COMSOL CONFERENCE
2014 BOSTON

Vaughn College of aeronautics and technology

Drag fluctuations of a fully deployed flow actuator embedded inside turbulent boundary layer flow

Presented by:

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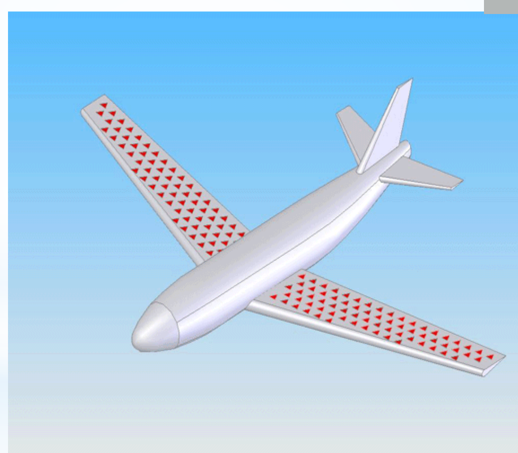
OMotivations

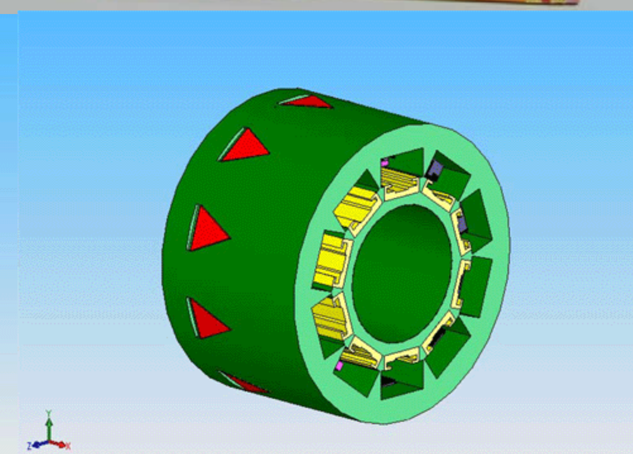
▪UAV (Unmanned Arial Vehicles) & MAV (Micro Arial Vehicles)
Low Reynolds number flight to be designed based on transient condition.

▪Flight Control

➢Redundant control elements improve system safety

➢Potential to improve maneuverability.

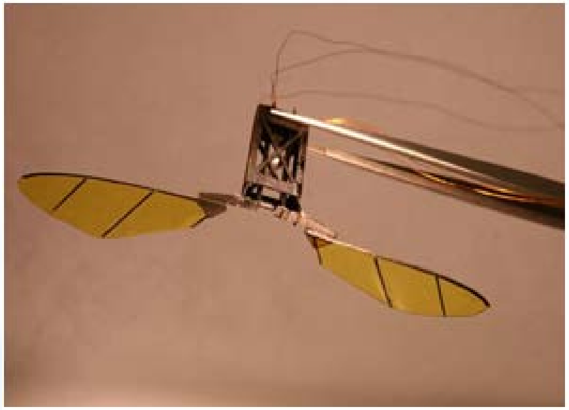




Motivations

- Increasing desire to understand <u>flapping flight</u> to mimic birds and insects flight.

Conceptual design by DARPA



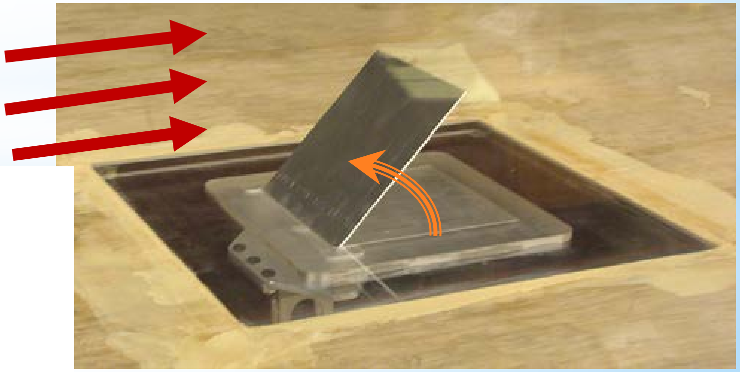
left: M. L. Anderson and N. J. Sladek (Air Force Institute of Technology), Right: H. Lipson and C. Richter (Cornell University)

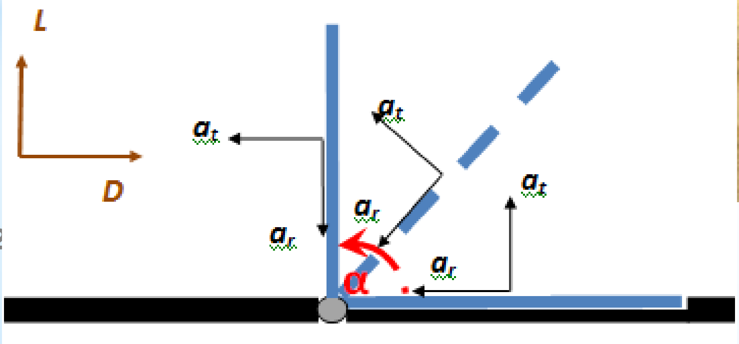
Previous Experimental Work

- Low Speed Wind Tunnel (up to 11 m/s) with testing area of 8.4 m^2.

- An embedded actuator in the WT wall is deployed against the incoming TBL.

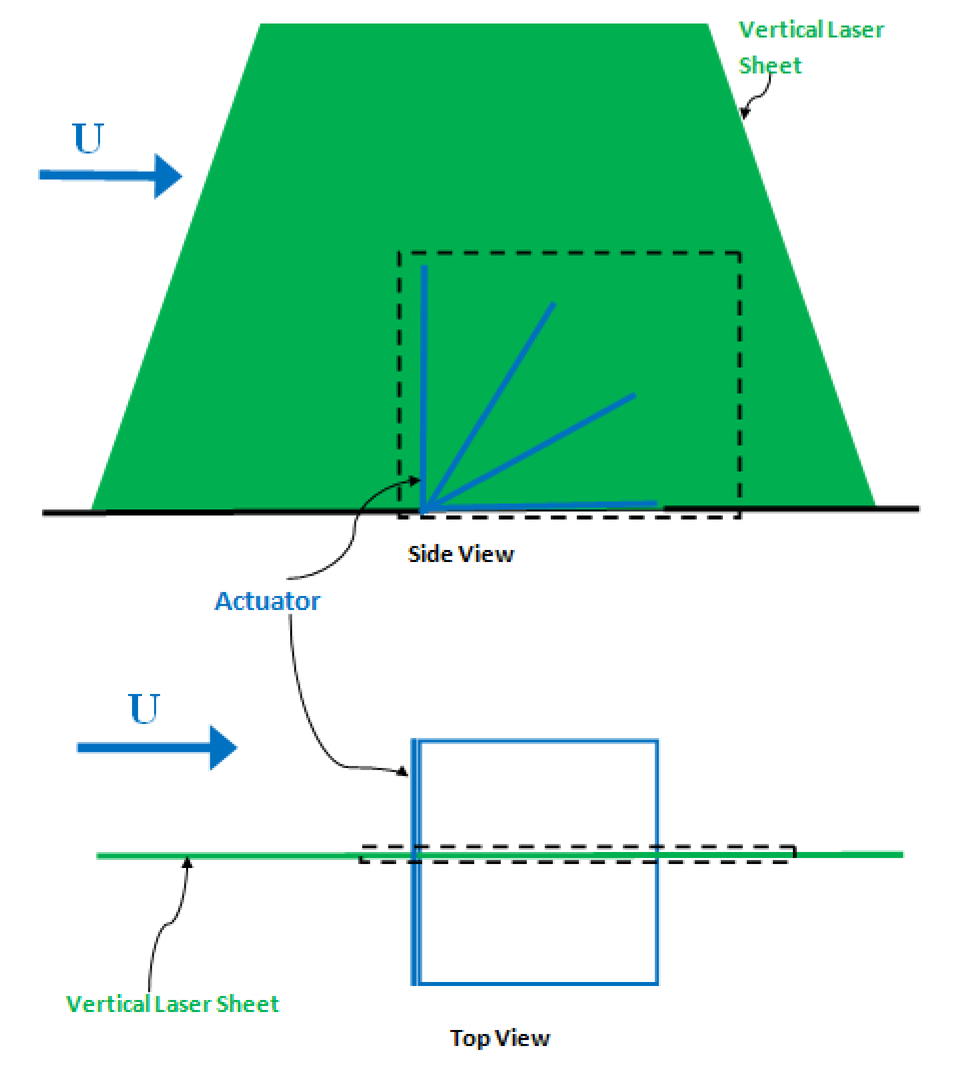
- In these experiments, the focus is on the unsteadiness of the flow field during the deployment





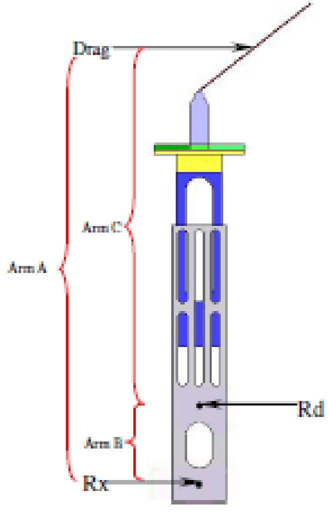
Experiments Parameters:

U (Freestream)	Range from 3.7~ 11 m/s
Deployment Speed (servo motor)	2 ~ 26 rad/sec
Strouhal Number defined here as: $Str=U_{tip}/U_{freestream}$	0.03 ~ 0.54

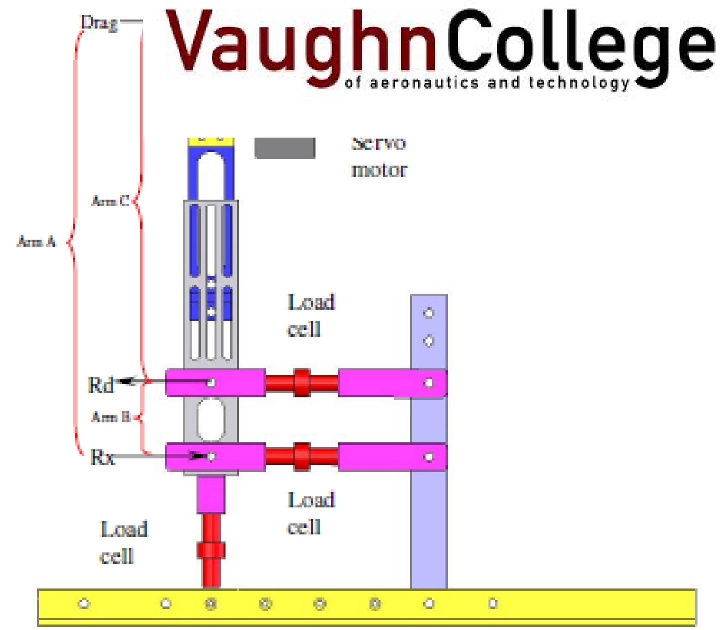


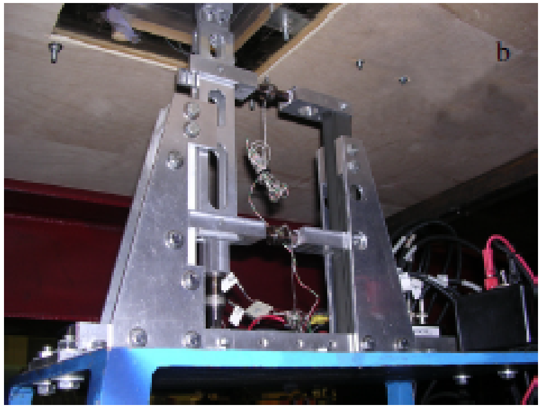
Aerodynamics Forces Direct Measurements:

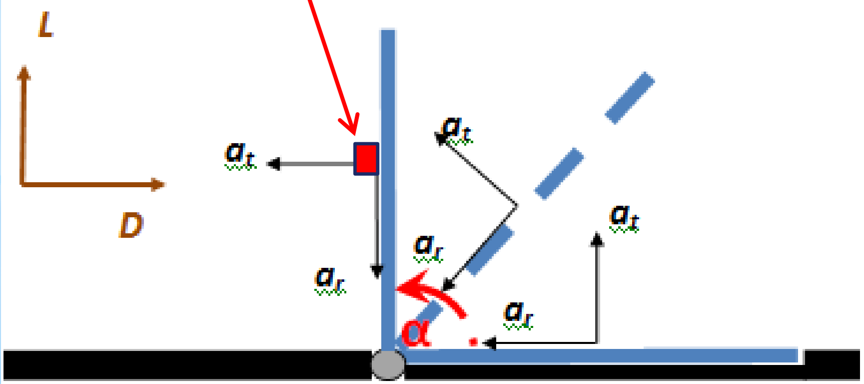
- Drag and Lift are measured using Three load cells.
- The Inertia Forces are also accounted for by measuring the actual Tangential and Radial accelerations.



