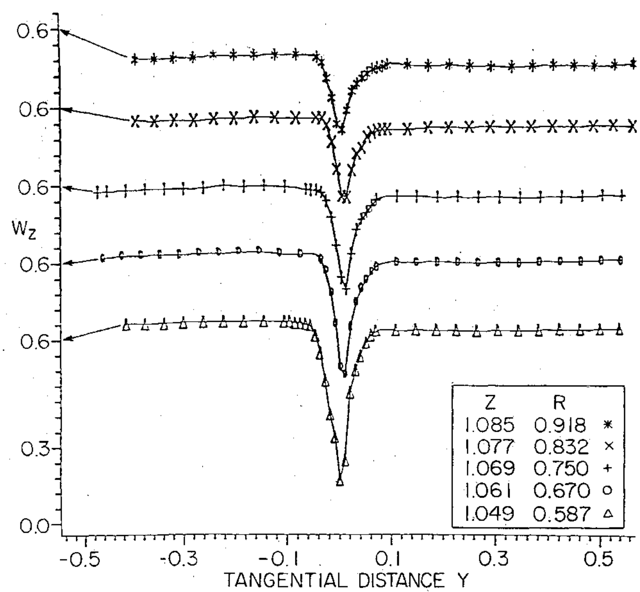

Fig. 2 **Axial velocity at the exit of the rotor.**

that the axial location of the measurements at lower radii are closer to the trailing edge than those at the higher radii.

The radial variation of the passage averaged axial $\bar{W}_z$ and tangential $\bar{W}_\theta$ velocities are shown in Fig. 3. The radial distribution of $\bar{W}_z$ is almost identical at inlet ($Z = -0.75$) and exit ($Z = 1.07$) with substantial changes in between caused mainly by the blade blockage and flow turning effects. $\bar{W}_\theta$ is changing almost uniformly from $Z = -0.75$ to 0.83. There is little change between $Z = 0.83$ and 1.07. This indicates that the turning of the flow has been completed around $Z = 0.8$.

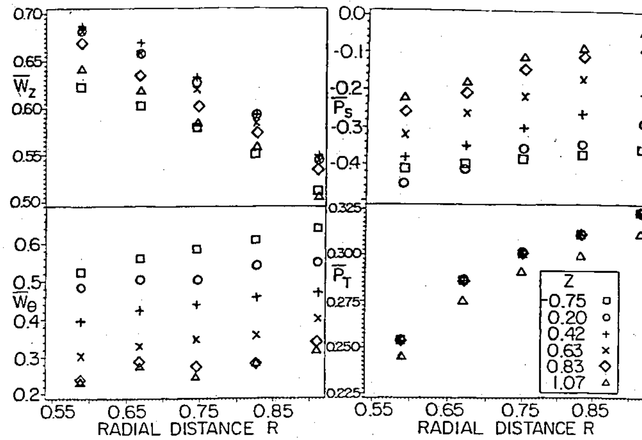

Fig. 3 **Radial variation of the passage averaged axial and relative tangential velocities, static, and relative total pressures.**

The radial variation of the passage averaged static pressure $\bar{P}_S$ and total pressure $\bar{P}_T$ are also shown in Fig. 3. As expected, the radial pressure gradient is always positive. At the first five axial locations the values of $\bar{P}_T$ are identical, as expected. At these locations, there are no losses since the measurements do not include the blade or the endwall shear layers. At the exit of the rotor, a reduction in $\bar{P}_T$ can be seen since the measurements include the wake region and the associated profile and mixing losses.

Conclusions

Some of the conclusions of this work are the following:

1) In the inviscid regions of the rotor passage, the radial velocity is small. The flow is basically two dimensional. At the exit of the rotor, the radical velocity is mostly outwards in the wake region.

2) In the leading-edge region, the relative tangential velocity is varying almost linearly from the suction to the pressure surface. It reaches nearly uniform values near the exit.

3) The blockage due to the blade thickness has appreciable influence on the axial velocity.

4) The static pressure is varying almost linearly from the suction side to the pressure side.

5) The passage averaged relative total pressure remains constant with respect to the axial distance in the inviscid region of the blade passage.

6) The measurements at the exit show that all properties are uniform in the exit, except in the wake region. Periodicity exists in the tangential direction.

Acknowledgement

This work was supported by NASA through Grant NSG 3266, with Dr. P. M. Sockol as the Project Monitor.

References

[1]Sitaram, N., Lakshminarayana, B., and Ravindranath, A., "Conventional Probes for the Relative Flow Measurement in a Rotor Blade Passage," *Journal of Engineering for Power,* Vol. 103, No. 2, April 1981, pp. 406-414.

[2]Pouagare, M., "Measurement and Computation of Rotor Flow Field," Ph.D. Thesis (in preparation) Dept. of Aerospace Engineering, The Pennsylvania State University, University Park, 1983.