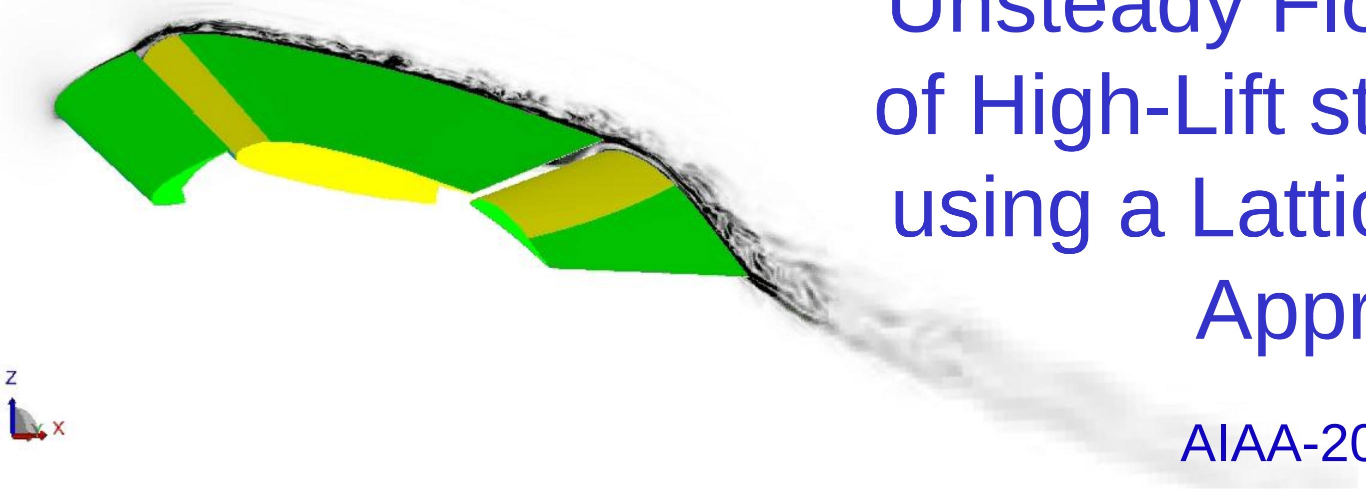

Unsteady Flow Simulation of High-Lift stall Hysteresis using a Lattice Boltzmann Approach

AIAA-2012-2922

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Exa GmbH

Acknowledgements

Judith A. Hannon

Bruno Moschetta

30th Applied Aerodynamics Conference

25-28 June, 2012, New Orleans, LA

Overview

- Introduction
  - *TrapWing Geometry*
- Numerical Method
  - *Lattice-Boltzmann based code (PowerFLOW)*
    - Turbulence Modeling
    - Boundary Conditions
- Results
  - *1st High-Lift Workshop / AIAA 2011 - 0869 results review*
  - *Simulation Overview*
  - *Sensitivity to laminar regions*
  - *Investigation of hysteresis effect*
    - Coarse and fine simulation
- Conclusions & Outlook

Introduction

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

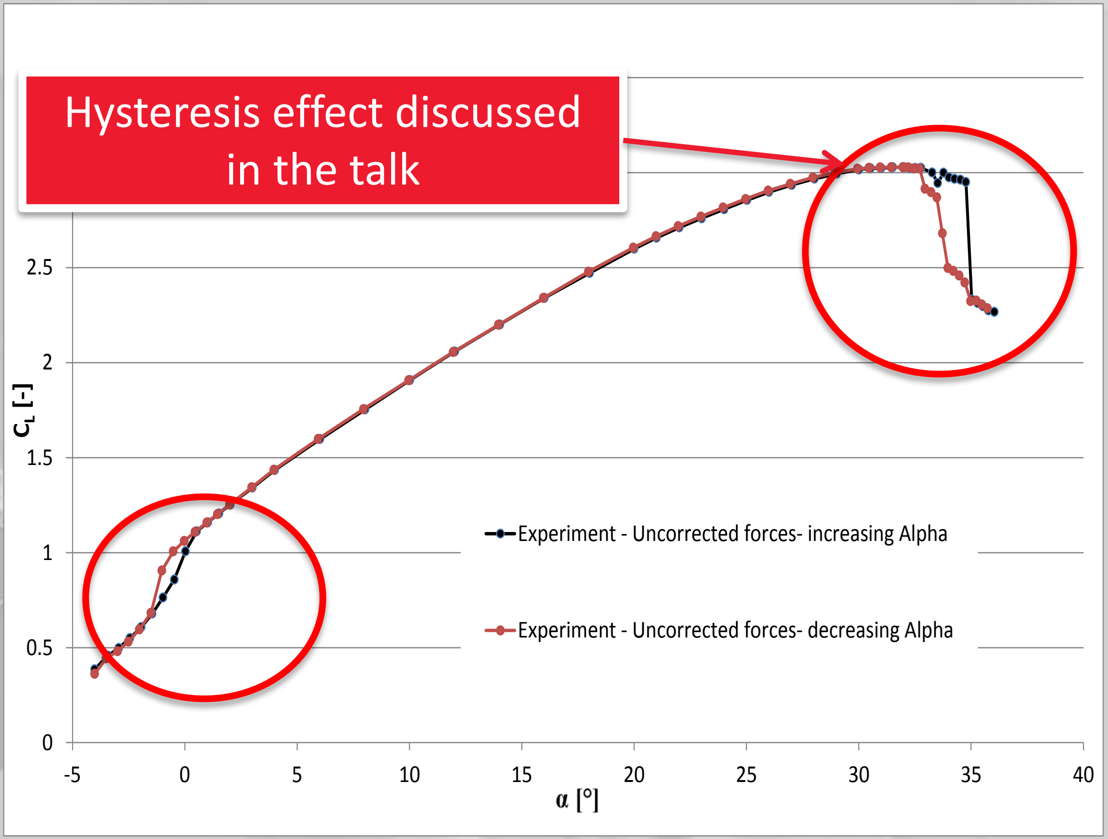
Shown in NASA Ames tunnel

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

Eliasson P., Hanifi A., Peng S.-H., "Influence of transition on high - lift prediction for the NASA trap wing model", AIAA Paper, 2011-3009, 2011

Introduction

Trap Wing in the NASA Langley WT



Windtunnel Measurement
~30s per AoA
ΔAoA ~0.5°-2°
(~20s rotating, 8s data acquisition & 2s data writing)

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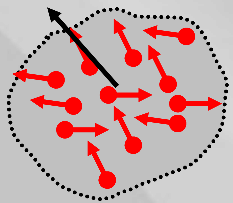
Lattice Boltzmann Method

- Fluid properties are described by distribution functions

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

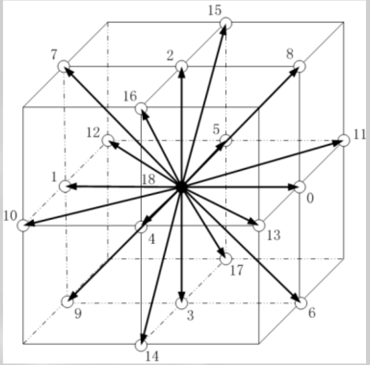


Shan X., Yuan X.-F, and Chen H. “Kinetic theory representation of hydrodynamics: a way beyond the Navier Stokes equation”, J. Fluid Mech., Vol. 550, 2006, pp. 413-441

Chen H., Orszag S., Staroselsky I., and Succi S., “Expanded analogy between Boltzmann Kinetic Theory of Fluid and Turbulence”, J. Fluid Mech., Vol 519, 2004, pp. 307-314

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

- Discrete 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:*

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

Turbulence Modeling

- LBM – VLES 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*

Chen, H., Kandasamy, S., Orszag, S., Shock, R., Succi, S., and Yakhot, V., "Extended Boltzmann Kinetic Equation for Turbulent Flows," *Science*, Vol. 301, 2003, pp. 633-636.
Chen H., Teixeira C., and Molving K., "Realization of Fluid Boundary Condition via Discrete Boltzmann Dynamics", *Int. J. Mod. Phys. C*, vol.9, pp.1281-1292, 1998.

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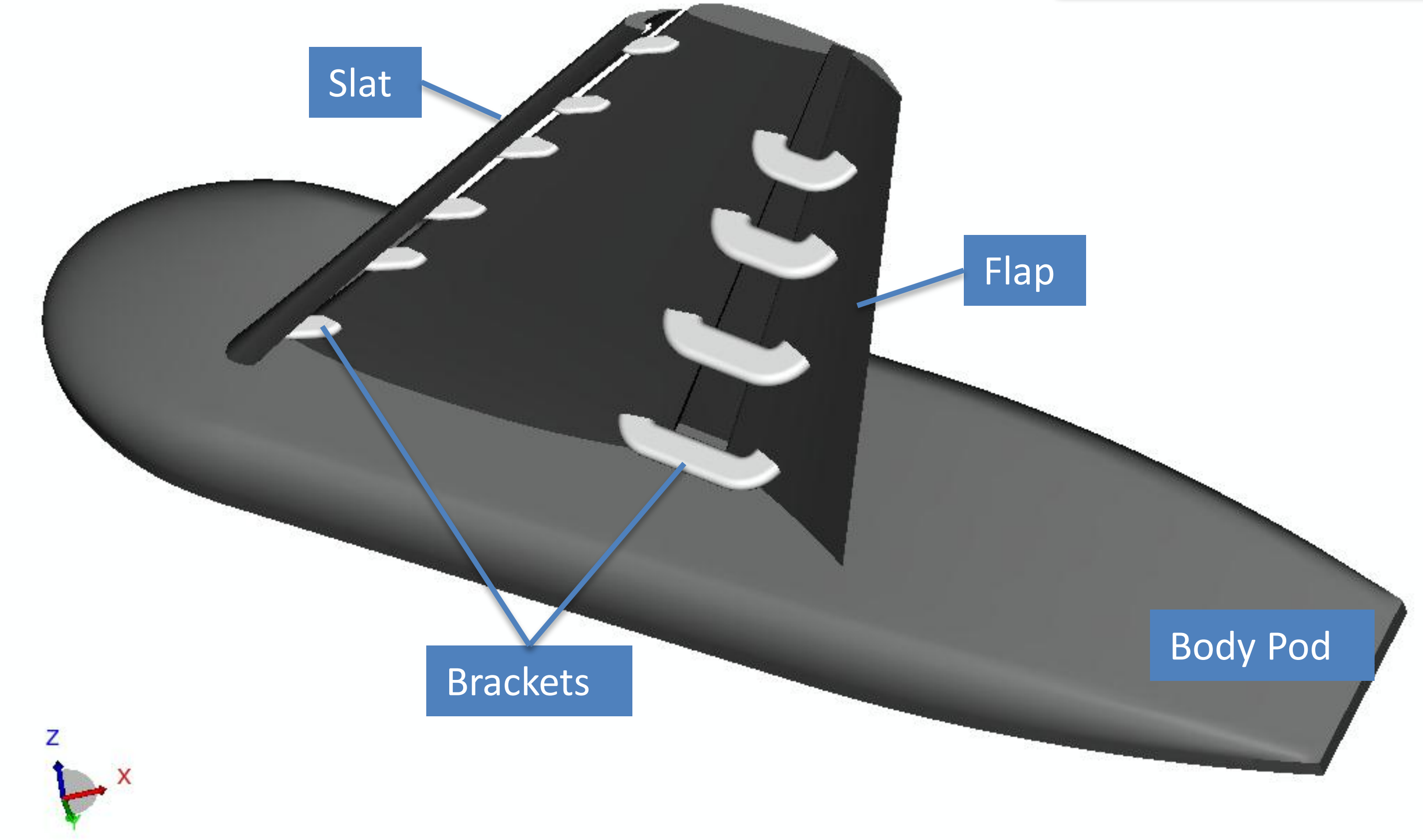
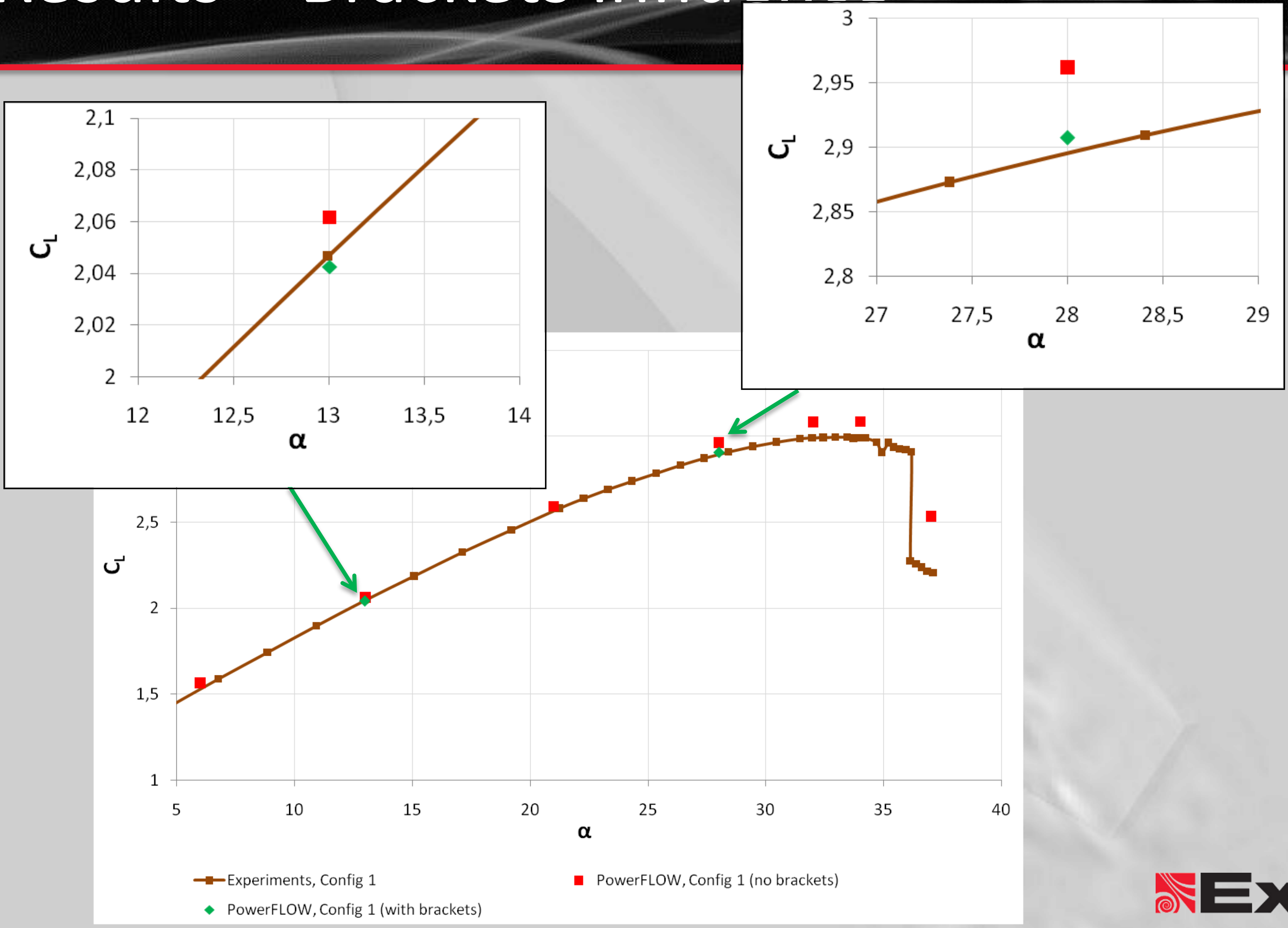
Results – Brackets influence

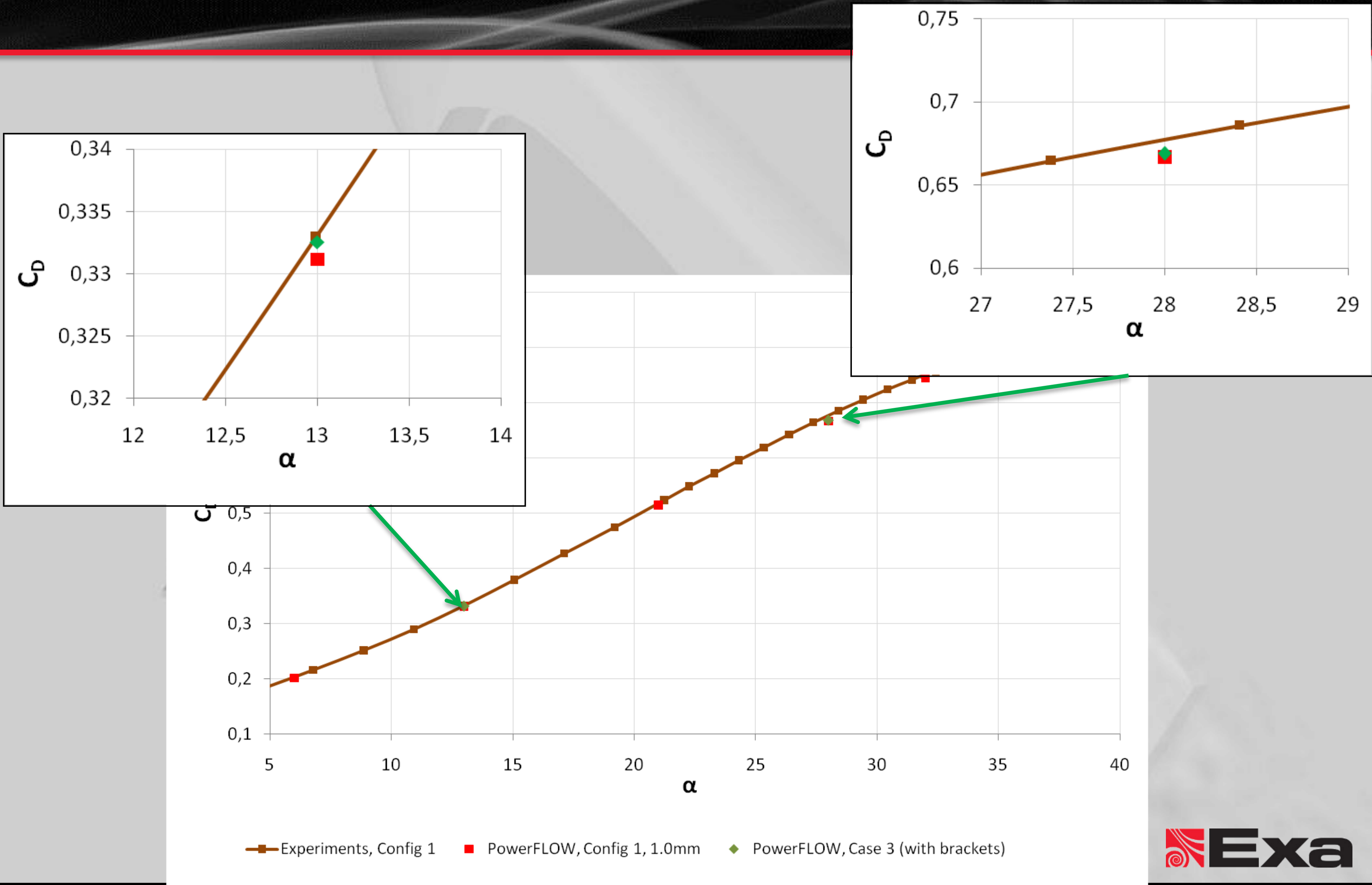
1st High Lift Prediction Workshop
http://hiliftpw.larc.nasa.gov/index-workshop1.html



