N96- 15604

FLAME-VORTEX INTERACTIONS IMAGED IN MICROGRAVITY

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The scientific objective of this program is to obtain high quality color-enhanced digital images of a vortex exerting aerodynamic strain on premixed and nonpremixed flames with the complicating effects of buoyancy removed. The images will provide universal (buoyancy free) scaling relations that are required to improve several types of models of turbulent combustion, including KIVA-3, discrete vortex, and large-eddy simulations. The images will be used to help quantify several source terms in the models, including those due to flame stretch, flame-generated vorticity, flame curvature and preferential diffusion, for a range of vortex sizes and flame conditions. The experiment is an ideal way to study turbulence-chemistry interactions and isolate the effect of vortices of different sizes and strengths in a repeatable manner [1-5]. A parallel computational effort is being conducted which considers full chemistry and preferential diffusion [6].

The status of the project, which began eight months ago is as follows.

a) The Flame-Vortex Experiment to be dropped in the NASA 2.2 second drop tower has been constructed and has been transported to NASA Lewis for a safety inspection; a final safety clearance is pending. Drops are scheduled to begin in one month.

b) One-g baseline tests have been conducted which have yielded one hundred high resolution PIV images showing the time history of the velocity field for ten different vortex conditions; considerable improvements to the PIV diagnostics also were made. The flame-generated vorticity was imaged and some determinations of flame stretch rates were made.

c) A two-color white light PIV system that is suitable for the drop experiment was designed and is being tested. A second experiment to study nonpremixed flames is being designed; results will be compared to new modeling approaches developed by Dahm, et al. [7].

d) The numerical simulation effort has begun [6]; a graduate student (Fernando Costa) spent several months at The Naval Research Laboratory using the code FLAME1D

-DFLM93 to identify the effects of full chemistry and differential diffusion on unsteady diffusion flames. Plans have been made by Dr. Kailasanath to simulate some of the experiments.

The one-g baseline test results will be compared to the drop tower results in order to quantify the complicating effects of buoyancy, including the generation of baroclinic torques and the buoyancy-induced stabilizing mechanisms that inhibit flame wrinkling. The factors that are of primary interest are the unsteady physics of a vortex passing through the flame, and the flame curvature that is caused by the wrinkling process. It is now known that aerodynamic strain/stretch effects are not simply of academic interest but cause large, measurable changes in the burning velocity, local extinction, and the production of CO, NO and soot.

The Experimental Apparatus

The flame-vortex experiment to be dropped in the NASA 2.2 sec Drop Tower next month is shown in Fig. 1. The experiment is a rectangular tube of dimensions 10 cm by 10 cm by 60 cm. All four walls have Lexan shockproof windows. The chamber is filled with a lean premixed fuel air mixture; fuels to be used are methane, propane and hydrogen. A loudspeaker is pulsed to create a toroidal laminar vortex ring and the ignitor near the upper wall creates a flat, non-wrinkled laminar flame. There is sufficient time available during the 2.2 sec drop to observe the 90 millisecond interaction. The following diagnostic techniques will be employed for the premixed flame studies.

(i) <u>Temperature Field</u> 2-D Images	-to determine temperature profiles across the flames, heat losses, and to identify local quenching- using an array of 50 Thin Film Pyrometers and video camera
(ii) <u>Flame Shape, Curvature</u> Images	-using Mie scattering from oil drops, a white light sheet, a CCD camera; flame emission is imaged on a 16 mm movie camera
(iii) PIV Images of <u>Strain Field</u> and <u>Vorticity Field</u>	- using two pulsed white light sources to create red and green light sheets, imaged on 35 mm film

(iv) <u>Conserved Scalar</u> (nonpremixed flame) - by seeding the fuel with alumina particles

In the later stages of the project, the feasibility of OH PLIF imaging will be investigated. Such measurements are not critical to the success of the work, but would provide important information about the flame chemistry during an unsteady stretch process. In year three it is planned to add a fuel spray into the nonpremixed experiment in order to determine the effect of vortex-induced motion on spray boundaries and the spray flame. The spray flame results will be compared to the analysis of Shiah and Sichel [8].

A computational effort [6] is being conducted in parallel with the experimental effort. Under the present plan, researchers at NRL will simulate the premixed flame-vortex interactions with full chemistry for the case of hydrogen-air flames. The simulation of heat losses, preferential diffusion, and unsteady effects are important in the understanding of the problem. For the case of nonpremixed flames, the approach has been to first simulate an unsteady 1-D diffusion flame with full chemistry and realistic diffusion coefficients; this type of simulation later will be combined with a simulation of the velocity field induced by a vortex.