Free Body Diagram

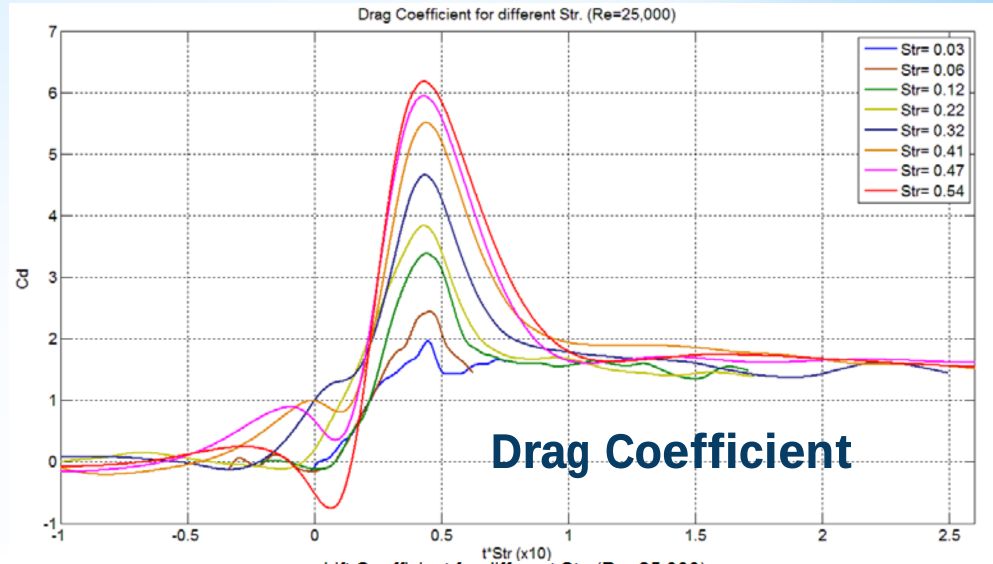


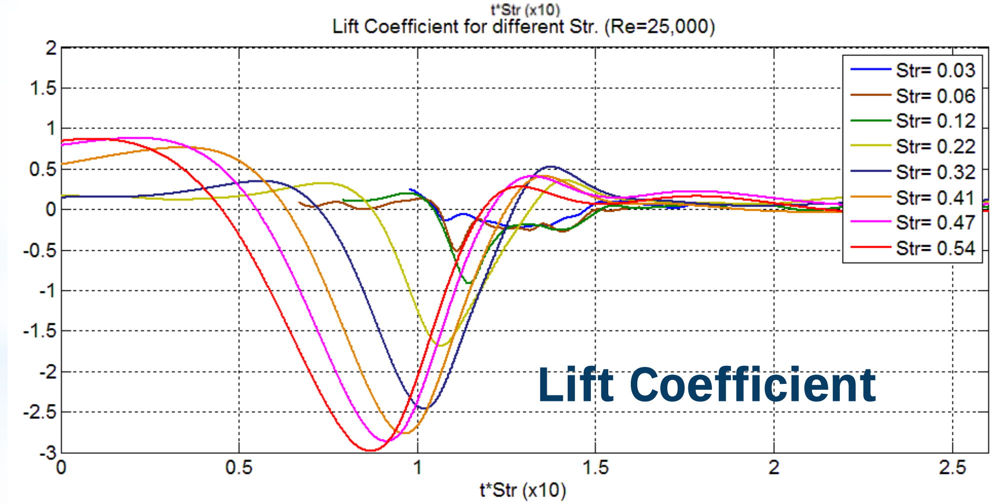




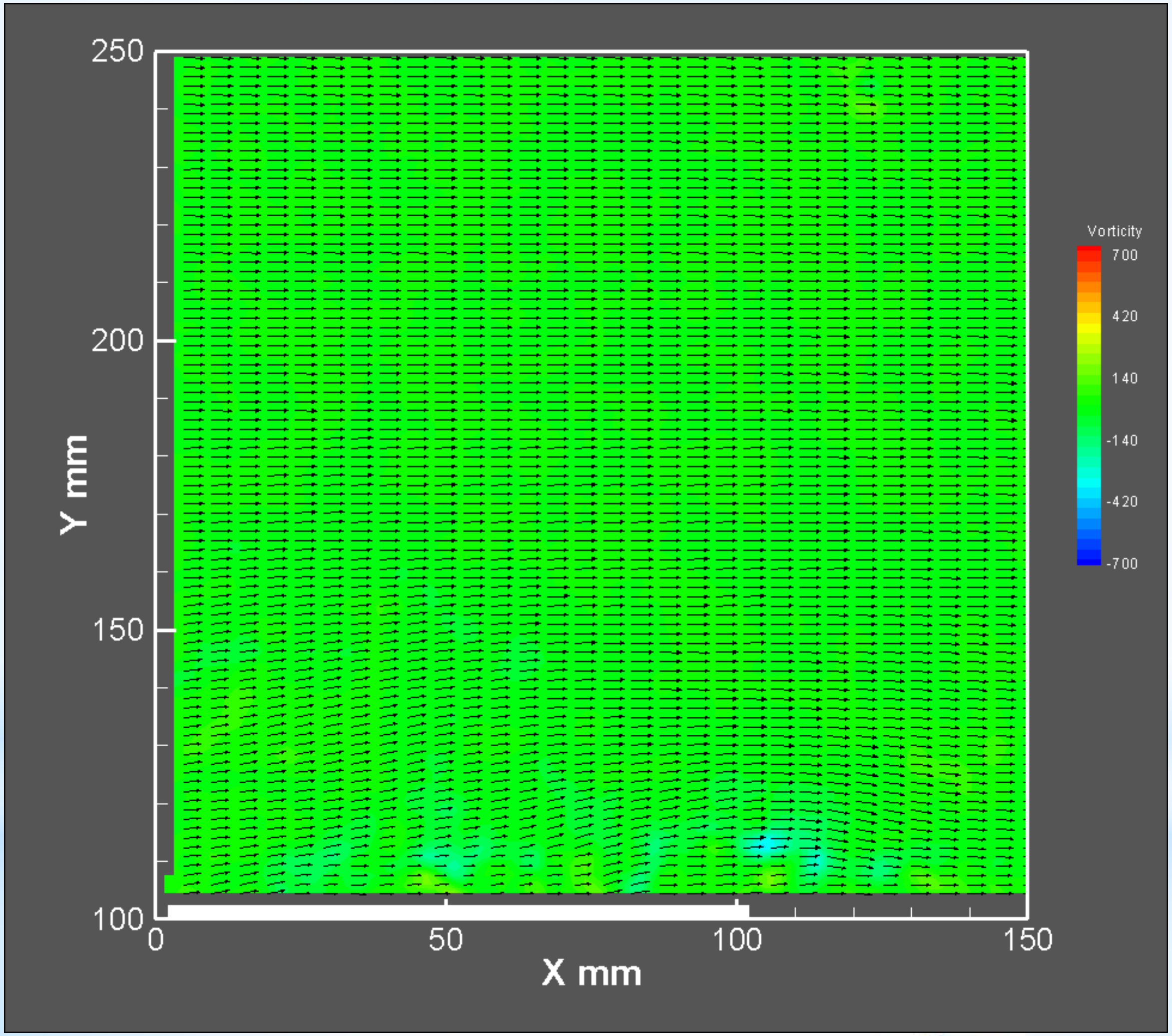
➢Aerodynamic force measurements indicated:

1. At low Strouhal number the aerodynamic coefficients show quasi-steady state behavior
2. With the increase of Str. Number, the aerodynamic coefficients showed enhancement in their transient response for both the Lift and the Drag.

