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**The Center of Excellence for Hypersonics
Training & Research
at
The University of Texas at Austin**

Final Report

Prepared by

David S. Dolling, Director

(NASA-CR-193070) THE CENTER OF
EXCELLENCE FOR HYPERSONICS TRAINING
AND RESEARCH AT THE UNIVERSITY OF
TEXAS AT AUSTIN Final Report
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ABSTRACT

Over the period of this grant (1986–92), 23 graduate students were supported by the Center and received education and training in hypersonics through MS and Ph.D. programs. An additional 8 Ph.D. candidates and 2 MS candidates, with their own fellowship support, were attracted to The University of Texas and recruited into the hypersonics program because of the Center. Their research, supervised by the 10 faculty involved in the Center, resulted in approximately 50 publications and presentations in journals and at national and international technical conferences. To provide broad-based training, a new hypersonics curriculum was created, enabling students to take 8 core classes in theoretical, computational, and experimental hypersonics, and other option classes over a two to four semester period. The Center also developed an active continuing education program. The Hypersonics Short Course was taught 3 times, twice in the USA and once in Europe. Approximately 300 persons were attracted to hear lectures by more than 25 of the leading experts in the field. In addition, a hypersonic aerodynamics short course was offered through AIAA, as well as short courses on CFD and Advanced CFD. The existence of the Center also enabled faculty to leverage a substantial volume of additional funds from other agencies, for research and graduate student training. Overall, this was a highly successful and highly visible program.

1 INTRODUCTION

1.1 Background

This report provides a brief overview of the activities of the Center for Hypersonics Training and Research at the University of Texas at Austin from 1986-1992. The mission of the Center was three-fold: (i) formal training/education of graduate students in hypersonics through organized classes and seminars; (ii) training in research in hypersonics through preparation of thesis/dissertations for the M.S./Ph.D. degrees and through presentation of their work at national and international meetings; and (iii) continuing education of practicing engineers in industry and government and of university/college faculty. Each of these elements is described in this report.

1.2 Personnel Associated with Center

1.2.1 Faculty

At the beginning of the grant period, Dr. John Bertin was Director of the Center. Approximately two years into the grant, Dr. Bertin resigned from the University of Texas at Austin, and Dr. Dolling became Director. Approximately 7 faculty from the Department of Aerospace Engineering & Engineering Mechanics (ASE/EM) and 3 from Mechanical Engineering (ME) have been involved in Center activities. Their names and research interests are listed below.

<i>Faculty Member</i>	<i>Affiliation</i>	<i>Research Interests</i>
Dr. John Bertin	ASE/EM	aerothermodynamic environment
Dr. Graham Carey	ASE/EM	computational fluid dynamics
Dr. Michael Crawford	ME	turbulence modeling, heat transfer
Dr. David Dolling	ASE/EM	experimental gas dynamics, unsteady flow
Dr. Klaus Hoffmann	ASE/EM	computational fluid dynamics
Dr. John Kallinderis	ASE/EM	computational fluid dynamics
Dr. J. P. Lamb	ME	experimental/analytical high speed fluid mechanics
Dr. John Westkaemper	ASE/EM	experimental aerodynamics
Dr. Dennis Wilson	ME	theoretical fluid mechanics
Dr. Philip Varghese	ASE/EM	physical gas dynamics, high temperature flows

1.2.2 Graduate Students

During the period of the grant, 13 Masters and 10 Ph.D. students were either totally or partially supported by the Center. In addition, 8 Ph.D. and 2 MS students who had their own support, but were attracted to The University of Texas because of the Center, were involved in the program. Their names and details of their research work are given in Section 2.2.1.

2 OVERVIEW OF ACTIVITIES

2.1 Curriculum

During the period of the grant several new classes were developed and existing classes were modified to include modern hypersonics, such that the student could take a logical series of classes focusing on

analytical, experimental, and computational aspects of hypersonic flows. This program was highly successful, attracting not only students supported by the Center, but many others who wished to learn more about specific areas in the field. The titles of the classes and names of instructors are listed below.

