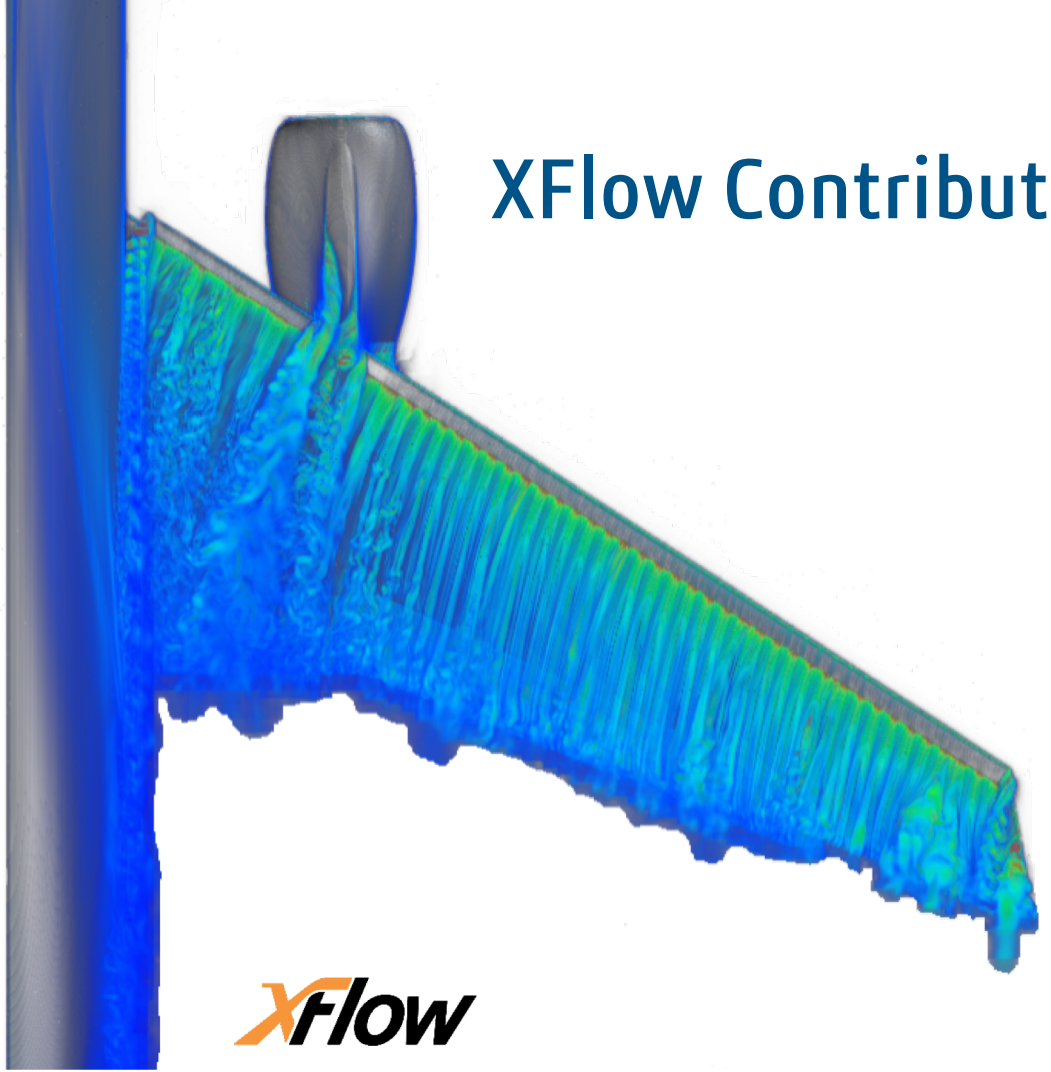

XFlow Contribution to the HiLiftPW-3

Dassault Systèmes
PID 031

Ruddy Brionnaud
Giuseppe Trapani
David M. Holman
Jonatán Felipe Santiago Cruz

AIAA Aviation Conference
Atlanta, GA June 25-29, 2018

XFlow

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Numerical Methodology

XFlow solver

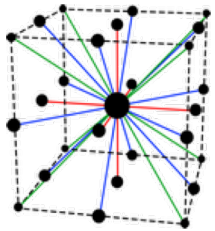
- Lattice-Boltzmann Method (LBM):
  - Mesoscopic scale
  - D3Q27 lattice scheme
  - Central moment collision operator [1]

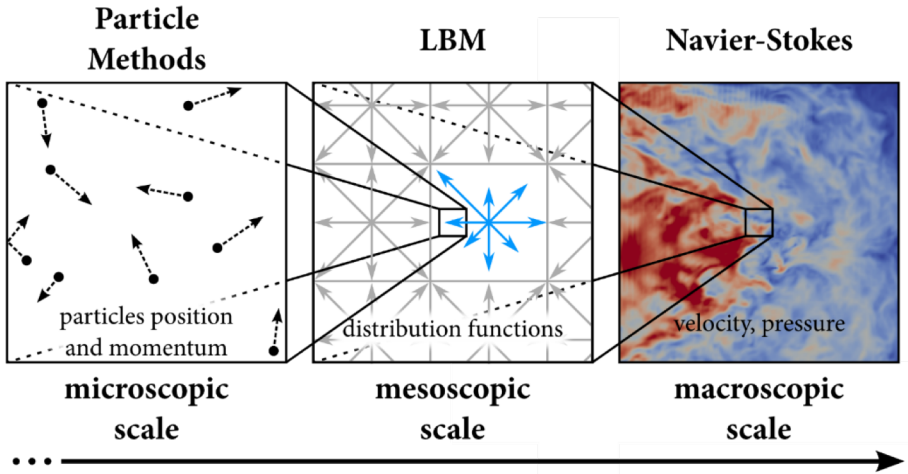
- LBM in classical CFD terms:
  - Explicit scheme → intrinsically transient
  - 2nd order in space and time
  - Mildly compressible

Boltzmann transport equation

$$\underbrace{\frac{\partial f}{\partial t} + \mathbf{e} \cdot \nabla f}_{\text{Streaming}} = \underbrace{\Omega}_{\text{Collision}}$$

D3Q27





[1] Geier, M., Greiner, A., and Korvink, J., "A factorized central moment lattice Boltzmann method," The European Physical Journal Special Topics, Vol. 171, No. 1, 2009, pp. 55-61.

