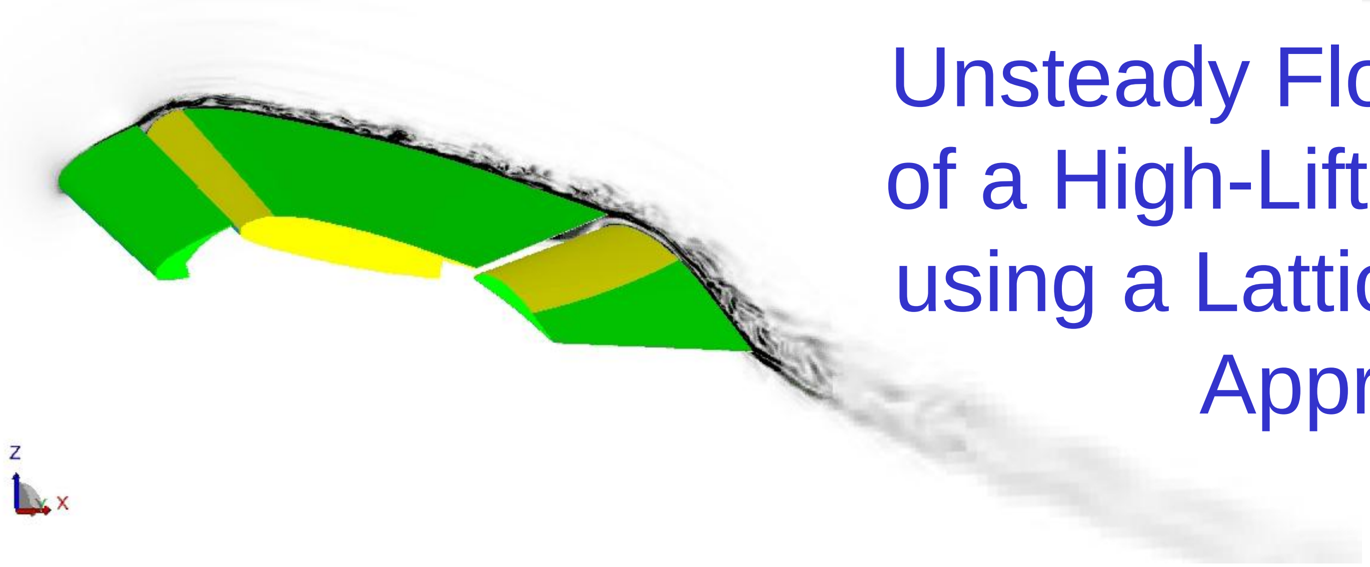

Unsteady Flow Simulation of a High-Lift configuration using a Lattice Boltzmann Approach

Ehab Fares, Swen Nölting - Exa GmbH

49th Aerospace Sciences Meeting and Exhibit
4-7 January, 2011, Orlando, Florida

Acknowledgements
Tony Keating, Rupesh Kotapati, Joaquin Gargoloff
Judith A. Hannon

Overview

- Introduction
  - *TrapWing Geometry*
- Numerical Method
  - *Lattice-Boltzmann based code (PowerFLOW)*
    - Turbulence Modeling
    - Boundary Conditions
- Results
  - *Simulation Overview*
    - Grid Convergence
  - *Free Stream Simulations (Workshop Data)*
    - Effect of including brackets
    - Influence of transition
  - *Investigation of blockage effects*
- Conclusions & Outlook

Introduction

- Geometry and Measurements
  - *provided through 1st High-Lift prediction workshop held in June 2010*

    http://hiliftpw.larc.nasa.gov/
- Model details:
  - *Semi-span, three-element configuration mounted on a body pod*
  - *Untwisted trapezoidal wing*
  - *MAC of 39.6”, AR of 4.56, LE Sweep 29.97°*
  - *$Re_{MAC}=4.3e^6$, Ma=0.2*
- Experimental details:
  - *NASA Langley 14’x22’*
  - *Forces, moments, Cp distributions*
  - *Free transition documented in*

    McGinley C.B., Jenkins L.N., Watson R.D., and Bertelrud A., “3-D High-Lift Flow-Physics Experiment - Transition Measurements”, AIAA Paper, 2005-5148, 2005.

Shown in NASA Ames tunnel

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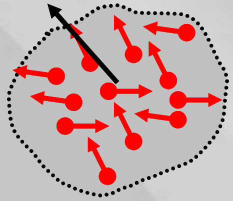
Lattice Boltzmann Method

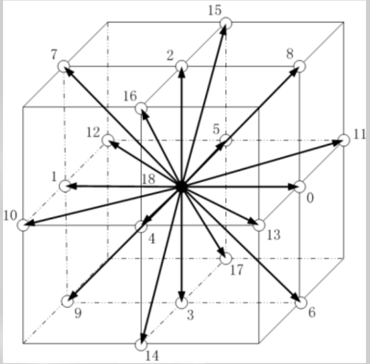
- Fluid properties are described by distribution functions

$$f(\vec{x},\vec{v},t)$$



  - *f is the number density for particles with velocity value v at* $(\vec{x},t)$

- Lattice Boltzmann Equation (LBE)



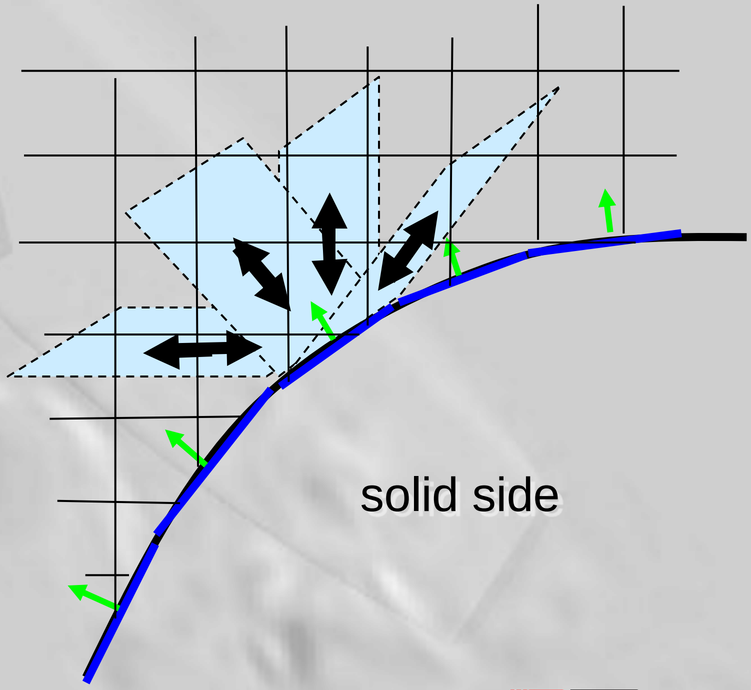
$$f_i(\vec{x}+\vec{v}_i\Delta t,t+\Delta t)=f_i(\vec{x},t)+\Omega_i(\vec{x},t)$$

  - *Advection is by a constant velocity*
  - *BGK collision term*
  - *Fluid variables are obtained via simple summations:*

$$\rho(\vec{x},t)=\sum_i^b f_i(\vec{x},t) \quad \rho\vec{u}(\vec{x},t)=\sum_i^b \vec{v}_i f_i(\vec{x},t)$$

Boundary Conditions

- Boundary condition process in PowerFLOW:
  - *Original solid surface*
  - *Facetization with a a set of flat surface elements ("surfels") with normals*
  - *Surface facetization intersects cubic volume grid*
  - *In-coming particle directions*
  - *Finite number of parallelograms*
  - *Reflected particle directions*
    - > *Surfaces reflect particles, changing their momentum*
    - > *Momentum changes correspond to changes in pressure/friction*



Turbulence Modeling

- Turbulence modeling approach
  - *'Coherent' statistically anisotropic eddies at larger scales computed*
  - *Statistically universal eddies in the inertial & dissipation ranges modeled*
    - Boltzmann-τ model, uses a modified relaxation parameter
    - Extended RNG 2-equation model
  - *Swirl term used to switch between modeling & simulating eddies*
- Extended wall model
  - *Rescale the thickness of the turbulent boundary layer to account for pressure gradient effects*
- DDES-like turbulence model

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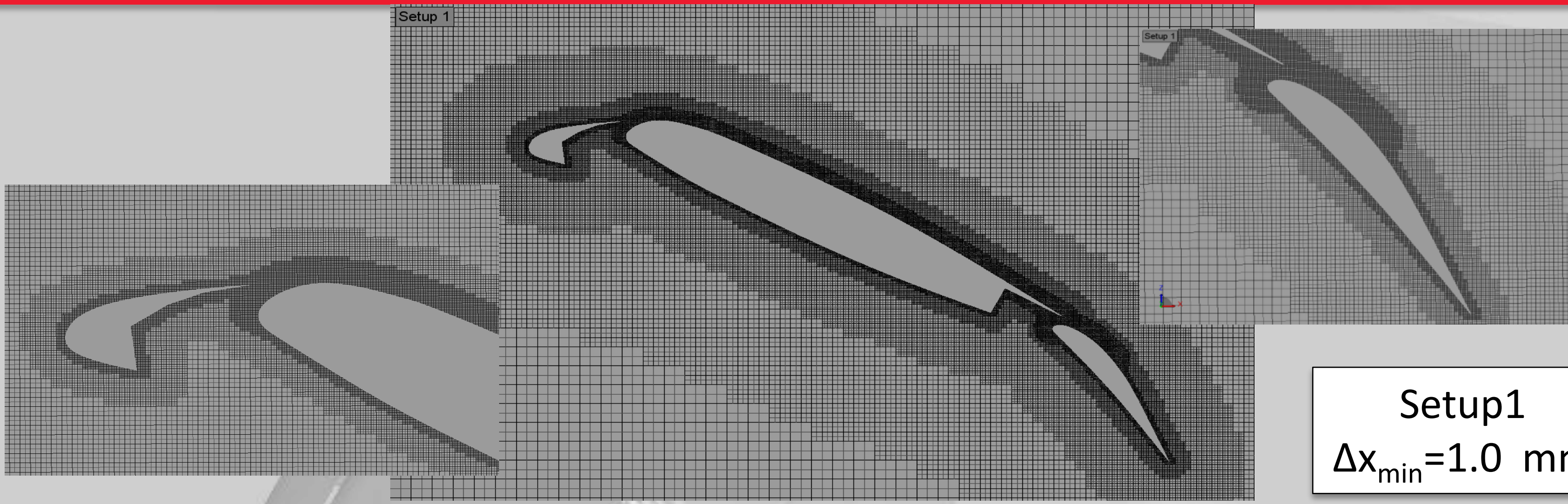
Exa

Simulations Overview (Workshop Data)

		Config 1			Config 8	Config 1 (brackets)
	Resolution	1,00	1,25	1,50	1.0	1.0
Angle of attack	6	√			√	
	13	√	√	√	√	√
	21	√			√	
	28	√	√	√	√	√
	32	√			√	
	34	√			x	
	37	√			x	

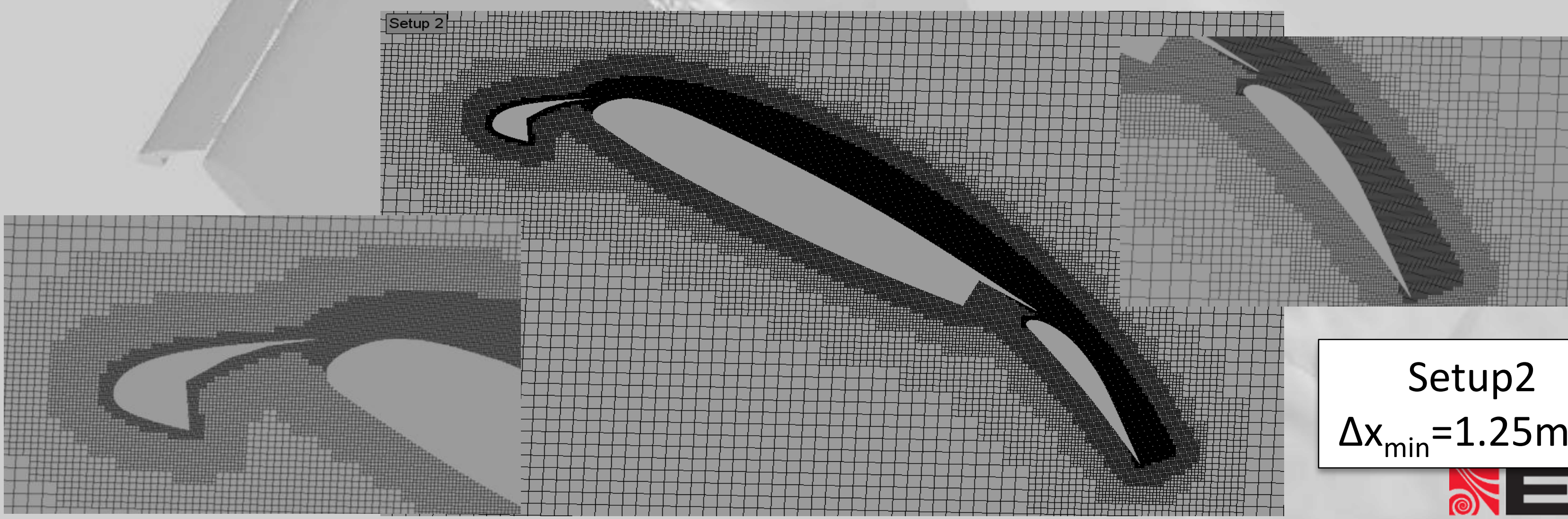
- All simulations started from parallel flow
  - *No seeding*
- Intel Cluster (248 – 512 cores)
  - *Xeon Harpertown CPU, 3.00GHz*
  - *OS: Red Hat Enterprise Linux 5*