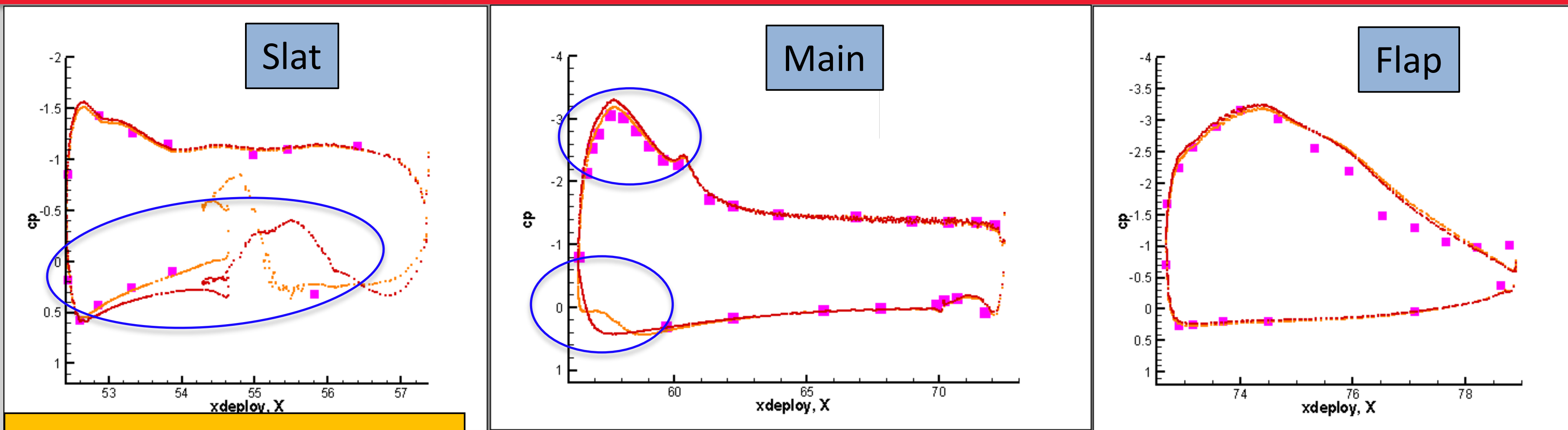
Results – Brackets influence



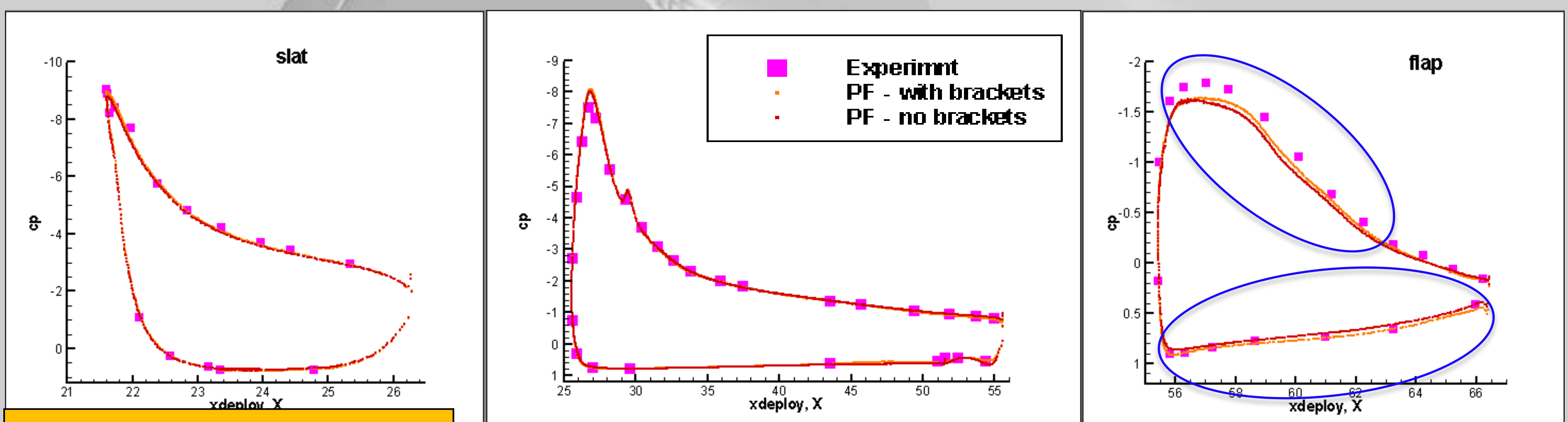
Results – Brackets influence



Results – Brackets sensitivity



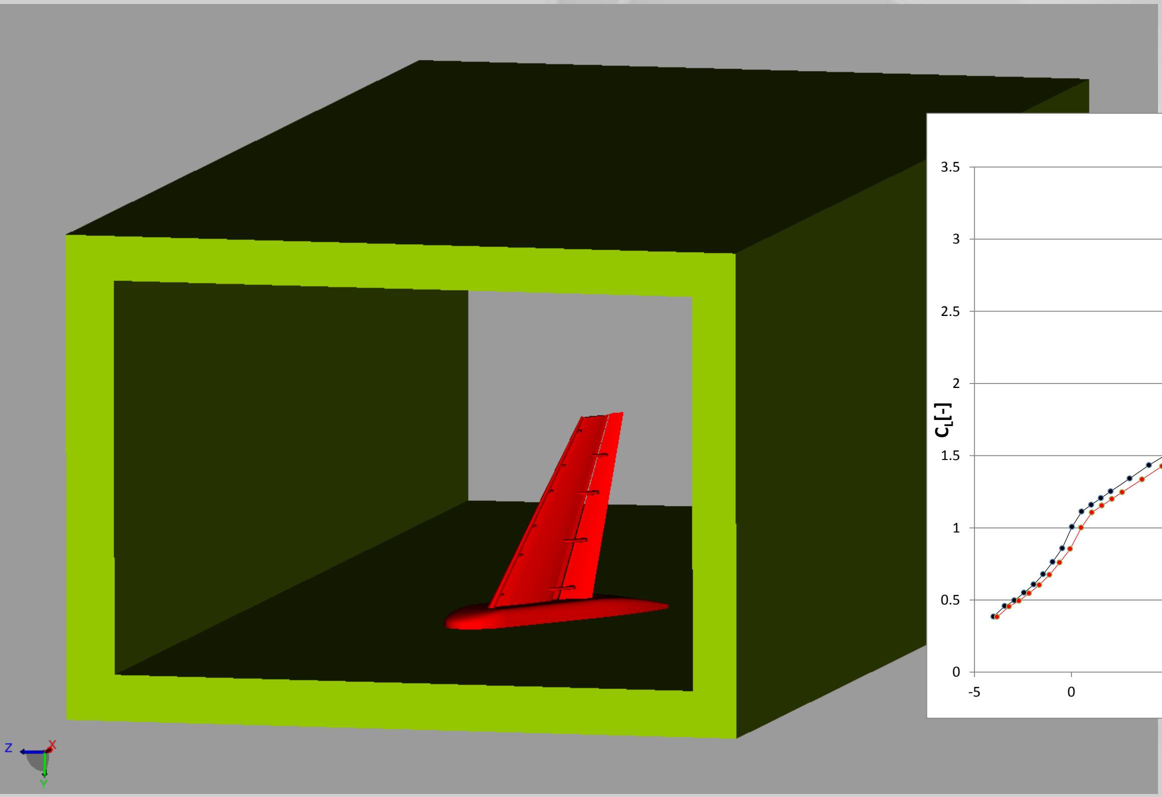
α=13º, Config1, 95% span

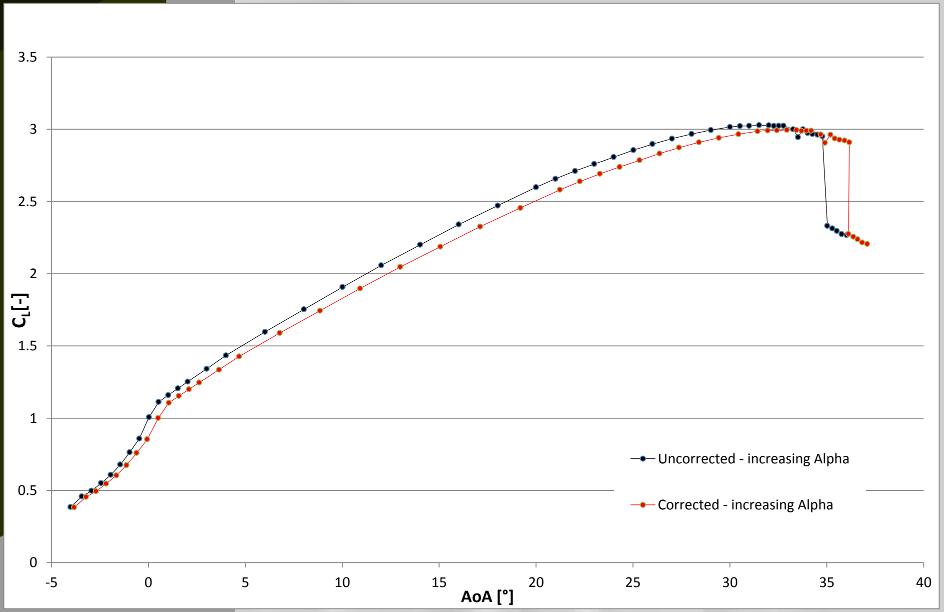


α=28º, Config1, 41% span

Results – Blockage effect

Unsteady Flow simulation of a High Lift Configuration using a Lattice Boltzmann Approach
AIAA 2011 – 0869

