Experimental Investigation of Flow Characteristics around a Novel Structure for Passive Flow Control

Speaker: Tyler Moore

Co-Author: Wen Wu, PhD

Co-Author: Taiho Yeom, PhD

Presentation Outline

- Motivation and Objective
- Background
- Micro Airfoil Structure (MAS)
- Experimental Setup and Conditions
- Results
- Conclusions

Motivation and Objective

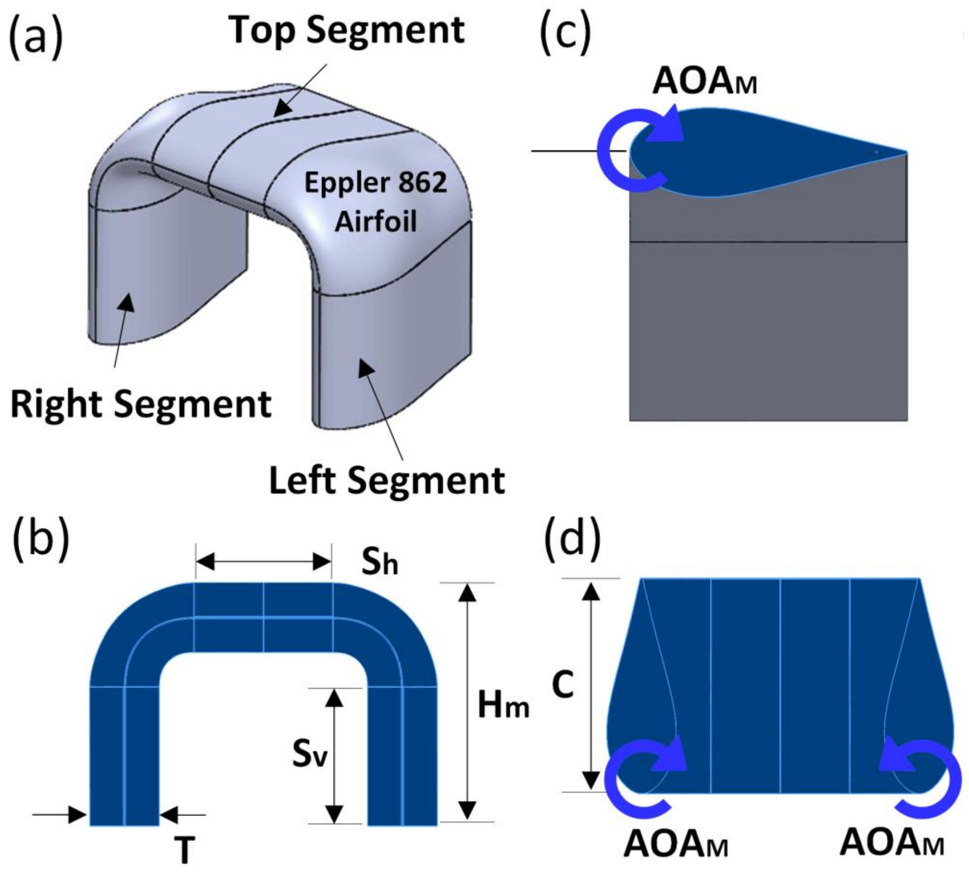
- Skin-friction drag (SFD) in turbulent boundary layers (TBLs) creates a large amount of energy loss in shipping industries.
- An implementation of a flow control scheme can reduce SFD in TBLs, saving energy and cost.
- A passive method of controlling TBLs is proposed, utilizing technological advancements in 3D-printing.
  - The Micro-Airfoil Structure (MAS)
- The objective of the study is to demonstrate the flow control capabilities of larger mock-up MAS samples, leading to recommendations for smaller samples in the future.

Background

- **Existing Methods for Flow Control**
- Active Flow Control
  - Synthetic jets, piezo fans, etc.
  - Require sub-components and external energy to operate.
- Passive Flow Control
  - Typically manipulate surface topologies (grooves, riblets, additives).
- What are the optimal surface structures to control TBLs effectively, reducing SFD?
- 3D-Printing technology can be utilized to create well-defined surface structures.
  - Experimental analysis; numerical analysis counterpart in Session J08, Room 135.