Simulation Overview - Grids



Setup1

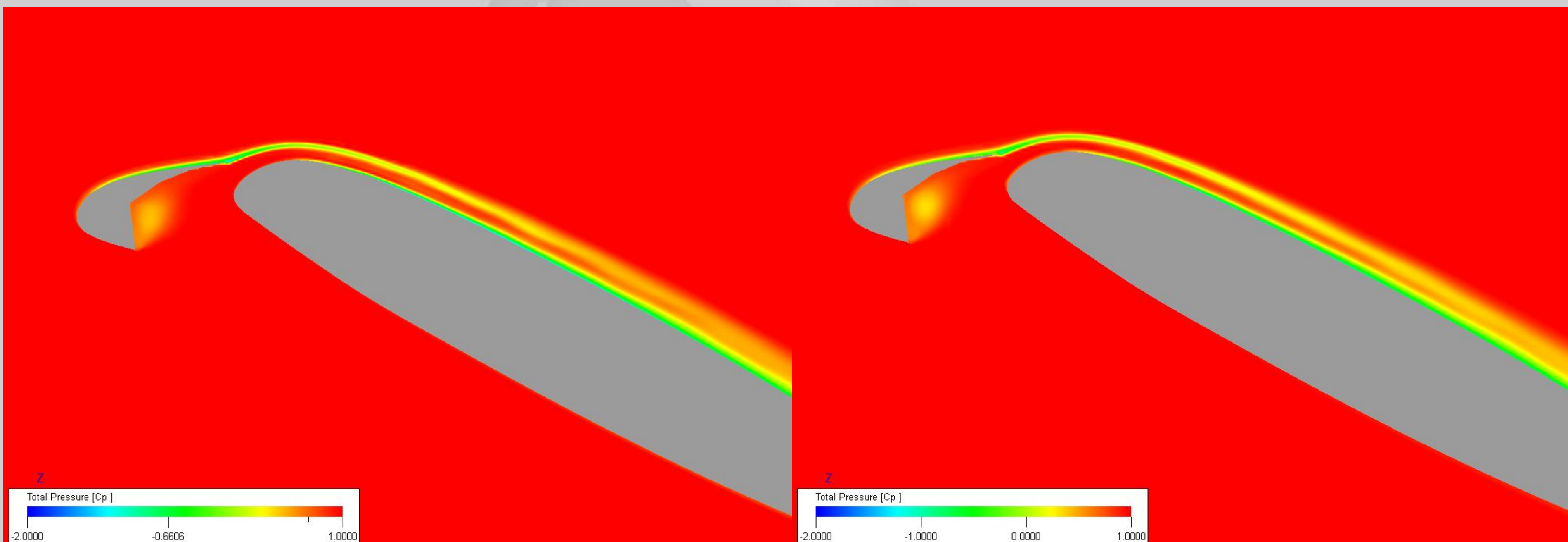
Δx_{min}=1.0 mm



Setup2

Δx_{min}=1.25mm

Simulation Overview – Grids*

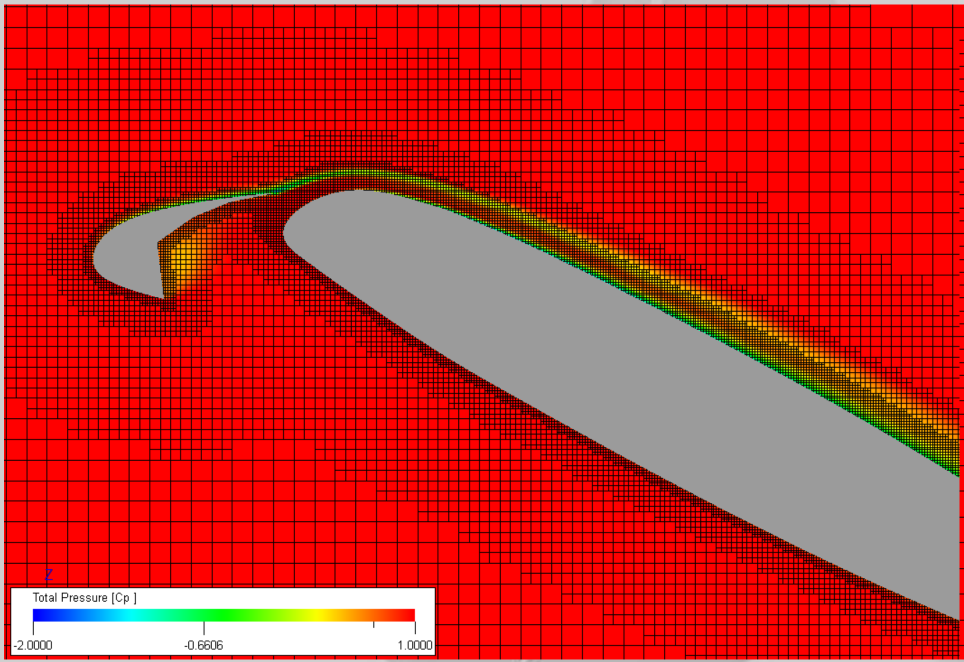


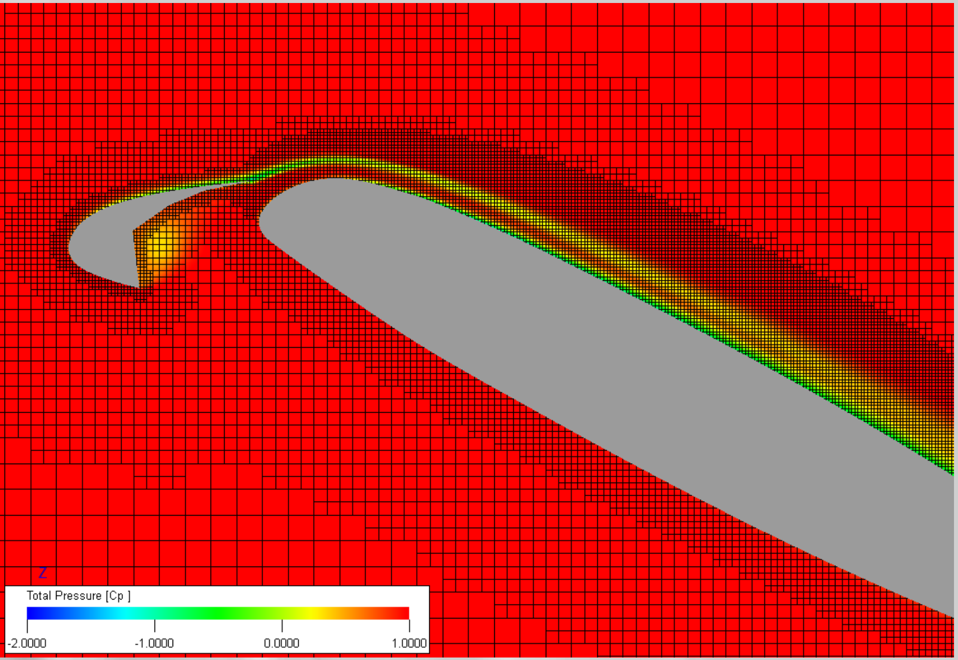
Setup1
Δx_{min}=1.0 mm

Setup2
Δx_{min}=1.25mm

* Y-section for α=28°

Simulation Overview – Grids*





Setup1
Δx_{min}=1.0 mm

Setup2
Δx_{min}=1.25mm

* Each second gridpoint is shown

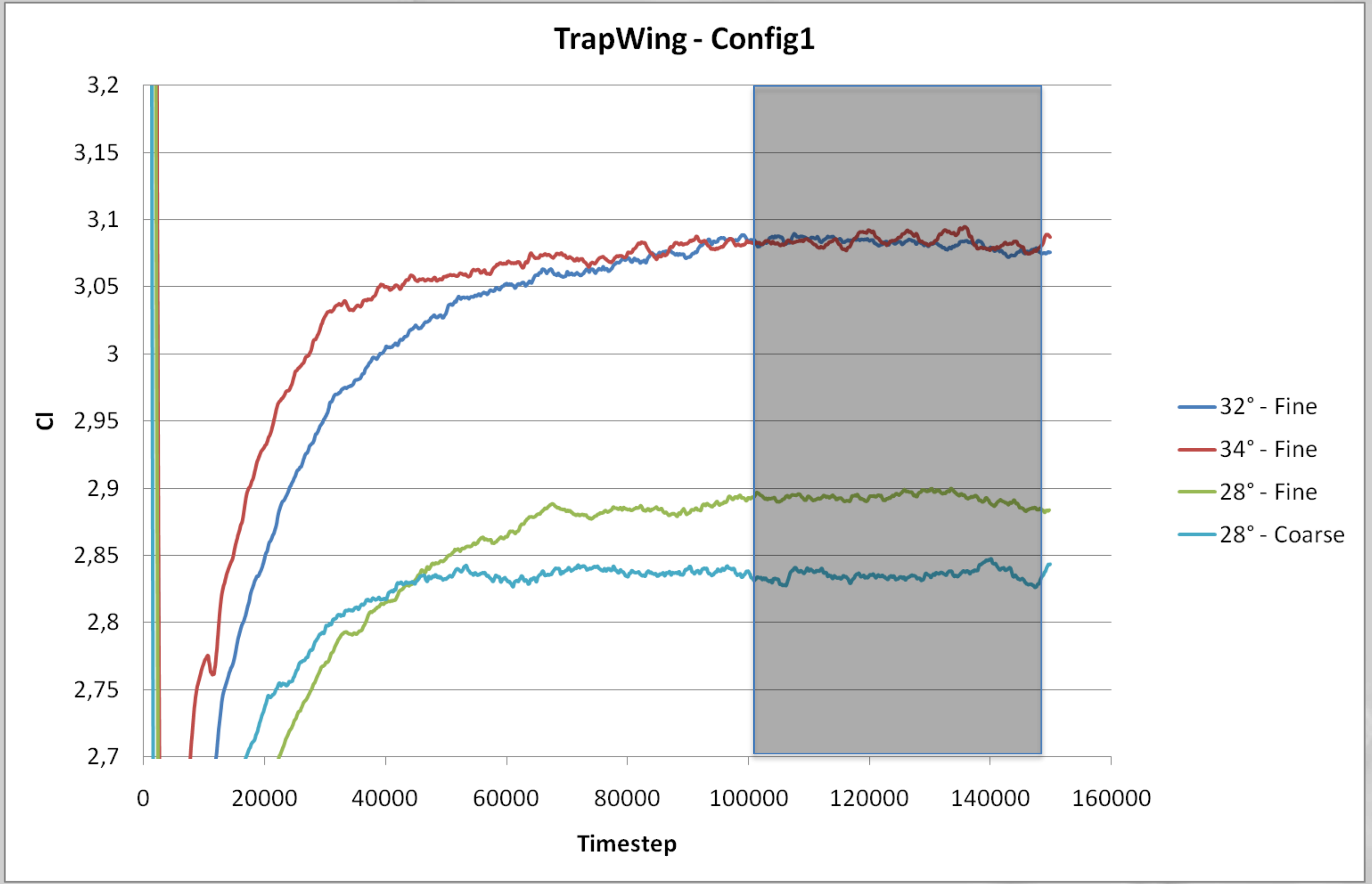
Simulation Overview - CPU Requirements*

	Setup1			Setup 2
Finest voxel size	1.5mm	1.25mm	1.0mm	1.25mm
Total number of Voxels	62 million	101 million	193 million	135 million
Total number of Surfels	5.6 million	7.3 million	9.7 million	9.4 million
Total number of Timesteps	150,000	150,000	150,000	72,000
Grid Generation	***0.8 hours***	***1.1 hours***	***1.4 hours***	***1.6 hours***
CPU-Hours	4,600	6,900	9,300	4,300
Wall-clock Time (248 cores)	***19.5 hours***	***29 hours***	***38.5 hours***	***17.4 hours***