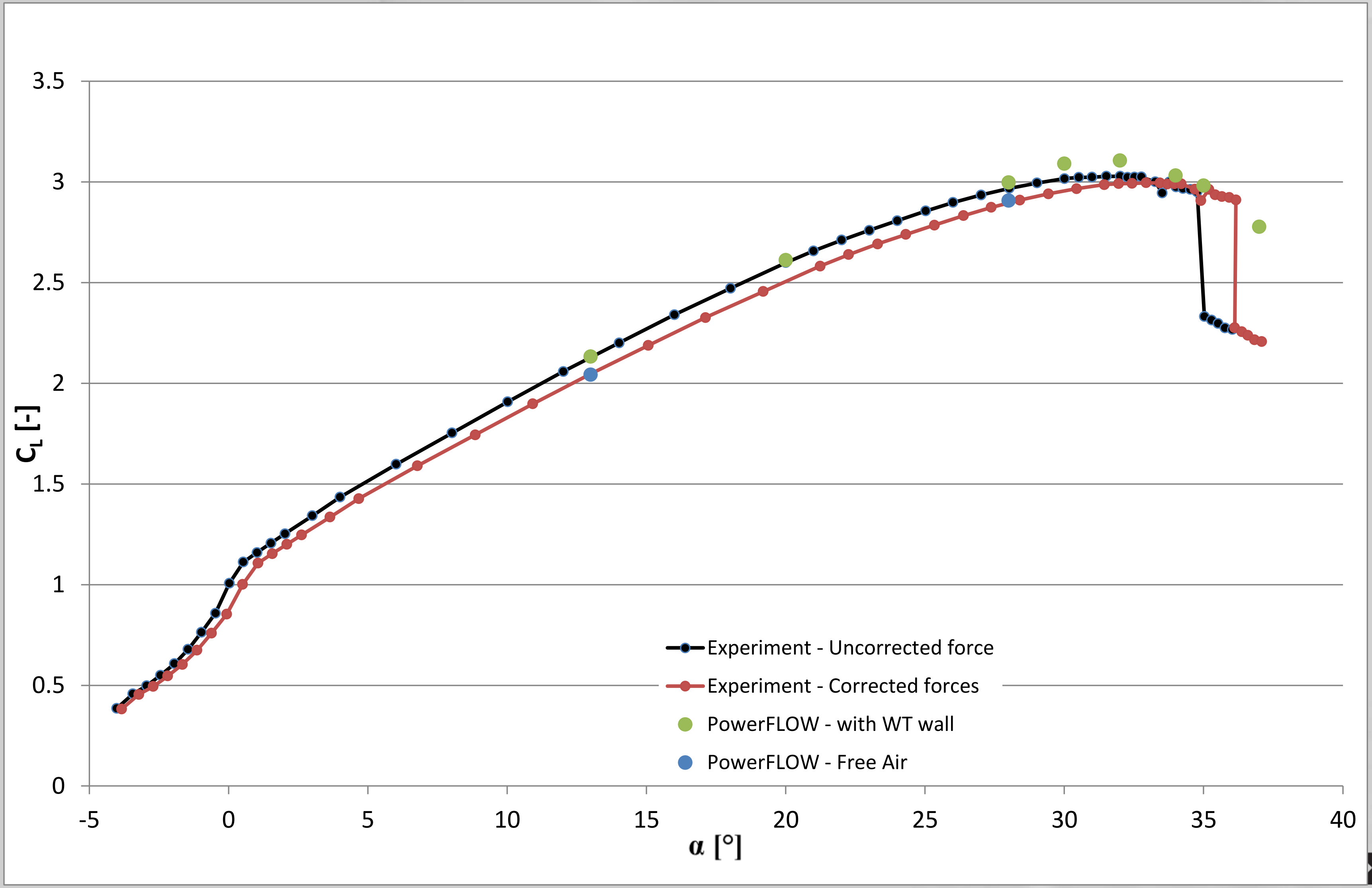




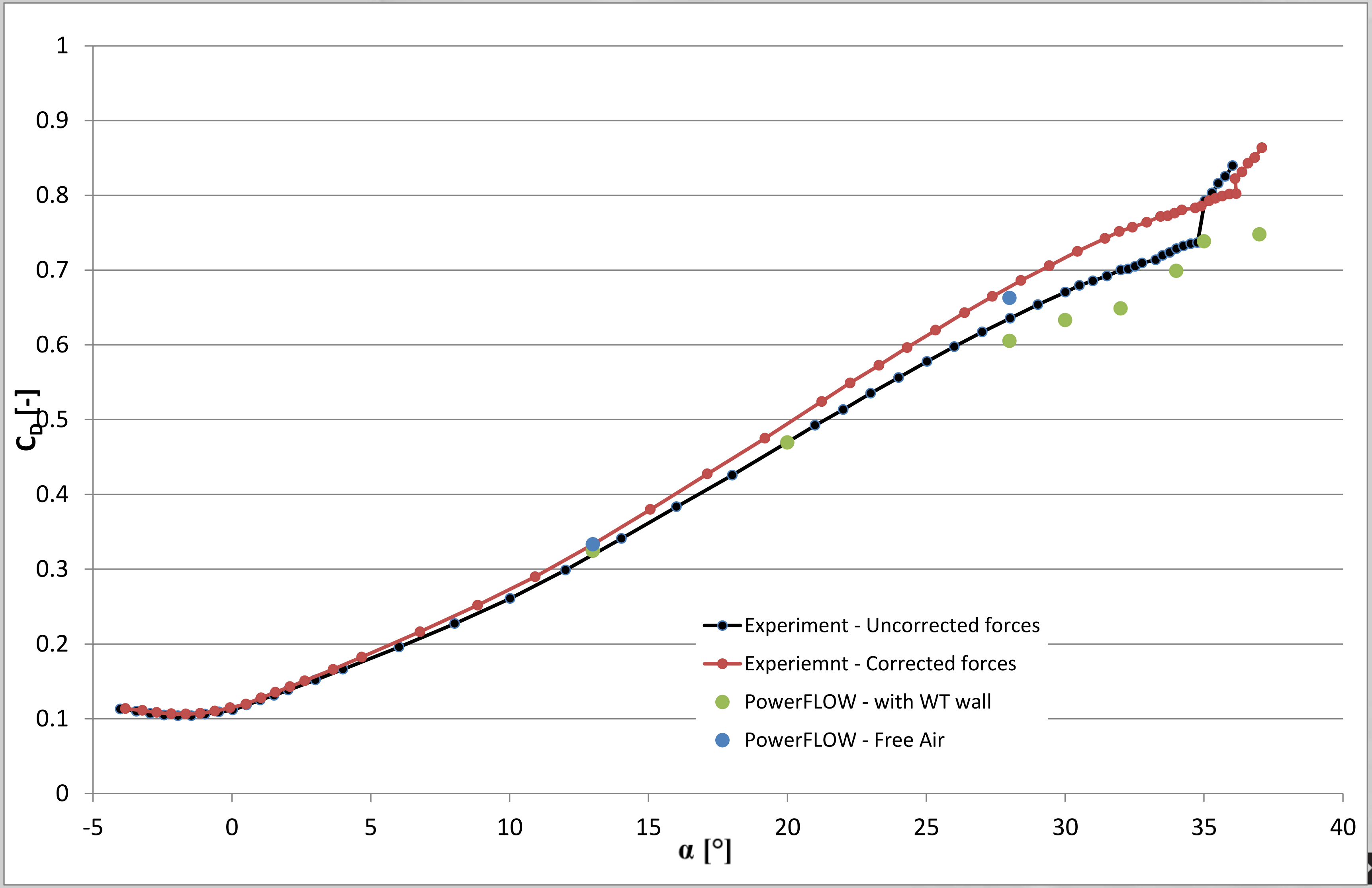
Experimental lift polar

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

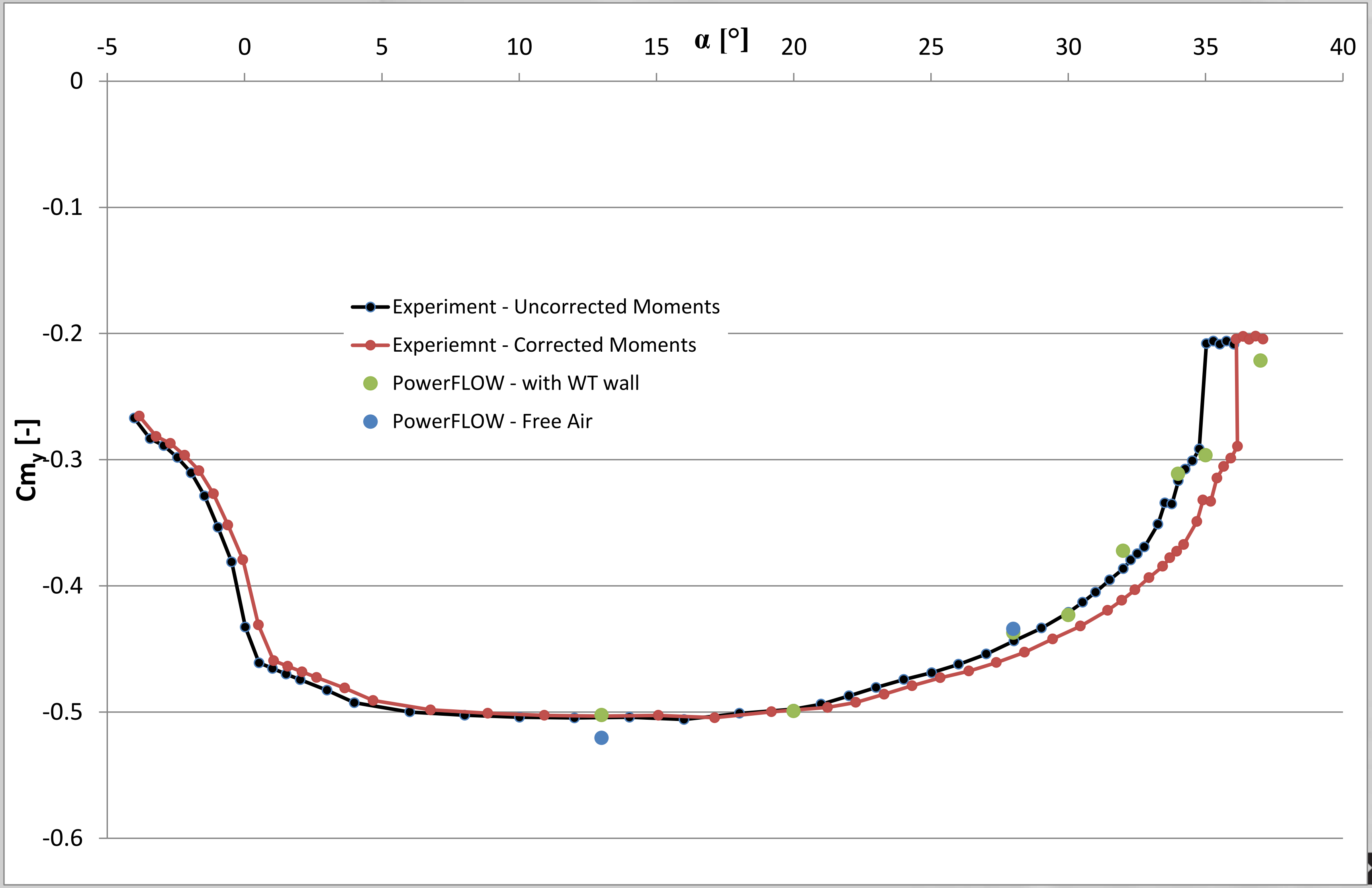
Results - Blockage Effects - Lift



Results - Blockage Effects - Drag

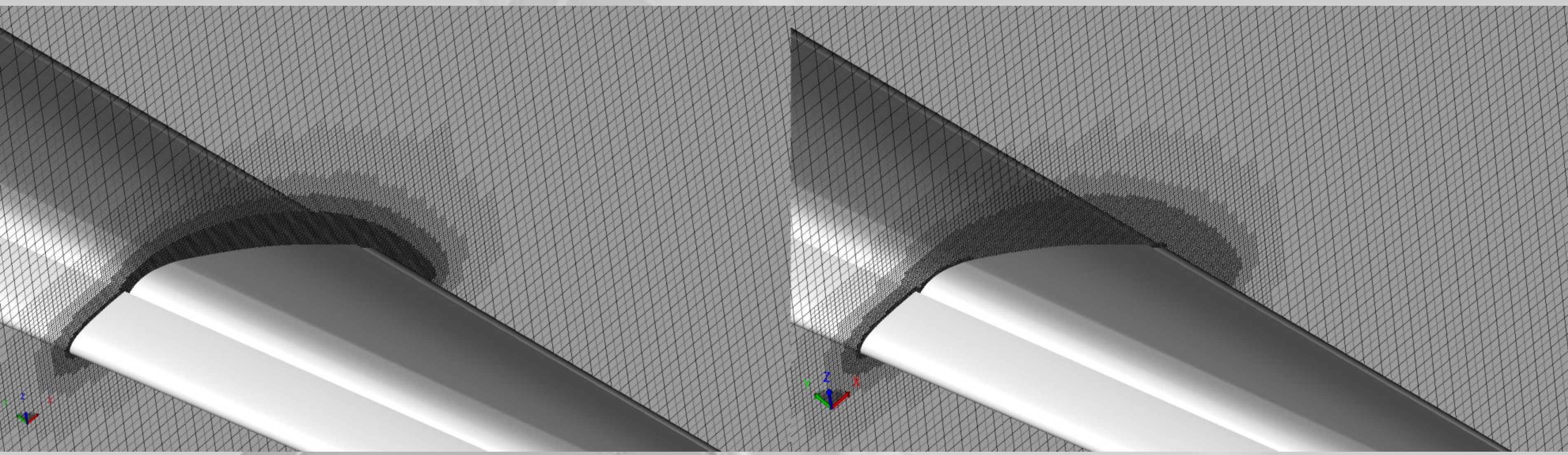


Results - Blockage Effects - Pitching Moment



Simulation Overview – Meshes

Setup 1 | **Setup 2**

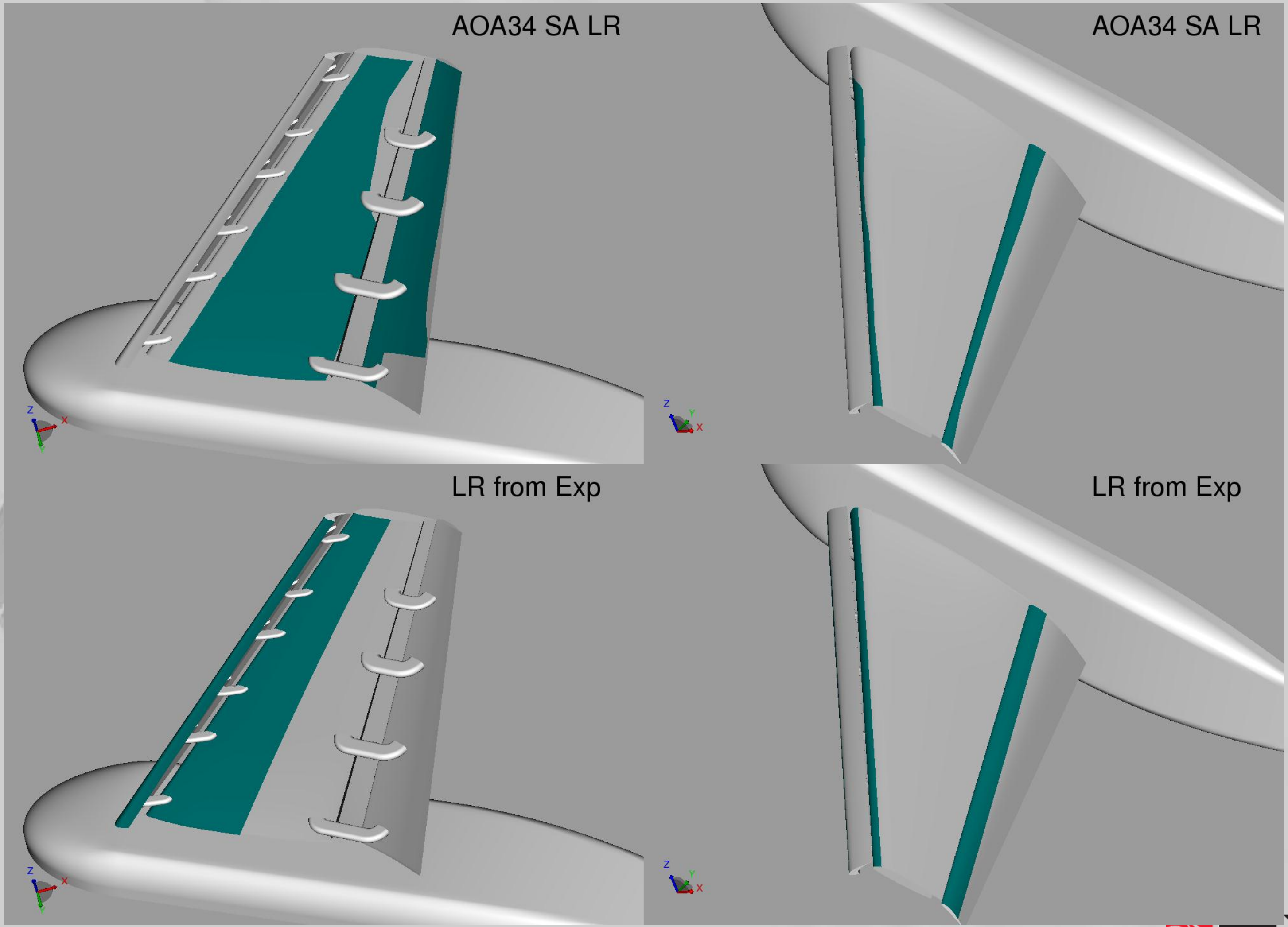


	Setup1	Setup 2
Finest voxel size	1.25mm	1.25mm
Total number of Voxels	127 million	79 million
CPU-Hours	16,000	12,000

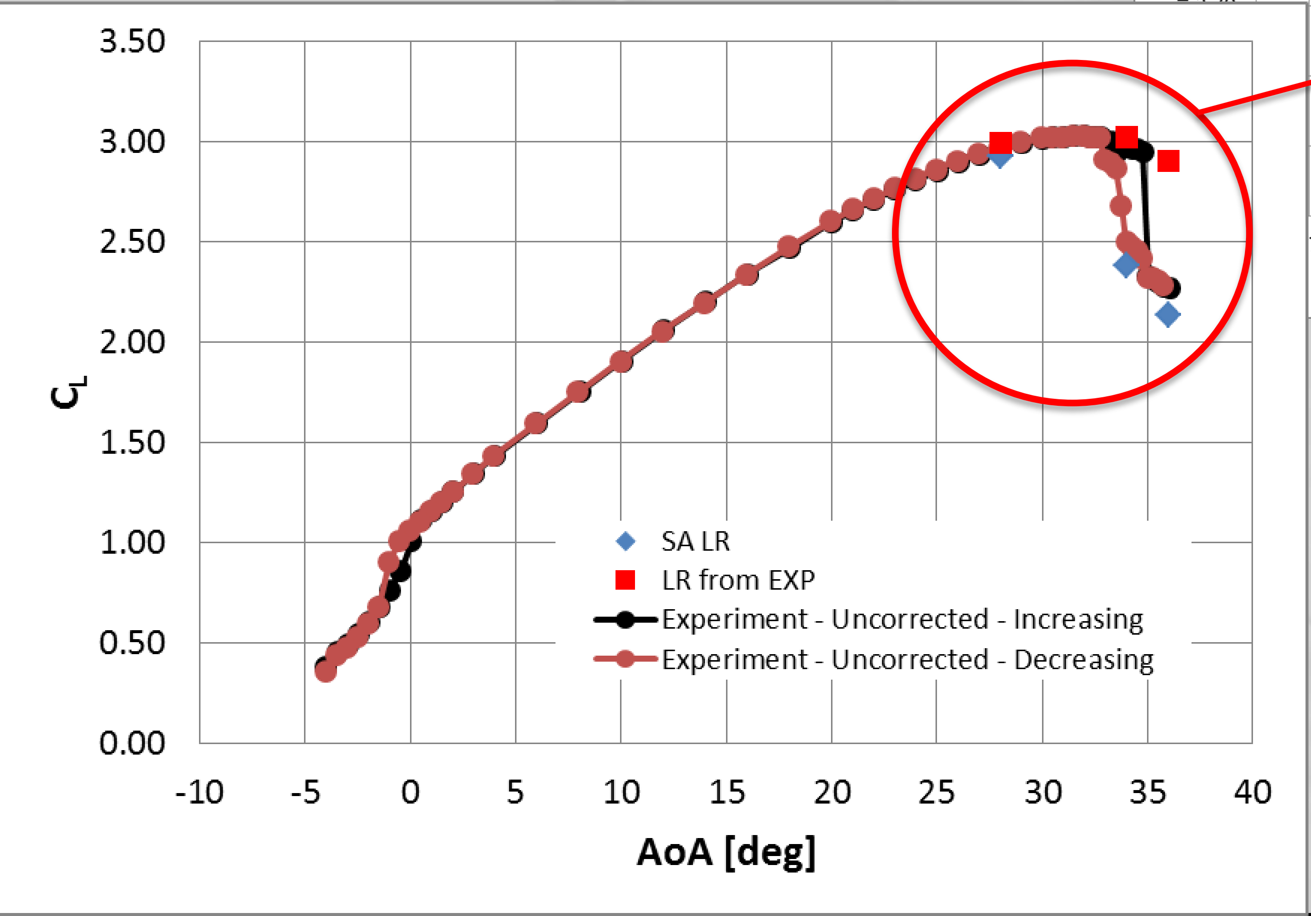
Results – Sensitivity to laminar regions