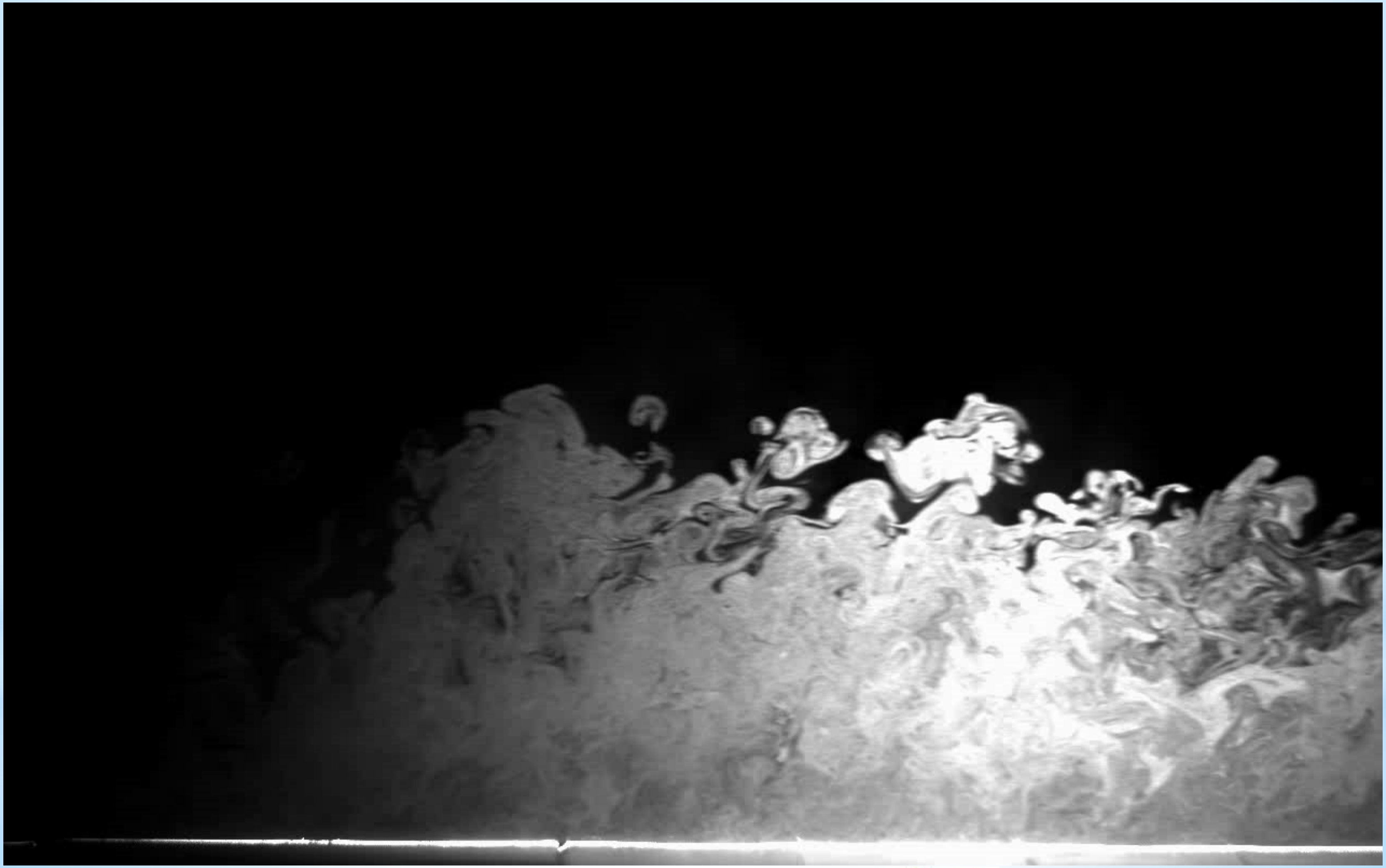




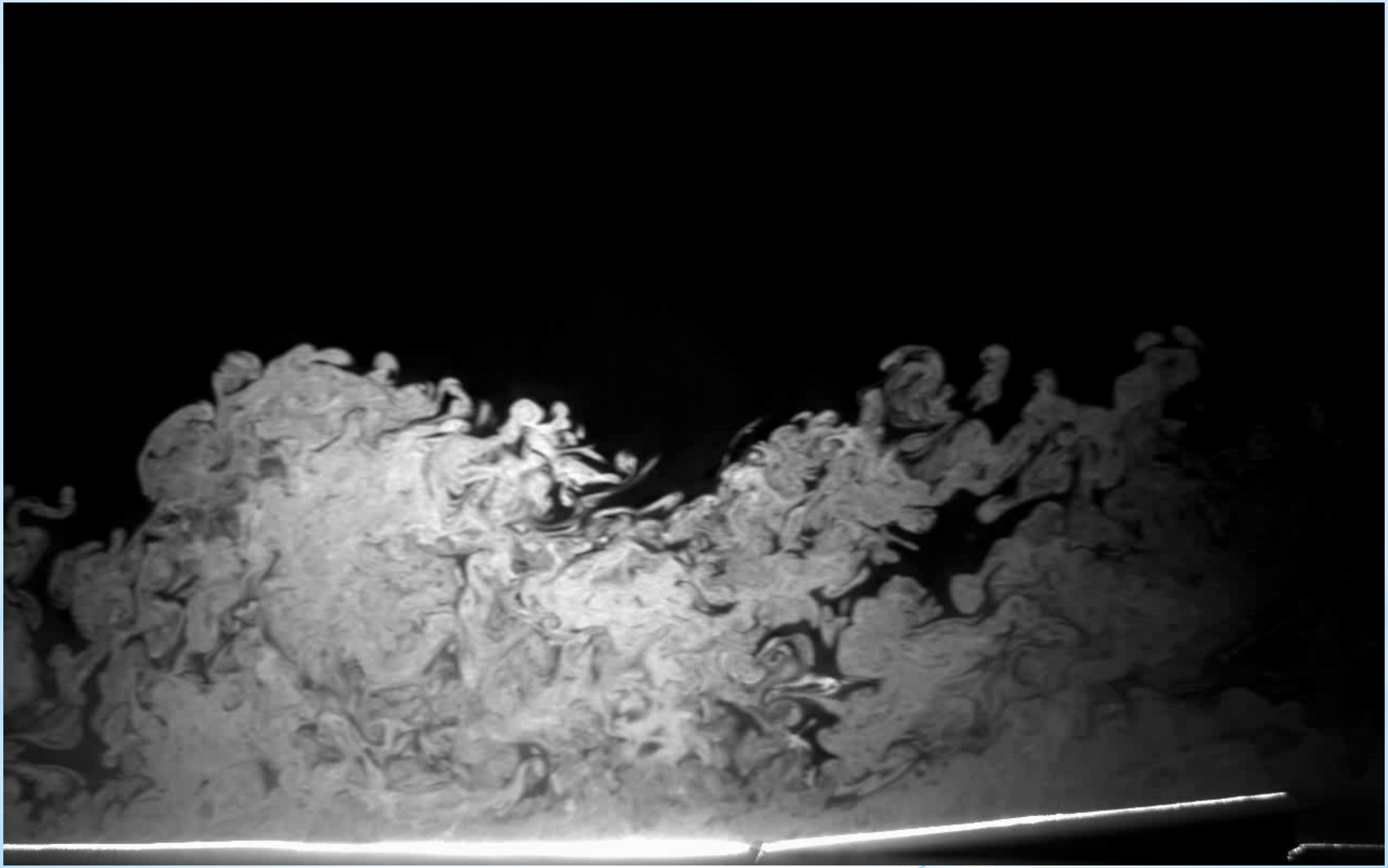
TR-PIV Results: Vorticity (Str=0.27, U=3.7m/s)



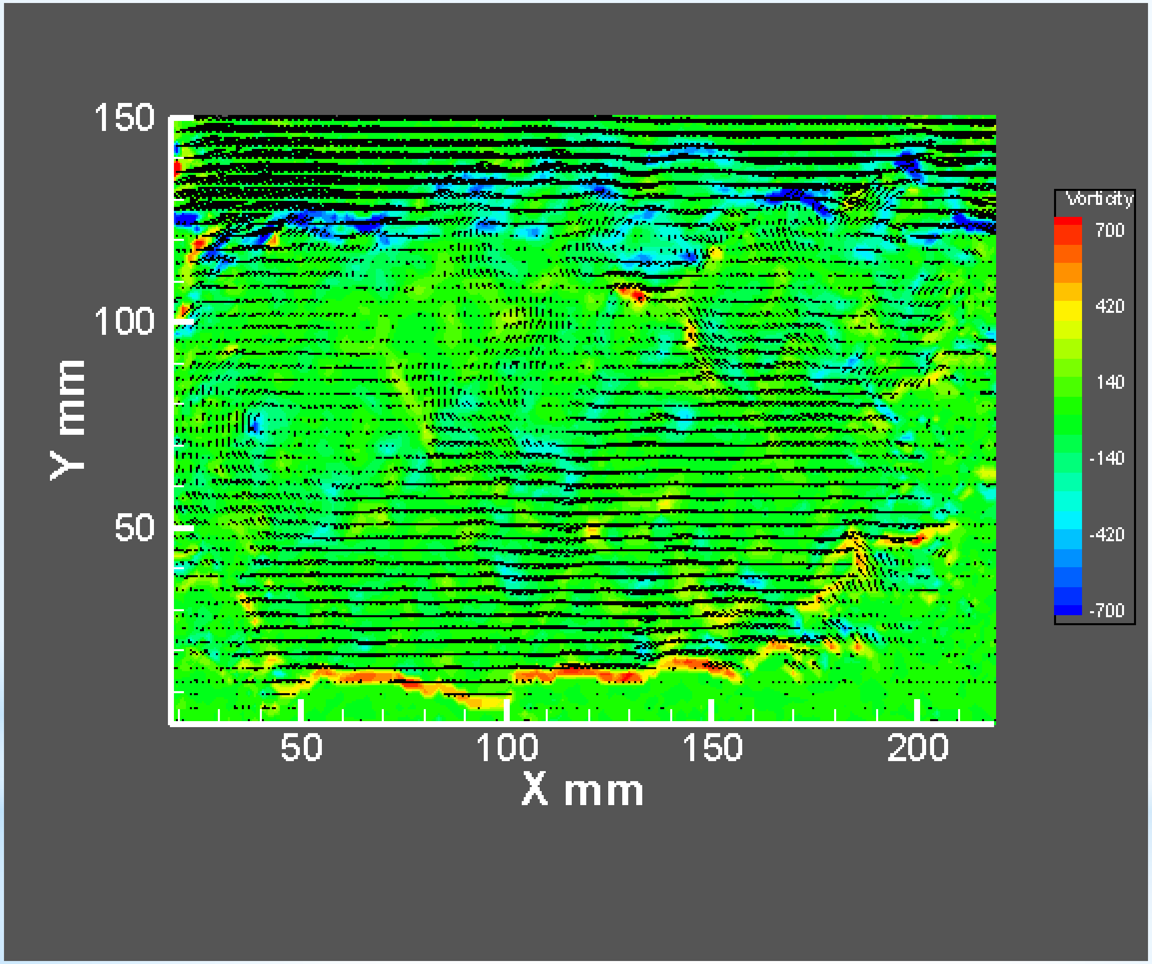
Flow visualization for dynamic deployment, downstream case (U=3.7m/s)



Flow visualization for dynamic deployment, upstream case (U=3.7m/s)

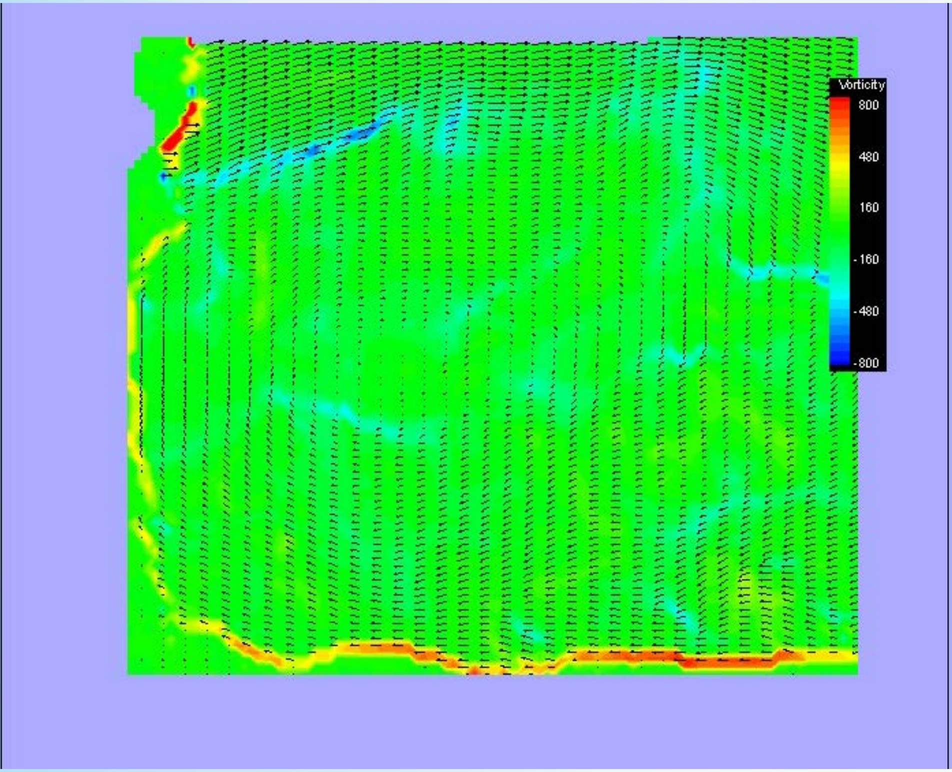


TR-PIV Results: Vorticity (Steady State, U=3.7m/s)

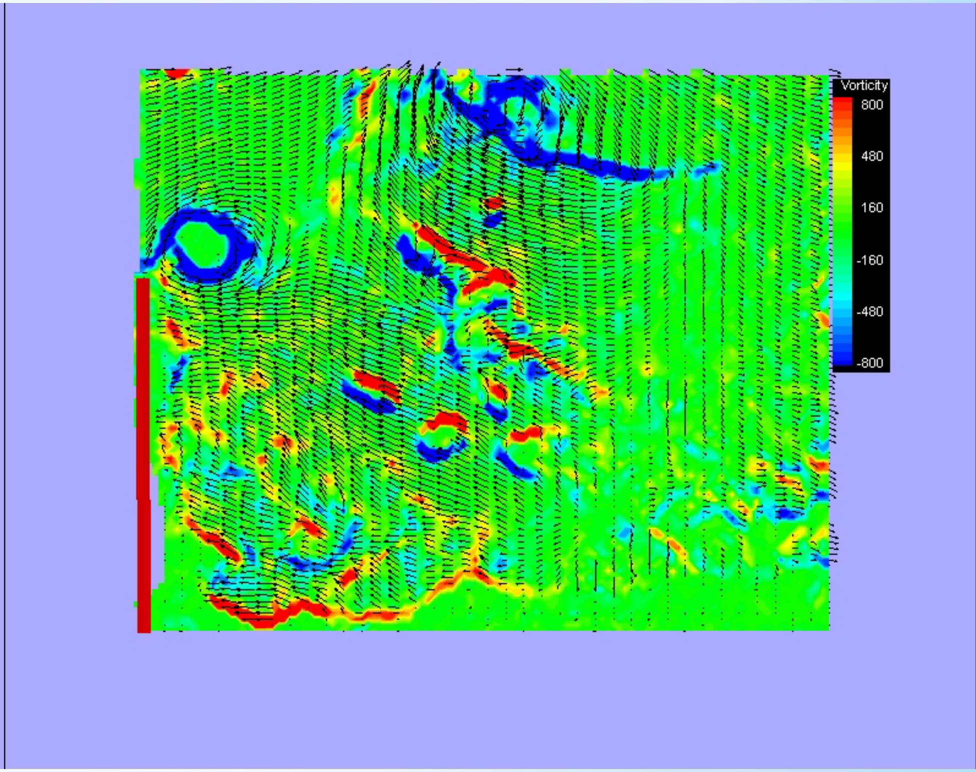


ts:

Vorticity Str=0.03



Vorticity Str=0.27

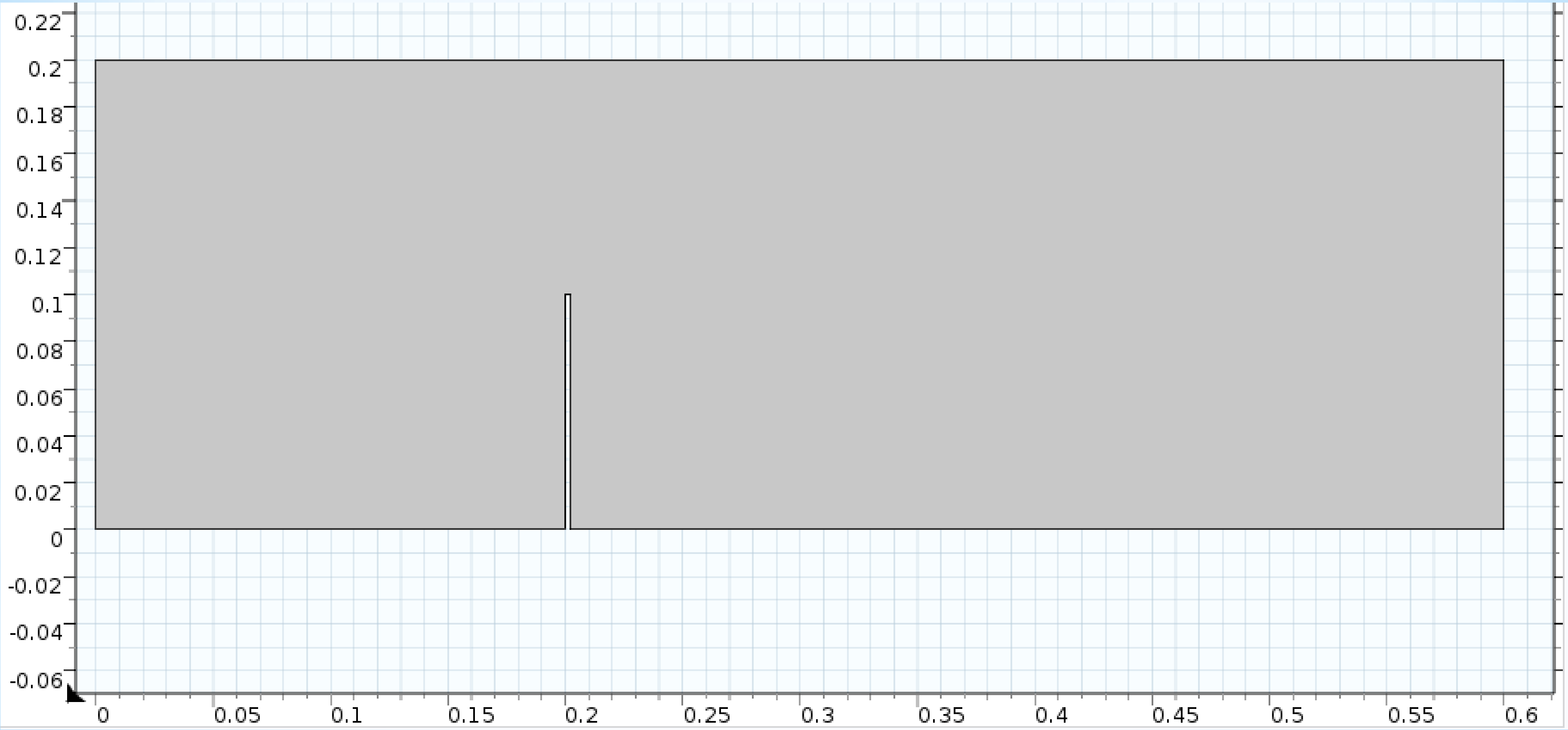


Initial COMSOL Model Objective:

* The objective of this model is establish common grounds between the experimental and the CFD problem.
* This model will be used to compare the flow developing structure such as vortices, stagnation points, etc.
* Identify a meshing size and/or meshing technique using the PIV results as a benchmark.

*COMSOL Model Setup (1):

- 2 Dimensional model: to allow us to use fine meshing
- Static case for 90° degree fully deployed actuator.



COMSOL Model Setup (2):

Physics: Time dependent - Turbulent Flow, k-ε

Boundary Conditions:

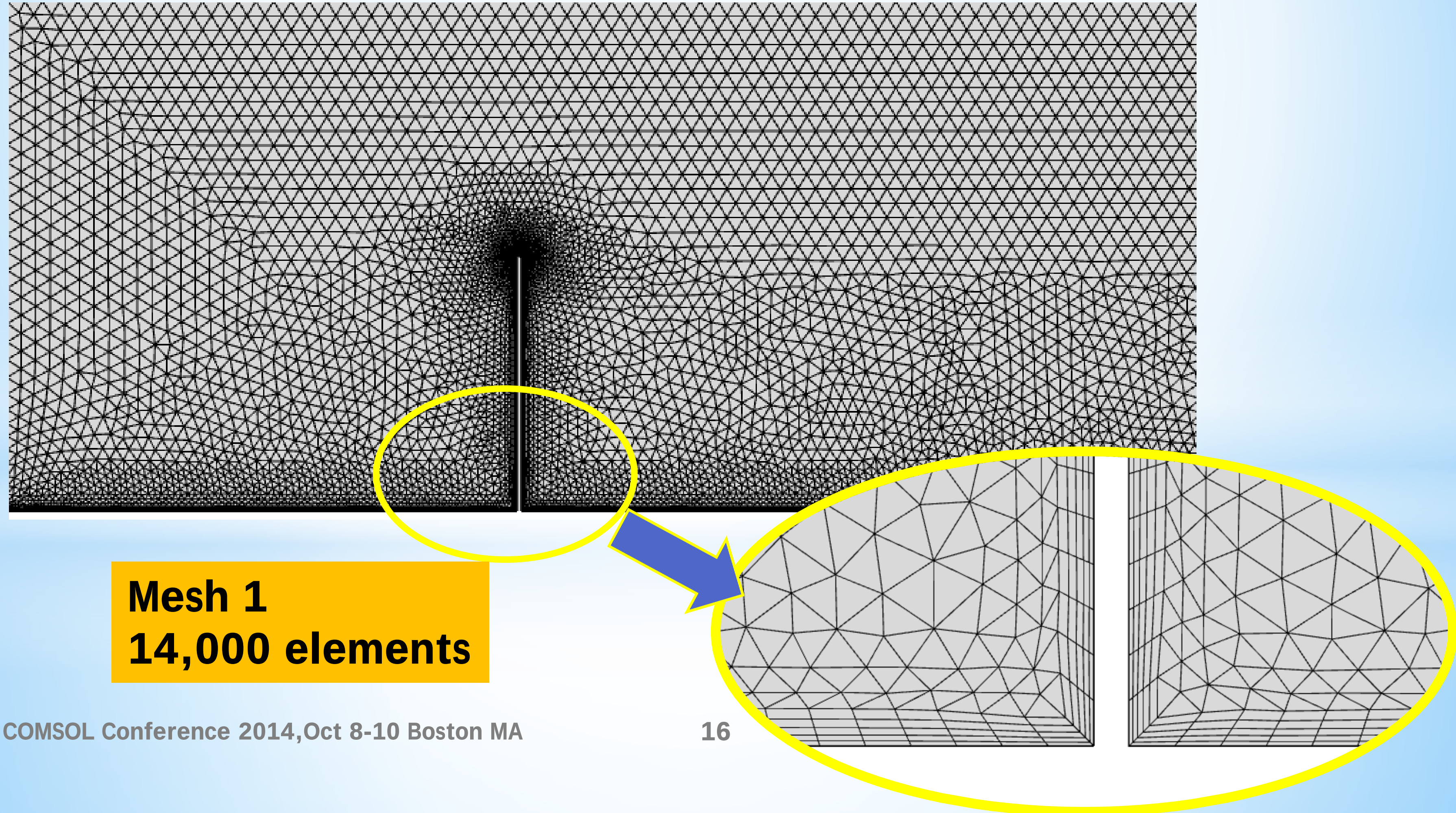
* Velocity inlet on the left (U=3.74m/s)
* Pressure Outlet on the right (p=0)
* Pressure outlet on the top (p=0)

Initial Condition

* Velocity =3.74 m/s (for quick conversion)

Meshing :

- Adaptive mesh refinement (Physics Controlled mesh)
- Intensive boundary layer meshing.