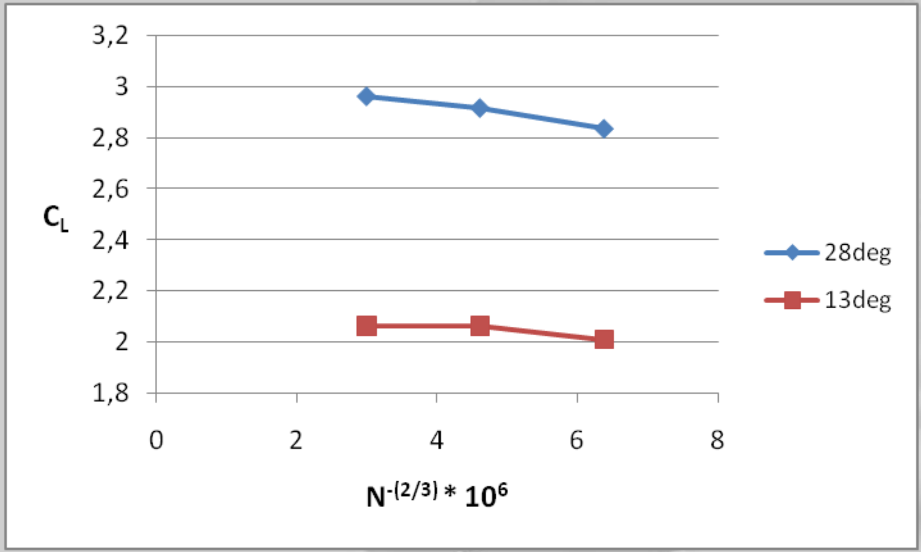
* For 13deg. case

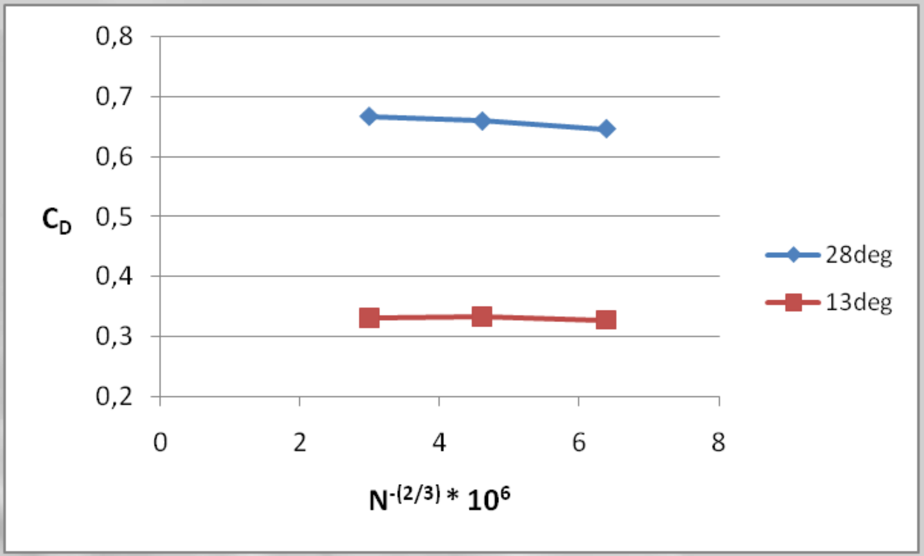
Exa

Simulation Overview - Convergence

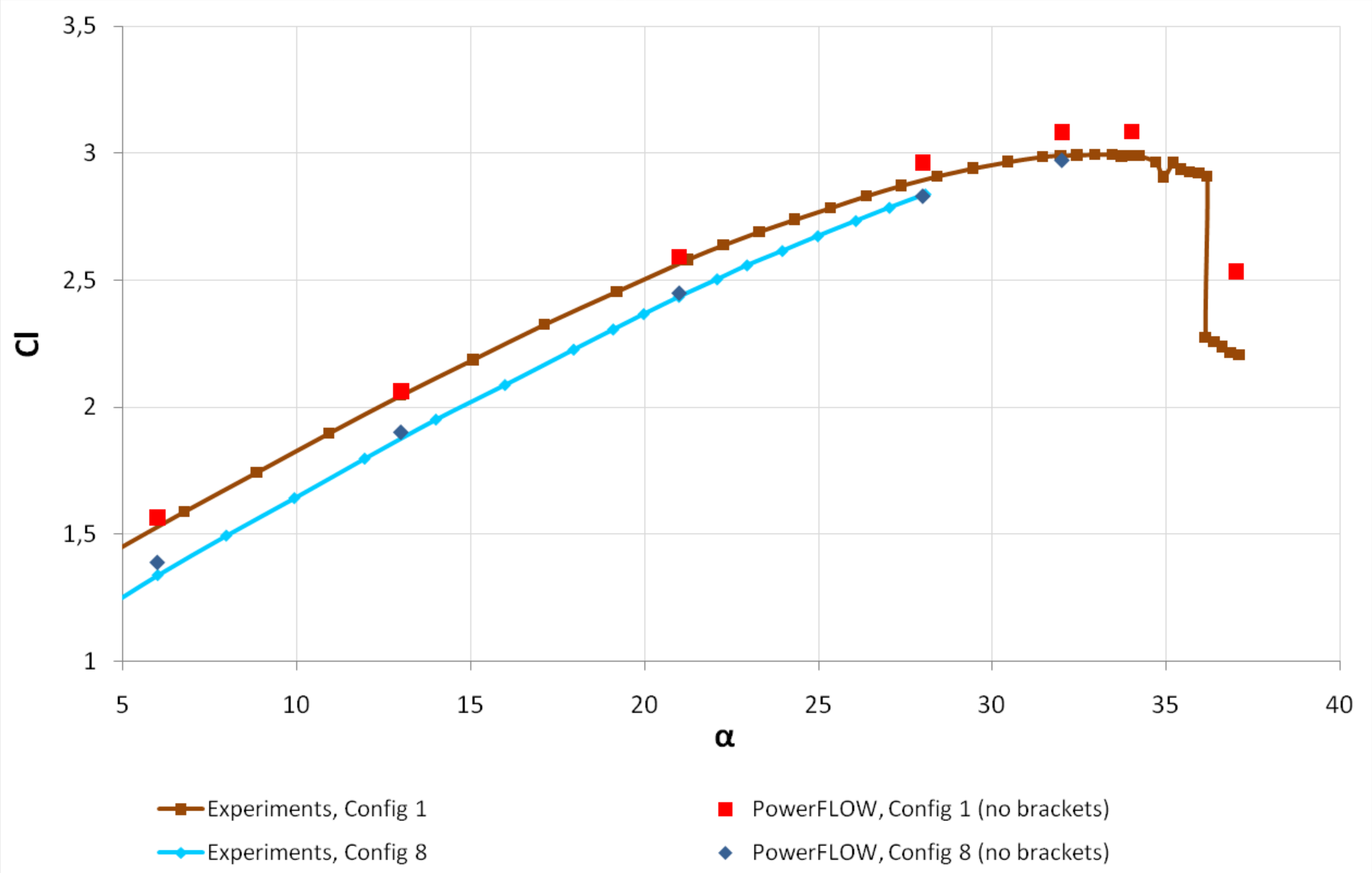


Grid Convergence

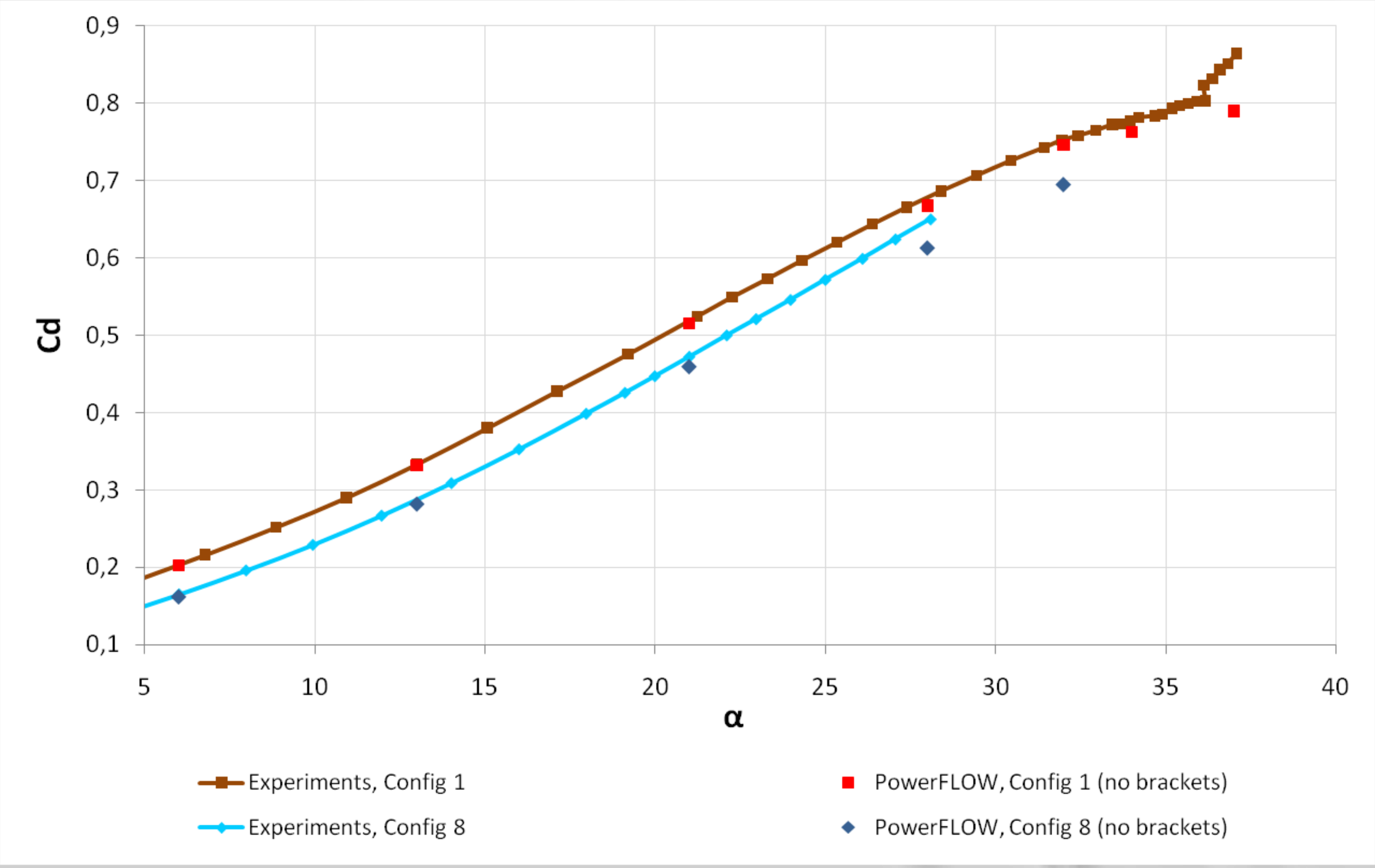




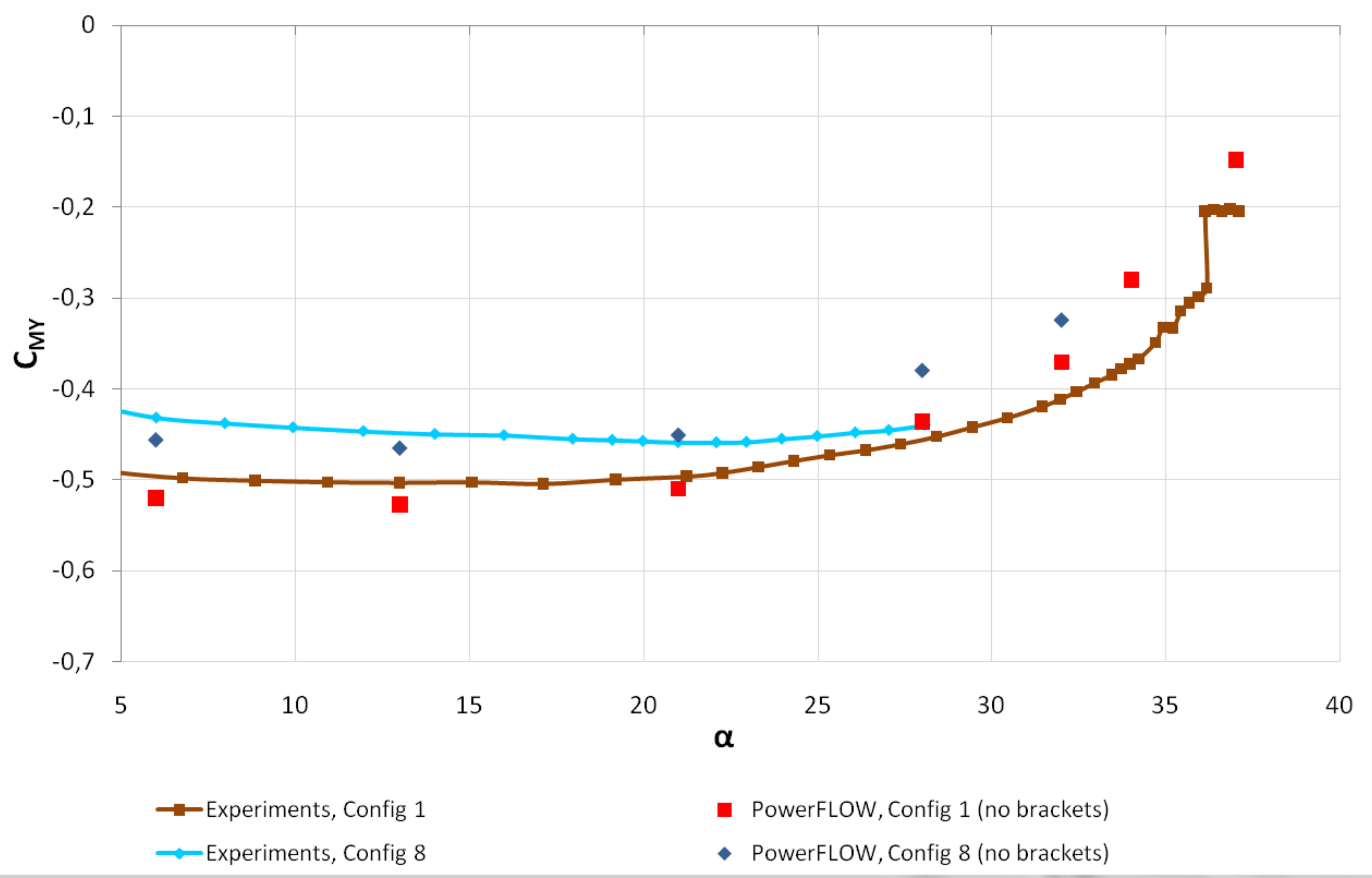
Results – Config 1&8 – Lift



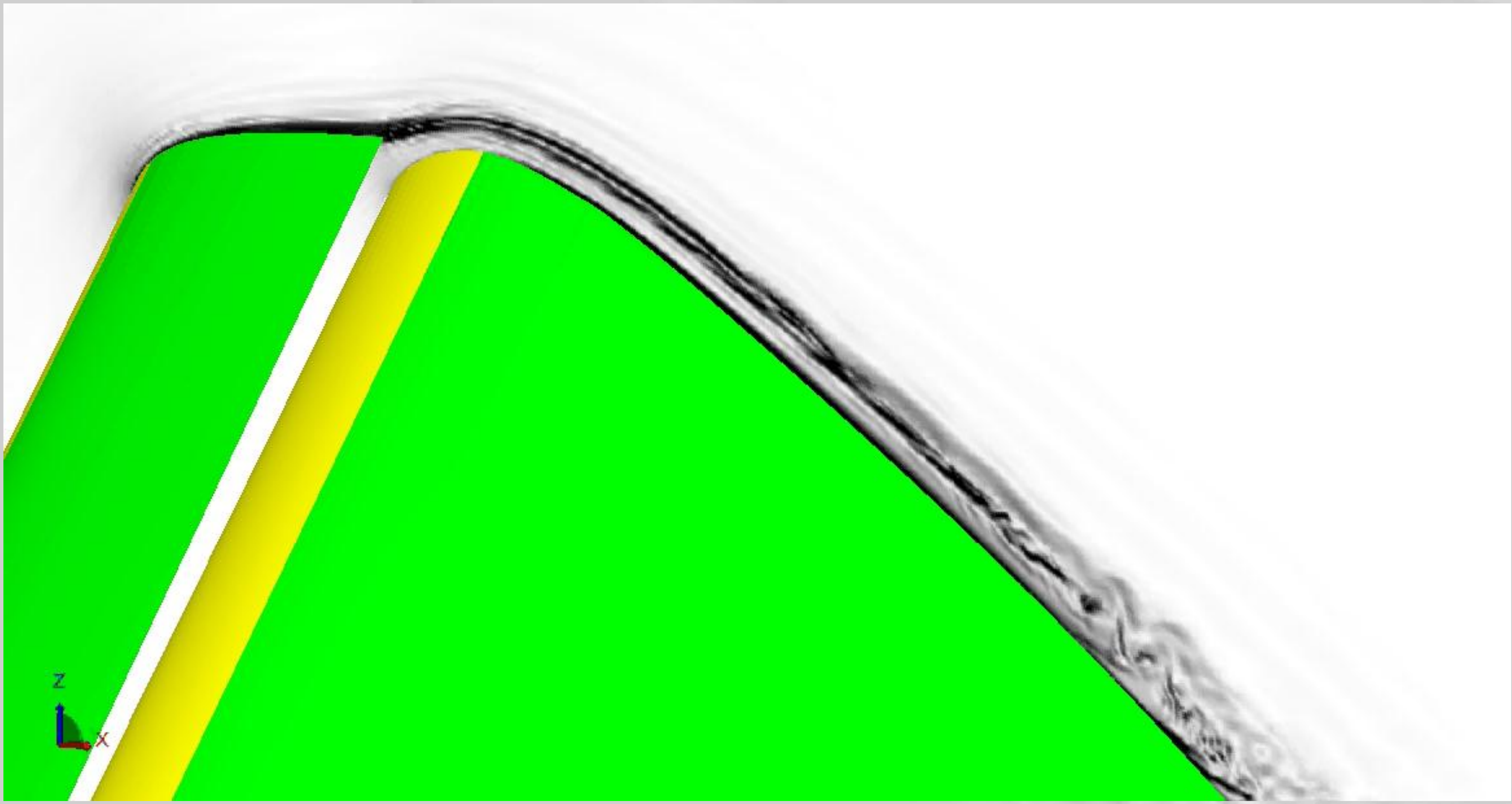
Results – Config 1&8 - Drag



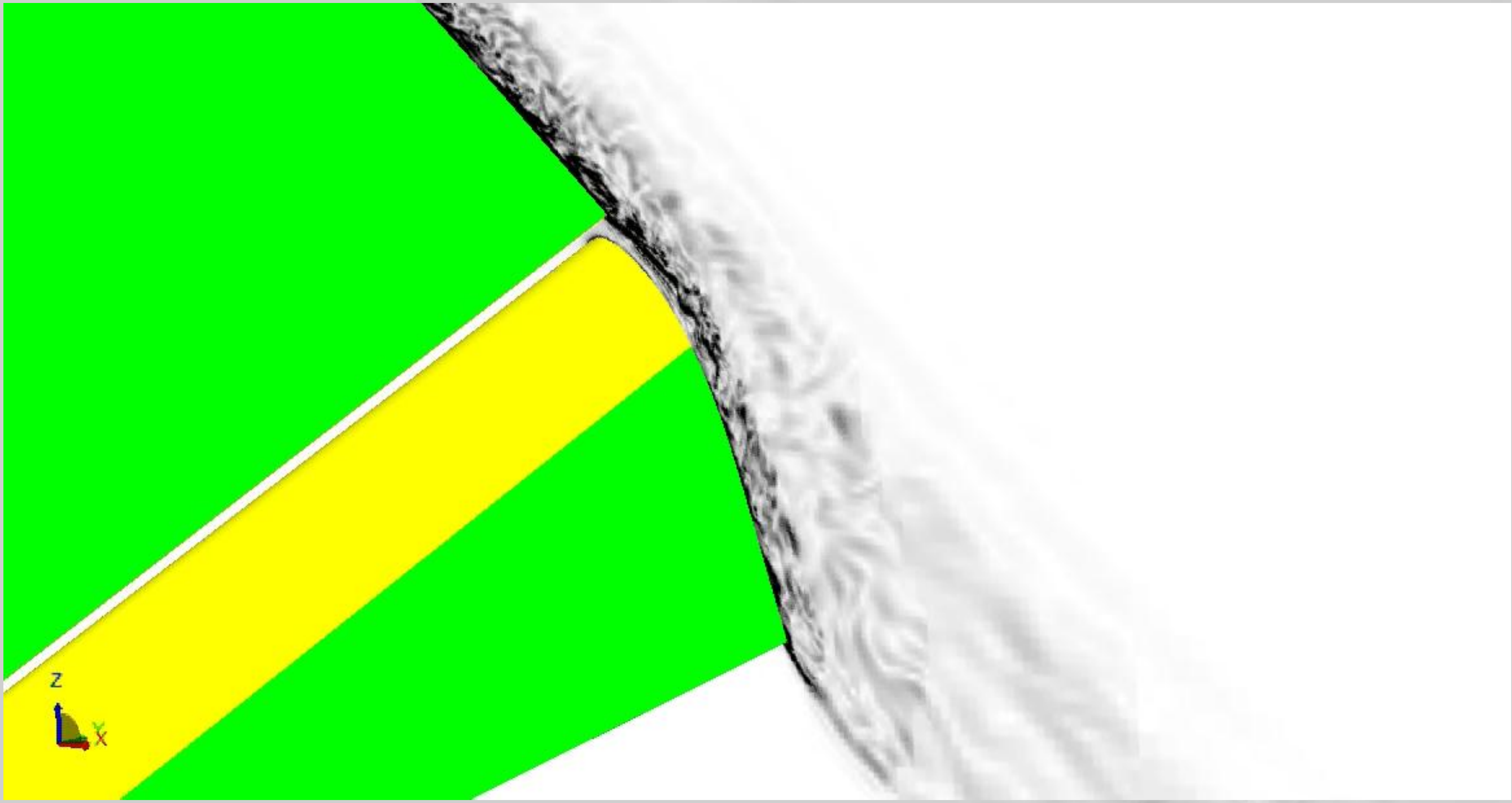
Results – Config 1&8 – Pitching Moment



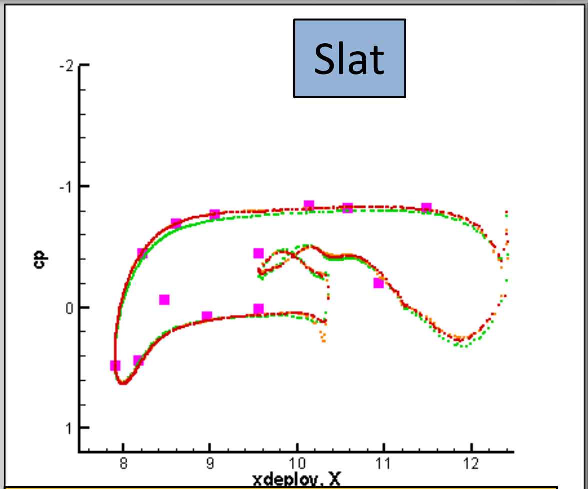
Unsteady Flow Animations (α=34°)

