Beam Propagation through Plasma Laden Flow

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Experiments were conducted to investigate the optical properties of a laser beam passing through a plasma. A capacitive discharge plasma operating at 300 volts was generated using dielectric barrier discharge (DBD) plasma actuator. The actuator was mounted on an optical window in a flat plate that was installed in a specially designed wind tunnel. It was found that plasma laden flow causes laser beam distortions, dislocations and changes in beam intensity. Additional results and observations are discussed.

Nomenclature

I_o	=	initial intensity of laser
I	=	intensity of laser after passing through plasma
s	=	reflective index and Strehl ratio

I. Introduction

PLASMA actuators are devices that use atmospheric pressure electrical discharges. Common examples of these include coronas, glow, arc discharges, and dielectric barriers. A dielectric barrier discharge plasma actuator is composed of two rectangular electrodes, one of which is exposed to the atmosphere, separated by a dielectric substance. With the application of high voltage a DBD plasma is created in the airspace between the two electrodes. Linear plasmas, like the DBD, form a horizontal wall jet, which can be used to control flow separation. Plasmas can also be created as a circular jet. This is done by imbedding a circular electrode, covering it with a dielectric, and then placing the exposed electrode over the imbedded one. The exposed electrode is essentially circular as well with an inner diameter equivalent to the diameter of the imbedded electrode removed. Use of plasma actuators has been reported in experiments for virtual flaps and slats, low pressure turbine blade separation control, and lift enhancement on airfoils[1]. A type of plasma also cause a change in density of the matter they are displacing. This density change causes optical anomalies within the vicinity of the plasma and immediately down stream in the flow. The effect has been compared to the natural phenomenon of a visually blurred region just above a hot surface. This phenomenon poses a problem for devices relying on the accuracy of light beams. One such device is the airborne laser platform. A laser mounted within a high speed airplane would experience plasma-like distortions across its turret and the laser's accuracy would diminish greatly. The main purpose of this experiment is to test plasma actuators for flow control over the turret through which the laser beam is to pass. It is therefore important to investigate the laser-plasma interactions. This would supply a known gradient for the laser beam and would, theoretically, increase the laser's accuracy by negating the effects of density variations associated with high speed flight. The purpose of this paper is to compare the changes in intensity and position of a laser exposed to a DBD (linear) plasma and circular plasma jet prior to wind tunnel testing.

II. Experimental Arrangements

A. Actuator Construction and Power Supply

Each plasma actuator was comprised of two copper electrodes separated by a dielectric strip. The linear plasma actuator was constructed by cutting kapton tape into rectangular strips approximately 5mm wide and 25 mm in length. The embedded electrode was then mounted onto a flat mirror. This arrangement allowed the plasma to be tested without requiring a flow to circulate the plasma into the path of a laser. The embedded electrode was then covered by two layers of a thin dielectric material. Next, the upper electrode was placed asymmetrically alongside the embedded electrode. The upper electrode was fundamentally different from the embedded electrode in that the

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edge furthest from the region of plasma was shaped with vane like teeth as in Figure 1. This was so the air flow across the plasma would be smooth.

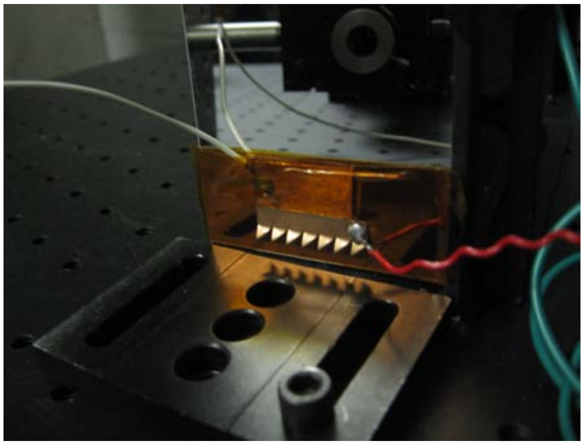

Figure 1. DBD (linear) Plasma Actuator

The circular plasma actuator was comprised of the same kapton tape and dielectric material as the linear actuator. The circular actuator was made by using a 7mm diameter hole punch to cut a 7mm diameter circle in the kapton tape. The inner copper circle was mounted onto an optical glass plate followed by two layers of dielectric material. The upper electrode was the remains of the kapton tape from which the embedded electrode was cut. This is this is mounted over the embedded electrode so that the two circles are concentric as in Figure 2.

Each type of plasma actuator was tested separately. For each experiment, the electrodes were connected to a PVM 400 Plasma Driver operating at 300 volts. The lowest power setting of the PVM Plasma Driver was used for all experiments.

