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**TURBINE AERO THERMAL
RESEARCH**



Richard B. Rivir

JULY 9, 1996

INTERIM REPORT 1 NOVEMBER 1995--9 JULY 1996

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**AERO PROPULSION & POWER DIRECTORATE
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1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE July 9, 1996	3. REPORT TYPE AND DATES COVERED Interim 1 Nov 95 - 9 Jul 96		
4. TITLE AND SUBTITLE TURBINE AERO THERMAL RESEARCH			5. FUNDING NUMBERS PE 61102F JON 2307s315	
6. AUTHOR(S) Richard B. Rivir				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Aero Propulsion & Power Directorate Wright Laboratory Air Force Materiel Command Wright-Patterson Air Force Base, OH 45433-7650			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Aero Propulsion & Power Directorate Wright Laboratory Air Force Materiel Command Wright-Patterson Air Force Base, OH 45433-7650 POC: Richard B Rivir, WL/POTT, 513-255-5132			10. SPONSORING / MONITORING AGENCY REPORT NUMBER WL-TR-96-2082	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION / AVAILABILITY STATEMENT APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This report indicates current areas of turbine aero thermal research in house at the Aero Propulsion and Power Directorate and lists current publications (17) from Nov 95 to Jul 96.				
14. SUBJECT TERMS IN HOUSE TURBINE AERO THERMAL RESEARCH			15. NUMBER OF PAGES 7	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

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1995-1996 Task Report 2307S315

LRIR: 92WL013

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Research Objectives:

- Establish fundamental understanding of heat transfer mechanisms in gas turbine engines.
- Provide an understanding of the effects of unsteady free stream turbulence on turbine blade heat transfer.
- Improve the accuracy of heat transfer predictions.
- Develop concepts and strategies for the control of turbulent heat transfer.
- Transition basic research results to the gas turbine industry and to IHPTET Technology Demonstrations

Progress for 1995-1996: The Low Pressure, Low Reynolds Number Turbine experiment have been conducted on a Langston cascade at the Air Force Academy and at UC Davis with freestream turbulence levels of 0.5%, 1%, 8% and 10%. Reynolds numbers of 67.5K, 110K, 134K, and 144K have been run. Different pitch to chord ratios and cascade flow angles significantly affect the transition and separation processes and have been documented. Pratt low pressure blade profiles are being used in the cascade experiment at WL with a moving stator section and free stream turbulence levels to 17%. Computations have been run here using the Allison Blade Vane Interaction Program for all cases investigated for the Langston cascade at AFA and UC Davis.

Extensive Particle Image Velocimetry measurements on our 2D Boundary layer high turbulence film cooling experiments have been carried out for the forced and unforced film cooling flows. The double pulsed YAG exposures provide flow visualization in addition to the vector velocity field. These photos show details such as the shear layer resulting from the film hole walls rolling up in the opposite direction to the primary flow, shear layer growth, jet spread, and the changes in film cooling flow turbulence scales with changes in freestream turbulence that have not been possible to documented with conventional measurements.

Two members of our team completed their PhD's this year. Rolf Sondergaard from Stanford University (Palace Knight) and Ed Michaels, from the University of Dayton. Dr Sondergaard received the Balhaus Award for the best Stanford Aero Dissertation for 1995. Dr Michaels worked on a two scale turbulence model for about 7 years here in our lab. His model now predicts Stanton Number and skin friction for turbulence levels of 0.5 to 20%, far more accurately than any other model (within $\pm 2\%$ of measured values). Dr Sondergaard's and Dr Michaels Dissertations are availble from the authors. R. Rivir and J. Bons received the 1995 S. D. Heron Award from the Aero Propulsion and Power Directorate for High Turbulence Effects on Film Cooling. R. Rivir organized and hosted the 1995 AFOSR Contractors and Grantees Meeting on Turbulence and Internal Flows. Dr Won Chang joined the group in May of 1996. Our PIV work was selected for the American Physical Society's Gallery of Fluid Motion for 1996.

PUBLICATIONS 1996:

Baughn J. W., Butler R. J., Byerley A. R., and Rivir R. B., "An Experimental investigation of Heat Transfer, Transition, and Separation on Turbine Blades at Low Reynolds Number and High Turbulence Intensity," 1995 International Mechanical Engineering Congress and Exposition, accepted for publication in The ASME Journal Of Turbomachinery, San Franisco CA, Nov. 1995.

Duncan CIC J., and Petersen CIC K., "Aero-Thermal Cascade Tunnel Flow Quality: Turbulence Generation and Prediction," Air Force Academy Aeronautical Engineering 471, Nov. 1995.

J. Bons, C. D. MacArthur, and R. B. Rivir, "The Effect of High Freestream Turbulence on Film Cooling Effectiveness," Accepted for publication in the ASME Journal of Turbomachinery.