Micro Airfoil Structure (MAS) I

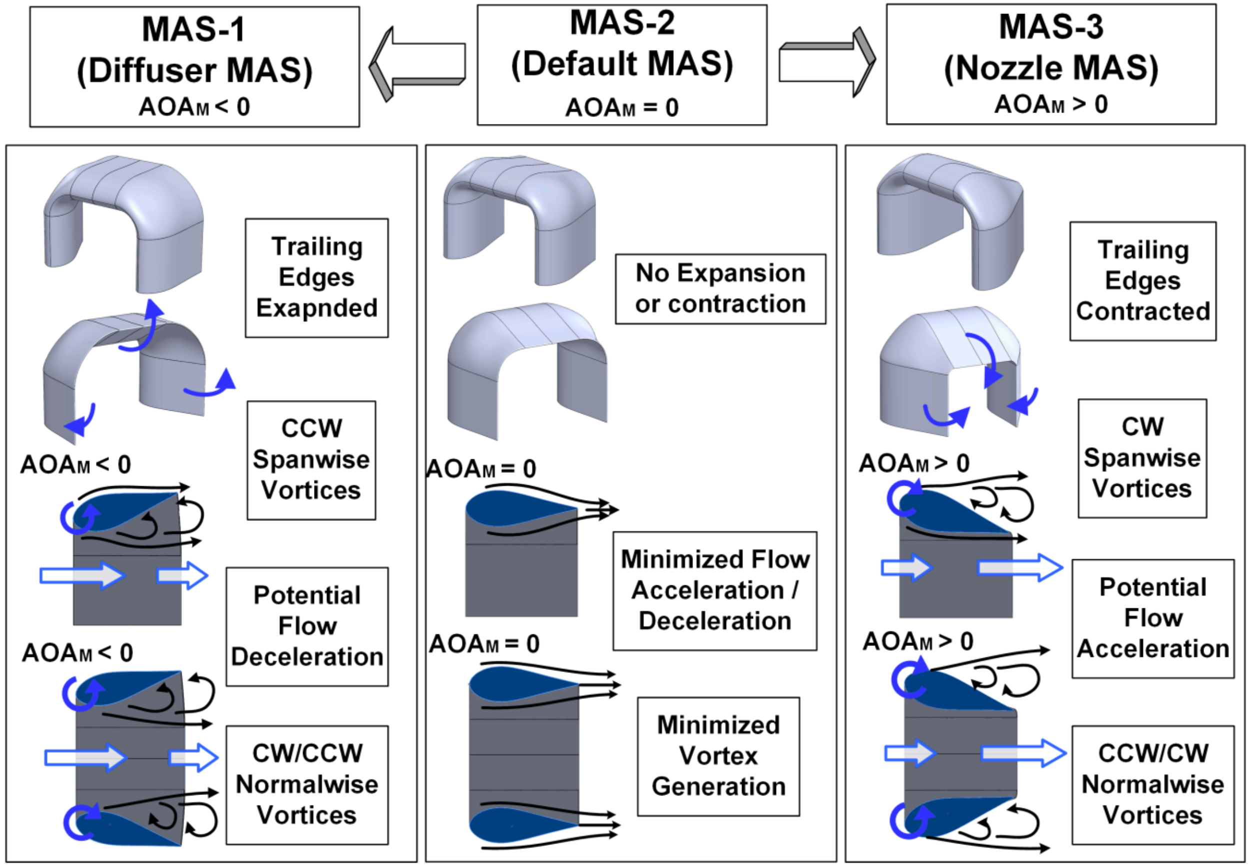
- 3D-printed structure with two side segments and a top segment (a).
- Structure segment height, width, and thickness can be manipulated (b).
- Angle of attack (AOA) of each segment may also be manipulated ((c) & (d)).
- Standard airfoil geometries may be incorporated for each segment.



Schematic of MAS Sample

Micro Airfoil Structure (MAS) II

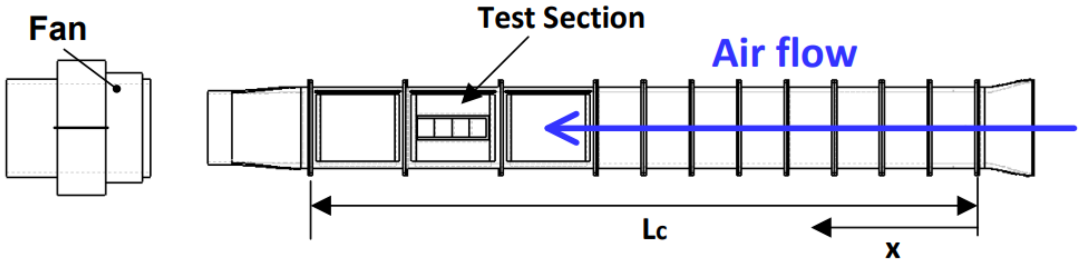
- AOA manipulation creates three distinct sample variants:
  - Diffuser (MAS – 1)
  - Default (MAS – 2)
  - Nozzle (MAS – 3)
- Desired control outputs include flow acceleration, deceleration, and vortex generation.
- 3D-Printing technology allows for a minimum MAS height of around a few hundred micrometers.
- Larger sample height/width of 15 mm selected for this study, thickness of 1.5 mm.



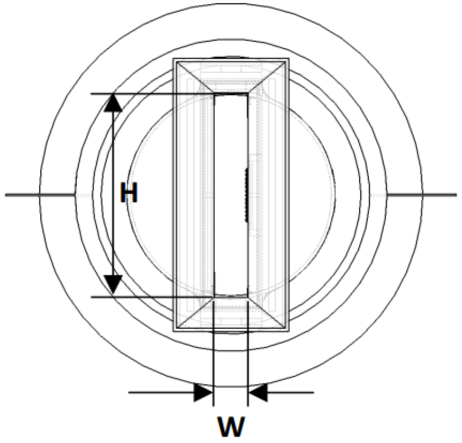
MAS Working Principles and Variants

Experimental Setup – Wind Channel

- Wind channel created using custom 3D-printed sections.
  - W = 50 mm
  - H = 400 mm
  - Lc = 3 m
- Test section approximately 2.4 m from inlet, selected to allow for fully developed turbulent flow.
- Minimum inlet velocity of 3.1 m/s.
- Turbulent boundary layer of 25 mm (half channel width).
  - Tested MAS design height (15 mm) is 60% of BL thickness.



