10th EAWE PhD Seminar on Wind Energy in Europe
October 28-31, 2014 in Orléans, France

Testing airfoils for wind turbines

The 3D challenges

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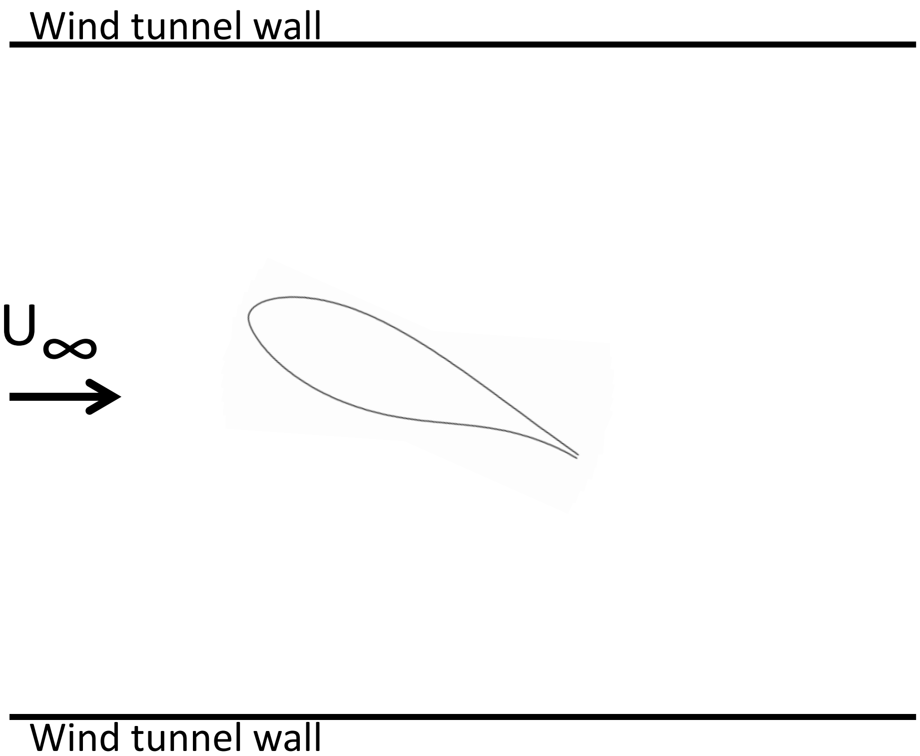
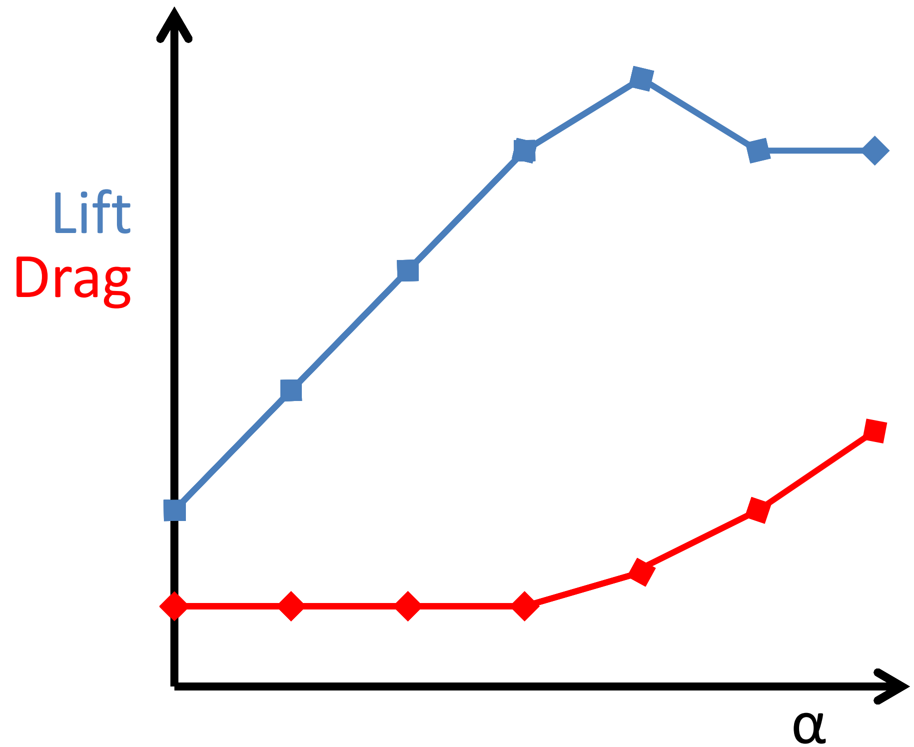
Fluids Section

Introduction

2D wind tunnel polars for airfoils

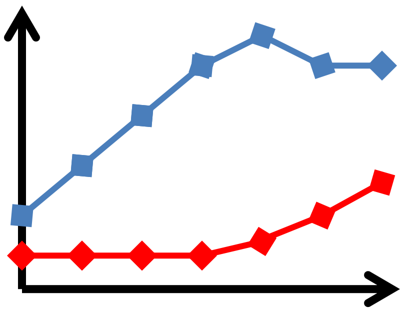




Incompressible, “external”, wall bounded flow, Re O(10^6)

Introduction

2D wind tunnel polars for airfoils



Blade Element Momentum (BEM) Code

- Annual Energy Production
- Loads on blades

Main assumption:

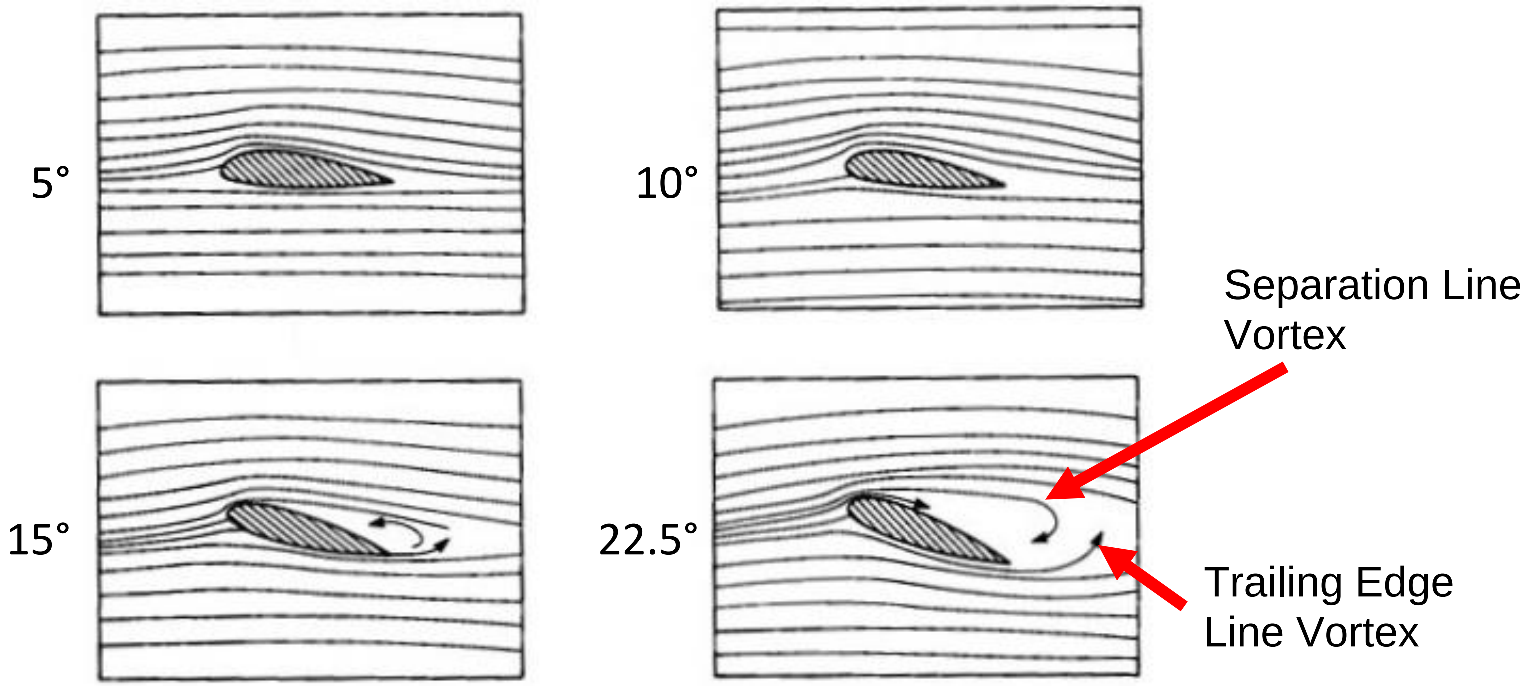
The flow around the airfoil is 2D.

Question:

Does a symmetric 2D set-up result in symmetric 2D flow?

Introduction

2D wind tunnel polars for airfoils



[Nakayama, 1988]

Main assumption:

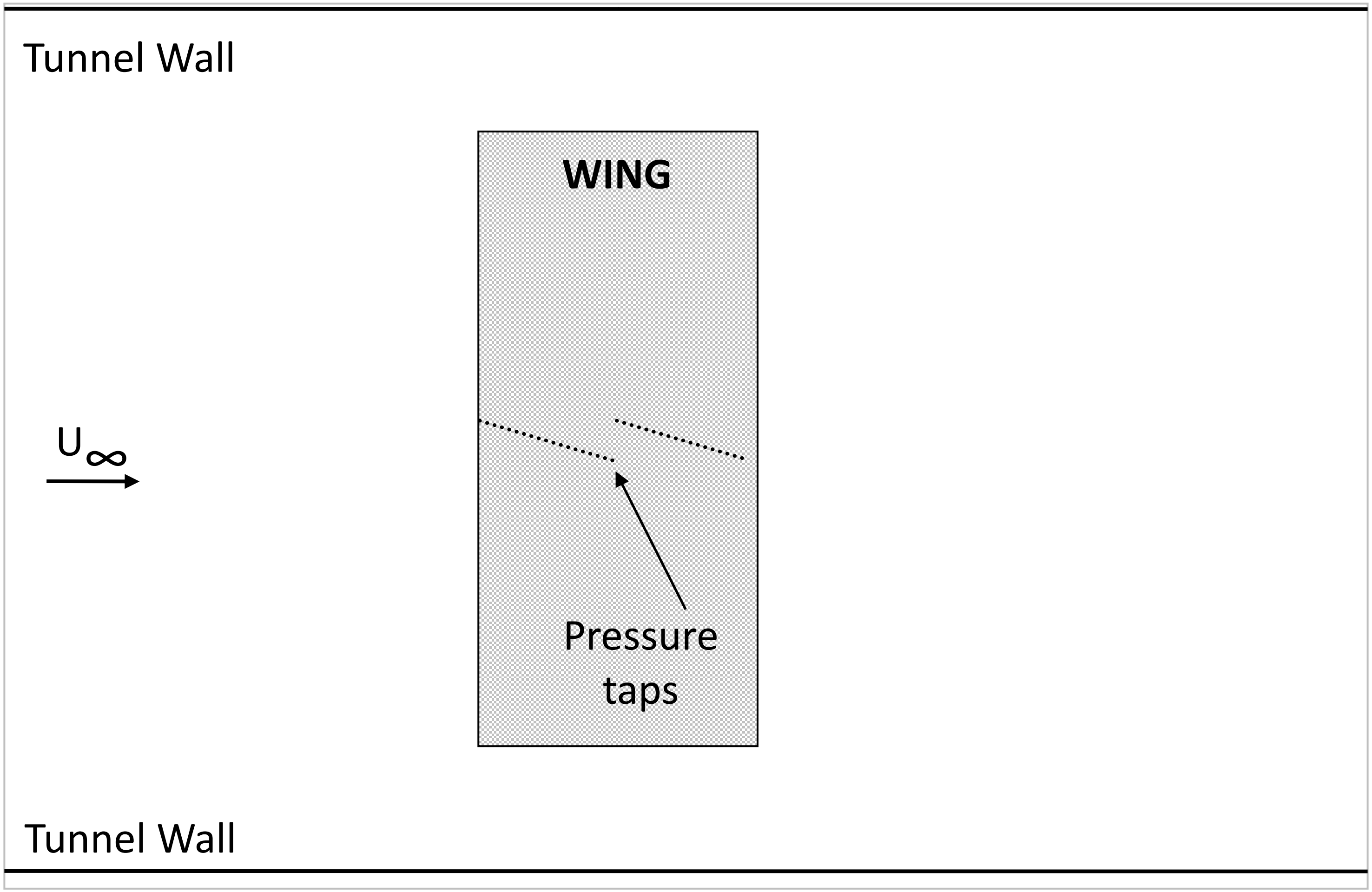
The flow around the airfoil is 2D.

Question:

Does a symmetric 2D set-up result in symmetric 2D flow?

