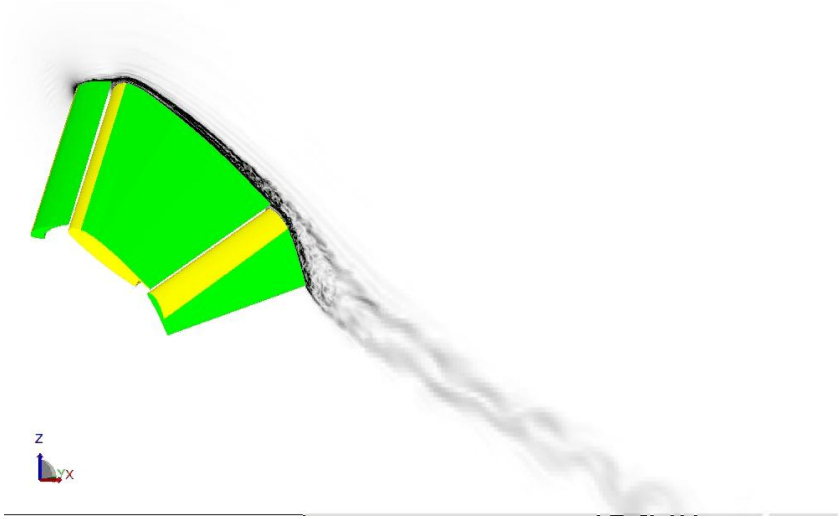

HiLiftPW-1 Workshop, Chicago (June 2010)

Simulations of Trapwing Case with PowerFLOW

Swen Noelting, Ehab Fares - Exa GmbH
Tony Keating

Overview

- Lattice-Boltzmann based code (PowerFLOW)
- Transient, time accurate simulations
- DDES-like turbulence model
- Grid scheme similar to immersed boundary methods
- Extended wall model
  - *Used fixed transition locations*
  - *Based on published experiments (McGinley & al, AIAA-2005-5148)*

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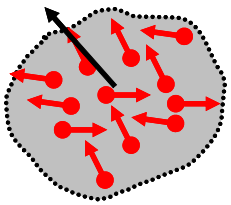
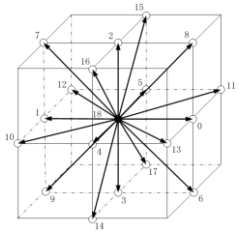
Lattice Boltzmann Method

- The Boltzmann equation :



$$\frac{\partial}{\partial t} f(\vec{x},\vec{v},t) + \vec{v} \cdot \nabla f(\vec{x},\vec{v},t) = \Omega$$

- The discrete Boltzmann equation can be written



$$f_i(\vec{x}+\vec{v}_i\Delta t, t+\Delta t) - f_i(\vec{x},t) = \bar{\Omega}_i \Delta t, \quad i = 1,\ldots,b$$

- This is an exact form if both $\vec{x}$ and $\vec{x}+\vec{v}_i\Delta t$ are nodes on a lattice (mesh). It corresponds to:

$$CFL \equiv |\vec{v}_i \Delta t| / \Delta x = 1$$

  - *Using a set of constant discrete velocities, a fixed lattice (mesh) can be chosen to allow CFL = 1 everywhere at all times*

- Macroscopic quantities can be recovered by a simple summation

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

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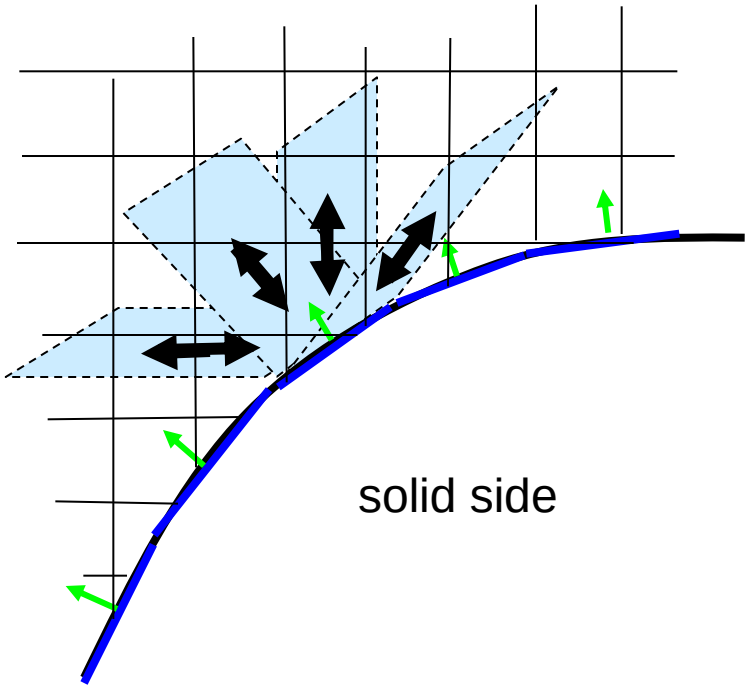
LB methods: Boundary realization

- 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*
  - *Extended wall model is used to simulate under-resolved wall layer*



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Turbulence Model

- DDES-like turbulence model
  - *'Coherent' statistically anisotropic eddies at larger scales computed*
  - *Statistically universal eddies in the inertial & dissipation ranges modeled*
    - 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*

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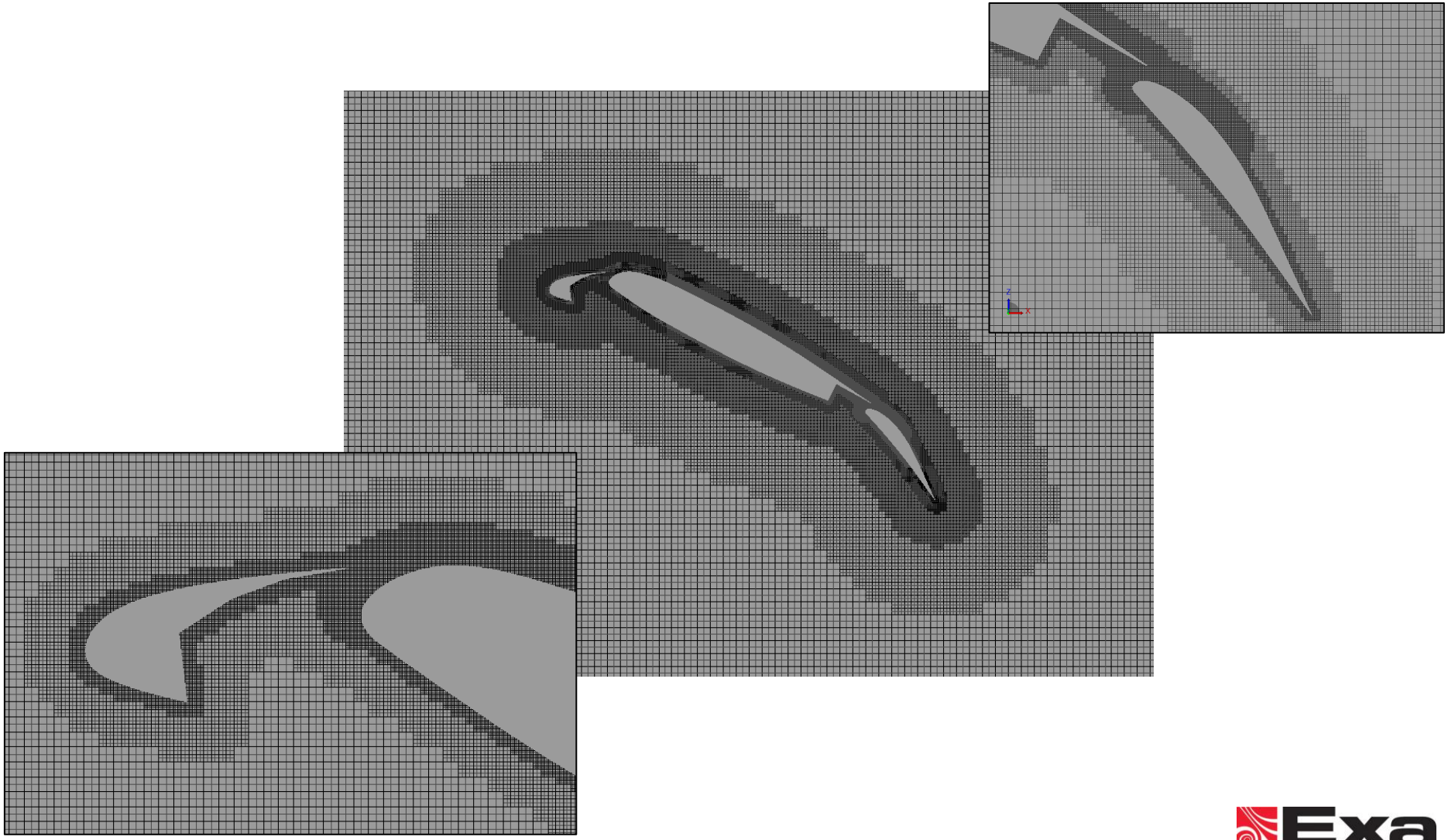
Grid Scheme



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Simulations Overview

		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*

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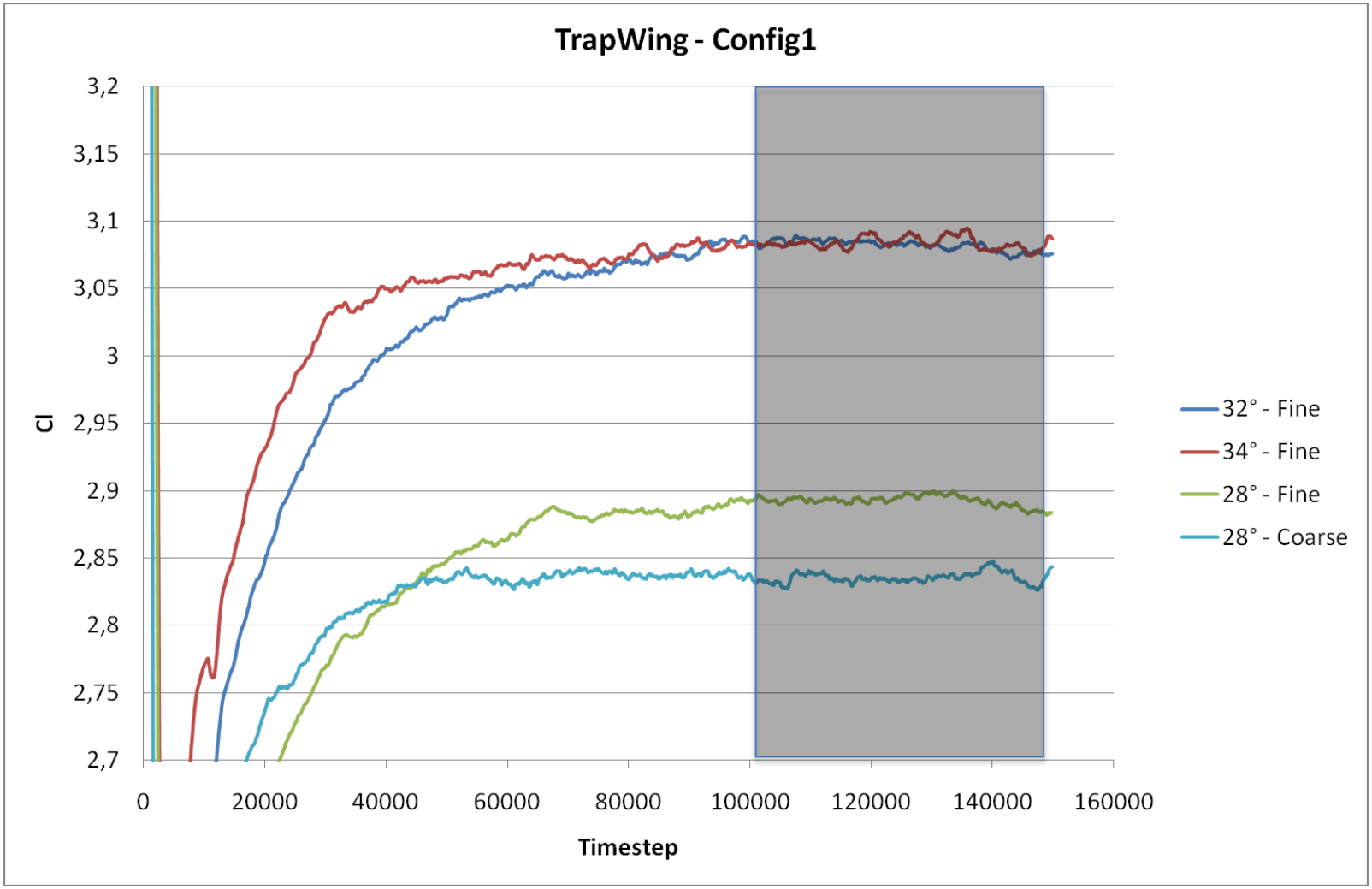
Simulation Convergence



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CPU Requirements*

Case	Coarse	Medium	Fine
Finest voxel size	1.5mm	1.25mm	1.0mm
Total number of voxels	62 million	101 million	193 million
Grid Generation	0.8 hours	1.1 hours	1.4 hours
CPU-Hours	4,600	6,900	9,300
Wall-clock Time (248 cores)	19.5 hours	29 hours	38.5 hours

