The Evolution of a 2D SDBD Plasma Generated Disturbance Along a Flat Plate Boundary Layer

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Abstract

We track the stages of temporal and spatial evolution of a localized 2D disturbance within a boundary layer over a flat plate. The disturbance is generated via a Single Dielectric Barrier Discharge (SDBD) plasma actuator. 3D visualizations of the spatial structure of the disturbed flow field are obtained by hot-wire measurements that include the streamwise velocity component. We track the advanced stages of disturbance transition in which a single 2D wave breaks down to 3D coherent structures.

SDBD Plasma Actuation Technique

A common configuration of SDBD plasma actuators consists of two electrodes in an asymmetrical arrangement, separated by dialectic material, as depicted in Fig. 1. One electrode is grounded and encapsulated, whereas the other is exposed to ambient air. When large enough voltage is applied between the electrodes, it causes the air over the encapsulated electrode to weakly ionize (which appears as purple glow). In the presence of the electric field produced by the electrodes, the ionized air ('plasma') generates a body force vector field that acts on the ambient (non-ionized, neutrally charged) air [Corke et al., 2009].

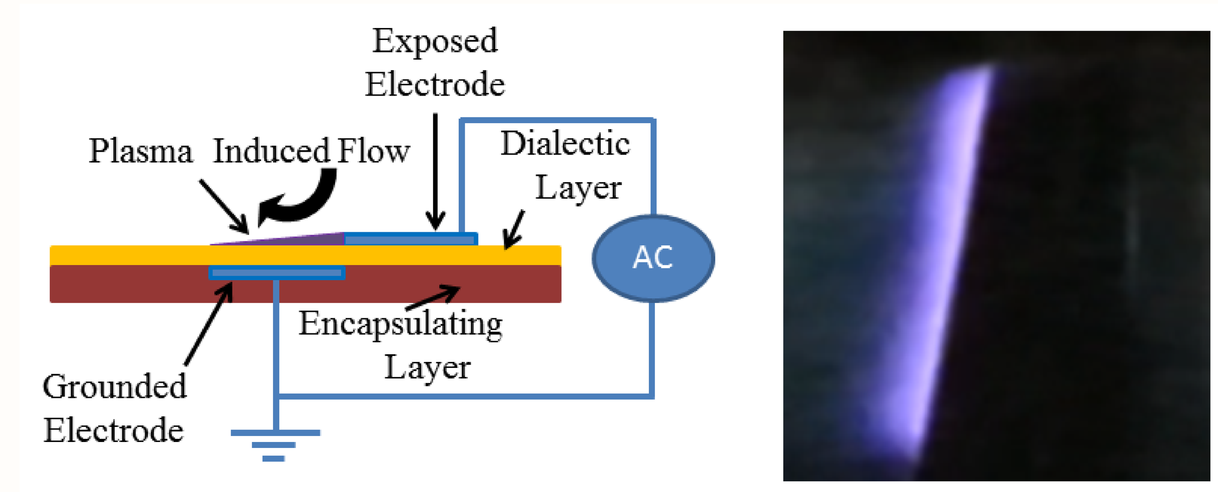

Figure 1: Left figure: Schematic illustration of an SDBD plasma actuator. Right figure: Ionized air over an electrode covered by dielectric layer, at atmospheric pressure. The electrodes are made of aluminum tape, and the dialectic layer is a 1 mm perspex sheet. Photo taken at the Wind Tunnel Labs of the Technion's Faculty of Aerospace Engineering.

