Characterization of flow perturbations generated by a femtosecond laser pulse
(With applications to FLEET)

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1 Introduction

Accurate velocimetry measurements are essential for improving our understanding of complex fluid phenomena and validating our numerical approaches. **F**emtosecond **L**aser **E**lectronic **E**xcitation **T**agging (**FLEET**) is an unseeded molecular tagging method for velocimetry measurements in flows which contain nitrogen. Since its discovery in 2011, FLEET has been used to collect high resolution ($< 40\mu m$) velocimetry measurements in a variety of intricate flow fields [1, 2, 3].

To collect velocimetry measurements, a femtosecond laser is used to ionize and dissociate nitrogen molecules within its focal zone. This decaying plasma fluoresces in the visible and infrared spectrum over a period of microseconds. The displacement of this fluorescing or 'tagged' region is then photographed and processed to determine the local velocity of the fluid.

2 Statement of Purpose

Recent investigations indicate that the tagged gas can experience heating of between $200K$ and $2000K$ depending on the focus and pulse energy of the laser shot [4, 5]. The addition of large amounts of thermal energy to the flow generate a number of perturbations which may affect FLEET's ability to measure accurate velocimetry data. These perturbations include:

- blast waves which result from the rapid heating of the focal zone.
- radial perturbations of the tagged region generated by the blast waves.
- effects associated with the increased local fluid viscosity in the tagged region.
- the modification of turbulent flow structures resulting from the blast waves or hot tagged region.

Numerical modeling will be used to characterize these perturbations. Simulations will begin in laminar conditions before moving to turbulent flows. A RANS $k-\varepsilon$ model will be used to explore the effect of local energy addition to turbulent flow structures. This thesis aims to to quantify the measurement errors of FLEET and provide recommendations to minimize the identified errors.

3 Progress Report

A brief summary of my progress is outlined below:

- Two and Three dimensional Navier-Stokes solvers have been coded in FORTRAN based on MacCormack's Predictor-Corrector Method. A simple technique to extend to the Flux Corrected transport (FCT) method of Boris and Book to higher dimensions was developed and implemented. To increase the fidelity of the simulations the effects of temperature on the specific heat capacities and gas viscosity have been included.

- Efforts to characterize the blast wave and the radial dynamics of the focal zone have yielded excellent results. Comparison of the numerical and experimental data has provide a new method of calculating the energy deposited into the flow by the femtosecond laser.

- The interaction of high temperature focal zones with laminar boundary and shear layers have been simulated and artificial thickening of the measured shear layer was observed [6].

4 Future Work

More work needs to be done to characterize the artificial thickening effect observed in the simulated shear layer test case. It is hypothesized that the thickening is a function of **a)** the temperature of the hot channel, **b)** the hot channel geometry and **c)** the shear stress of the flow field.

The $k - \varepsilon$ RANS solvers must be written and validated before the interaction of focal zone with the turbulent flow field can be studied numerically. To correctly implement the $k - \varepsilon$ RANS model a radially symmetric code will first be written and tested. This will be followed by an axis-symmetric two-dimensional solver and finally a fully three-dimensional $k - \varepsilon$ RANS solver.

References

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