NUMERICAL INVESTIGATION OF PLASMA ACTUATOR CONFIGURATIONS FOR FLOW SEPARATION CONTROL AT MULTIPLE ANGLES OF ATTACK

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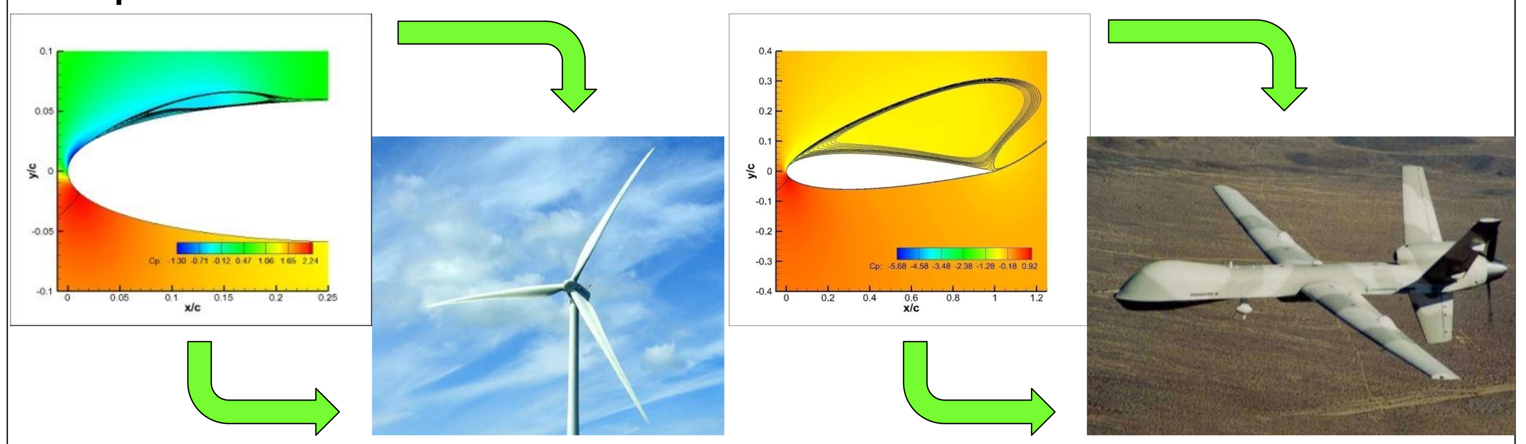
OBJECTIVES

- Investigate, using computational fluid dynamics, the plausibility of using plasma actuators as a means of active flow control over a NACA 0012 airfoil for two types of low Reynolds number (100,000) flow separation: Laminar Separation Bubbles and Turbulent Separation at Stall Conditions.
- Improve aerodynamic performance which may provide fuel savings, increase the efficient flight envelope, improve maneuverability of aircraft, improve the efficiency of wind turbines, etc.
- Demonstrate the use of steady and unsteady actuators in single and multiple array configurations.
- Relate the inputs for the actuators into the numerical analysis to physical inputs of plasma actuators.



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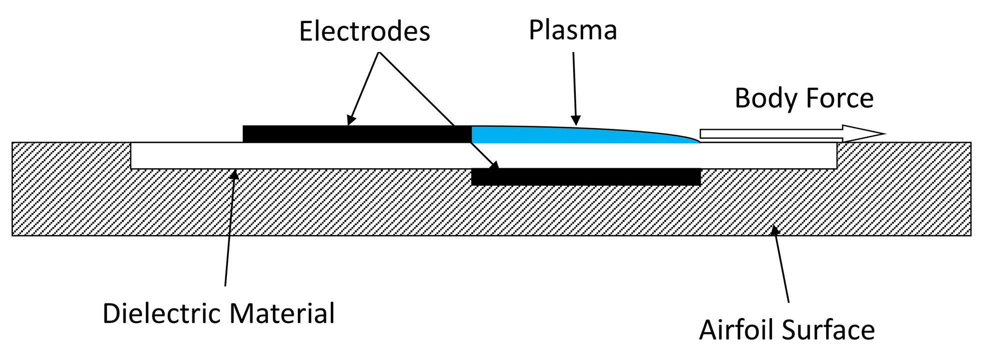
PLASMA ACTUATOR BACKGROUND

- Single dielectric barrier discharge (SDBD) plasma actuators are comprised of two electrodes (one exposed, one buried) separated by a dielectric material.
- Appling a high voltage (10 – 20 kV) and high frequency (1 – 10 kHz) between the electrodes ionizes the air and creates an electric field between the electrodes.
- The ionized air (Plasma) in the presence of the electric field is accelerated away from the exposed electrode, creating a body force on the order of micro-Newtons.