* For 13deg. case

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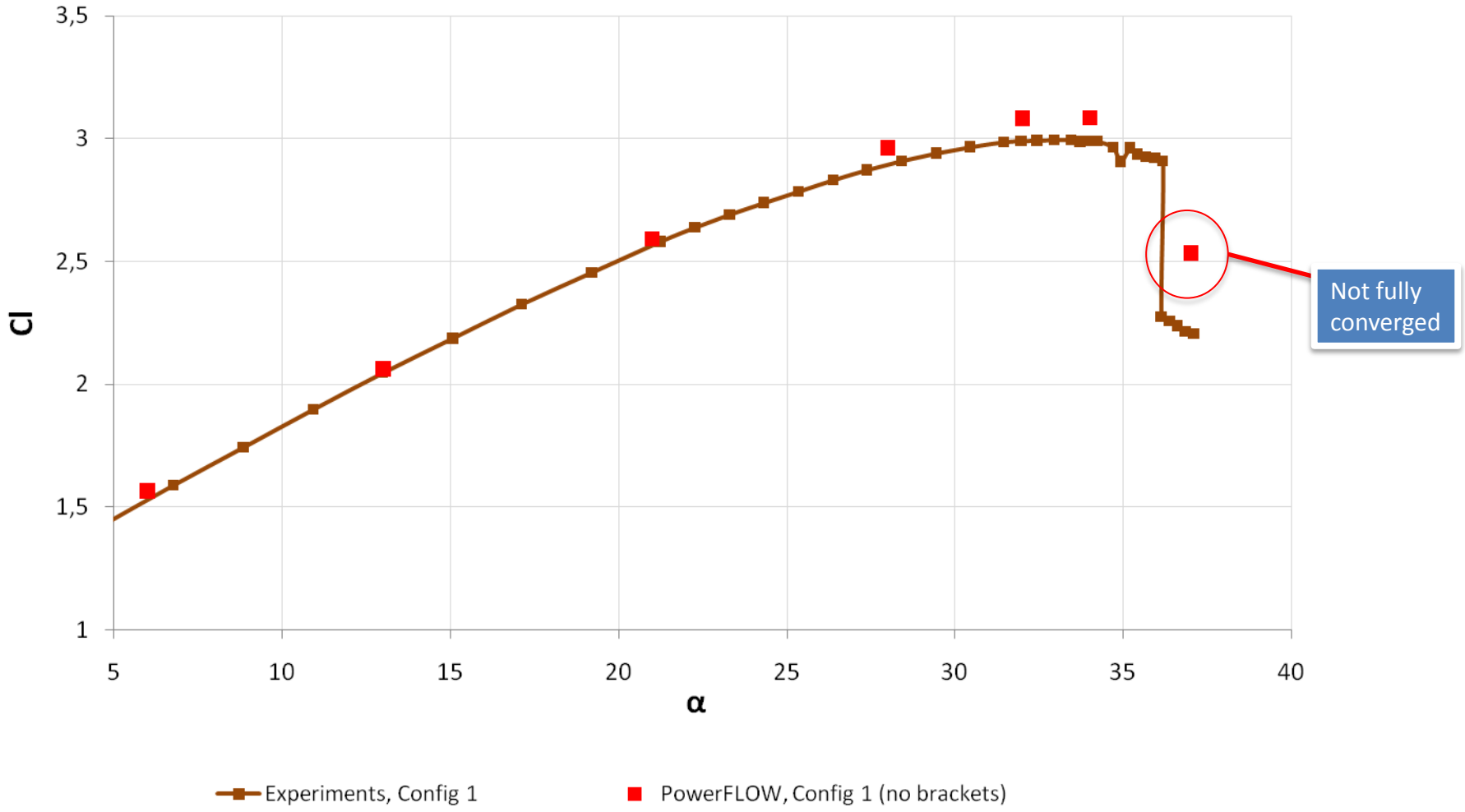
Case 1 (1mm): Lift Prediction



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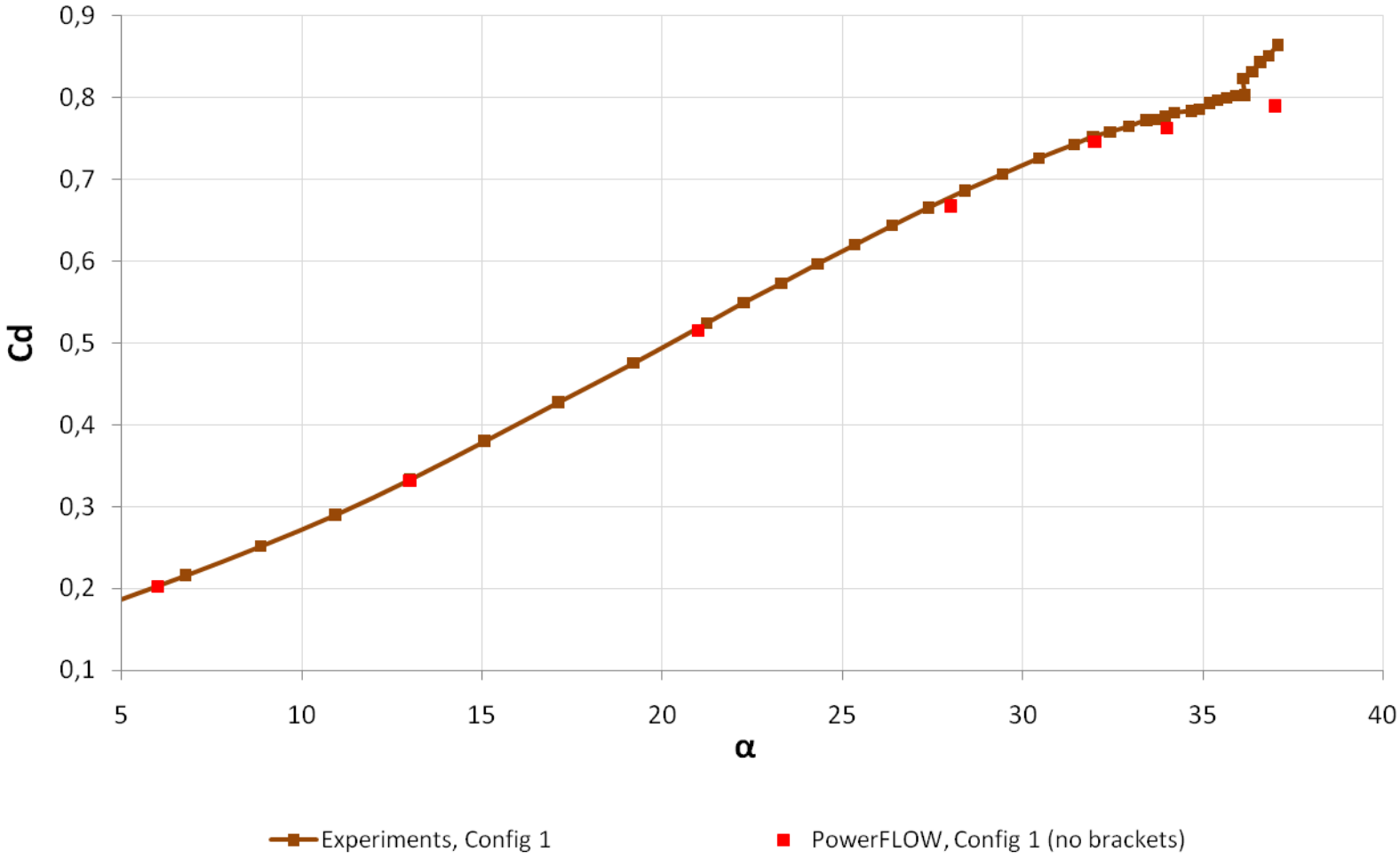
Case 1 (1mm): Drag Prediction



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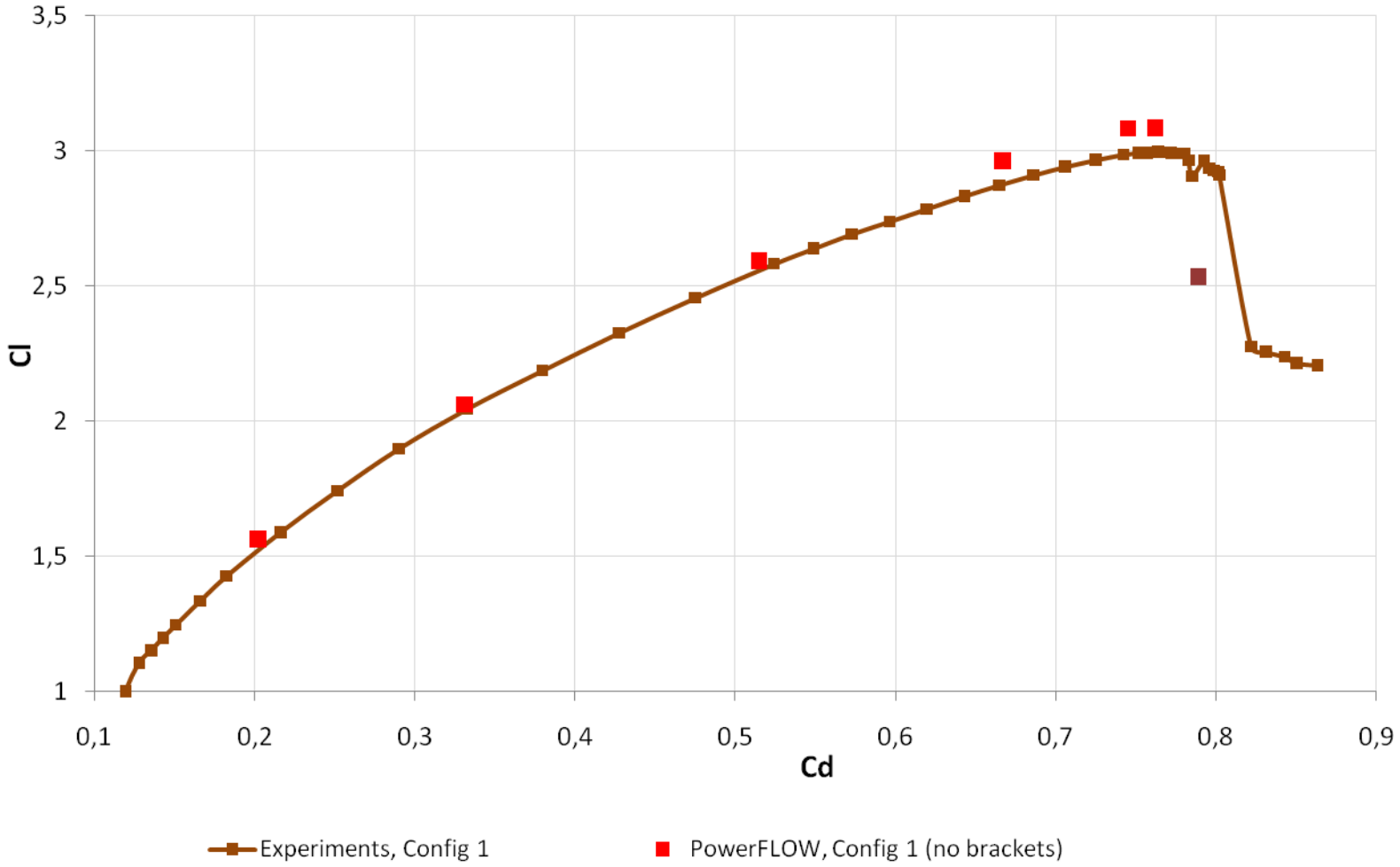
Case 1 (1mm): Drag Polar



