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19. ABSTRACT (Continue on reverse if necessary and identify by block number) The Penn State Gas Dynamics Lab has an active, ongoing program in experimental high-speed fluid dynamics research. The current research of the Laboratory, sponsored by AFOSR, ONR, and NASA, concerns supersonic viscous/inviscid interactions, compressible turbulent mixing, and high-speed vortex dynamics pertaining to external and internal aerodynamics and propulsion. The Laboratory specializes in development and use of advanced, non-intrusive optical flow diagnostics in such research studies. These optical instruments and techniques are brought to bear on basic fluid dynamic experiments in the Penn State Supersonic Wind Tunnel, which has a high Reynolds number capability and a continuously-variable Mach number range of Mach 1.5 to 4.0. This grant extends the non-intrusive optical flow diagnostic tools of the Gas Dynamics Laboratory by adding the following major capabilities: 1) high-speed data acquisition of optical signals, and 2) high-speed pulsed-laser light-screen imaging. With this equipment, the Lab is in a much better position to carry out current research related to DOD interests, develop new DOD-related research, and educate students in advanced experimental fluid dynamics. The (over)			
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equipment provided by the grant has been purchased and implemented in the Laboratory. This equipment is already having a significant positive impact on our ability to perform research related to DoD interests.

This report provides a detailed list of the equipment actually purchased under the subject grant, along with justification of minor variations from the budget. A concise summary is also given of current DoD related research in the Gas Dynamics Laboratory, which is benefitting from this equipment grant.

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OVERVIEW

The Penn State Gas Dynamics Lab is one of the very few academic laboratories in the US with an active, ongoing program in experimental high-speed fluid dynamics. The current research of the Laboratory, sponsored by AFOSR, ONR, and NASA, concerns supersonic viscous/inviscid interactions, compressible turbulent mixing, and high-speed vortex dynamics pertaining to external and internal aerodynamics and propulsion. The reputation of the Penn State Gas Dynamics Lab is built upon the development and use of advanced, non-intrusive optical flow diagnostics such as the Laser Interferometer Skin Friction Meter. This and other optical instruments and techniques are brought to bear on basic fluid dynamic experiments in the Penn State Supersonic Wind Tunnel, which has a high Reynolds number capability and a continuously-variable Mach number range of Mach 1.5 to 4.0.

The proposal which led to the subject Grant aimed to extend the non-intrusive optical flow diagnostic tools of the Gas Dynamics Laboratory by adding the following major capabilities: 1) laser-Doppler velocimetry, 2) high-speed data acquisition of optical signals, 3) high-speed pulsed-laser light-screen imaging, and 4) digital image processing. With this equipment, it was proposed that the Gas Dynamics Lab would be in a much better position to carry out current research related to DOD interests, develop new DOD-related research, and educate students in advanced experimental fluid dynamics.

Due to DoD budgetary constraints, the first and last items in the above list, laser-Doppler velocimetry equipment and digital image processing, were not approved in the subject Grant. However, the other items were approved and have been purchased and implemented in the Laboratory. This equipment is already having a significant positive impact on our ability to perform research related to DoD interests.

In the following section, a detailed list is given of the equipment actually purchased under the subject Grant. This list is essentially equivalent to that included in the original Grant, with minor variations. These variations are listed and accounted for in a subsequent section of the Report. Finally, a concise summary is given of current DoD and related research in the Gas Dynamics Laboratory which is benefitting from this equipment grant.

