Control of Flow Structure over a Nonslender Delta Wing Using Periodic Blowing

Cenk Çetin, Alper Çelik and Dr. M. Metin Yavuz

Middle East Technical University, Department of Mechanical Engineering, 06800 Ankara, TURKEY

Motivation and Objective:

Increasing interest in micro air vehicles (MAV), unmanned combat air vehicles (UCAV) and unmanned air vehicles (UAV) for commercial and military purposes in recent years, attracts aerodynamicists to work on the enhancement of flow over nonslender delta wings, typically Λ ≤ 50 deg, which can be considered as the simplified planforms of these vehicles. Among different flow control strategies, blowing through different locations of the wing has been commonly used due to its high effectiveness.

Figure 1. Current unmanned air vehichles and schematic configurations.

Delta wing planforms do not have regular aerodynamic control surfaces and suffer from flow instabilities thus they experience complex flow structures during steady flight conditions or under defined maneuvers which significantly affect the flight performance. In order to determine and extend the operational envelope of these vehicles with particular interest in delaying stall and eliminating the three dimensional surface separation, complex flow structures over low swept wings need to be understood and controlled. The present study aims to investigate the effect of unsteady blowing through the leading edge on the flow structure of a nonslender delta wing in comparison to steady blowing and absence of control.

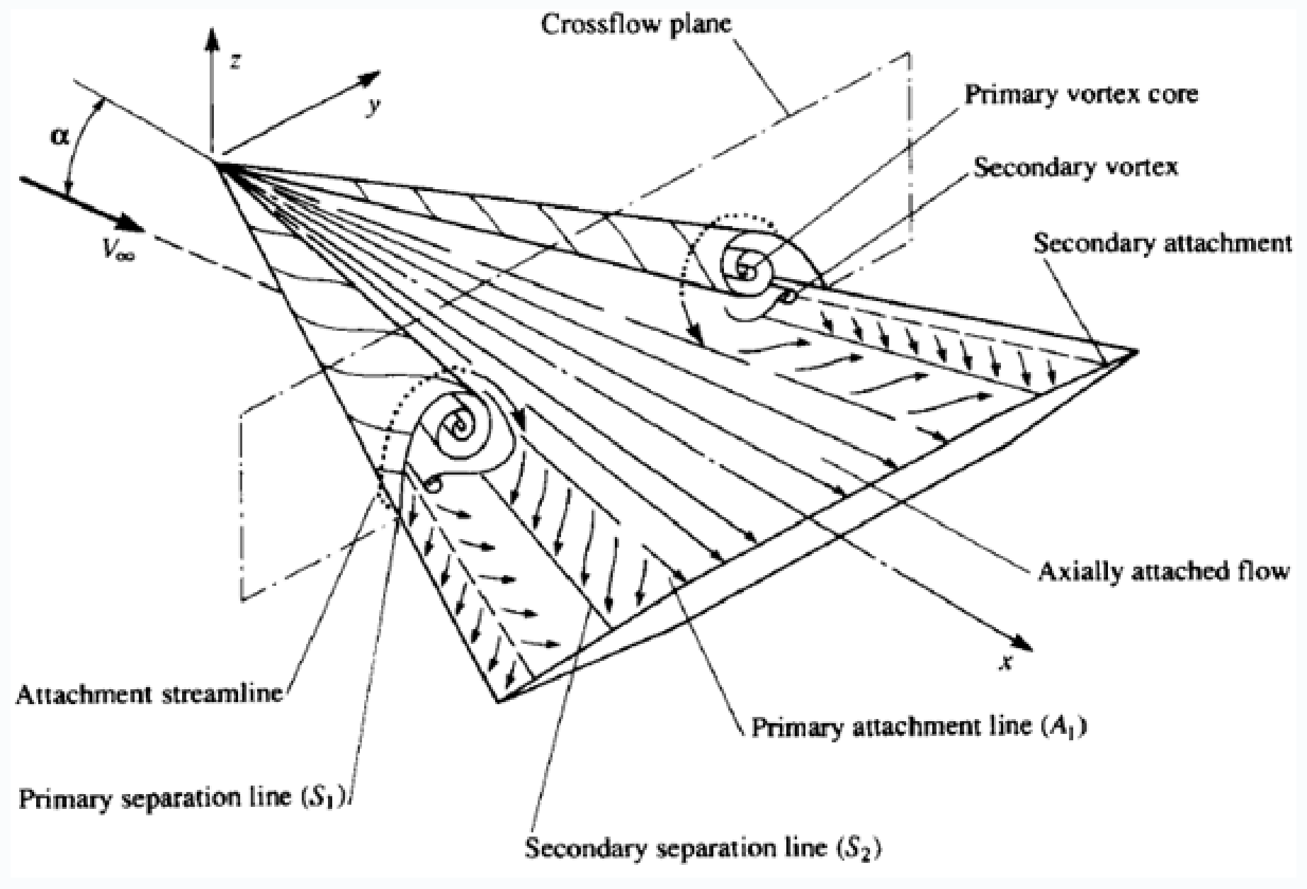


Figure 2. Illustration of delta wing vortex formation with main and secondary flow features (Anderson, J.D., 1985).

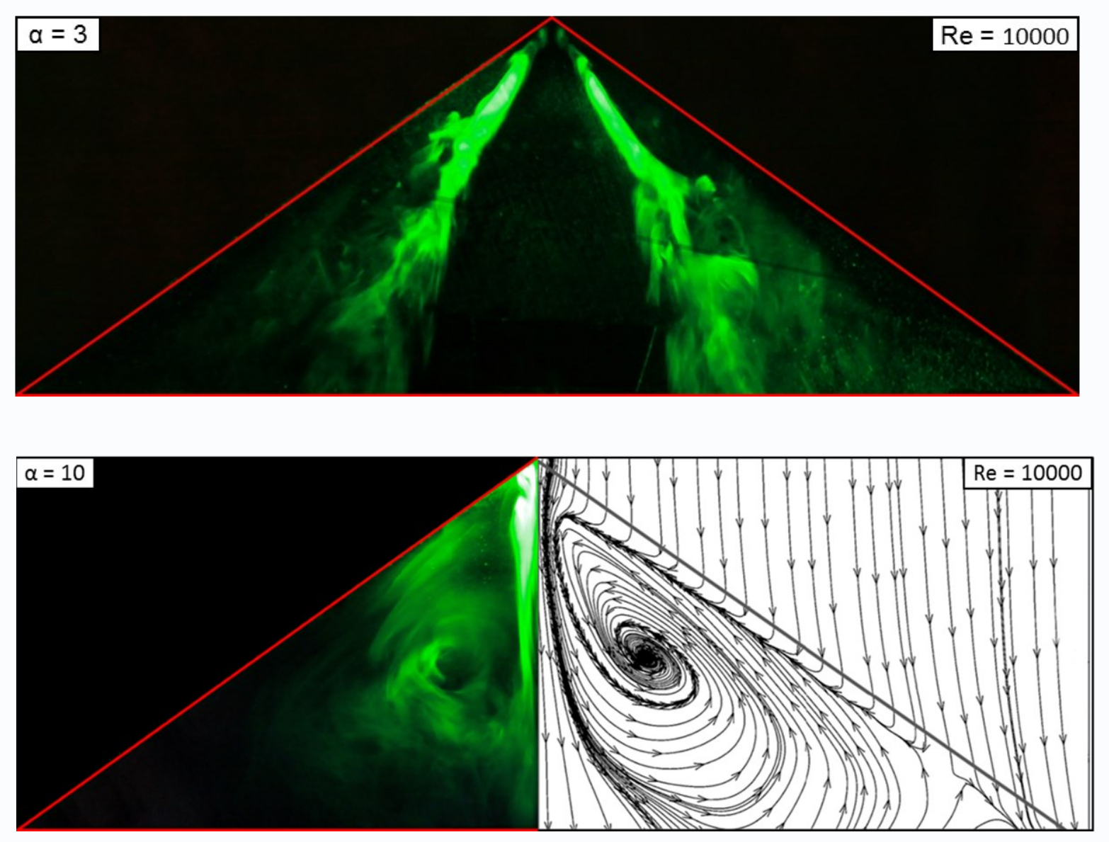


Figure 3. Flow structure over a nonslender delta with 35 sweep angle: burst characteristics and surface separation. (Zharfa, M. et. al., 2016)

Methodology:

Experiments were performed in a low speed wind tunnel.