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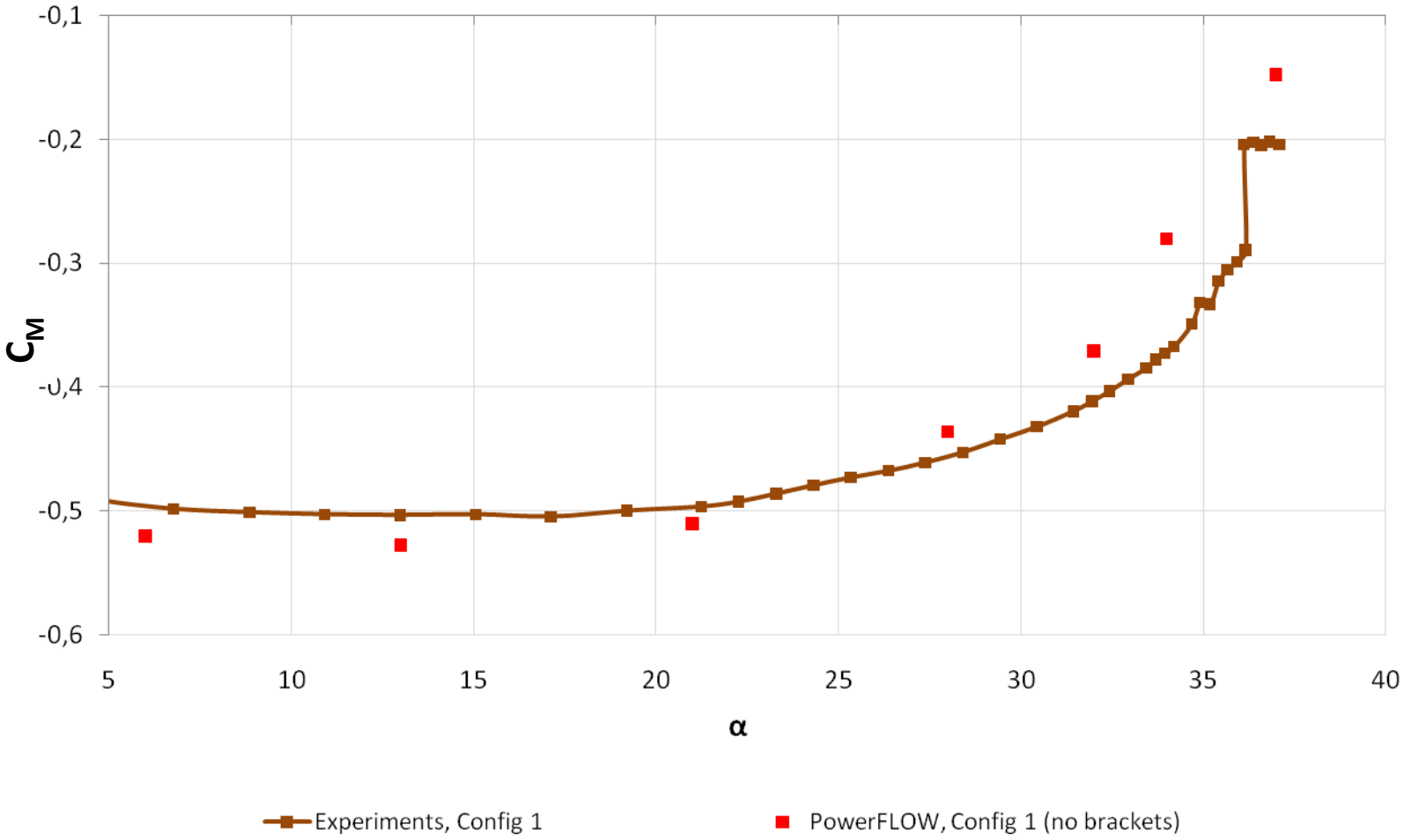
Case 1 (1mm): Pitching Moment



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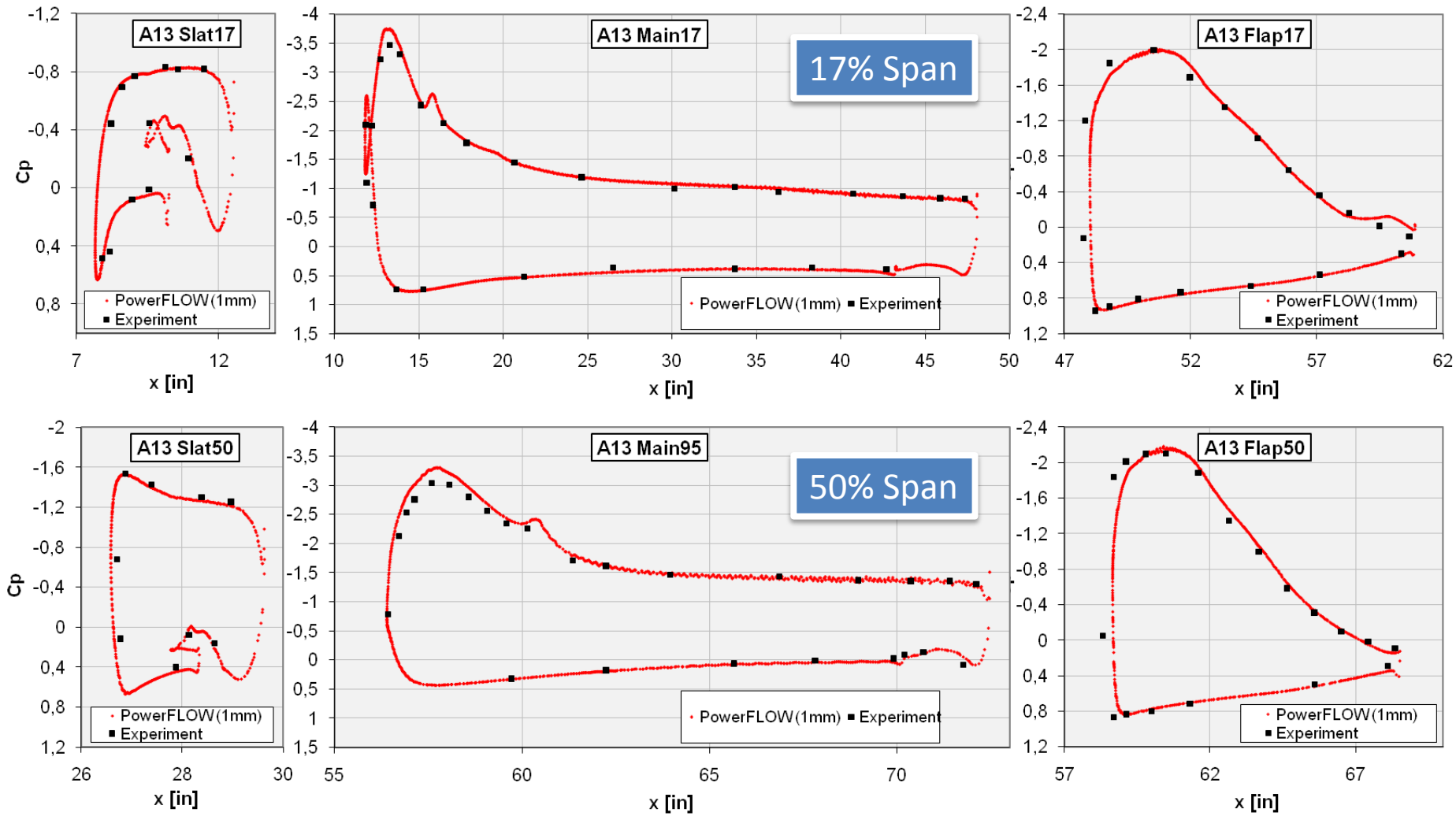
Case 1 (1mm): c_p (α=13°)



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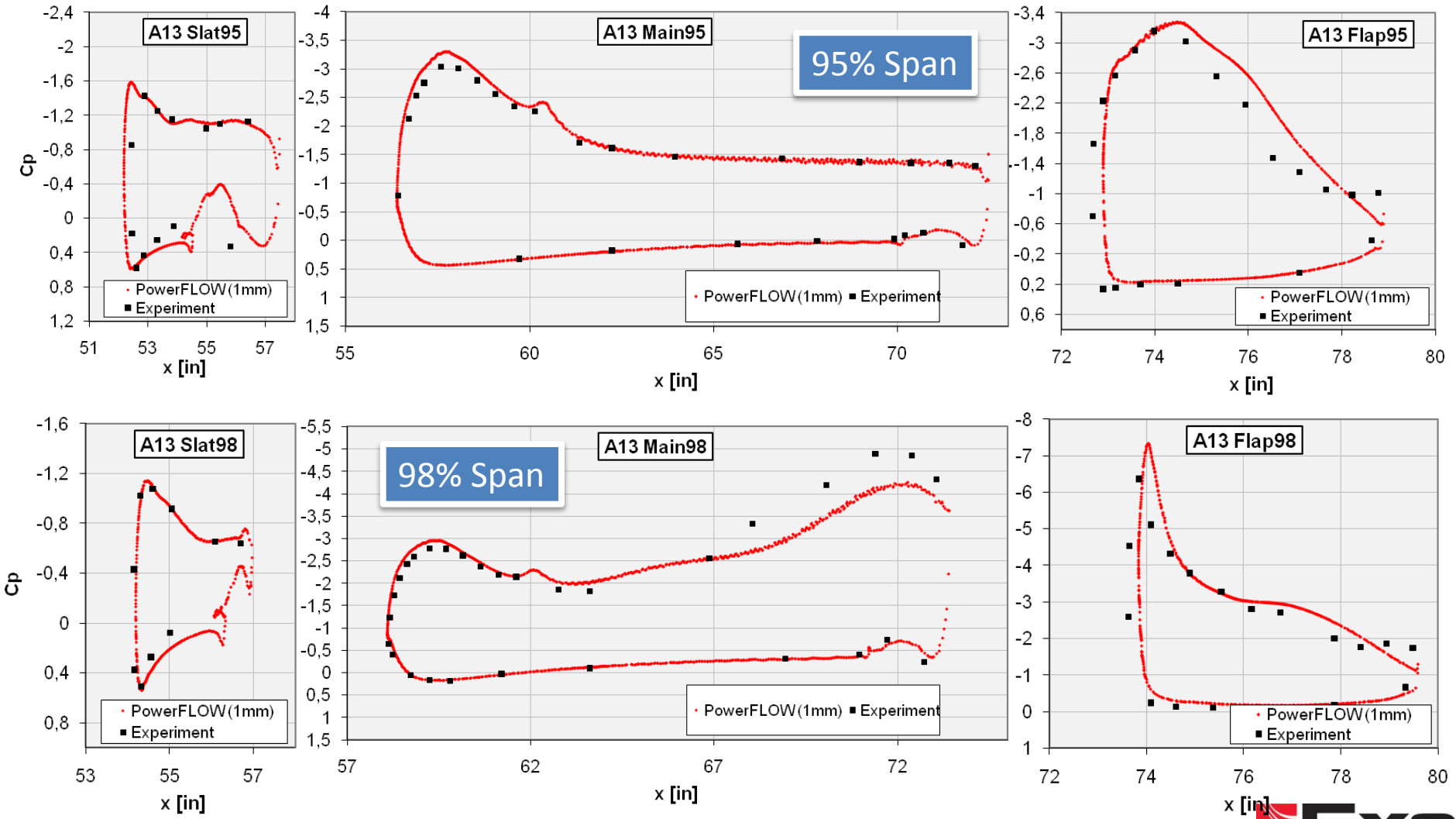
Case 1 (1mm): c_p (α=13°)



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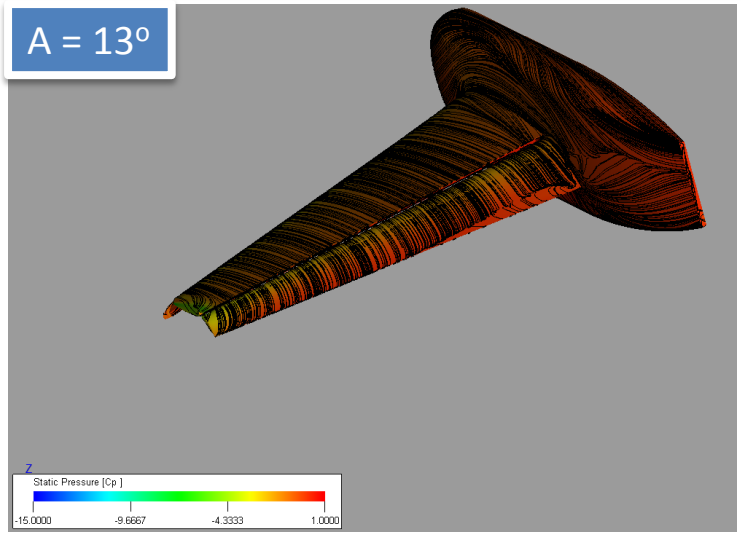
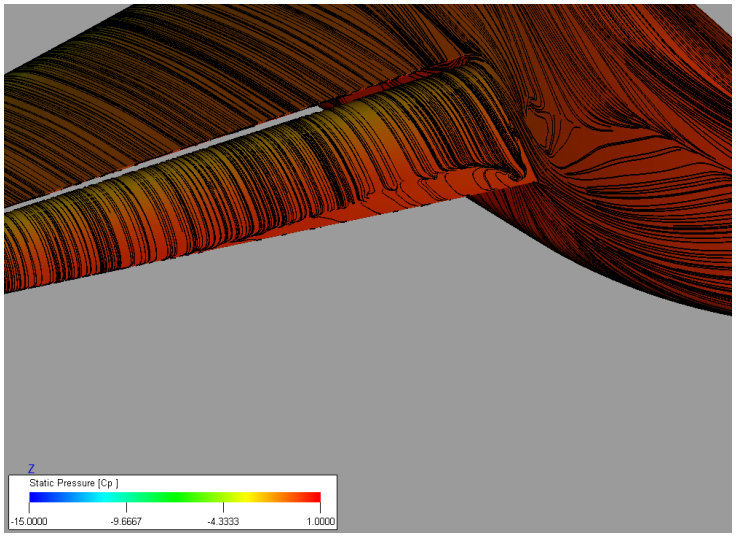
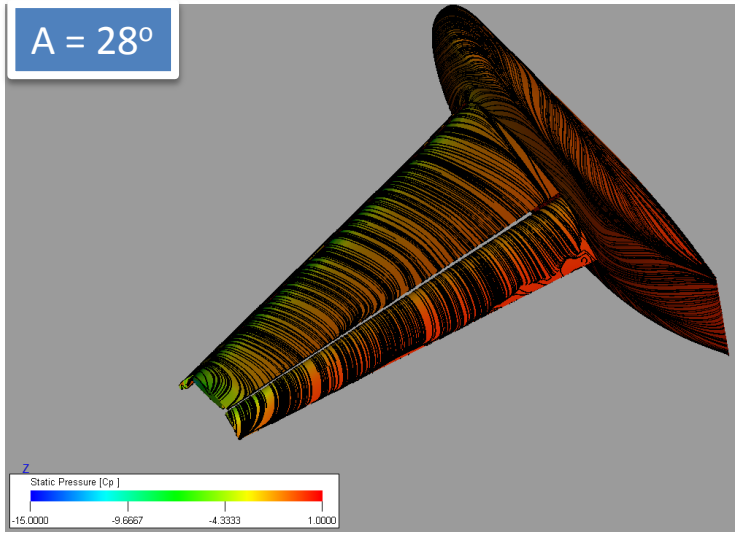
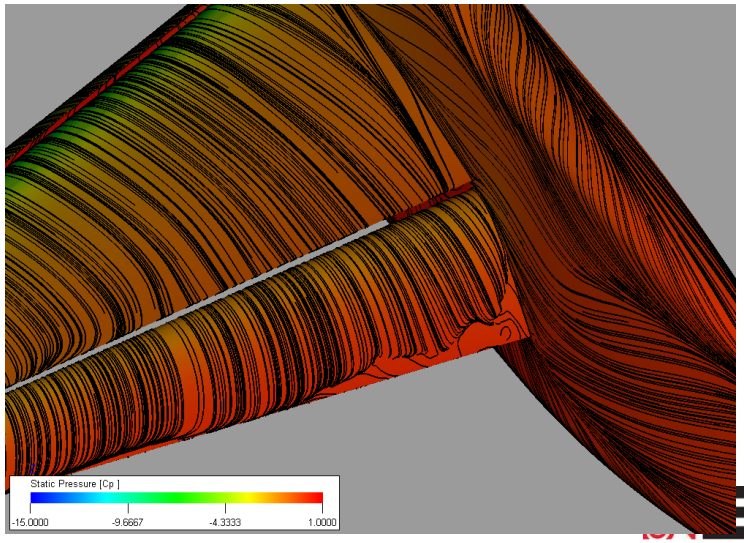
Flow Structures