EQUIPMENT PURCHASED

Quantity	Vendor	Item	Price
Schlieren-Quality Gasss Wind Tunnel Windows:			
4ea	Glass Fab Inc.	BK-7 NH-2 polished Schlieren windows	\$ 2,991.40
Copper-Vapor Laser:			
1ea	CJ Laser Corp.	CU Vapor Laser, setup, 1 yr. warranty	37,000.00
High-Speed, Multi-Channel Data Acquisition System			
1ea	LeCroy Corp.	High-speed multi-channel data acquisition System	23,477.35
1ea	LeCroy Corp.	32 channel 12 bit digitizer & (2 ea) 12 bit memory	5,467.23
1ea	Cumberland Elect.	Rack mount - to house Lecroy system	1,140.30
1ea	Asyst Software	Asyst Software package	1,717.48
1ea	Asyst Software	1 Year warranty package	295.00
1ea	Master Computer	AT 386	3,705.00
1ea	Hewlett Packard	Laserjet II printer	2,169.75
Telemicroscope			
1ea	Questar	Questar DR-1 (vider vers) telemicroscope	9,142.50
High-Speed Video Recording Tapes			
1ea	Spin Physics	High speed video cassetts	1,350.00
Optical Parts			
	Hamamatsu Co.	Photo Multiplier Tube	307.00
	Pacific Inst.	PMT Housing, Cable	223.46
	Space Glass	Apollo Lamps	566.95
	Hai Tech Electro Optics	Energy meter for pulsed ruby laser; 3" flash lamp; 6" flash lamp	1,977.75
	Newport Corp.	High speed photodetector w/optical fiber; cable	1,107.04
	Newport Corp.	2" spherical lenses w/3, 4, & 5" FL; 2 cylindrical lenses	777.60
	George W. Gates Co	End view optical glass	338.05

Quantity	Vendor	Item	Price
Optical Parts Con't			
	Edmund Scientific	Achromat lenses; ring mounts; light meter; beam detector; various filters	1,327.50
	47th St. Photo	Minolta camera bodies	723.80
	A. Jaegers	2ea. 6" Achromat lenses	2,018.81
	CVI Laser Co.	Beam splitters	1,238.56
	Ealing Elect-Optics	Trans/Vert. slides; misc. mounts	2,822.45

CHANGES IN THE EQUIPMENT LIST

Items Purchased but not Proposed

1)	Midwest Communications	Hercules Tripod	2,078.00
2)	Optical Apparatus Co.	DAGE-MTI 86 Series Camera	3,815.00
3)	Controlomatic Corp.	High Mass Flow Regulator	535.94
4)	MMI (Intel)	Visual Edge II expansion board	431.00
5)	47th St. Photo	S-VHS Video Deck	655.00
6)	Webco Controls	Transmation Voltage Calibrator	498.22
7)	Global Computer Sup.	LaserDesk for AT Computer	550.70
8)	Stanford Research Systems	Dual Channel, programmable low-pass filter	3,004.54
9)	Pacific Instruments	Digital rack mount, power support	795.26
			<u>\$114,248.64</u>

Items Proposed but not Purchased

Neslab Instruments Inc.	Laser Recirculative Cooler	5,450.00
Newport Corporation	Vibration-Isolating Optical Table	5,440.00

DISCUSSION OF CHANGES IN THE EQUIPMENT LIST

The two items budgeted but not purchased, ie the laser recirculative cooler and the vibration-isolation optical table, amount to support equipment for the major items purchased and listed earlier. As it turned out, the funds earmarked for these two items were, in fact, spent for similar support equipment, but not the equipment originally budgeted. The reason for this is as follows: The environment of experimental research is dynamic and in a constant state of flux, with new electronic and optical capabilities becoming available almost on a monthly basis. When proposing equipment for which funds may not be available for about a year, it is not possible to anticipate such a situation exactly. Further, major equipment items like the laser and data acquisition system acquired here invariably require ancillary equipment items in order to function optimally. Often these ancillary items are not known *a priori*, and can only be specified during the setup phase of the major equipment installation. Such was the case here. Although the recirculative cooler and optical table were serious equipment needs (and still are) in the Laboratory, they were superceded in precedence by the alternate support equipment listed above in order to achieve full functionality of the major equipment items of the Grant. Thus items 1)-5) above constitute optically-related support equipment required in order to apply the copper-vapor laser to the experimental research at hand. Similarly, items 6)-9) were required in order to put the high-speed data acquisition system to use. These changes are under 10% of the total Grant budget, the other 90% having been spent as budgeted. Even so, these changes are believed to be fully within the spirit of the Grant.

