JOINT INSTITUTE FOR ADVANCEMENT OF FLIGHT SCIENCES

FINAL REPORT

EXPERIMENTS IN THE THERMAL AND FLUID SCIENCES (NCC1-217)

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ABSTRACT

Experiments were designed, implemented, and evaluated in the thermal and fluid sciences at the NASA Langley Research Center. This research was conducted cooperatively with NASA employees using, where necessary, equipment and facilities provided by the U.S. Government. The research fell within the scope of the University Agreement between the NASA Langley Research Center and The George Washington University for Joint Research and Education Projects dated June 7,8, 1994, which continues the Joint Institute for the Advancement of Flight Sciences (JIAFS).

BACKGROUND

The National Aeronautics and Space Administration has, from its inception, recognized the need for close association and interaction with universities. Through its efforts in university-related programs, NASA has been instrumental in creating centers of excellence and has helped to accelerate the growth of new departments and new graduate programs. The reasons for such activities stem partly from the Space Act which encourages and fosters NASA participation with the scientific and academic communities and partly from national needs. Thus, NASA academic programs help create new knowledge, assist universities in their growth, benefit industry by increasing the number and quality of trained engineers and scientists, and give an impetus to NASA scientific missions through two-way transfer of knowledge between NASA and the universities.

The Langley Research Center (LaRC) joined with The George Washington University's (GW) School of Engineering and Applied Science (SEAS) in 1971 to create the Joint Institute for Acoustics and Flight Sciences. In 1976 the name was changed to Joint Institute for Advancement of Flight Sciences to reflect the expanded research and academic activities. This jointly operated Institute is dedicated to increasing the nation's research and engineering capabilities in technical fields related to the NASA mission. In 1994 this relationship was extended by a new University Agreement between the NASA LaRC and GW. This agreement reiterates that one of the purposes of the JIAFS is to maximize beneficial interaction among LaRC researchers and GW faculty and students through the joint coordination and supervision of student projects.

The Institute, which is located at the NASA-LaRC, also provides a center for advanced research by bringing together researchers and scholars for the exchange of ideas and findings. Furthermore, it is also the purpose of the Institute to provide the necessary facilities for qualified researchers and scholars who want to engage in research relevant to national needs.

The research opportunities offered in the Institute uniquely combine the academic resources of the university and the professional staff and the extensive scientific and engineering equipment and facilities at the LaRC. Visiting research scientists and engineers also have the opportunity to associate closely with LaRC engineers and scientists, faculty and other visiting members who are conducting research on related problems.

The Graduate Research Scholar Assistants (GRSA) are enrolled in the Master of Science (MS) or the Doctor of Science (DSc) program of the SEAS at Langley under the direction of and in close association with the PI and a NASA researcher. The program of research and study leading to the MS degree requires about two years for completion while the DSc program normally requires about three years after completion of a Masters degree. The GRSAs can apply themselves to important and necessary research, study in courses related to their research, associate with classmates who are conducting research on related problems, and also have the opportunity to meet and learn from accomplished NASA engineers and scientists. The close association of students, teachers, and practicing scientists and engineers in the consideration of "real world" research problems has generated a shared community of interest that emphasizes and underscores the uniqueness of this successful approach.

STATISTICAL SUMMARY

The program began in September 1995 and was funded through November 1999 with awards totaling $560,654 (Appendix 1). During this period, there have been 7 GRSA supported along with a portion of the PI's time (Appendix 2). Of these GRSA, 3 have completed advanced degrees and 2 are still enrolled as students. The theses produced by these students and 13 publications and presentations produced under the support of the Cooperative Agreement are listed in Appendix 3.

RESEARCH DETAILS

Hypersonic Airbreathing Propulsion Research

Research in scramjet combustor fundamentals and diagnostics was conducted in support of the programs of the Hypersonic Airbreathing Propulsion Branch (HAPB), jointly and in consultation with Branch personnel. Experiments in HAPB facilities, including the Transverse Jet Facility (TJF), the Direct-Connect Supersonic Combustion Test Facility (DCSCTF), and the associated diagnostics laboratories, were planned, executed, and the results from these experiments were analyzed.

Research was conducted in the following areas:

- Two experiments were conceived and implemented to obtain high quality flow field data for the development and validation of computational fluid dynamics (and other) codes to be used in the design of supersonic combustion ramjet (scramjet) engines. In the first experiment, data were acquired in a supersonic coaxial jet in which a Mach 1.8 central jet of helium mixes with a Mach 1.8 coannular jet of air. Data acquired in this flow have been used to test turbulence models used by the VULCAN and SPARK codes. In the second experiment, both probe-based and non-intrusive (laser based) techniques have been developed and applied to a simple supersonic combustor in which hydrogen is injected from the wall at 30 degrees into and burns in a Mach 2 ducted flow of vitiated air of Mach 7 enthalpy. This research is still in progress.