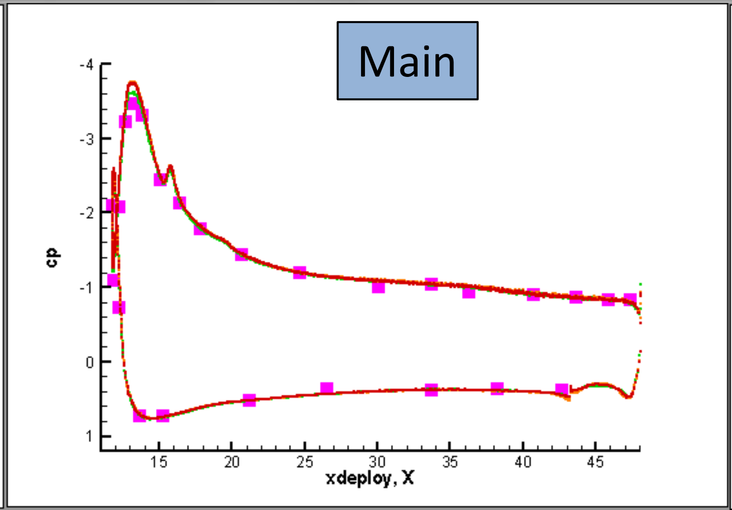


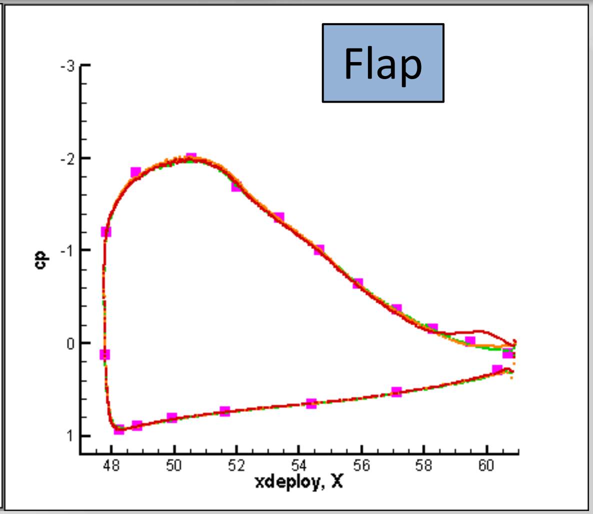
Unsteady Flow Animations (α=34°)