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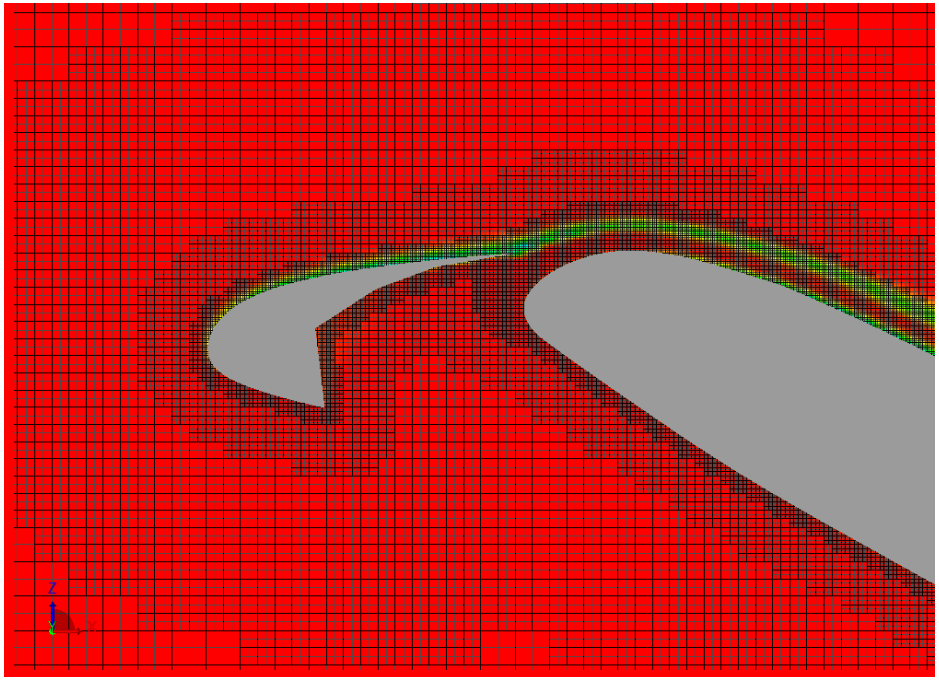
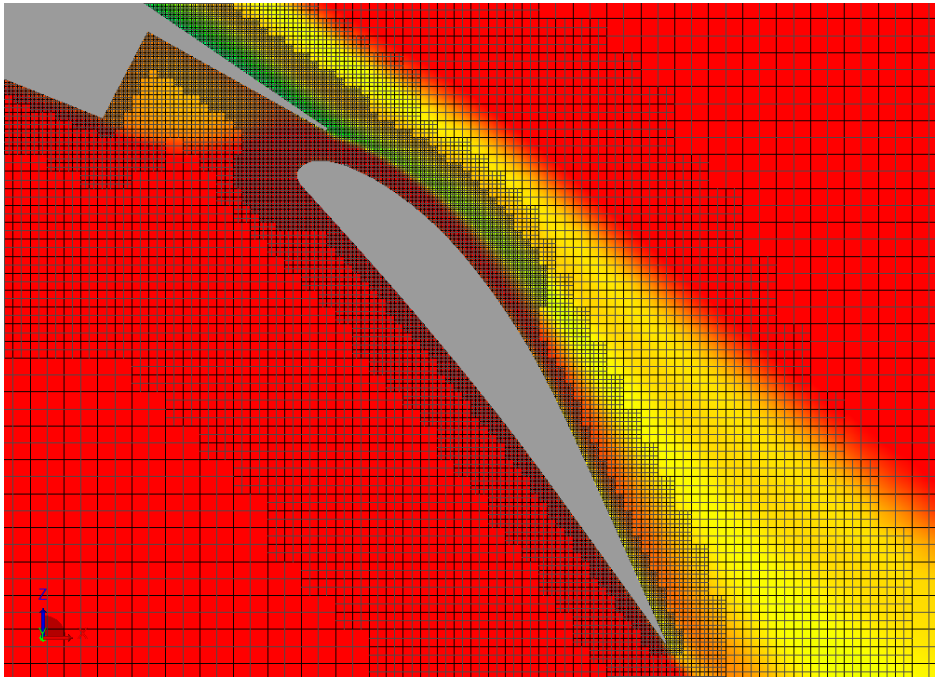
Slat and Flap Wakes (α=28°)





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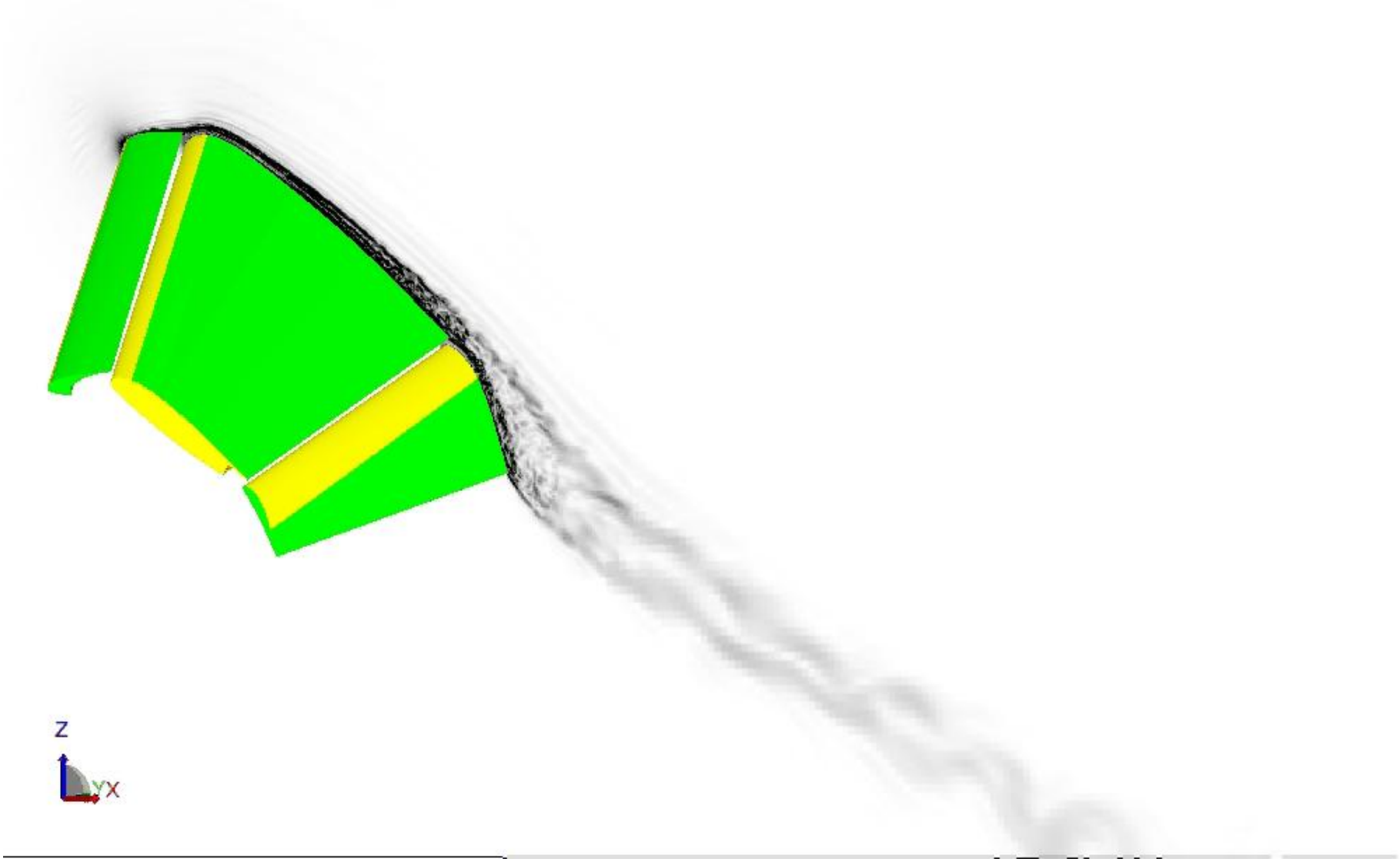
Unsteady Flow Animations (α=34°)



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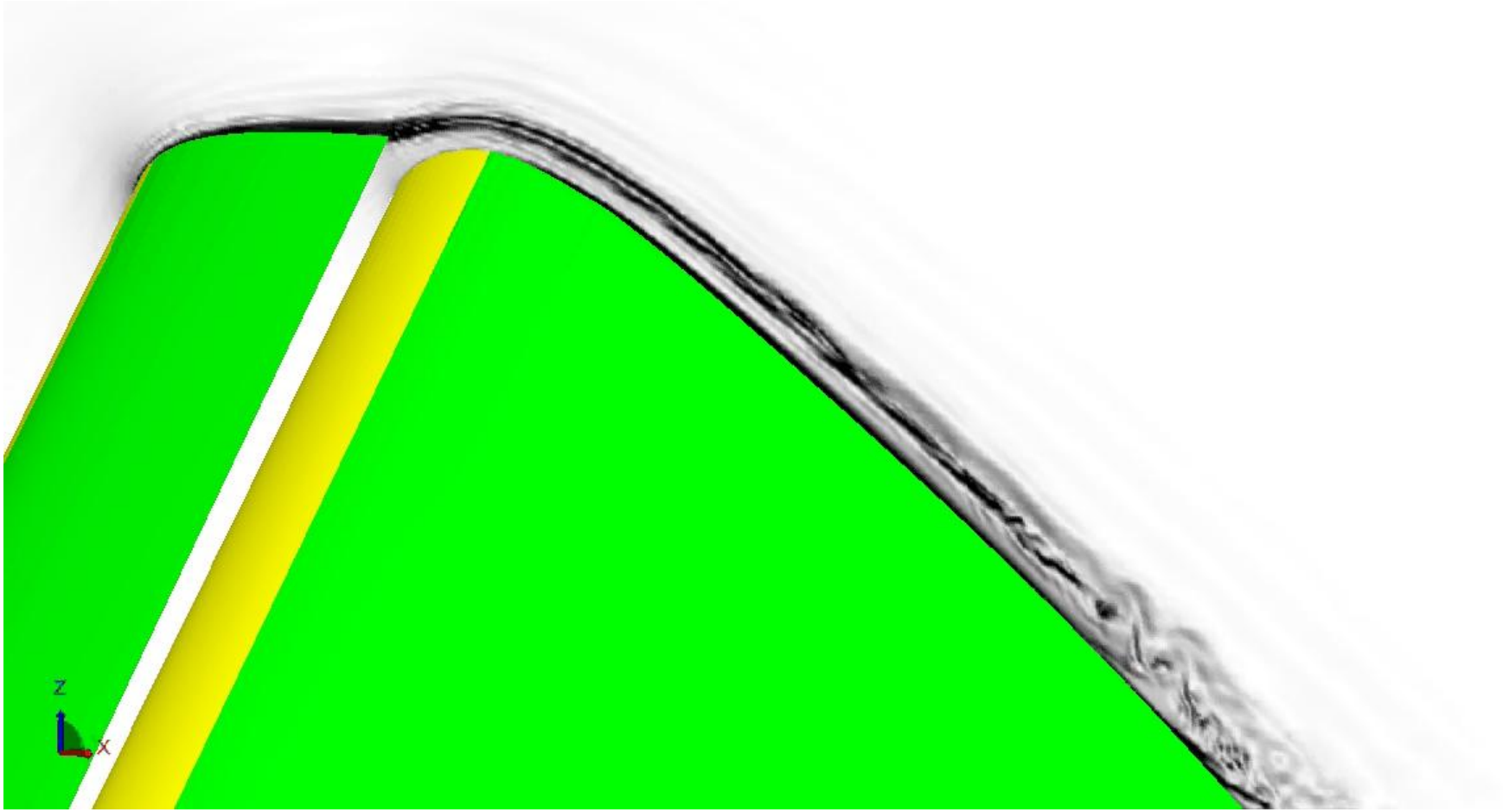
Unsteady Flow Animations (α=34°)