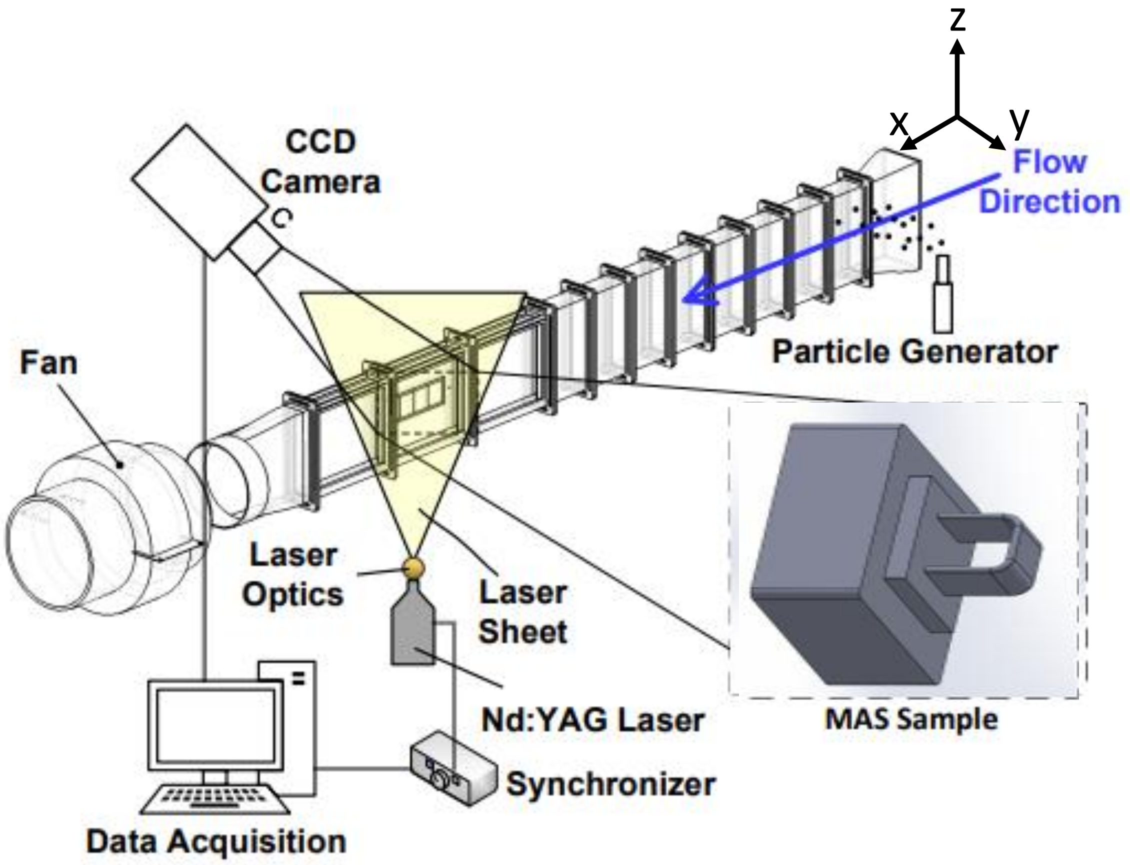
<Channel Side View>



<Channel Front View>

Experimental Setup – PIV

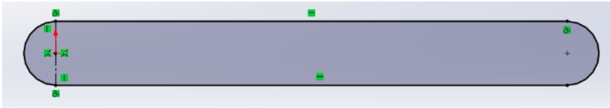
- **Particle Image Velocimetry (PIV)**
- A double-pulse YAG Laser, high speed CCD camera, synchronizer, and olive oil droplets produced from a particle generator were used to create a 2D-PIV visualization of flow.
- 1000 image pairs were captured sequentially for each test.
- Post-processing produced time averaged results.



Schematic of Wind Channel/PIV Setup

Experimental Conditions I

- **Wind Channel Characteristics**
  - Inlet Velocity: 3.1 m/s
  - Reynolds Number: 7038
- **PIV Characteristics**
  - Delta T: 15 microseconds
  - Pulse Repetition Rate: 5 Hz
  - Laser Power: Medium
- **Geometry Study**
  - a) Flat Plate, b) NACA 0010, c) NACA 2410, d) NACA 6409
- **Angle of Attack (AOA) Study**
  - A) 5∘ Diffuser, B) 10∘ Diffuser, C) 5∘ Nozzle, D) 10∘ Nozzle



a) Flat Plate

b) NACA 0010

c) NACA 2410

d) NACA 6409

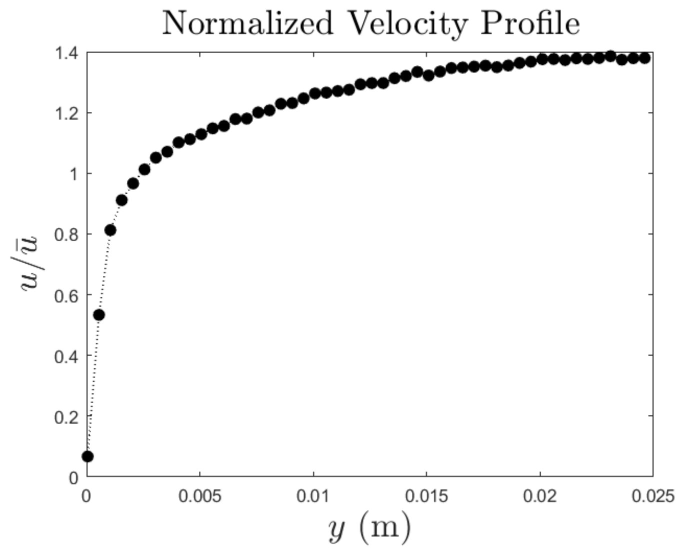
Geometry Study Cross Sections

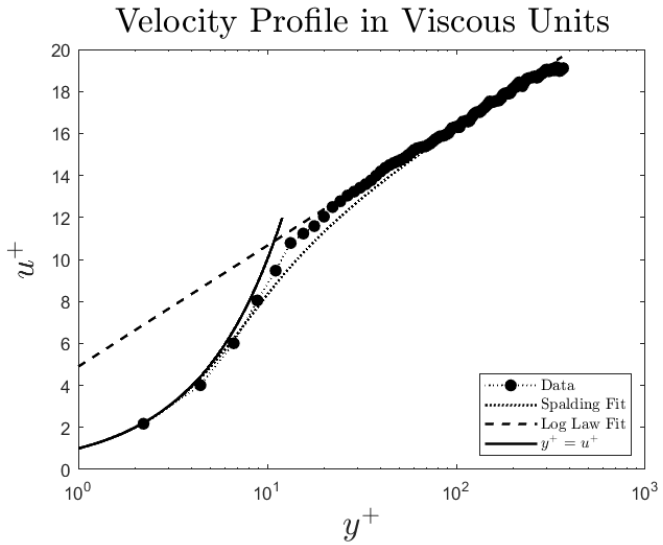
A) 5∘ Diffuser B) 10∘ Diffuser C) 5∘ Nozzle D) 10∘ Nozzle