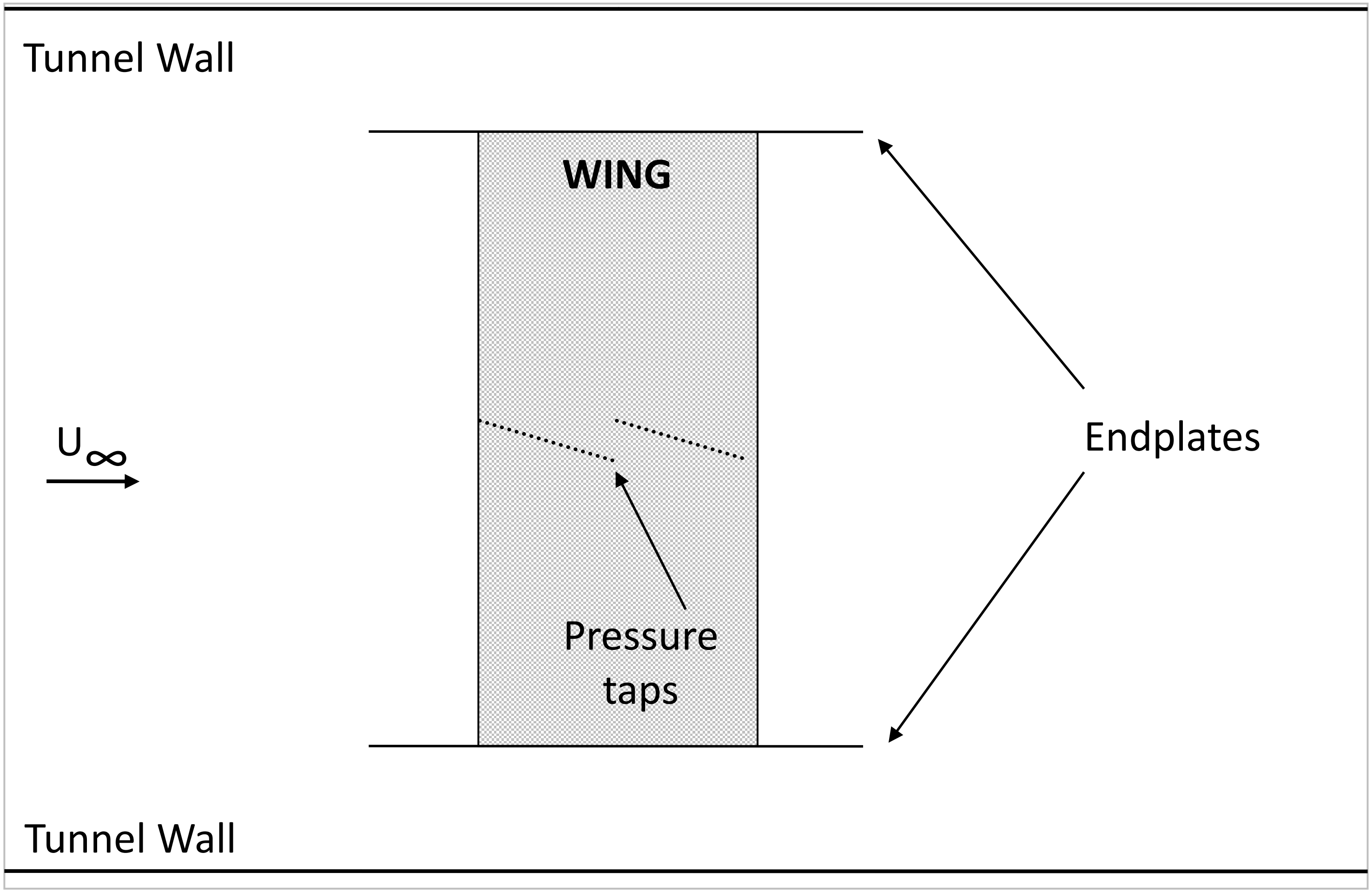
Experimental Set Up

Wing with free tips



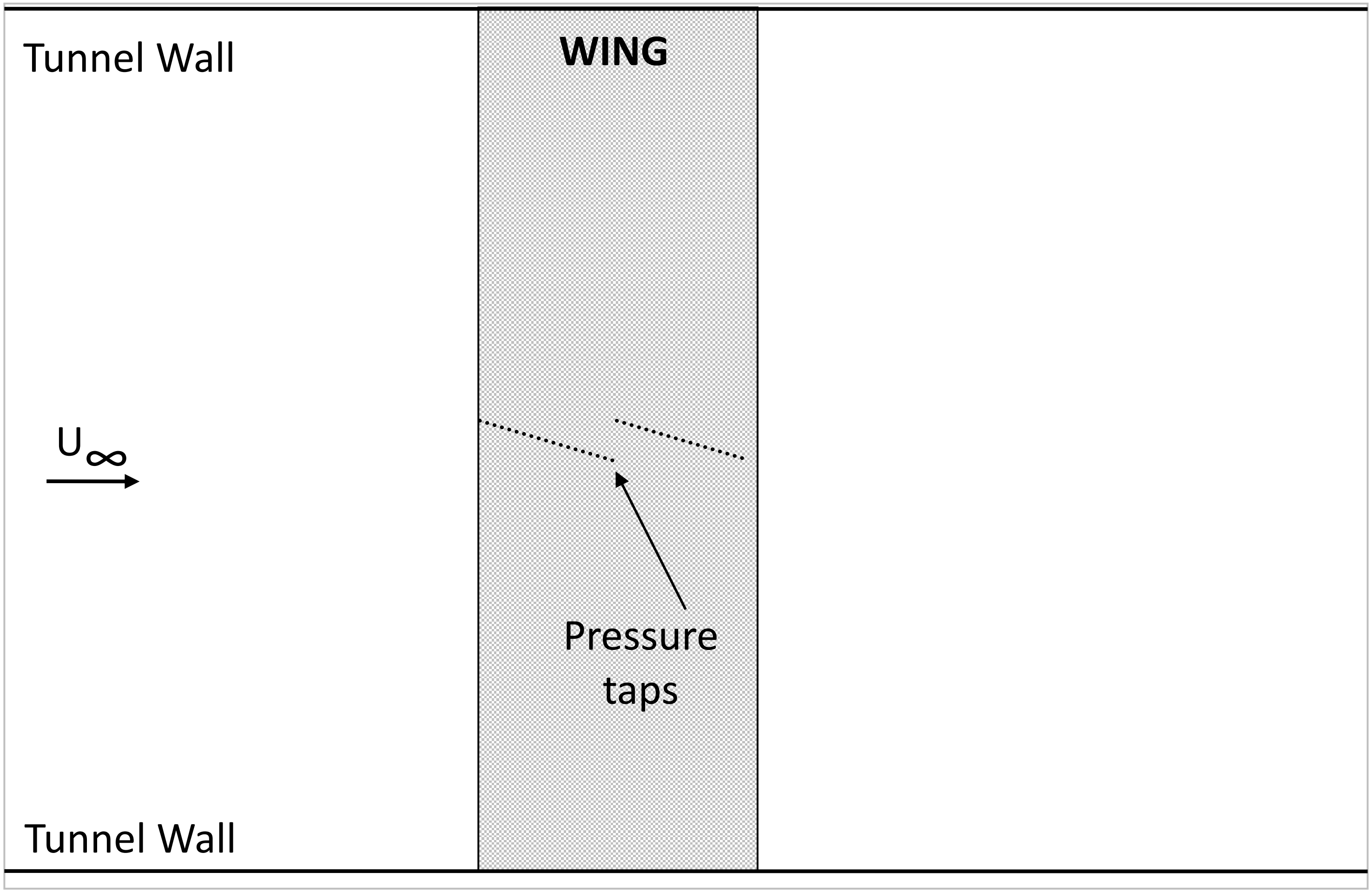
Experimental Set Up

Wing with endplates



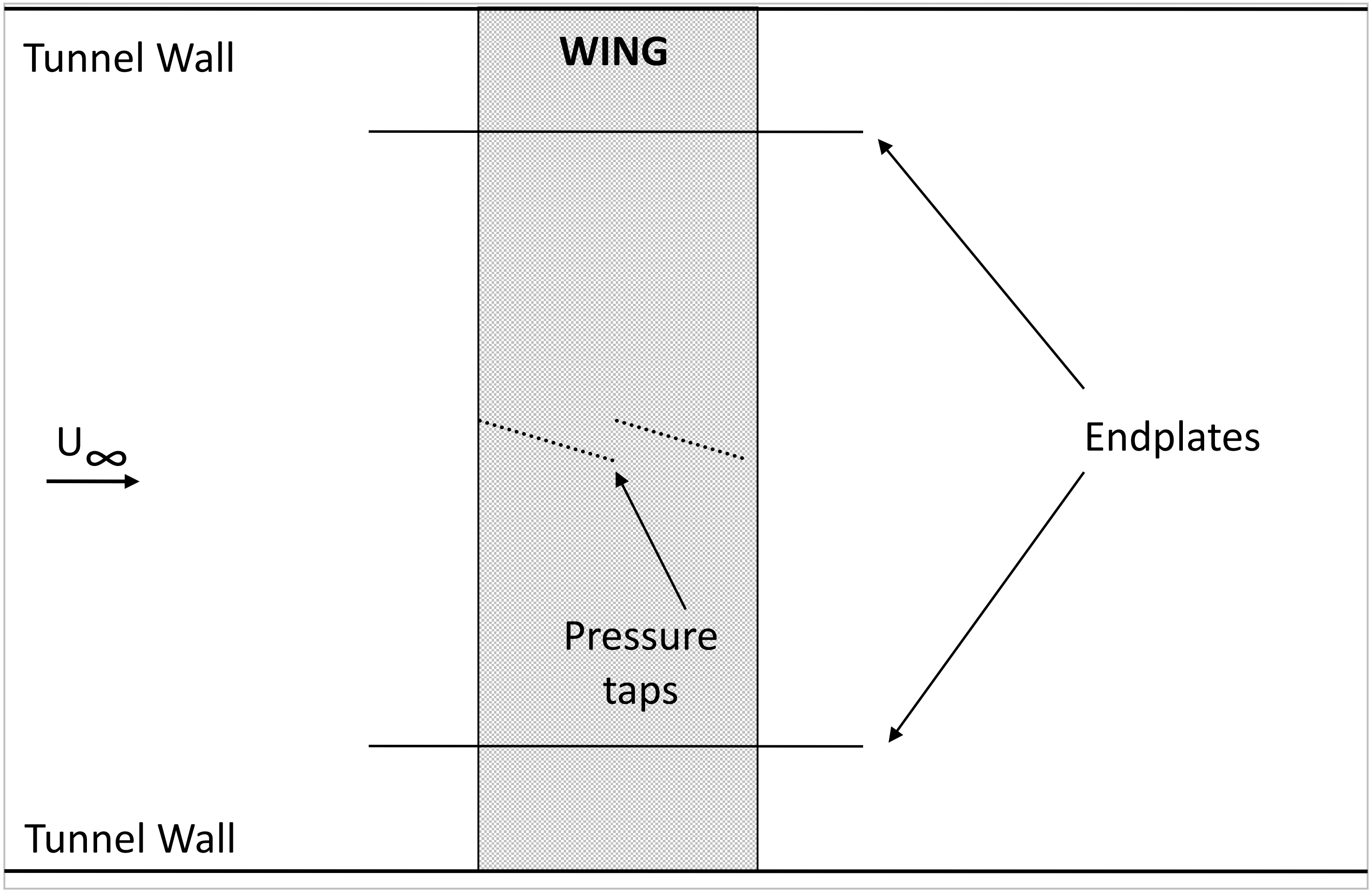
Experimental Set Up

Wall to wall wing model



Experimental Set Up

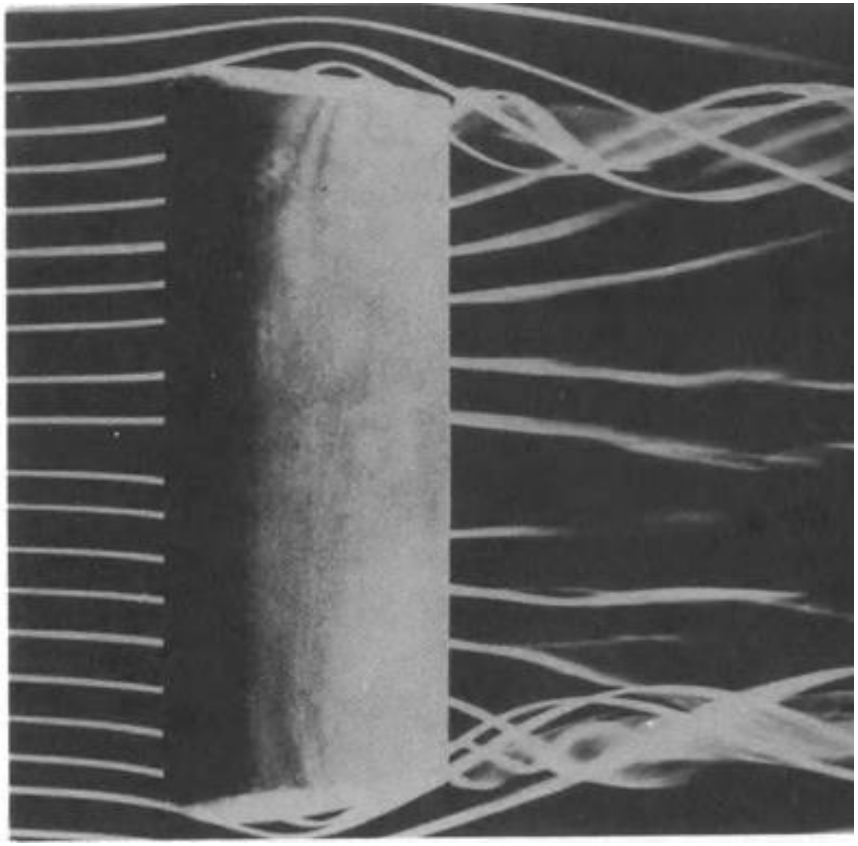
Wall to wall wing model + endplates



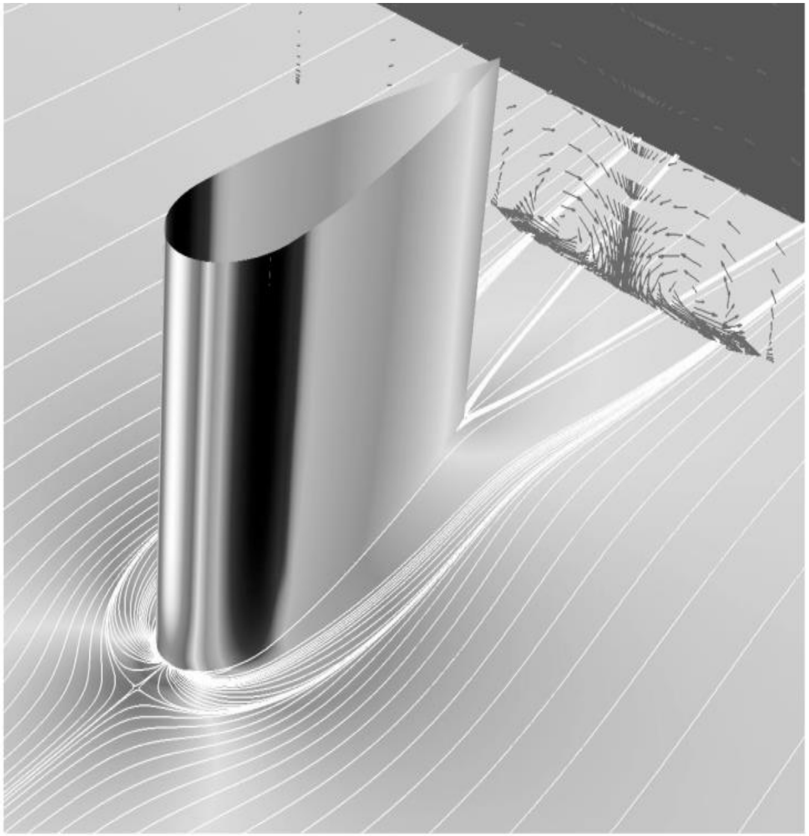
Experimental Set Up

The flow is always 3D at the tips

Free tips | **Wall to wall/endplate models**