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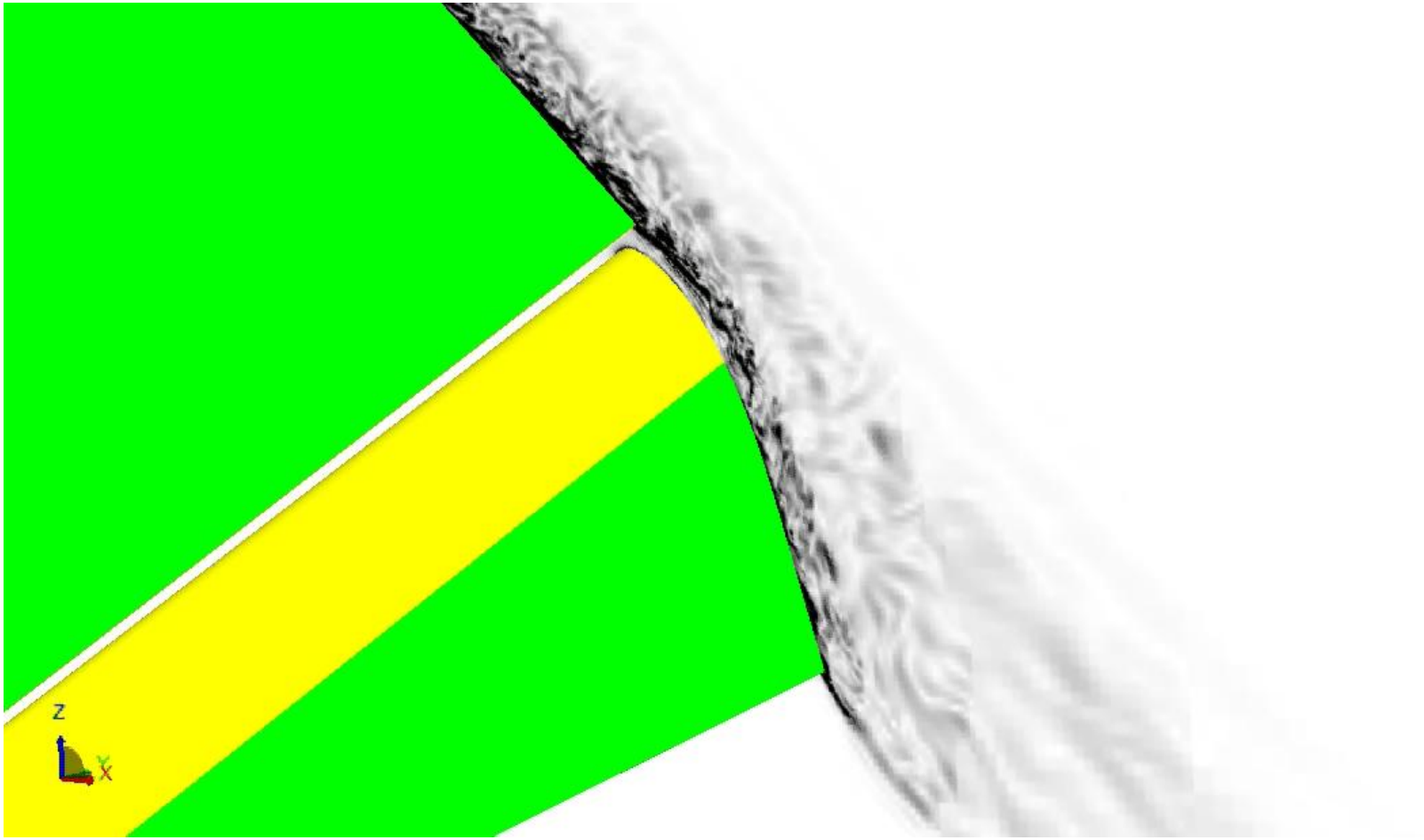
Unsteady Flow Animations (α=34°)



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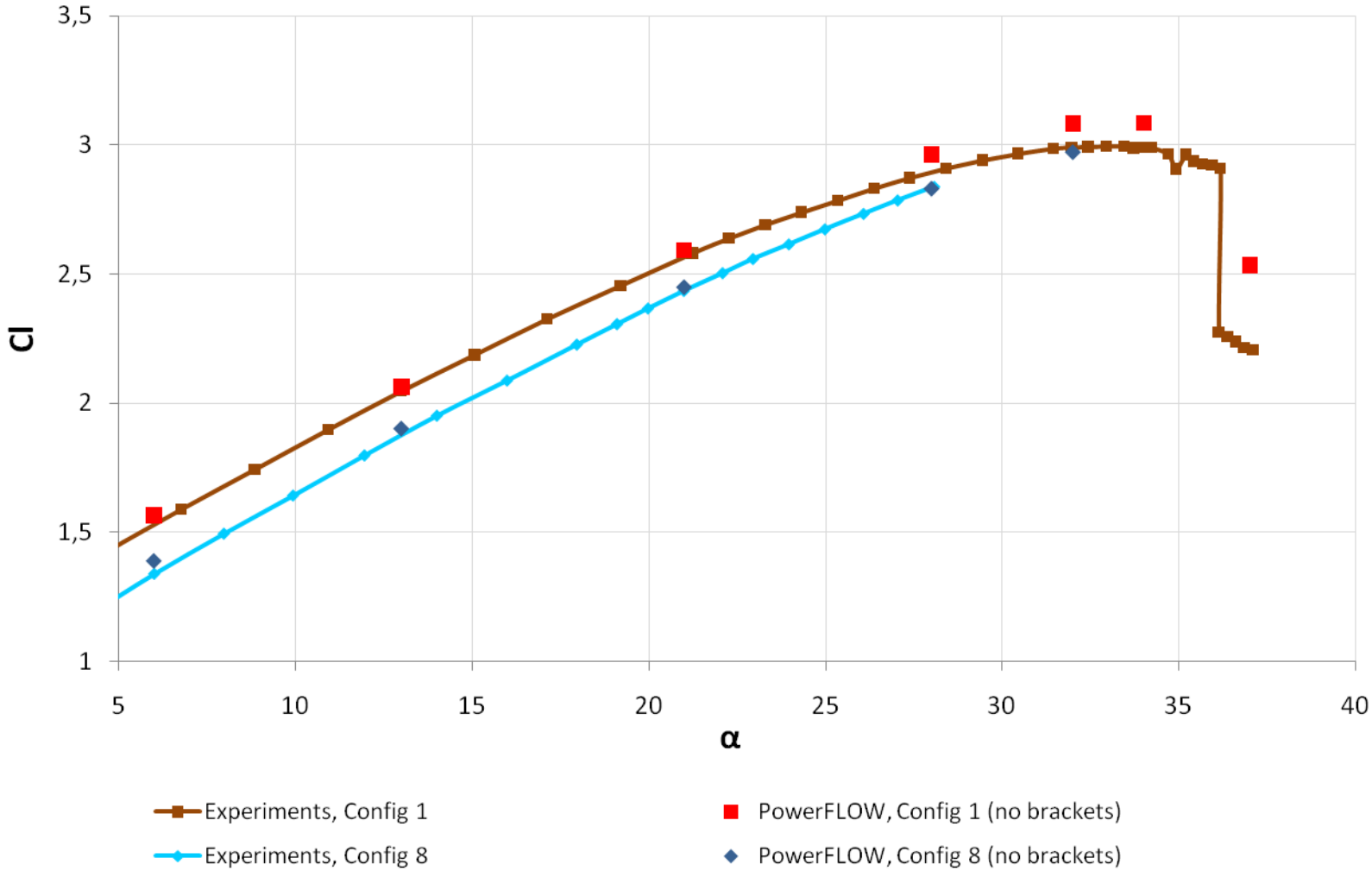
Case 2: Lift



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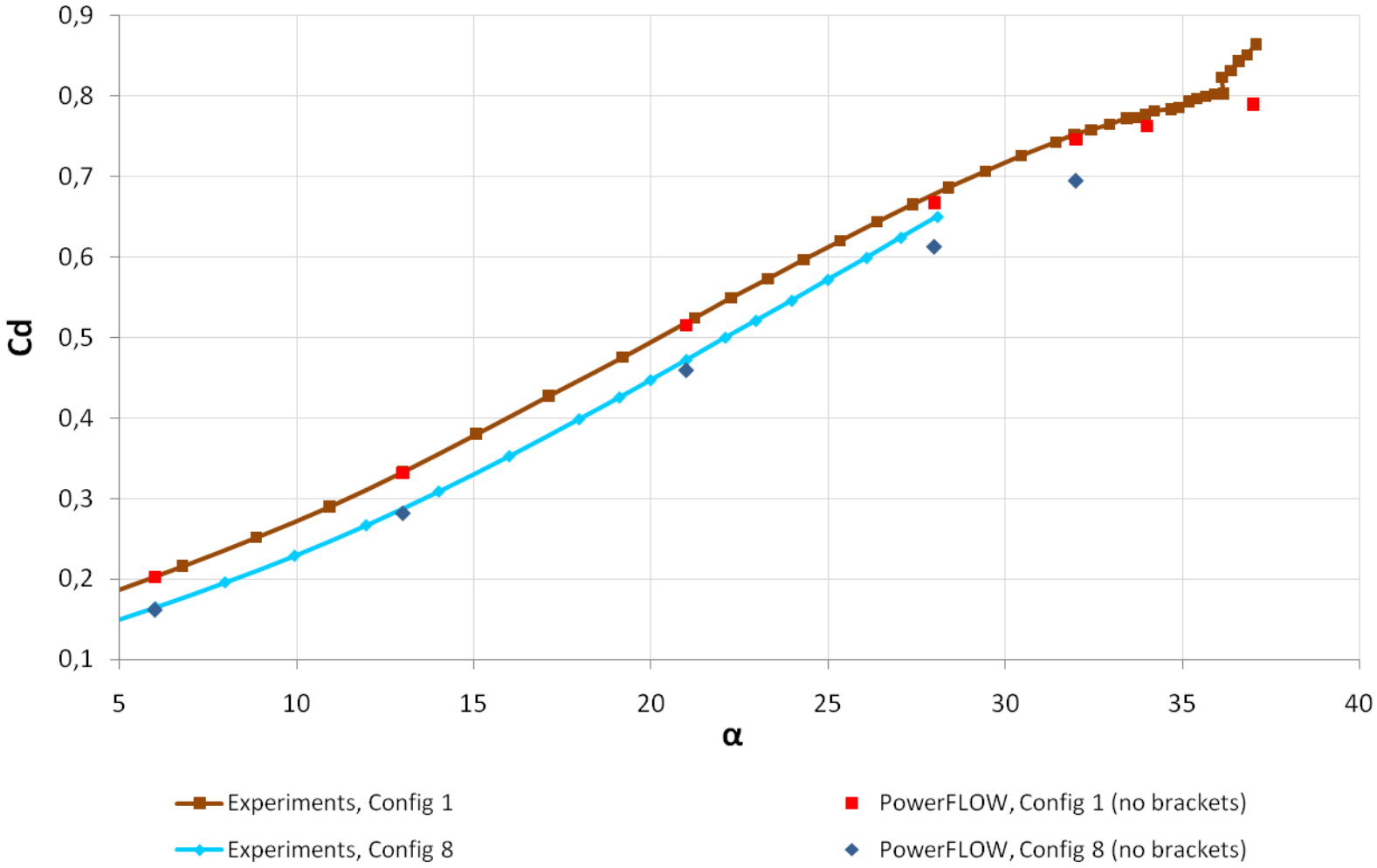
Case 2: Drag