SUMMARY OF RESEARCH PROJECTS ON WHICH EQUIPMENT IS BEING USED

Two DOD agencies, AFOSR and ONR, currently support research in the Penn State Gas Dynamics Lab. These research studies are briefly described below.

AFOSR Grant 86-0082

"Experimental Research on Swept Shock Wave/Turbulent Boundary Layer Interactions"

PI: Prof. Gary S. Settles

Program Manager: Dr. Len Sakell

In effect since: April, 1986

Yearly funding level: \$98,000

The structure of the viscous/inviscid interactions of swept shock waves and boundary layers is explored and mapped in this study. 3-D holographic interferometry and high-speed conical shadowgraphy are the key non-intrusive tools employed. A better understanding of the behavior and potential for control of these crucial interactions is being gained in this work. Detailed skin friction distributions are also being obtained using the Laser Interferometer Skin Friction Meter for high-speed flows, which was developed in our Laboratory. Significant results obtained in this research include:

- * The effect of Mach number on swept interactions (AIAA Paper 87-1365)
- * Skin friction validation of Navier-Stokes codes (AIAA Papers 88-0497 and 90-0378)
- * The jet-impingement structure of swept interactions (AIAA Papers 88-3803 and 89-1849)

ONR Contract N00014-88-K-0242

"Mixing Control in a Supersonic Shear layer"

PI's: Profs. G. S. Settles, P. J. Morris, & D. K. McLaughlin

Program Manager: Dr. Spiro G. Lekoudis

In effect since: February, 1988

Yearly funding level: \$130,000

The characterization, control, and enhancement of supersonic turbulent mixing is addressed in this research study. Optical flow diagnostics are applied to measure the mixing rates of both axisymmetric and planar mixing layers over a broad Mach number and Reynolds number range. Acoustic excitation and unsteady shock wave interaction are then applied to influence the mixing rate, particularly to increase it. A parallel analytical effort aims to better understand supersonic mixing and its modification by way of a wave-model analysis. This study concerns one of the most important limiting factors in high-speed propulsion.

Current Non-DOD Research

Three current NASA-supported research studies in the Gas Dynamics Lab also directly concern DOD research interest. Brief descriptions of these studies follow:

NASA-Ames Grant NAG 2-592

This effort explores the heat transfer phenomenon in swept shock/boundary layer interactions. The Grant is currently funded at \$55,000 in its second year. Prof. Gary S. Settles is Principal Investigator. The Grant Monitor is Dr. C. C. Horstman. Dr. Horstman is carrying out numerical solutions of the Navier-Stokes equations for comparison with our experimental results. A key goal of this research is to define the experimentally-observed heat transfer phenomenon more clearly in both its mean and fluctuating character.

NASA-Ames Grant NAG 2-575

This research effort is a highly exploratory study of the phenomenon of shock wave interaction with a vortex. A supersonic vortex generator has been fabricated and mounted on the supersonic wind tunnel test section centerline. Experiments are now in progress to define the vortex using a 5-hole yaw probe, and to observe its interaction with a shock wave using optical diagnostics. This Grant is funded at the \$60,000/year level. PI: Prof. Gary S. Settles. Grant Monitor: Dr. C. C. Horstman.

NASA-Langley Grant NAG-1-872

Supersonic mixing enhancement by vortex breakdown is explored in this research study, which has direct application in high-speed SCRAMJET propulsion. An axisymmetric supersonic vortex is generated along the axis of the supersonic wind tunnel. Vortex breakdown is promoted by way of the adverse pressure gradient due to a normal shock wave. The resulting mixing behavior of air, heated air, and helium is then explored by way of non-intrusive optical flow diagnostics.

NASA-Langley Grant NAG-1-1070

An experimental study of the sources of fluctuating pressure loads beneath swept shock/boundary-layer interactions, this study begins in early 1990. The P.I. is Prof. G. S. Settles and the Grant Monitor is Dr. W. E. Zorumski.