[Head, 1981]

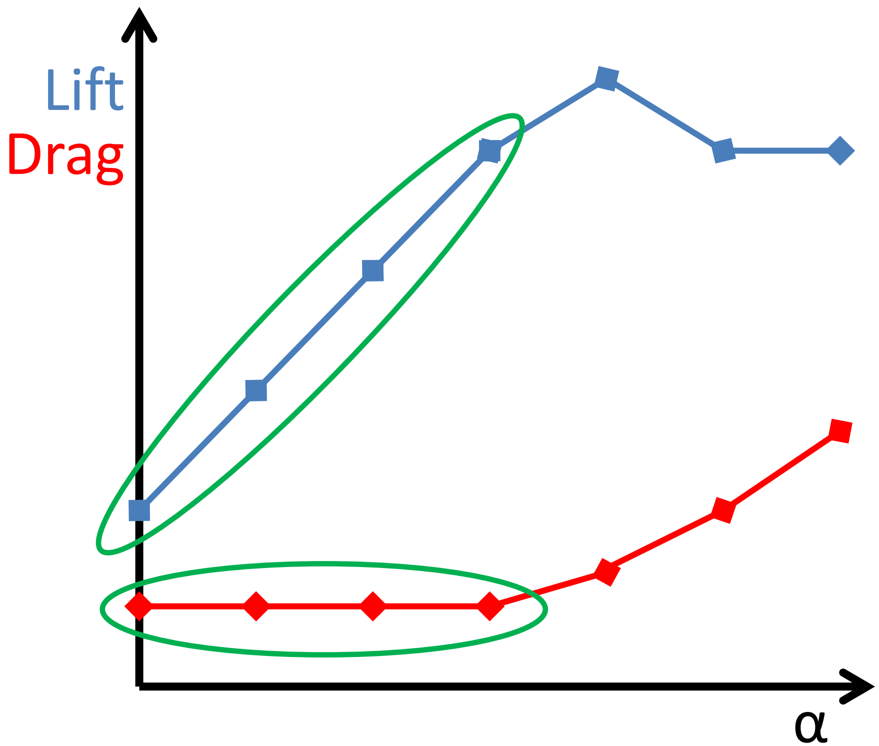


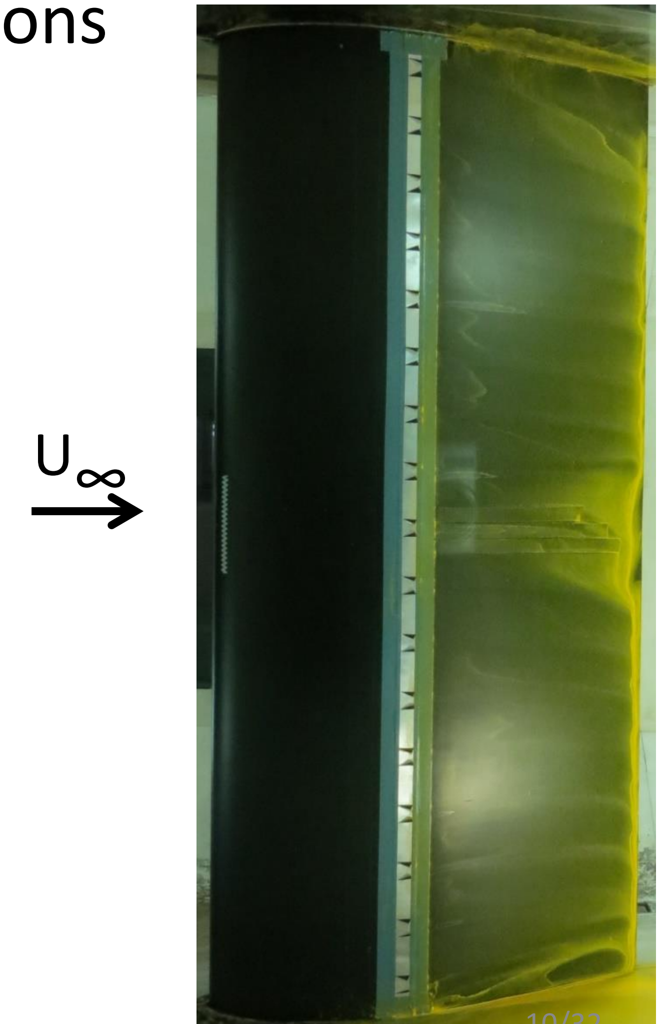
[Apsley, 2001]

Experimental Set Up

What happens away from the tips?

2D flow under attached flow conditions



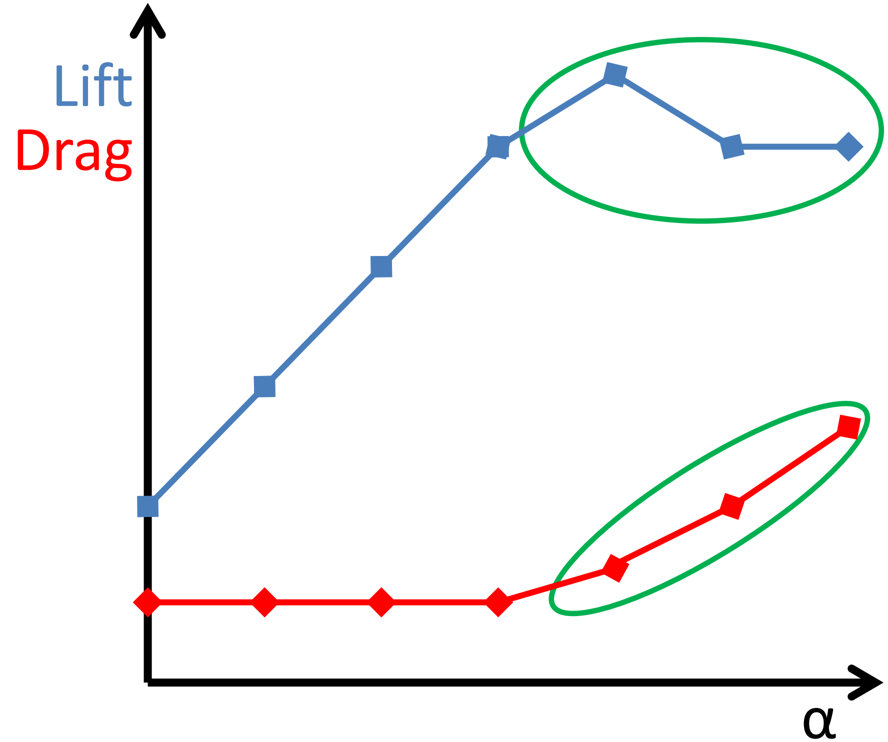


Experimental Set Up

What happens away from the tips?

3D flow around maximum Lift

Stall Cells are formed



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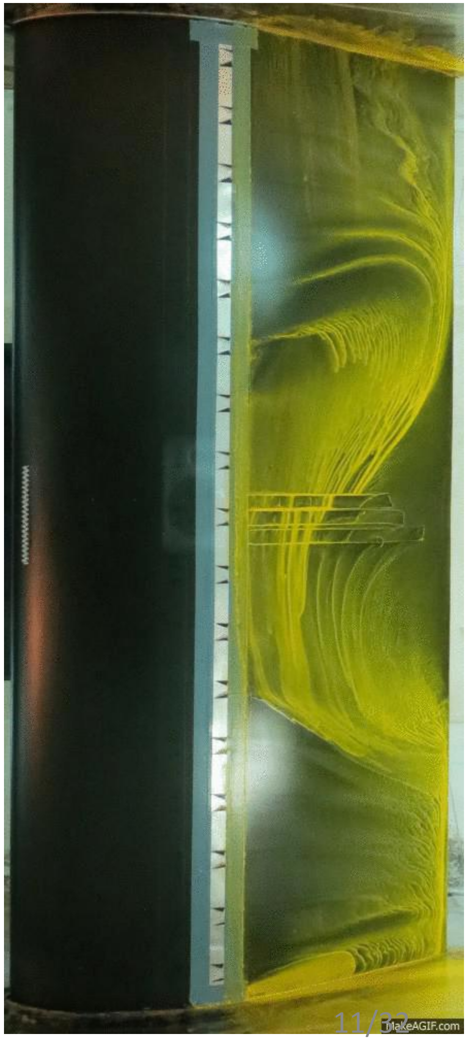
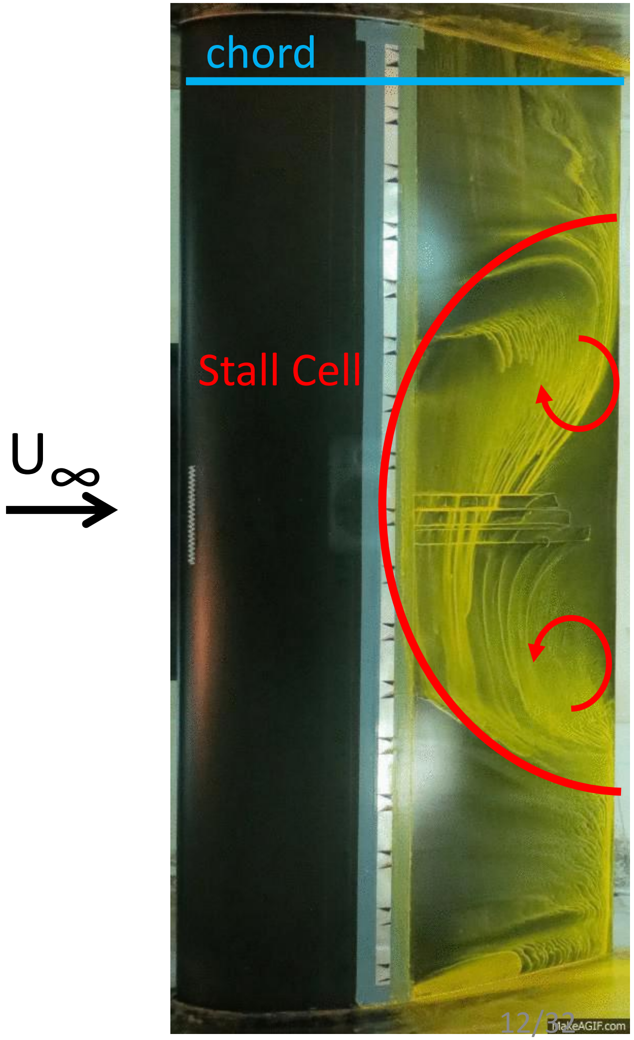