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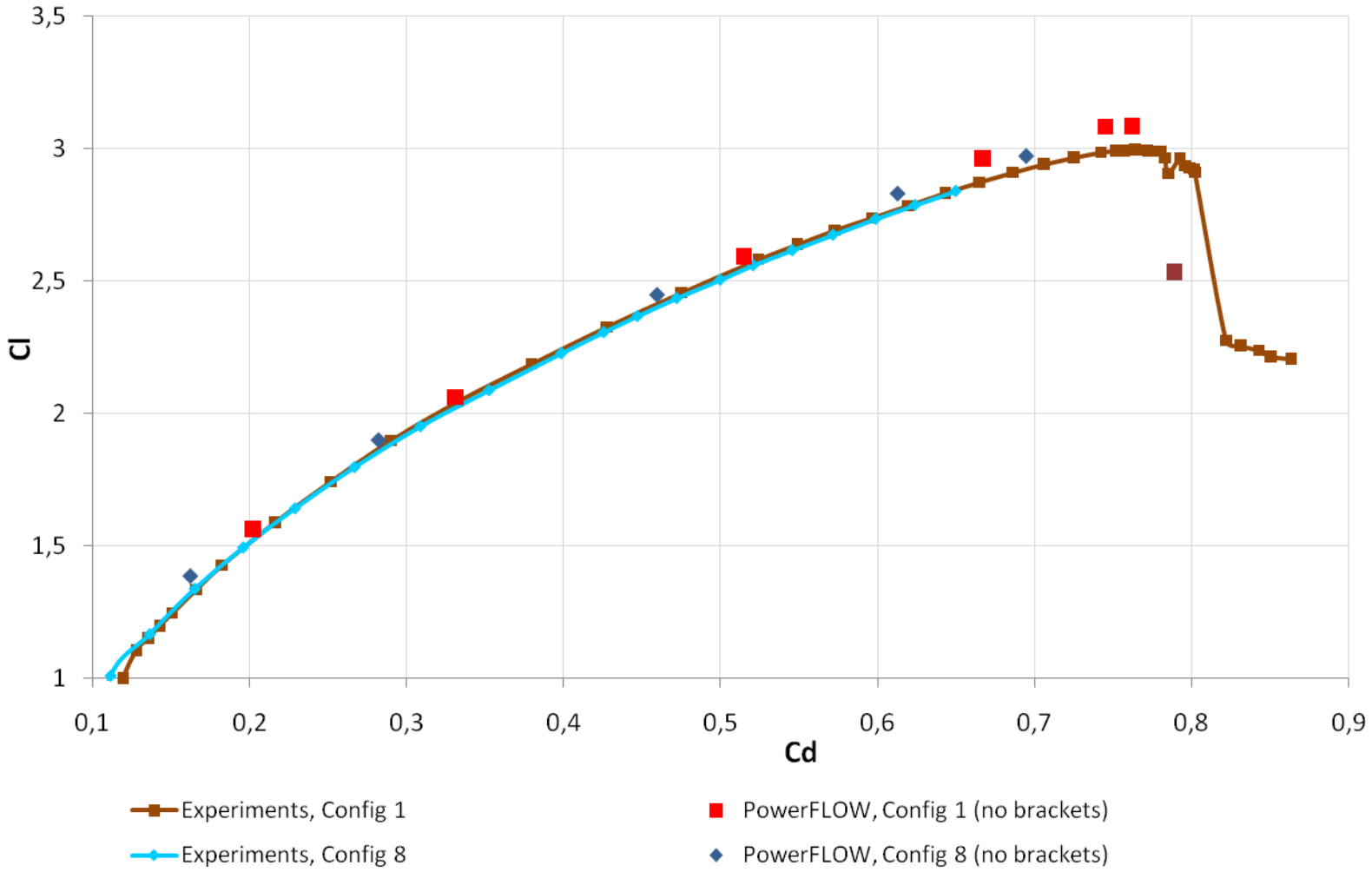
Case 2: Drag Polar



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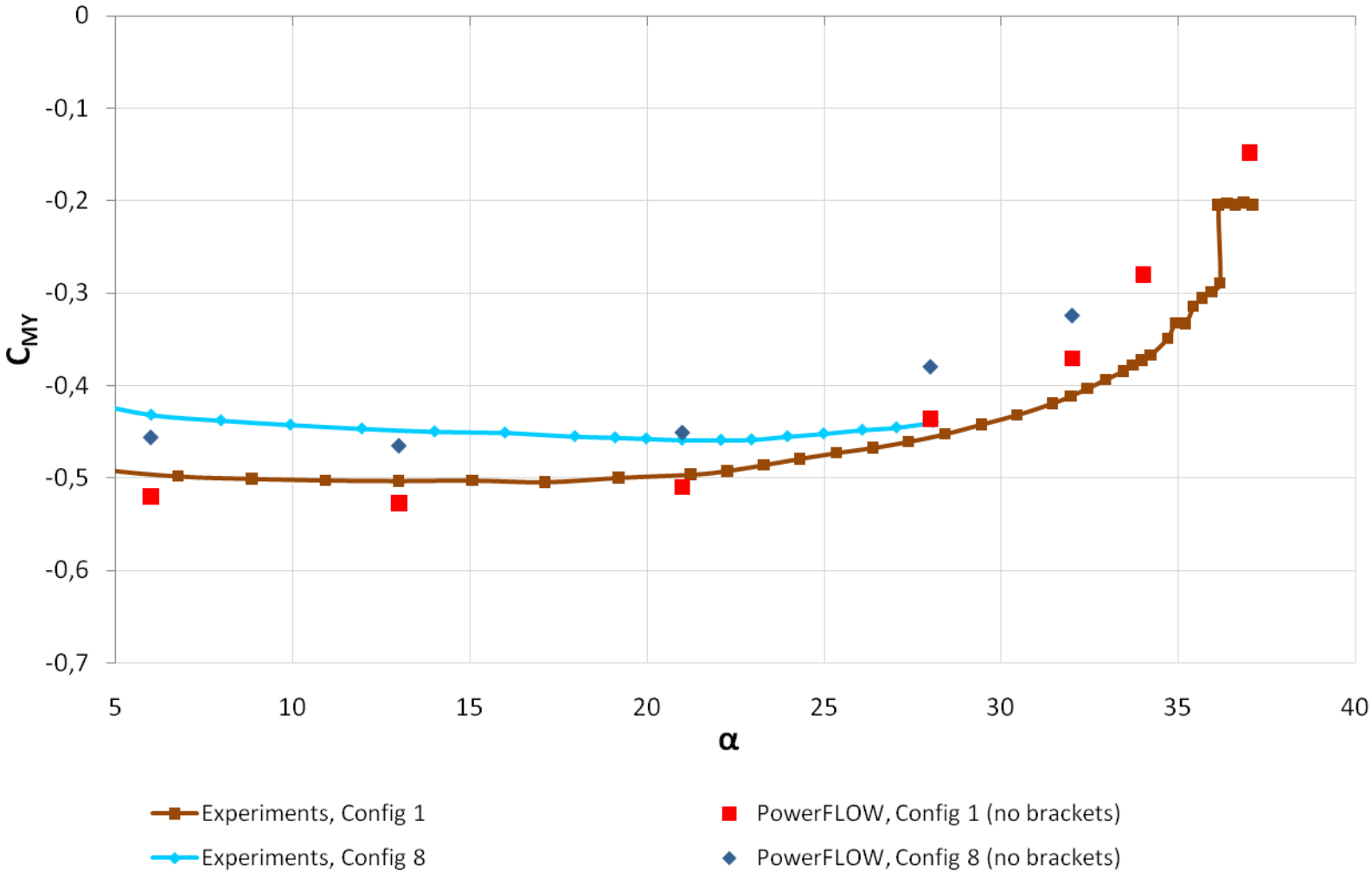
Case 2: Pitching Moment



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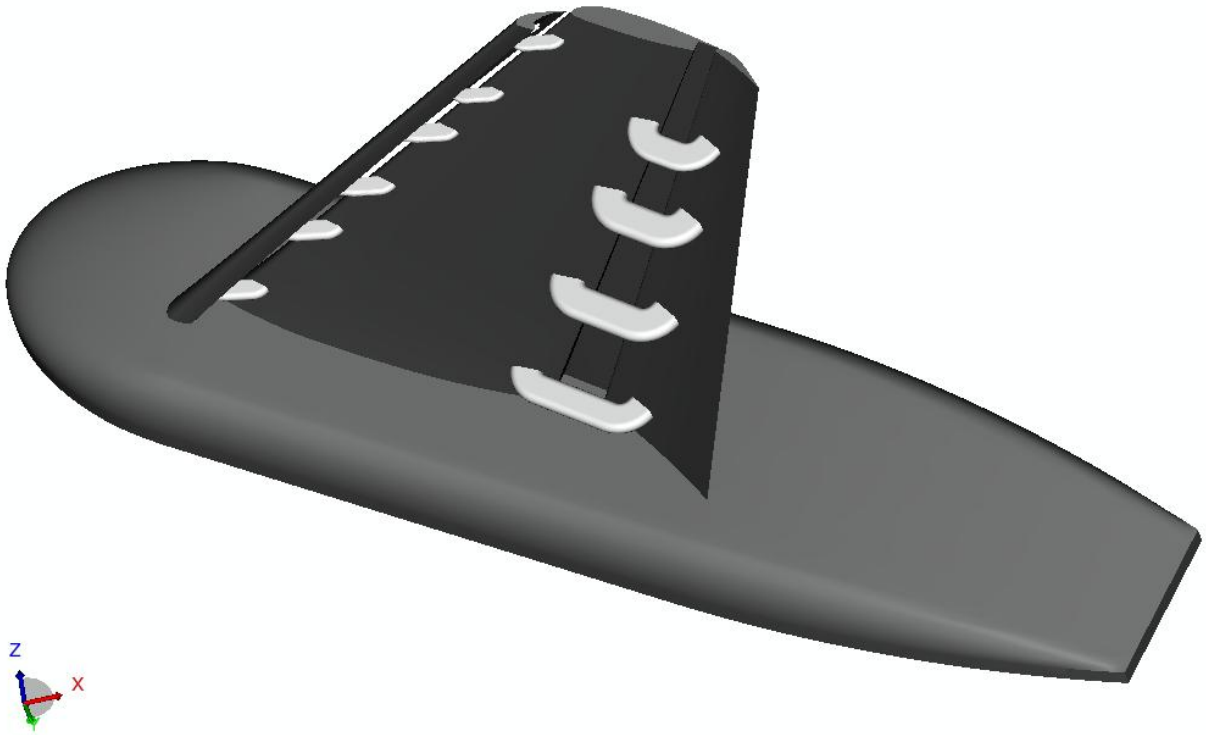
Case 3



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

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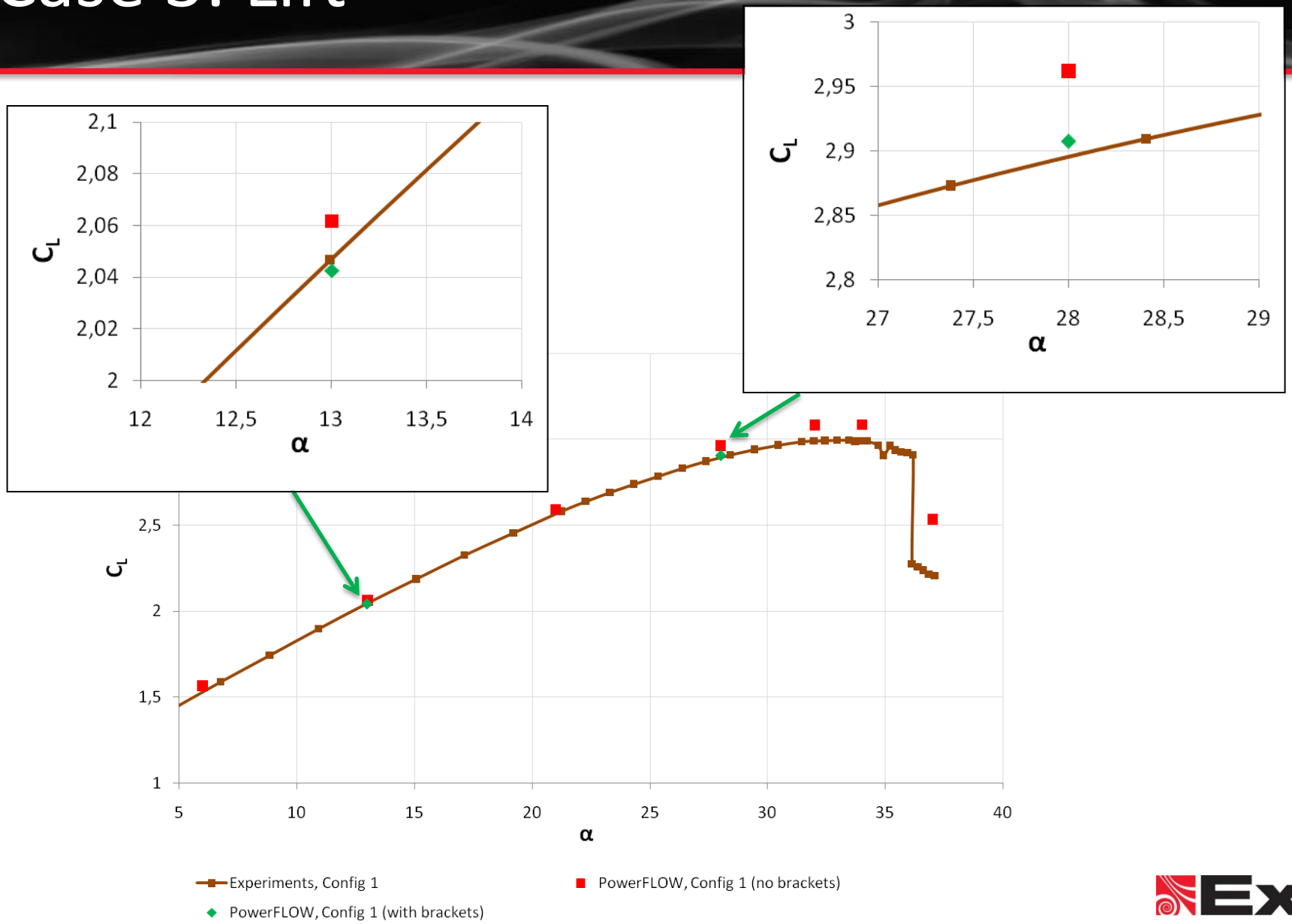
Case 3: Lift