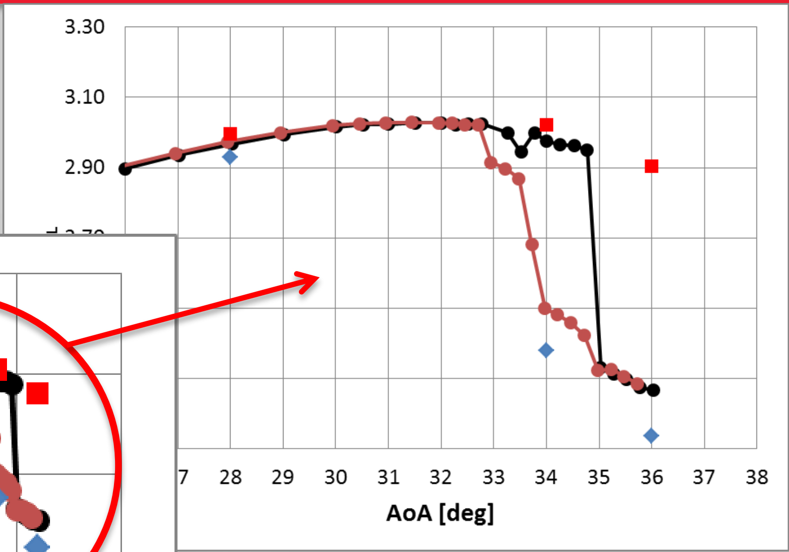
Stability analysis Laminar Regions

Laminar regions from Experiment



Results – Sensitivity to LR – Lift



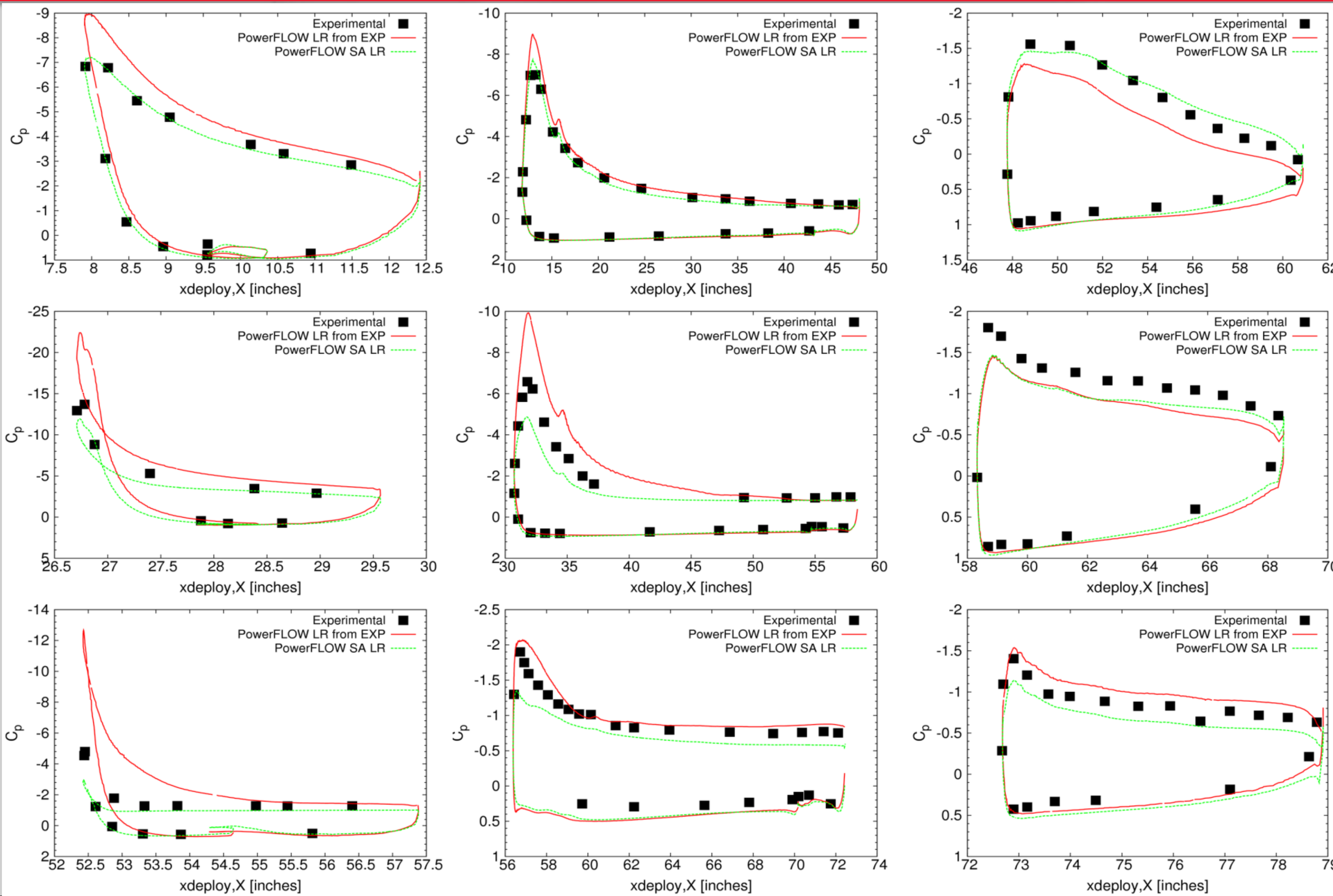


Results – Sensitivity to LR – AoA 36°

η = 17%

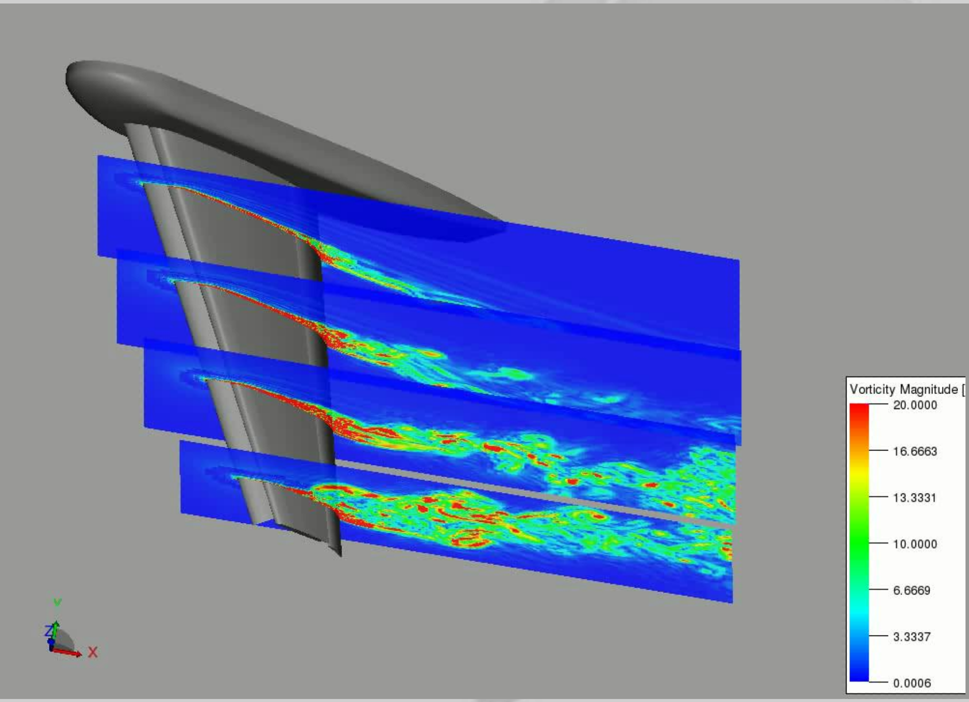
η = 50%

η = 95%

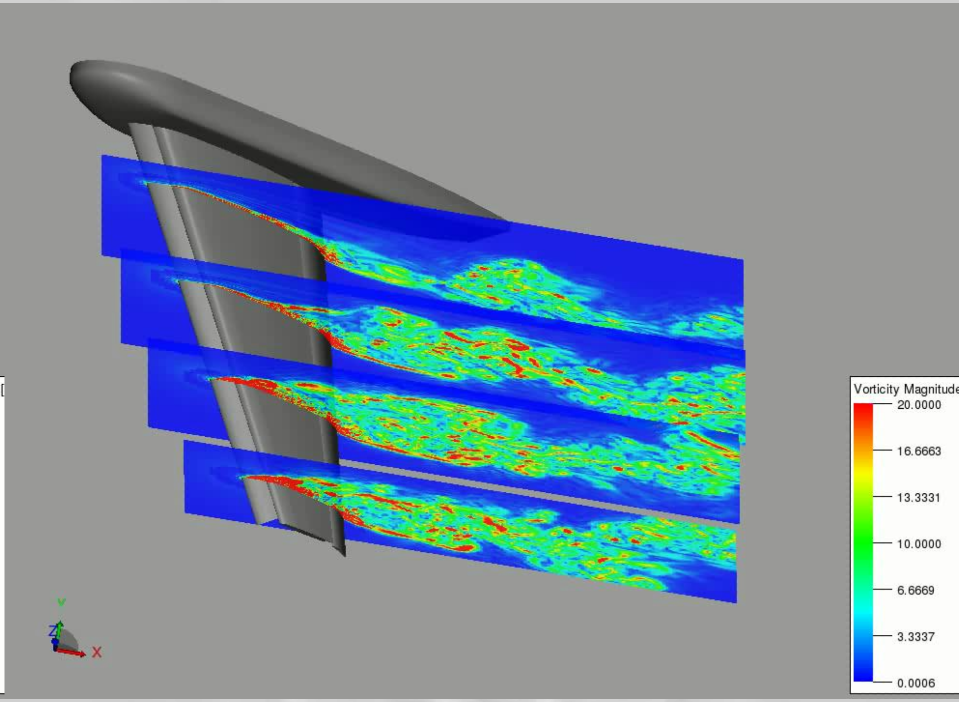


Results – Sensitivity to LR – AoA 36°

LR from Experiment



SA Laminar Regions

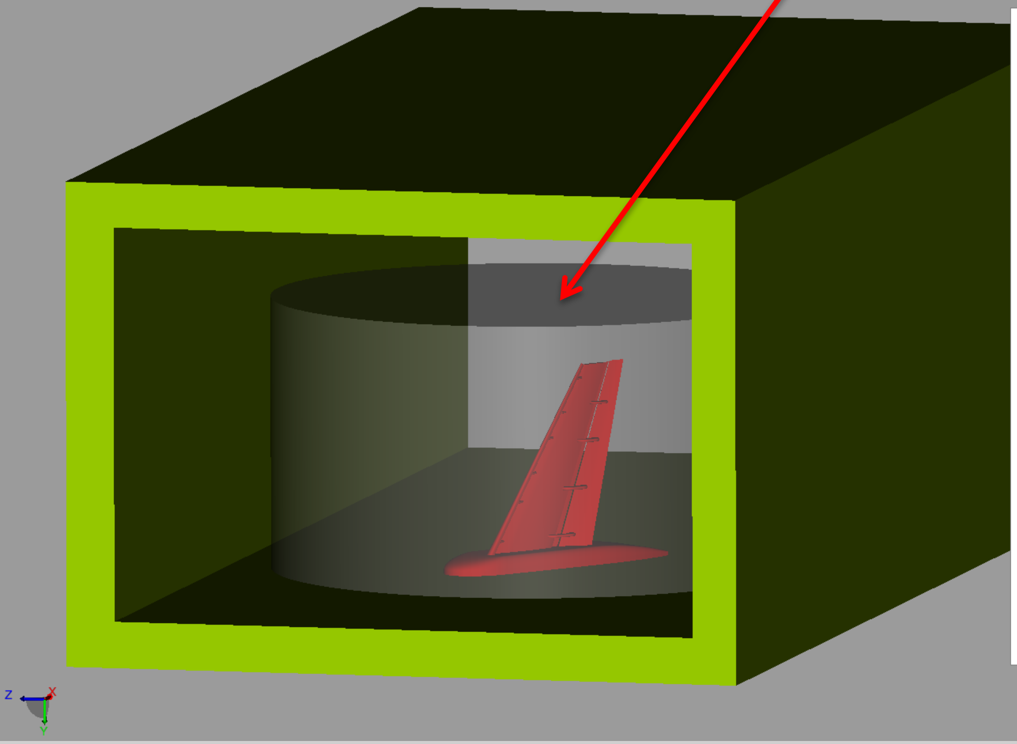


Results – hysteresis effect

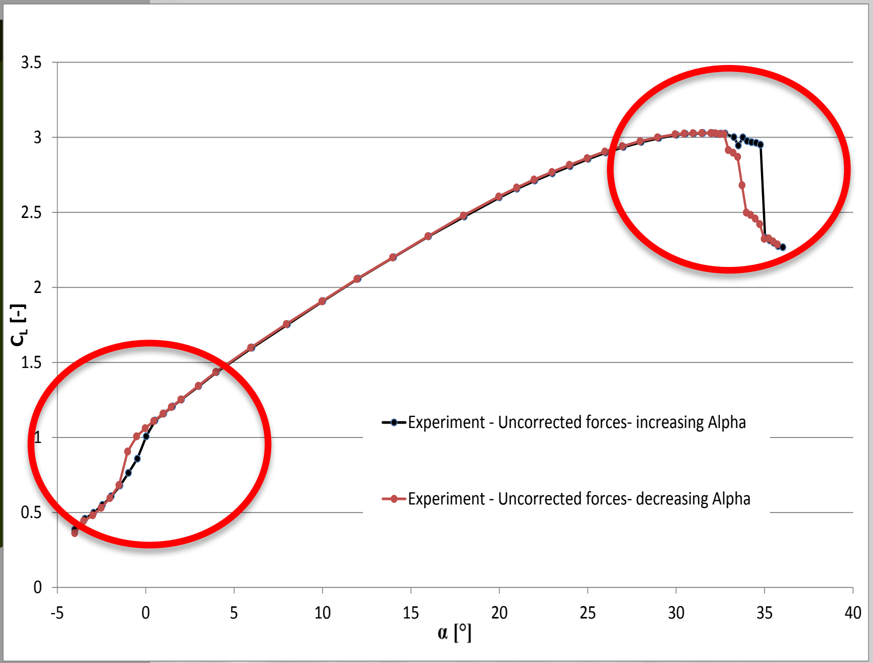
Rotation zone used to pitch the trapwing with an LBM specific sliding mesh approach

Lattice Boltzmann approach for local reference frames

Commun. Comput. Phys Vol. 9, No. 5, May 2011



Model of TrapWing (with brackets) in the NASA Langley WT
Used in the present simulations

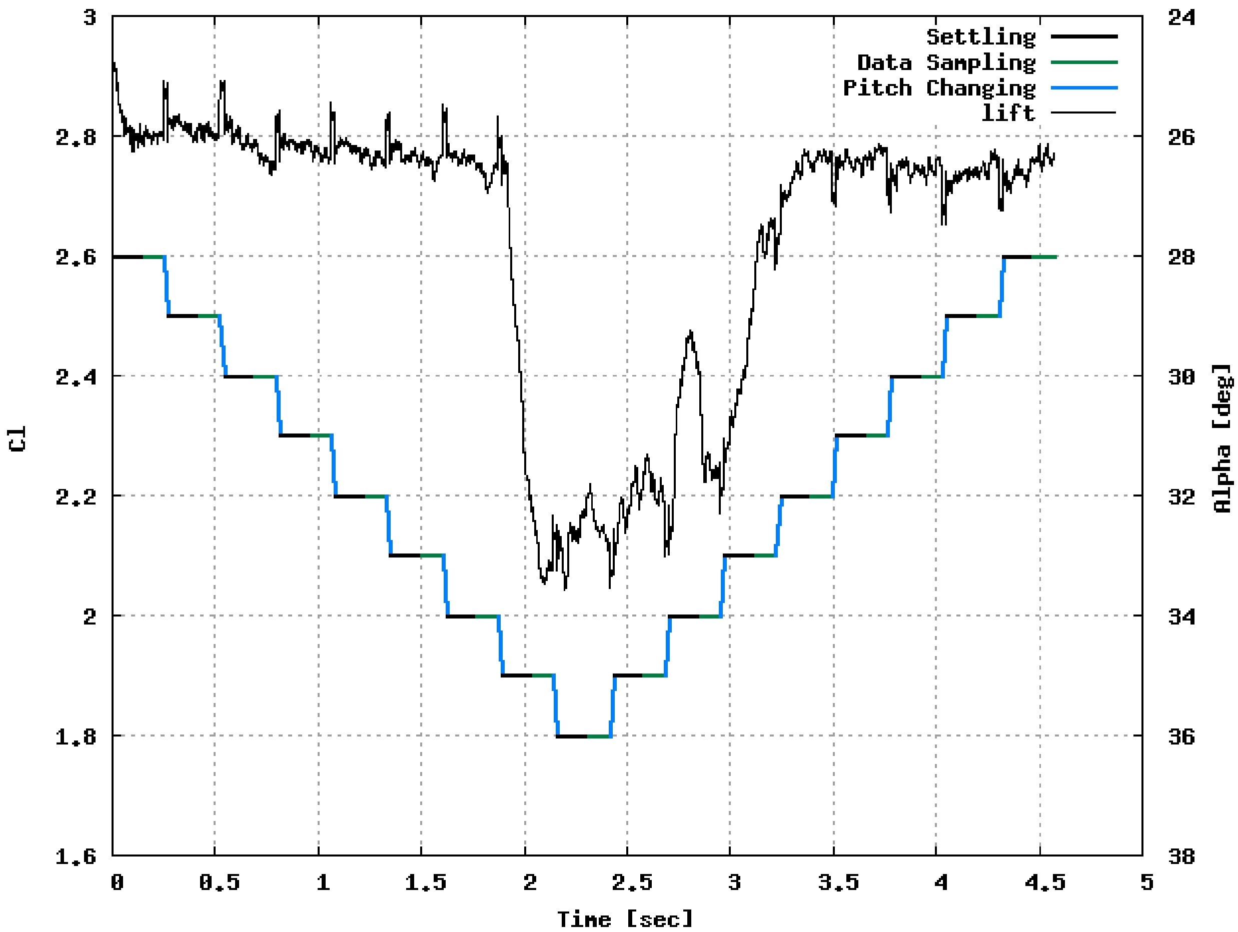


Experimental lift polar.
Hysteresis effect

Results – hysteresis effect

	Coarse case	Fine case
Finest voxel size	1.875mm	1.25mm
Total number of Voxels	37 million	79 million
Total number of Surfels	5.4 million	9 million
Total number of Timesteps	1,454,700	3,313,660
Physical time	4.570s	5.280s
Covered AoA range	28° – 36° – 28°	32° – 36° – 32°
CPU-Hours	54,200	166,000

Results – hysteresis effect – Coarse case



Coarse case

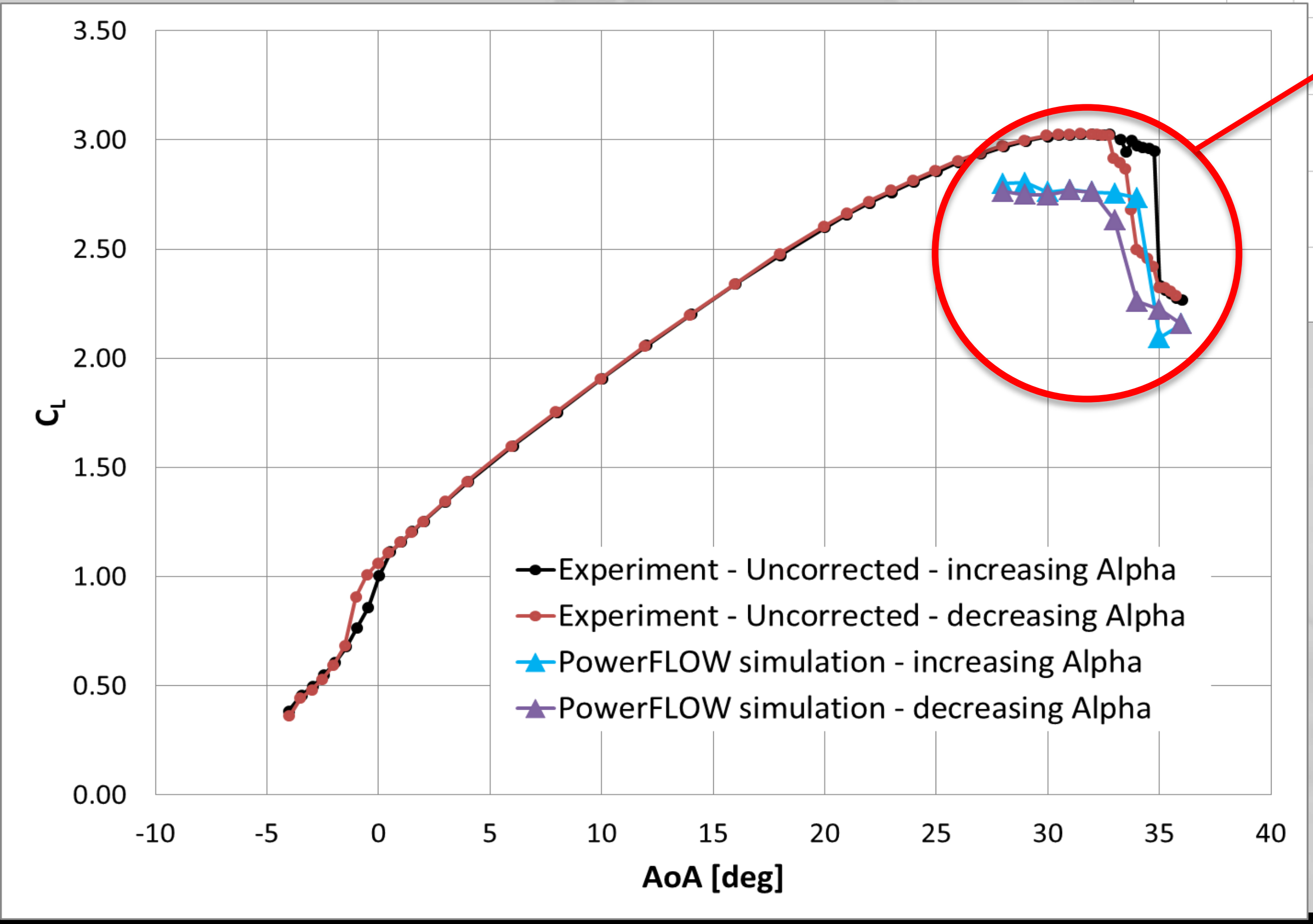
α=28°-36°-28° in 1° steps

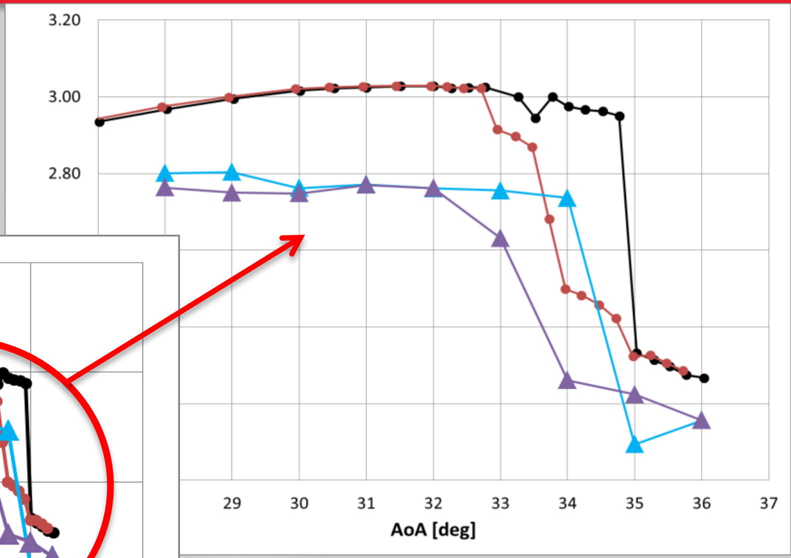
Initialized from steady 28°

0.27s per 1°

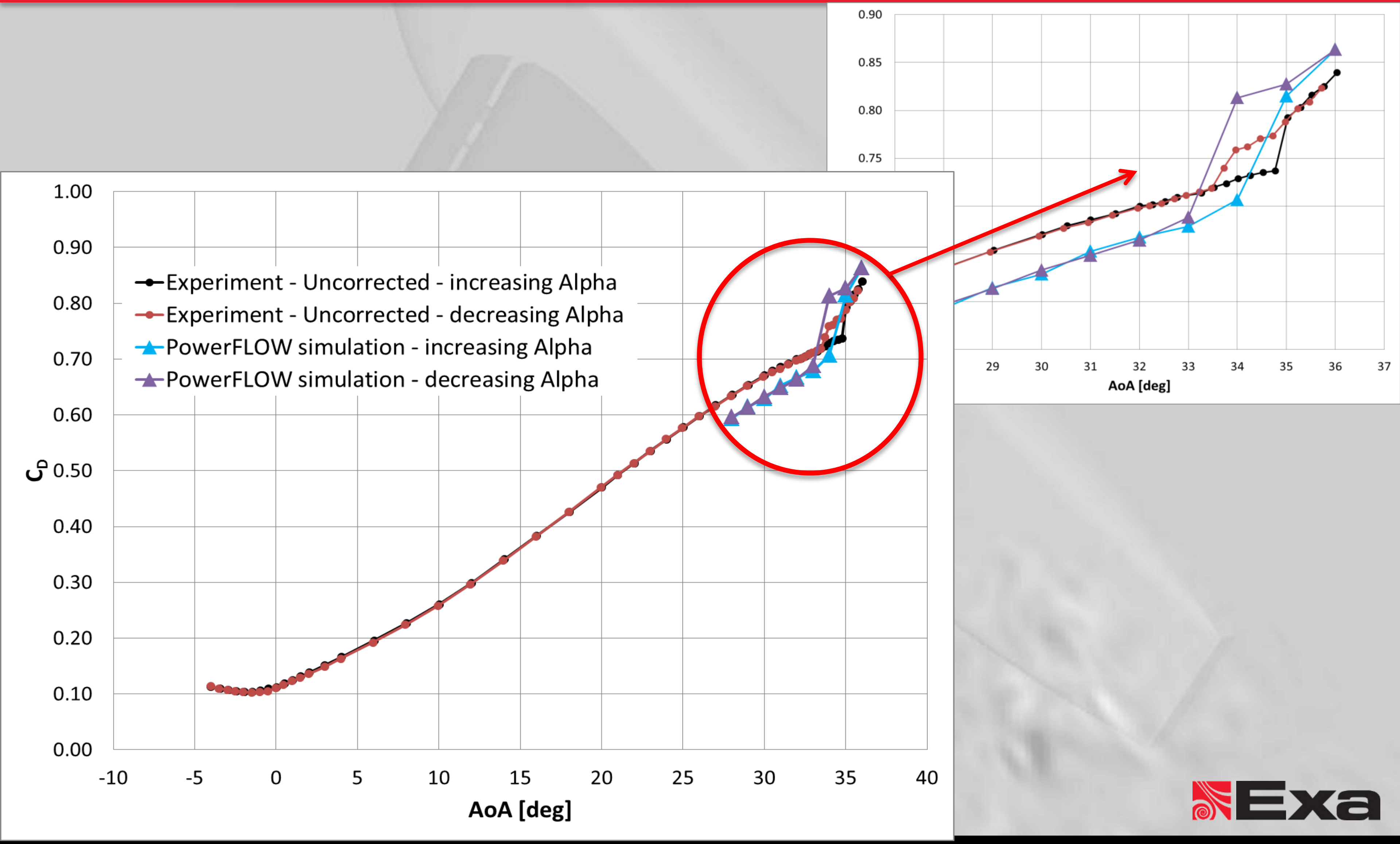
(0.02s rotating, 0.15s settling & 0.1s sampling)