• Scaling and similarity issues in supersonic combustor testing were investigated, especially the simulation of flight combustor thermodynamics in tests utilizing hydrogen- or methane-combustion vitiated air. Techniques developed allow the optimal specification of facility operating conditions for simulation of flight.

• Scramjet fuel injector concepts for minimum combustor length were investigated. Injectors utilizing pitched and skewed swirling jets were designed and used to inject helium into a Mach 2 ducted air flow. Injectant mixing was evaluated by obtaining flow field surveys using pitot and gas sampling probes. In addition, an injector which creates a high frequency pulsed jet has been developed for future evaluation.

The following GWU students were associated with this work: Atherton Carty (MS, supported by another grant), Steven Doerner (MS), Gregory Harding (MS candidate), Marcie Kam (MS candidate), Ron Springer (DSc candidate).

Aerothermodynamics Research

Research was conducted in conjunction with the Aerothermodynamics Branch on the "3ω" technique for measuring the thermal conductivity of films and solids. The specific objective was to develop a probe suitable for determination of the thermal conductivity of surface layers of ceramic models used in aerothermodynamic testing.

The following GWU student was associated with this work: Robert Fangmeier (MS candidate).

Environmental Interactions Research

The efficiency (actuator output power versus transmitter input power) and viability of microwave-driven smart material actuators utilizing rectennas and piezoelectric materials was established. Such actuators are potentially simpler (less wiring) and lighter than hard-wired actuators in space telescope applications which require thousands of discrete actuators to effect high precision distributed shape control of the primary reflector.

In a second project, experimental facilities were developed to test laser diode submounts utilizing high thermal conductivity carbon-carbon composite materials. Such submounts, because of their better thermal performance, should provide better laser beam quality and stability than those of conventional materials. Applications include space deployable LIDAR and Micro-LIDAR systems.

The following GWU student was associated with this work: Mia Kwak (MS and Professional Degree candidate).

APPENDIX 1

Summary of Awards and Dates for NCC1-217

Sep 11, 1995	New Co-operative Agreement - Funding period: 09/11/95 - 03/10/96 $36,820
Feb 20, 1996	Continuation - 03/11/96 - 03/10/97 (Suppl # 1 $113,339)
Mar 13, 1997	Continuation - 03/11/97 - 03/10/98 (Suppl # 2 $74,352)
Jun 3, 1997	Supplemental funding - 03/11/97 - 03/10/98 (Suppl # 3 $7,322)
Dec 9, 1997	Incremental funding - 12/03/97 - 03/10/98 (Suppl # 4 $60,329)
Apr 14, 1998	Supplemental funding - 03/11/98 - 04/14/98 (Suppl # 5 $6,595)
May 14, 1998	Continuation - 04/15/98 - 04/14/99 (Suppl # 6 $96,584)
Jan 29, 1999	Incremental funding - 01/29/99 - 03/10/99 (Suppl # 7 $52,273)
May 19, 1999	Renewal - 03/11/99 - 11/30/99 (Suppl # 8 $101,838)
Feb 10, 2000	Deobligation of Funds - eff: 02/08/00 - exp: 11/30/99 (Suppl # 9 <$8,798>)
Nov 30, 1999	NCC1-217 expiration date

APPENDIX 2

Summary of Personnel for NCC1-217
and GRSA Employment Upon Graduation

PERSONNEL

Academic Year 95-96 - Faculty: A. D. Cutler

Students
Ronald R. Springer
Jason E. Quinn

Academic Year 96-97 - Faculty: A. D. Cutler

Students	Graduates
Steven E. Doerner	Jason Quinn
Ronald R. Springer	

Academic Year 97-98 - Faculty: A. D. Cutler

Students	Graduates
Steven E. Doerner	
Robert J. Fangmeier	
Ronald R. Springer	

Academic Year 98-99 - Faculty: A. D. Cutler

Students	Graduates
Steven E. Doerner	Steven E. Doerner
Gregory C. Harding	Mia Kwak/MS
Mia Kwak	
Ronald R. Springer	

Academic Year 99-00 - Faculty: A. D. Cutler

Students	Graduates
Gregory C. Harding	
Marcie S. H. Kam	
Mia Kwak	
Ronald R. Springer	

GRSA - EMPLOYMENT UPON GRADUATION

Jason E. Quinn	97	Dynamic Engineering Inc, Newport News, VA
Steven E. Doerner	99	Raytheon System Co, Tucson, AZ
Mia Kwak	99/MS	GW/JIAFS (Prof)
Ronald R. Springer	pending/DSc	Lockheed Martin Launching Systems, Baltimore, MD

APPENDIX 3

Summary of Publications, Presentations and Theses for NCC1-217

PUBLICATIONS/PRESENTATIONS

D. K. Kraus and A. D. Cutler, "Mixing of Swirling Jets in a Supersonic Duct Flow." Published: Journal of Propulsion and Power, Vol. 12, No. 1, pp. 170-177, January-February, 1996.