Of particular interest in the nonpremixed case is the way in which a vortex creates pockets of unburned fuel or air. Such pockets may not burn completely due to stain effects, leading to excessive levels of CO and soot. The numerical code developed to date simulates the burning of strips and bubbles of fuel which are surrounded by unsteady diffusion flames. The FLAME1D/DFLM93 code developed at NRL was used. A vectorized kinetics solver (VSIAM) is employed, and a method to treat open boundaries uses an implicit Lagrangian calculation. An asymptotic coupling method is applied in conjunction with time step splitting, in order to couple the chemical kinetics and the other physical processes.

Some numerical simulations are shown in Figure 3 for the unsteady diffusion flame. Results quantify the importance of including full chemistry and preferential diffusion effects. Comparisons were made with solutions obtained assuming single step chemistry and constant diffusion coefficients.

ACKNOWLEDGMENT

This research is supported by NASA Microgravity Contract NAG3-1639.

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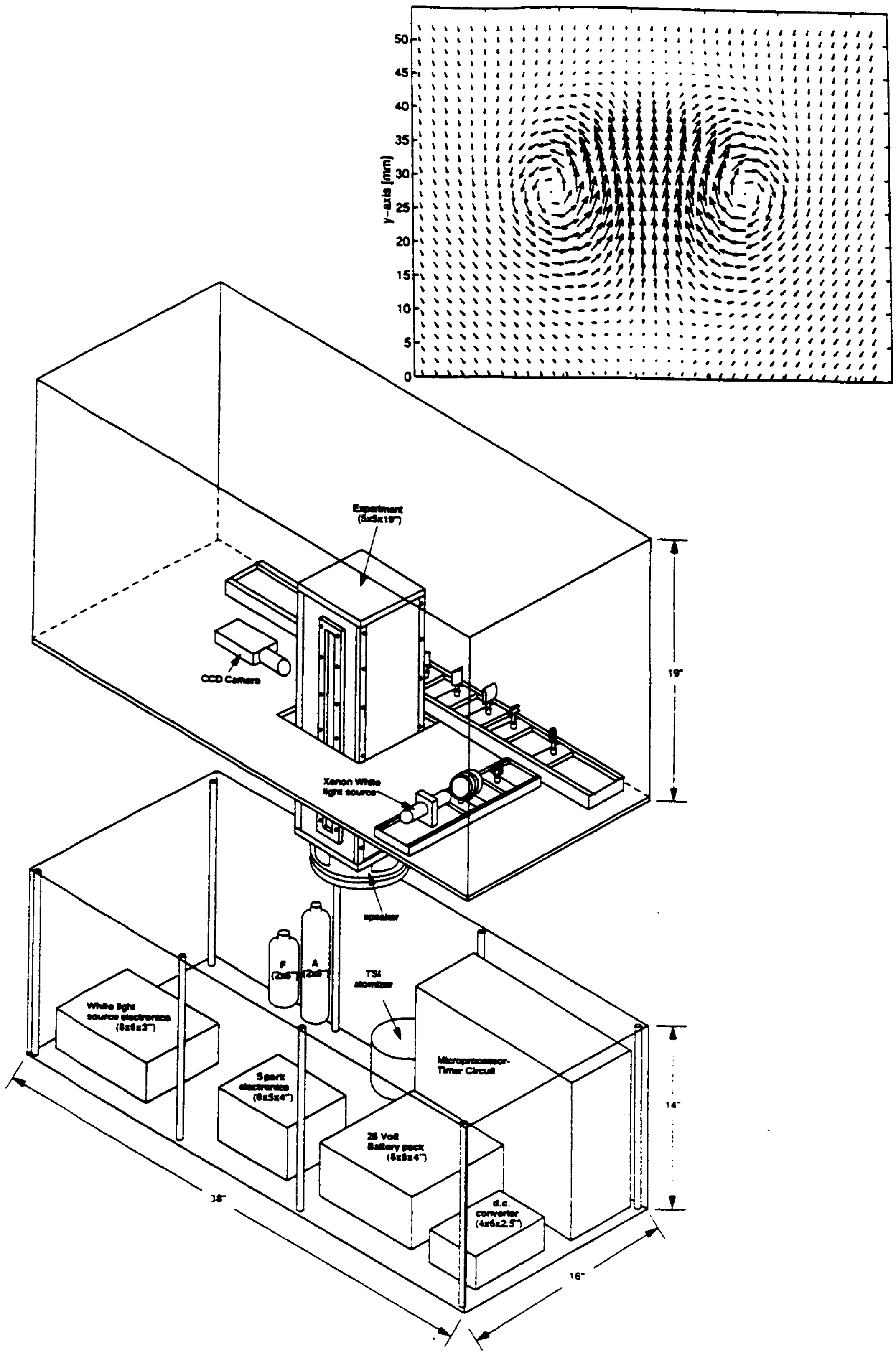