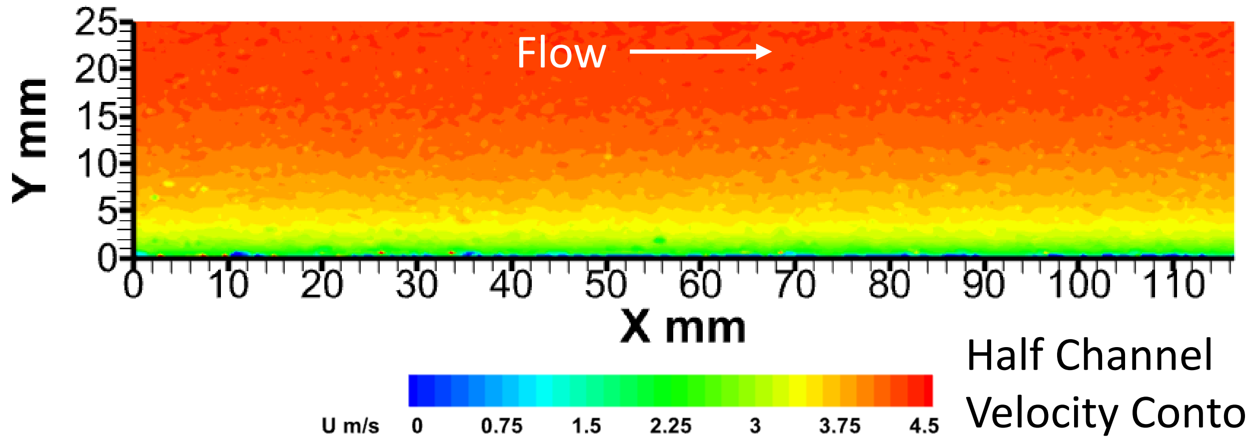
AOA Study Samples

Experimental Conditions II

- **Default Channel**
  - Flow was found to be fully developed at test section.
  - Profile matches accepted data using log law of the wall (k = 0.4, B = 4.9).
- **Characteristics**
  - u_τ = 0.2242 m/s
  - τ_w = 0.0616 Pa
  - Re_τ = 368.11
  - H = 1.4861