Experimental Results

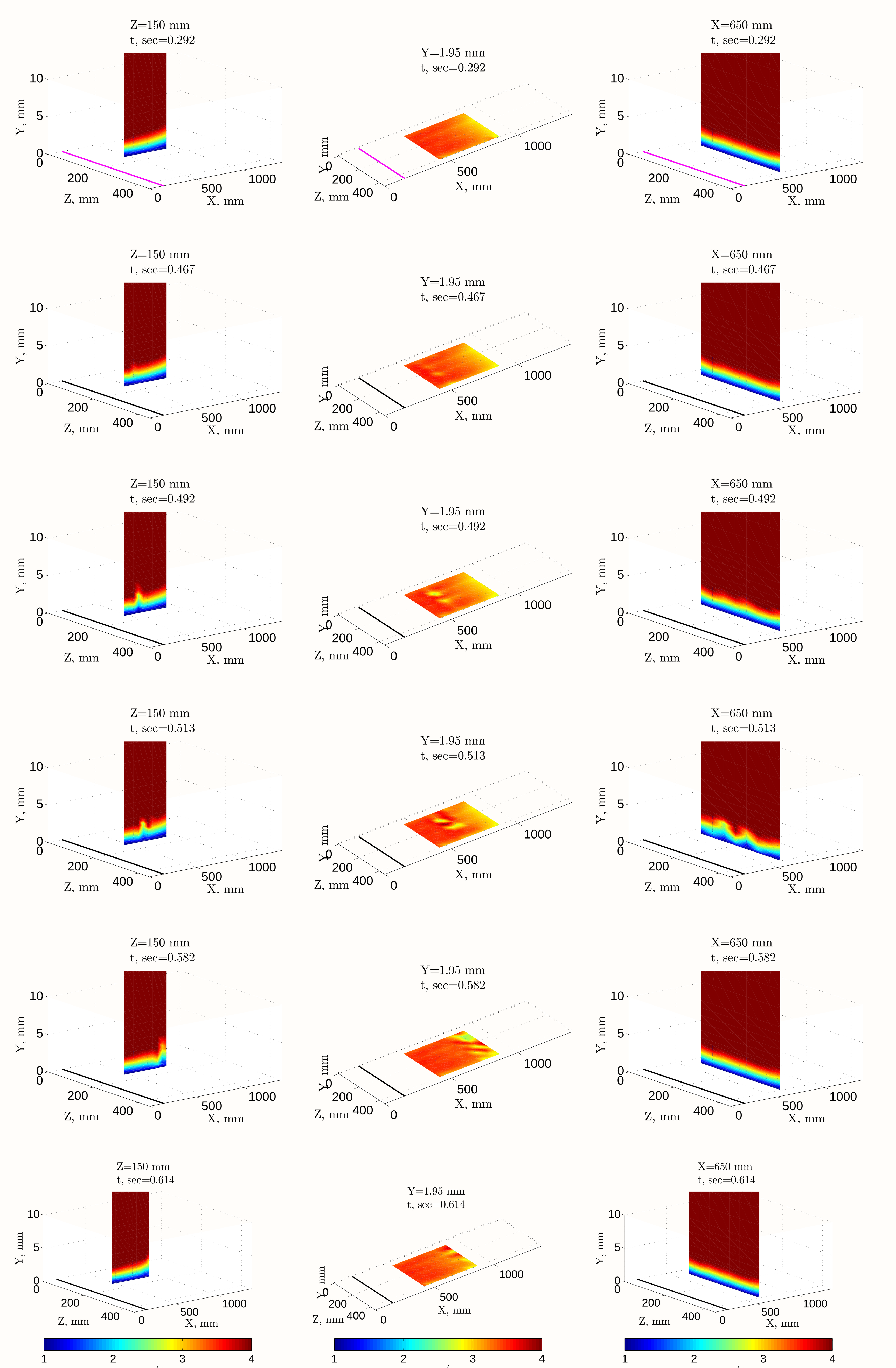

Figure 2: Streamwise propagation structure of a disturbance at different times. The disturbance is generated by an SDBD plasma actuator acted upon by a single pulse input of 10 msec duration. The structure is shown on three plane slices (X-Y, X-Z, Y-Z) at specific locations (detailed above each figure). The aspect ratio of the experimental setup is shown in the figures occupying the central column (for X-Z plane slices). The plasma actuator is shown as the purple(on)/black(off) strip at $x = 150$ mm.