Figure 1. The Michigan Microgravity Flame-Vortex Experiment.

Shown above is a PIV velocity field image obtained at one-g; only one-third of the velocity vectors are plotted. The velocity resolution of 0.5 mm is sufficient to obtain consistent, repeatable images of the vorticity field and strain rates on the flame.

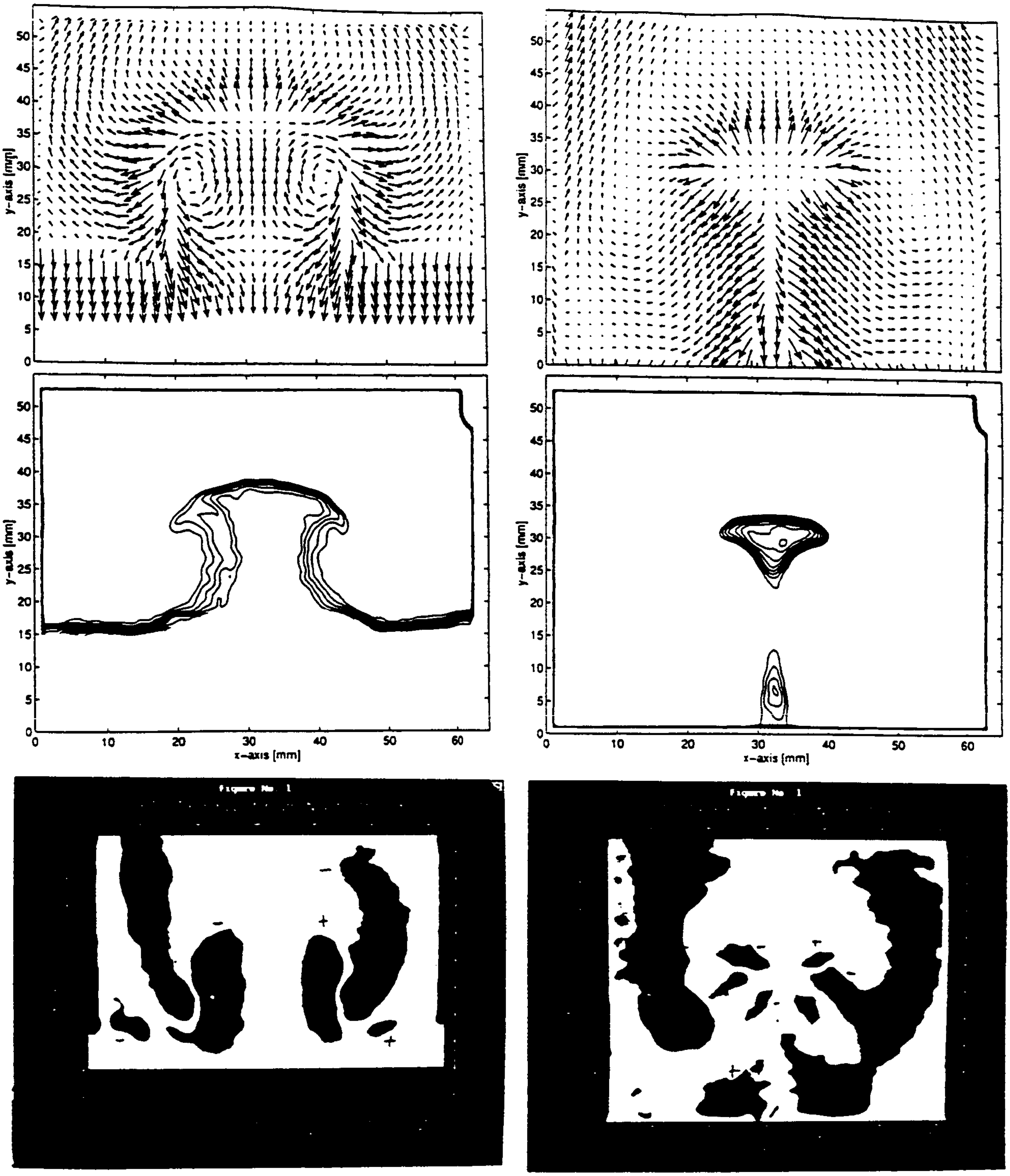

Figure 2. PIV Images of the Flame-Vortex Interaction Obtained During the One-G Baseline Tests.