Mesh 1
14,000 elements

COMSOL MULTIPHYSICS

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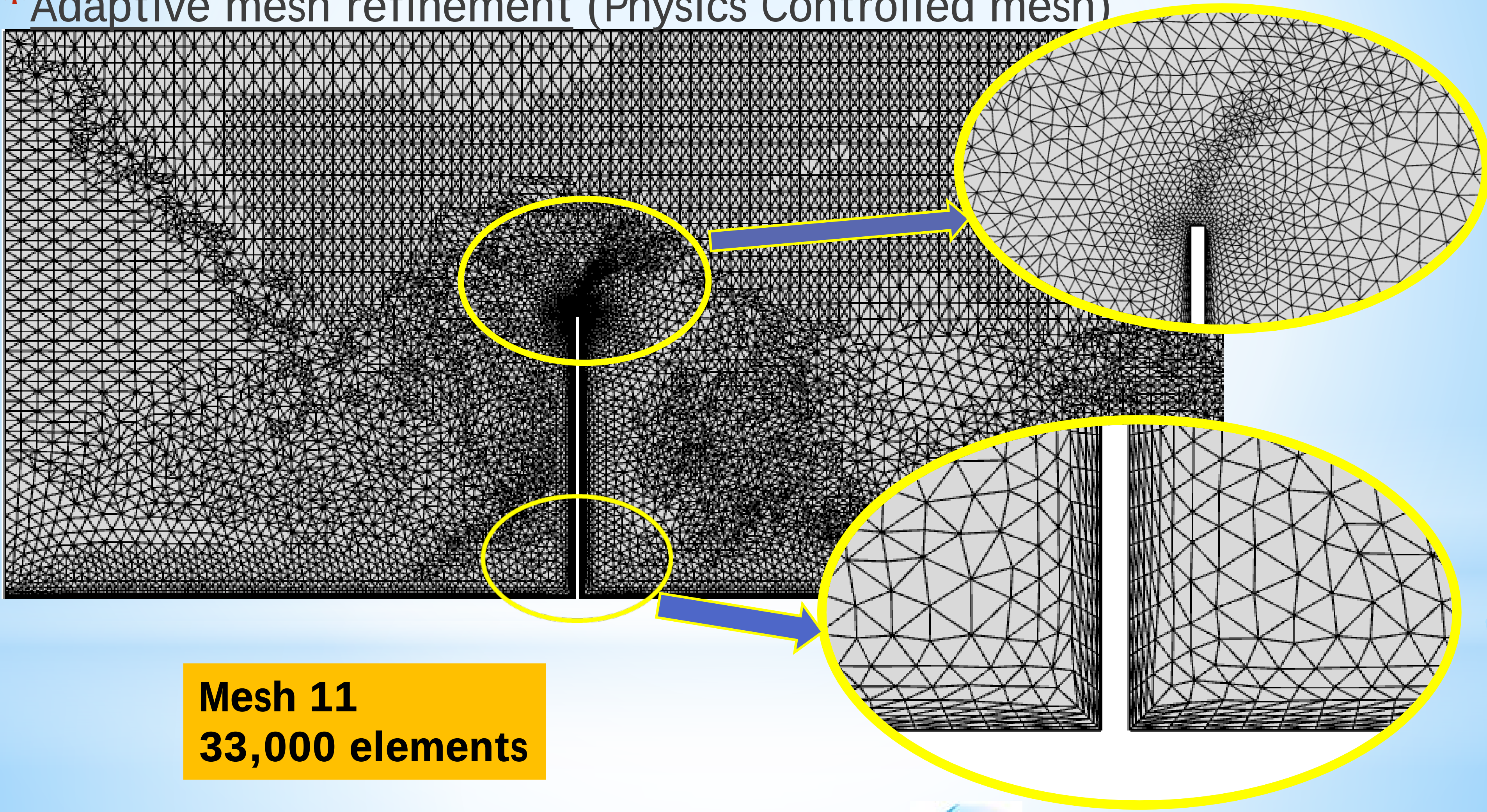
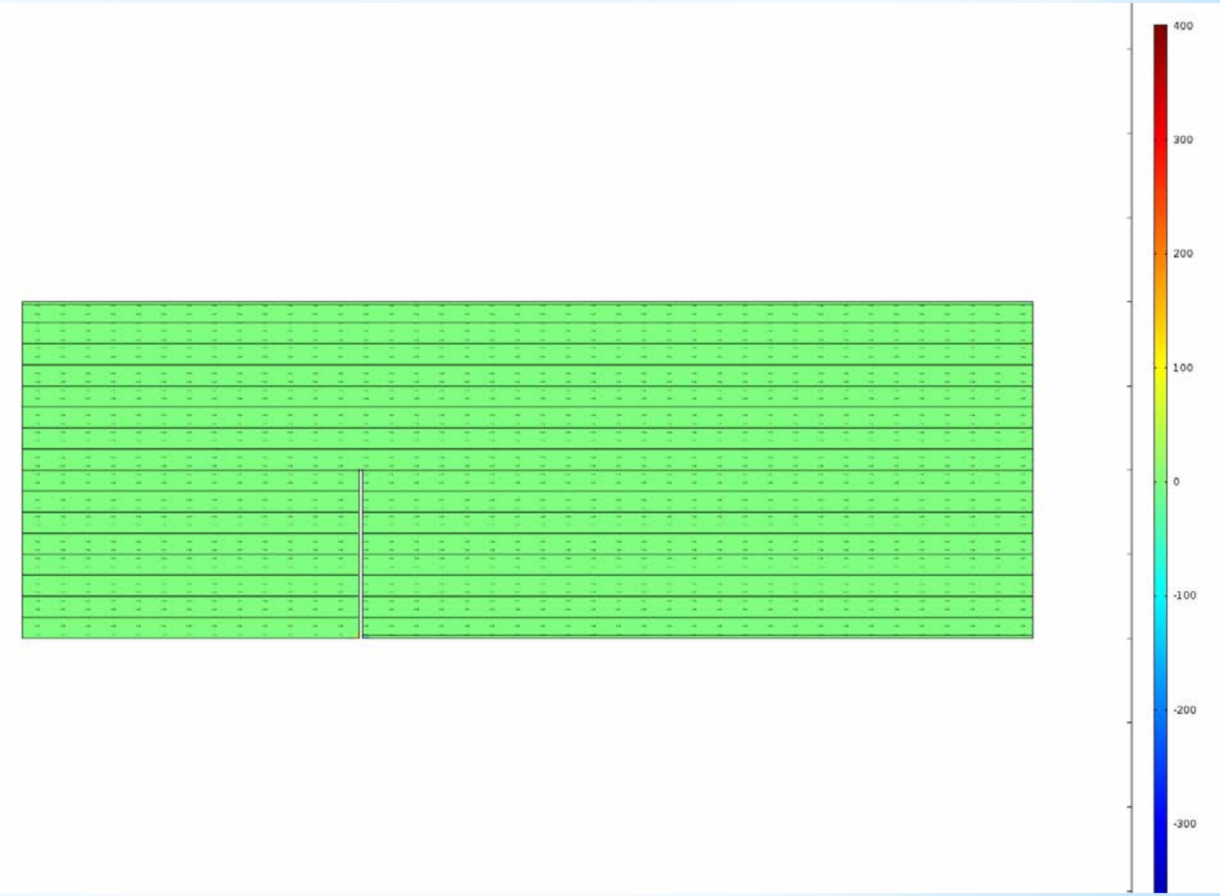
Meshing :

* Adaptive mesh refinement (Physics Controlled mesh)



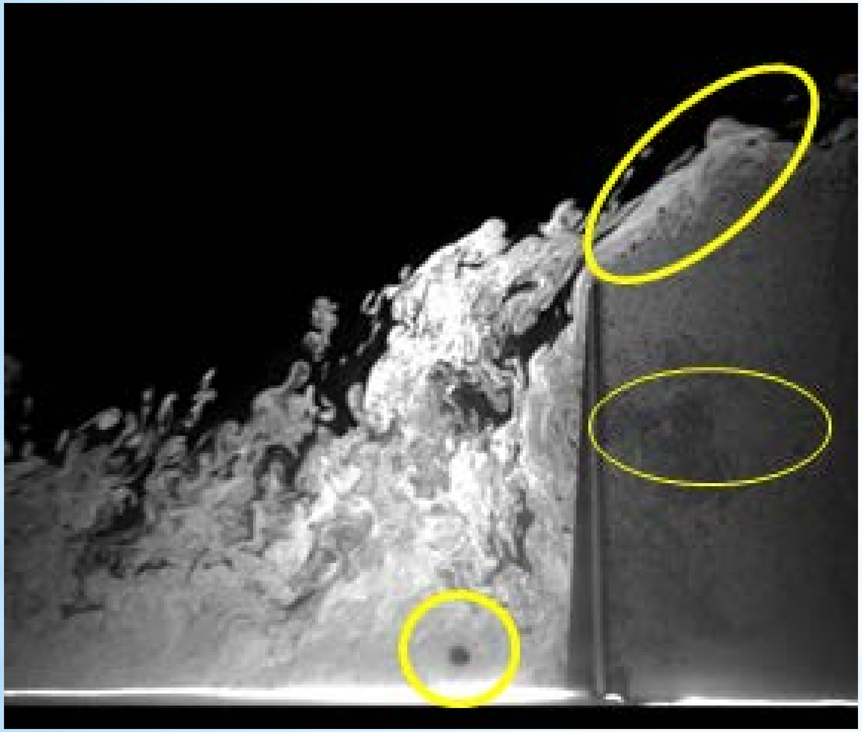
Mesh 11
33,000 elements

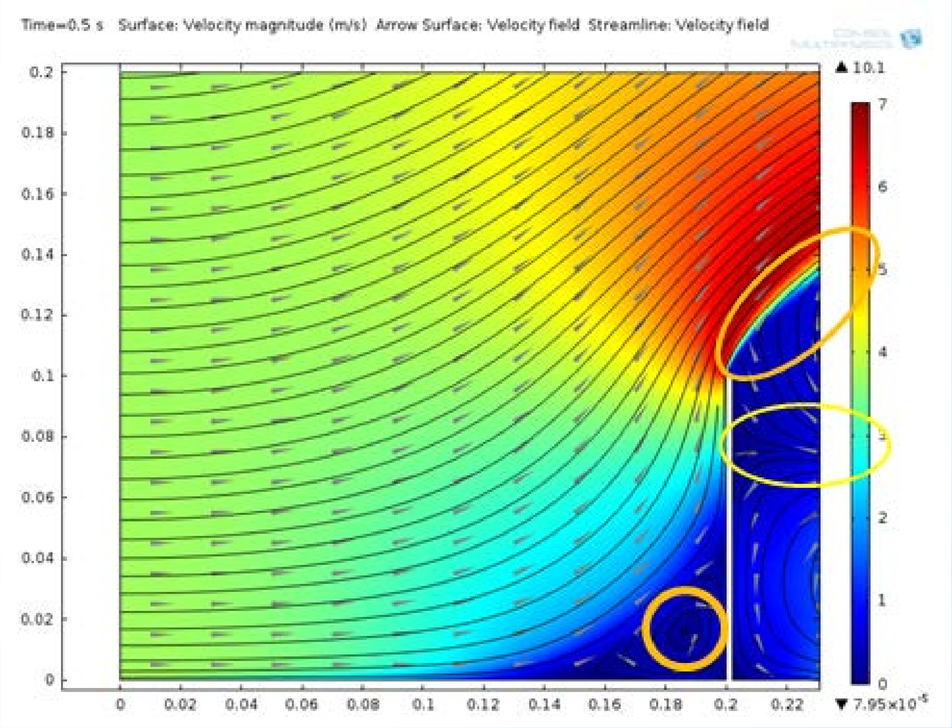
Results (Vorticity field in the z-direction) streamlines and velocity vectors)



Results

* flow structure flow visualization experiment and COMSOL model.