Results – hysteresis effect – Coarse case



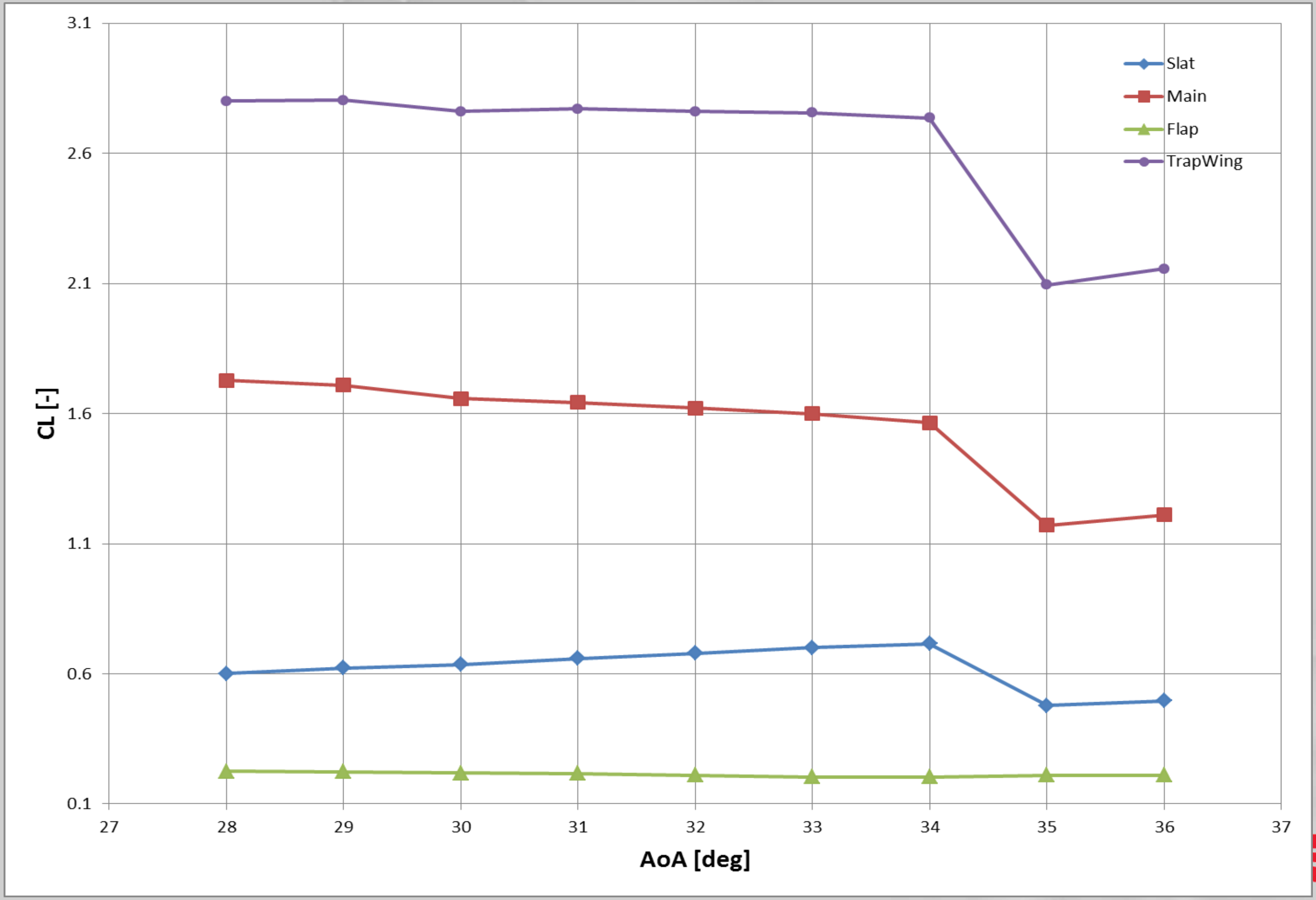


Results – hysteresis effect – Coarse case



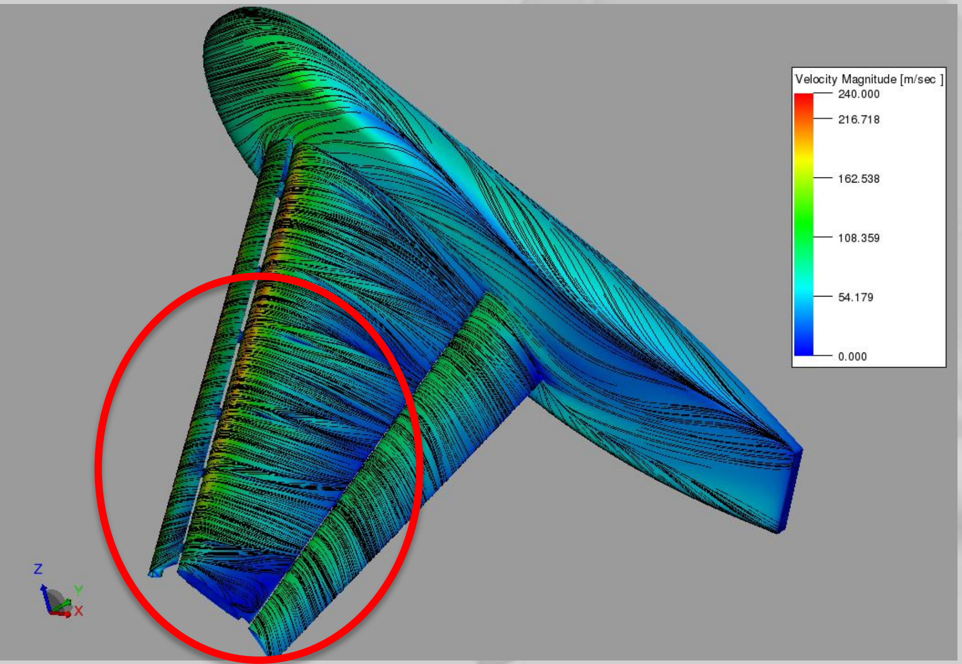
Results – hysteresis effect – Coarse case