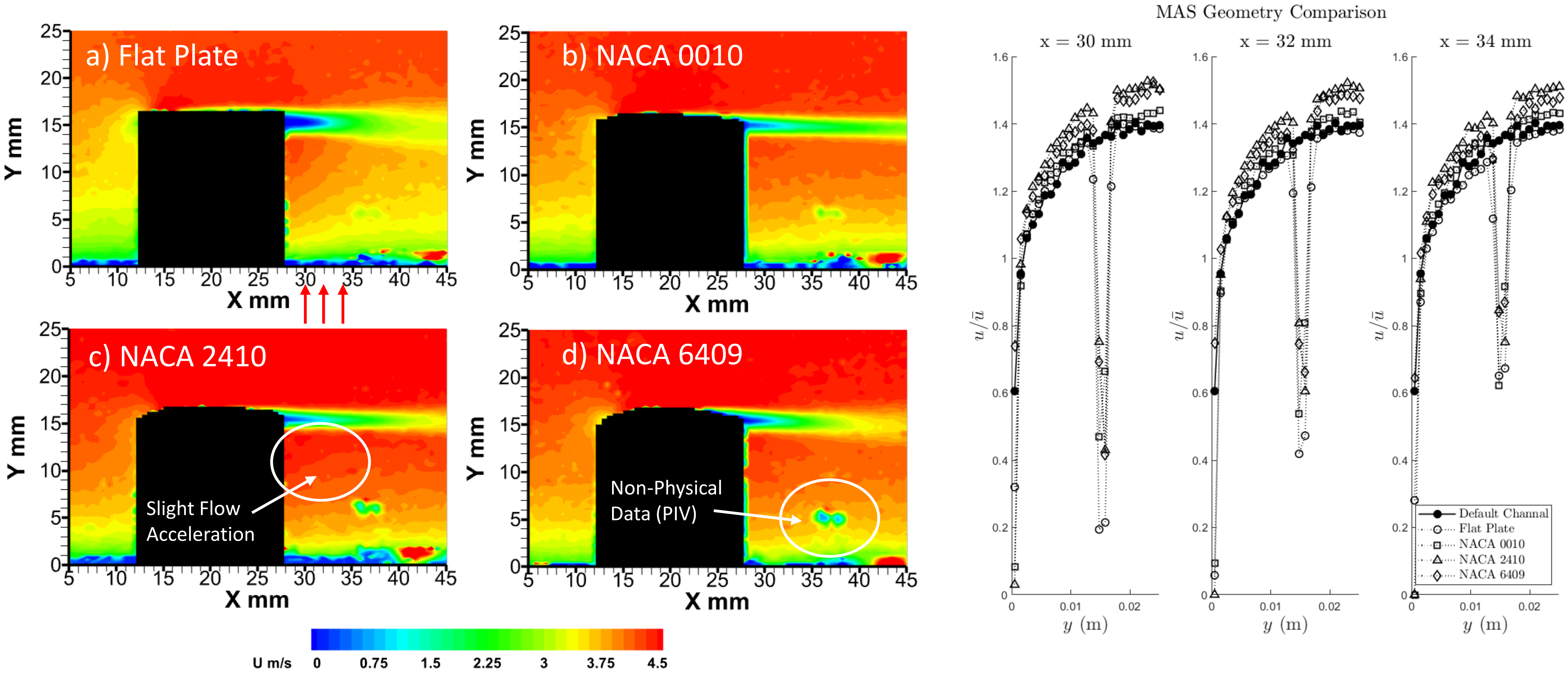




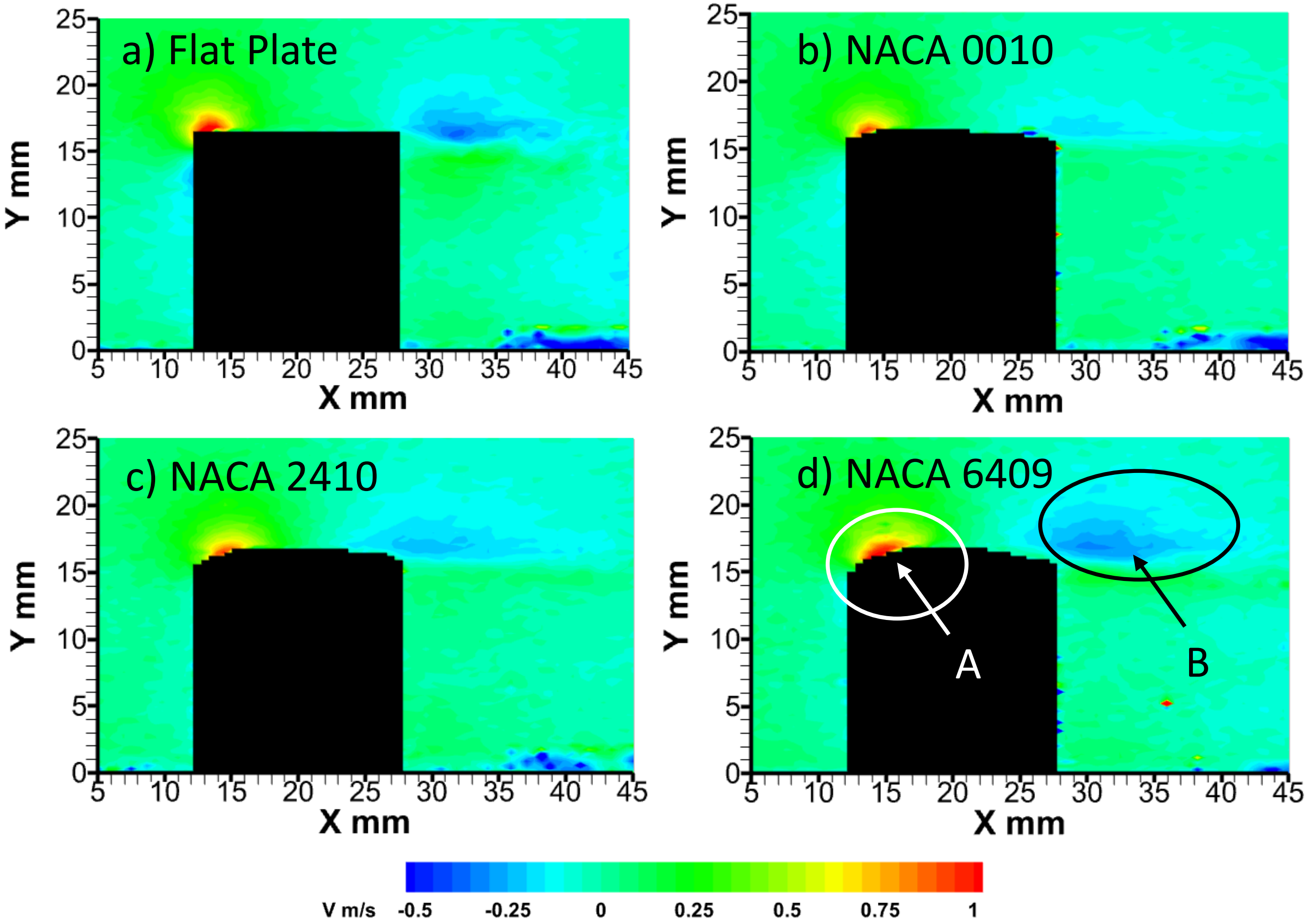


Half Channel Velocity Contour

Results – Geometry Study: U Velocity

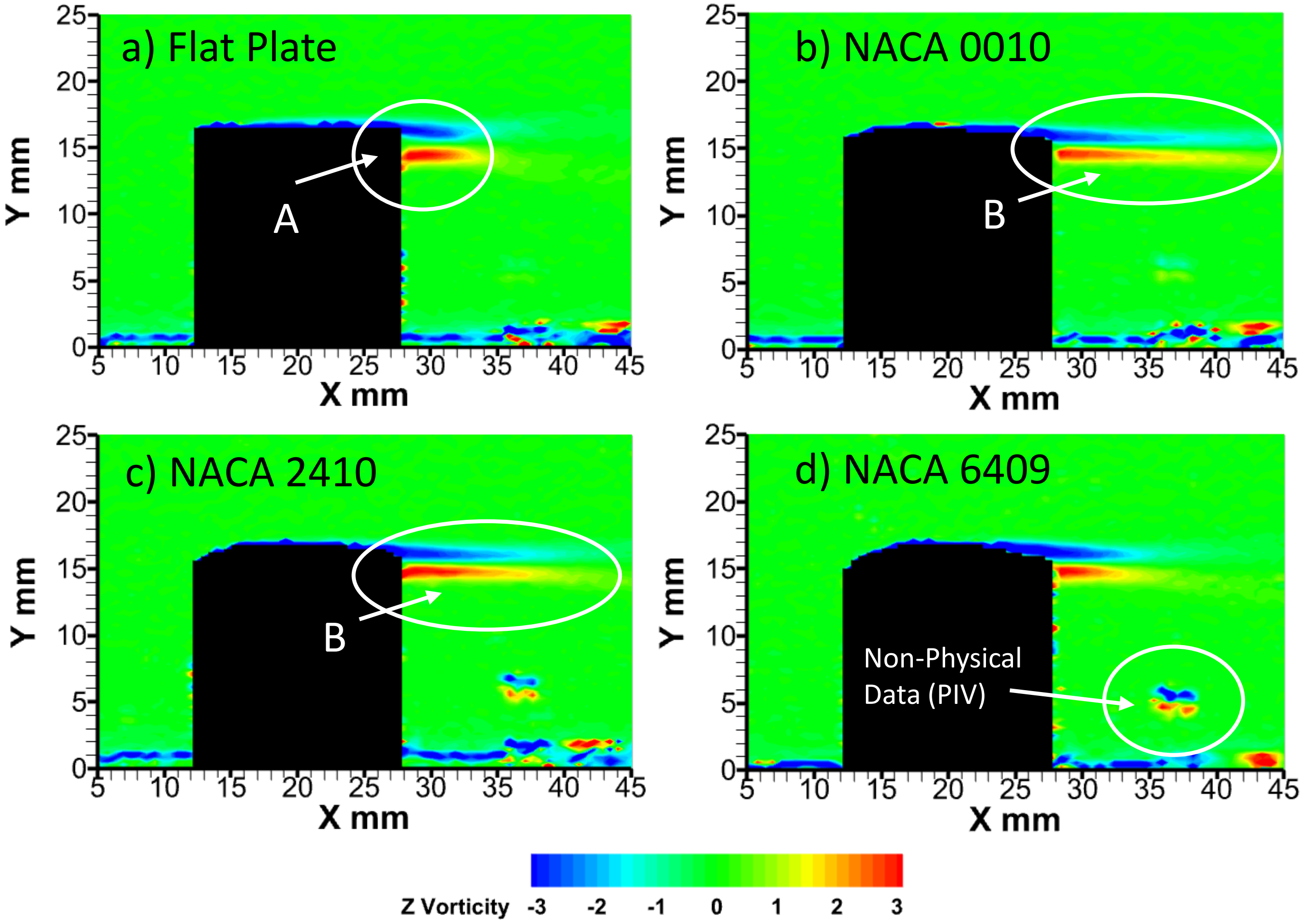


Results – Geometry Study: V Velocity