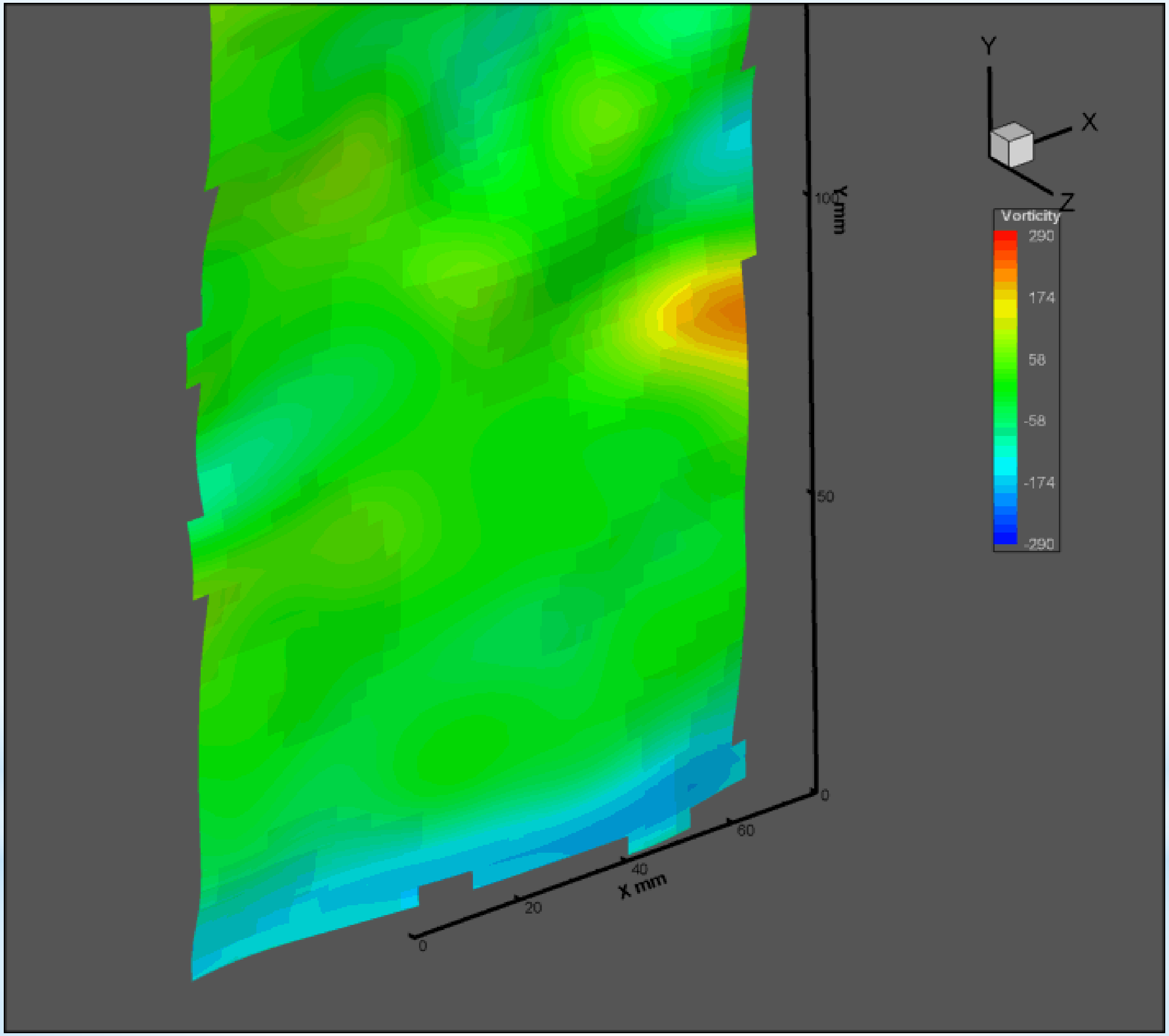
Summary

- Time dependent Flow for a fully deployed actuator in turbulent boundary layer is simulated in COMSOL.
- The 2D flow model is compared to a similar experimental case.
- The time dependent modeling of the flow showed similarities to the experimental study.
- flow characteristics that is seen in the experimental case such as the upstream vortex and the tip vortex.
- An extension to this analysis to 3D dynamic deployment to the actuator to investigate the increase of transient drag seen in the experiments.

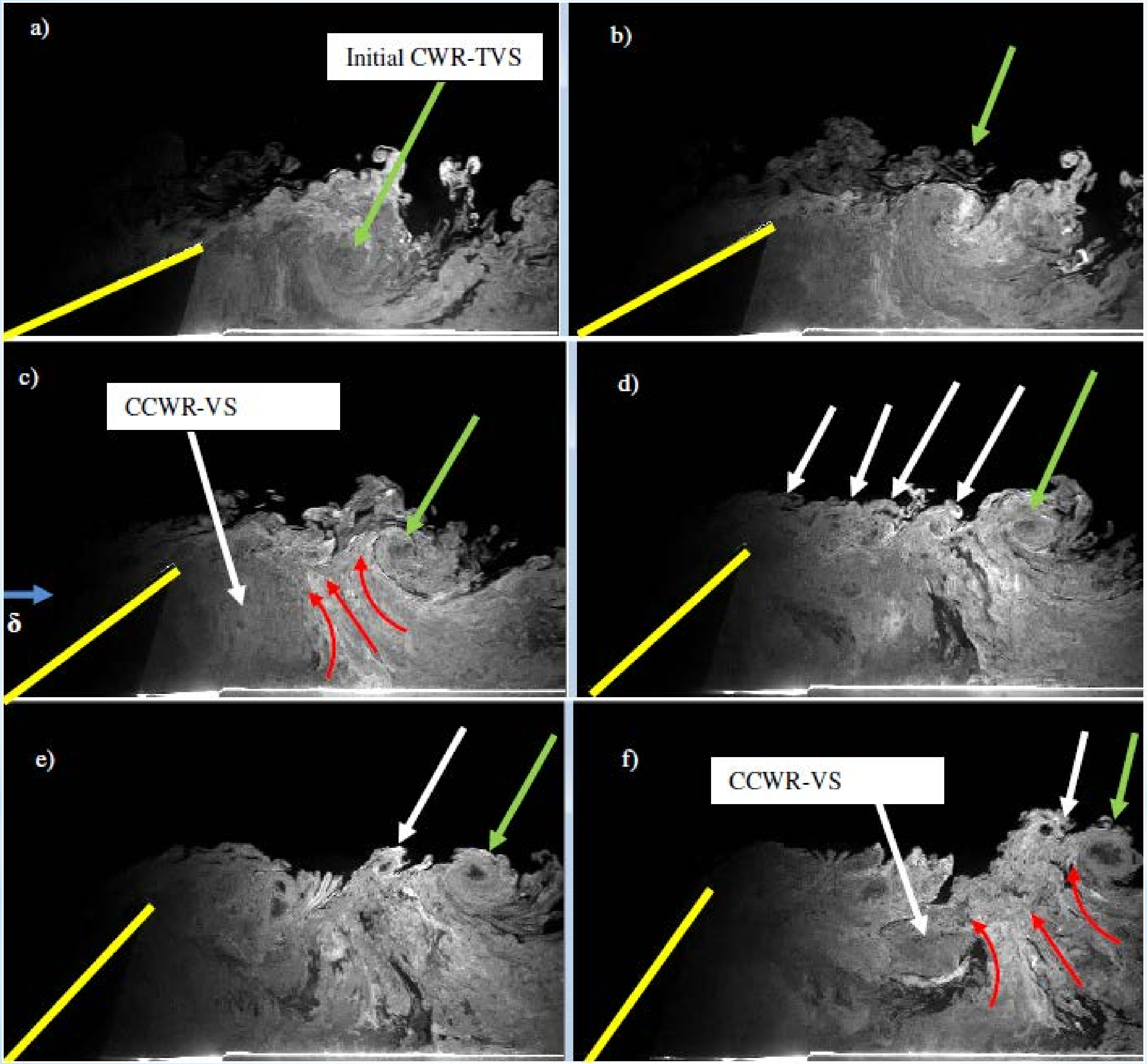
*Thank You!

Questions??

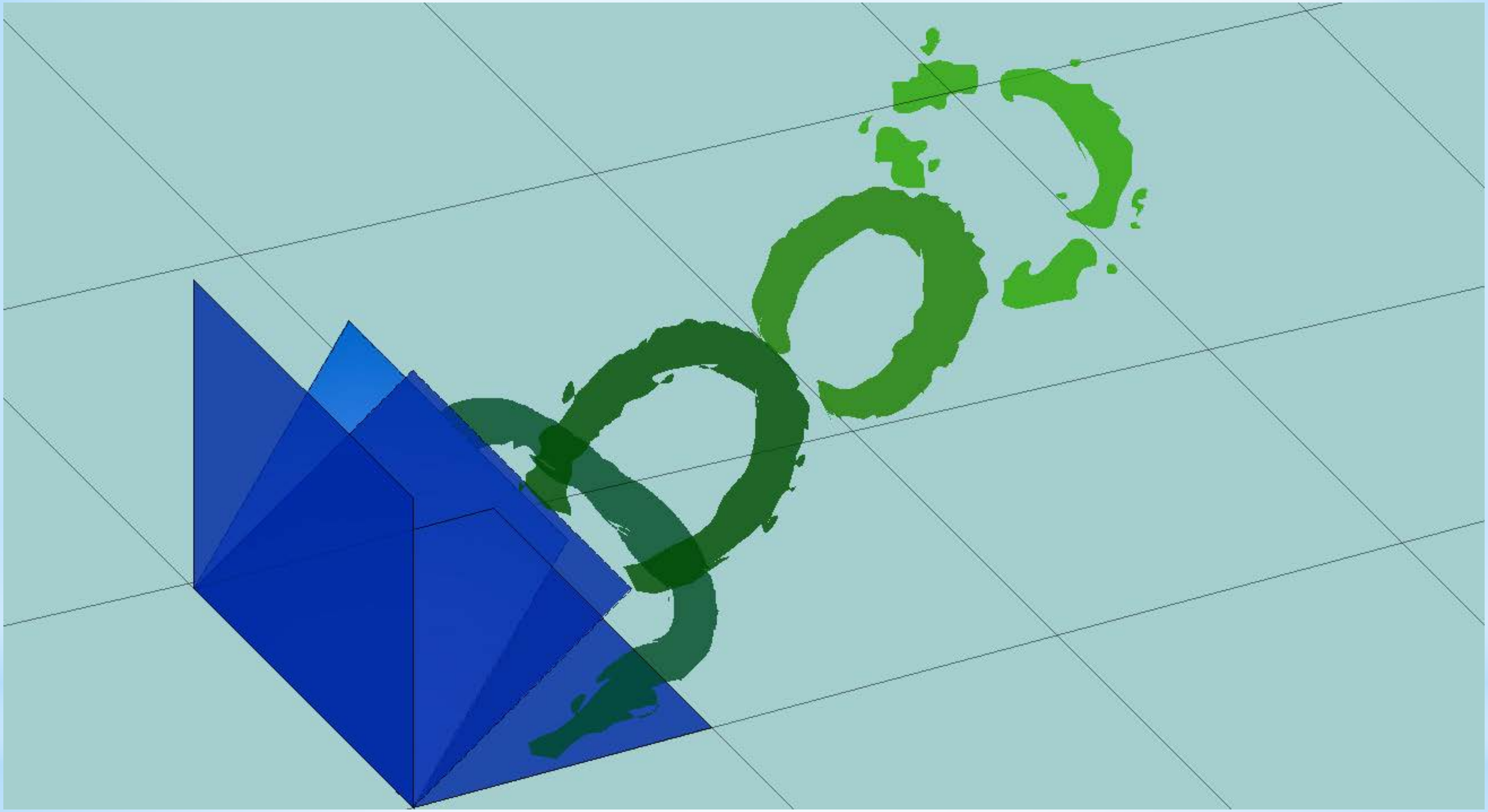
tereo-PIV Results (Vor



Flow Structure and Generated Vortices



Flow Structure and Generated Vortices



Summary:

- Modern Flight control and low speed flights such as UAV require the use of transient flow condition to improve aerodynamics.
- The impulsive deployment of a wall embedded actuator against turbulent boundary layer flow is investigated:
  - First, wind tunnel experiments are conducted to measure the transient forces generated on the actuator.
  - Second, Time Resolved PIV with CW laser experiments are conducted to compute the velocity field and the vorticity around the actuator during the deployment.
- TR-PIV is a velocity measurements technique to acquire the velocity field during unsteady condition, where many aerodynamics applications can be applied.
- Split View TR-SPIV is improvements to the technique allowed us to obtain 3-compnents of the velocity.

Current & Future Research area work:

- Applying the technique in other Transient Aerodynamics applications that mimic birds and insect flight (with 3D measurements).

(Recent Mathematical models uses the Far-Field velocity information to calculate the aerodynamic forces)

- Energy Harvesting applications using Piezo Elements.
- Interaction of Shock-Wave and Expansion waves.
- Solid Interaction with shock wave.

*Thank You!

Questions??

➢ Time Resolved-PIV

- Little is known about velocity of the flow transient conditions.
- There is a need Emerging aerodynamic applications "i.e. low Re flight, flight control applications" to design to be based on unsteady conditions for improved aerodynamics.
- TR-PIV made it possible to obtain the aerodynamics forces for unsteady flow using the Far-field velocity data (Wu 2005).