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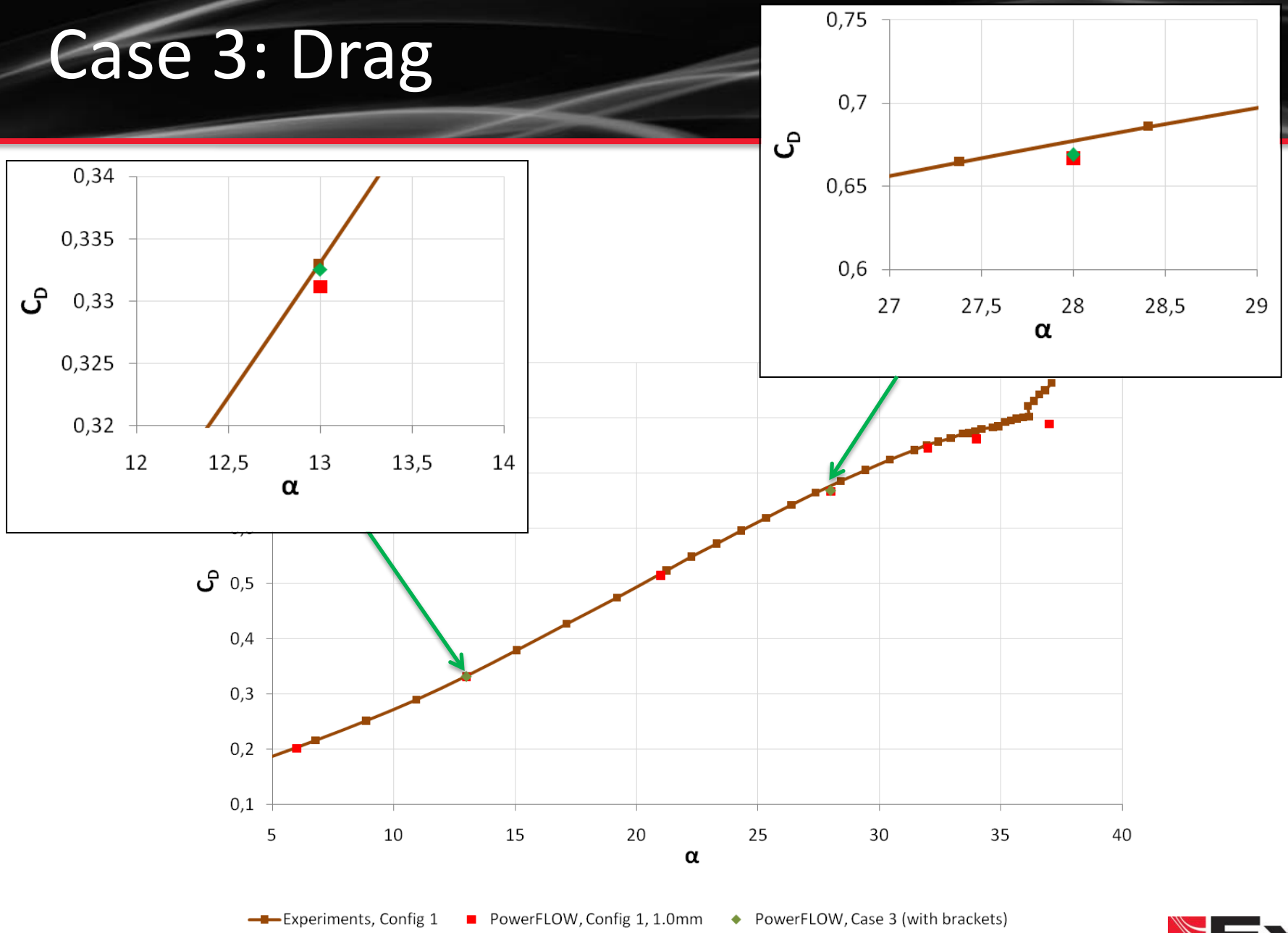
Case 3: Drag



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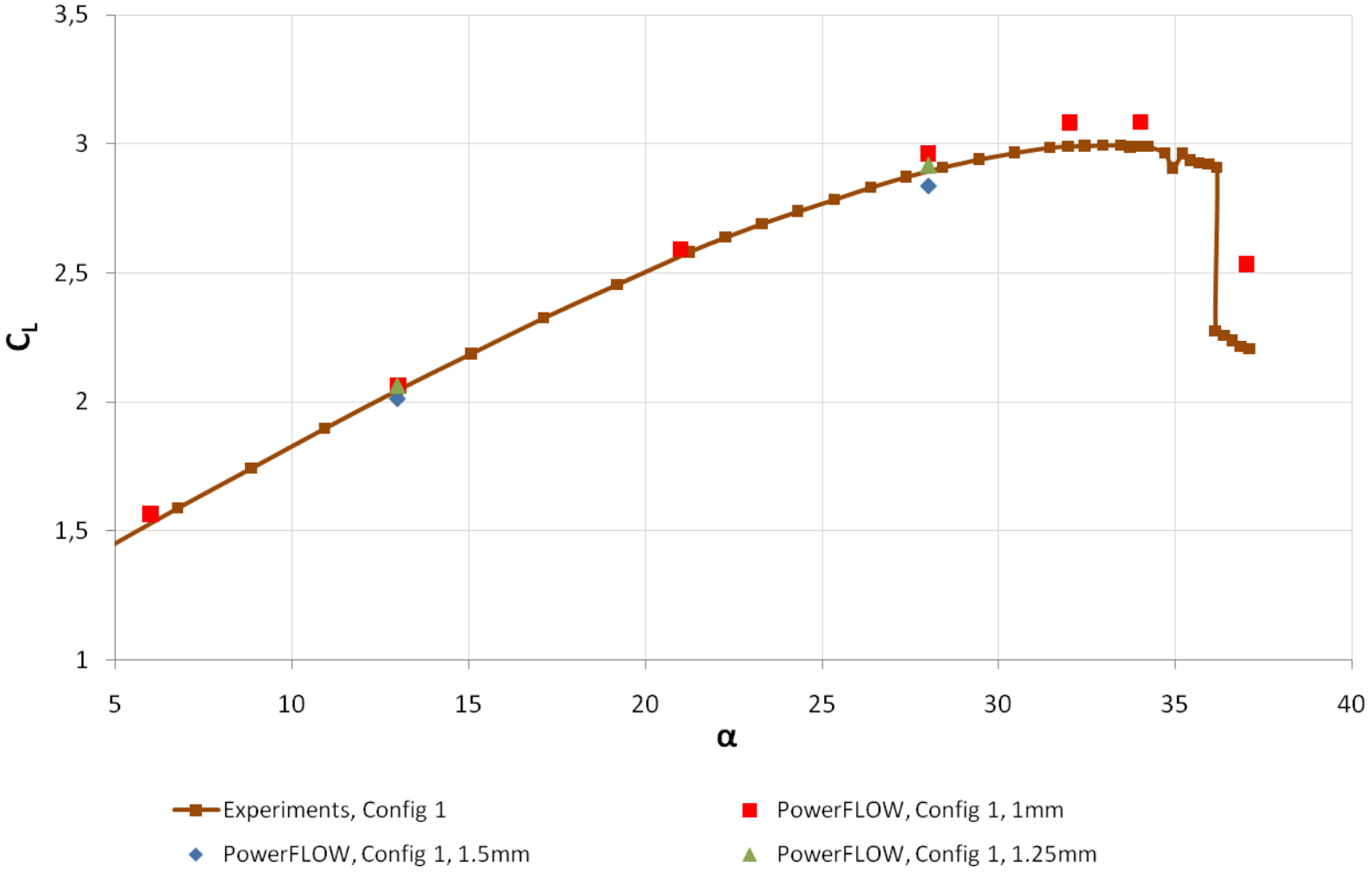
Grid Convergence: Lift



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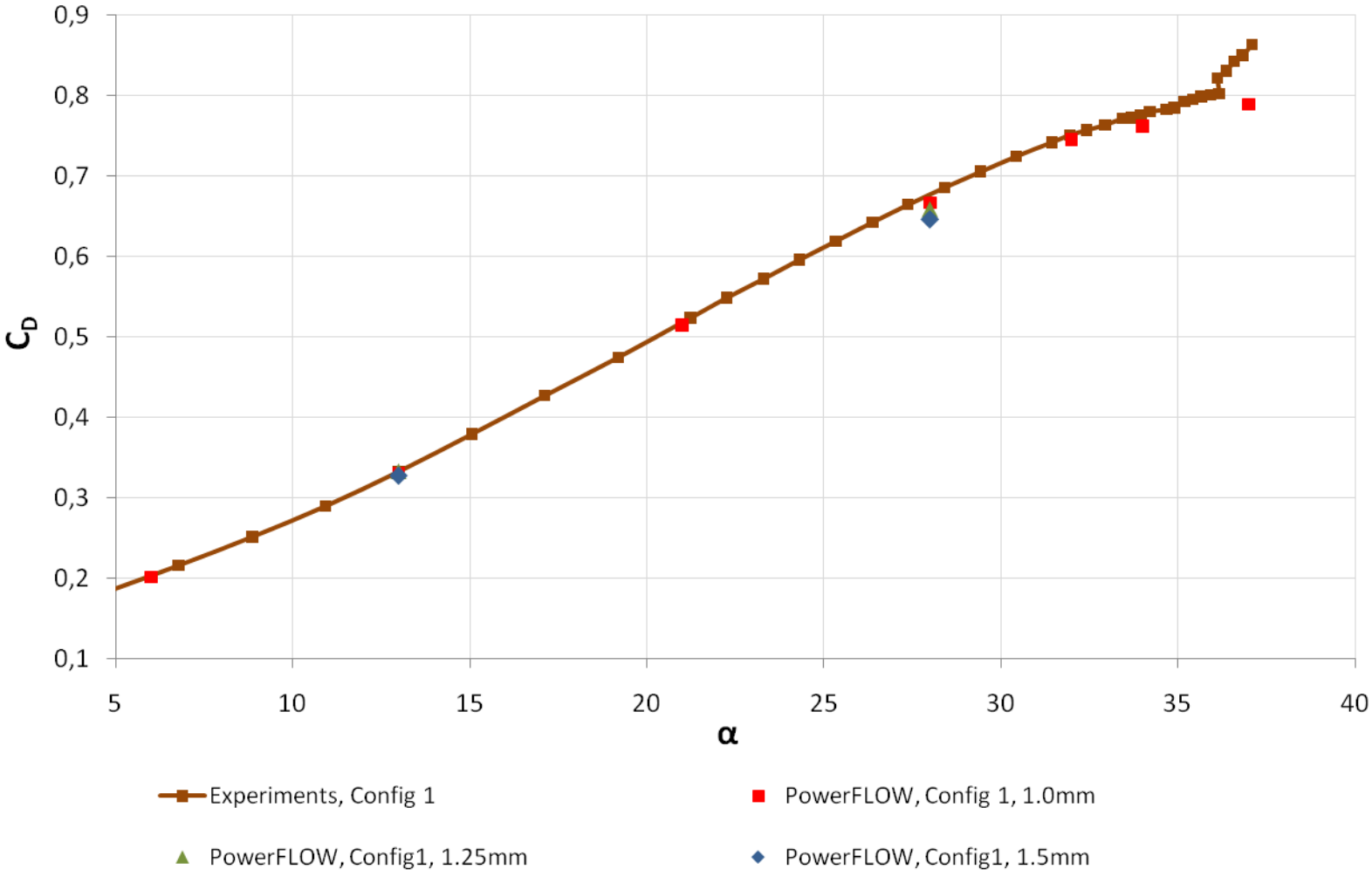
Grid Convergence: Drag