Stall Cells

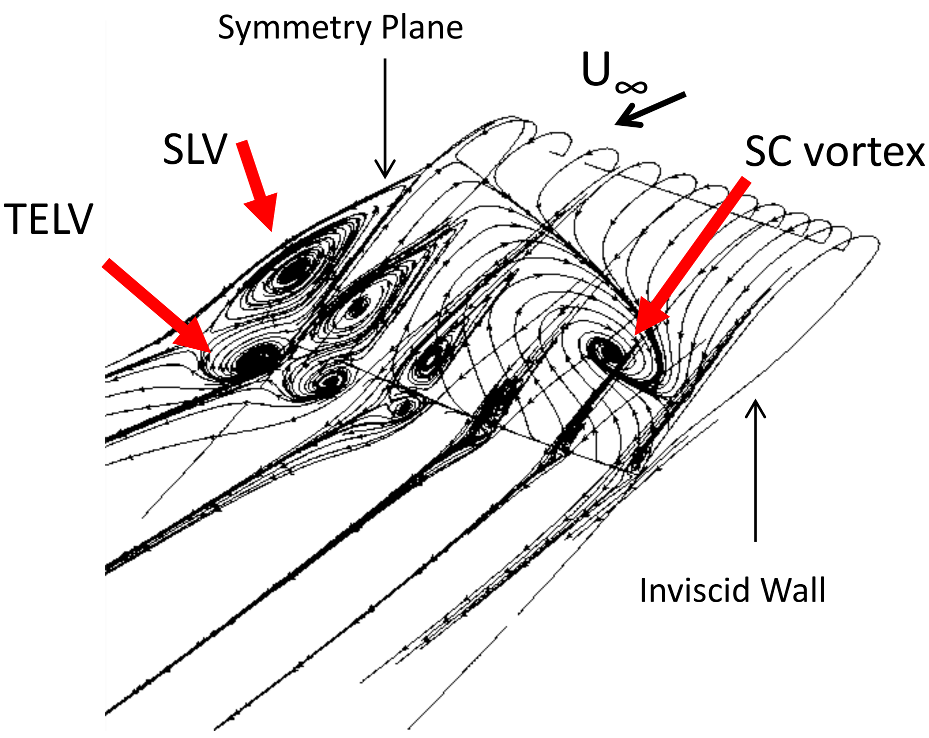
Stall Cells are coherent structures of separated flow

- large scale
- consist of a pair of counter rotating vortices
- are unstable
- have been observed for a very wide range of Reynolds (Re) numbers
- <u>are not a tip effect</u>



Stall Cells

Structure

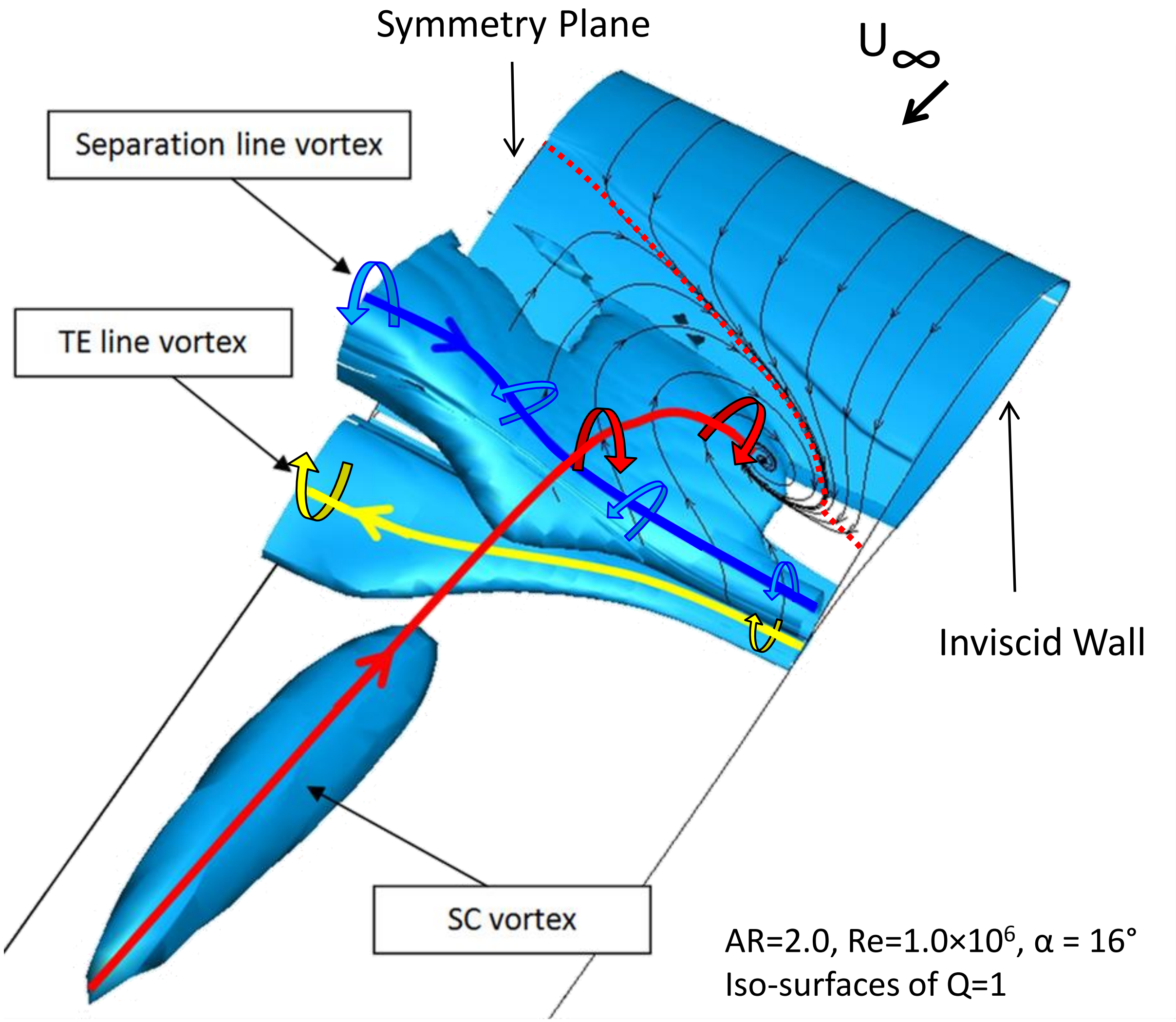


AR=2.0, Re=1.0×10^6, α = 16°

- The SC vortex
  - starts normal to the wing surface
- The Separation Line Vortex (SLV)
  - parallel to the wing TE
- The TE line vortex (TELV)
  - parallel to the SLV but with vorticity of opposite sign