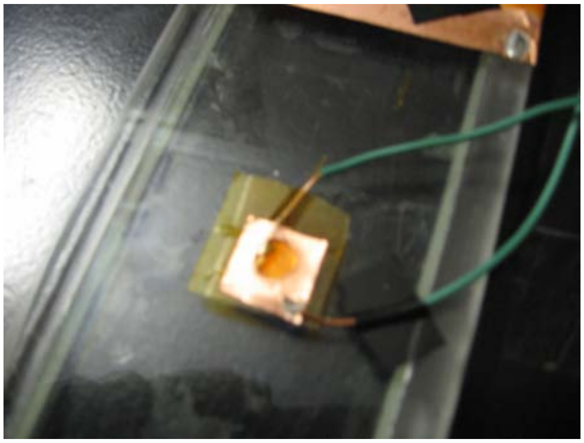

Figure 2. Circular Plasma Actuator

B. Optical Arrangement

The main focus of this series of experiments was the optical anomalies associated with plasmas. The optical set up consisted of a Melles Griot Helium Neon Class III B Laser which passed through collimating optics, which reduced the beam's diameter to 1.5 mm, before reaching the mirror mounted plasma actuator as in Figure 3. The reflected beam then reflected off a second flat mirror towards a convex lens. This lens was used to focus the beam to a pinpoint so that its translation on a set of two dimensional coordinate axes could be determined. The focused point of the laser was projected onto an Ontrak optical position detector (OPD). The signal from this detector was sent through a Photonics Inc. OT 300 Position Sensing Amplifier. The x and y channels were read into a data acquisition board, National Instruments CB-68LP, and the signals were analyzed in a spreadsheet program.

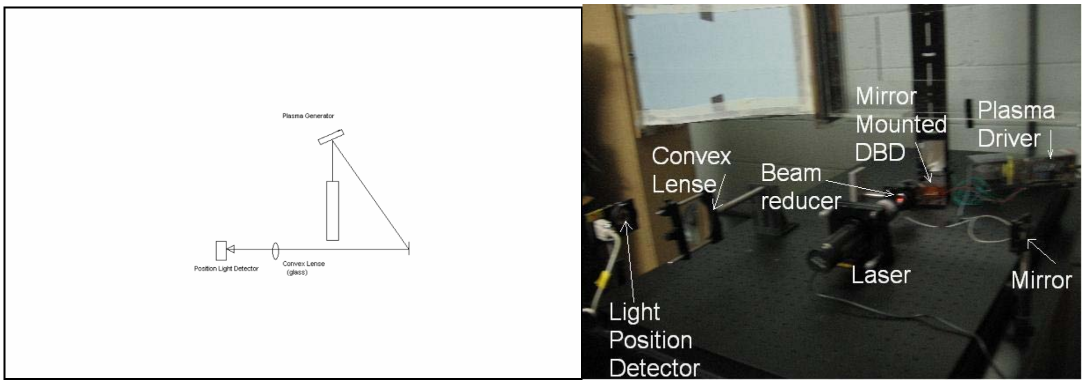

Figure 3. Diagram of Optical Setup.

The circular plasma actuator had an identical optical setup with one exception. The optical glass plate on which the circular plasma actuator was mounted was placed horizontally between the beam reducer and the flat mirror. This resulted in the circular, jet like plasma being transversed by the laser beam. Further experiments will be conducted on the behavior of a laser passing through the center of a circular, jet like plasma.

III. Results and Discussion

A. Beam Displacement and Intensity due to DBD (linear) Plasma

In order to determine if the laser beam dislocated due to the presence of a linear plasma as in Figure 4, data was collected using an OPD. This detector is 4mm by 4mm in size. The detector converted the motion of the beam across its photoreceptor into voltages along X and Y coordinates. These voltages were read into an Excel program and were plotted onto graphs comparing the voltage differences in the X and Y directions. It was also observed that the data in Figure 5 represents relatively large looping motions away from the origin that have high velocity but low acceleration[2]. The Y axis in all cases represents movement in the horizontal and the X represents the vertical. The beam intensity is shown by the data to vary with time in an erratic manner. This is due to changes in air density immediately above the plasma. This change in air density also affects the reflective index and the Strehl (intensity) ratio Eq. (1).

