N88-11162

PREDICTION OF TURBINE BLADE HEAT TRANSFER*

Suhas V. Patankar
University of Minnesota

INTRODUCTION

Although numerical computation of heat transfer has been attempted for at least the last twenty years, the current capability still requires considerable improvement and refinement. The reason that it is so difficult to predict the heat transfer on turbine blades lies in the simultaneous presence of many complicating factors such as transition to turbulence, relaminarization, free-stream turbulence, rotation, curvature, unsteadiness, generation of vortices, secondary flows, and three-dimensionality. Some of these aspects are discussed in references 1-4.

The purpose of the present project is to evaluate the current state of the art and to propose appropriate turbulence models for the prediction of the turbine blade heat transfer.

AVAILABLE EXPERIMENTAL DATA

The development of a satisfactory turbulence model is dependent on the availability of reliable and relevant experimental data. From a careful search of the literature, the experimental data given in references 5-9 are judged to be satisfactory for this purpose. The development of turbulence models will be done primarily by reference to these sets of data. Also, useful related information is available in references 10-11.

RELEVANT TURBULENCE MODELS

The main difficulty in the correct prediction of heat transfer on a turbine blade lies in the determination of transition to turbulence. Purely empirical criteria for transition cannot properly account for the influence of free-stream turbulence, curvature, and other factors. Only the low-Reynolds number versions of the differential turbulence models have, at least in principle, the ability to "predict" the transition. In these models, the turbulence parameters are computed even in the laminar-flow region. They have very small values as long as the flow remains laminar. When the conditions are right for transition, the imbalance between the generation and dissipation of the turbulence parameters leads to a rapid growth of the predicted turbulent viscosity, and the turbulent-flow region begins. Some of the relevant low-Reynolds-number turbulence models are described in references 12-15.

Since curvature is an important aspect of the flow over a turbine blade, the turbulence model should respond to the presence of the streamline curvature. References 16-22 present turbulence models with special emphasis on curvature.

PROPOSED WORK

It is planned to incorporate a number of low-Reynolds-number turbulence models in a general two-dimensional boundary layer calculation procedure. This will be applied to different flow conditions over turbine blades and the predictions will

*Work done under NASA Grant NAG3-579.

compared with experimental data. The prediction activity will lead to a recommendation about a satisfactory turbulence model for turbine blade heat transfer.

REFERENCES

1. Graham, R. W.: Fundamental Mechanisms that Influence the Estimate of Heat Transfer to Gas Turbine Blades. ASME, 79-HT-43.

2. Priddy, W. J.; and Bayley, F. J: Heat Transfer to Turbine Blading. 14th Int'l. Center for Heat and Mass Transfer Symposium. August 1982.

3. Metzger, D. E.: Fundamental Heat Transfer Research for Gas Turbine Engines. NASA Workshop Overview, 1982.

4. Marlin, B. W.; and Brown, A.: Factors Influencing Heat Transfer to the Pressure Surface of Gas Turbine Blades. Int. Journ. of Turb. and Jet Engines, vol. 1, 1984, pp. 247-258.

5. Hylton, L. D. et al: Analytical and Experimental Evaluation of the Heat Transfer Distribution over the Surfaces of Turbine Blades. NASA CR-168015, 1983.

6. Turner, A. B.: Local Heat Transfer Measurements on a Gas Turbine Blade. J. of Mech. Eng. Science, No. 1, vol. 13, 1971.

7. Liebert, C. H.; Gaugler, R. E.; and Gladden, H. J.: Measured and Calculated Wall Temperatures on Air Cooled Turbine Vanes with Boundary Layer Transition. ASME 83-GT-33.

8. York, R. E. et al: An Experimental Investigation of Heat Transfer to a Turbine Vane at Simulated Engine Conditions. ASME 79-GT-23.

9. Nicholson, J. H. et al: Heat Transfer Optimized Turbine Rotor Blades - An Experimental Study Using Transient Techniques. ASME 82-GT-304.

10. Danials, L. D.; and Brown, W. R.: Calculation of Heat Transfer Rates to Gas Turbine Blades. Int. J. of Heat and Mass Transfer, No. 5, vol. 24, 1981. pp. 871-879.

11. Wang, J. H.; Jen, H. F.; and Hartel, E. O.: Airfoil Heat Transfer Calculation Using Low Reynolds Number Version of a Two Eq. Turb. Model. ASME 84-GT-261.

12. Jones, W. P.; and Launder, B.E.: The Calculation of Low-Reynolds Number Phenomena with a Two-Equation Model of Turb. Int. J. of Heat and Mass Transfer, No. 6, vol. 16, 1973, pp. 1119-1130.

13. Gori, F., El Haddy, M.A.; and Spalding, D. B.: Numerical Prediction of Heat Transfer to Low Pr. Number Fluids. Numeri. Heat Transfer, vol. 2, 1979, pp. 441-454.

14. El Hadidy, M. A.; Gori, F.; and Spalding, D. B.: Further Results on the Heat Transfer to Low Pr. Number Fluids in Pipes. Numeri. Heat Transfer, vol. 5, 1982, pp. 107-117.

15. Patel, V. C.; Rosi, W.; and Scheurrer, G.: A Review and Evaluation of Turbulence Models for Near Wall and Low Reynolds Number Flows. To appear in AIAA Jl.

16. Launder, B. E.: Priddin, C. H.; and Sharma, B. I." The Calculation of Turbulent B. Ls on Spinning and Curved Surfaces. J. of Fluids Eng., March 1977, pp. 231-239.

17. Rodi, W.; and Scheurer, G., Calculation of Curved Shear Layers with Two-Equation Turbulence Models. SFR 80/T.211. July 1982.

18. Chambers, T. L.; and Wilcox, D. C.: Critical Evaluation of Two-Equation Turbulence Models for Boundary Layers. AIAA Jl., No. 6, vol. 15, 1977. pp.

19. Gibson, M. M.: An Algebraic Stress and Heat-Flux Model for Turbulent Shear Flow with Streamline Curvature. Int. J. of Heat and Mass Transfer, No. 8, vol. 21, 1978, p. 1069.

20. Gibson, M. M.; and Rodi, W., A Reynolds-stress Closure Model of Turbulence Applied to the Calculation of a Highly Curved Mixing Layer. J. Fluid Mechanics, vol. 103, 1981, p. 161.

21. Gibson, M. M.; and Younis, B. A., Modeling the Curved Turbulent Wall Jet, AIAA Jl., No. 12, vol. 20, 1982, p. 1707.

22. Kline, S. J.; Cantwell, B. J.; and Lilley, G. M.: editors. 1980-1981, AFOSR-HTTM-STANFORD Conference on Complex Turbulent Flows (1980-1981).