R. B. Rivir, and M. K. Chyu, P. K. Maciejewski, "Turbulence and Scale Measurements in Ribbed Channels," International Journal of Rotating Machinery, Vol 2, No. 3, 1996, pp. 209-218.

Gogininni, Rivir, Pestian, and Goss, "Effect of High Freestream Turbulence on Turbine Film Cooling Flows," American Physical Society Meeting, Winner Gallery of Fluid Motion, Publication 1996, November 1995.

Gogininni, Rivir, Pestian, and Goss, "PIV Measurements of Flat Plate Film Cooling Flows with High Freestream Turbulence," ASME International Gas Turbine Institute Meeting, Birmingham, UK, 96-GT-236, June 1996,

Holmberg D. G., and Pestian D. J., "Wall-Jet Turbulent Boundary Layer Heat Flux, Velocity and Temperature Spectra and Time Scales," ASME International Gas Turbine Institute Meeting, Birmingham, UK, 96-GT-529, June 1996,

Gogininni, Rivir, Pestian, and Goss, "PIV Measurements of Periodically Forced Flat Plate Film Cooling Flows with High Free Stream Turbulence," AIAA Aerospace Sciences Meeting, AIAA 96-0617, January 1996.

Rivir, Sondergaard, Dalstrom, and Ervin, "Low Reynolds Number Turbine Blade Cascade Calculations," ISROMAC-6 The 6th International Symposium on Transport Phenomena and Dynamics of Rotating Machinery, Honolulu, HA, February 1996.

Gogininni, Rivir, Pestian, and Goss, "PIV Technology for Simulated Turbine Film Cooling Flows," The 6th International Symposium on Flow Modeling and Turbulence Measurements, Florida A&M and Florida State Universities, Tallahassee FL, Sept 8-10, 1996.

Rivir R. B., "Transition on Turbine Blades and Cascades at Low Reynolds Numbers," 14th AIAA Fluid Dynamics Conference, New Orleans, AIAA 96-2079, June 1996.

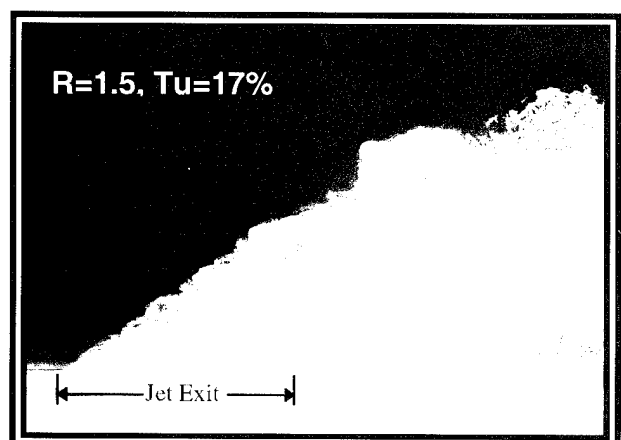
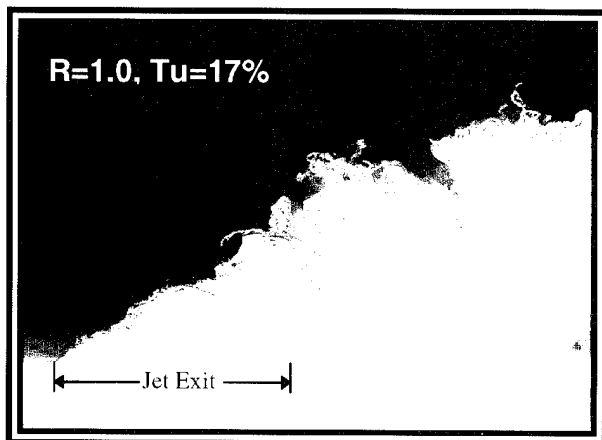
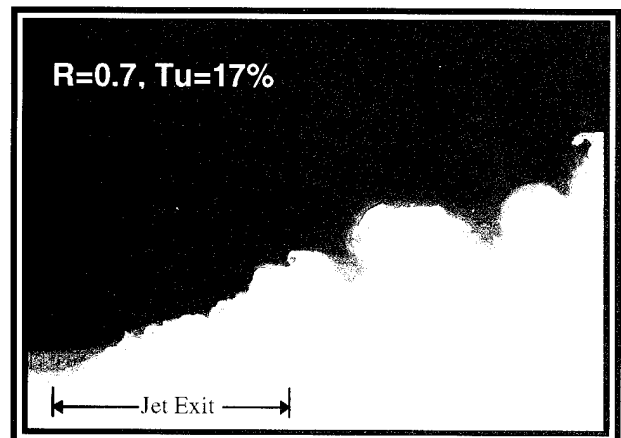
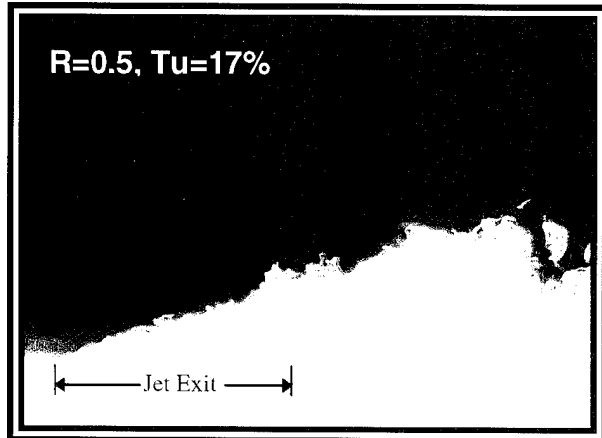
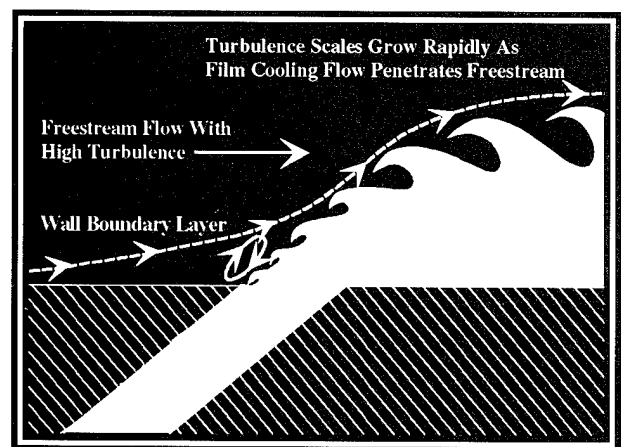
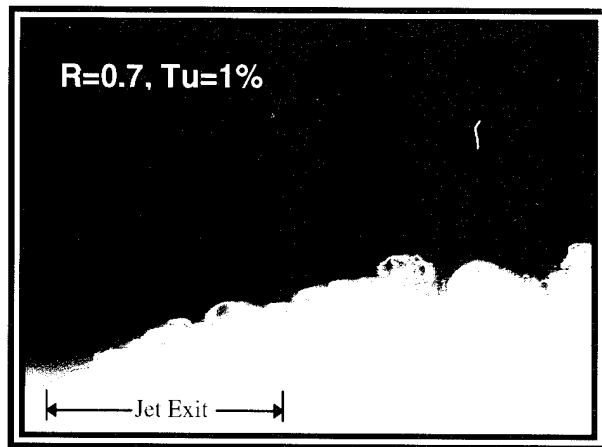
Gogininni, Trump, Rivir, Pestian, and Goss, "High Resolution Digital Two-Color PIV (D2CPIV) and Its Application to High Freestream Turbulence," Eighth International Symposium on Applications of Laser Techniques to Fluid Mechanics, Lisbon, Portugal, July 1996.