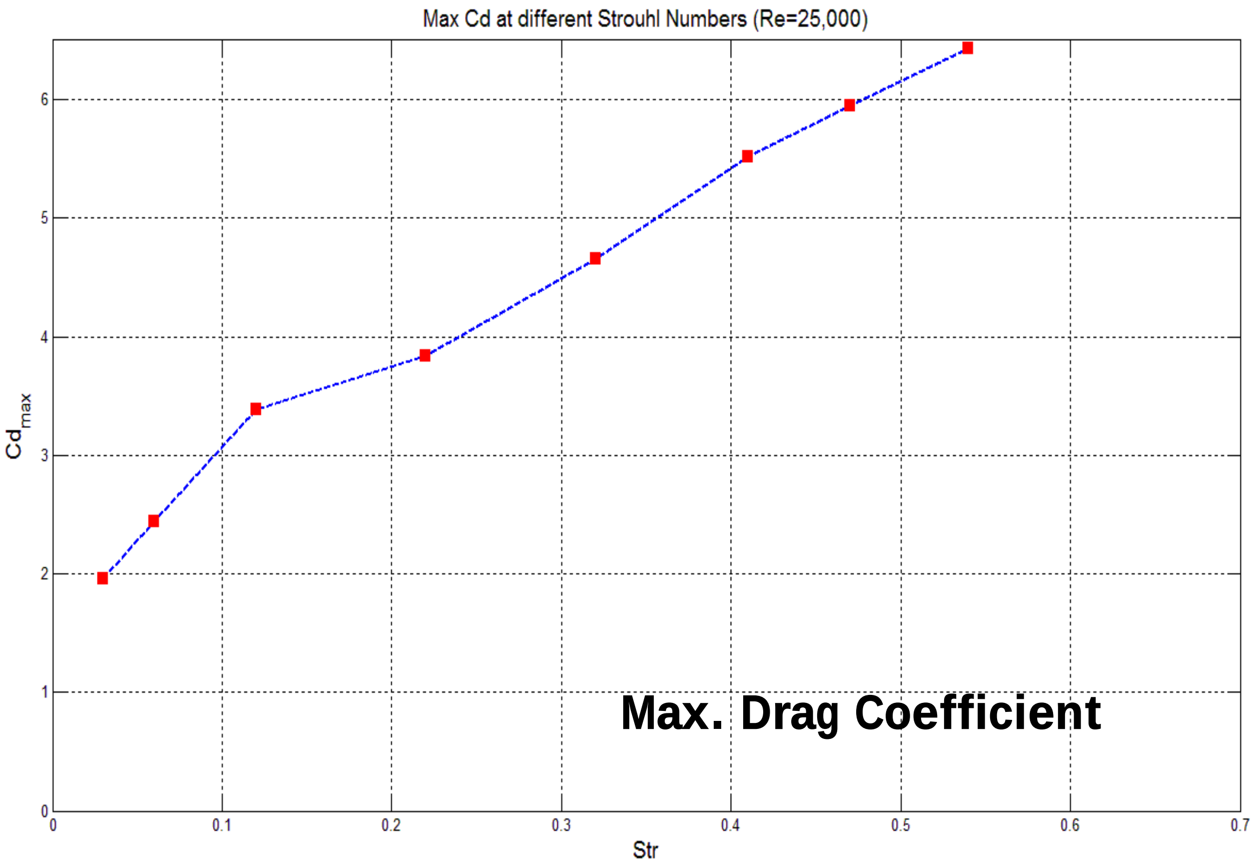
➢ **Other benefits of TR-Stereo PIV**

- In many 2D-flow applications, the 3rd velocity component “*w*” needs to be evaluated.
- Highly 3D-flow requires the measuring three components of the velocity.

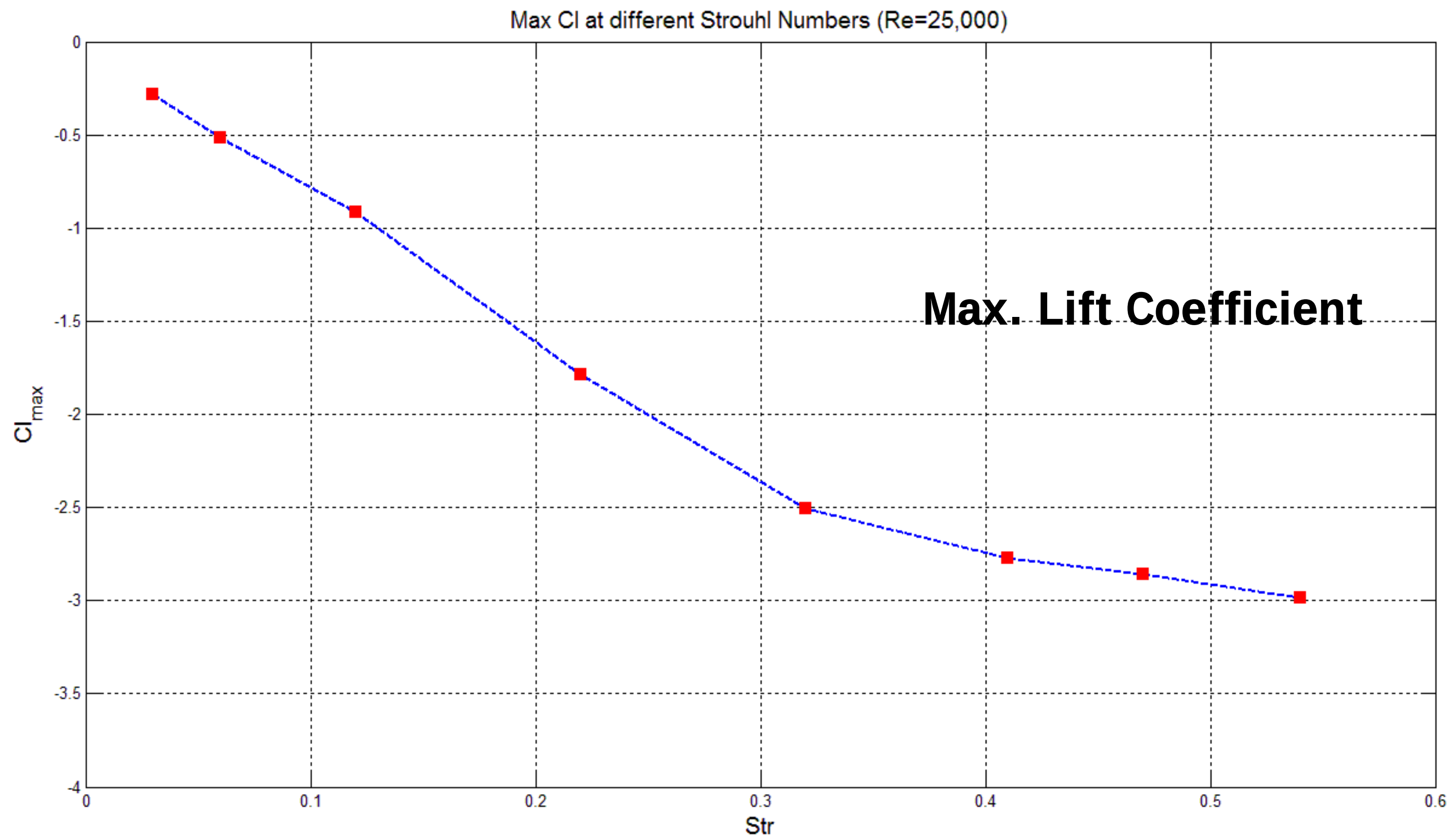
CW Laser with PIV (some info)

- Pulsed laser commonly used with PIV to reduce measurements uncertainty due to exposure time.
- CW laser was investigated and characterized to be used for TR-PIV for low to moderate Re number gas flow.
- The uncertainty is controlled reduced through optimizing the experimental settings and the images conditioning.

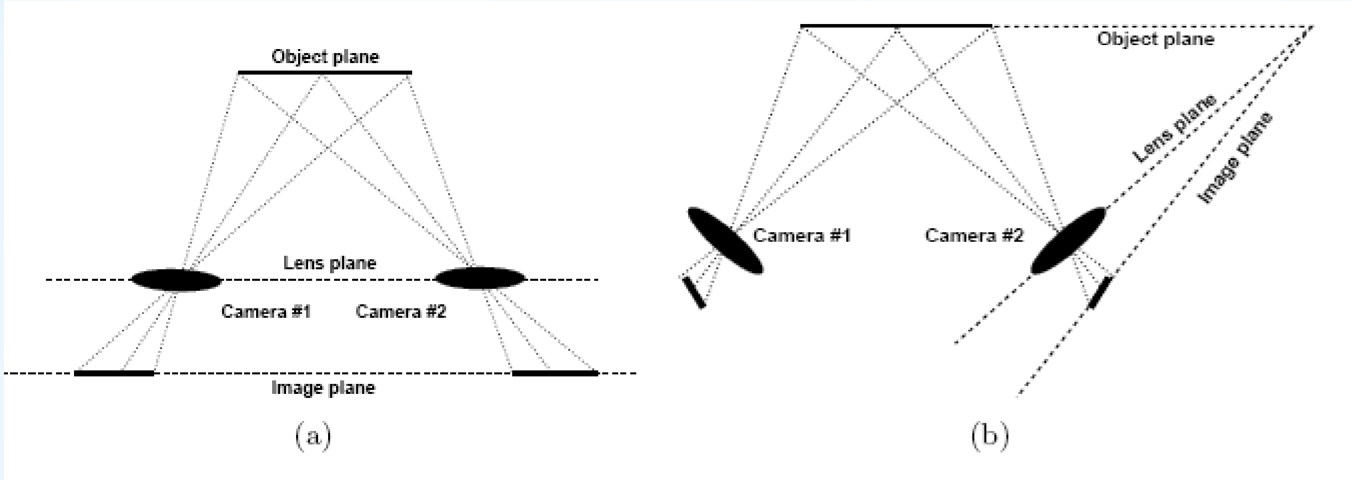
Comparative analysis (Maximum Drag Coeff. Against Str



Comparative analysis (Maximum Lift Coeff. Against Str)



Scheimpflug Condition



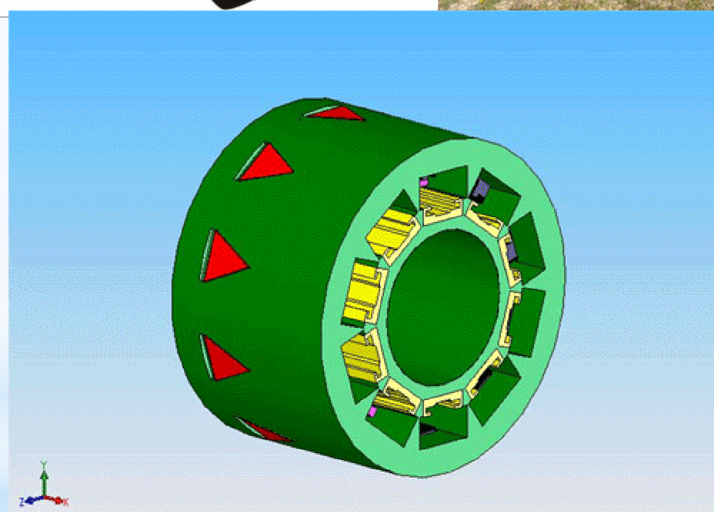
Solution:

Smaller focal lens is used to reduce the effect of reduced MTF at the edges.

The trade off:

We have to reduces the spatial resolution or the FOV.





