Engineering Notes

ENGINEERING NOTES are short manuscripts describing new developments or important results of a preliminary nature. These Notes cannot exceed 6 manuscript pages and 3 figures; a page of text may be substituted for a figure and vice versa. After informal review by the editors, they may be published within a few months of the date of receipt. Style requirements are the same as for regular contributions (see inside back cover).

Freestream Turbulence Effects on Compressor Cascade Wake

R. K. Sullerey* and M. A. Sayeed Khan†
Indian Institute of Technology, Kanpur, India

Introduction

THE study of the characteristics of the wakes of a cascade of airfoils has direct relevance to the aerodynamic design of axial compressors and turbines. It is also known that the freestream turbulence intensity increases from stage to stage in a multistage compressor.[1] Emery et al.[2] observed from cascade tests that an increase in freestream turbulence resulted in a decrease in drag coefficient, particularly at low values of Reynolds number. Evans[3] investigated the freestream turbulence effects on the boundary layer on a flat plate and observed that an increase in turbulence increased the fullness of the velocity profile, kinetic energy, shear stress, and skin friction; and noted a decrease in displacement and momentum thickness. Citavy and Norbury[4] have studied the performance of a compressor prescribed velocity distribution (PVD) cascade and the behavior of separation bubble at several Reynolds numbers and turbulence intensities of upstream flow. The upstream turbulence intensity had an effect on the bursting of the separation bubble at various Reynolds numbers and affected the aerodynamic loading. It was also observed that the transition within the separated shear layer was delayed at lower turbulence intensities.

Experimental measurements in the compressor cascade wake are presented by Raj and Lakshminarayana[5] at 0.16% freestream turbulence intensity. The analysis for similarity in the wake flow is also reported in Refs. 5 and 6. The purpose of the present investigations is to present the results of wake flow measurements in a compressor cascade at varying freestream turbulence levels (Tu). The measurements have been carried at a Reynolds number of 1.31×10^5 and three values of Tu (1.18, 1.61, and 2.78%) at three incidence angles (−4, 0, and 12 deg). The low Reynolds number was chosen, as the effect of freestream turbulence was expected to be more pronounced. The analytical formulation of Ref. 5 has been used in choosing the length and velocity scales in presenting the curves for similarity in the velocity distribution. The results indicate that the freestream turbulence level has an effect on the rate of wake decay and the drag coefficient at different incidence angles.

Apparatus

The experiments were carried out in a cascade tunnel with a test section of 38.1×30.5 cm, and a maximum airspeed of 45 m/s. The cascade consisted of five blades of airfoil section NACA 65-(12A_{10})10 (Ref. 7). The blade chord was 10.16 cm and the solidity (chord/spacing) 1.33. The blades were fabricated out of seasoned wood and were given a shellac finish. The air inlet angle was 45 deg. The freestream turbulence was measured just upstream of the midblade using a 0.008-mm-diam platinum-tungsten wire and the DISA 55A01 constant temperature hot wire anemometer. A five-hole spherical probe with a diameter of 7 mm (Ref. 8) was used for mean velocity measurements in the wake. A special jig was fabricated for its calibration for yaw and pitch angles. The calibration curves were of a similar nature as in Ref. 8, but owing to the smaller sphere diameter used in the present investigations, numerical values differed slightly. The grids used for turbulence generation were made of circular rods of varying diameters (maximum diameter 1.27 cm) and varying spacing arranged in a square pattern.[4] The grid was fitted at the inlet of a 80-cm-long duct which preceded the test section. A three-dimensional traverse system was used for wake surveys using a spherical probe. The experiments were carried out at three values of incidence angles of −4, 0, and +12 deg.

Results and Discussion

The mean velocity profiles for 0-deg incidence are shown in Fig. 1. These correspond to 1.18 and 2.78% turbulence levels. With an increase in turbulence intensity, the ratio of the centerline wake edge velocity decreases. The typical values for the above two cases are 0.62 and 0.56 at $x/c=0.0125$ and 0.93 and 0.94 at $x/c=2.0$, respectively, where x is the axial length and c is the chord. This indicates a faster wake decay with increasing freestream turbulence intensity (Tu). Near the trailing edge, the asymmetry of velocity profile is more

