The Center of Excellence for Hypersonics
Training & Research

at

The University of Texas at Austin

Final Report

Prepared by

David S. Dolling, Director

NASA Grant NAGW-964

April 1993
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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 threefold: (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.

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

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).

<table>
<thead>
<tr>
<th>Name</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryan Sehlke</td>
<td>MS</td>
</tr>
<tr>
<td>Todd Sterk</td>
<td>MS</td>
</tr>
<tr>
<td>Steven Doerr</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Douglas Cline</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Hans Baade</td>
<td>MS</td>
</tr>
<tr>
<td>Leon Brusniak*</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Nancy Mayer*</td>
<td>MS</td>
</tr>
<tr>
<td>Robert Nordyke</td>
<td>MS</td>
</tr>
<tr>
<td>Michael Sheller</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Charles Hamburger</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Eric Koss*</td>
<td>MS</td>
</tr>
<tr>
<td>Berry Gibson</td>
<td>MS</td>
</tr>
</tbody>
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* work still in progress
<table>
<thead>
<tr>
<th>Name</th>
<th>Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael Schwartz</td>
<td>MS</td>
</tr>
<tr>
<td>Kurt Hoover</td>
<td>MS</td>
</tr>
<tr>
<td>Spencer Swift</td>
<td>MS/Ph.D.</td>
</tr>
<tr>
<td>David Fritz</td>
<td>MS</td>
</tr>
<tr>
<td>Anthony Hanford</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Steven Bova</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Alan Stagg</td>
<td>Ph.D.</td>
</tr>
<tr>
<td>Taunya Boitnott</td>
<td>MS</td>
</tr>
<tr>
<td>John Schmisseur</td>
<td>MS</td>
</tr>
<tr>
<td>Steven Petullo</td>
<td>MS</td>
</tr>
<tr>
<td>Steven Ward</td>
<td>Ph.D.</td>
</tr>
</tbody>
</table>

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”
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”
10. Charles Hamburger (Ph.D.) “Numerical Computation of a Mixing Layer by a Method of Successive Approximations”
11. Eric Koess (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”
14. Kurt Hoover (MS) “Chemically Reacting Hypersonic Aerodynamics”


17. Antony Hanford (Ph.D.) “Augmentation of Stagnation Point Heat Transfer by Quasi-Periodic Freestream Fluctuations”


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 Schmisseur (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”


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.

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

Their research topics are listed below.

1. Walter Rutledge (Ph.D.) “High Altitude Hypersonic Aerodynamics of Blunt Bodies”


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


### 2.3.2 Papers Presented at National AIAA Conferences


2.3.3 **Papers Presented at Other National Technical Conferences**


2.3.4 **Papers Presented at International Conferences**


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. Barthelemy – 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


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.