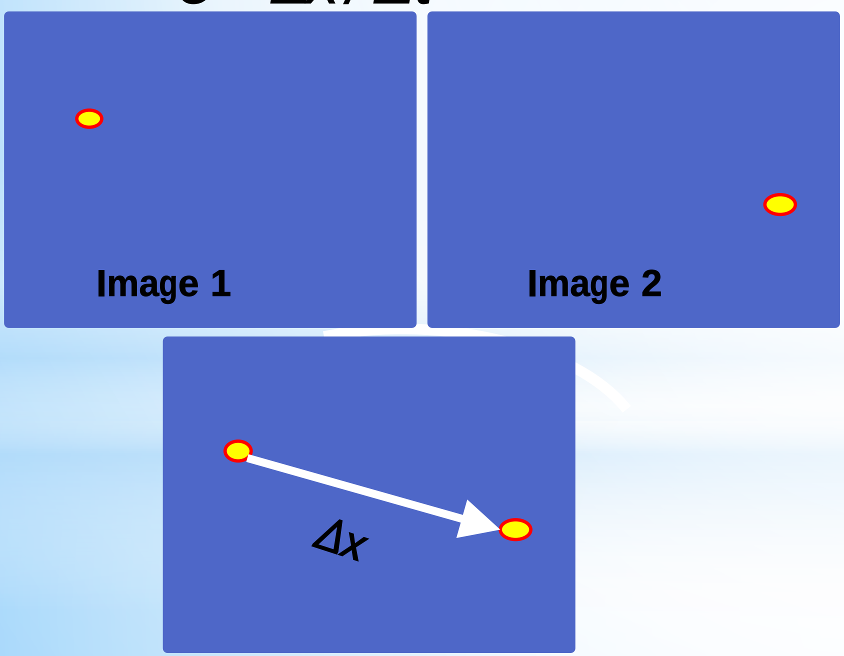
System Components

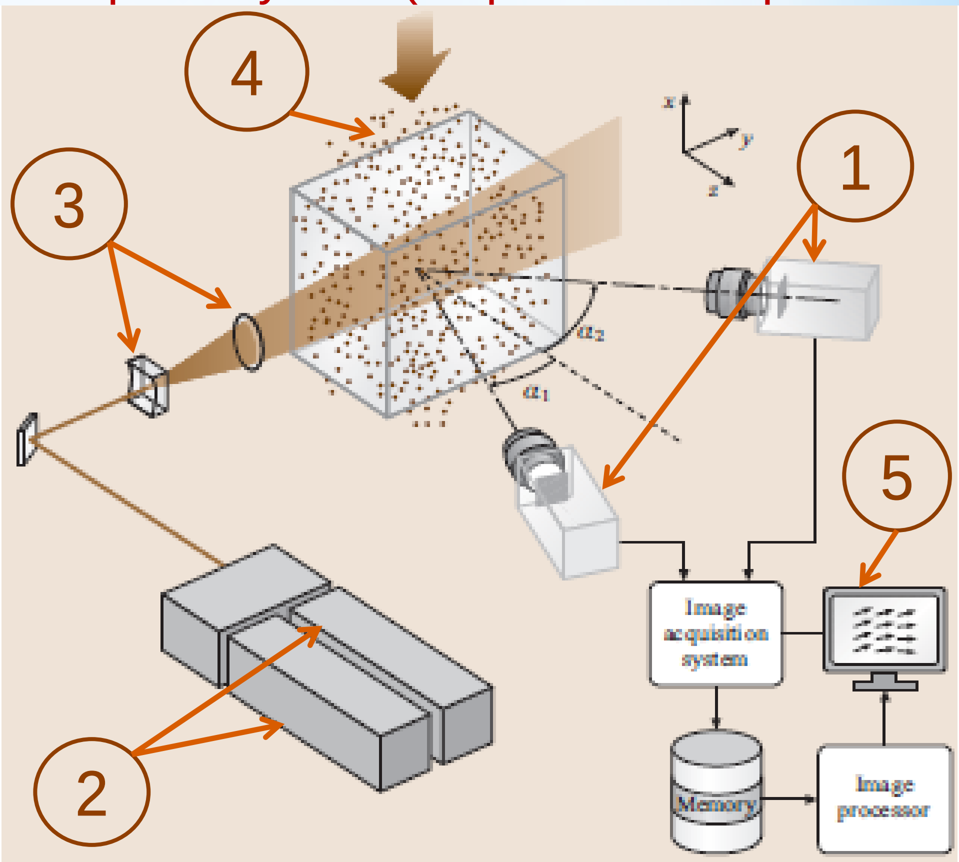
1. Camera(s)
2. Laser system
3. Optical arrangements (to create light sheet)
4. Seeding particles (i.e. atomized oil)
5. Computer system (Acquisition and processing)

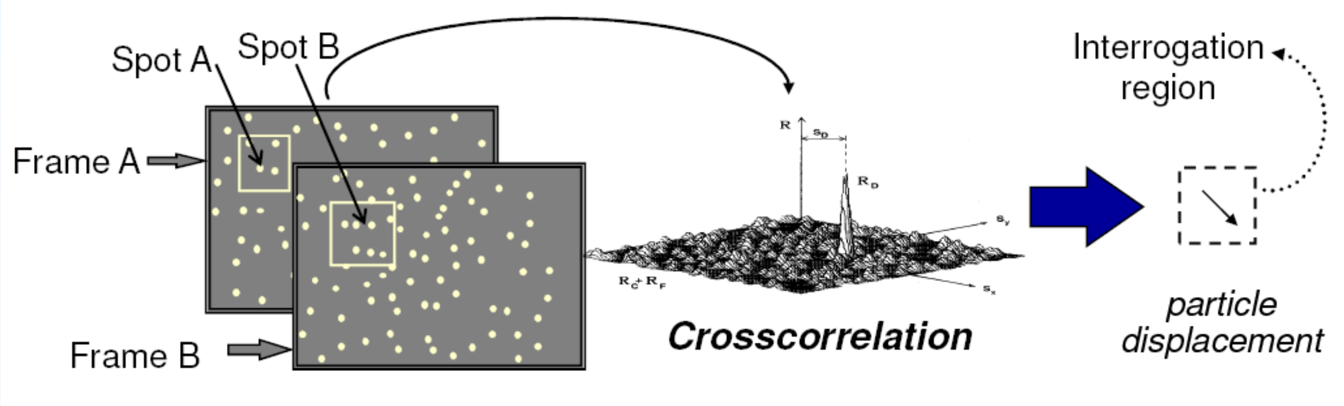
PIV (Particle Image Velocimetry)

- Imaging Technique (Non-Intrusive)
- Two Images are taken with time difference of Δt

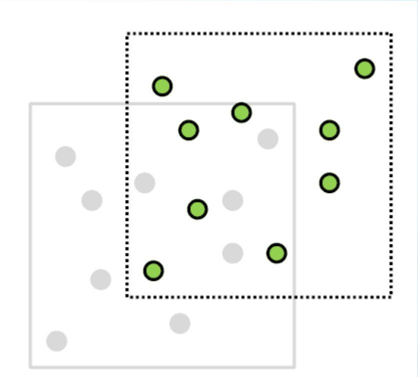
$$U = \Delta x / \Delta t$$



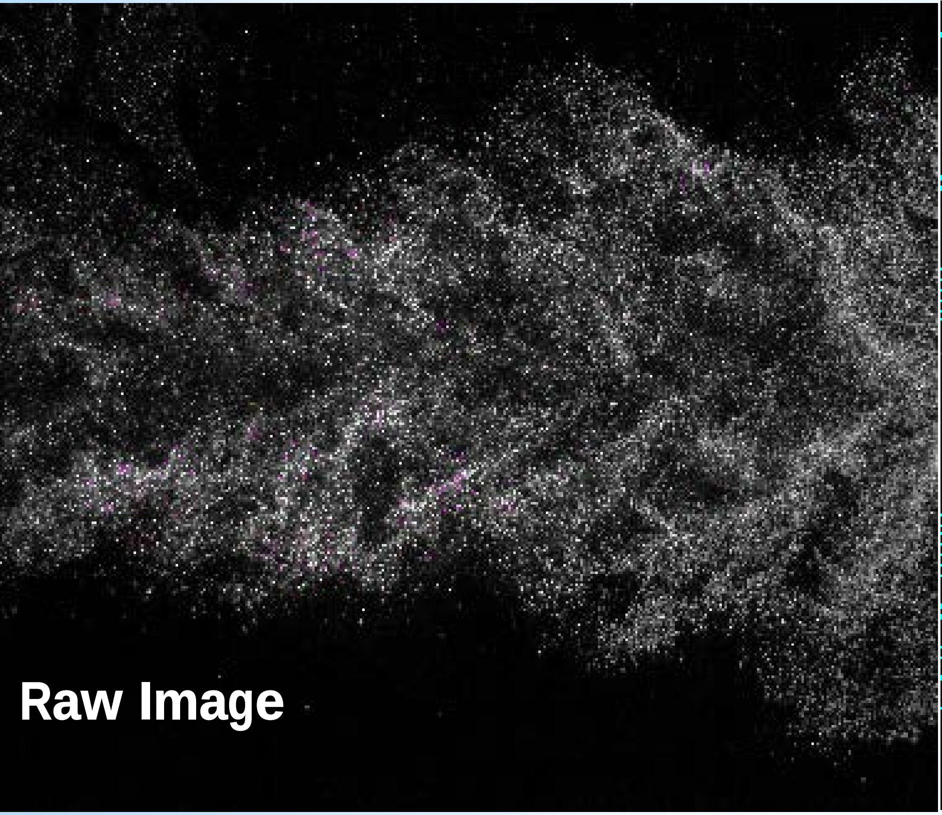


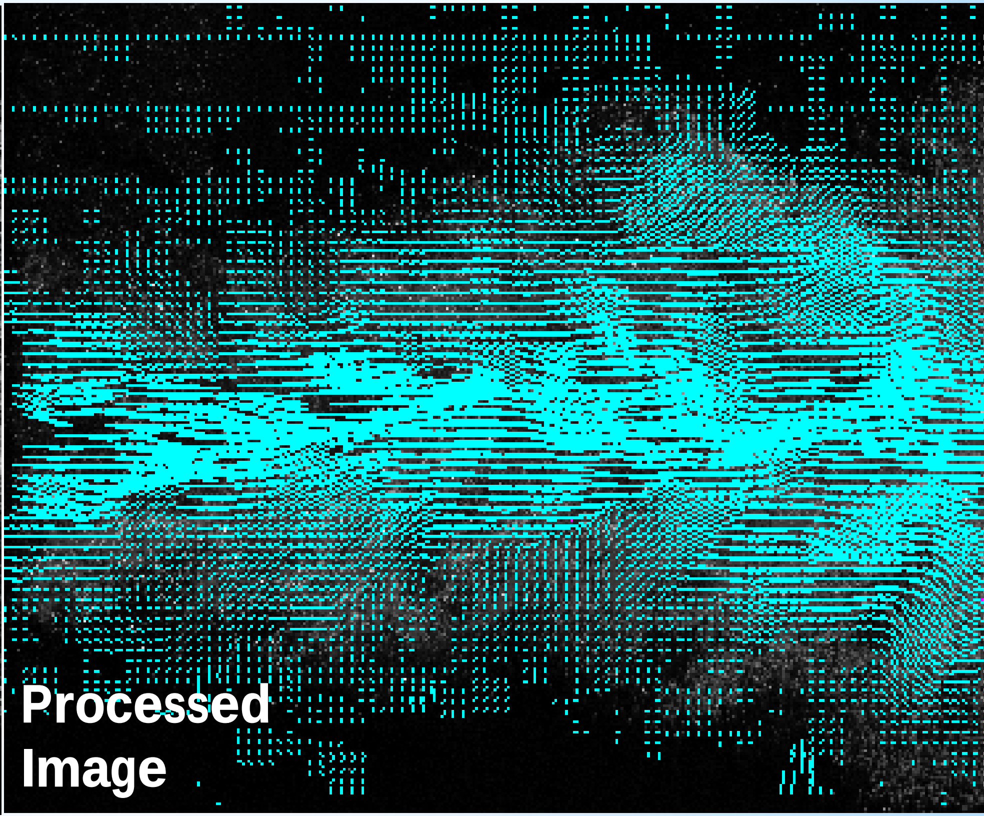


- High Density seeded Image to resolve the Velocity Everywhere.
- The image is divided into smaller rectangular areas (Interrogation Areas or Spots).
- The small areas are processed using pattern matching techniques (cross-correlation) to calculate the displacement.



Velocity Calculated





TR PIV (Time Resolved PIV) With CW (Continuous Wave) Laser

- Classical PIV give a steady-state information of the velocity, where little is known about velocity of the flow transient conditions.
- Using Time Resolved PIV allows to study the unsteady process in flow applications.
- High speed Camera Systems (Imacon 200 & Phantom 710)
- CW Laser (5 Watt Diode laser @ 532 nm (green)

Camera System Phantom 710v	
Frame Rate/sec	7500 at full resolution
Chip Resolution	CMOS (1280X800 pixel)
CW Laser	
Diode Laser	Green @ 532 nm
Power	>5 watt
Experiment Parameters	
PIV Rate/sec	3 K
Camera Lens	85 mm
FOV	140X160X1 mm^3