(1) $S=I/I_o$

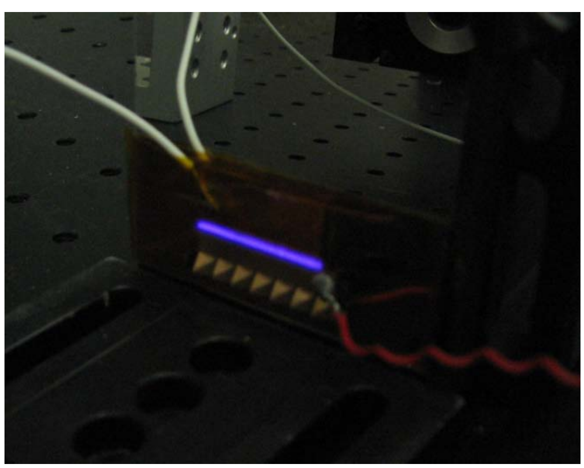

Figure 4. Linear Plasma

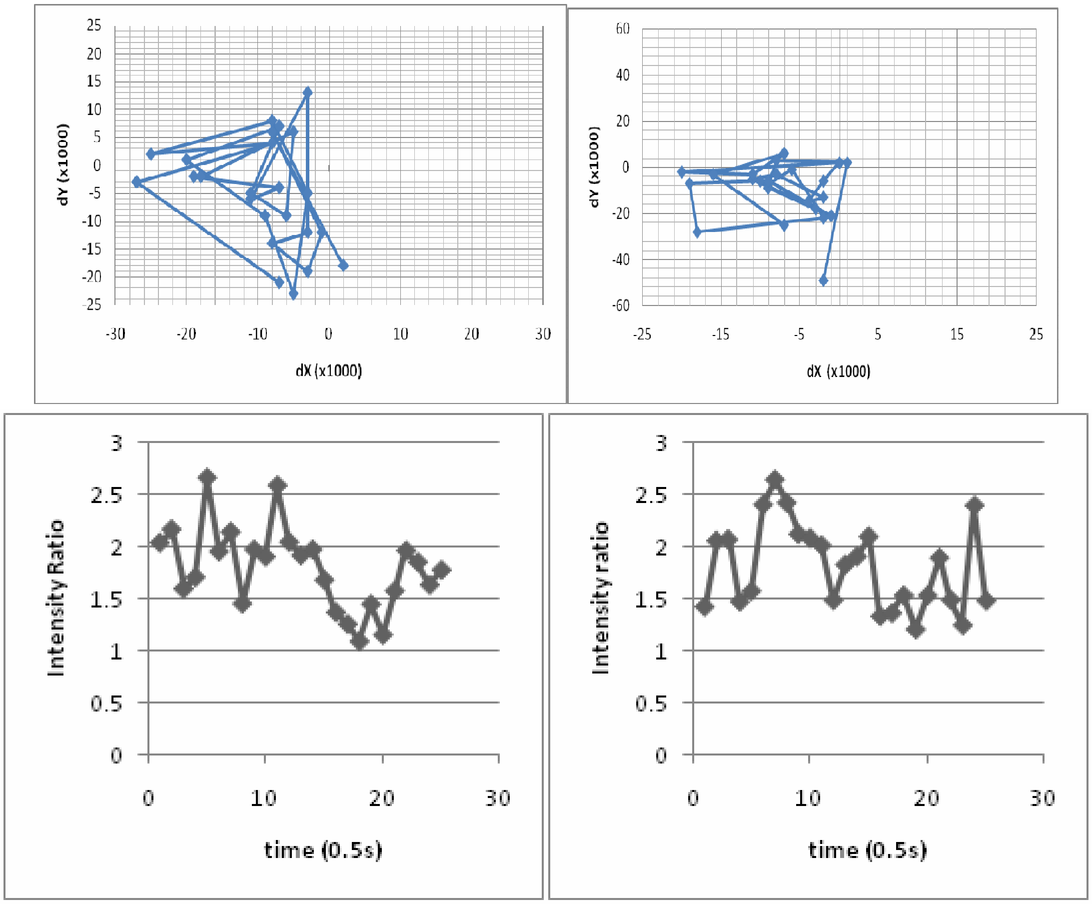

Figure 5. Linear Plasma, Displacement, and Intensity Plots.

B. Beam Displacement and Intensity due to Circular Plasma

The experiments with a circular plasma were conducted such that the beam crossed a circular plasma jet as in Figure 6. The beam crossed the plasma such that it passed through two walls of the plasma. Displacement was markedly different than the linear plasma experiment. Displacement of a laser beam due to a circular plasma jet tends to decrease slightly as in Figure 7. The acceleration of the beam increases and the velocity has on average decreased[3]. The intensity ratio was also considered and the beam's intensity showed clear fluctuations as it passed through the plasma. This is also due to a change in density of the air above the plasma with respect to time just as in the case of the linear plasma.