Fall

- Fundamentals of Hypersonics (Dolling, Bertin)
- Introduction to CFD (Hoffmann, Wilson, Kallinderis)
- Experimental Methods in Gas Dynamics (Dolling)
- Finite Difference Computations in Fluid Dynamics (Hoffmann, Kallinderis)

Spring

- Hypersonic Viscous Flow (Wilson)
- Advanced CFD (Hoffmann, Bertin, Kallinderis)
- Molecular Processes in Fluid/Thermal Systems (Varghese)
- Advanced Gas Dynamics (Dolling, Bertin)

In addition, a number of “option” classes could be taken, depending on the students’ interests and research focus. These include: (i) High Temperature Gas Dynamics (Varghese); (ii) Radiation Heat Transfer (Howell); (iii) Modeling of Turbulent Flows (Crawford).

2.2 Research

2.2.1 Graduate Students

Those graduate students who received either total or partial support for their studies from the grant are listed below (in chronological order).

<i>Name</i>	<i>Degree</i>
Bryan Sehlke	MS
Todd Sterk	MS
Steven Doerr	Ph.D.
Douglas Cline	Ph.D.
Hans Baade	MS
Leon Brusniak*	Ph.D.
Nancy Mayer*	MS
Robert Nordyke	MS
Michael Sheller	Ph.D.
Charles Hamburger	Ph.D.
Eric Koss*	MS
Berry Gibson	MS

...continued next page

* work still in progress

<i>Name</i>	<i>Degree</i>
Michael Schwartz	MS
Kurt Hoover	MS
Spencer Swift	MS/Ph.D.
David Fritz	MS
Anthony Hanford	Ph.D.
Steven Bova	Ph.D.
Alan Stagg	Ph.D.
Taunya Boitnott	MS
John Schmisser	MS
Steven Petullo	MS
Steven Ward	Ph.D.

Their research topics are listed below.

1. Bryan Sehlke (MS) "Rapid Numerical Calculations of Re-entry Aerodynamics"
2. Todd Sterk (MS) "Flowfields Associated With an Underexpanded Nozzle Exhausting Into a Vertical Launching System"
3. Steven Doerr (Ph.D.) "Measurement of a Three Dimensional Hypersonic Density Field Using Holographic Interferometry"
4. Douglas Cline (Ph.D.) "Effect of Disparate Shock Eigenvalues on the Numerical Solution of Super/Hypersonic Conical Flows"
5. H. Baade (MS) "Time Series Analysis of Separation Shock-Induced Pressure Fluctuations in Turbulent Interactive Flows"
6. Leon Brusniak (Ph.D.) "Dynamics of Hypersonic Blunt Fin-Induced Flowfields"
7. Nancy Mayer (MS) "Effects of Shock Impingement on Growth Rate of Compressible Turbulent Shear Layers"
8. Robert Nordyke (MS) "Spanwise Properties of the Unsteady Separation Shock Wave in a Mach 5 Compression Ramp Interaction"
9. Michael Sheller (Ph.D.) "Effect of Unsteady Expansion & Compression Waves on a Compressible Boundary Layer"
10. Charles Hamburger (Ph.D.) "Numerical Computation of a Mixing Layer by a Method of Successive Approximations"
11. Eric Koss (MS) "Effects of Vibrational Non-Equilibrium on High Temperature Gas"
12. Berry Gibson (MS) "Experimental Study of Wall Pressure Fluctuations Near Separation in a Mach 5, Sharp Fin-Induced Interaction"
13. Michael Schwartz (MS) "Navier Stokes Analysis of the 2-D Separated Shock Wave-Laminar Boundary Layer Interaction in a Compression Corner"
14. Kurt Hoover (MS) "Chemically Reacting Hypersonic Aerodynamics"