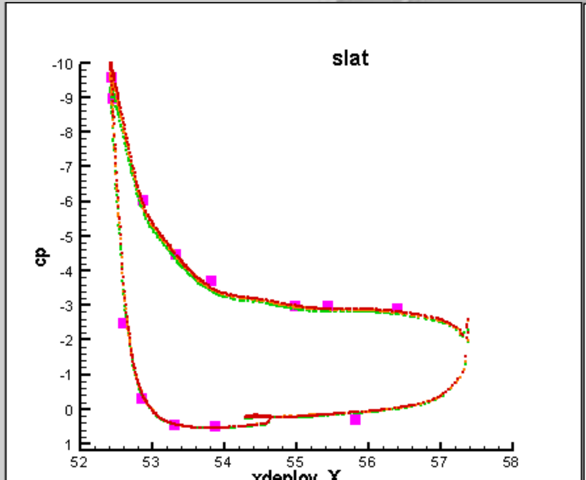
Results – Config1 – 28° - c_p

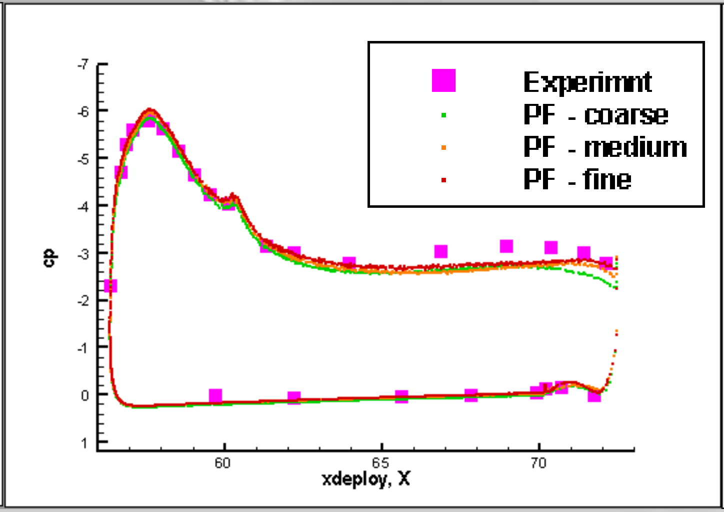


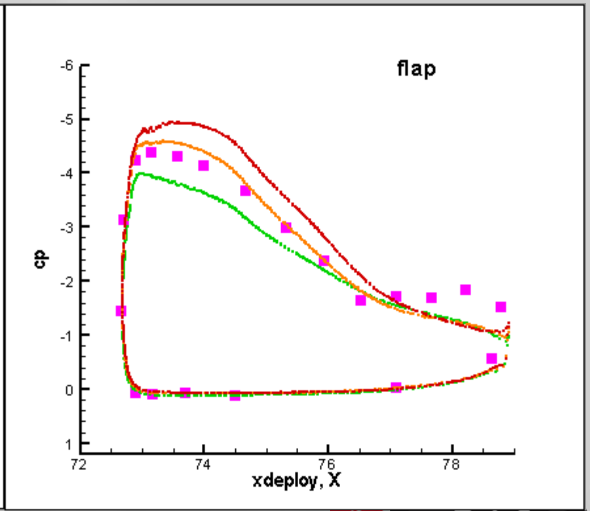




α=13°, Config1 , 17% span

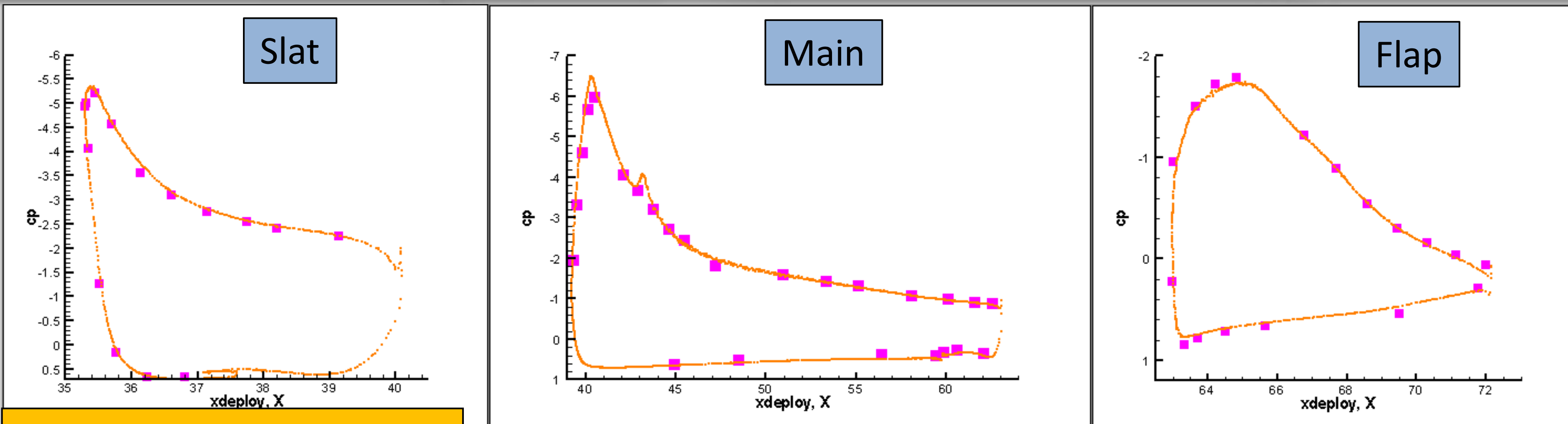




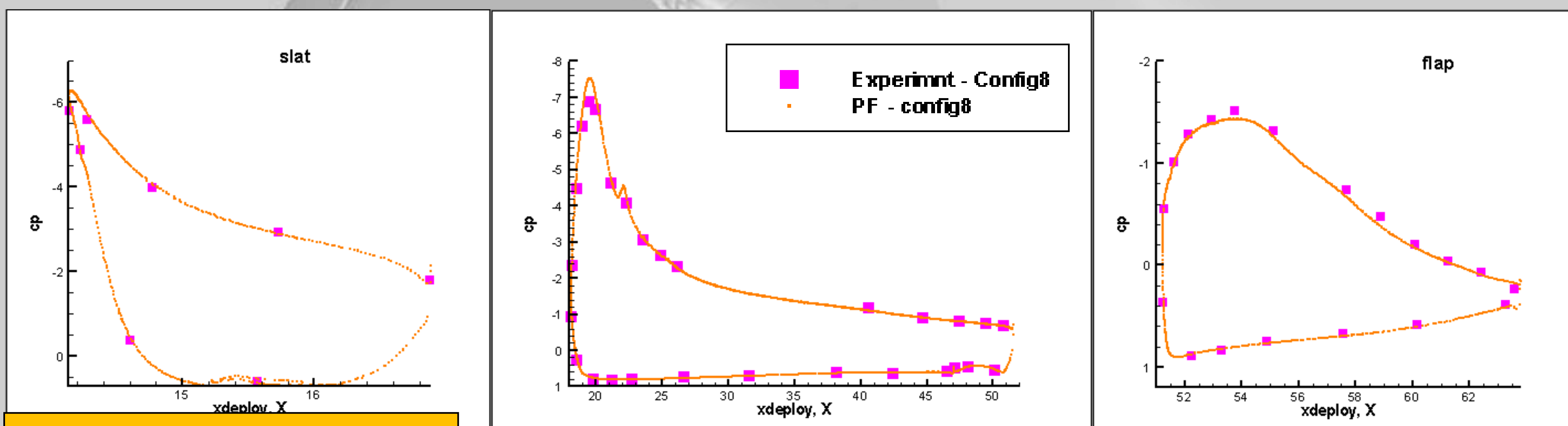


α=28°, Config1, 95% span

Results – Config8 - c_p

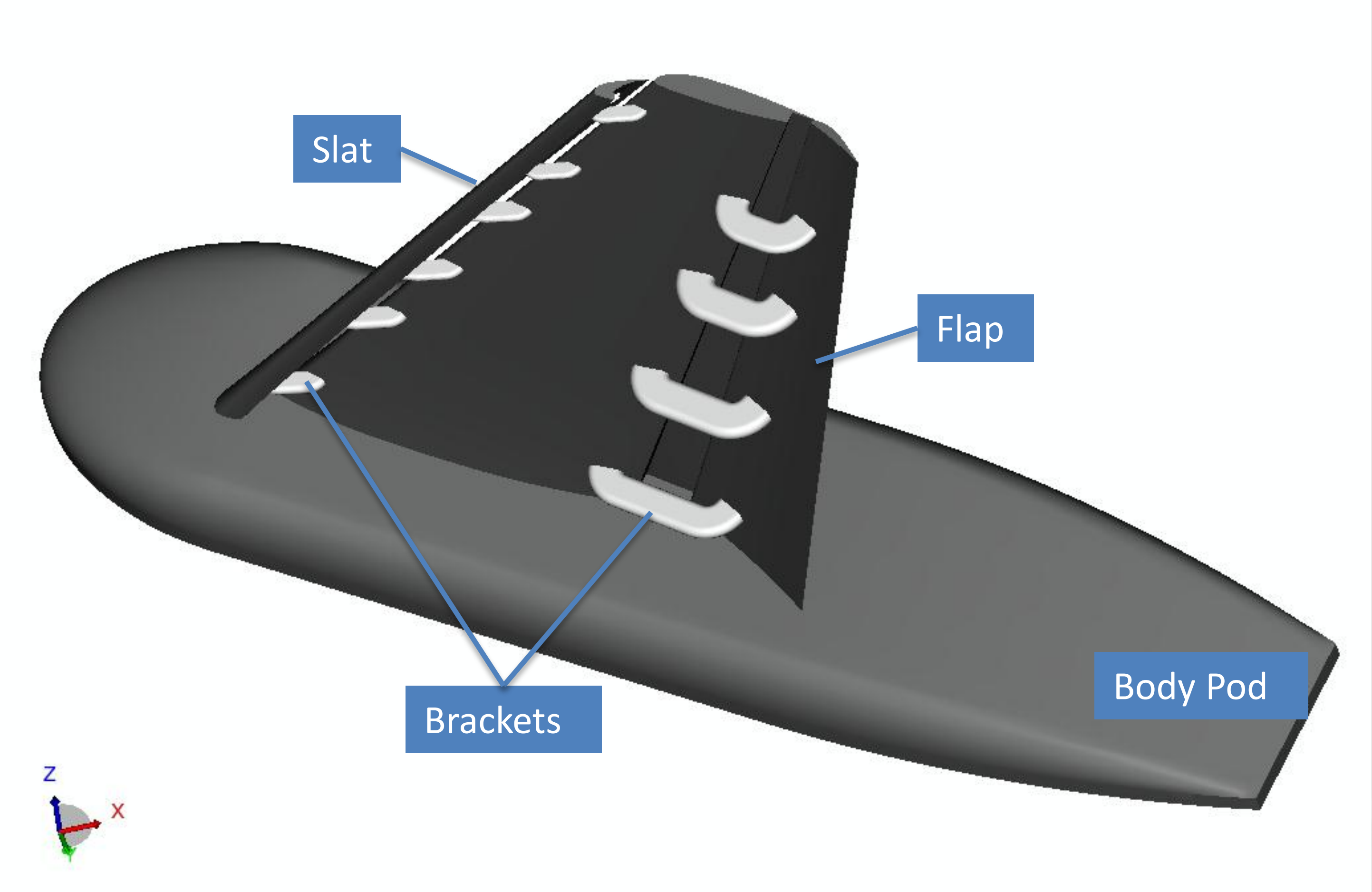


α=21°, Config8 , 65% span



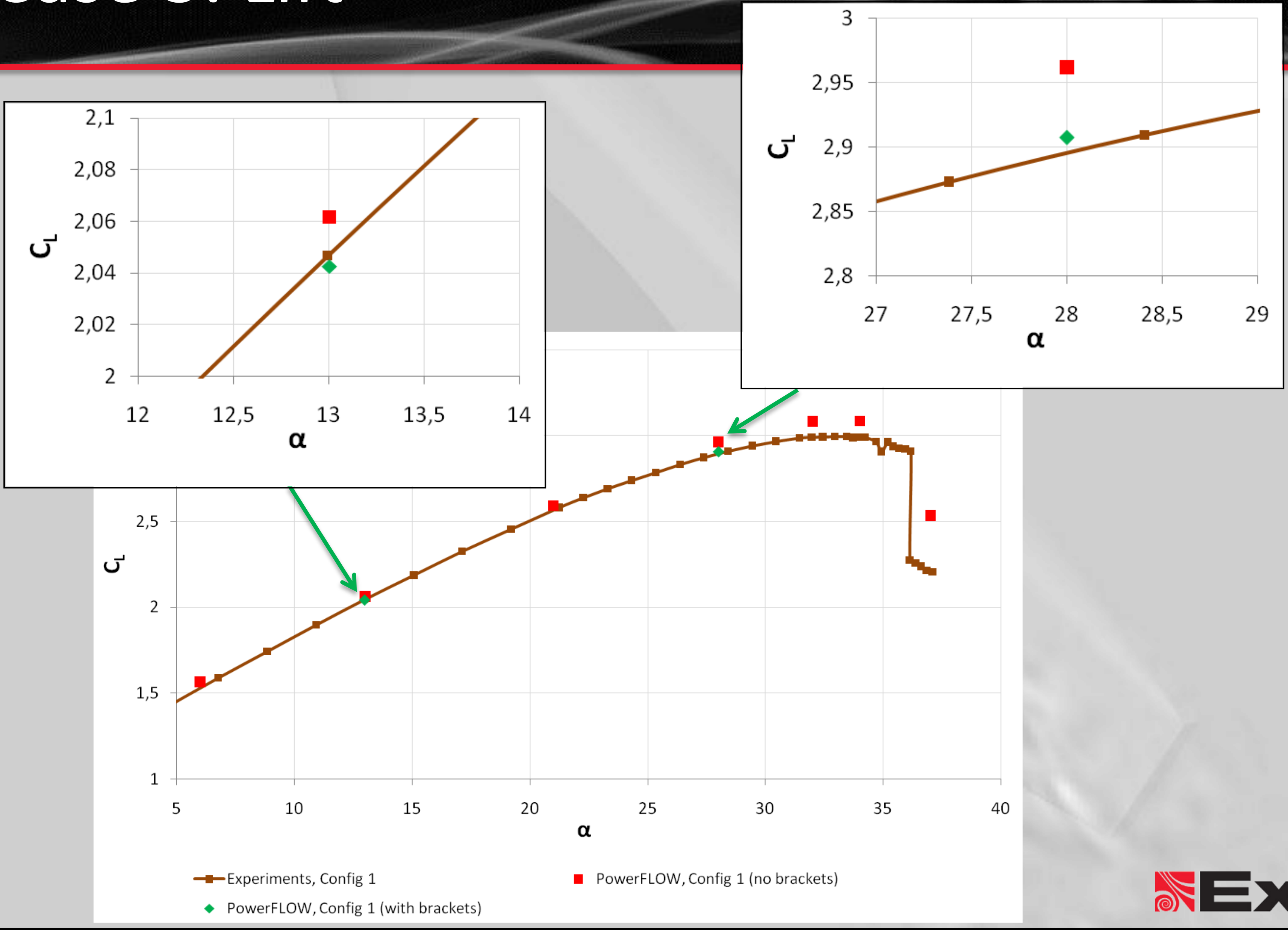
α=28°, Config8, 28% span

Results – Influence of brackets



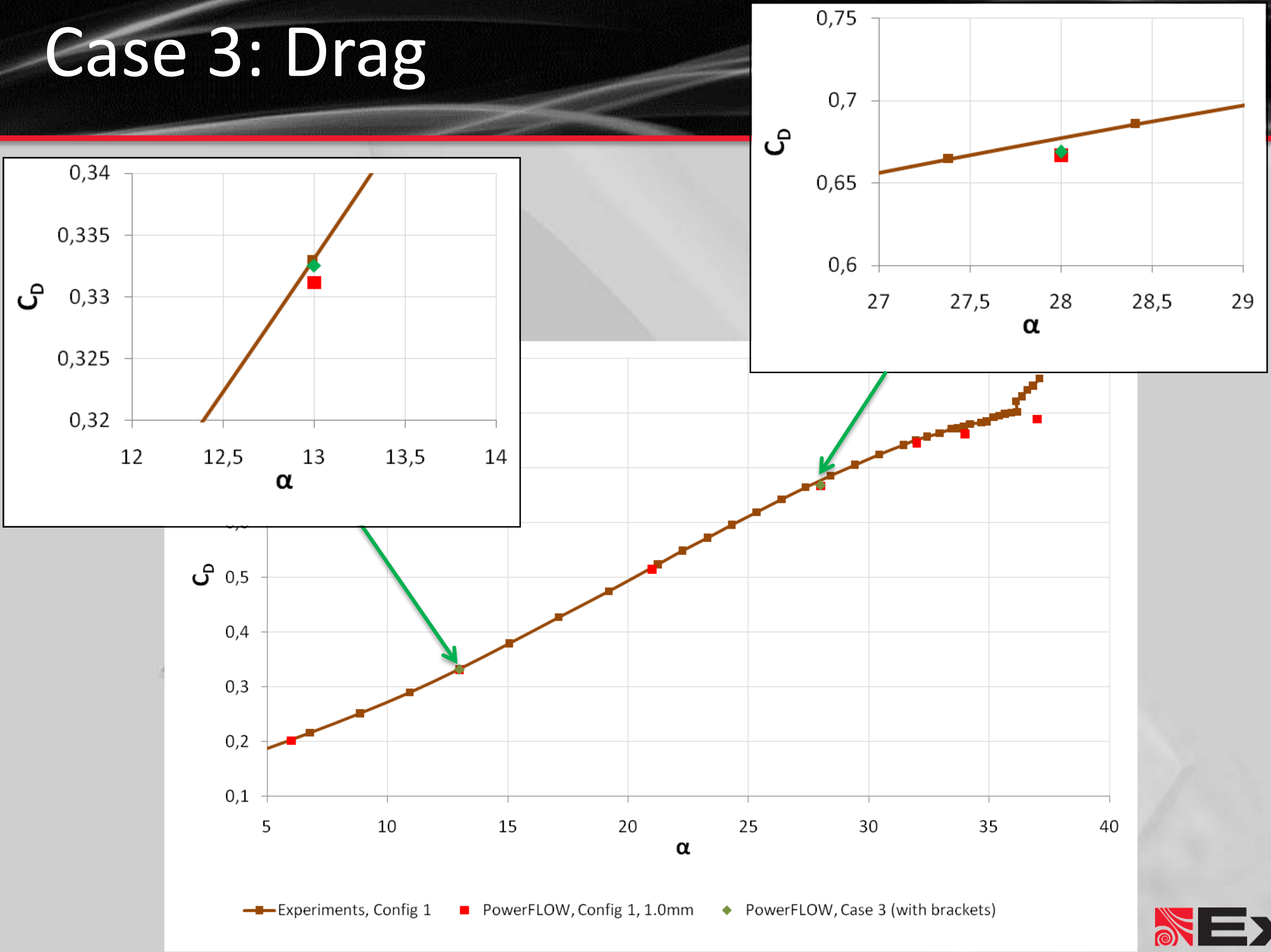
- Effort to add additional geometry very low in PowerFLOW
  - *Addition of brackets and new case setup took < 1 hr*

Case 3: Lift



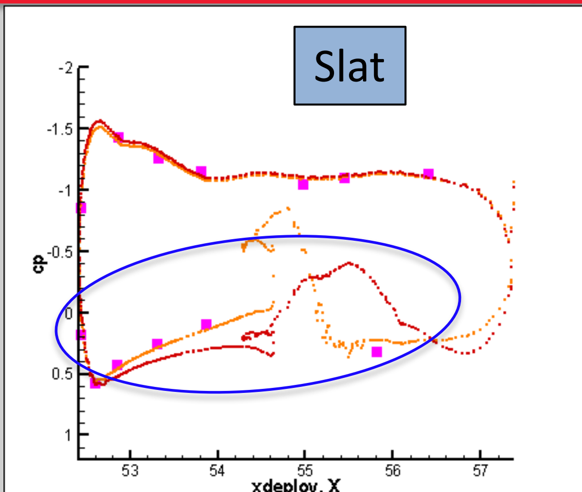
Exa

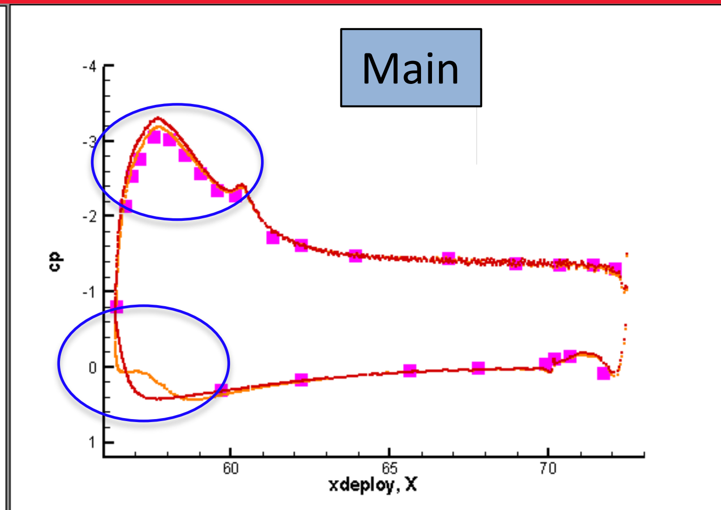
Case 3: Drag

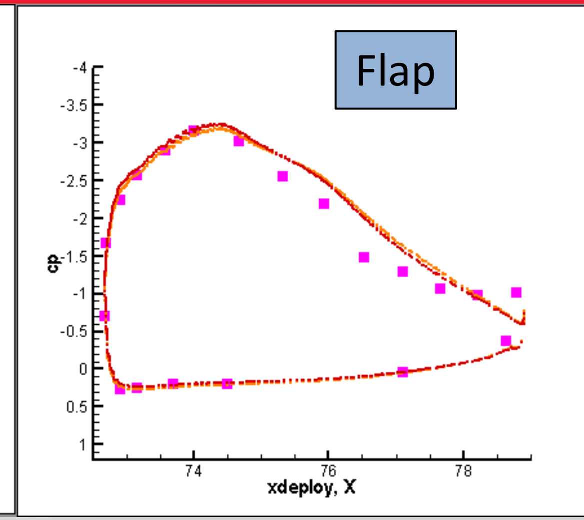


0,75
0,7
0,65
0,6
C_D
27
27,5
28
28,5
29
α
0,34
0,335
0,33
0,325
0,32
12
12,5
13
13,5
14
0,1
0,2
0,3
0,4
0,5
5
10
15
20
25
30
35
40
Experiments, Config 1
PowerFLOW, Config 1, 1.0mm
PowerFLOW, Case 3 (with brackets)

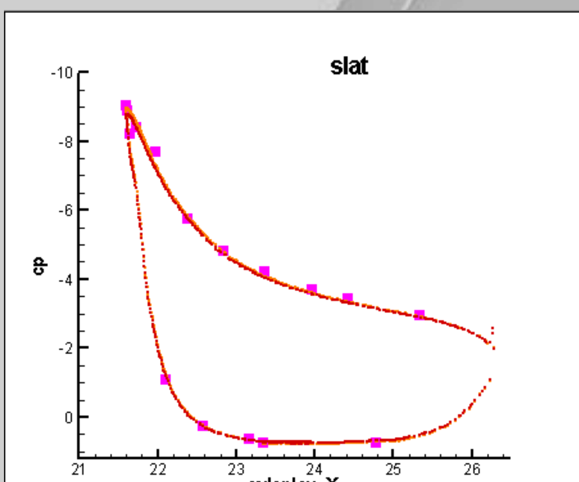
Results – Case 3 – Influence of brackets