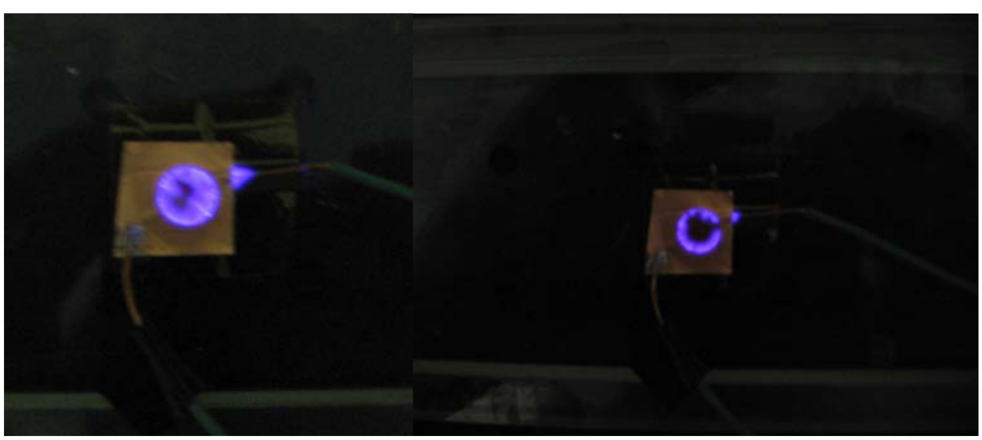

Figure 6. Circular Plasma

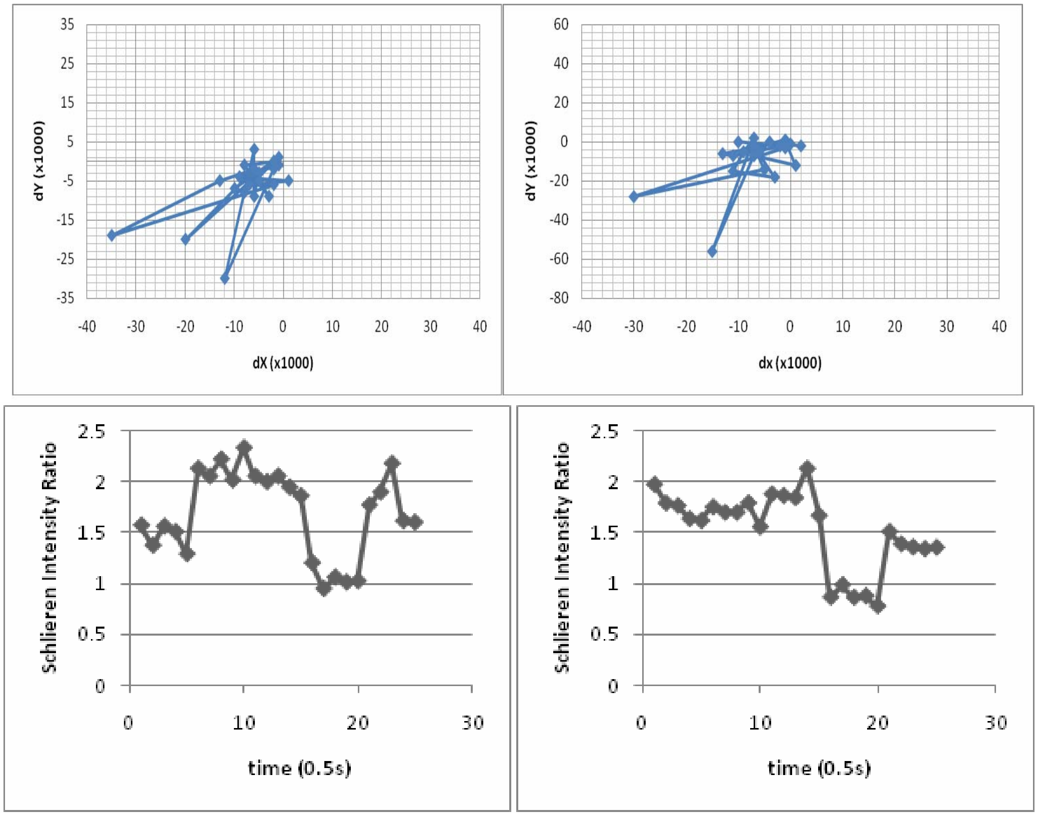

Figure 7. Circular Plasma, Displacement, and Intensity Plots.

IV. Conclusion

Experiments were successfully conducted to demonstrate the changes in position and intensity of a laser passed through both linear and circular plasmas. It is concluded that drastic changes in position, often referred to as jitter, were present in all cases. In the linear plasma case the displacement plots showed movement in large loops away from the origin. The circular case showed that the beam slowed but increased its acceleration around a central point. Random changes in beam intensity were also present. Together these two factors greatly diminish the accuracy of any laser device that might possibly encounter flows similar to the plasma. The airborne laser project is just one example. Current data suggests that the laser-plasma interaction can place additional strain on adaptive optics for use in beam steering. Future testing of plasmas and their interactions in a flow as well as time lapsed images of the displacement of the laser are planned for.

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References

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