15. Spencer Swift (Ph.D.) "Comparative Study of Equilibrium and Non Equilibrium Chemistry Models"
16. David Fritz (MS) "Development of a Parabolized Navier-Stokes Code and Its Application to Planar Axisymmetric Flows"
17. Antony Hanford (Ph.D.) "Augmentation of Stagnation Point Heat Transfer by Quasi-Periodic Freestream Fluctuations"
18. Stephen Bova (Ph.D.) "Finite Element Solution of Systems of Non-Linear, Hyperbolic Conservation Laws on Unstructured Meshes"
19. Alan Stagg (Ph.D.) "Scalable Parabolized Navier-Stokes Applications on Massively Parallel MIMD Architectures"
20. Taunya Boitnott (MS) "Experimental Study of Dynamics of Moderately Swept Compression Ramp-Induced Separation at Mach 5"
21. John Schmisser (MS) "Experimental Study of Fluctuating Wall Pressures in Highly Swept, Sharp Fin-Induced Mach 5 Turbulent Interactions"
22. Steven Petullo (MS) "Organized Structure of Compressible Turbulent Shear Layers"
23. Steven Ward (Ph.D.) "Prismatic Grid Generation Techniques Using Efficient Algebraic Methods for Aircraft Configurations"

The existence of the program enabled The University of Texas to recruit and retain graduate students who had their own support (i.e., fellowships, etc.) and who doubtlessly would have gone into other areas (both here and at other institutions). Those students are listed below.

<i>Name</i>	<i>Degree</i>	<i>Source of Funds</i>
Walter Rutledge	Ph.D.	Sandia Doc. Program
David Gonzales	Ph.D.	NASA Minority Fellowship
Richard Gramann	Ph.D.	ARO Fellowship
Patrick Rodi	Ph.D.	NASA Fellowship
Ting L. Chiang	Ph.D.	UT Fellowship
Christophe Harlé	Ph.D.	French Govt. Fellowship
Douglas Smith	MS	Air Force Officer
Zhiqiang Tan	Ph.D.	TX Research Program
Darrin Willauer	MS	TX Adv. Research Program
William McClure	Ph.D.	Air Force Officer

Their research topics are listed below.

1. Walter Rutledge (Ph.D.) "High Altitude Hypersonic Aerodynamics of Blunt Bodies"
2. David Gonzales (Ph.D.) "Models for Vibration – Dissociation Coupling in High Temperature Gases"
3. Richard Gramann (Ph.D.) "Dynamics of Separation and Reattachment in a Mach 5 Unswept Compression Ramp Flow"

4. Patrick Rodi (Ph.D.) "An Experimental/Computational Study of Heat Transfer in Sharp Fin-Induced Shock Wave Turbulent Boundary Layer Interactions at Low Hypersonic Mach Numbers"
5. Ting L. Chiang (Ph.D.) "Computation of Non Equilibrium Chemically Reacting Flows in Hypersonic Flowfields"
6. Christophe Harlé (Ph.D.) "Finite Element Modeling of Flow in Supersonic Nozzle Driven by an Arc Jet"
7. Douglas Smith (MS) "Effects of Incoming Boundary Layer Thickness on Mach 5 Unsteady Shock Wave Boundary Layer Interaction"
8. Zhiqiang Tan (Ph.D.) "New Numerical Methods for Some Linear and Non-Linear Transport Equations"
9. Darrin Willauer (MS) "Monte Carlo Simulation of Rotational Relaxation in Para-Hydrogen Using State-to-State Collision Cross-Sections"
10. William McClure (Ph.D.) "Experimental Study of Driving Mechanism and Control of Unsteady Shock-Induced Separated Flow in a Mach 5 Compression Corner Flow"

2.3 Publications

2.3.1 Refereed Journal Articles

- Gramann, R. A. and Dolling, D. S., "Intermittent Separation in Shock Wave Turbulent Boundary Layer Interaction," *AIAA Journal*, Vol. 25, No. 12, pp. 1545-1546, 1987.
- Dolling, D. S. and Brusniak, L., "Separation Shock Motion in Fin, Cylinder and Compression Ramp Interactions," *AIAA Journal*, Vol. 27, No. 6, pp. 734-742, June 1989.
- Dolling, D. S. and Smith, D. R., "Unsteady Shock-Induced Separation in Mach 5 Cylinder Interactions," *AIAA Journal*, Vol. 27, No. 12, pp. 1698-1706, Dec. 1989.
- Tan, Z-Q., Chen, Y-K., Varghese, P. L., and Howell, J. R., "New Numerical Strategy to Evaluate the Collision Integral of the Boltzmann Equation," *Rarefied Gas Dynamics: Theoretical and Computational Techniques*, E. P. Muntz, D. P. Weaver, and D. H. Campbell (eds.), Progress in Aeronautics and Astronautics, 118, AIAA, pp. 359-373, 1989.
- Gramann, R., and Dolling, D. S., "Detection of Turbulent Boundary Layer Separation Using Fluctuating Wall Pressure Signals," *AIAA Journal*, Vol. 28, No. 6 pp. 1052-1056, June 1990.
- Hoffmann, K. A., Chiang, T. L. and Rutledge, W. H., "Computations of Flow Fields for Projectiles in Hypersonic Chemically Reacting Flow," *Journal of Space Craft and Rockets*, Sept./Oct. 1990.
- Chen, Y-K., Varghese, P. L., and Howell, J. R., "Numerical Solution of Two-Dimensional Compressible Radiating Flow Fields," *AIAA J. Thermophysics & Heat Transfer*, Vol. 4, pp. 285-291, 1990.
- Marshall, T. and Dolling, D. S., "Comments on the Computation of Supersonic, Unswept, Turbulent Compression Ramp Interactions," *AIAA Journal*, Vol. 30, No. 8, pp. 2056-2065, Aug. 1992.