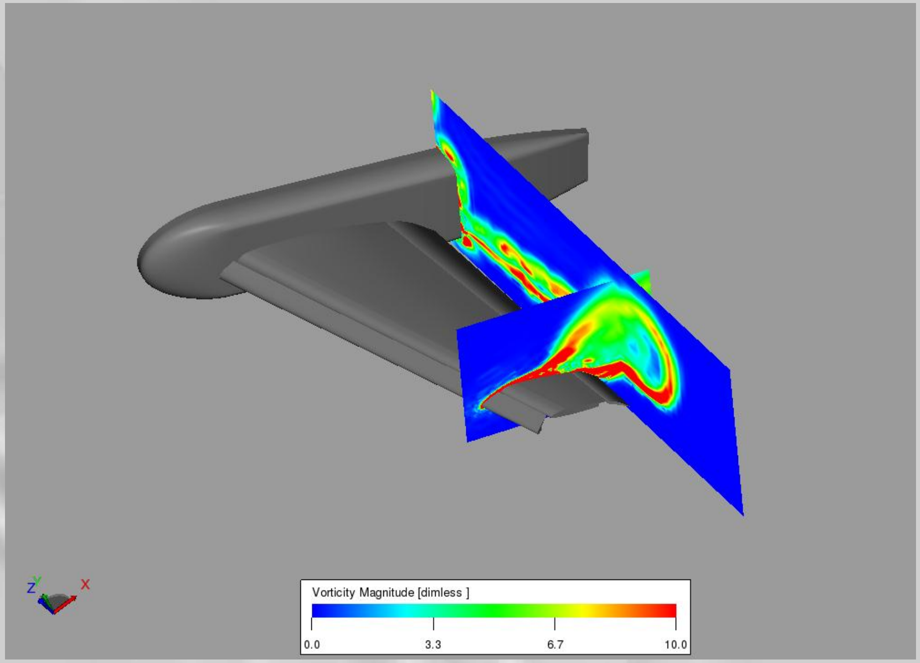
Stall sequence



Results – hysteresis effect – Coarse case

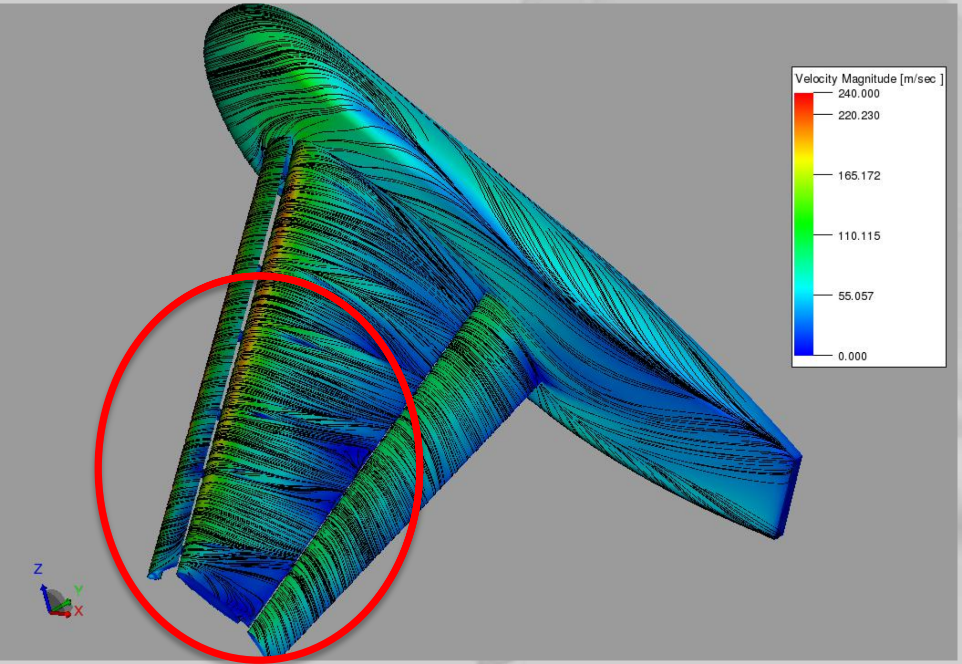
Stall sequence - AoA 33°

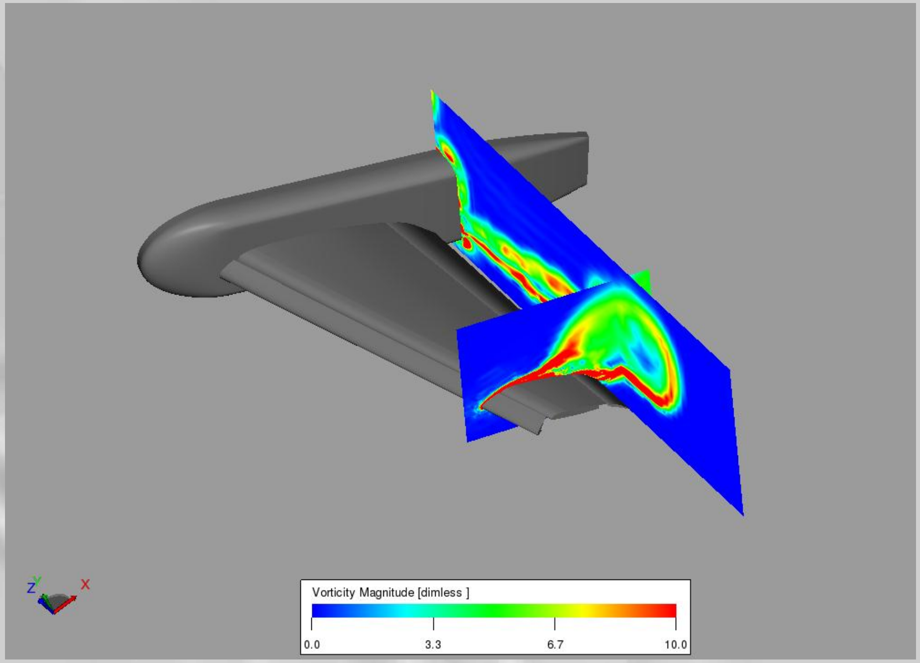




Results – hysteresis effect – Coarse case

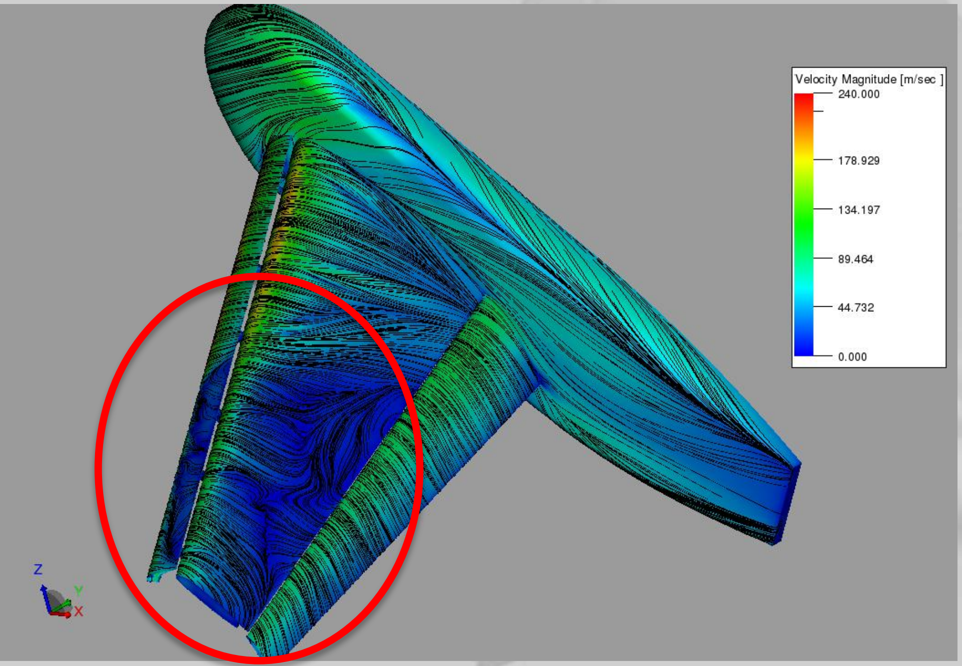
Stall sequence - AoA 34°

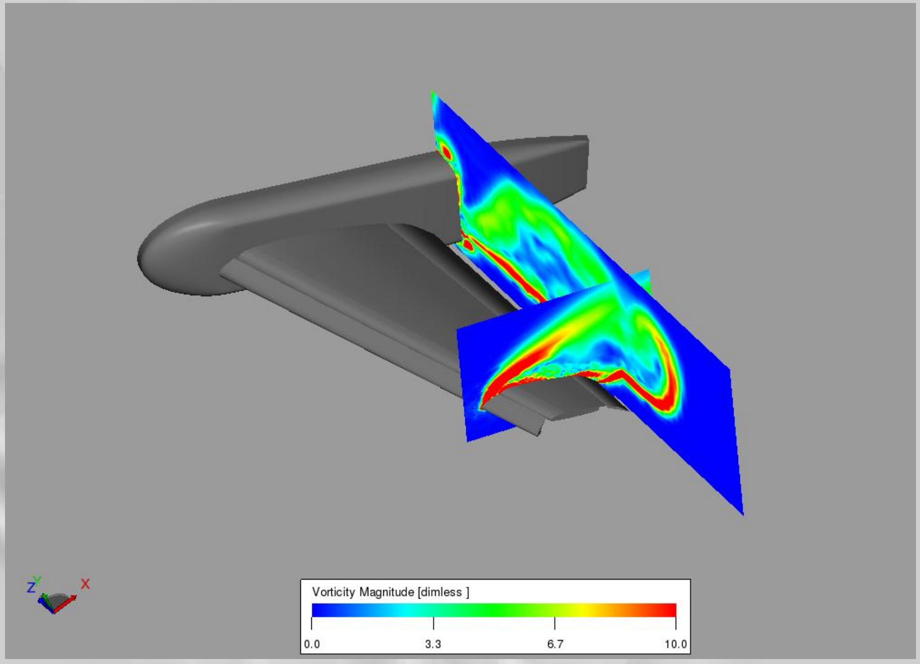




Results – hysteresis effect – Coarse case

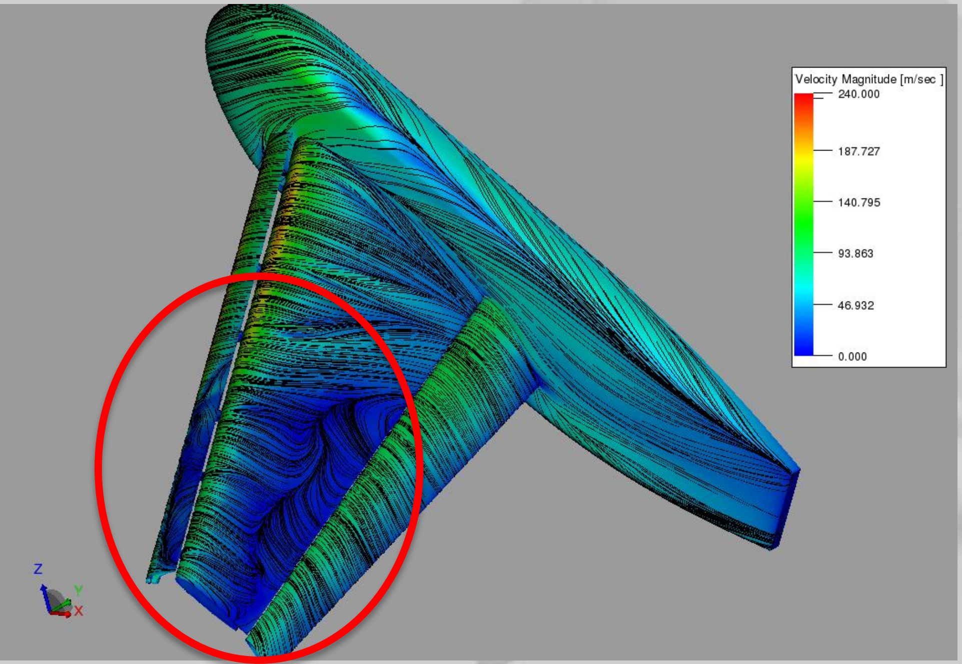
Stall sequence - AoA 35°

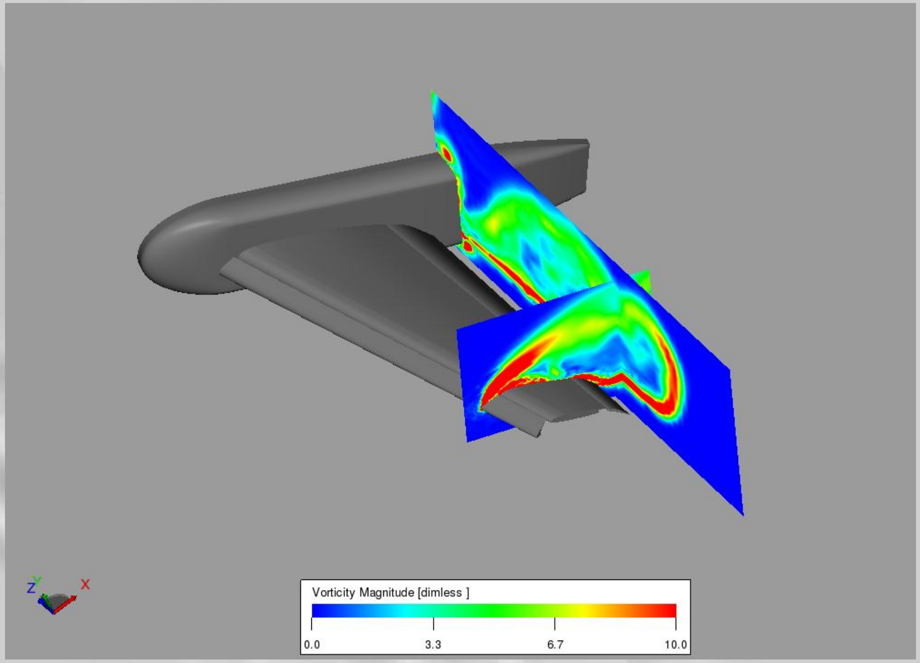




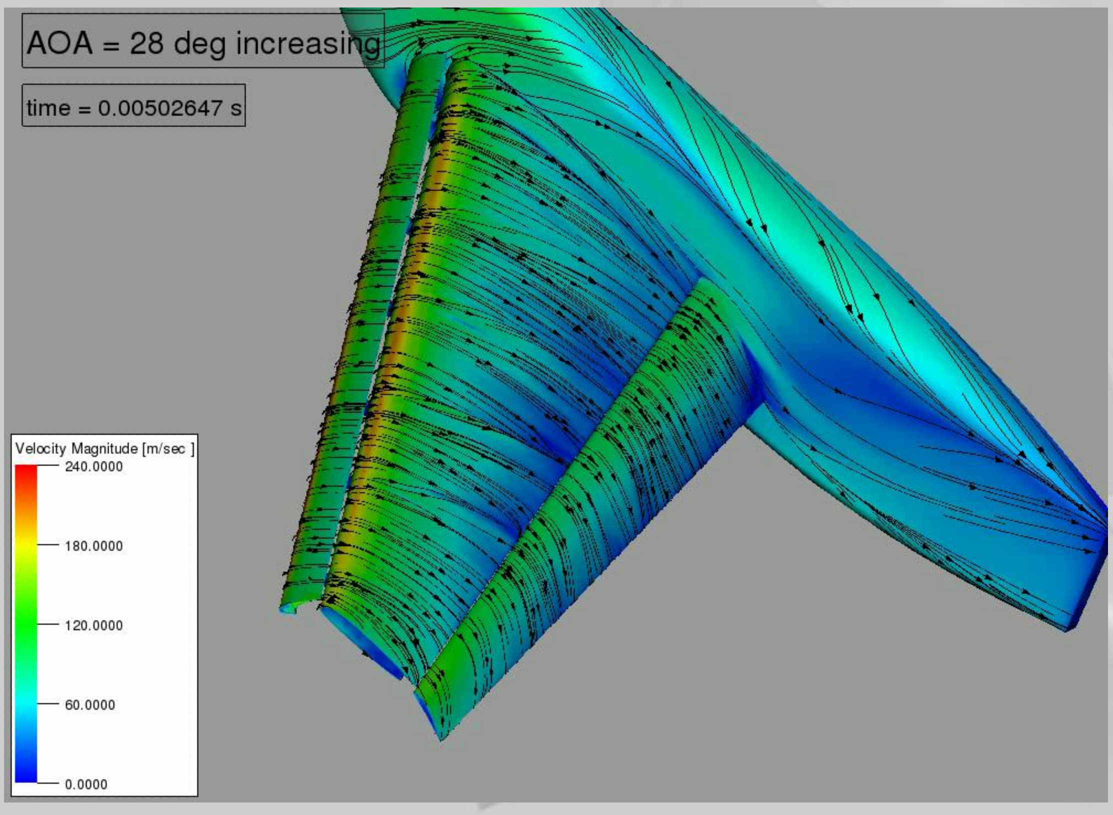
Results – hysteresis effect – Coarse case

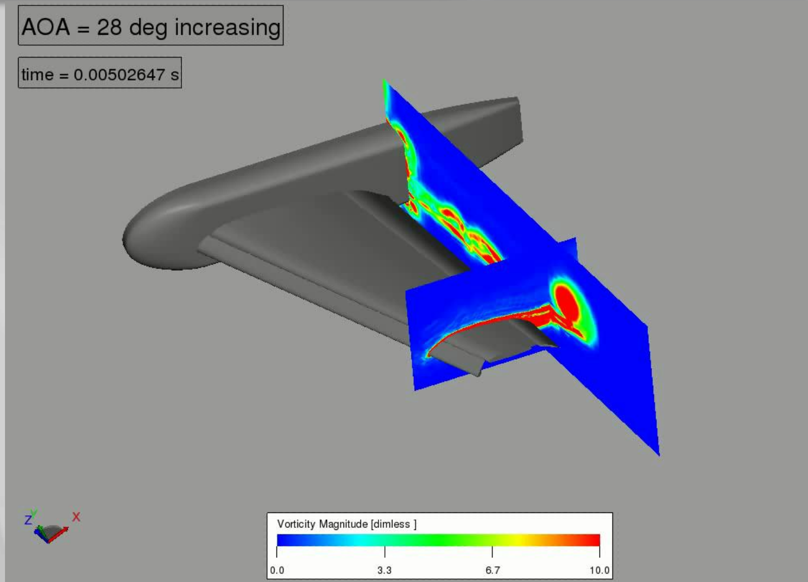
Stall sequence - AoA 36°

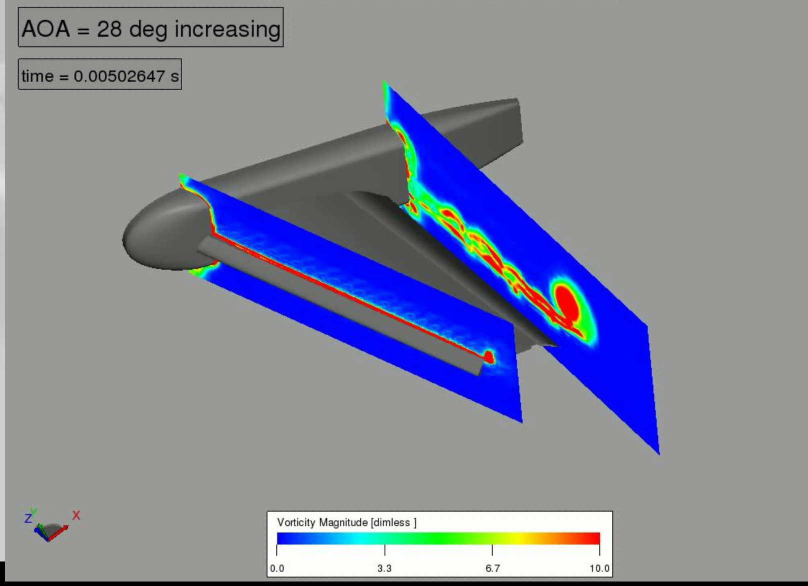




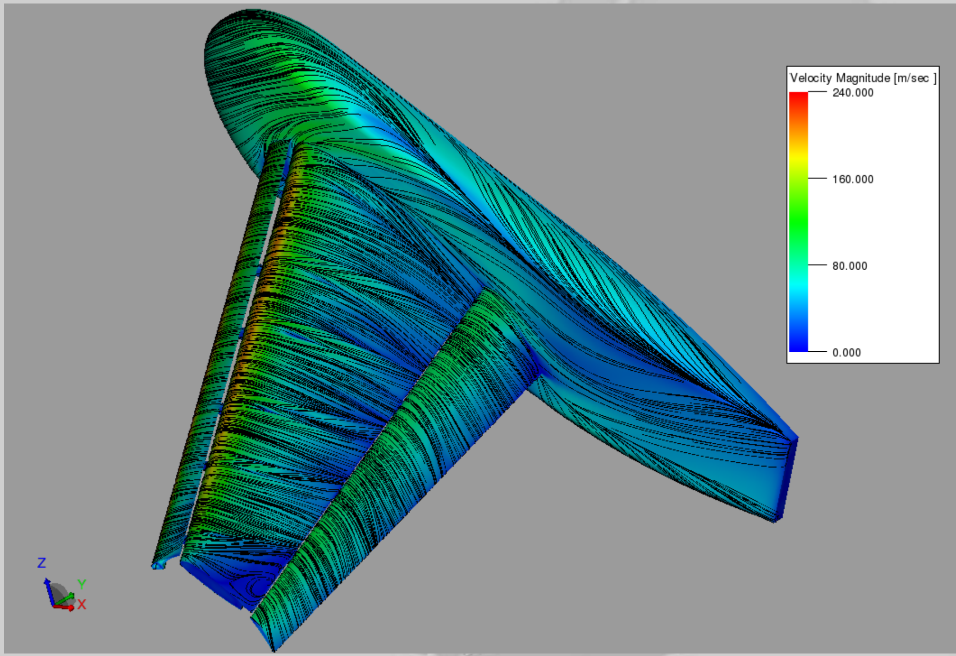
Results – hysteresis effect – Coarse case