Stall Cells

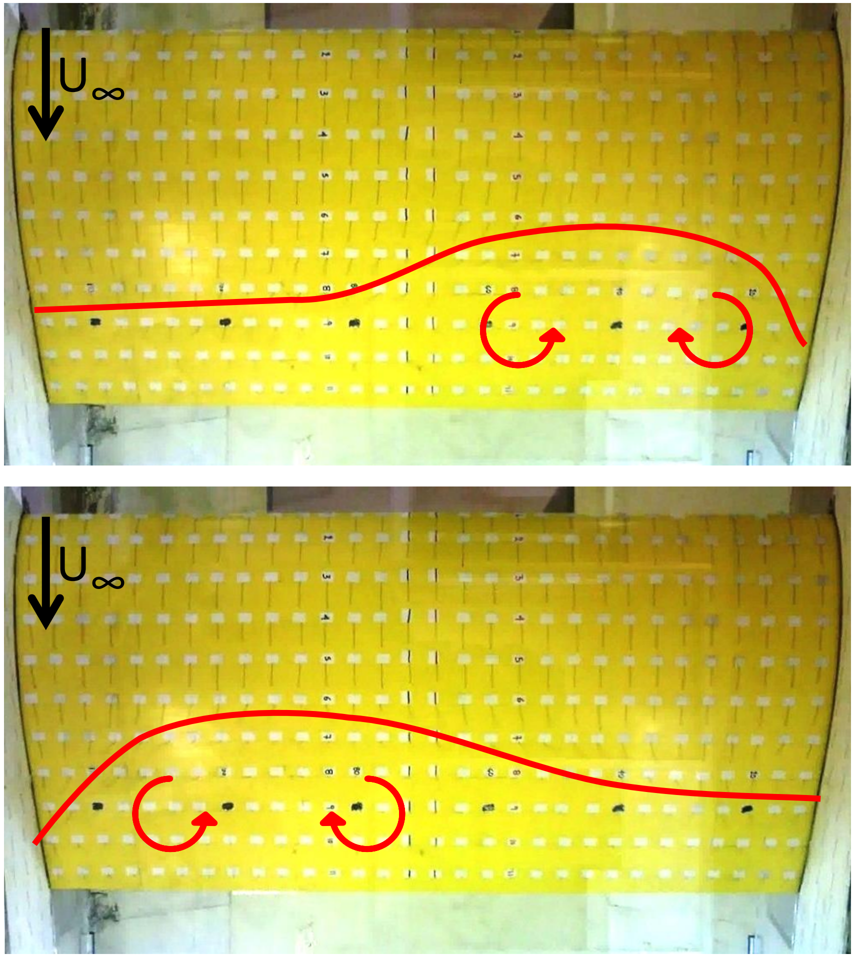
Structure



Stall Cells

Instability

- Their number or position can change arbitrarily

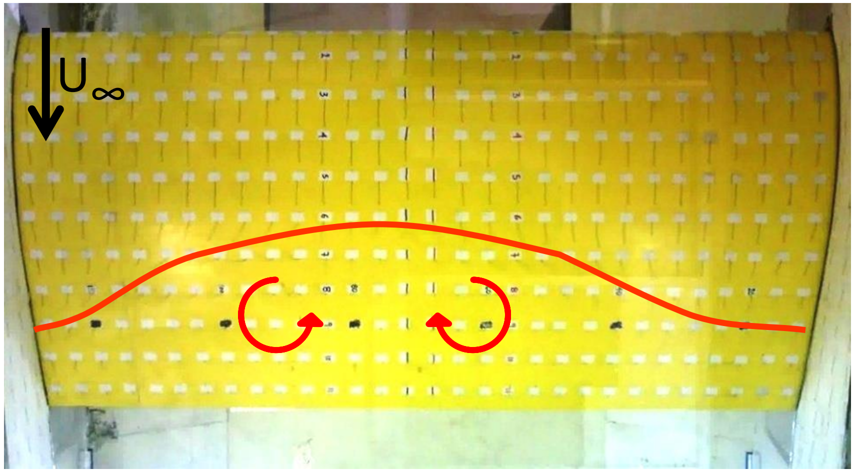


AR 2.0, α = 11°, Re = 1.0x10^6

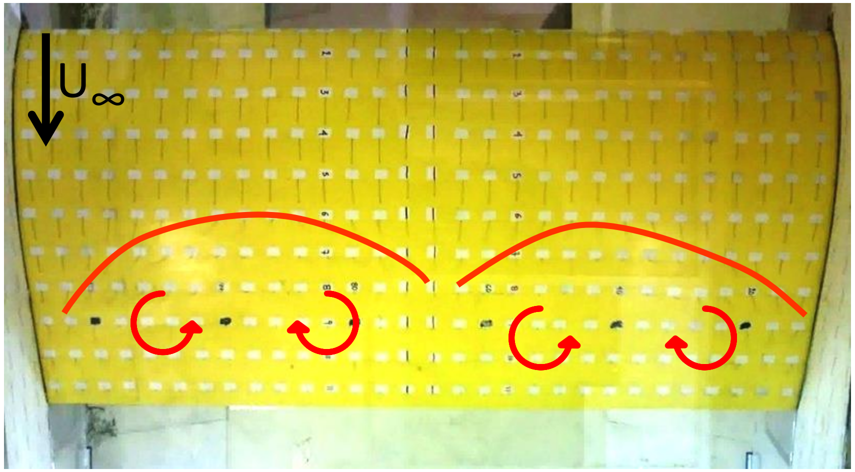
Stall Cells

Instability

- Their number or position can change arbitrarily



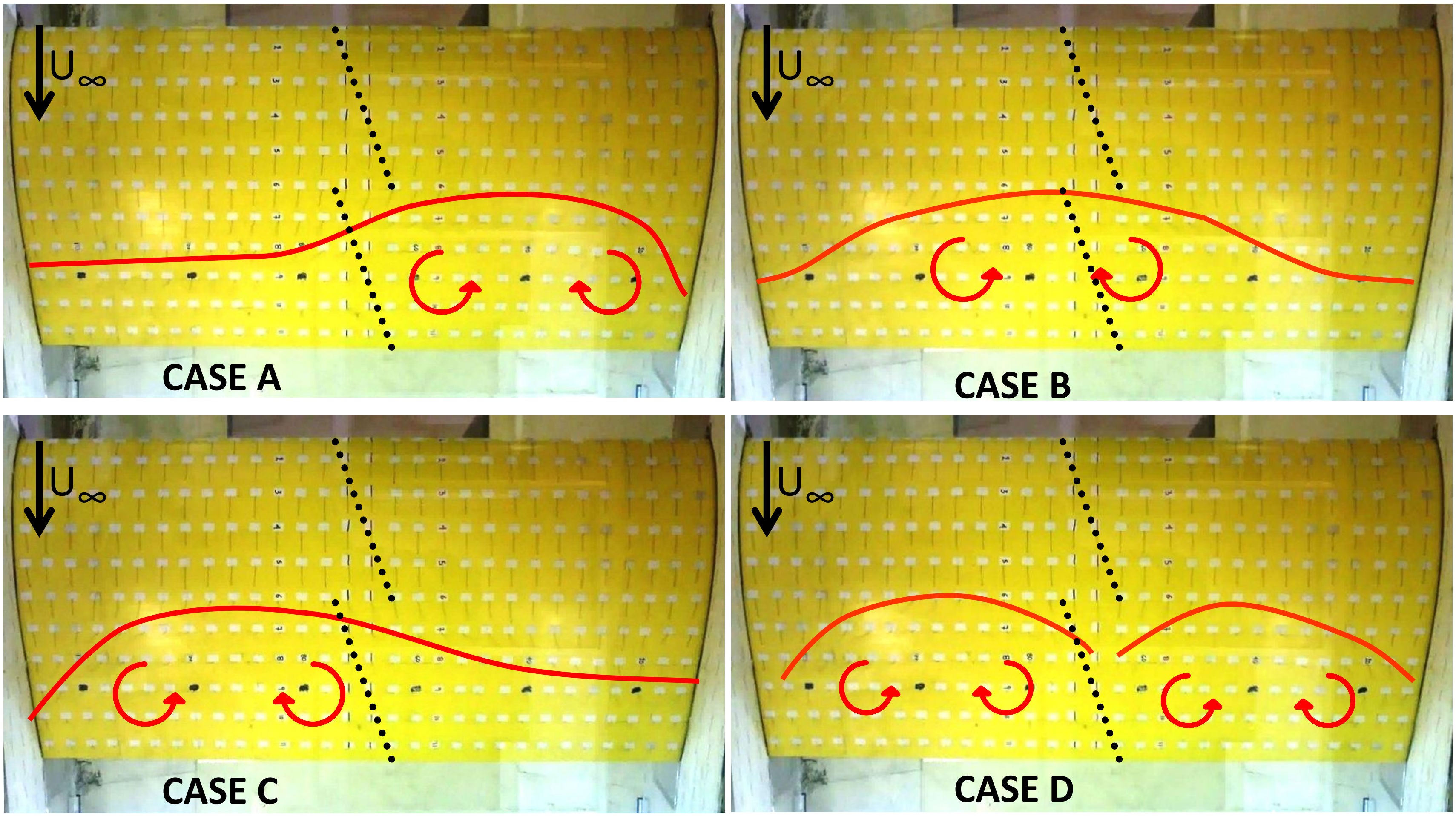
- Their movement/formation shows no apparent periodicity
  - No correlation with Re number, aspect ratio or angle of attack has been found.