J. E. Quinn, A. D. Cutler, and G. B. Northam, "Drag Reduction of Supersonic Cavities via Mass Injection with Applications to Scramjets." Presented: 35th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, January 6-10, 1997. Published: AIAA Paper 97-0550.

A. D. Cutler and C. H. Johnson, "Analysis of Intermittency and Probe Data in a Supersonic Flow with Injection." Published: Experiments in Fluids, 23, pp. 34-47, Springer-Verlag, 1997.

A. D. Cutler, "Specification of Combustor Entrance Conditions in Ground-Based Scramjet Testing." AIAA Paper 98-0710, 36th Aerospace Sciences Meeting, Reno, NV, Jan. 12-15, 1998.

A. D. Cutler, "Specification of Model Entrance Conditions for Scramjet Testing in Vitiated Air." Published: AIAA Journal, Vol. 36, No. 7, July 1998, pp. 1200-1207.

S. H. Choi, S-H. Chu, M. Kwak, and A. D. Cutler, "A Study on a Microwave-Driven Smart Material Actuator." Presented: SPIE 6th Annual International Symposium on Smart Structures and Materials, Newport Beach, CA, March 1-4, 1999. Published: Proceedings of the SPIE, Smart Structures and Integrated Systems, SPIE, Vol. 3668, March 1-4, 1999, pp. 853-859.

R. R. Springer, A. D. Cutler, G. S. Diskin, M. W. Smith "Conventional/Laser Diagnostics to Assess Flow Quality in a Combustion-Heated Facility." Presented: 35th AIAA/ASME/SAE/ ASEE Joint Propulsion Conference and Exhibit, Los Angeles, CA, June 20-24, 1999. Published: AIAA Paper-99-2170.

A. D. Cutler, A. A. Carty, and S. E. Doerner, G. S. Diskin, J. P. Drummond, "Supersonic Coaxial Jet Experiment for CFD Code Validation." Presented: 30th AIAA Fluid Dynamics Conference, Norfolk, VA, June 28-July 1, 1999. AIAA Paper 99-3588.

S. H. Choi, S-H. Chu, M. Kwak, A. D. Cutler, and K. D. Song, "Microwave-Driven Smart Material Actuators." Presented: 34th Intersociety Energy Conversion Engineering Conference, Vancouver, British Columbia, Canada, August 1-5, 1999.

S-H. Chu, S. H. Choi, M. Kwak, A. D. Cutler, and K. D. Song, "Smart Material Actuator Driven by Networked Rectenna Array." Presented: 34th Intersociety Energy Conversion Engineering Conference (IECEC), Vancouver, Canada, August 2-5, 1999. Published: Proceedings of the Meeting, IECEC. Published: Paper No. 1999-01-2646.

S. H. Choi, U. N. Singh and A. D. Cutler, "Development of Hot Diodes With New Thermal Dissipating Submount." Presented: Conference on Lasers and Electro-Optics/Pacific Rim, 1999, Seoul, Korea, August 30-September 3, 1999.

A. D. Cutler and R. W. Barnwell, "Vortex Flow in a Convergent-Divergent Nozzle." Published: AIAA Journal, Vol. 37, No. 10, October 1999, pp. 1329-1331.

A. A. Carty and A. D. Cutler, "Development and Validation of a Supersonic Helium-Air Coannular Jet Facility." Published: NASA/CR-1999-209717, November 1999.

S. E. Doerner and A. D. Cutler, "Effects of Jet Swirl on Mixing of a Light Gas Jet in a Supersonic Airstream." Published: NASA/CR-1999-209842, December 1999.

THESES

"Effects of Mass Injection on Supersonic Cavity Drag with Applications to Scramjets," J. E. Quinn, Summer 1997.

"Development of Microwave-Driven Smart Material Actuators," M. Kwak, Spring 1999.

"Effects of Jet Swirl on Mixing of a Light Gas Jet in a Supersonic Airstream," S. E. Doerner, Spring 1999.