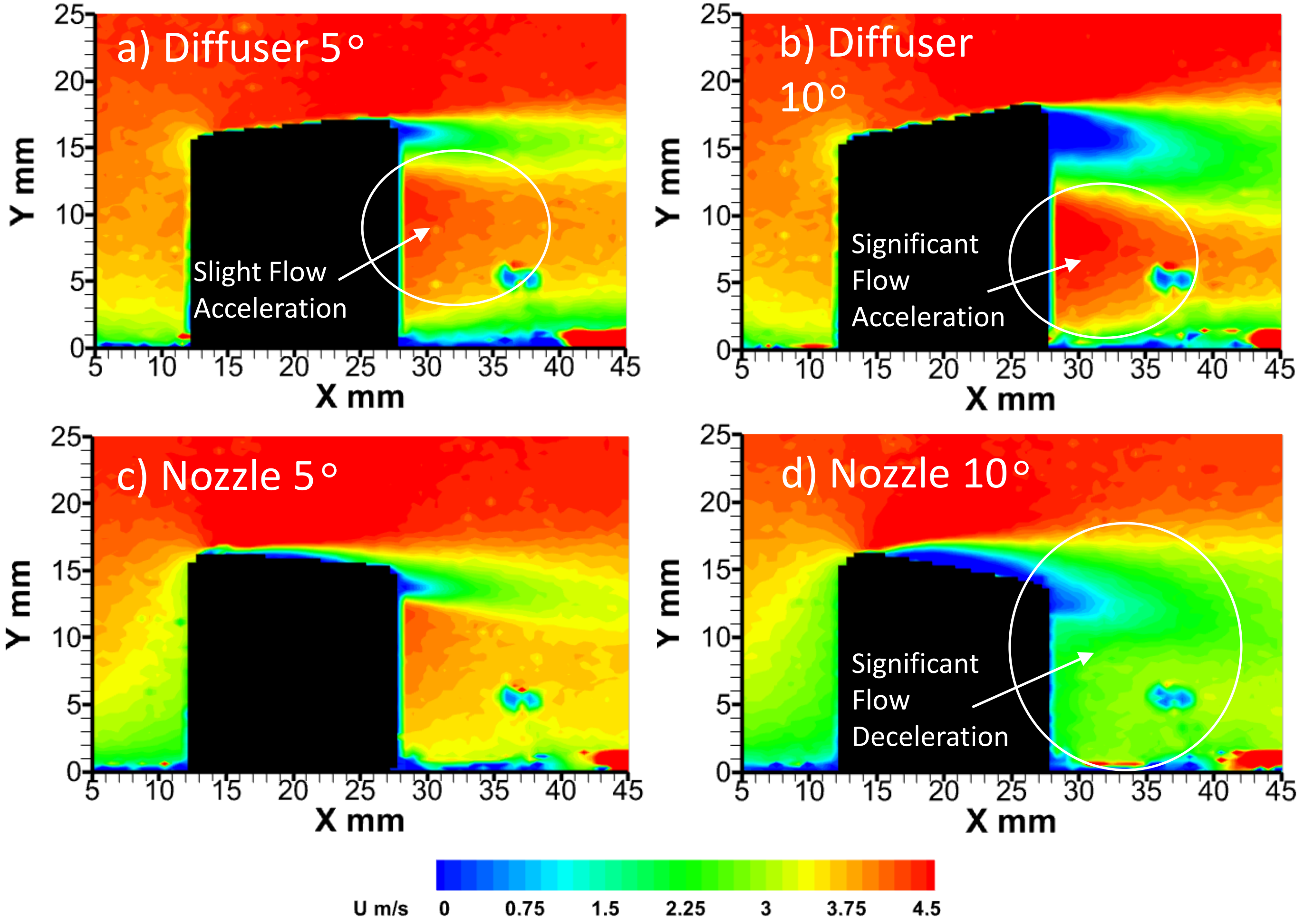
- Notable upward flow at the forefront of each top surface.
- A) NACA 6409, the most cambered geometry, produces the most upward flow.
- B) Apparent upward flow is paired with less dense downward flow behind the structures.