AR 2.0, α = 11°, Re = $1.0x10^6$

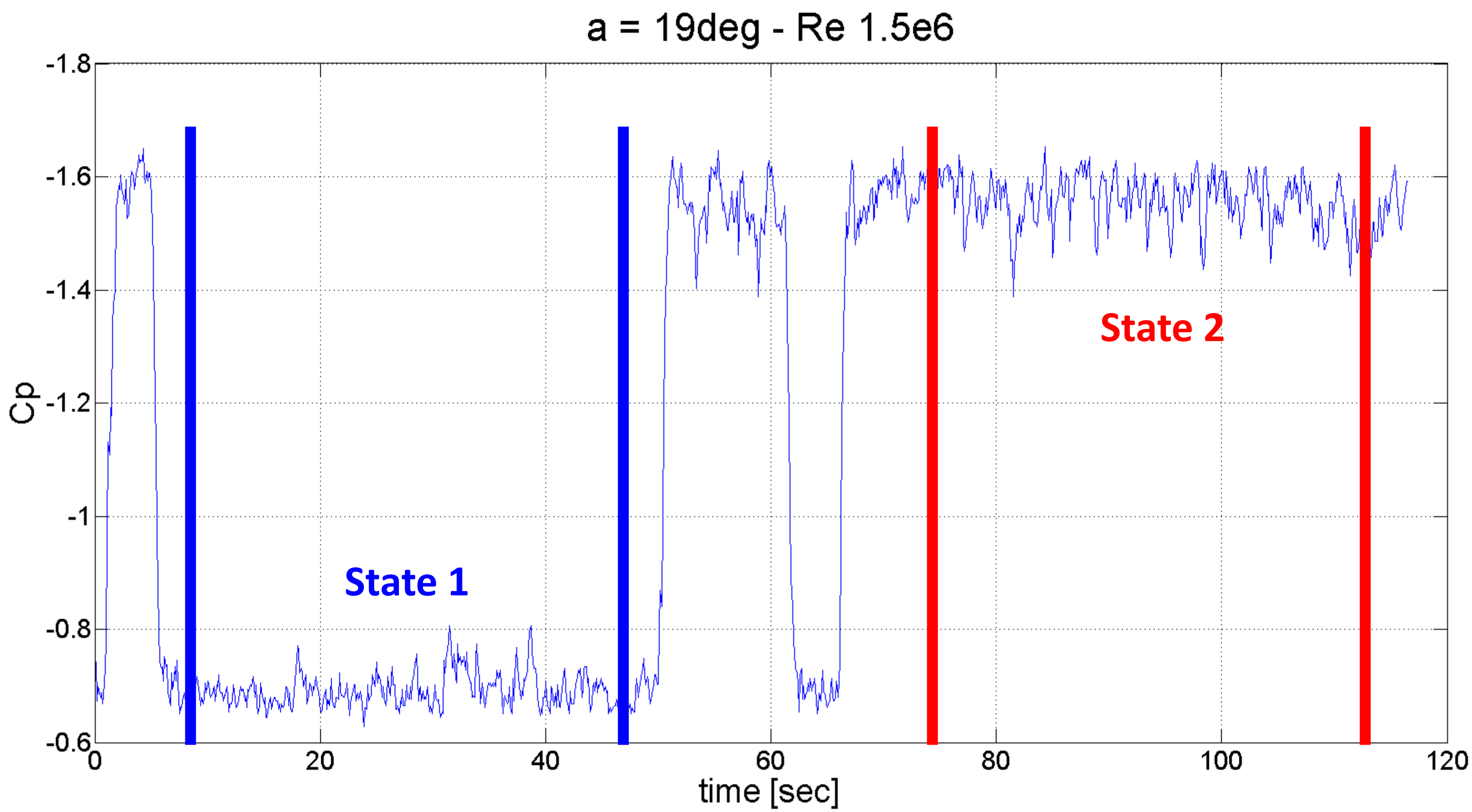
Implications

Know what you measure



Implications

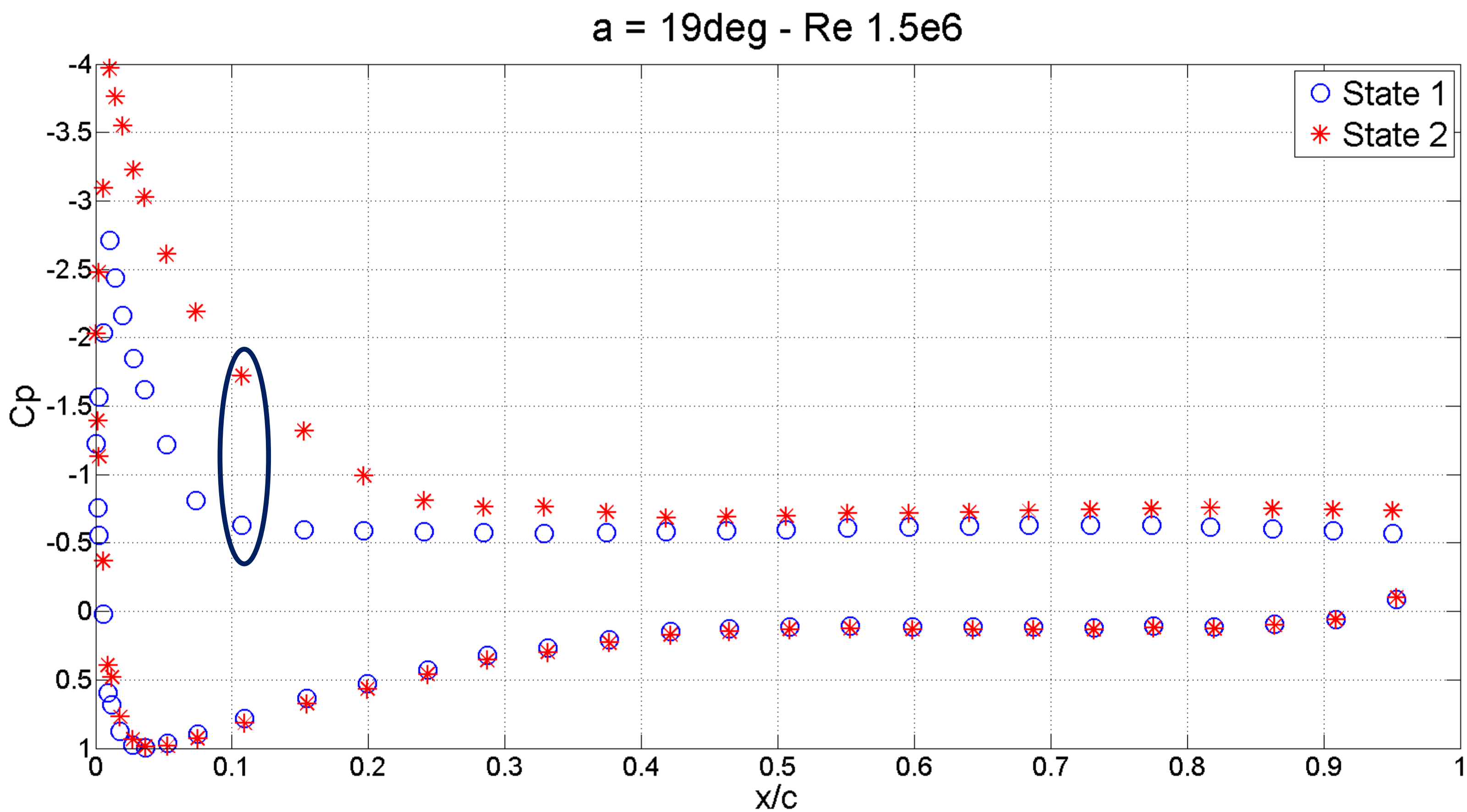
Know what you measure



Pressure time series from tap at x/c =0.11

Implications

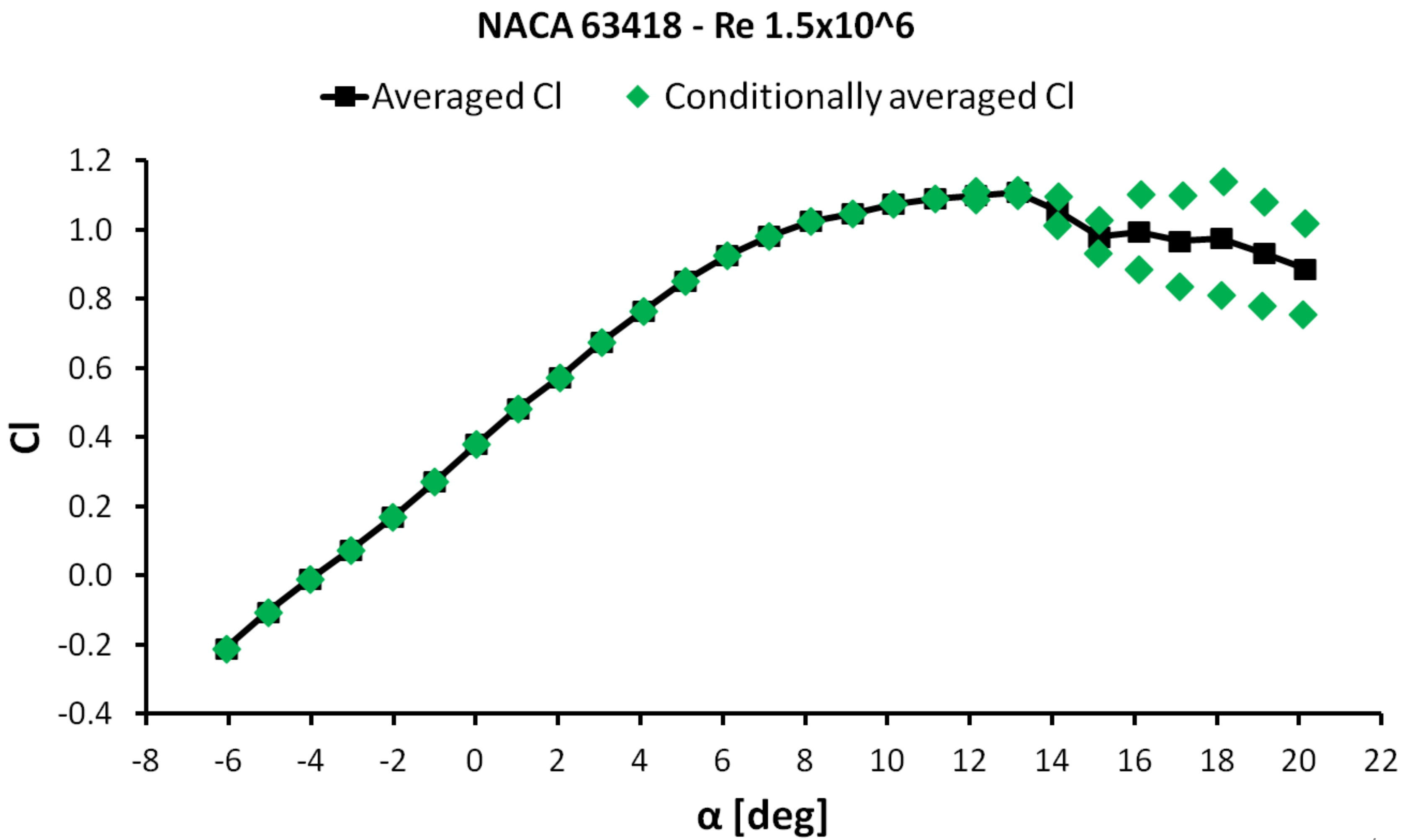
Know what you measure



Cp distribution, conditional averaging

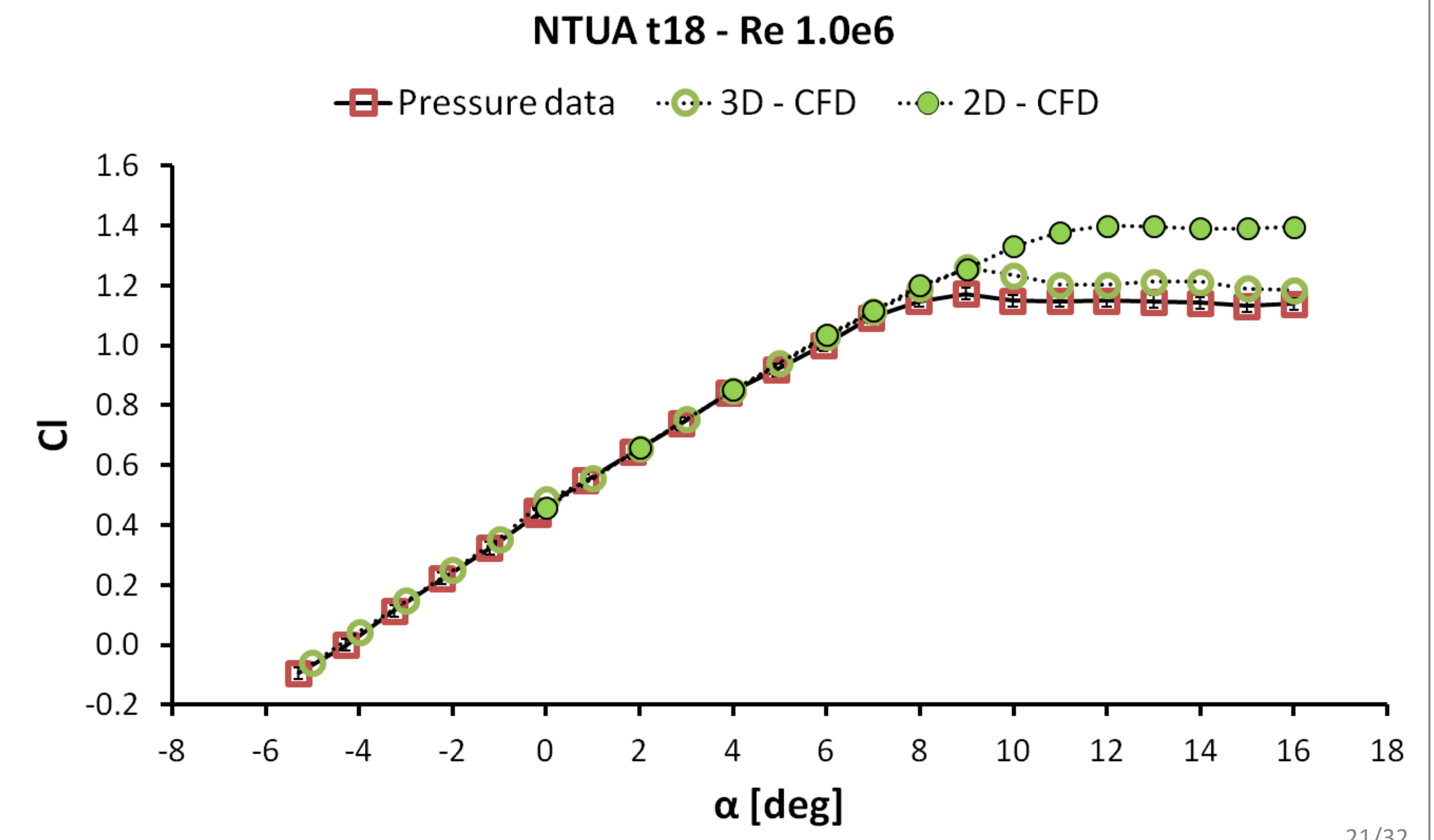
Implications

Know what you measure



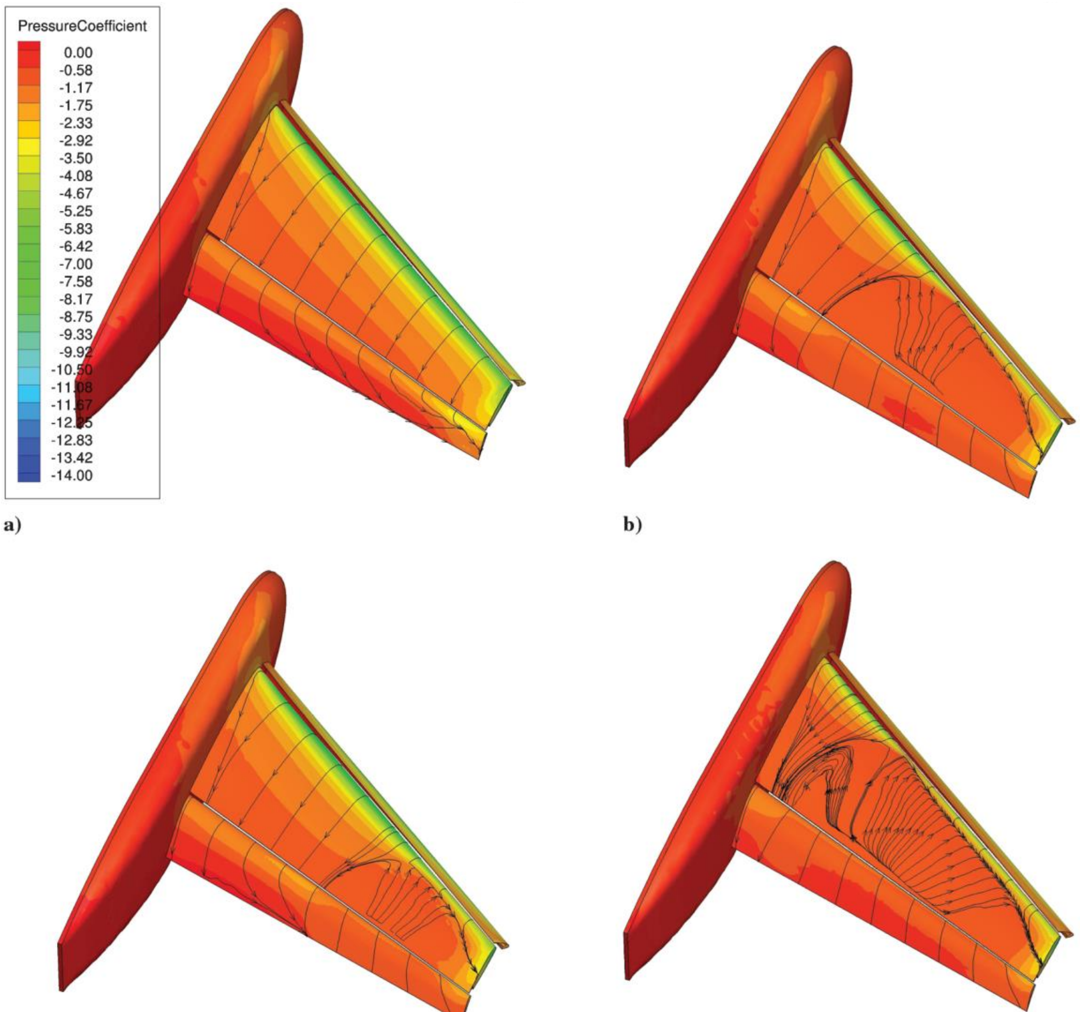
Implications

Know what you compare to



Implications

Know what you compute



c) [Kamenetskiy, 2014] d)

Multiple solutions exist for the discretized RANS equations

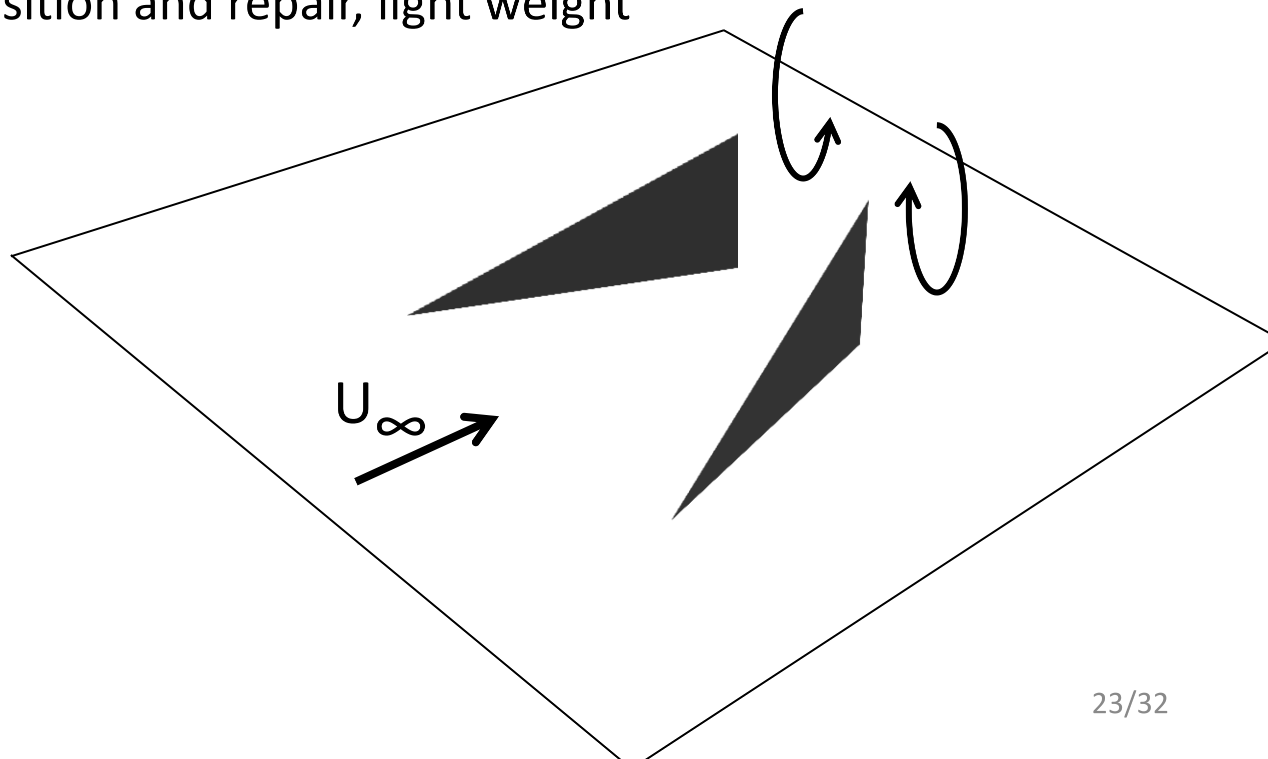
- Grid
- Turbulence model
- Convergence
- Initial conditions
- Implementation of boundary conditions
- Perturbations

Which solutions correspond to real flow?