Top image: velocity field (one-third of vectors plotted); middle images: premixed flame position from digitized Mie images; bottom images: vorticity field showing that the initial vortex has disappeared but flame-generated vorticity remains.

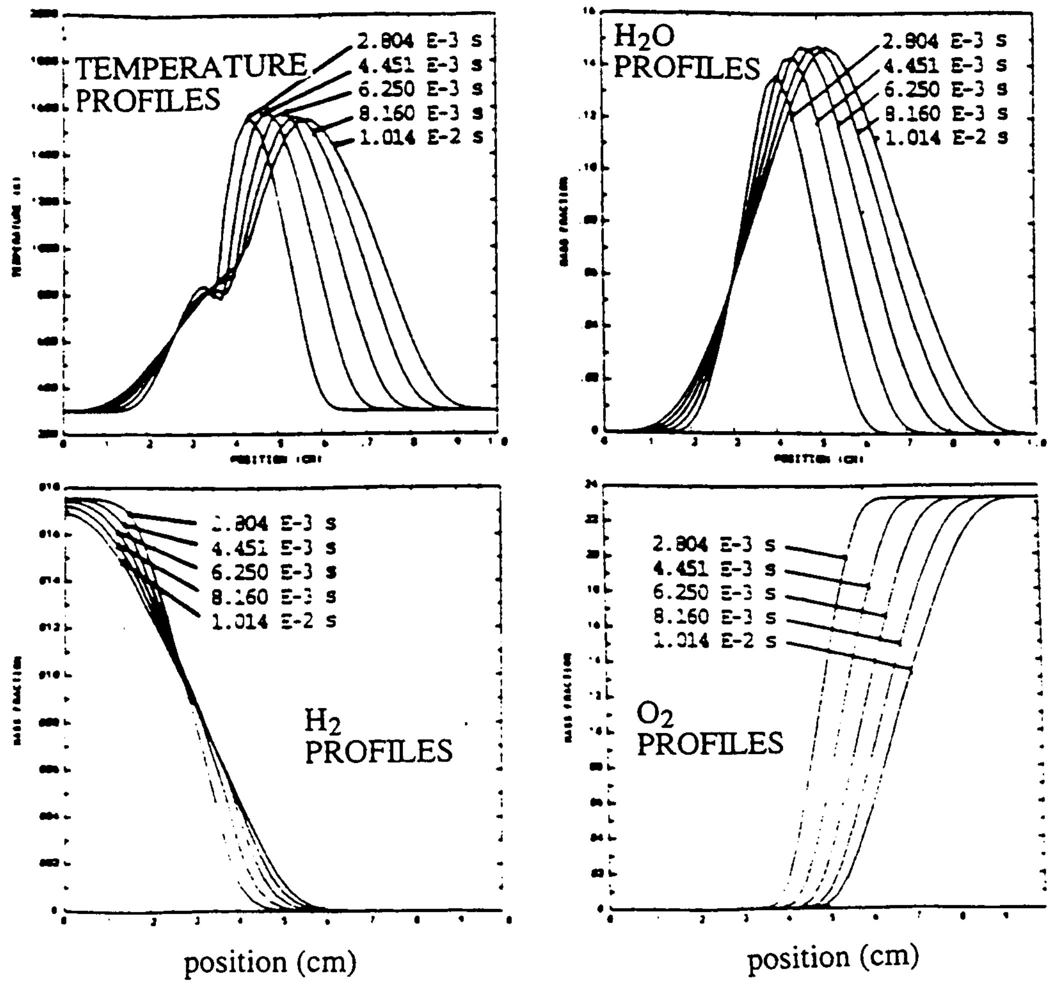

Figure 3. Calculated Temperature and Species Profiles at Different Times for An Unsteady Diffusion Flame With Full Chemistry and Differential Diffusion - to be included in future flame-vortex simulations. Collaborative effort involving F.S. Costa, K. Kailasanath (NRL), and M. Sichel.