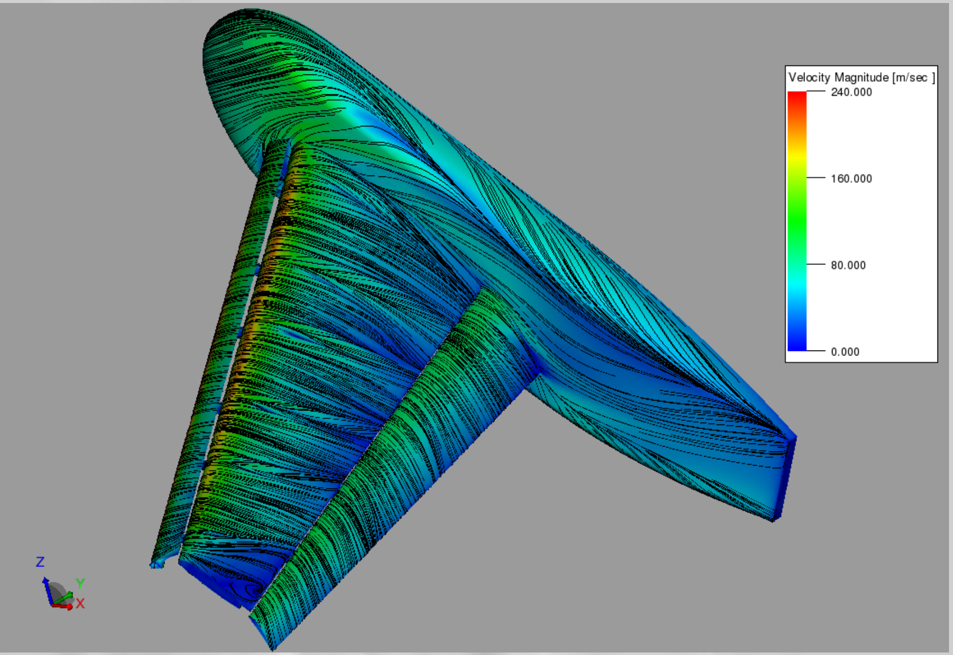




Results – hysteresis effect – Coarse case

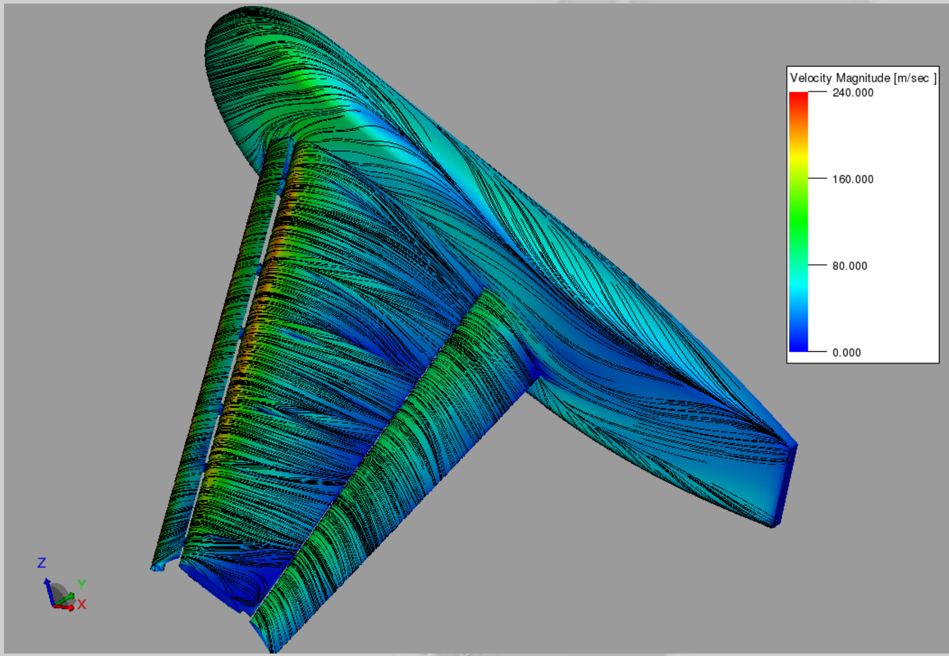


AoA 32 Increasing

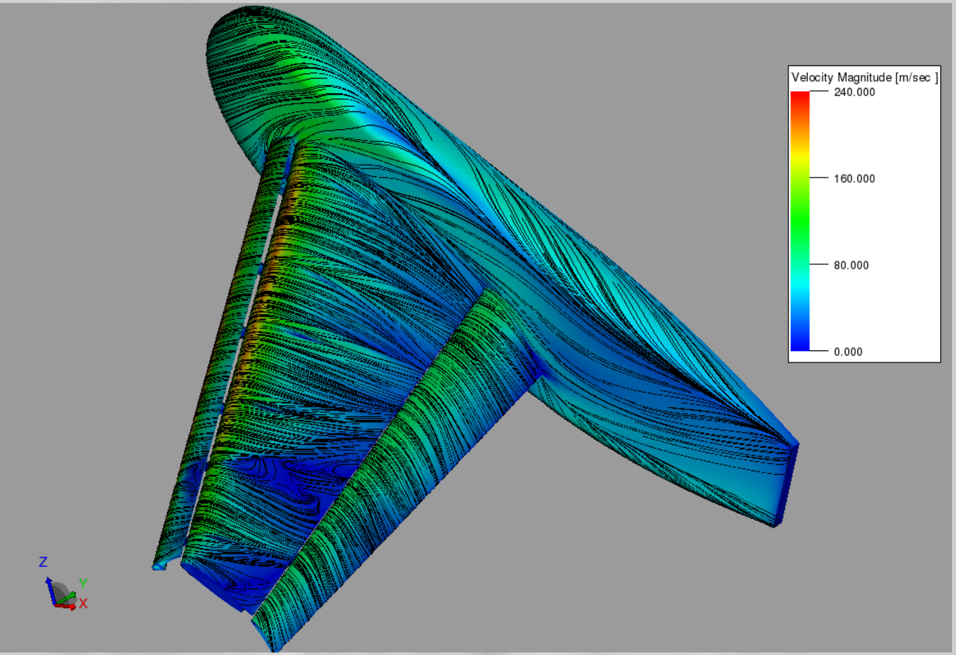


AoA 32 Decreasing

Results – hysteresis effect – Coarse case

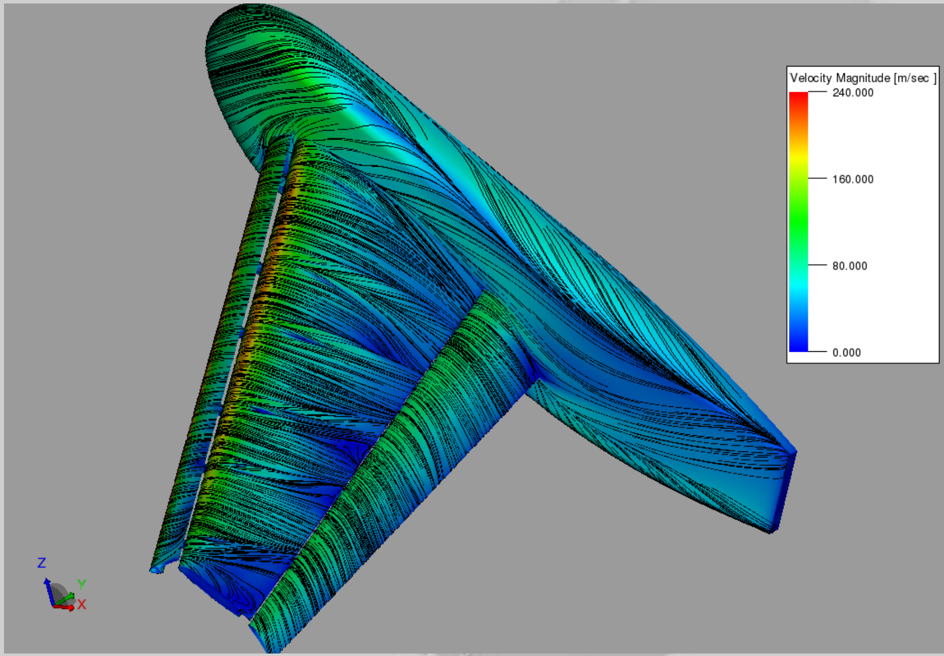


AoA 33 Increasing

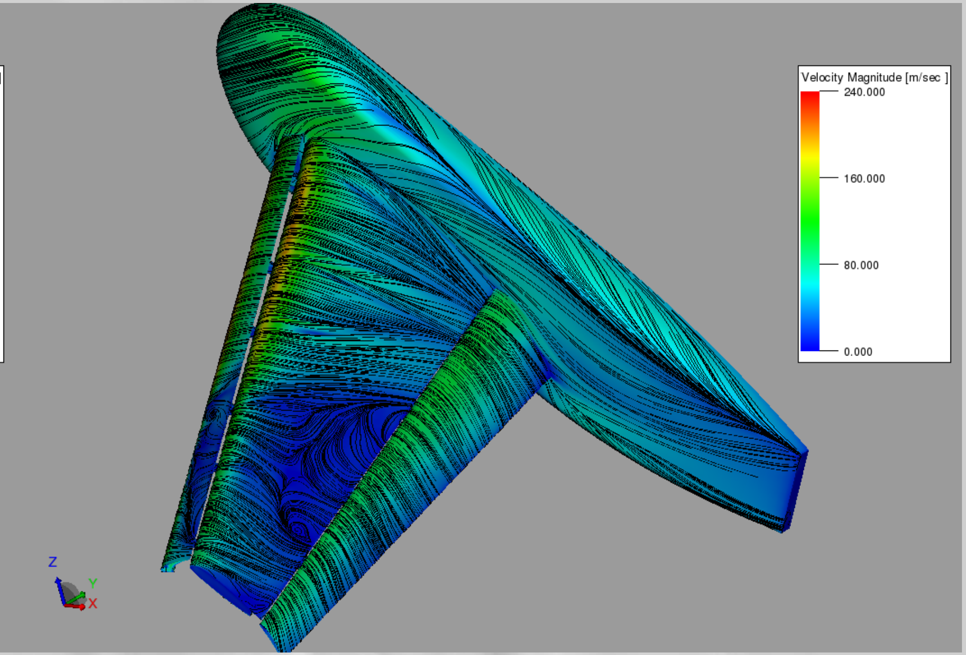


AoA 33 Decreasing

Results – hysteresis effect – Coarse case

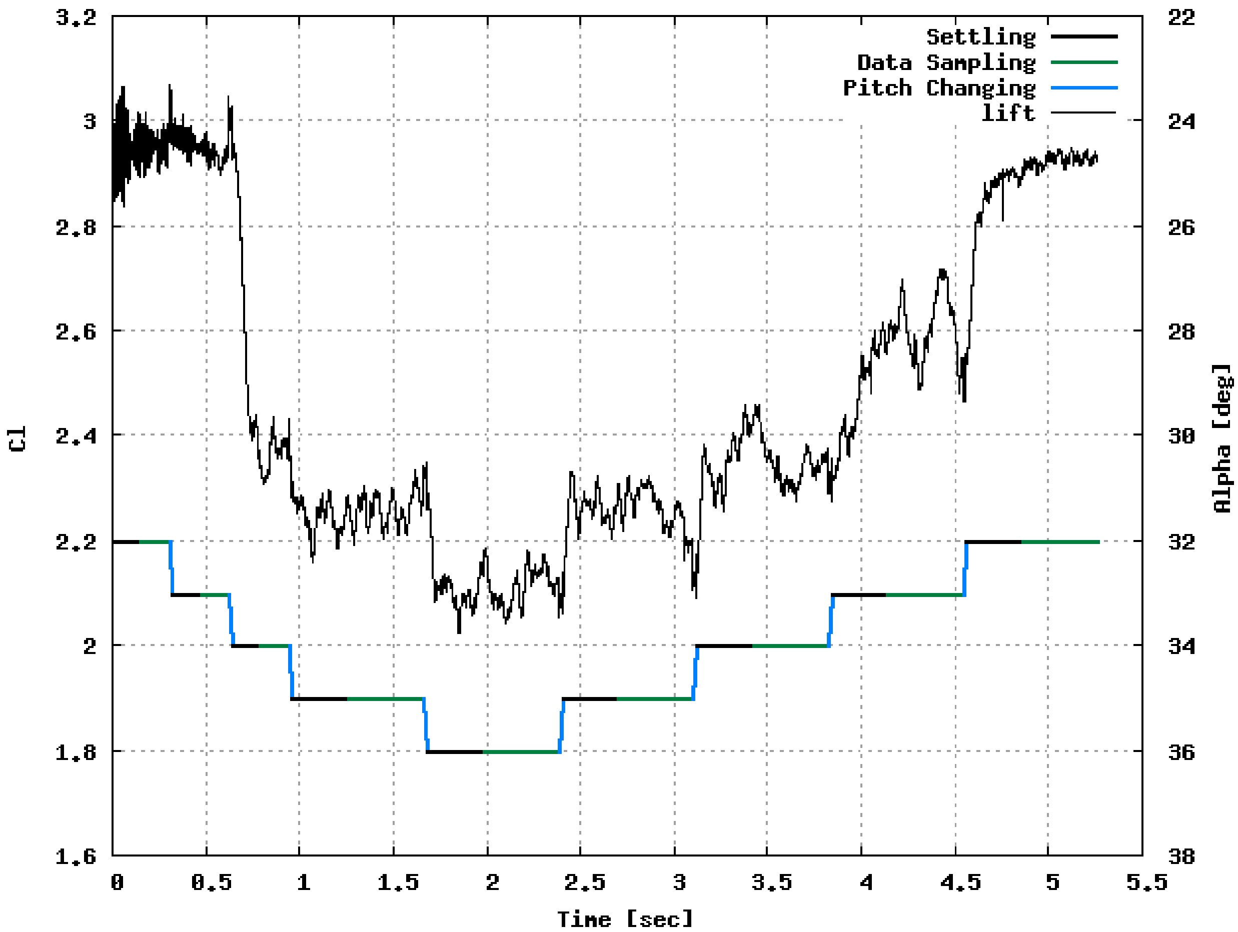


AoA 34 Increasing



AoA 34 Decreasing

Results – hysteresis effect – Fine case



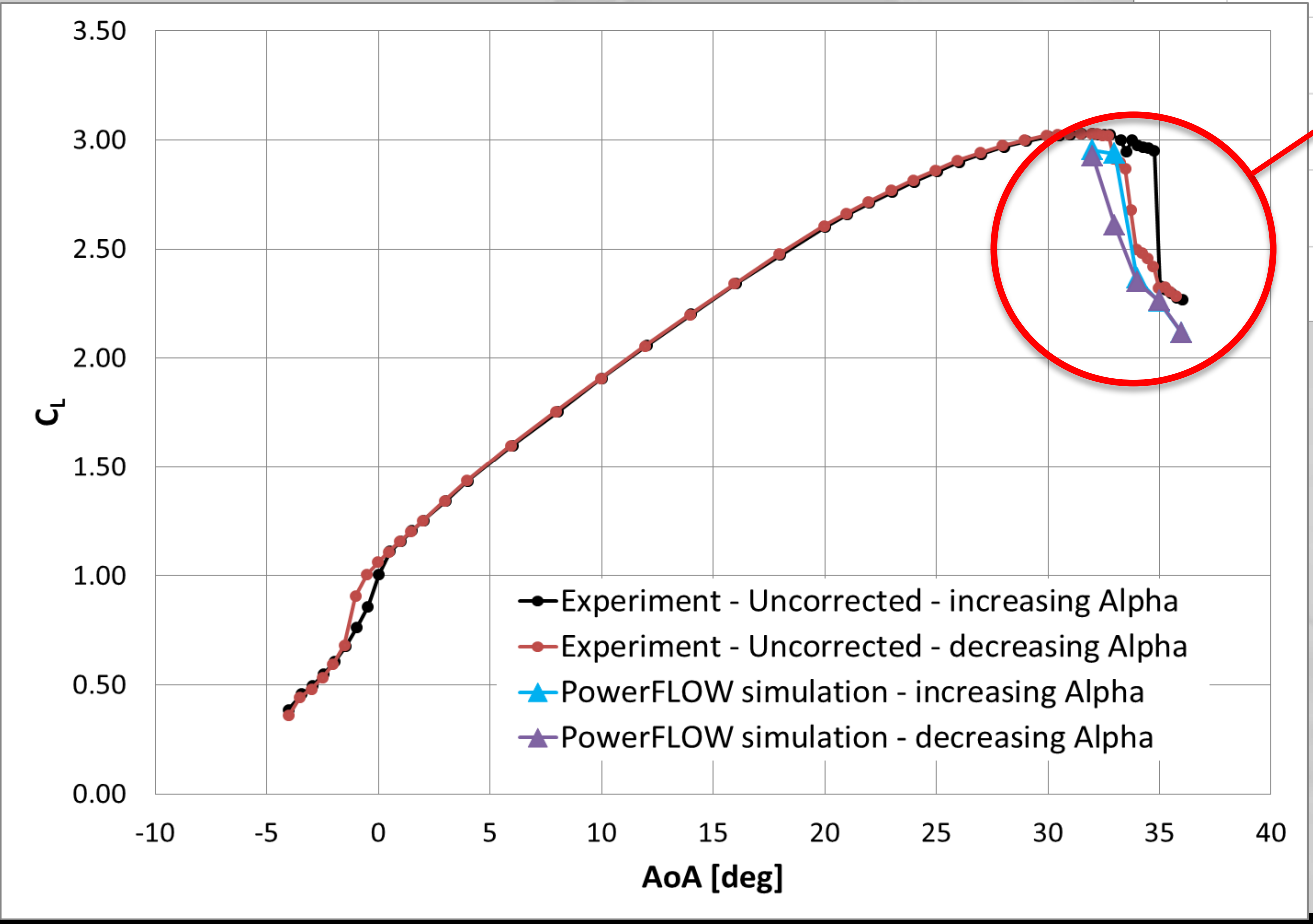
Fine case

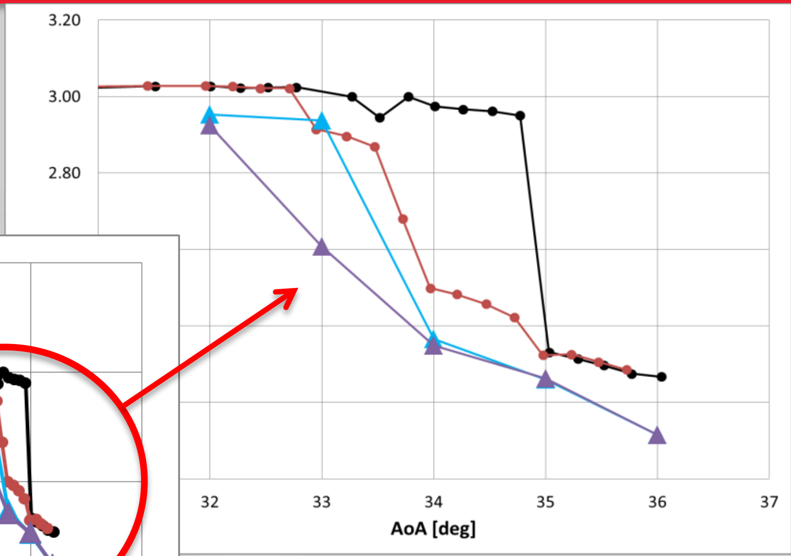
α=32°-36°-32° in 1° steps

Initialized from steady 32°

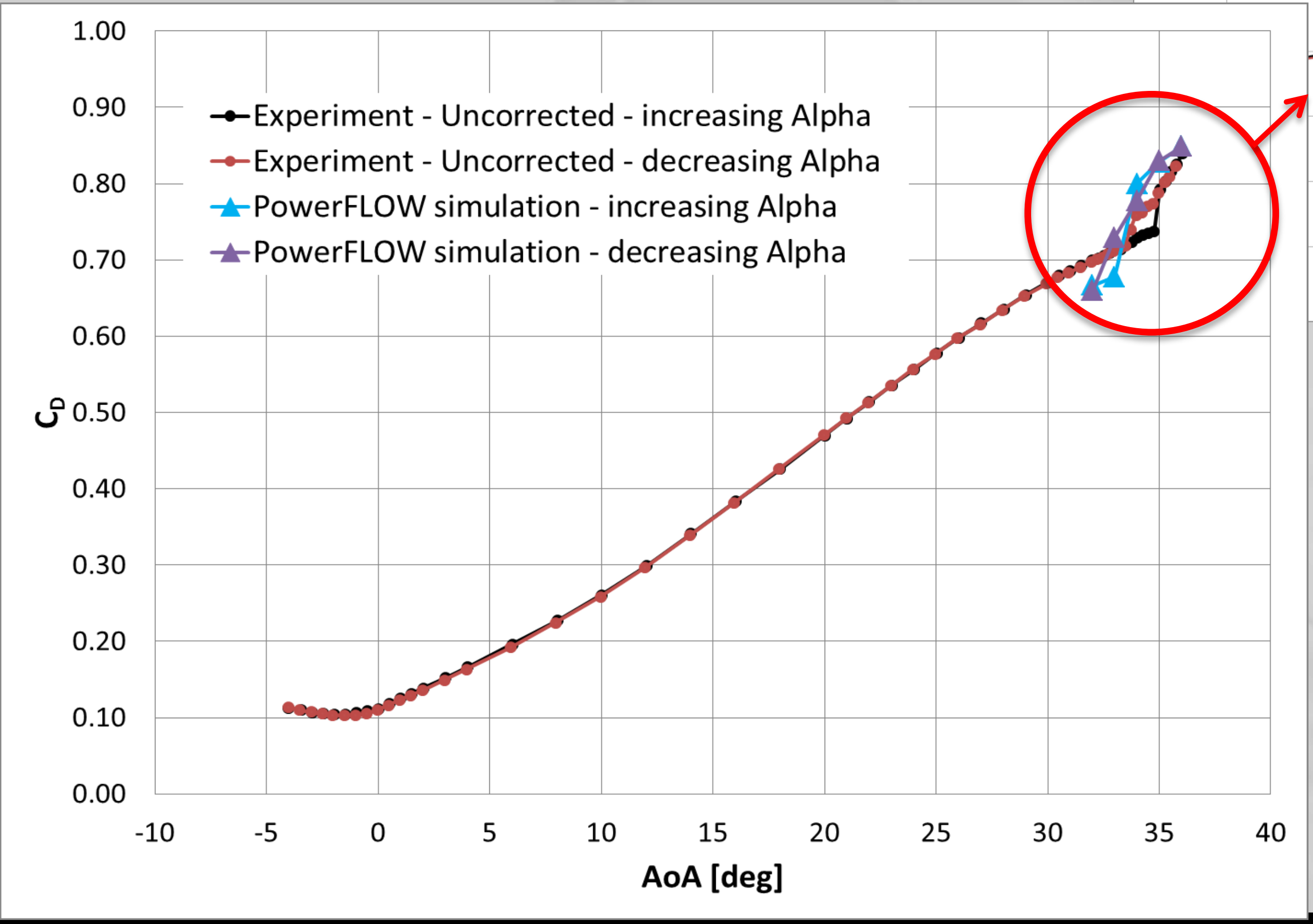
Variable settling time

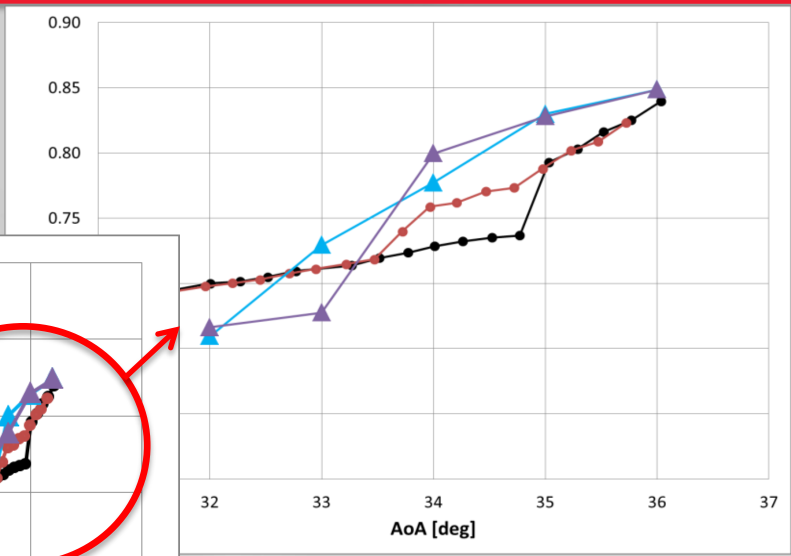
Results – hysteresis effect – Fine case



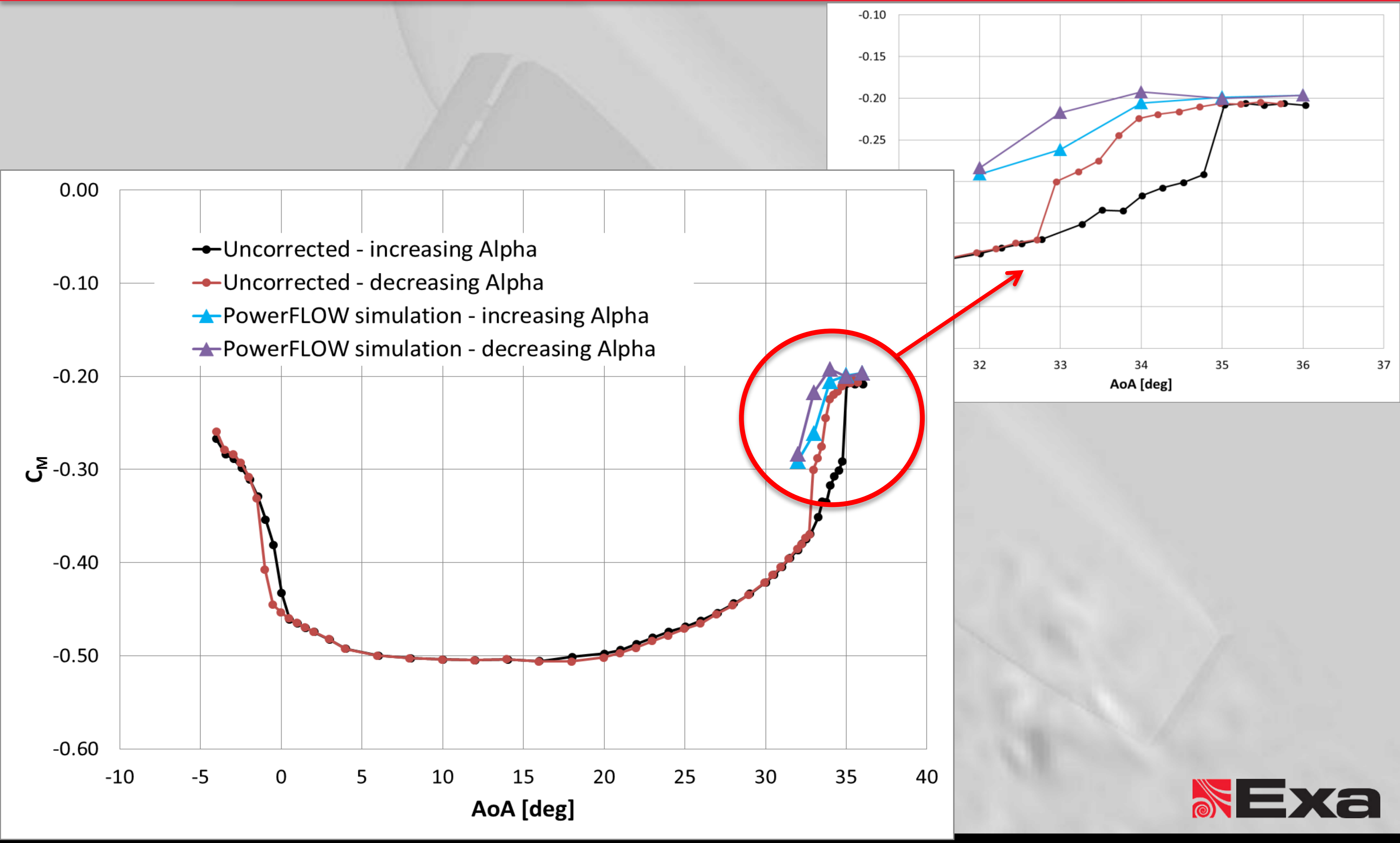


Results – hysteresis effect – Fine case

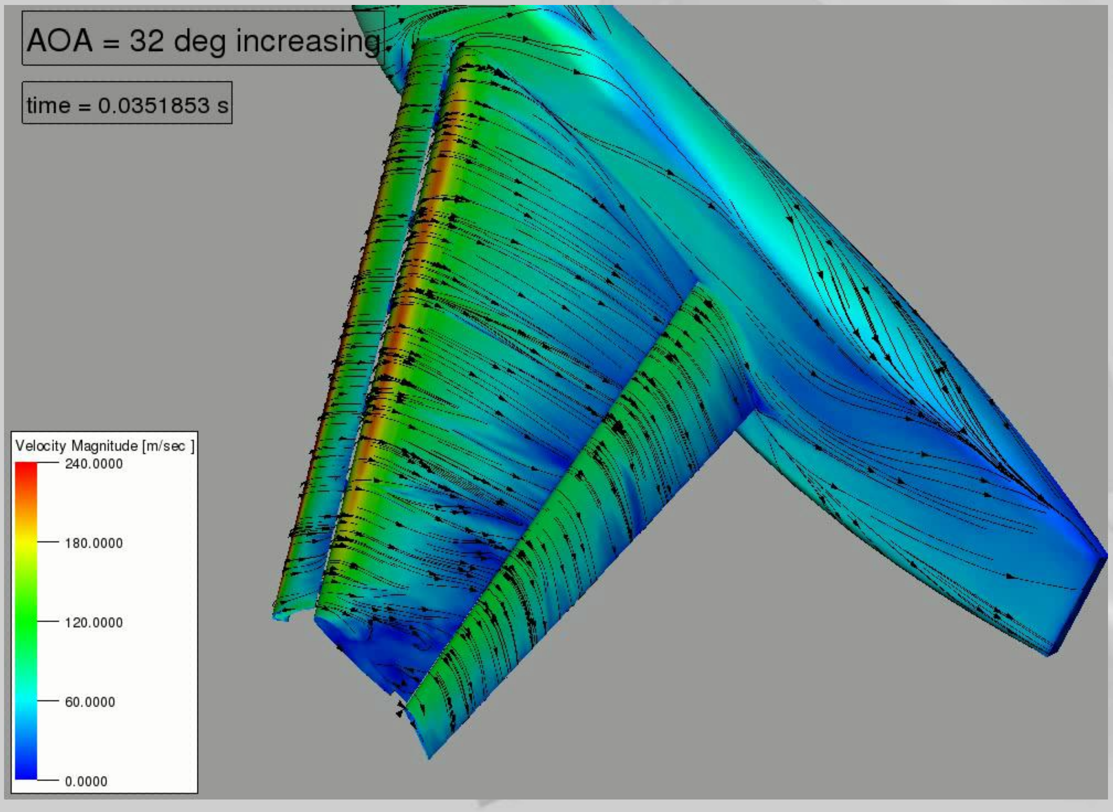


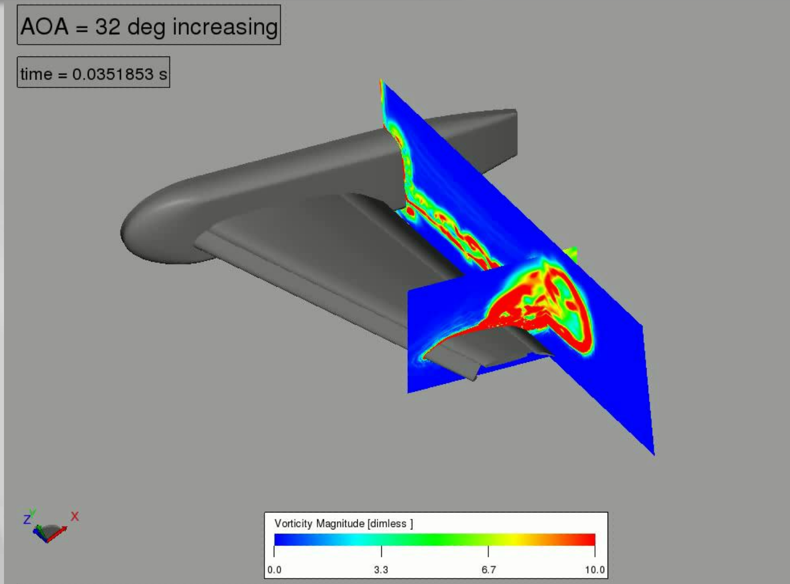


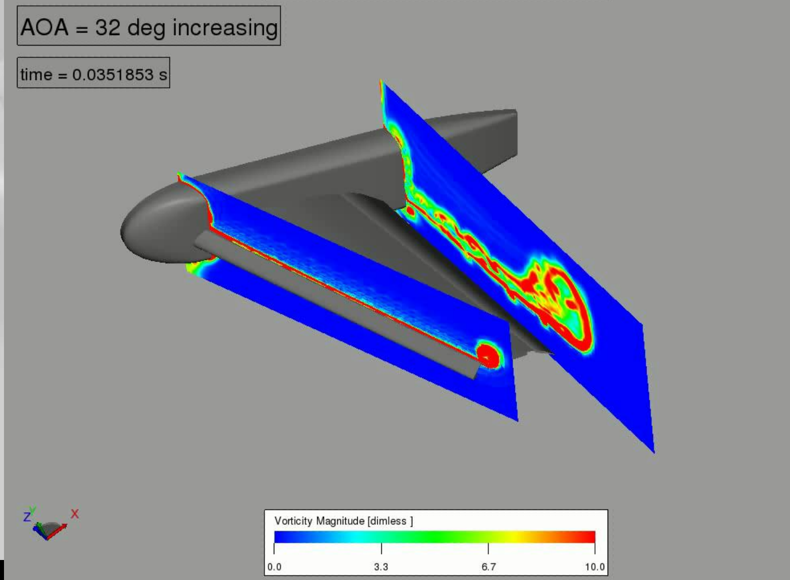
Results – hysteresis effect – Fine case



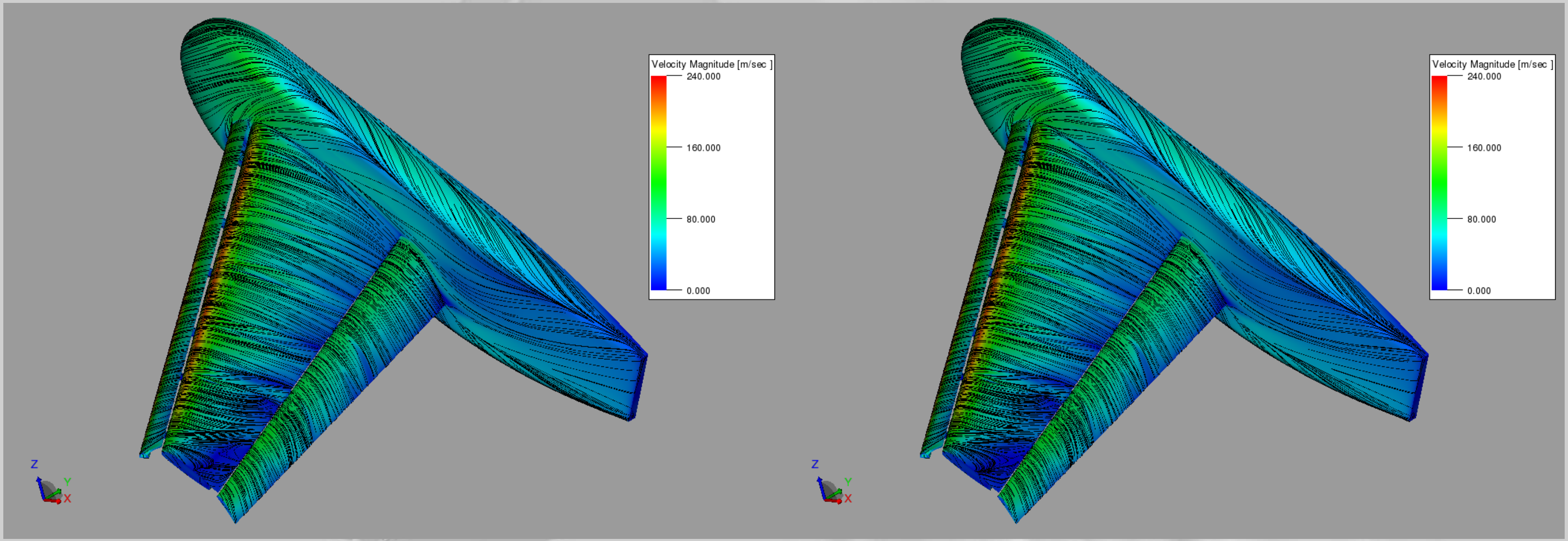
Results – hysteresis effect – Fine case







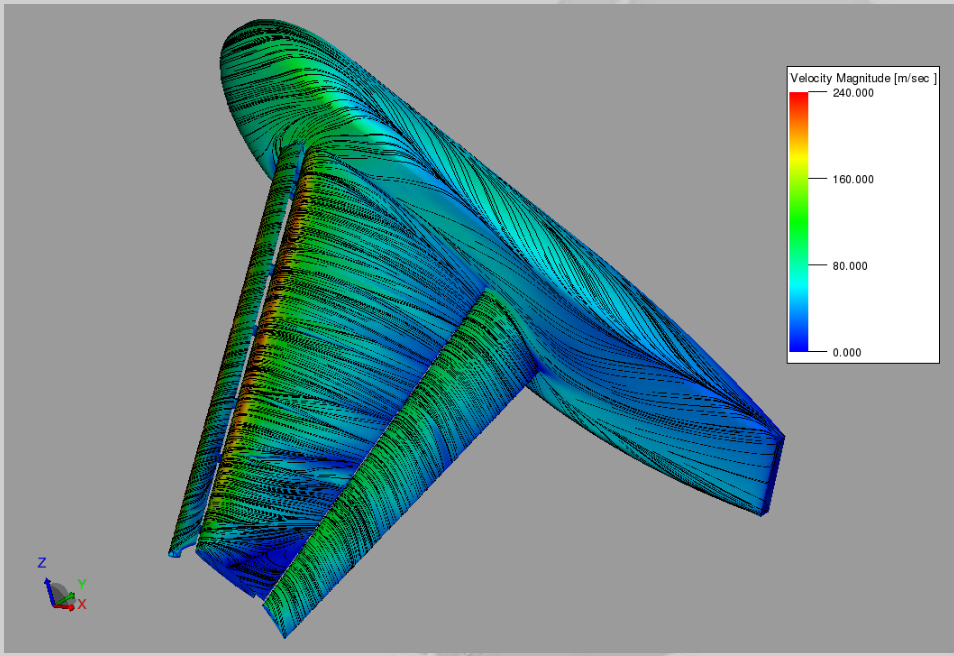
Results – hysteresis effect – Fine case



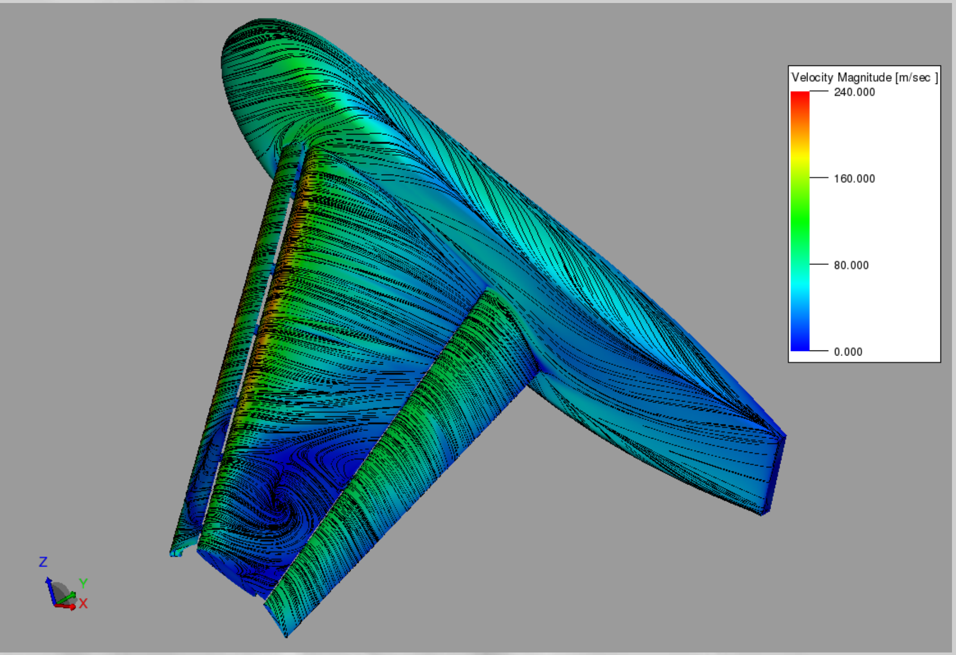
AoA 32 Increasing

AoA 32 Decreasing