- Willauer, D. L. and Varghese, P. L., "Direct Simulation of Rotational Relaxation Using State-To-State Cross Sections," *AIAA Journal of Thermophysics and Heat Transfer*, Vol. 7, pp. 49-54, 1993.
- Gibson, B. T. and Dolling, D. S., "Exploratory Study of Wall Pressure Fluctuations in a Mach 5, Sharp Fin-Induced Turbulent Interaction," *AIAA Journal*, Vol. 30, No. 9, pp. 2188-2195, Sept. 1992.
- Tan, Z. and Varghese, P. L., "The Δ - ξ Method for the Boltzmann Equation," submitted to *Journal of Computational Physics*, Jan. 1993.
- Gonzales, D. A. and Varghese, P. L., "A Simple Model for State-Specific Diatomic Dissociation," accepted for publication in *J. Physical Chemistry*, submitted Feb. 1993.
- Gonzales, D. A. and Varghese, P. L., "Evaluation of Simple Rate Expressions for Vibration-Dissociation Coupling," accepted for publication in *J. Thermophysics and Heat Transfer*, submitted Feb. 1993.

2.3.2 Papers Presented at National AIAA Conferences

- Dolling, D. S. and Brusniak, L., "Separation Shock Motion in Fin, Cylinder and Compression Ramp Interactions," AIAA Paper 87-1368, 19th Fluid Dynamics, Plasma Dynamics and Lasers Conference, HI, June 1987.
- Bertin, J. J., Tedeschi, W. J., Bustamante, A. C., and Reece, E. W. "The Aerothermodynamic Environment for Holes in Hypersonic Configurations", AIAA Paper 87-2631 CP, 5th Applied Aerodynamics Conference, Monterey, CA, Aug. 1987.
- Bertin, J., et al., "Analysis of Shear Layer Probe Data for Holes in Hypersonic Configurations," AIAA Paper 88-0373, 26th Aerospace Sciences Meeting, Reno, NV, Jan. 1988.
- Dolling, D. S. and Smith, D. R., "Unsteady Shock-Induced Separation in Mach 5 Cylinder Interactions," AIAA Paper 88-0305, 26th Aerospace Sciences Meeting, Reno, NV, Jan. 1988.
- Nordyke, R. and Dolling, D. S., "Spanwise Properties of the Unsteady Separation Shock Wave in a Mach 5 Unswept Compression Ramp Interaction," AIAA Paper 88-3802, First National Fluid Mechanics Congress, July 1988.
- Gramann, R. and Dolling, D. S., "Detection of Turbulent Boundary Layer Separation Using Fluctuating Wall Pressure Signals," AIAA Paper 88-4676, AIAA/NASA/AFWAL Conference on Sensors and Measurement Techniques for Aeronautical Applications, Sept. 1988.
- Hoffmann, K. A., Chiang, T. L., and Rutledge, W. H., "Effect of Dynamic Changes in Body Configuration on Shock Structure," AIAA Paper 89-0526, 27th Aerospace Sciences Meeting, Reno, NV, Jan. 1989.
- Erengil, M. E. and Dolling, D. S., "Separation Shock Wave Motion and Ensemble Averaged Wall Pressures in a Mach 5 Compression Ramp Interaction," AIAA Paper 89-1853, 20th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Buffalo, NY, June 1989.
- Hoffmann, K. A. and Chiang, T. L., "Determination of Computational Time Step for Chemically Reacting Flows," AIAA Paper 89-3376, 20th Fluid Dynamics, Plasma Dynamics and Lasers Conference, Buffalo, NY, June 1989. Proceedings published by AIAA.
- Hoffmann, K. A., Wilson, D. E., and Hamburger, C., "Aerothermodynamic Analysis of Projectiles at Hypersonic Speeds," AIAA 7th Applied Aerodynamics Conference, Seattle, WA, July 1989. Proceedings published by AIAA.