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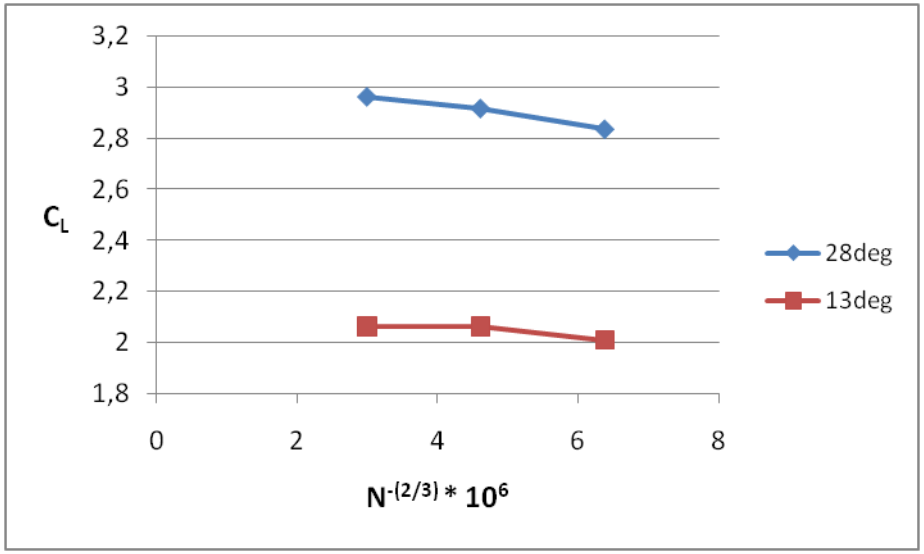
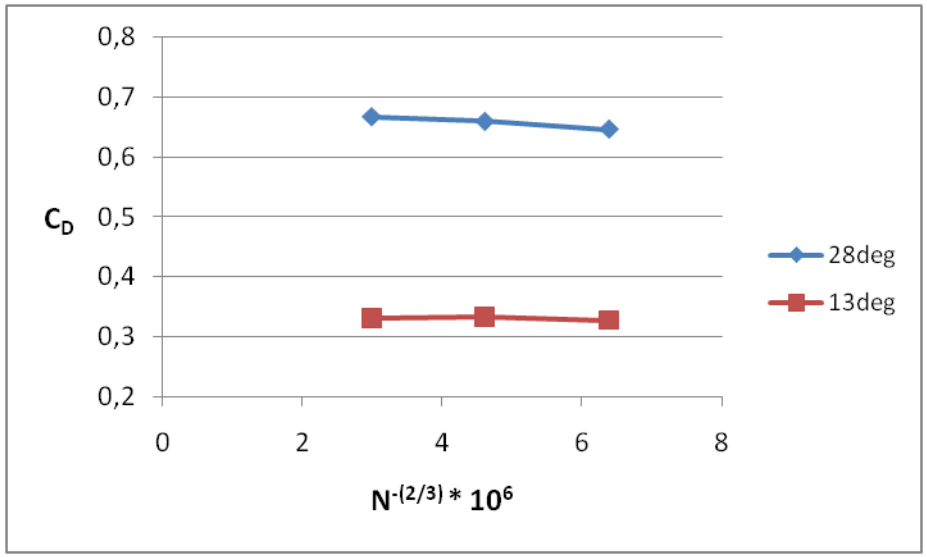
Grid Convergence





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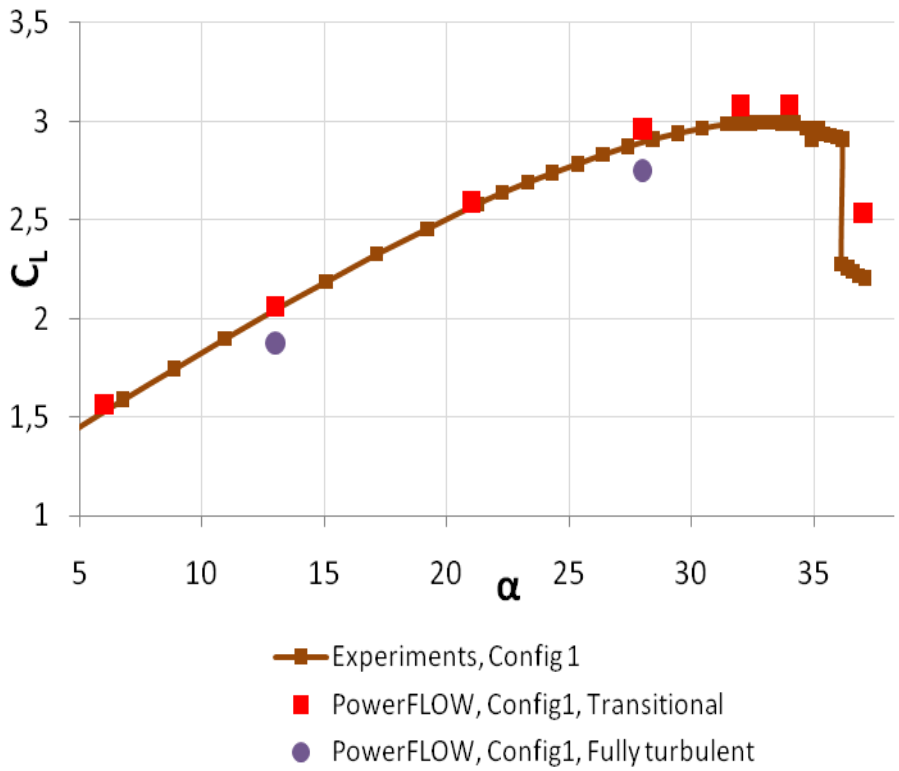
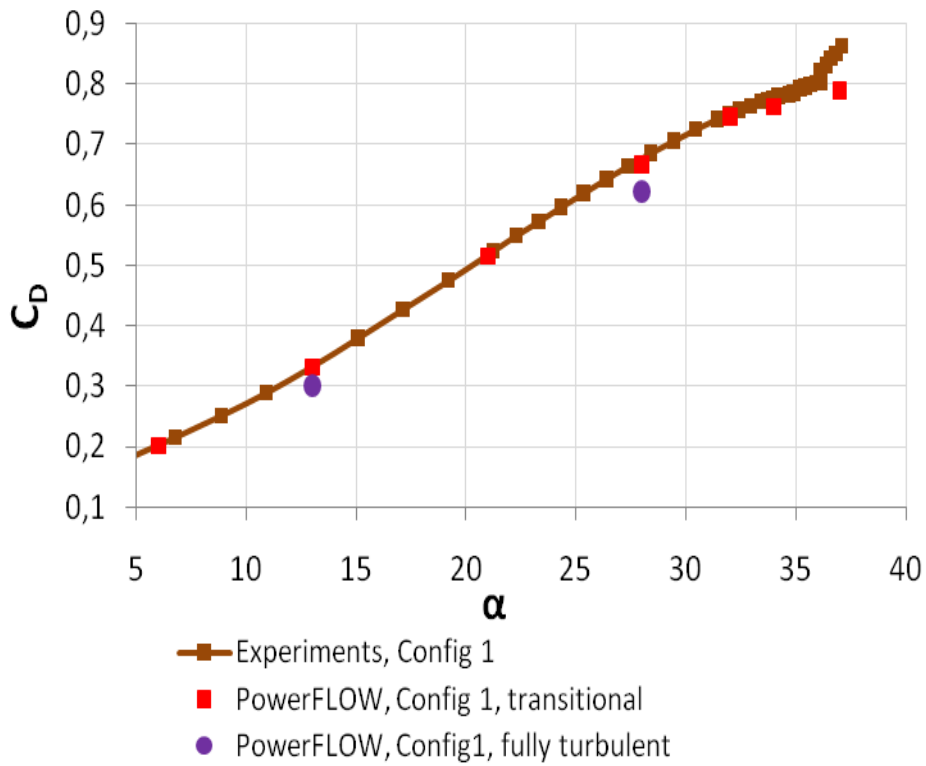
Specified Transition v. Fully Turbulent (α=28°)





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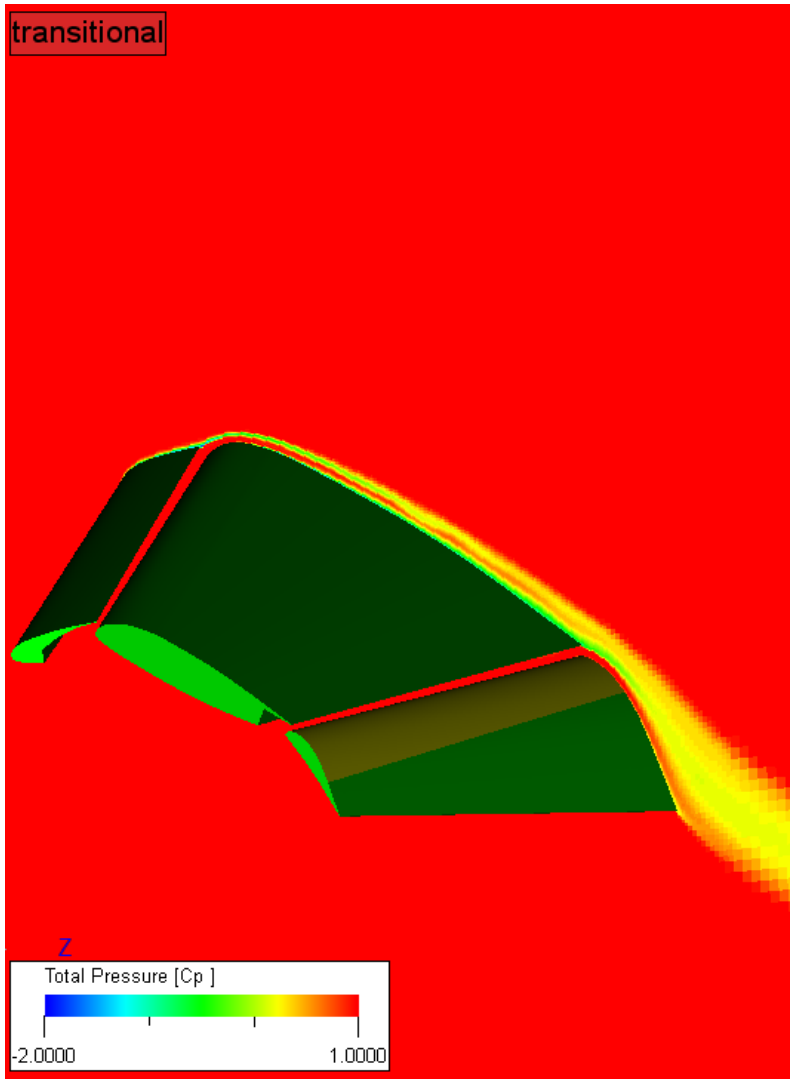
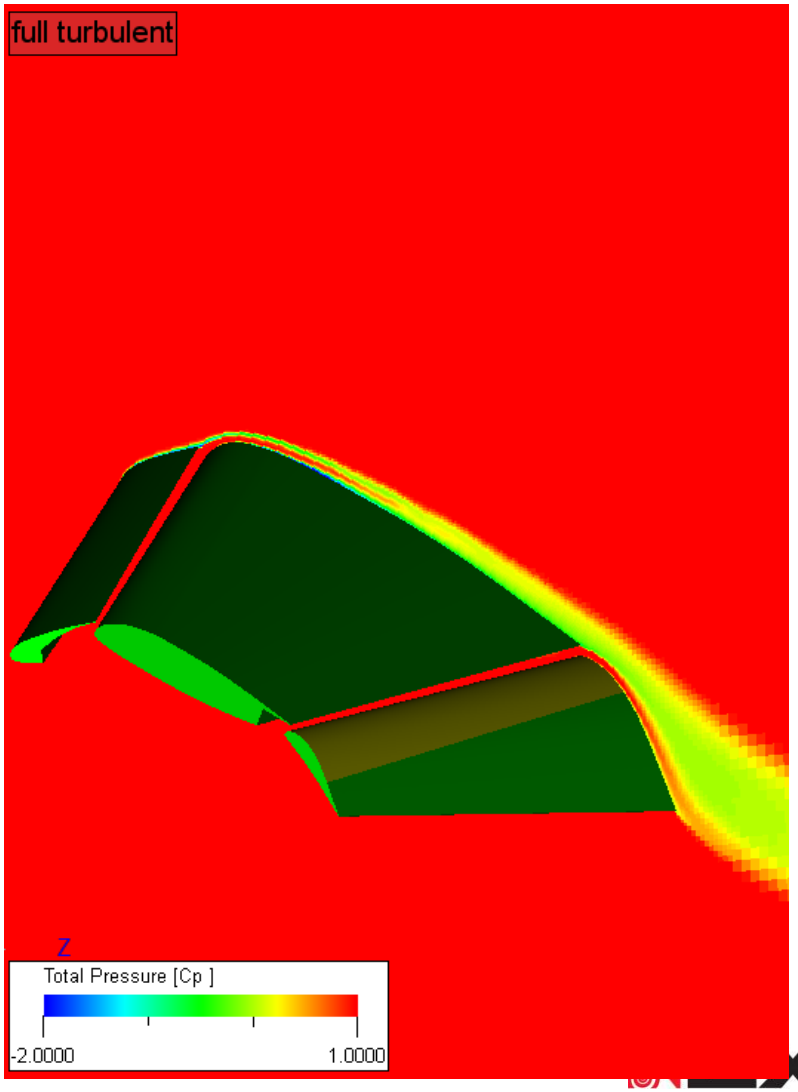
Specified Transition v. Fully Turbulent (α=28°)





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Conclusions

- Overall good agreement with experiments
  - *Lift slightly overpredicted for case 1 and case 2*
  - *Adding brackets (case 3) provides excellent agreement for both lift and drag*
- Resolution study
  - *Good grid convergence demonstrated*
- Transitional v. fully turbulent
  - *Correct specification of transition locations appears to be critical*

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Next Steps

- Complete HiLiftPW tasks
  - *Complete analysis of surface pressures*
  - *Complete simulations and analysis of post-stall behavior*
  - *Deeper investigation of impact of transition locations*
- Optimize grids to improve efficiency
- Investigate WT blockage effects
  - *Simulate with WT walls*
  - *Compare to uncorrected measurements*
- Investigate hysteresis effects
  - *Use moving geometry capability to increase and decrease alpha in single run*

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