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13. ABSTRACT (Maximum 200 words)

This report describes the equipment purchased under ARO Research Instrumentation Grant No. DAAD19-01-1-0692. This equipment is used to support the ARO research program entitled “Experimental Studies of High-Speed Separated Flows” (ARO Grant No. DAAD19-01-1-0367). The equipment purchased is used to make Rayleigh/Mie scattering, planar laser-induced fluorescence, particle image velocimetry, pressure-sensitive paint, and conventional pressure-tap measurements in high-speed flows with embedded separated regions. The specific pieces of equipment, vendors, and purchase prices are detailed.

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FINAL PROGRESS REPORT

Research Instrumentation for Measurements of High-Speed Separated Flows

ARO Grant No. DAAD19-01-1-0692

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Introduction

The purpose of the subject instrumentation grant was to purchase equipment to be used in conjunction with an ongoing ARO-funded research grant entitled "Experimental Studies of High-Speed Separated Flows" (Grant No. DAAD19-01-1-0367; Proposal No. 41642-EG). The research efforts of this program are focused on experimental investigation of the fluid dynamic mechanisms and interactions within separated flow regions embedded in high-speed compressible flows. In particular, the fundamental objective of this program is to improve understanding of the detailed flow processes in the near-wake of missile and projectile-type base flows with the long-term goal of optimizing and controlling these flows to derive flight vehicle performance benefits. The funds were used to repair the heads of two Nd:YAG lasers that we use heavily in our PIV (particle image velocimetry), Rayleigh/Mie scattering, and PLIF (planar laser-induced fluorescence) experiments. These replacements/repairs will extend the lives of these lasers for at least five years, which is a much more cost-effective alternative than replacing them. We also used the equipment funds for purchase of an intensified CCD array camera system that may be used for experiments with low signal levels, *e.g.*, for ongoing acetone PLIF experiments. Finally, the funds were used to purchase a state-of-the-art pressure transducer calibration dead-weight tester. In all cases, purchase of this equipment will help to maintain and strengthen our ability to make significant contributions to the research area of compressible, separated flows, which is of significant importance to the U.S. Army.

Brief Description of Equipment Purchased

The equipment purchased is described on an item-by-item basis below. A corresponding budget, listing the costs of each piece of equipment, is also attached.

Nd:YAG Laser Upgrade

In the Gas Dynamics Laboratory, we have two Continuum YG681C-10 Nd:YAG lasers that were purchased under ARO DURIP support in 1989. These lasers have been used heavily over the intervening years in our experiments on high-speed separated flows. In particular, they have been used in the PIV experiments that formed the basis of the Ph.D. theses by M.J. Molezzi and M.G. Olsen and in the Rayleigh/Mie scattering experiments that were the subject of the Ph.D. theses of K.M. Smith and C.J. Bourdon. Thus, these lasers have logged thousands of hours of use and millions of laser shots.

As might be expected for such heavily used pieces of equipment, careful maintenance must be done to keep these laser systems in proper working condition. Recently, we had a seal between the head packing and rod cooling system fail on one of the lasers, so that it would not lase when powered up. The cause of the problem was simply degradation over time of the seal material. We replaced the seal using equipment funds from an existing grant, and it is now in good working condition. However, we also needed to replace the seal on the other YG681C system, as failure of it was imminent. We used equipment funds from the subject grant to purchase and replace the seal on the second laser. We emphasize that the new seals have an improved design so that they will never fail, even under extended usage.

The new laser head seals have upgraded our two existing YG681C Nd:YAG lasers to a "nearly new" condition. Since the replacement cost of these lasers is on the order of $150K, the funds utilized for refurbishment were a very cost-effective solution for maintaining our ability to do PIV, Rayleigh/Mie scattering, and PLIF experiments in high-speed base flows.

Intensified CCD Camera System

For many years, we have performed Rayleigh/Mie scattering, pressure- and temperature-sensitive paint (PSP and TSP), and coherent anti-Stokes Raman scattering (CARS) experiments in conjunction with our ARO-supported program on high-speed separated flows. In each of these cases, the signal levels are high, so that we have used *unintensified* Photometrics (now Roper Scientific) digital CCD cameras to acquire the corresponding images. These cameras are thermoelectrically cooled and have very low noise, making them excellent choices for high signal-level applications.

However, in a recent set of experiments in the Ph.D. thesis work of C.J. Bourdon, we began to investigate the mixing characteristics in the near-wake of a cylindrical afterbody immersed in supersonic flow. In these experiments, mass was bled through the base into the near-wake, *i.e.*, we performed base-bleed experiments. Gaseous acetone was seeded into the bleed flow and was excited with a quadrupled (266 nm) Nd:YAG laser sheet. The resulting broadband fluorescence images were recorded with one of our Photometrics unintensified CCD systems. Unfortunately, the signal level for these acetone PLIF experiments is quite low. In fact, the side-view images in these base-bleed mixing experiments utilized only 4% of the dynamic range of the unintensified CCD array. Worse yet, oblique end-view images, which are necessary to understand the full unsteady, three-dimensional nature of the instantaneous mixing field, could not be obtained at all due to the low signal level.