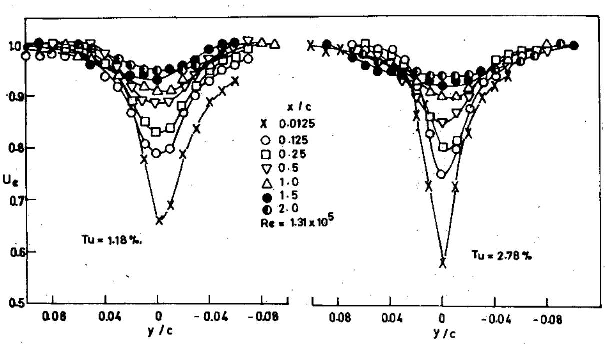

Fig. 1 Mean velocity profile at 0-deg incidence.

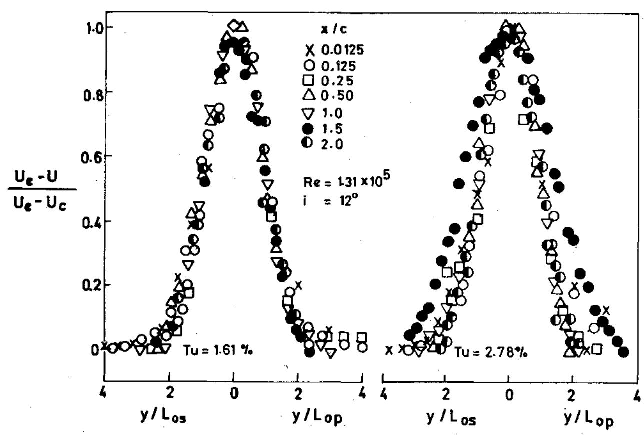

Fig. 2 Similarity in mean velocity profiles.

Received Sept. 2, 1982; revision received Oct. 22, 1982.

*Assistant Professor, Department of Aeronautical Engineering.
†Assistant Professor, Department of Aeronautical Engineering; present address: Hindustan Aeronautics Limited, Bangalore, India.

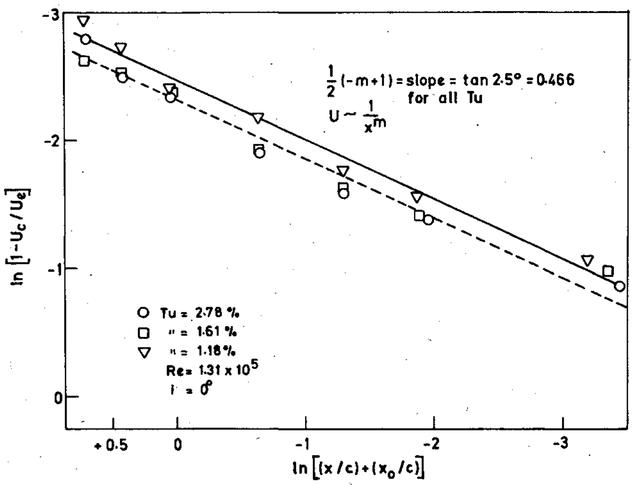

Fig. 3 Variation of wake centerline velocity with downstream distance.

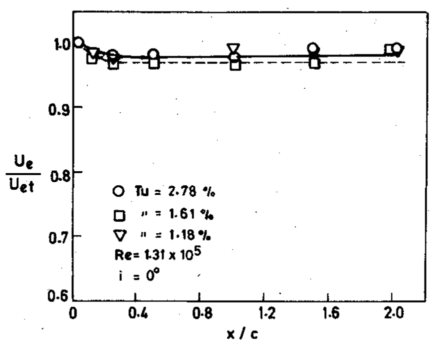

Fig. 4 Variation of wake edge velocity with downstream distance.

pronounced. The velocity distribution tends to become uniform faster at higher values of *Tu*.

Using scaling velocity as the difference between the maximum and minimum velocity $(U_e - U_c)$, and two different scaling lengths L_{0s} and L_{0p} (Ref. 5) for suction and pressure sides, respectively, the mean velocity distribution shows similarity at various values of x/c. The similarity curves for a 12-deg incidence angle are shown in Fig. 2. L_{0s} and L_{0p} are respectively the distances on the suction and pressure sides of the wake centerline, from the point of minimum velocity to a point where velocity is $\frac{1}{2}(U_e - U_c)$. Figure 3 shows the variation of wake centerline velocity with downstream distance on a logarithmic scale. x_0/c (the virtual origin) has been obtained using the method of Ref. 5. Its values range from 0.019 to 0.032. x_0/c is observed to decrease with an increase in *Tu*. The ratio of centerline velocity to wake edge velocity increases with freestream turbulence in the far wake. Figure 4 presents the variation of wake edge velocity with downstream distance. The velocity is nearly constant in the far wake.