Results – hysteresis effect – Fine case

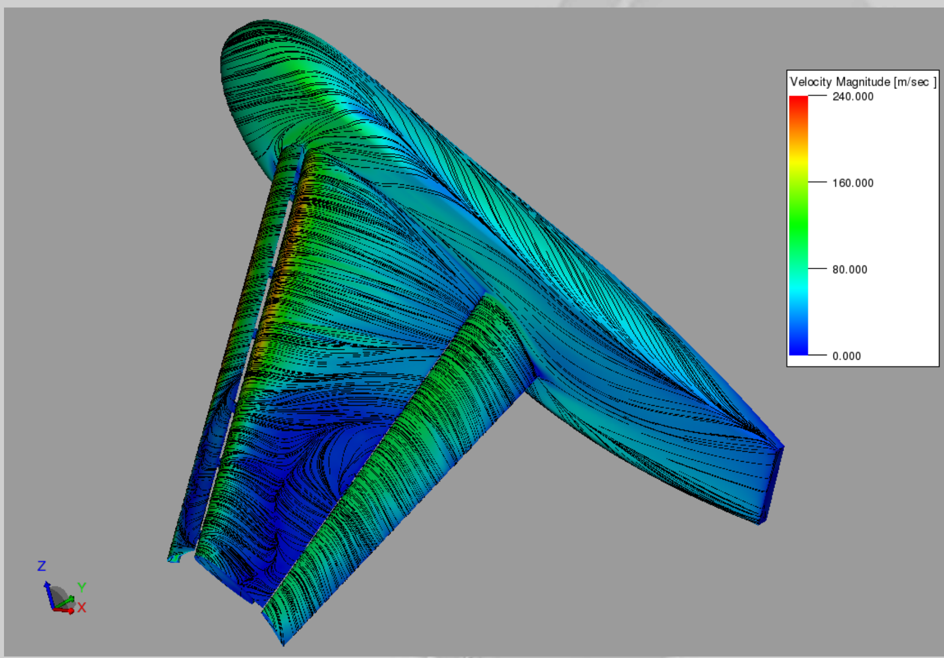


AoA 33 Increasing

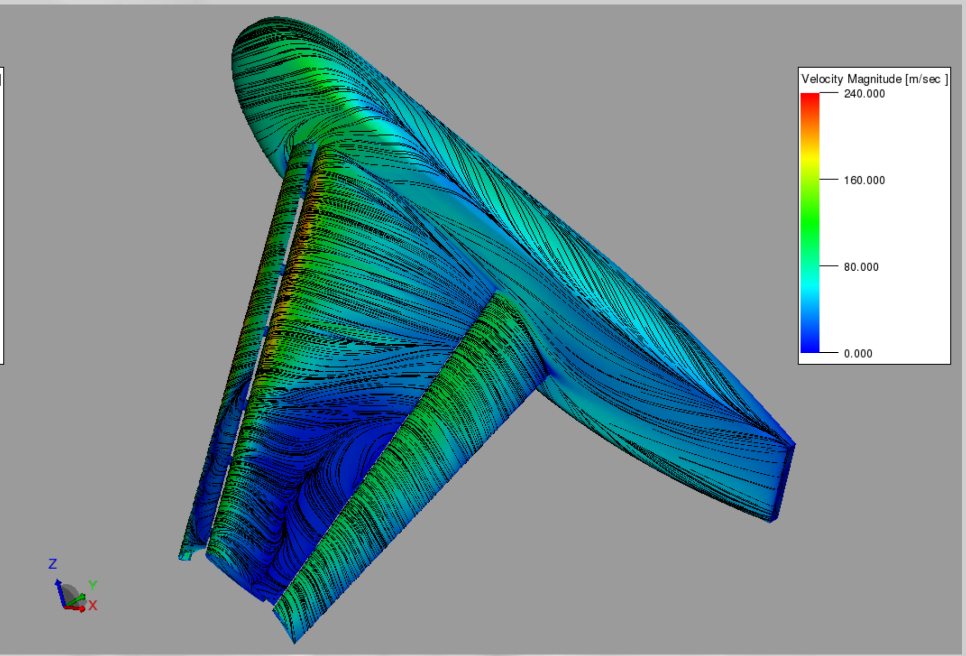


AoA 33 Decreasing

Results – hysteresis effect – Fine case



AoA 34 Increasing



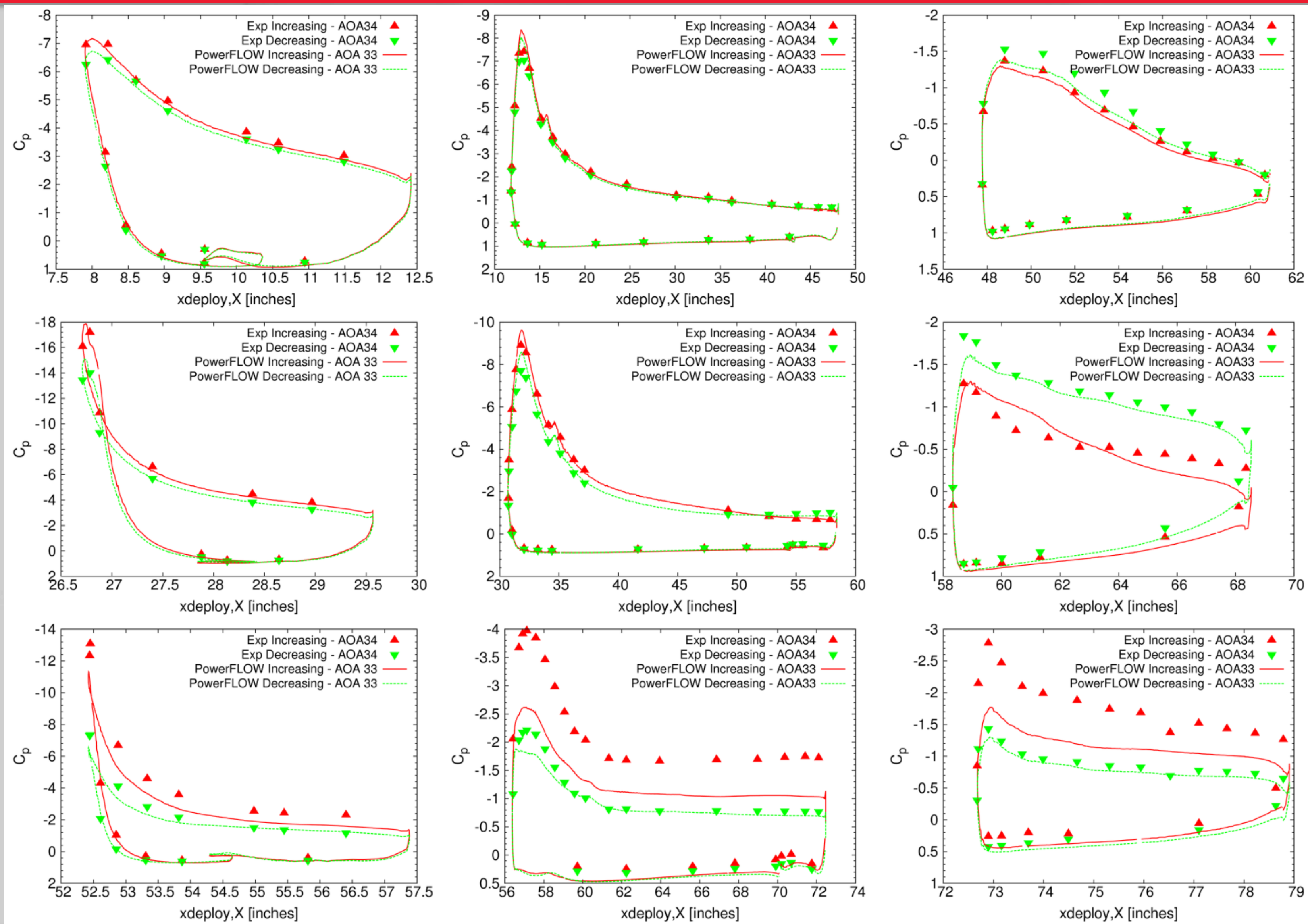
AoA 34 Decreasing

Results – hysteresis effect – Fine case

η = 17%

η = 50%

η = 95%



Overview

- Introduction
  - *TrapWing Geometry*
- Numerical Method
  - *Lattice-Boltzmann based code (PowerFLOW)*
    - Turbulence Modeling
    - Boundary Conditions
- Results
  - *1st High-Lift Workshop / AIAA 2011 - 0869 results review*
  - *Simulation Overview*
  - *Sensitivity to laminar regions*
  - *Investigation of hysteresis effect*
    - Coarse and fine simulation
- Conclusions & Outlook

Conclusions & Outlook

- Unsteady Flow Simulations
  - *Lattice Boltzmann Approach*
  - *Trap Wing with brackets in the NASA Langley WT*
- Hysteresis Study
  - *Sensitivity to laminar regions for HiLift flows*
    - Stall behavior
  - *Reasonable prediction of the hysteresis effect*
    - Underlying physical phenomena correctly captured
    - Hysteresis predicted ~1° AoA compared to Experiment
- Future studies will address
  - *Larger settling time per AoA*
    - Better agreement with exp. pitch – pause approach
  - *Other transition data?*
  - *Dynamic laminar regions modification*

Exa