- Hoffmann, K. A., Chiang, T. L., and Rutledge, W. H., "Aerodynamic Analysis of Segmented Configurations in High Speed Flight," AIAA 7th Applied Aerodynamics Conference, Seattle, WA, July 1989. Proceedings published by AIAA.
- Hoffmann, K. A., Chiang, T. L., and Wilson, D. E., "The Effect of Unsteady Free-Stream Disturbances on Surface Pressure of Hypervelocity Segmented Projectiles," *Proceedings of AIAA Atmospheric Flight Mechanics Conference*, AIAA Paper 89-3376, Aug. 1989.
- Gramann, R. A. and Dolling, D. S., "Dynamics of Separation and Reattachment in a Mach 5 Compression Ramp Flow," AIAA Paper 90-0380, 28th Aerospace Sciences Meeting, Jan. 8-11, 1990.
- Marshall, A. and Dolling, D. S., "Spanwise Properties of the Unsteady Separation Shock in a Mach 5 Unswept Compression Ramp Interaction," AIAA Paper 90-0377, 28th Aerospace Sciences Meeting, Jan. 8-11, 1990.
- Settles, G. S. and Dolling, D. S., "Swept Shock/Boundary Layer Interaction - Tutorial and Update," AIAA Paper 90-0375, 28th Aerospace Sciences Meeting, Jan. 8-11, 1990.
- Erengil, M. and Dolling, D. S., "Correlation of Separation Shock Motion in a Compression Ramp Interaction with Pressure Fluctuations in the Incoming Boundary Layer," AIAA Paper 90-1646, 21st Fluid Dynamics, Plasma Dynamics and Lasers Conference, June 1990.
- Gramann, R. and Dolling, D. S., "Dynamics of the Outgoing Turbulent Boundary Layer in a Mach 5 Compression Ramp Interaction," AIAA Paper 90-1645, 21st Fluid Dynamics, Plasma Dynamics and Lasers Conference, June 1990.
- Hoffmann, K. A., Chiang, T. L., and Siddiqui, M. S., "The Effect of Separation Distance on the Shock/Wake Interaction of Bi-Configuration Systems," AIAA Paper 90-1443, 21st Fluid Dynamics and Plasmadynamics Conference, Seattle, WA, June 1990.
- Dolling, D. S. and Brusniak, L., "Correlation of Separation Shock Motion in a Cylinder-Induced Interaction with Pressure Fluctuations Under the Separated Region," AIAA Paper 91-0650, 29th Aerospace Sciences Meeting, Jan. 7-10, 1991.
- Gibson, B. and Dolling, D. S., "Wall Pressure Fluctuations Near Separation in a Mach 5 Sharp Fin-Induced Turbulent Interaction," AIAA Paper 91-0646, 29th Aerospace Sciences Meeting, Jan. 7-10, 1991.
- McClure, W. B. and Dolling, D. S., "Exploratory Study of Effects of Suction Near Reattachment on the Unsteadiness of a Mach 5 Compression Ramp Interaction," AIAA Paper 91-1767, 22nd Fluid Dynamics, Plasma Dynamics and Lasers Conference, June 24-27, 1991.
- Gonzales, D. A. and Varghese, P. L., "Vibrational Relaxation and Dissociation in Nitrogen," AIAA Paper 91-1370, 26th Thermophysics Conference, Honolulu, HI, June 1991.
- Rodi, P. E., Dolling, D. S., and Knight, D. D., "An Experimental/Computational Study of Heat Transfer in Sharp Fin-Induced Turbulent Interactions at Mach 5," AIAA Paper 91-1764, 22nd Fluid Dynamics, Plasma Dynamics and Lasers Conference, HI, June 1991.
- Willauer, D. L. and Varghese, P. L., "Monte Carlo Simulation of Rotational Relaxation in Hydrogen Using State-To-State Collision Cross-Sections," AIAA Paper 91-1342, 26th Thermophysics Conference, Honolulu, HI, June 1991.
- Harlé, C., Carey, G. F., and Varghese, P. L., "Finite Element/Finite Volume Analysis for Reactive Gas Flows," Fourth International Symposium on Computational Fluid Dynamics, Davis, CA, Sept. 1991.