APPROACH

- Represent the presence of the body forced generated by the plasma actuator as a momentum source term in the momentum equation that governs fluid flow.

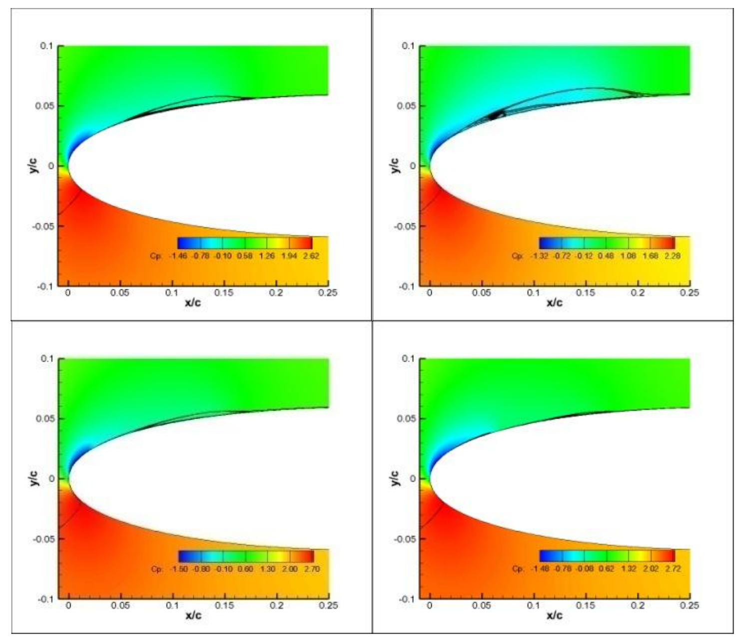
$$\rho \frac{D\bar{V}}{Dt} = -\nabla P + \mu \nabla^2 \bar{V} + \rho \bar{f}$$

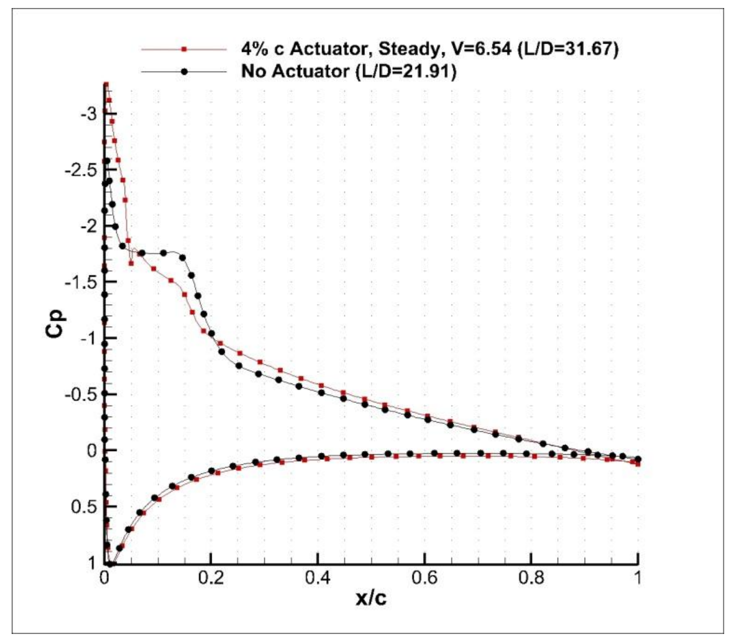
- Input for the numerical analysis is the force per unit volume of plasma. The source dimensions were taken to be 10 mm long by 0.1 mm thick (approximately the dimensions of electrodes used in experiments[1].)
- Experimental results[2] gave fitted data relations between the force per unit span and the input frequency and voltage. This study used a relationship for the force (mN/m) for a fixed 5 kHz frequency with changing voltage (kV.)

$$F_B = 3.26\, V - 17.32$$

LAMINAR SEPARATION CONTROL RESULTS: STEADY ACTUATORS

- Single actuator located at 2% (left) and 6% (right) of the chord at 5.93 kV (top) and 6.54 kV (bottom.)