Stall Cell Control

Passive Vortex Generators (VGs)

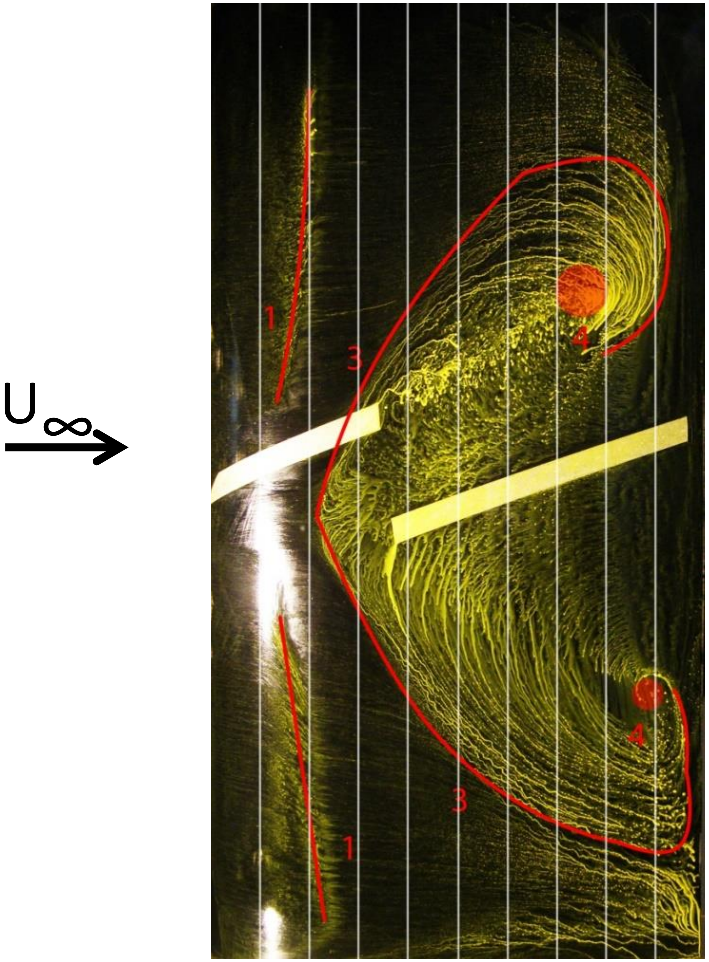
- VGs are vanes located normal to the wing surface
- Their height is at the order of the Boundary Layer height
- They create streamwise vortices that energize the boundary layer and thus delay separation
- Easy to construct, position and repair, light weight

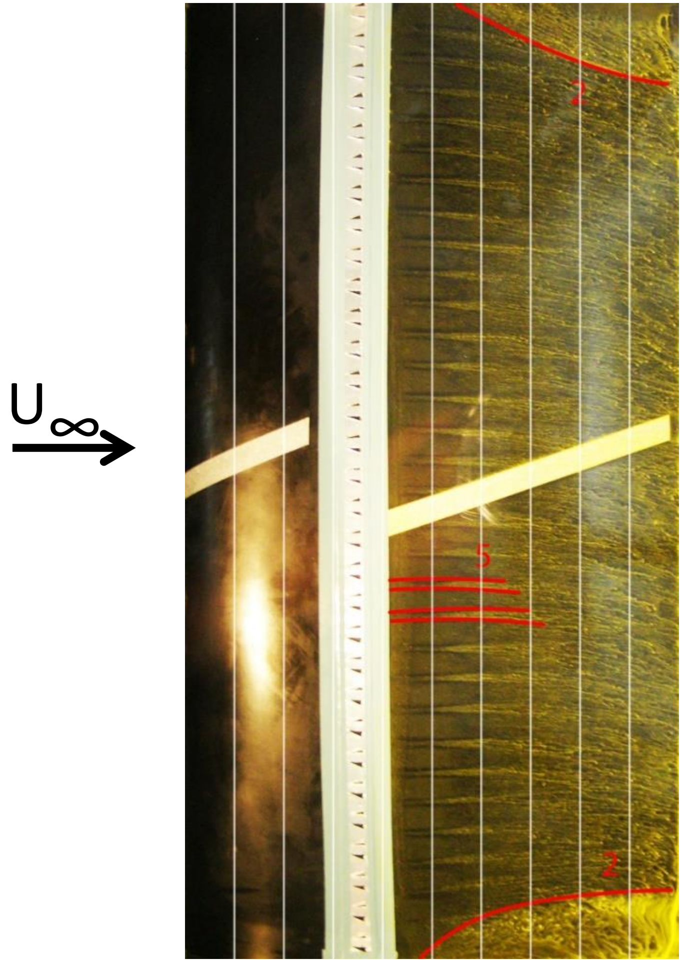


Stall Cell Control

Passive Vortex Generators can delay SC formation

without VGs | **with VGs**



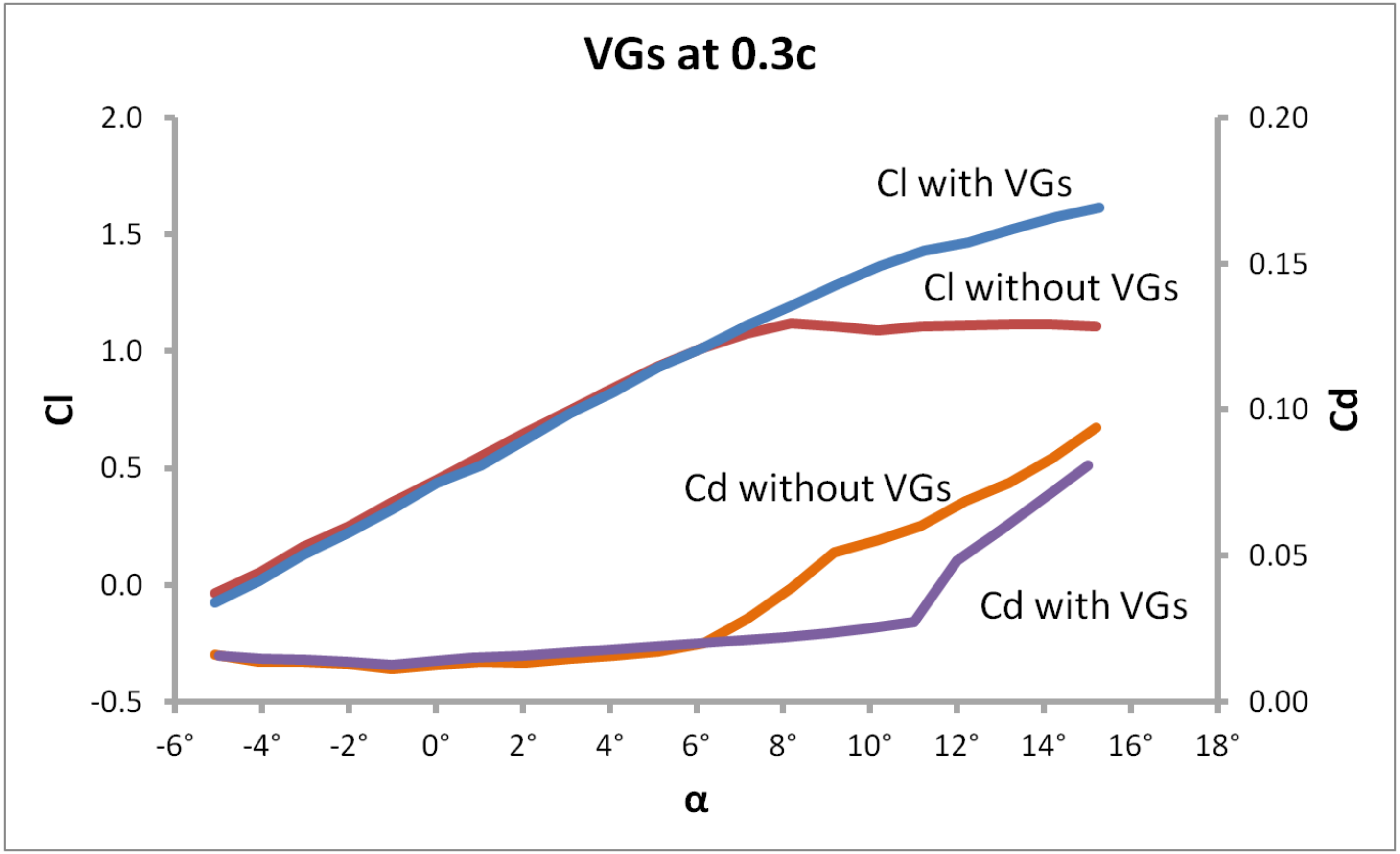


Re = 1.5x10^6, α = 14°

Stall Cell Control

Passive Vortex Generators can delay SC formation

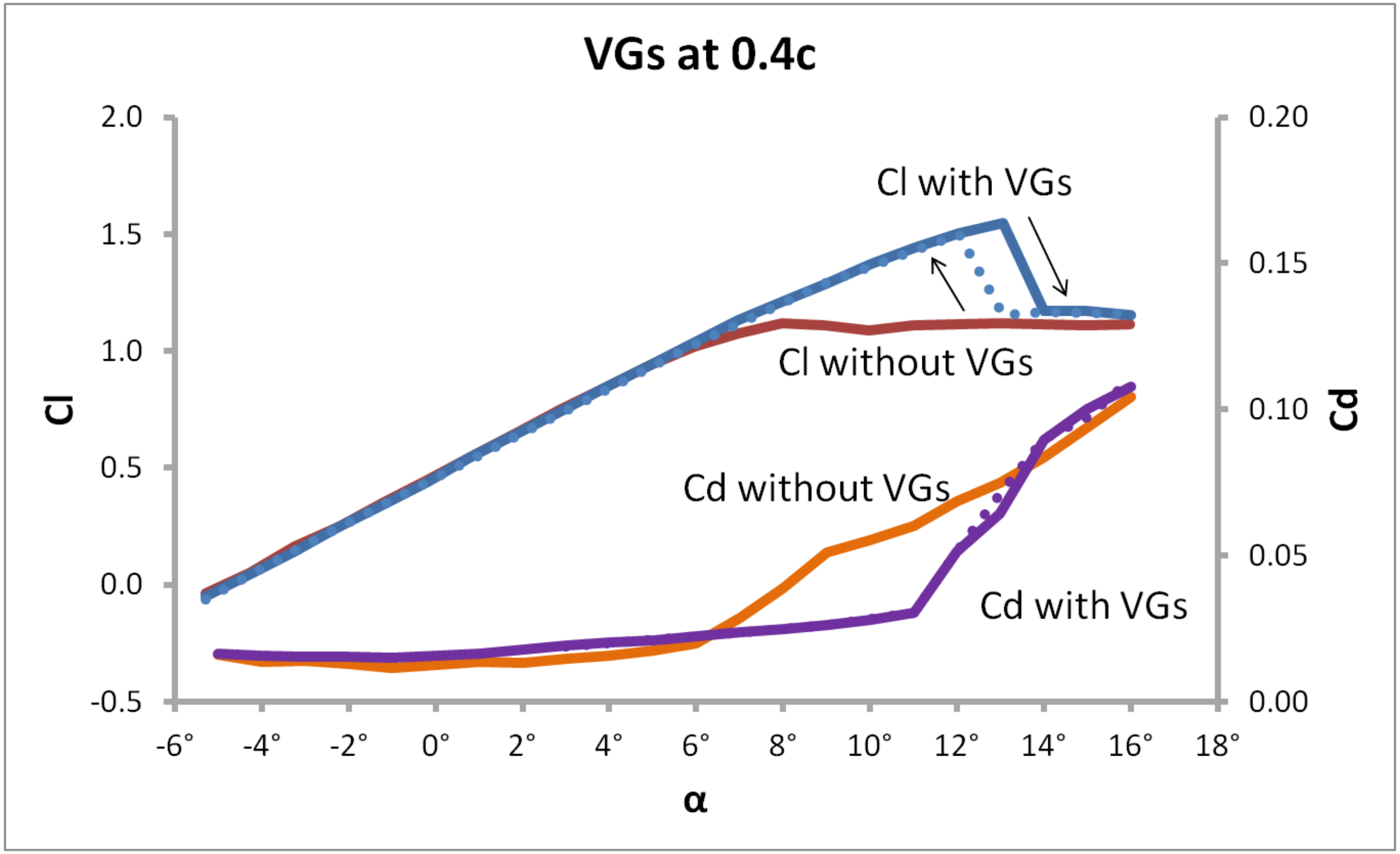
- Clmax increased substantially (~50%)
- Drag penalty at lower angles of attack (~0.002)