- Rodi, P. E. and Dolling, D. S., "An Experimental/Computational Study of Sharp Fin-Induced Shock Wave/Turbulent Boundary Layer Interaction at Mach 5: Experimental Results," AIAA Paper 92-0749, 30th Aerospace Sciences Meeting, Reno, NV, Jan. 6-9, 1992.
- Gonzales, D. A. and Varghese, P. L., "Rate Calculations for the Simultaneous Vibrational Relaxation and Dissociation of Nitrogen," AIAA Paper 92-0808, 30th Aerospace Sciences Meeting, Reno, NV, Jan. 1992.
- Harlé, C., Carey, G. F., and Varghese, P. L., "Computation of Non-equilibrium Flow Downstream of a Plasma Torch," AIAA Paper 92-0364, 30th Aerospace Sciences Meeting, Reno, NV, Jan. 1992.
- McClure, W. B. and Dolling, D. S., "An Examination of the Effects of Incoming Boundary Layer Modifications on the Dynamics of a Turbulent Compression Corner Interaction," AIAA Paper 92-3667, AIAA/SAE/ASME/ASEE 28th Joint Propulsion Conference, Nashville, TN, July 6-8, 1992.
- Gonzales, D. A. and Varghese, P. L., "Vibration-Dissociation Coupling in CO, N₂, and O₂: An Evaluation of Analytic Transition Rate Expressions," AIAA Paper 93-0481, 31st Aerospace Sciences Meeting, Reno, NV, Jan. 1993.
- Tan, Z. and Varghese, P. L., "Directionally Adaptive Finite Element Method for Multidimensional Euler and Navier-Stokes Equations," AIAA Paper 93-3320, to be presented at the 11th Computational Fluid Dynamic Conference, Orlando, FL, July 6-9, 1993.

2.3.3 Papers Presented at Other National Technical Conferences

- Hoffmann, K. A., Chiang, T. L., and Bertin, J. J., "Effect of the Grid System on the Solution of Euler Equations," The 2nd International Conference on Numerical Grid Generation in Computational Fluid Dynamics, Miami, FL, Dec. 1988. Proceedings published by Pineridge Press.
- Hoffmann, K. A., Rutledge, W. H., and Rodi, P. E., "Hyperbolic Grid Generation Techniques for Blunt Body Configurations," The 2nd International Conference on Numerical Grid Generation in Computational Fluid Dynamics, Miami, FL, Dec. 1988. Proceedings published by Pineridge Press.
- Tan, Z., Chen, Y. K., Varghese, P., and Howell, J., "A New Numerical Strategy to Evaluate the Collision Integral of the Boltzmann Equation," 16th International Symposium on Rarefied Gas Dynamics, Pasadena, CA, 1988.
- Hoffmann, K. A., Chiang, T. L., "Multi-Body Flow Interaction at Hypersonic Speeds," 11th U.S. National Conference of Applied Mechanics, Tucson, AZ, May 1990.
- Hoffmann, K. A., Chiang, T. L., and Wilson, D. E., "The Numerical Simulation of Exhaust Plume/Afterbody Interaction," 11th U.S. National Conference of Applied Mechanics, Tucson, AZ, May 1990.

2.3.4 Papers Presented at International Conferences

- Dolling, D. S. and Narlo, J. C., II, "Driving Mechanism of Unsteady Separation Shock Motion in Hypersonic Interactive Flow," AGARD CP 428, Conference on "Aerodynamics of Hypersonic Lifting Vehicles," Bristol, UK, 1987.
- Wilson, D., and Sheller, M. R., "The Effect of Unsteady Expansion and Compression Waves on a Compressible Boundary Layer," ASME Paper 88-GT-117, Gas Turbine Conference, Amsterdam, June 1988.