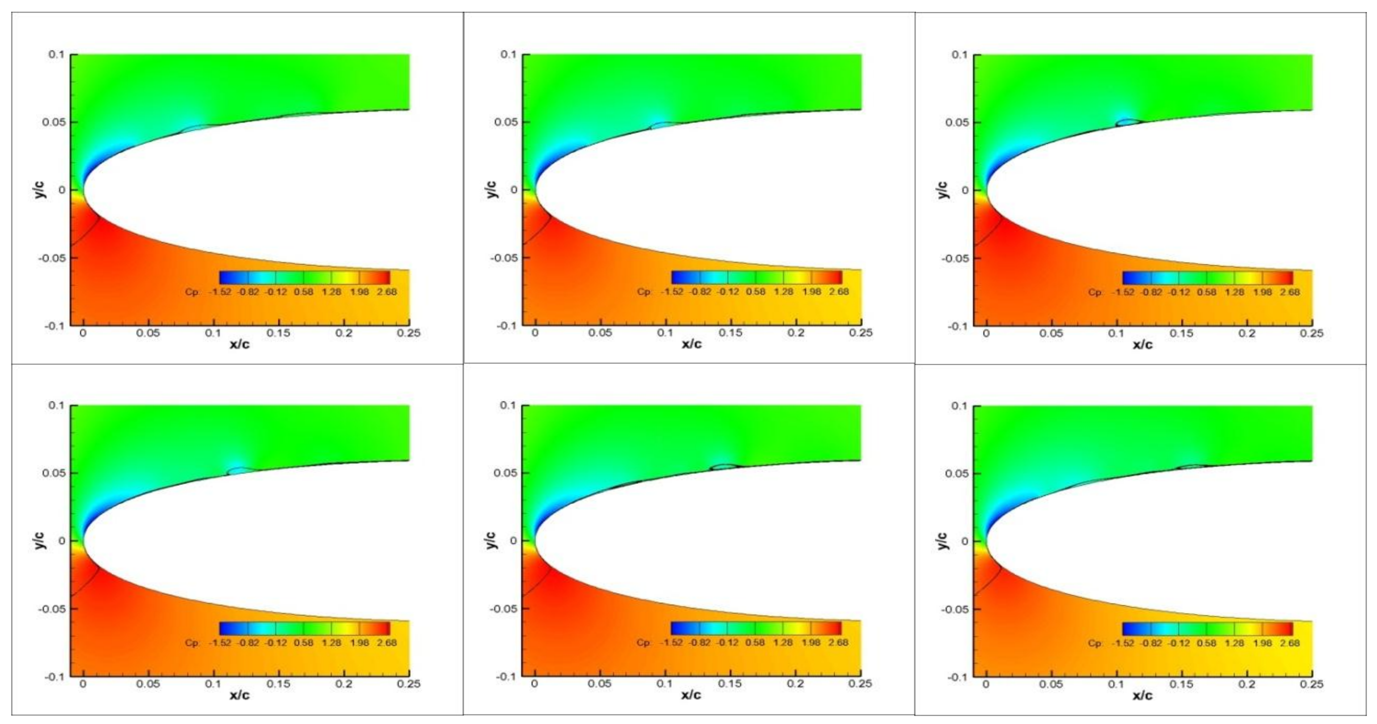




- Multiple actuator configurations are similar for the same total force as a single actuator as the combined effect of multiple actuators is additive.