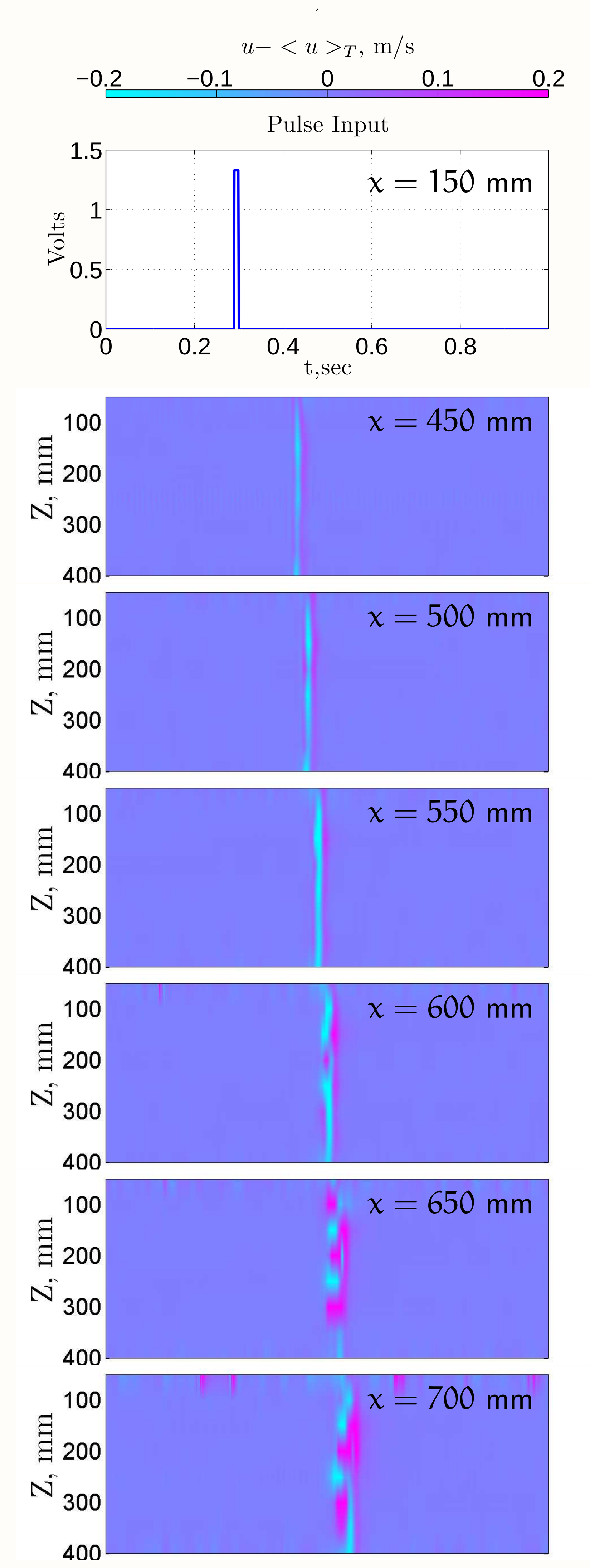

Figure 3: Time history of disturbance streamwise velocity during its passage through a fixed height $y = 0.55$ mm above the plate and fixed downstream locations from the leading edge: $x = 450, 500, \ldots, 700$ mm. The disturbance is generated via an SDBD plasma actuator located at $x = 150$ mm and acted upon by a single 10 msec pulse input.

Experimental Details

- The experiments have been performed in a closed-loop wind tunnel with concentration ratio of 5.76:1 and test section cross area of 0.5 m by 0.5 m and length of 1.37 m.
- The boundary layer is created on a flat plate made of three glass sheets, 4 mm thick each, with asymmetric leading and trailing edge flaps attached to the front and back of the plate, respectively. Plate dimensions are 1.4 m in length (from leading edge to trailing edge) and 0.45 m width.
- The free-stream velocity, U (in the x direction), is 5 m/s.
- SDBD plasma actuator is located at $x = 150$ mm downstream from the leading edge.
- The measurements of velocity are conducted using a single hot-wire probe with a 5 µm diameter tungsten sensor.
- The probe is mounted on a three-axis traversing mechanism, with resolution of 5 µm in the vertical direction, and 1 mm in streamwise and spanwise directions.
- The positioning of the probe within the boundary layer at a given downstream station is done automatically by using the computer to drive the stepping motors through LabVIEW software.
- The flow is sampled at 1760 locations: 10 downstream locations in the range $x =$ 450–900 mm, 8 spanwise locations in the range $z =$ 50–400 mm, with 50 mm steps in both directions, and 22 vertical locations with varying step lengths, to cover the boundary layer range of $y =$ 0.05–36 mm from the plate surface to the free stream velocity layer.
- The velocity record, consisting of 10^3 points, is digitized at 1 kHz rate such that the total measuring time is 1 sec for each (x, y, z) location.
- The measurement sequence is synchronized with a pulse from the computer that triggers the disturbance generator.
- At each measuring point, 10 realizations of the disturbance passage are recorded and an ensemble average is then computed. This number of realizations is sufficient to accurately represent the flow structure.

Discussion

Fig. 2 shows that the generated disturbance (starting at $t = 0.29$ sec) can be described as a spanwise-vortex that convects downstream at early stages up to $x = 550$ mm ($t = 0.492$ sec). The vortex rotation is counter-clockwise (positive direction of the z axis). This is evident from the X-Y plane slices: the vortex front transforms momentum from the bottom layer of the boundary layer to the upper layers, then the vortex tail does the opposite. In later stages the disturbance assumes a 3D structure, which is evident from the X-Z plane slices, whereas at $x = 650$ mm a 'streaky' pattern is observed in the Y-Z plane slices.

In Fig. 3 the wave character of the disturbance at $x =$ 450–550 mm is evident, whereas at $x \geq 600$ the structure appears more complicated due to nonlinear interaction (advanced stages of transition to turbulence).

Acknowledgments

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References

[Corke et al., 2009] T.C. Corke, M.L. Post, D.M. Orlov, Single dielectric barrier discharge plasma enhanced aerodynamics: physics, modeling and applications, *Exp. Fluids* **46** , pp. 1-26, 2009.