Dolling, D. S., "Review of Separation Shock Wave Dynamics in Supersonic Interactive Flows," presented at the Royal Aeronautical Society Conference, "The Prediction and Exploitation of Separated Flow," Apr. 1989. Published by R. Ae. Soc.

Dolling, D. S., "Unsteadiness of Supersonic and Hypersonic Shock-Induced Turbulent Boundary Layer Separation," presented at AGARD/VKI and NASA-Ames Special Course on "Three Dimensional Supersonic and Hypersonic Flows Including Separation," May 1989.

Wilson, D. and Hanford, A., "The Effect of Spatial and Temporal Nonuniformities on Stagnation Point Heat Transfer," ASME Gas Turbine Conference, Brussels, Belgium, June 1990.

Harlé, C., Varghese, P. L., and Carey, G. F., "Non-equilibrium Flow in an Arc Jet," Workshop on Hypersonic Flows for Reentry Problems – Part II, Antibes, France, Apr. 1991.

Gonzales, D. A. and Varghese, P. L., "Master Equation Calculations of Vibrational Non-Equilibrium and Dissociation Kinetics," presented at the IUTAM Symposium on Aerothermochemistry of Spacecraft and Associated Hypersonic Flows, Marseille, France, Sept. 1–4, 1992.

2.4 Continuing Education Program

Center faculty and staff were very active in continuing education. A brief summary of the activities is given below.

- Hypersonics Short Course, Oct. 1987, UT Austin (30 attendees)
- 1st Joint Europe/USA Short Course, Dec. 1987, Paris, France (200 attendees)
- Kelly AFB/AEDC NASP Logistics Program, 1987
- Introduction to CFD (through AIAA), April–Sept. 1988 (64 participants)
- Hypersonics Aerodynamics, Aug. 1989 (through AIAA)
- 2nd Joint Europe/USA Short Course, Jan. 1989, USAF Academy, Colorado
- Advanced CFD 1990 (through AIAA)

The national and international Hypersonics Short Courses were very successful. The last one, the Second Joint Europe/US Short Course in Hypersonics was held at the U.S. Air Force Academy in Colorado Springs from Jan. 16–20, 1989. This conference was jointly sponsored by The University of Texas at Austin, the United States Air Force Academy, and Groupe pour L'Avancement des Methodes Numeriques de L'Ingenieur-Societe de Mathematiques Appliquees et Industrielles. The course organizer was Dr. John Bertin. The speakers included:

- **R. R. Barthelemey** – Director, National Aerospace Plane Program
- **J. J. Bertin** – Professor of Engineering, The University of Texas at Austin
- **D. Dwoyer** – Manager, Hypersonic Technology Office, Langley Research Center (NASA)
- **P. Perrier** – Head, Aerodynamics Branch, Dassault Industries
- **C. Park** – Aerospace Technologist, Ames Research Center (NASA)
- **J. Warnatz** – Professor, the University of Heidelberg
- **C. Bruno** – CNR/CNPM
- **C. D. Scott** – Aerothermodynamics Group Leader, Johnson Space Center (NASA)

- **F. R. DeJarnette** – Professor of Mechanical and Aerospace Engineering, North Carolina State University
- **D. I. A. Poll** – Professor of Engineering, University of Manchester
- **K. F. Stetson** – Aerospace Research Engineer, Air Force Wright Aeronautical Laboratories
- **D. G. Arnal** – ONERA/CERT
- **J. G. Marvin and T. J. Coakley** – Experimental Fluid Mechanics Branch, Ames Research Center (NASA)
- **M. Lesieur** – Professor, University of Grenoble
- **G. Koppenwallner** – DFVLR
- **J. N. Moss** – Aerospace Technologist, Langley Research Center (NASA)
- **H. Neunzert** – Professor, Universitaet Kaiserslautern
- **P. Morice** – Head, Aerodynamics Branch, ONERA – Chatillon
- **W. D. Goodrich** – Special Assistant to the Director of Aerodynamics, NASA Headquarters
- **J. Wendt** – Professor and Head of Aeronautics, von Karman Institute
- **J. Periaux** – Chief, Numerical Analysis Group, Dassault Industries
- **C. P. Li** – CFD Group Leader, Johnson Space Center (NASA)
- **M. Linde** – Head of the Applied Fluid Dynamics Section F.F.A. (the Aeronautical Research Institute of Sweden)
- **R. W. MacCormack** – Professor, Stanford University
- **R. D. Neumann** – Technical Manager for Aerothermodynamics Air Force Wright Aeronautical Laboratories