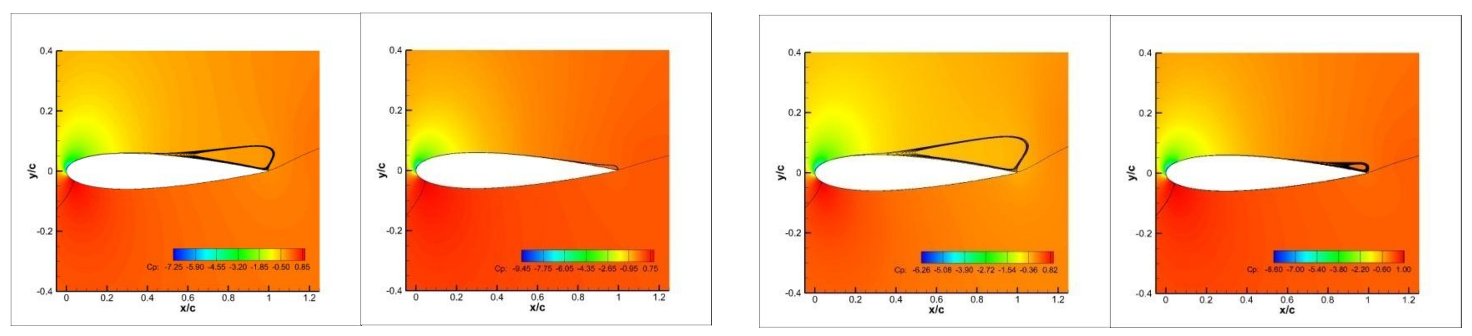
LAMINAR SEPARATION CONTROL RESULTS: UNSTEADY ACTUATORS

- Shown is a time sequence for an actuator at 4% of the chord with a 6.54 kV input. Results are similar for all configurations.



TURBULENT SEPARATION AT STALL CONDITIONS CONTROL RESULTS

- Single actuator located at 2% (left) and 6% (right) of the chord at 7.77 and 15.13 kV.



- Multiple actuator configurations are similar for the same total force as a single actuator as the combined effect of multiple actuators is additive.
- Unsteady actuators generate a periodic "grow and shrink" motion of the down stream separation bubble.

DISCUSSION

- For laminar separation bubble control, steady actuators provide as much as a 40% improvement in the lift to drag ratio (L/D). Unsteady actuators provide as much as 50% improvement at half of the power requirement.
- For turbulent separation at stall conditions, steady actuators are able to force the separation region downstream enough to significantly reduce the separation size. As much as a 700% increase in L/D is observed. Unsteady actuators do not provide the same enhancement at reduced power due to the nature of the separation for the airfoil at the prescribed Reynolds number.
- Actuator placement dominates effectiveness. While multiple actuators do not provide significant improvement, an array of actuators would be essential in dynamic environments where the separation location is changing.

CONCLUDING REMARKS

- Steady actuators add sufficient near wall momentum to the flow to suppress flow separation.
- Unsteady or pulsed operation causes flow disturbances that make the separation region unstable. A type of bursting effect is seen for laminar separation bubbles.
- Actuator placement is critical for efficient separation control. The best placement is just upstream of the separation location
- No significant advantage to multiple actuators is observed. However, would be essential in a dynamic environment where the separation location is changing.

References

1. Corke, T. C., Post, M. L., and Orlov, D. M., "SDBD plasma enhanced aerodynamics: concepts, optimization and applications" *Computers & Fluid,* Vol. 43, 2007, pp. 193-217.

2. Porter, C. O., Baughn, J. W., McLaughlin, T. E., Enloe, C. L., and Font, G. I., "Temporal Force Measurements on an Aerodynamic Plasma Actuator, AIAA-Paper 2006-104," *44th AIAA Aerospace Sciences Meeting and Exhibit,* Reno, Nevada.

3. **West IV, T. K. and Hosder, S., "Numerical Investigation of Plasma Actuator Configurations for Flow Separation Control at Multiple Angles of Attack", *6th AIAA Flow Control Conference*, New Orleans, Louisiana, June 2012 (Accepted for Presentation)**

FUTURE WORK

- Perform higher fidelity numerical simulations that include a more physical plasma actuator model where the Maxwell equations that govern the electromagnetic effects of the plasma actuator are incorporated into the Navier-Stokes equations that govern fluid flow.
- Develop a sophisticated wind tunnel experiment to determine the validity of the numerical results.
- Perform an analysis on other airfoils with different aerodynamic characteristics to determine the effect of the geometry on plasma actuator effectiveness.

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