In order to be able to obtain these acetone PLIF images of the base-flow mixing field, we used funds from the subject instrumentation grant to purchase an *intensified* CCD camera system from Roper Scientific. Note that base-flow mixing is one of the three projects to be addressed in our current ARO-supported effort on supersonic separated flows. Therefore, purchase of this camera system is of critical importance to the success of that effort. The intensified camera system can also be used for filtered Rayleigh scattering (FRS) experiments that we are contemplating under this research program. In addition, the fast gating time of this intensified camera allows for precise timing of image acquisition in applications such as convective velocity measurements of turbulent structures. "Combinedmeasurement" experiments are also enabled in which, for example, PLIF images are obtained simultaneously with PIV measurements.

Pressure Calibration Dead-Weight Tester

Fundamental data that we obtain in all of our separated-flow experiments are surface pressure measurements on both the afterbody and base of our models. These measurements form a critical basis of comparison for computations of these flows by other research groups across the world in order to evaluate the predictive capabilities of their RANS, LES, and DNS numerical methodologies. Our surface-pressure measurements are made using either conventional strain-gage transducers or pressure-sensitive paint (PSP). In either case, accurate measurements require highly accurate calibration of the transducers, which, in turn, are used to calibrate the PSP measurements. Up until recently we were able to use a pressure-calibration system maintained by the Department of Mechanical and Industrial Engineering. Unfortunately, this system has become unreliable due to its extended lifetime and is no longer fit for use in applications demanding high accuracy, such as ours.

As a result of these circumstances, we used funds from the subject equipment grant to purchase a state-of-the-art dead-weight pressure calibration system. This equipment allows calibration of pressure transducers over the ranges of 1 – 30 inches Hg (vacuum) and 2 – 600 psig. The accuracy of the calibration measurements is guaranteed to be ±0.025% of the reading. The dead-weight tester includes a calibration certificate traceable to NIST; the factory calibration of the tester is carried out by highly trained, experienced staff in laboratories operating under ANSI/NCSL Z540-1 (MIL-STD-45662A) certified quality assurance procedures. The stainless steel non-magnetic weights draw upon over 70 years of knowledge and experience to provide easy-to-use, dependable pressure calibration.

Purchase of this equipment allows us to continue to make fundamental and highly accurate surface-pressure measurements in our high-speed separated flows.

Budget

A detailed budget, listing the equipment purchased, model numbers, vendors, and prices, is presented below.

Item		**Price**
Nd:YAG Laser Upgrade		
Part #507-0700	Head Assembly, 811-U06	$1,475
Part #507-0900	Head Assembly, 812-V09	$1,795
Part #504-7501 (2)	Base Plate Side Fittings, 711	$615
N/A	Labor and Installation	$5,658
Total		**$9,543**
Vendor:	Continuum Lasers 3150 Central Expressway Santa Clara, CA 95051-0816 Phone: (408) 588-4332	

Intensified CCD Camera System		
PI-MAX 512SB 18-GII-FG-SBLU-P43	Digital ICCD Camera System with: - 7361-0010 thermoelectrically cooled camera head - Thomson TH7895M scientific grade 1 CCD - 512 x 512 pixel format, front-illuminated CCD - 1.27:1 fiber-optic bonded 18 mm Grade 1 Super-Blue Gen II image intensifier - 19 x 19 μm pixels (12.4 x 12.4 mm image area) - <2 ns gating capable - TTL gating input - MCP bracket pulsing - P43 phosphor	$36,500
ST-133 Dual 16/100 16/1M PTG	7438-0001 ST-133 Camera Controller with: - Programming timing generator - Dual 16 bit, 100 kHz, 16 bit, 1 MHz A/D converter - 7323-0002 high-speed PCI interface package with 25' cable - 6050-0336 15' camera head cable	$5,500
WinView95-ICCD	4412-0046 Windows-based acquisition software including: - Software-controlled "safe mode" - Software-controlled temperature settings - Software-controlled intensifier gain	---

- Automatic linear/exponential box-car lifetime measurement mode
- Flexible sequence repetition/averaging
- Easy master/slave experiment timing synchronization

Less University discount	-$2,000
Total	**$40,000**

Vendor: Roper Scientific
3660 Quakerbridge Road
Trenton, NJ 08619
Phone: (612) 865-4945

Computer for ICCD Camera Control

2 GHz Pentium 4, 512 MB RAM, 80 GB hard disk, 17" monitor	**$2,237**

Vendor: Dell Computer Corp.
1 Dell Way
Round Rock, TX 78682
Phone: (800) 274-7799

Gas Dead-Weight Tester

6390-4L	Pneumatic Single-Piston DWT	$4,560
6410-4L	Vacuum Conversion Kit	$1,660
Total		**$6,220**

Vendor: TTI, Inc.
8 Leroy Road
Williston, VT 05495
Phone: (800) 884-4967

Total Equipment Costs $58,000

The University of Illinois at Urbana-Champaign, together with the principal investigator and graduate student researchers, sincerely appreciate this investment of ARO instrumentation funds in our research program.