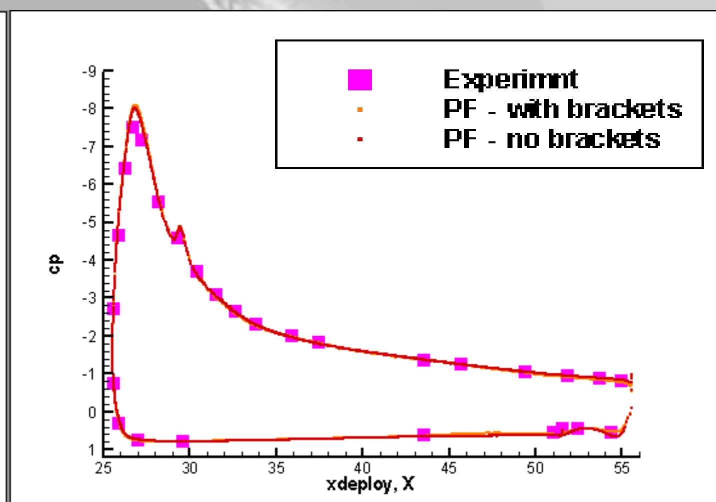


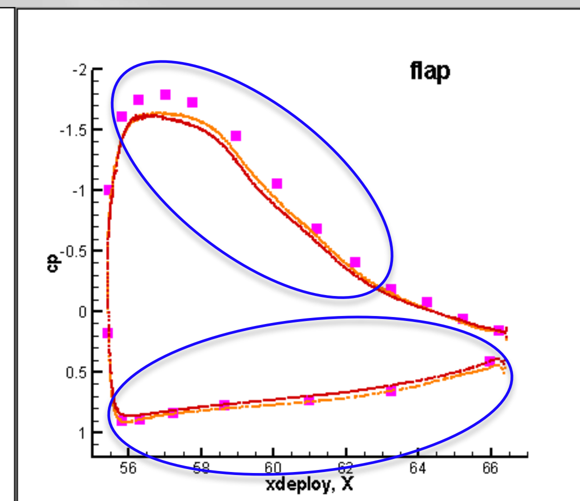




α=13º, Config1, 95% span

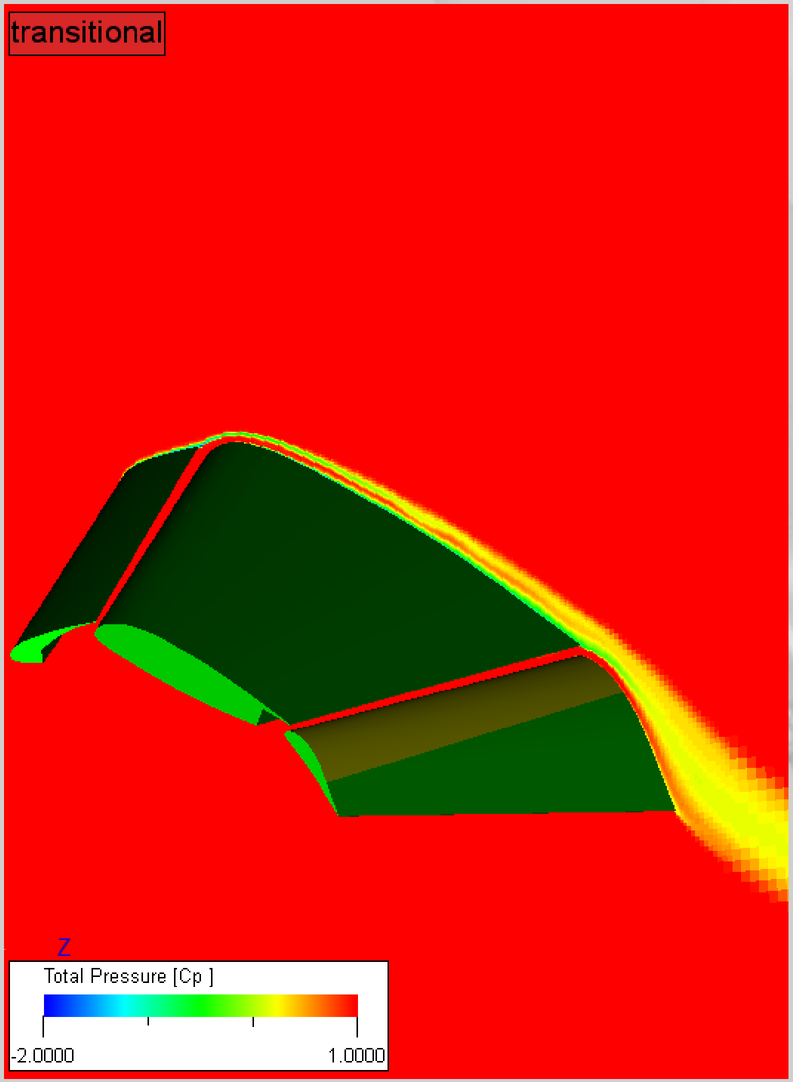


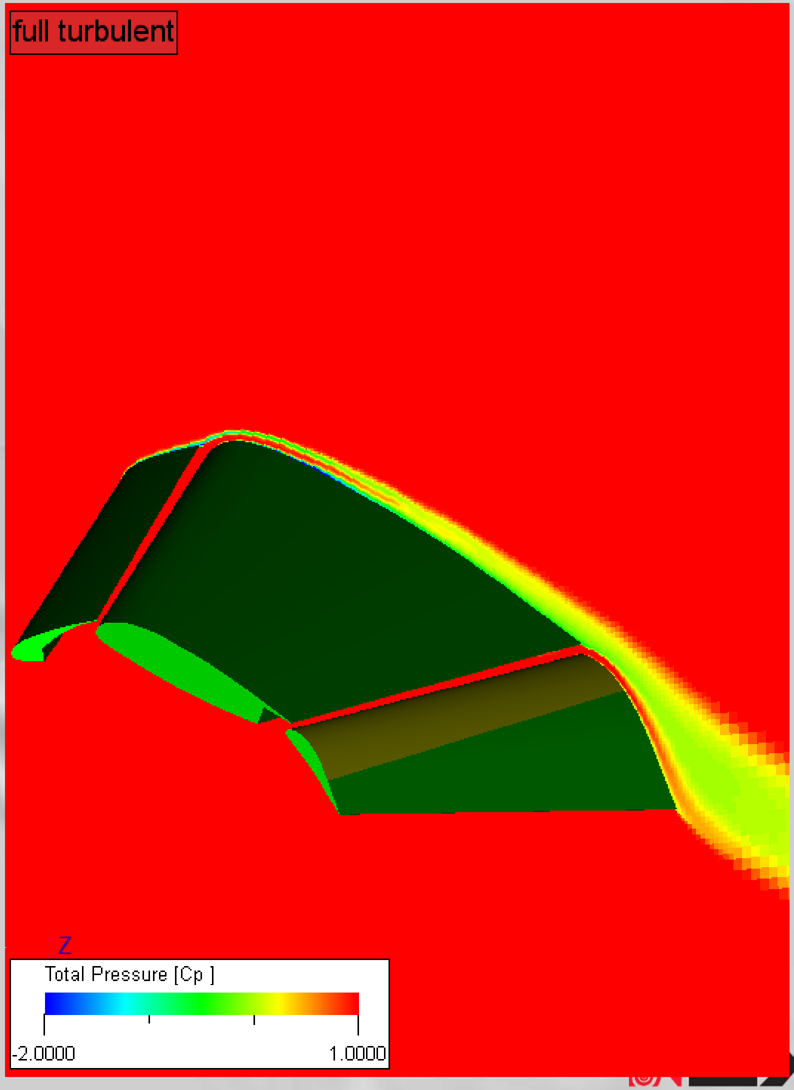




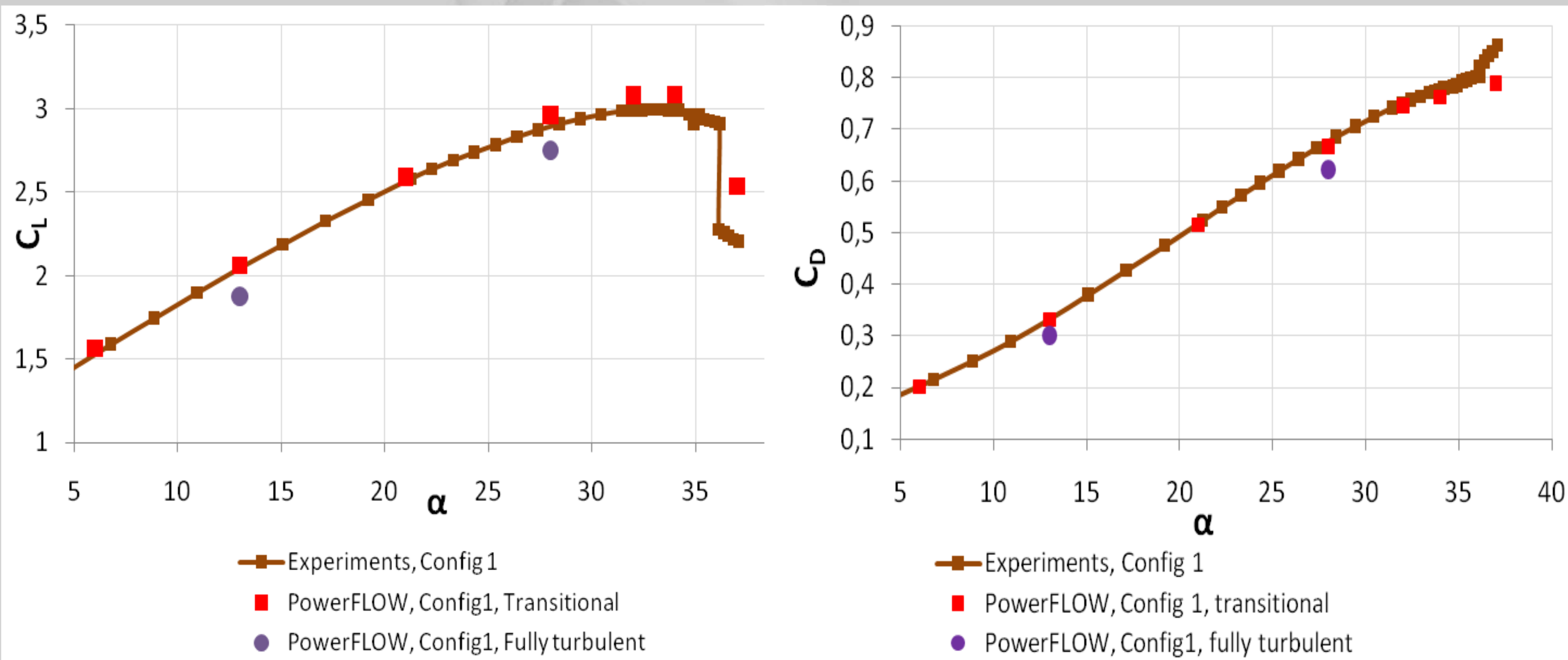
α=28º, Config1, 41% span

Specified Transition v. Fully Turbulent (α=28°)

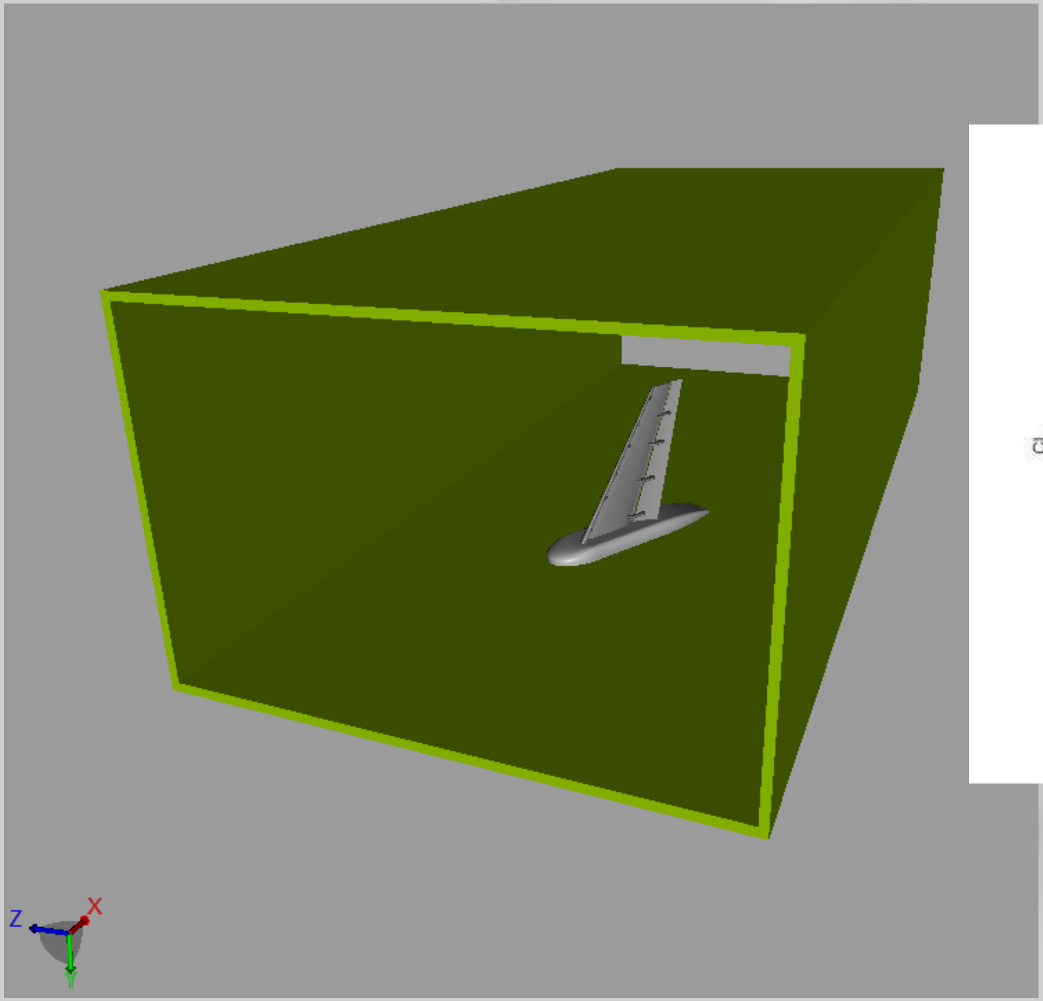


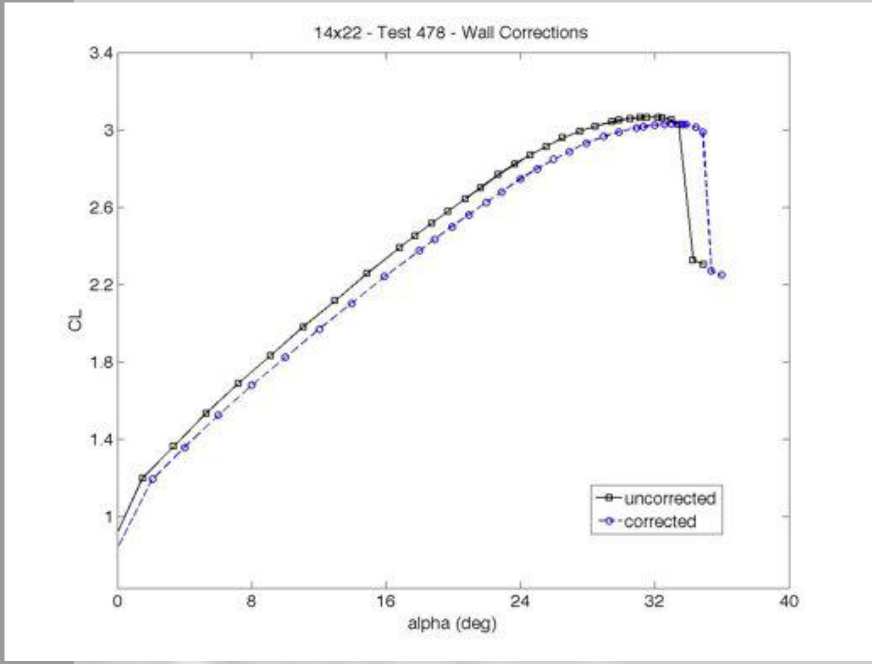


Specified Transition v. Fully Turbulent



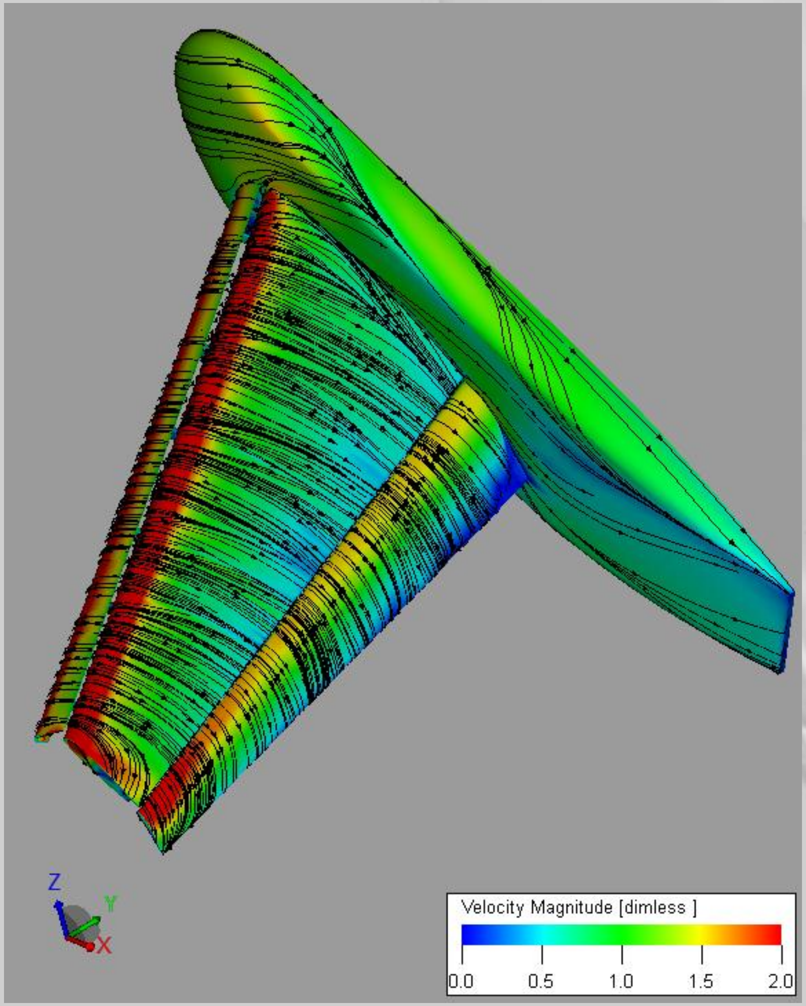
Results - Blockage Effects

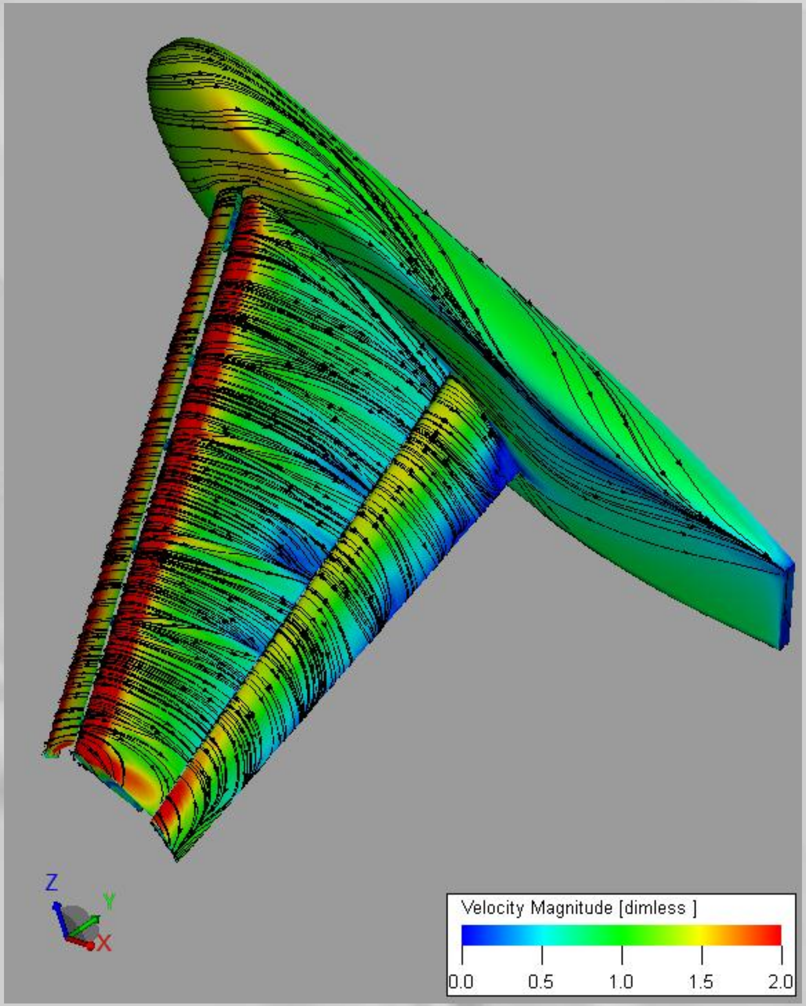




Model of TrapWing (with brackets) in the NASA Langley WT (simulations done with Setup2)