Gogininni, Rivir, Goss, and Pestian, "PIV Technology for Simulated Turbine Film Cooling Flows," The 6th International Symposium on Flow Modeling and Turbulence Measurements, Florida State University, Tallahassee, FL, September 1996.

Schauer J. J. and Pestian D. J., "Film Cooling Heat Transfer with High Freestream Turbulence," 1996 International Congress & Exposition (IMECE), Atlanta, GA, November 1996.

Simon T. W. and Volino R. J., "Documentation of Separating and Separated Boundary Layers," Final Report for: Summer Faculty Extension Program, Wright Laboratories, WPAFB, OH, February 1996.

Sharp, C1C J., and Harris, C2C P., "Turbulent Heat Transfer Investigation: Turbulent Length Scales and Heat Transfer," Air Force Academy Aeronautical Engineering 471, May 1996.



HIGH FREE STREAM TURBULENCE INFLUENCE ON TURBINE FILM COOLING FLOWS
 Submitted by S. Gogineni (Systems Research Laboratories), R. Rivir (Wright Laboratory), D. Pestian (Univ. of Dayton Research Institute), L. Goss (Innovative Scientific Solutions, Inc.), Dayton, OH

Double pulsed two-color Particle Image Velocimetry (PIV) images of simulated turbine film cooling flows are shown for a range of film cooling blowing ratios ($R = \rho c U_c / \rho \infty U \infty$) of 0.5, 0.7, 1.0 and 1.5. The simulated turbine conditions include the film cooling jet $l/d = 3$, film jet Reynolds number of 20,000 and free stream turbulence level of up to 17% among other characteristics described by Bons et. al. (1994). These images are obtained by seeding the jet flow only with sub-micron size smoke particles and illuminating the particles with a two-color PIV system. These images illustrate how the jet spreads and shear layer grows with two of the problem parameters, the blowing ratio and the free stream turbulence level. There is a decrease in film cooling effectiveness and increased heat transfer associated with the increase in turbulence intensity which is currently difficult to predict. PIV images and the reduced PIV data are useful in providing additional physics on mixing and dissipation for improved modeling of these flows.