In addition, a Hypersonic Aerodynamics Short course was offered through AIAA, as well as Short Courses on CFD and Advanced CFD. Brief details follow below.

1. Hypersonic Aerodynamics

- Offered by: AIAA, August 1989
- Developed and directed by: John J. Bertin and Klaus A. Hoffmann. The course included the following topics:
 - Parameters defining hypersonic flows
 - The equations of motion for hypersonic flows
 - Wind tunnel simulations of hypersonic flows
 - Flow in the stagnation region
 - Two-layer techniques for computing hypersonic flows
 - Aerodynamic force and moment coefficients
 - Fundamental concepts of computational fluid dynamics
 - Application of CFD to hypersonic flowfields

2. Introduction to Computational Fluid Dynamics

- Offered by: AIAA (Professional Study Series: Home Study Course)
- Developed and directed by: Klaus A. Hoffmann. The course included the following topics.
 - Classification of partial differential equations
 - Finite-difference equations
 - Parabolic partial differential equations
 - Stability analysis
 - Elliptic partial differential equations
 - Hyperbolic partial differential equations
 - Scalar representation of the Navier-Stokes equation

3. Advanced Computational Fluid Dynamics

- Offered by: AIAA (Professional Study Series: Home Study Course)
- Developed and directed by: Klaus A. Hoffmann. The course included the following topics:
 - Grid generation
 - Transformation of the equations of fluid motion from physical space to computational space
 - Euler equations

During the period of the grant, a large number of seminar speakers were invited to UT-Austin to give formal lectures or participate in classroom discussion. A sampling is given below.

1. *State of the Art Measurements in Supersonic and Hypersonic Wind Tunnels*: Bill Yanta, Aerodynamic Technology Group, Naval Surface Weapons Center
2. *Research in Nonequilibrium Chemistry and Transition for Hypersonic Flows*: Michele Macaraeg, NASA Langley Research Center
3. *A Defect Stream Function, Law of the Wall/Wake Method for Turbulent Boundary Layer*: Richard W. Barnwell, NASA Langley Research Center
4. *Overview of Hypersonic Research Program at NASA Langley*: G. Burton Northam, Hypersonic Propulsion Branch – NASA Langley Research Center
5. *Hypersonic Boundary Layer Transition*: K. Stetson, AFWAL
6. *Hypersonic Stability and Transition*: Ged Gasperas, Computational Methods Branch, Calspan-AEDC Division

Additional “informal” presentations:

7. J. Periaux, Dassault Industries, France
8. R. Glowinski, University of Houston

3 SUMMARY

Over the period of this grant (1986–92), 23 graduate students were supported by the Center and received education and training in hypersonics through MS and Ph.D. programs. An additional 8 Ph.D. candidates and 2 MS candidates, with their own fellowship support, were attracted to The University of Texas and recruited into the hypersonics program because of the Center. Their research, supervised by the 10 faculty involved in the Center, resulted in approximately 50 publications and presentations in journals and at national and international technical conferences. To provide broad-based training, a new hypersonics curriculum was created, enabling students to take 8 core classes in theoretical, computational, and experimental hypersonics, and other option classes over a two to four semester period. The Center also developed an active continuing education program. The Hypersonics Short Course was taught 3 times, twice in the USA and once in Europe. Approximately 300 persons were attracted to hear lectures by more than 25 of the leading experts in the field. In addition, a hypersonic aerodynamics short course was offered through AIAA, as well as short courses on CFD and Advanced CFD. The existence of the Center also enabled faculty to leverage a substantial volume of additional funds from other agencies, for research and graduate student training. Overall, this was a highly successful and highly visible program.