The unsteady leading edge blowing, in the form of periodic square pattern was generated using the built-in blowing test set-up, which was controlled through LabVIEW and characterized using Hot Wire Anemometry.

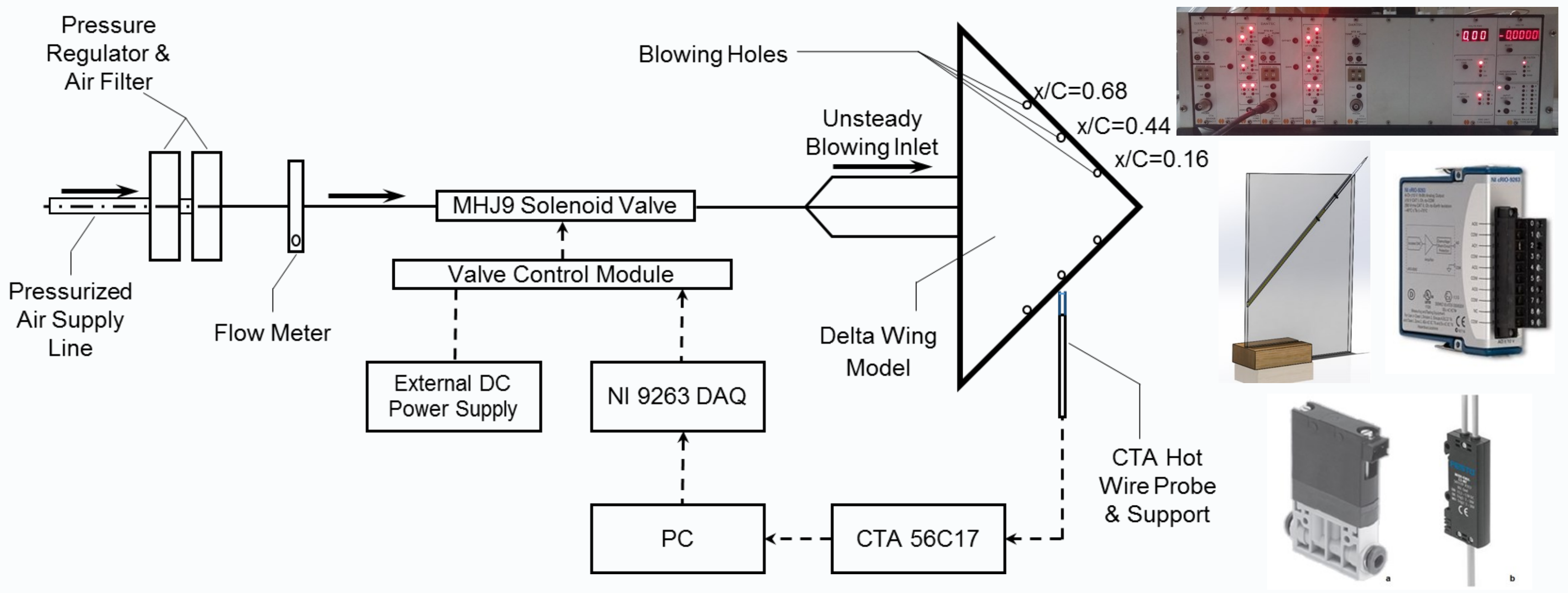
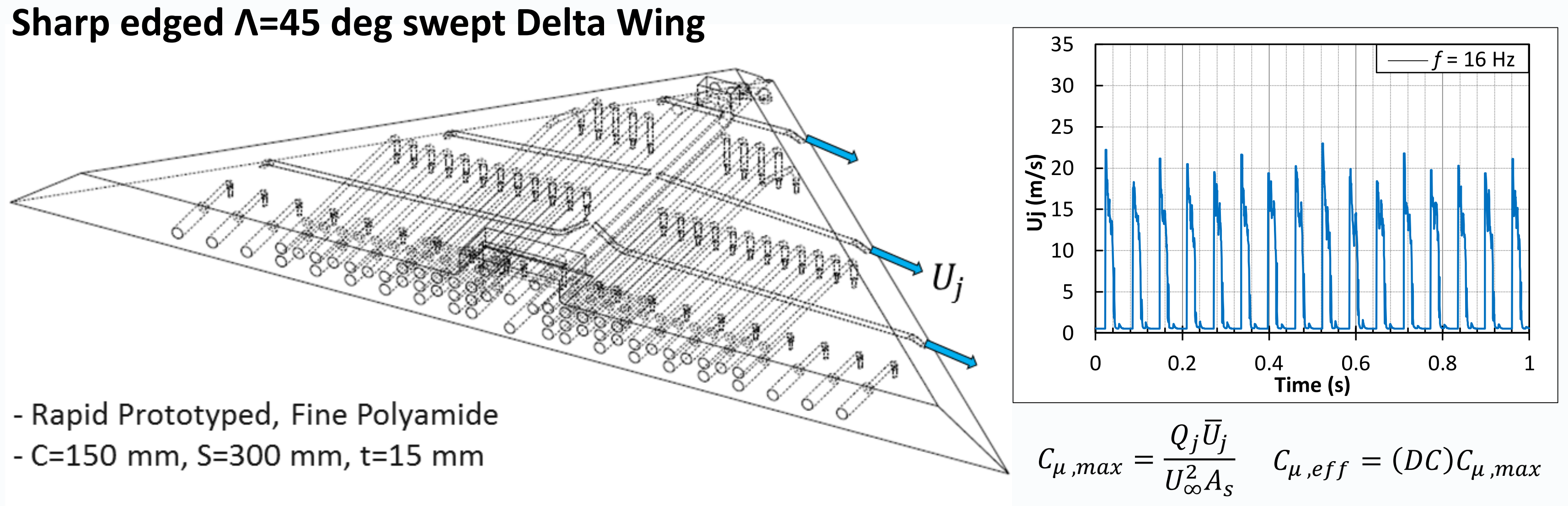