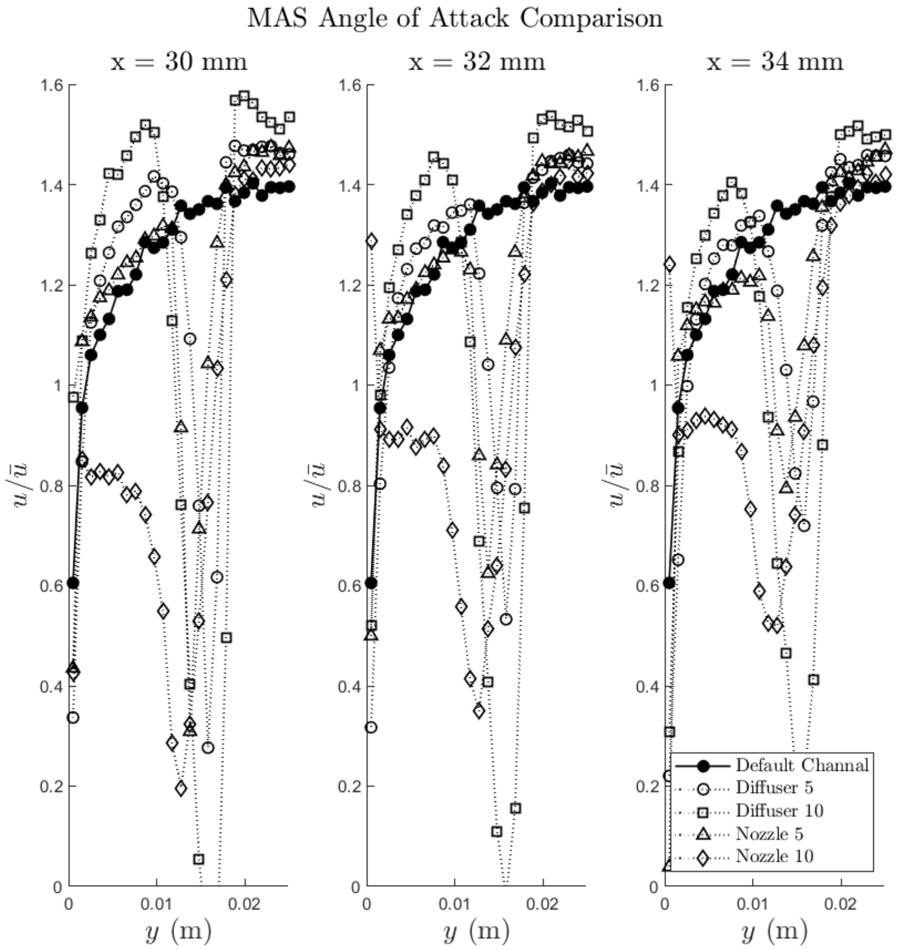
Results – Geometry Study: Z Vorticity



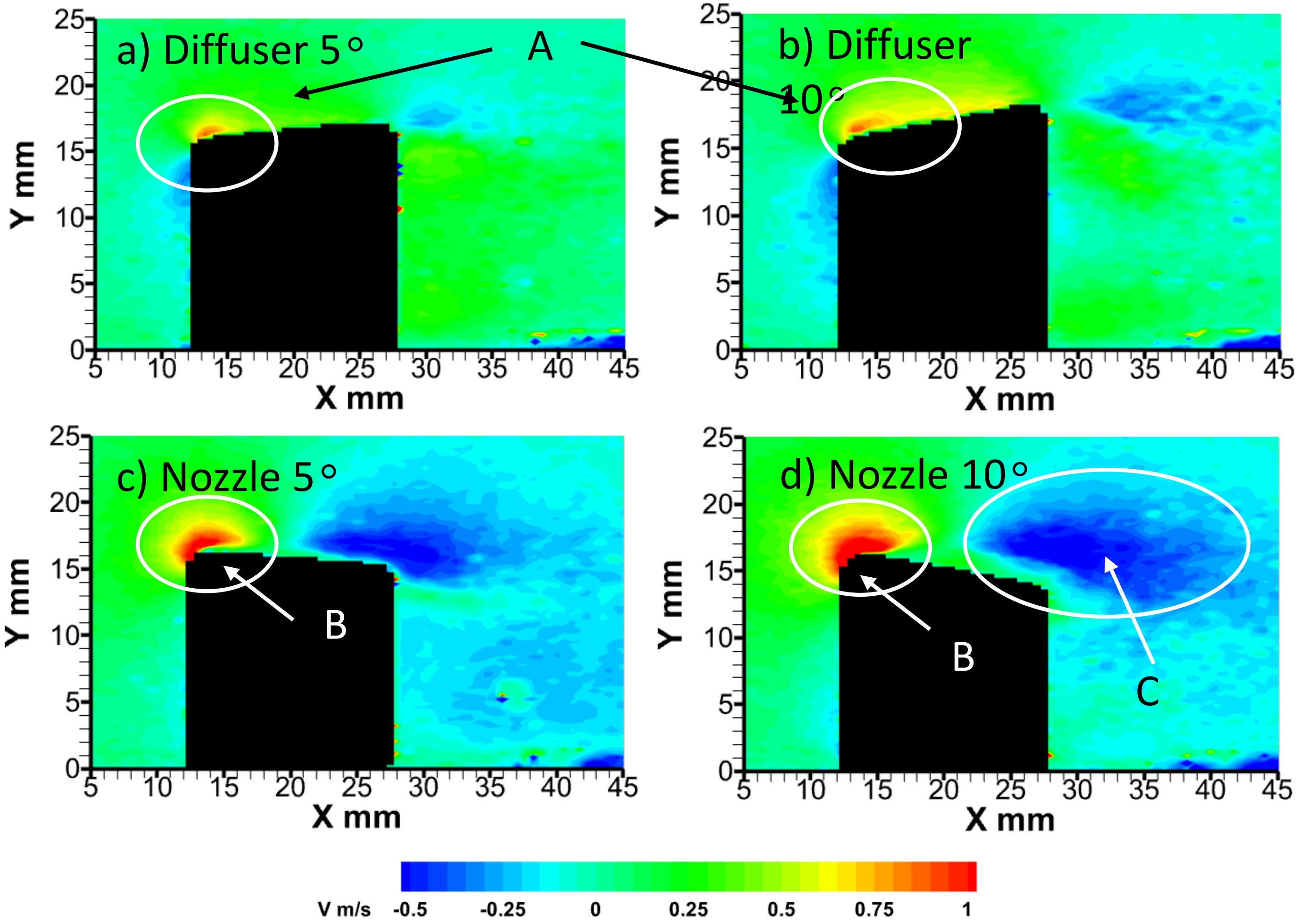
- A) Paired clockwise and counterclockwise rotation.
- B) Vorticity effects extend farther beyond the NACA 0010 and NACA 2410 structures.