Results – Blockage Effects



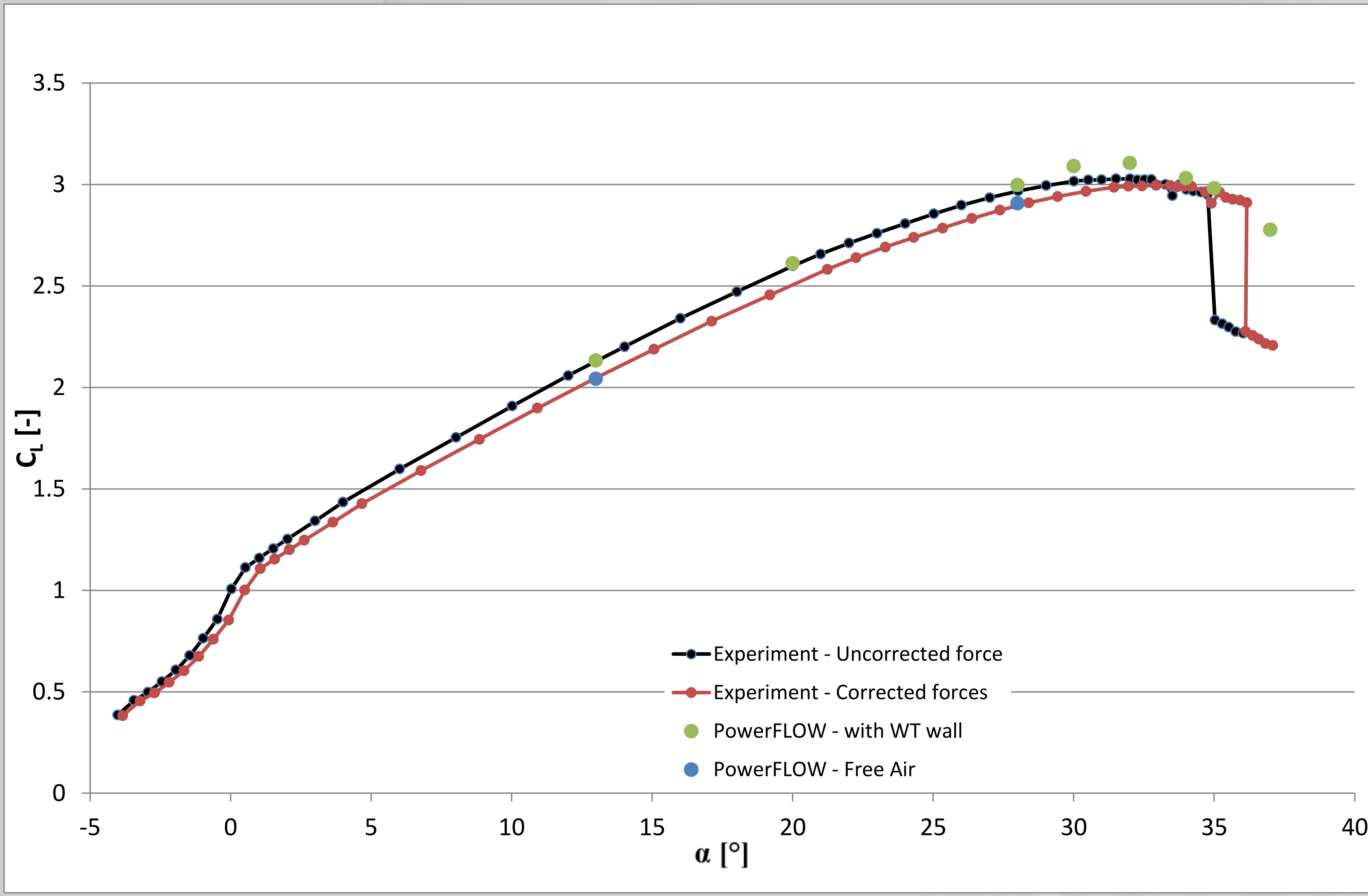


Free stream

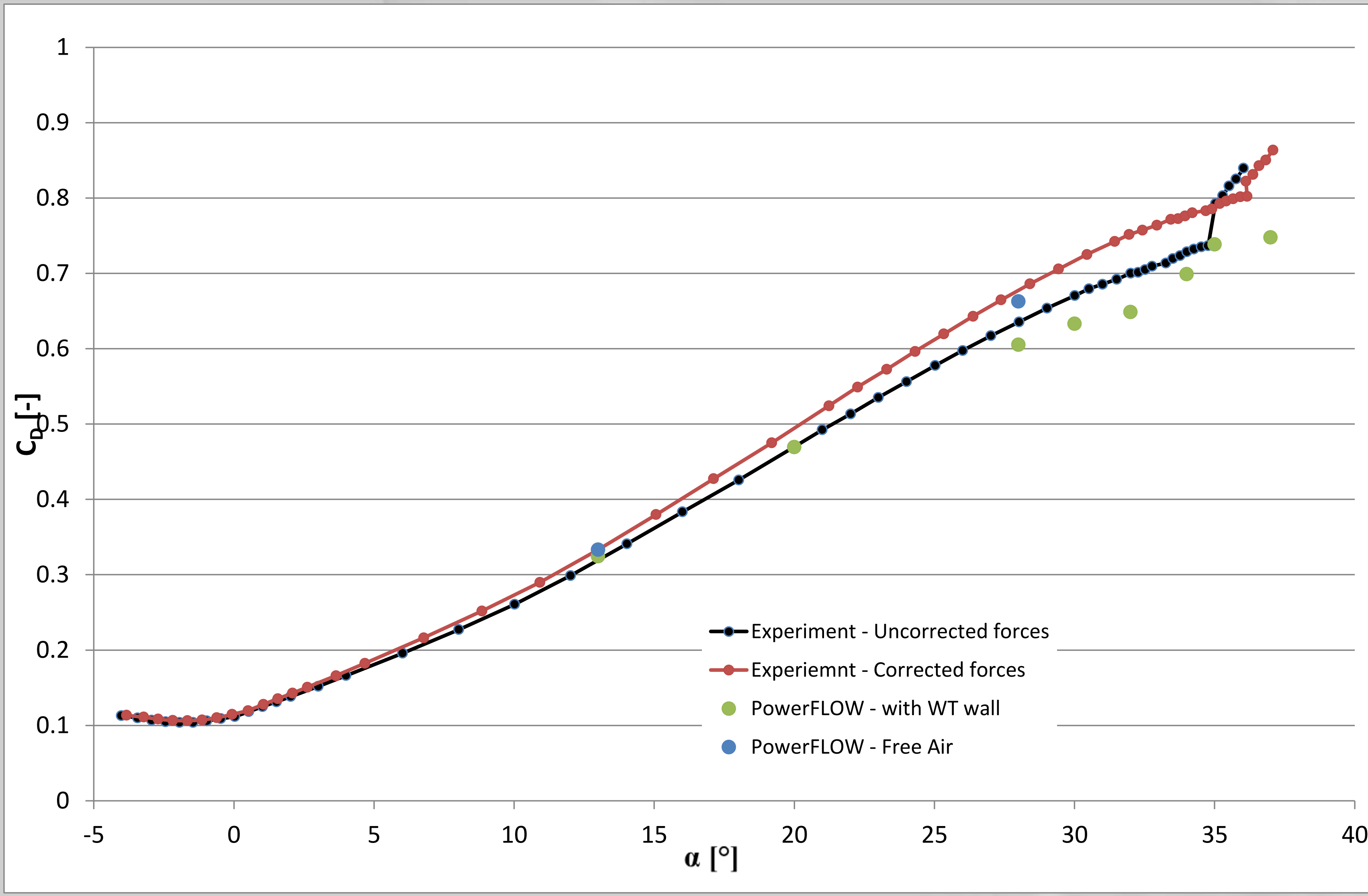
α=28° with brackets

with WT walls

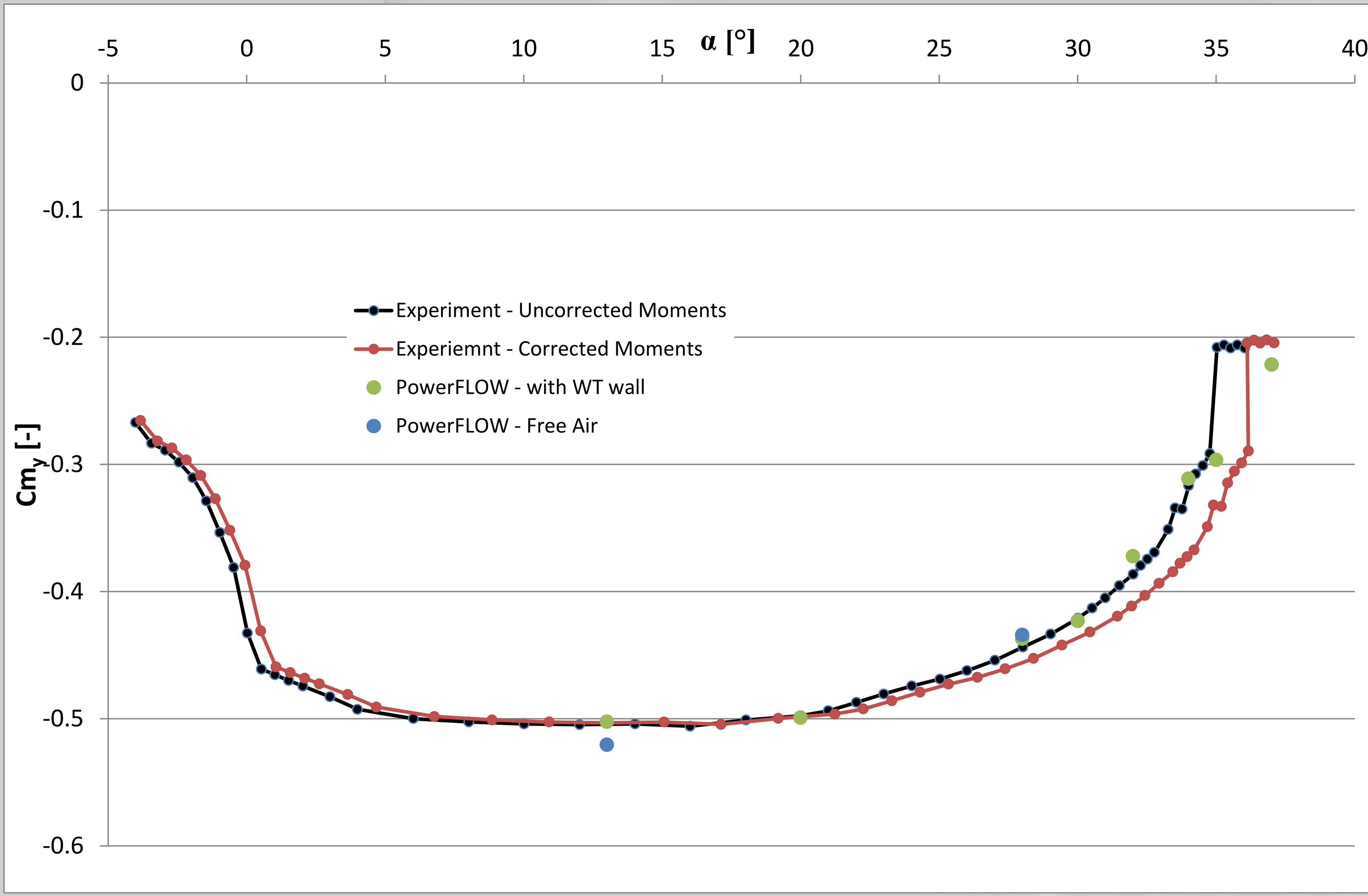
Results - Blockage Effects - Lift



Results - Blockage Effects - Drag



Results - Blockage Effects - Pitching Moment



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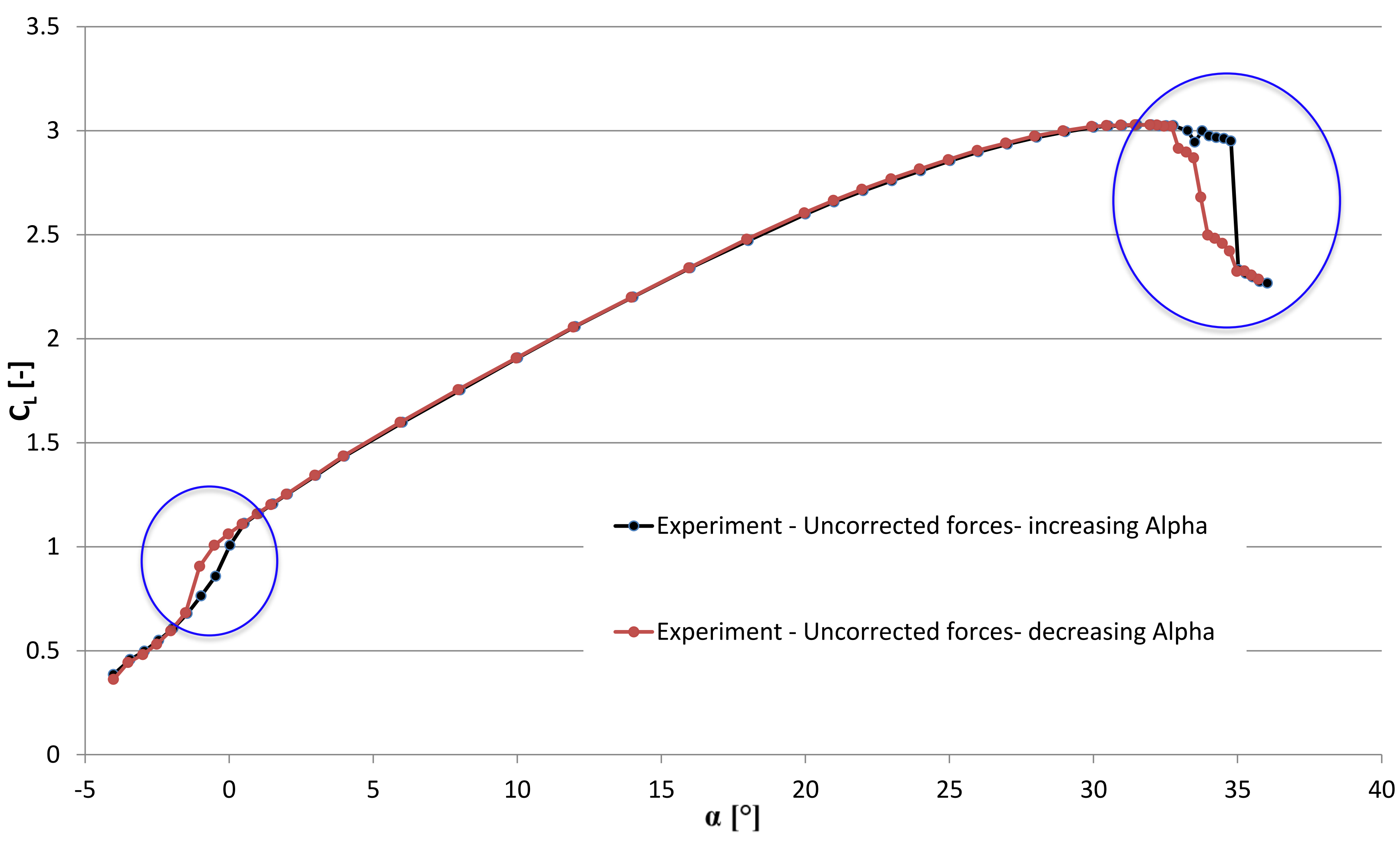
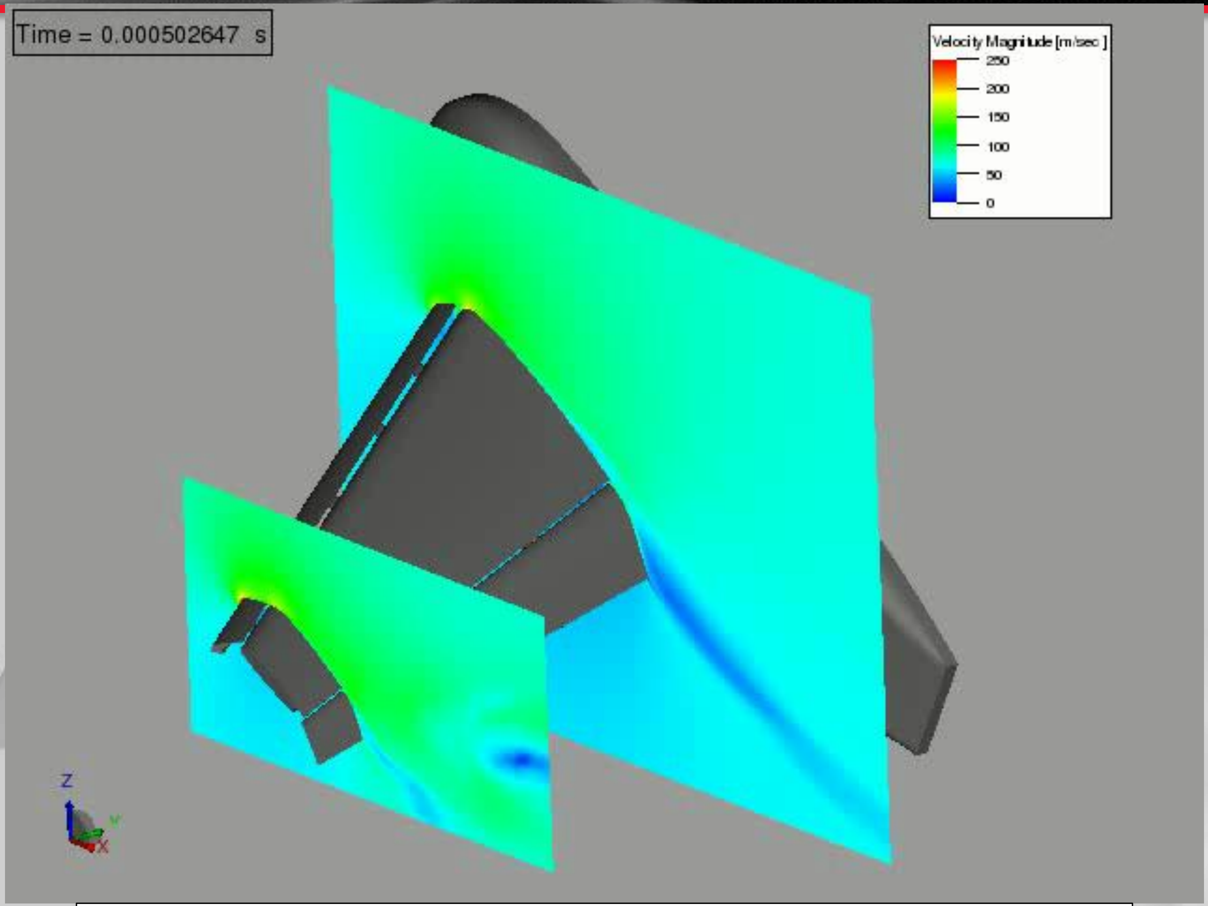
Conclusions

- Unsteady Flow Simulations
  - *Lattice Boltzmann Approach*
- Overall good agreement with experiments
  - *Excellent agreement in the linear range*
    - Forces, pitching moment and Cp distributions
  - *Good predictions in the region of maximum Lift*
    - Slight over-prediction around CL_{max}