The calculations for the drag coefficient C_d show that it decreases slightly with an increase in *Tu*. The values of C_d for three turbulence intensities of 1.18, 1.61, and 2.78% are respectively 0.013, 0.011, and 0.011 at an incidence angle of 12 deg. The value of the drag coefficient in Ref. 2 (for a solidity of 1.25) is 0.0170. The freestream turbulence may play a role in delaying separation in a low Reynolds number flow and this is likely to reduce C_d. Emery et al.[2] have also noted a decrease in drag coefficient when freestream turbulence was increased by placing a grid before the test section.

Conclusions

Experimental investigations have been carried out to determine the characteristics of a compressor cascade wake at three different values of freestream turbulence levels. The results indicate that the wake decay is faster for the case of higher freestream turbulence levels. A slight decrease in drag coefficient was also observed as the turbulence level was increased. The present investigations were limited to $Tu = 2.78\%$. At higher values of *Tu* these effects are expected to be more pronounced.

Similarity in the velocity distribution is observed in the near wake and far wake regions at all three values of incidence and turbulence levels.

References

[1] Schlichting, H. and Das, A., "On the Influence of Turbulence Level on the Aerodynamic Losses of Axial Turbomachines," *Symposium on Flow Research on Blading,* edited by L.S. Dzung, Elsevier, New York, 1970, pp. 243-274.

[2] Emery, C.J., Herring, L.J., Erwin, J.R., and Felix, A.R., "Systematic Two-Dimensional Tests of NACA 65-Series Compressor Blades at Low Speeds," NACA Report 1368, 1958.

[3] Evans, R.L., "Freestream Turbulence Effects on the Turbulent Boundary Layer," Aeronautical Research Council C.P. 1282, 1974.

[4] Citavy, J. and Norbury, J.F., "The Effect of Reynolds Number and Turbulence Intensity on the Performance of a Compressor Cascade with Prescribed Velocity Distribution (PVD)," *Journal of Mechanical Engineering Science,* Vol. 19, No. 3, 1977, pp. 93-100.

[5] Raj, R. and Lakshminarayana, B., "Characteristics of the Wake Behind a Cascade of Airfoils," *Journal of Fluid Mechanics,* Vol. 61, Dec. 1977, pp. 707-730.

[6] Gustafson, W.A. and Davis, D.W., "Analysis of the Turbulent Wake of a Cascade Airfoil," *Journal of Aircraft,* Vol. 14, April 1977, pp. 350-356.

[7] Felix, R.A. and Emery, J.C., "A Comparison of Typical National Gas Turbine Establishment and NACA Axial Flow Compressor Blade Sections in Cascade at Low Speed," NACA TN 3937, 1957.

[8] Nowack, C.F.R., "Improved Calibration Method for Five-Hole Spherical Pitot Probe," *Journal of Physics E,* Vol. 3, No. 1, 1970, pp. 22-26.

The Effect of Displacement Velocity on Propeller Performance

Michio Nishida*
Kyoto University, Kyoto, Japan

IN Refs. 1 and 2, simple vortex lattice methods were applied to propeller performance analysis. The propeller blade used in these papers is such that a single bound vortex is placed at the quarter-chord and a helical trailing vortex leaves both sides of each radial section on the quarter-chord line. The vortex method is to find the induced velocity due to the bound and helical vortices at the control points located on the three-quarter chord of each radial section by using the condition of no normal velocity to the surface. The analysis needs the position of the helical vortex. In Refs. 1 and 2 it is assumed that the helical trailing vortex leaves the blade at a freestream velocity V_∞. However, it is reasonable to consider that the trailing vortex moves with a velocity $V_\infty + \frac{1}{2}W$, where W is the axial displacement velocity at infinity. The purpose of this Note is to investigate the contribution of the displacement velocity to propeller performance.

At the control points the velocity normal to the blade surface must vanish:

$$V \cdot n = 0 \tag{1}$$

Received Sept. 17, 1982.

*Associate Professor, Department of Aeronautical Engineering.