Figure 4. Schematic of the unsteady blowing setup and illustrations of the components.

Sharp edged Λ=45 deg swept Delta Wing



- Rapid Prototyped, Fine Polyamide
- C=150 mm, S=300 mm, t=15 mm

$$C_{\mu,max} = \frac{Q_j \bar{U}_j}{U_\infty^2 A_s} \quad C_{\mu,eff} = (DC) C_{\mu,max}$$

Figure 5. Isometric drawing of the wing model with blowing direction (left) and a sample time history of periodic blowing at excitation frequency f =16 Hz (right).

In order to investigate the flow structure on the wing model quantitatively, surface pressure measurements and high-image-density Particle Image Velocimetry (PIV) techniques were performed

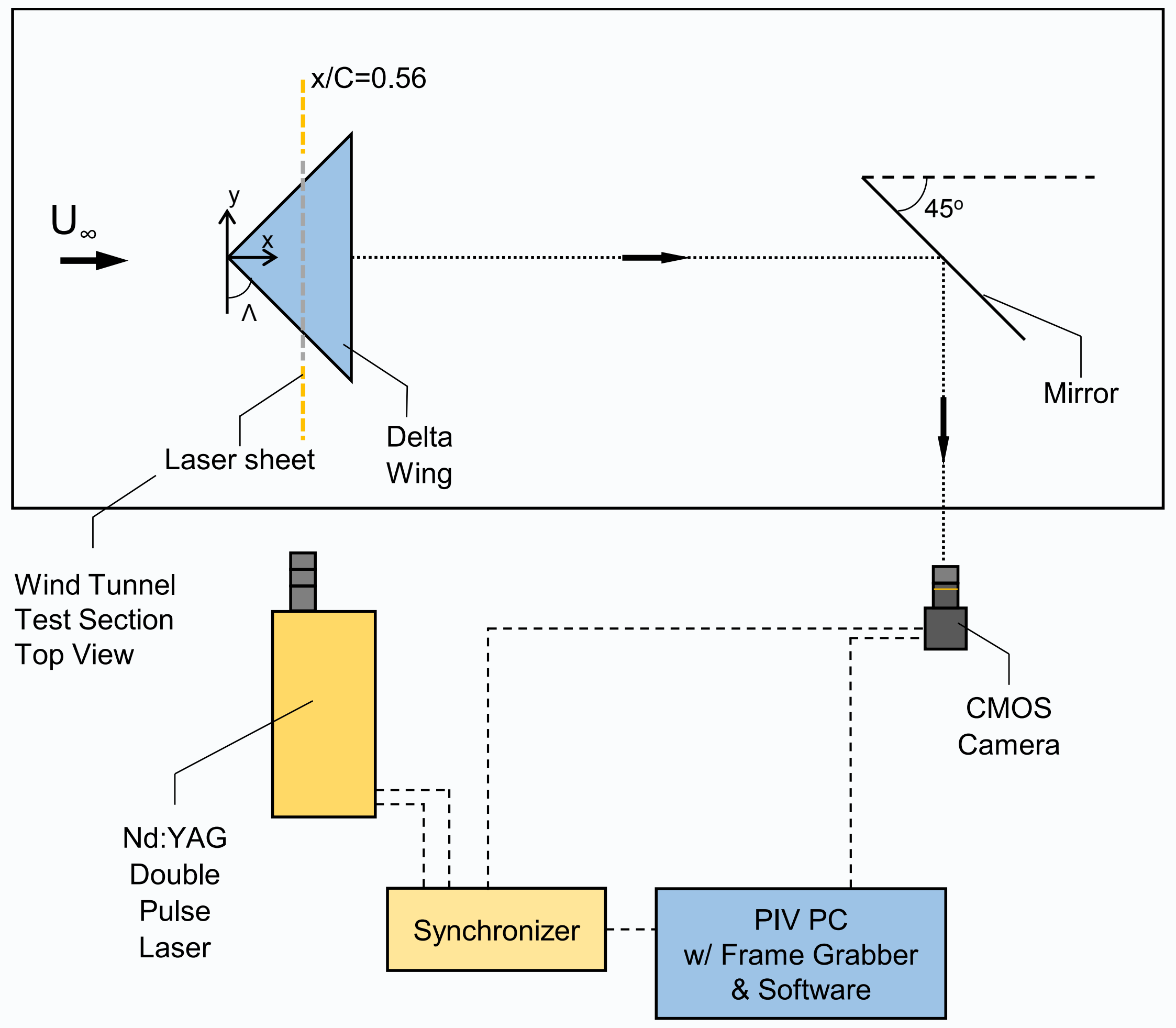


Figure 6. Schematic of the cross flow PIV setup.

Test Cases:

Reynolds Number

Re = 3.5x10^4

Attack Angles

α = 7 - 20 deg

Unsteady Blowing

- Square wave pattern
- 25 % Duty Cycle
- f = 2 - 24 Hz
- $C_{\mu,eff}$=0.0025

Steady Blowing

- C_μ=0.0025, 0.01

Results:

Surface Pressure Measurements

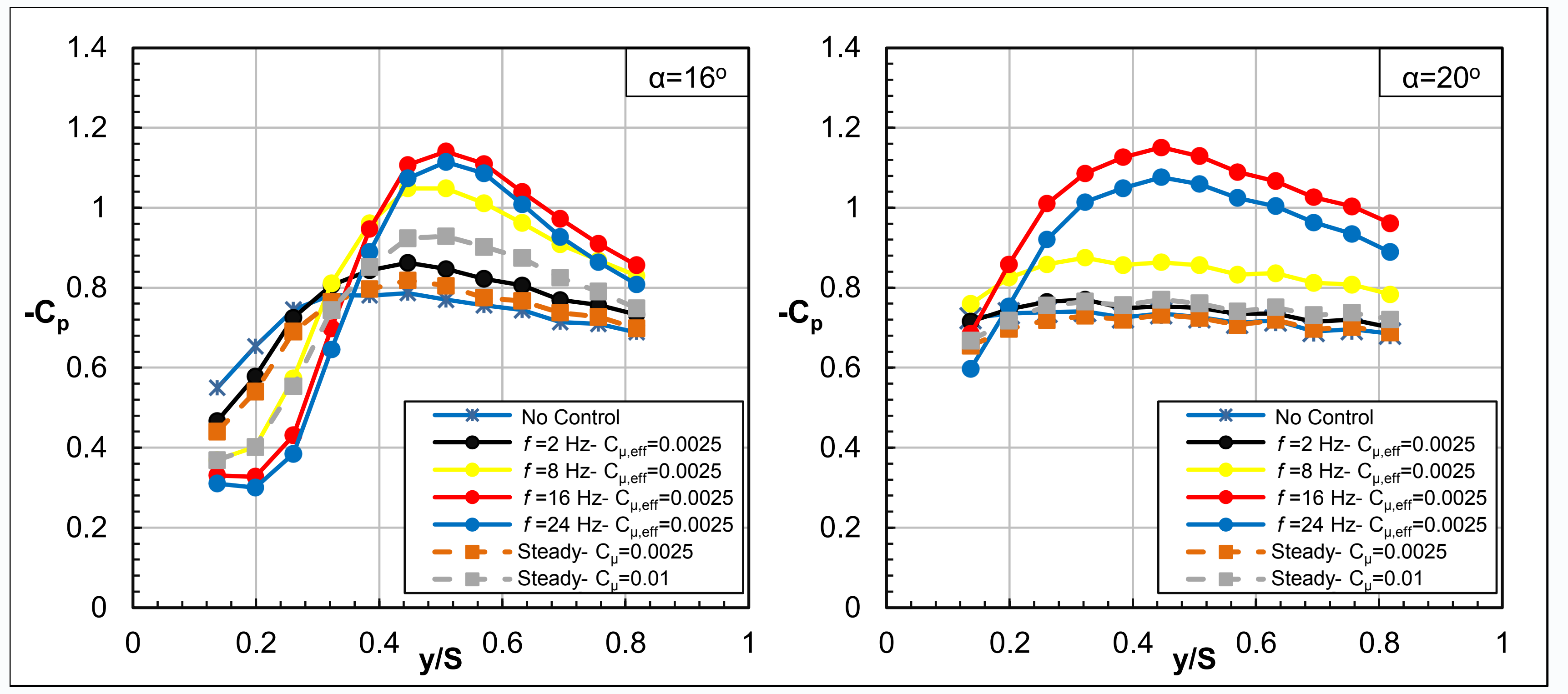


Figure 7. $-C_p$ distributions of half span wing for attack angles α=16 deg (left) and α=20 deg (right)

Flow Visualization

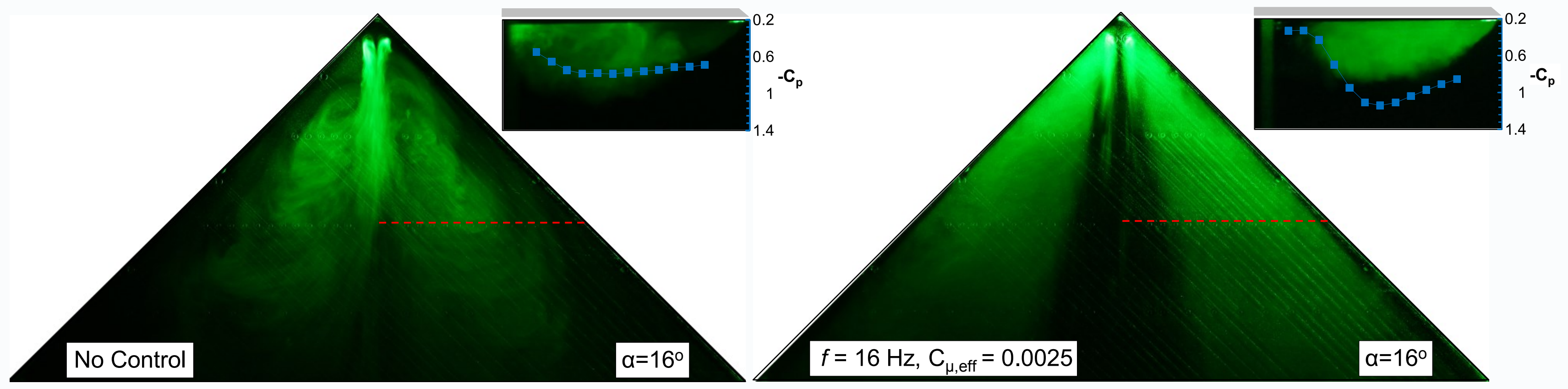


Figure 8. Surface and cross flow visualiazation at α=16 deg: no control (left), periodic blowing at f =16 Hz (right).