Results – AOA Study: U Velocity



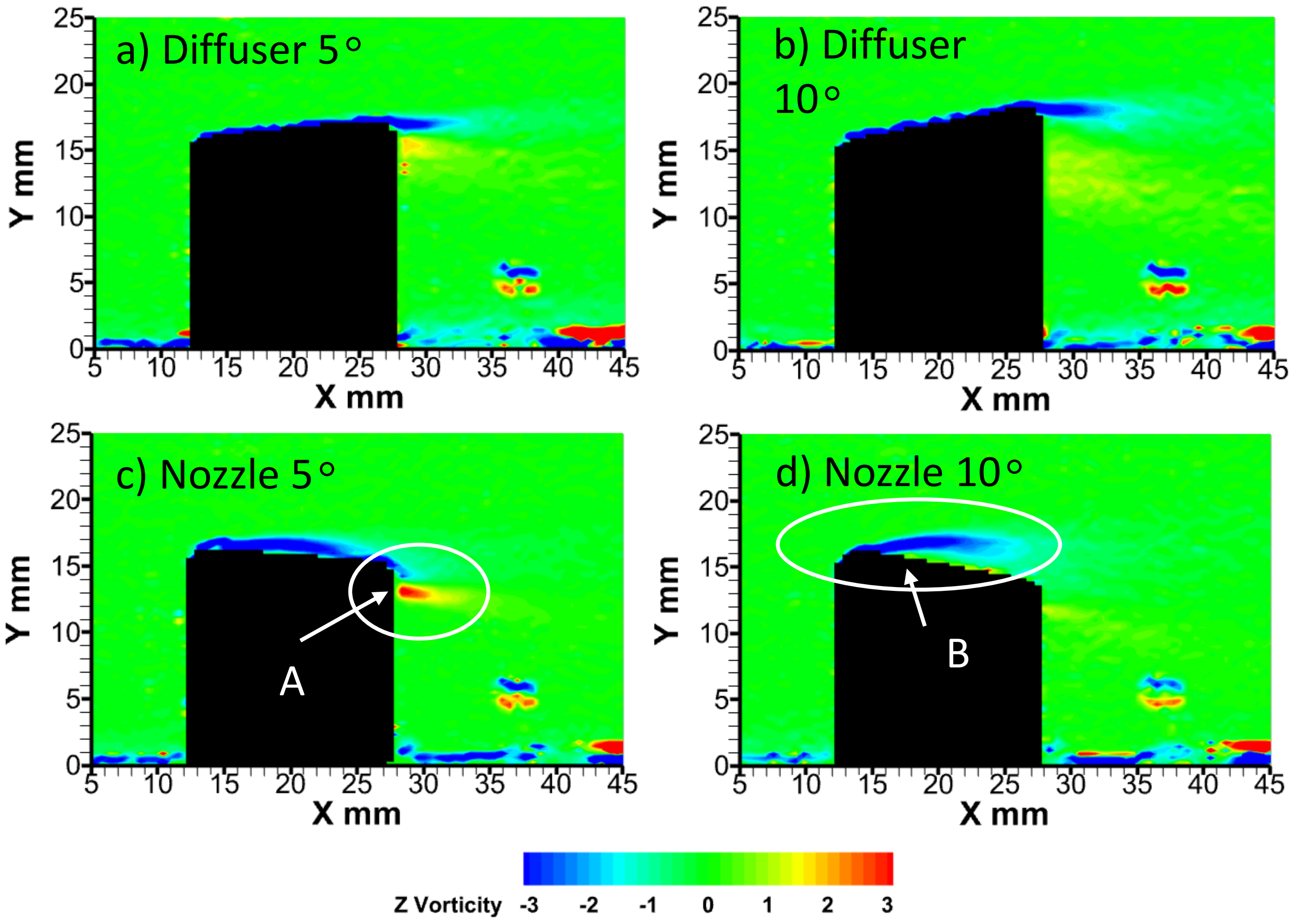


Results – AOA Study: V Velocity



- A) Minimal upward flow in diffuser samples.
- B) Significant increase in upward flow for nozzle samples.
- C) Paired downward flow beyond nozzle samples also exaggerated.
  - Mixing between turbulent layers.

Results – AOA Study: Z Vorticity



- A) Paired positive/negative vortical structures disappear except for case c).
- B) Clockwise vorticity separates from the top of the 10° Nozzle surface.

Conclusions

- The flat plate MAS geometry was found to perturb channel flow the least of the tested geometries.
- Flat plate MAS diffuser geometries were found to accelerate flow, while flat plate MAS nozzle geometries were found to decelerate flow; the inverse of initial estimations.
- MAS nozzle geometries impact V velocity significantly more than MAS diffuser geometries.
- Further studies are required using smaller MAS samples to confirm flow control characteristics and behaviors closer to the wall.
- Additionally, further visualization around the side walls may be required to fully characterize the effects of the MAS structures.

Thank you! Questions?

Graduate Student Tyler Moore, *Energy Management Laboratory*, University of Mississippi, tjmoore6@go.olemiss.edu