  - *Flap Change (Config1 vs. Config8) captured well*
  - *Influence of brackets captured*
    - Better match to experiment
  - *Influence of WT blockage*
    - consistent with WT correction done
  - *Influence of transition location observed*

Outlook – Hysteresis Effect

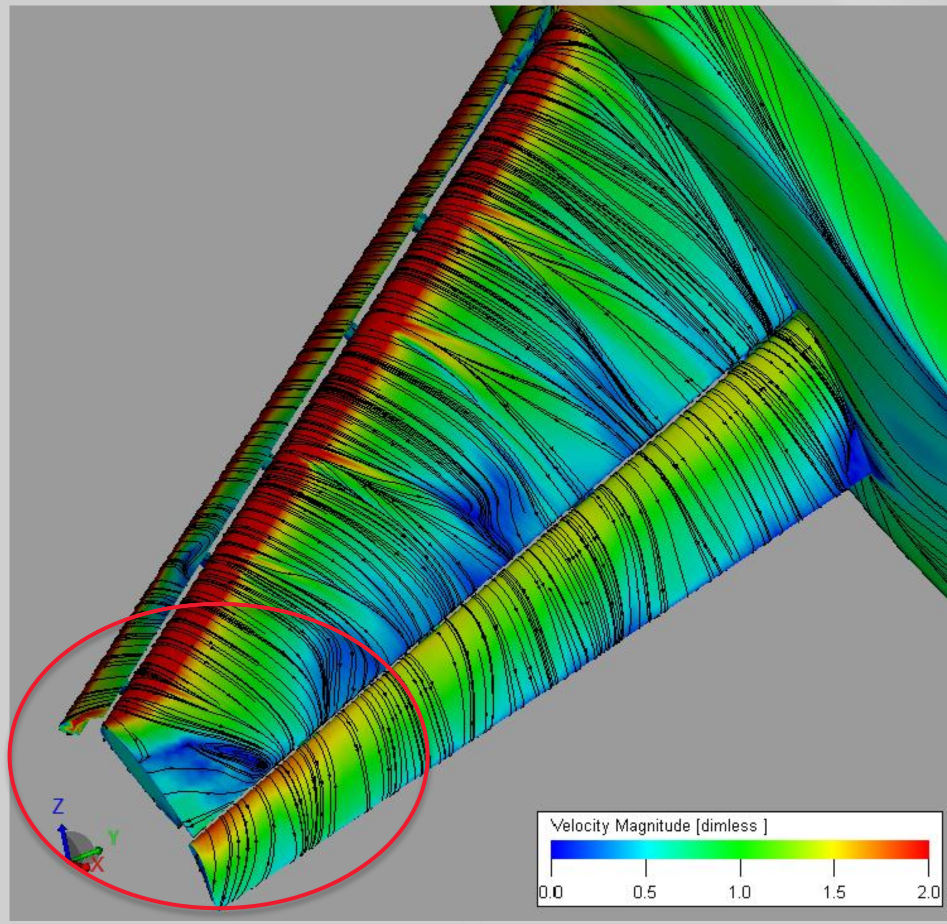


Outlook – Hysteresis Effect –preliminary result

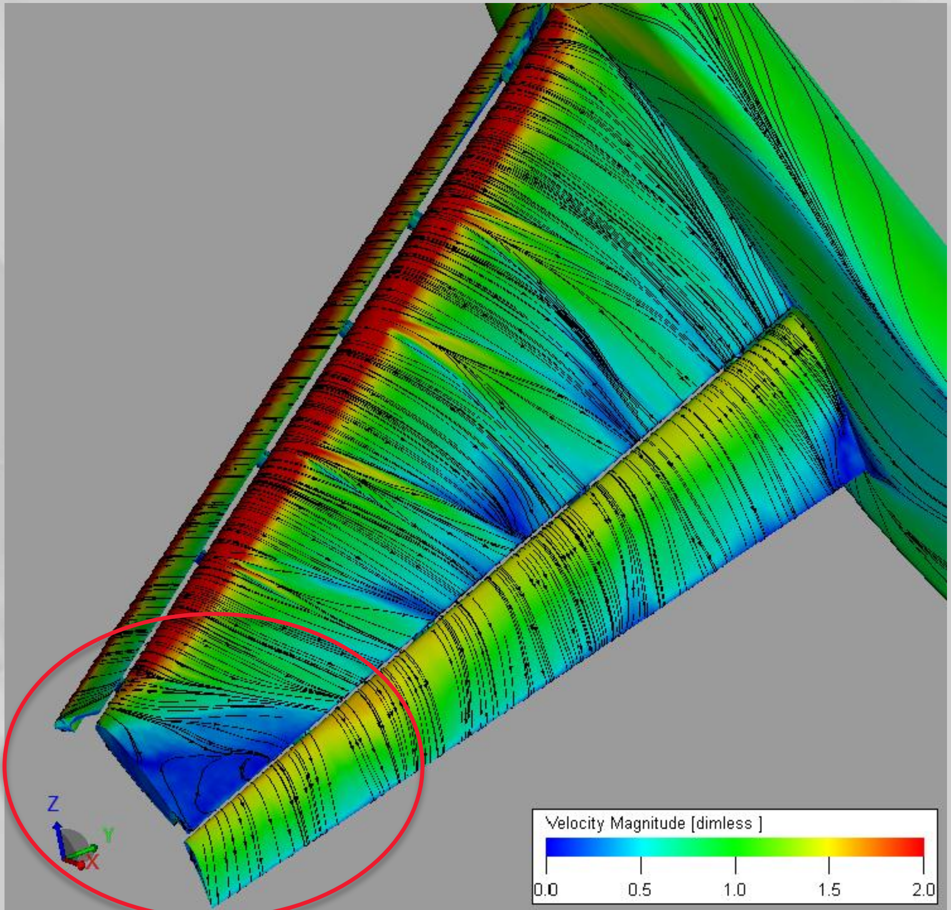


Pitching TrapWing in WT
α=28°-38°-28° in 1° steps
Initialized from steady 28°
0.05s per 1° (0.02s rotating & 0.03s settling)
~5days on 244CPUs

Outlook – Hysteresis Effect –preliminary result



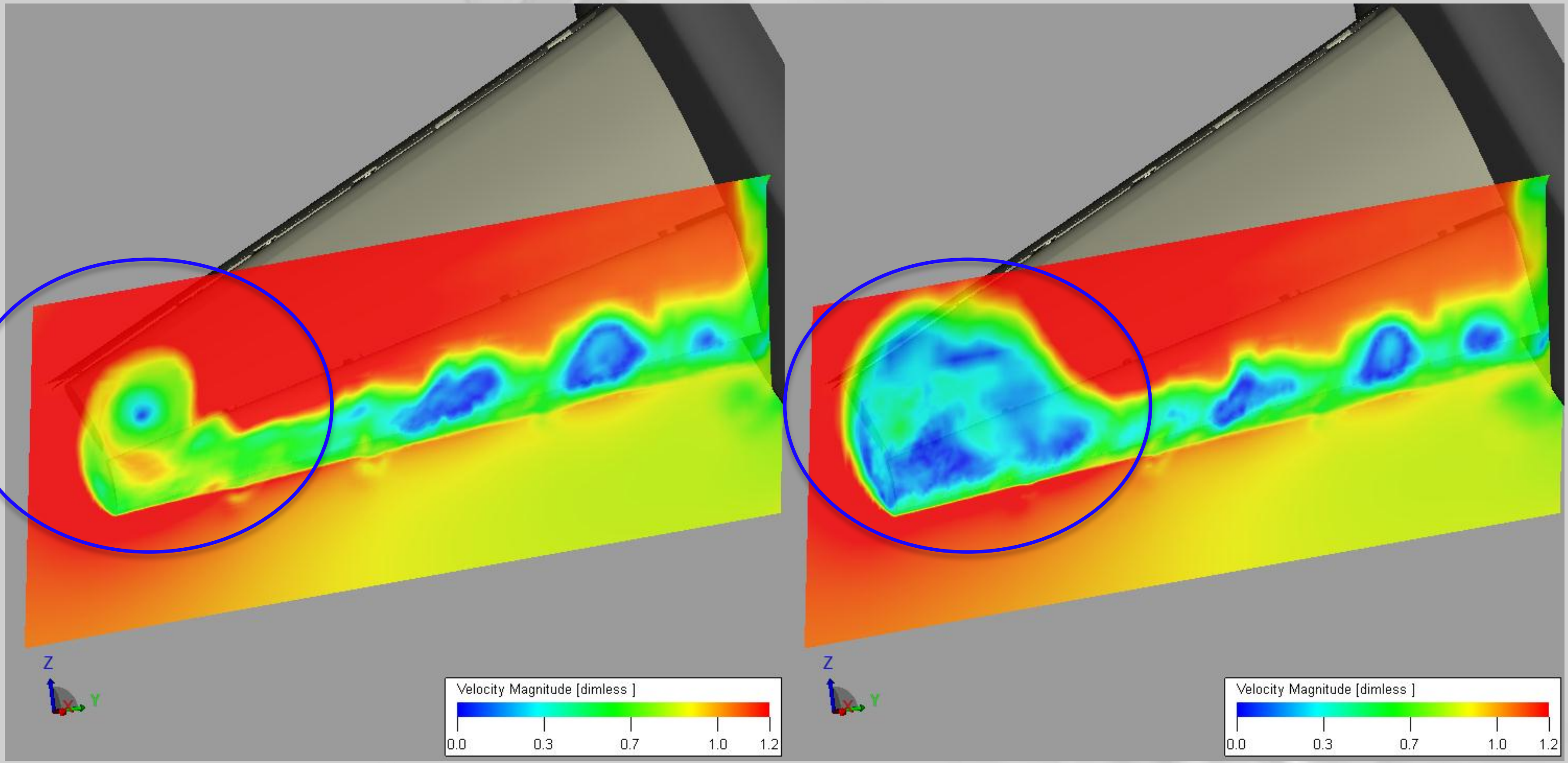
α=33° increasing



α=33° decreasing

Exa

Outlook – Hysteresis Effect –preliminary result



α=33° increasing

COMING NEXT!

α=33° decreasing

Exa