Stall Cell Control

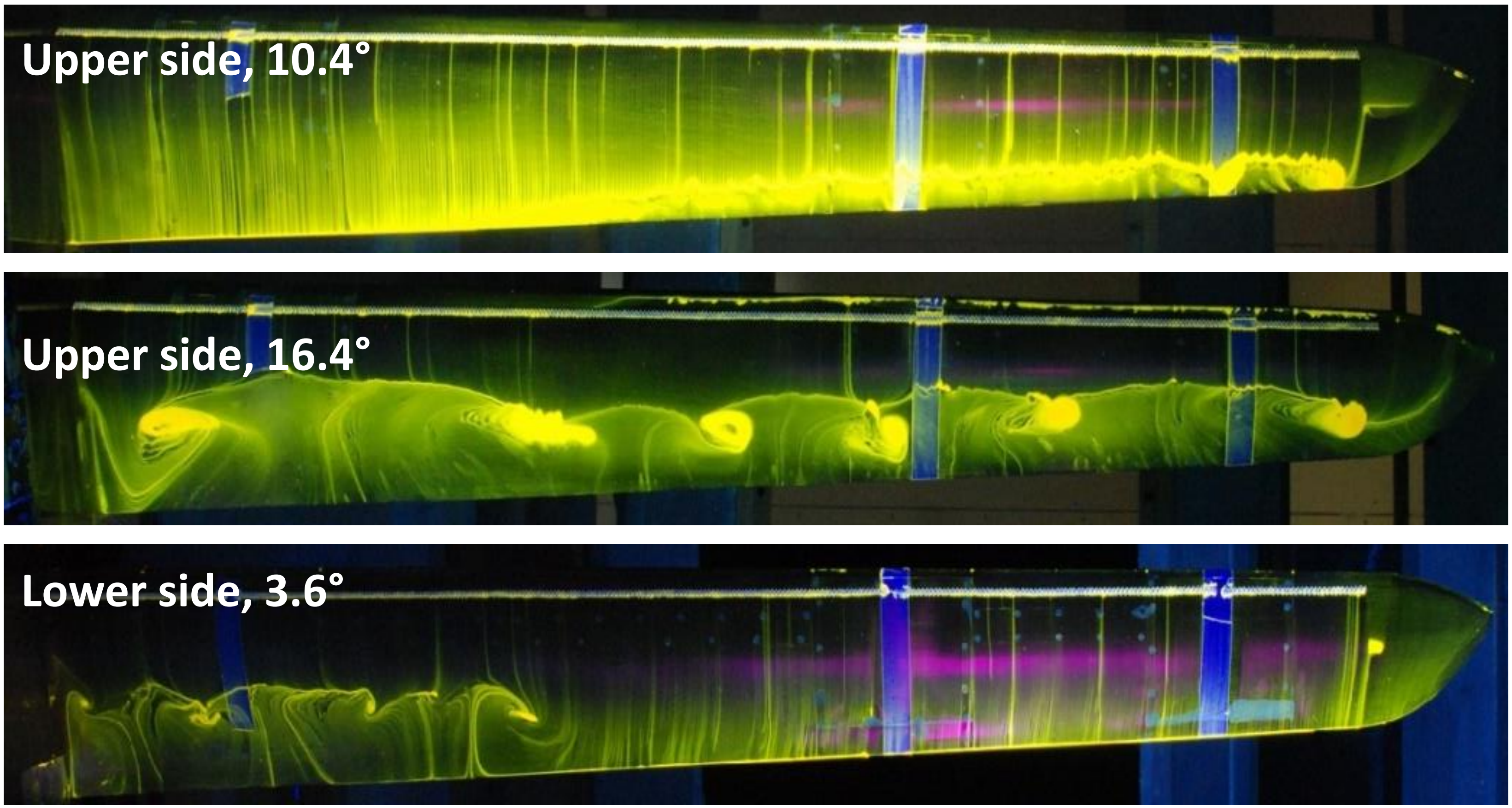
Passive Vortex Generators can delay SC formation

- Depending on the chordwise location of the VGs, flow hysteresis may appear



Stall Cells, where else?

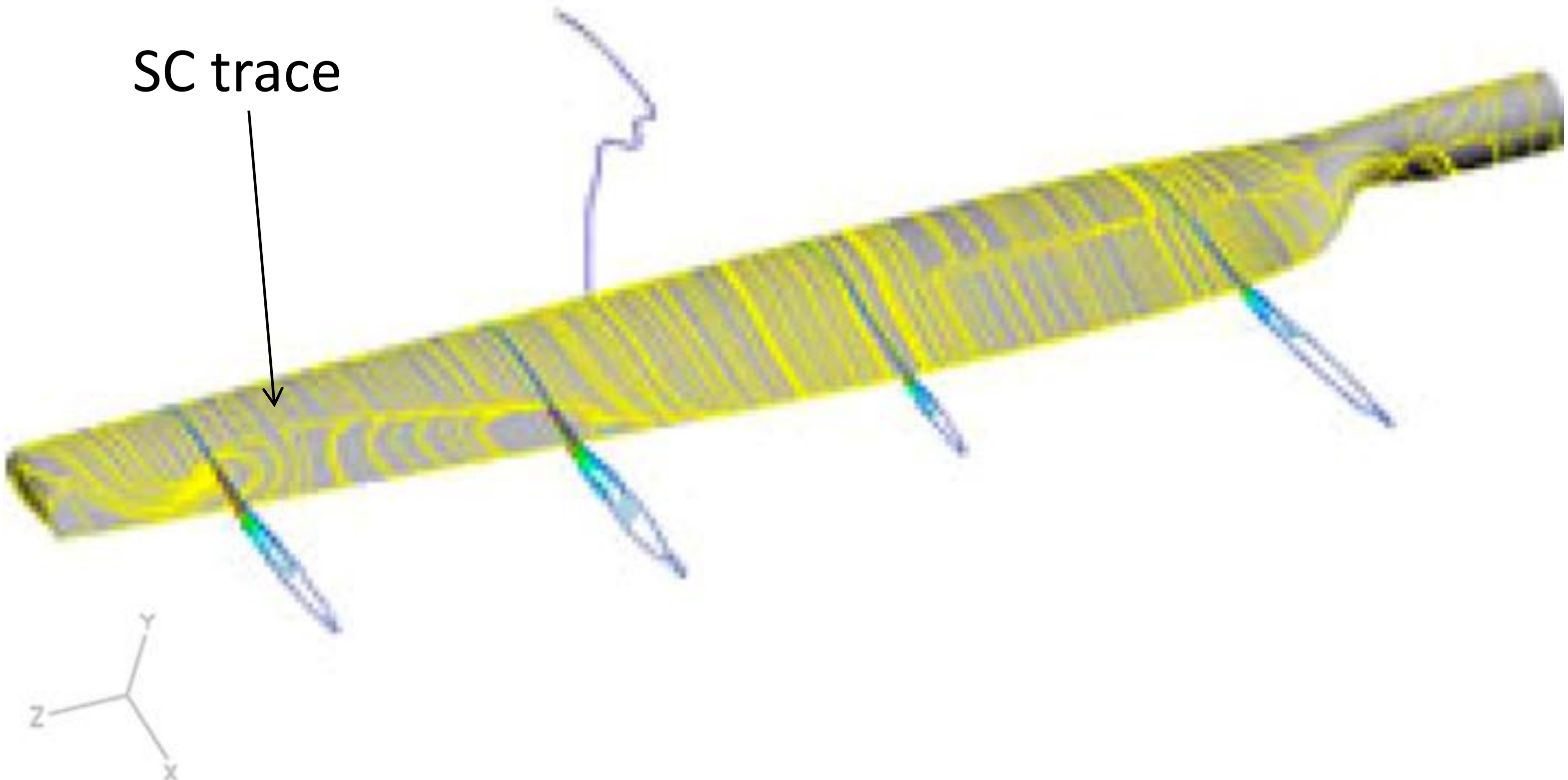
On wind turbine blades at standstill



[Boorsma, 2014]

Stall Cells, where else?

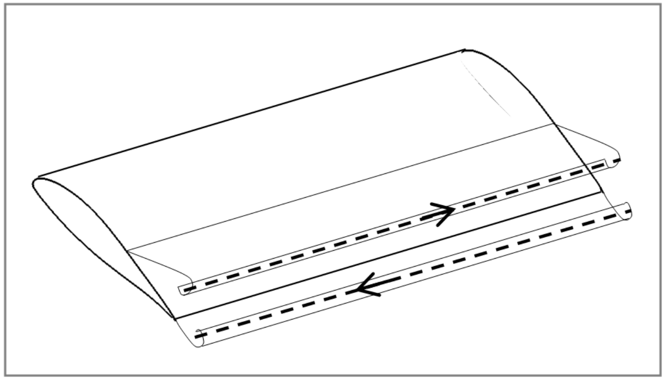
On wind turbine blades at standstill



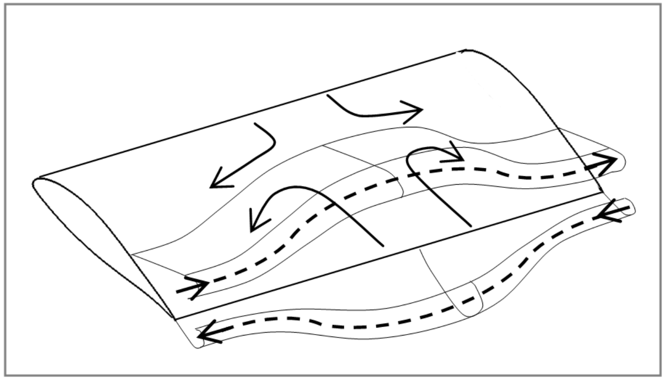
[Sorensen & Schreck, 2012]

Stall Cell Formation

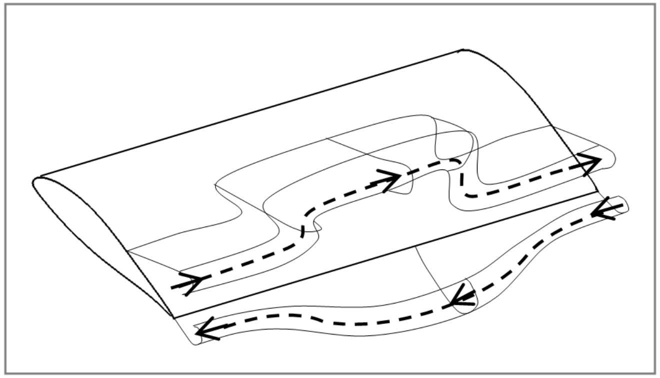
Formation Hypothesis



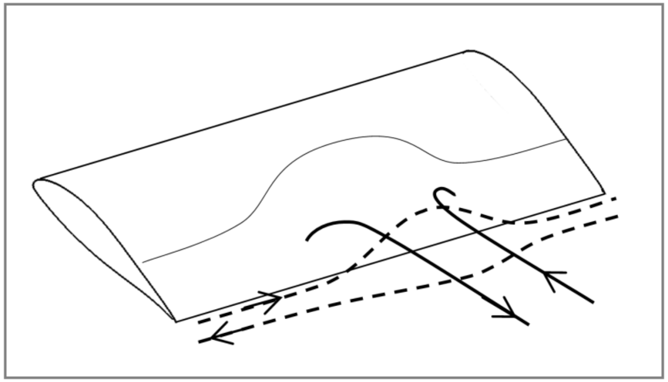
Initial 2D formation



3D instability develops



Separation shear layer folds up



Final time averaged flow

Conclusion

Does a symmetric 2D set-up result in symmetric 2D flow?

Yes, under attached flow conditions

Not in the case of 3D trailing edge separation

Outlook

What causes the Stall Cell unsteadiness?

How do adjacent Stall Cells interact with each other?

What is the link between Stall Cells and blade vibrations?

What happens on a rotating blade?

How do we determine whether a numerical solution is “real” or not?


Thank you for your attention.
Questions?

References

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