PIV Measurement Results

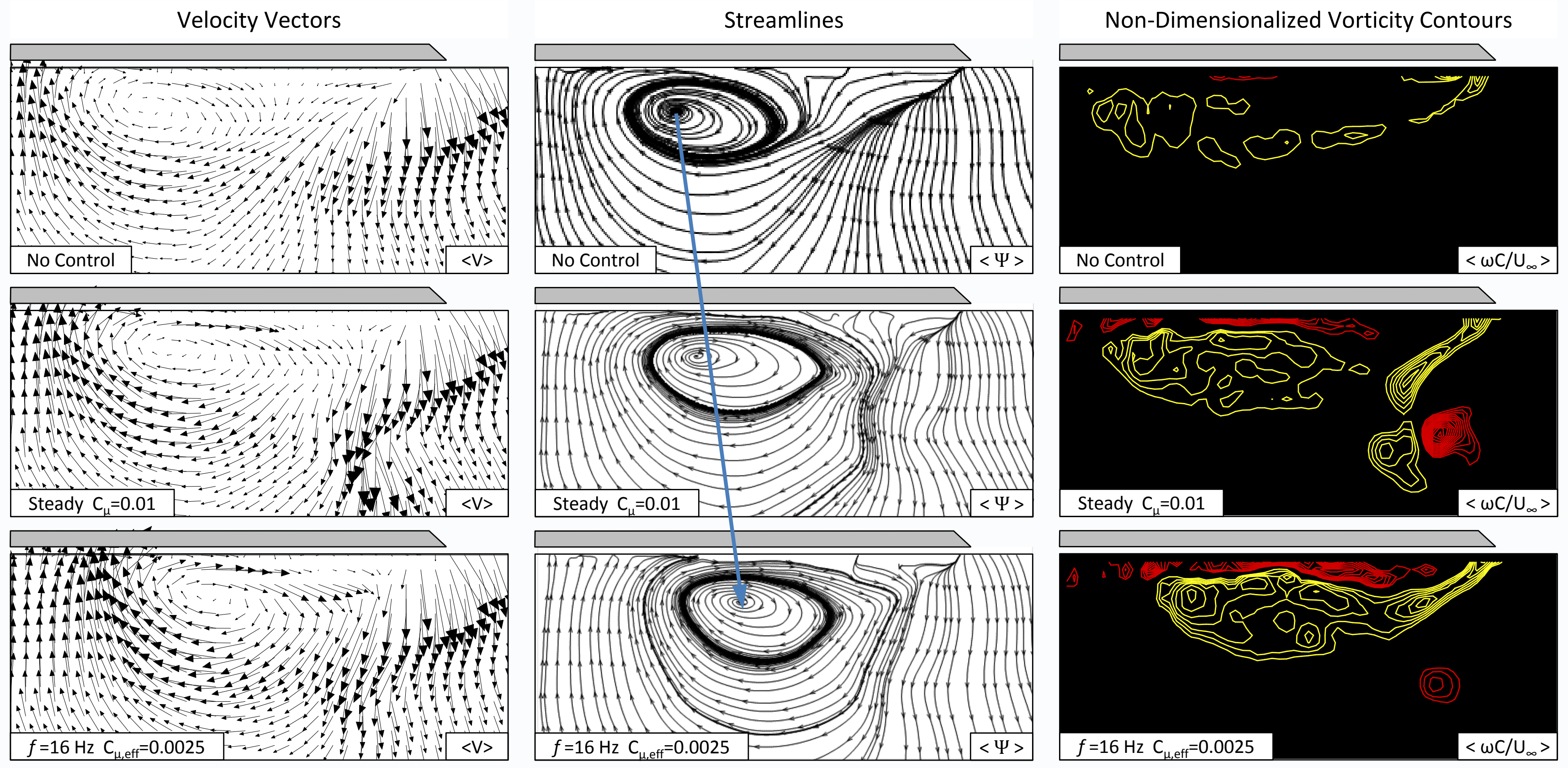


Figure 10. Patterns of time averaged velocity vectors, streamlines and contant contours of vorticity

Conclusions:

1) **Periodic blowing in the form of square wave applied through the leading edge substantially improves the flow structure on nonslender delta wing, such that it causes eradication of the three dimensional surface separation and recovery of vortical structue.**
2) **The effect of the periodic blowing on control of flow structure strongly depends on the frequency of the excitation.**
3) **Unsteady blowing exhibits superior performance compared to the steady blowing particularly at relatively high attack angles with injecting the only one fourth of the momentum induced by the steady blowing.**