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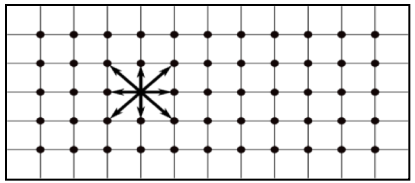
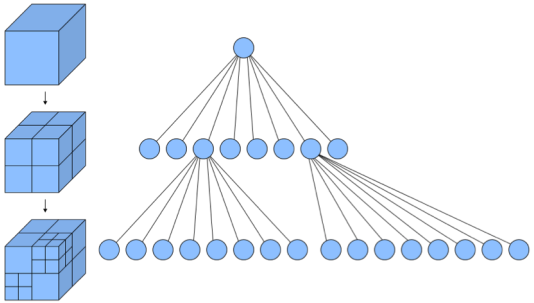
Numerical Methodology

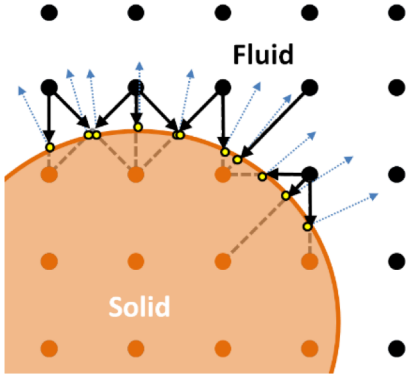
XFlow solver

- Spatial discretization:
  - Lattice structure
  - Multi-resolution with factor of 2
  - Space and time scales are local
- Turbulence and near-wall treatment:
  - LES turbulence model: Wall-Adapting Local-Eddy [2]
  - Generalized law of the wall [3]
  - Wall boundaries constructed based on geometry tessellation
    - → No surface elements/meshing required
    - → Handles complex geometries

Space	Time
dx	dt
dx/2	dt/2
dx/4	dt/4







[2] Ducros, F., Nicoud, F. and Poinsot, T., "Wall-adapting local Eddy viscosity models for simulations in complex geometries," Proceedings of 6th ICFD Conference on Numerical Methods for Fluid Dynamics, 1998, pp. 293-299
[3] Shih, T., Povinelli, L., Liu, N., Potapczuk, M., and Lumley, J., "A generalized wall function," *NASA Technical Report*, July 1999

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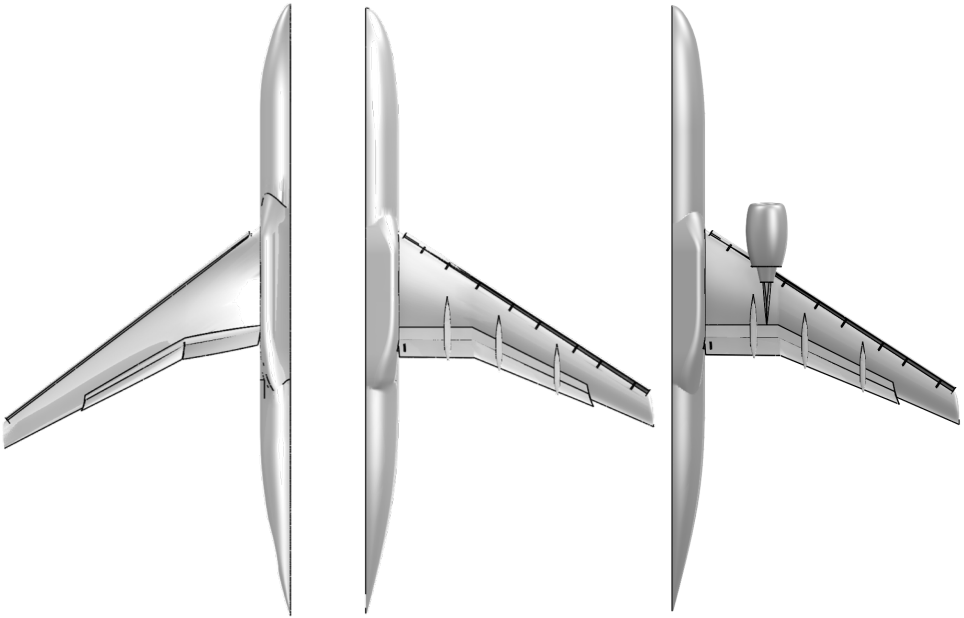
Cases Configurations

	Case1a	Case2a	Case 2c
Geometry	NASA HL-CRM	JAXA Standard Model (JSM) **No nacelle**	JAXA Standard Model (JSM) **With nacelle**
Wing semi-span	29.38 m	2.3 m	2.3 m
MAC	7.01 m	0.5292 m	0.5292 m
Reynolds	3.26 M	1.93 M	1.93 M
Mach number	0.2	0.172	0.172
Objective	Resolution study	Polar prediction	Polar prediction
Angles of attack	8º, 16º	4.37º, 10.47º, 18.58º, 21.57º, 23.50º	4.37º, 10.47º, 18.58º, 21.57º, 23.50º



Case1a Case2a Case2c

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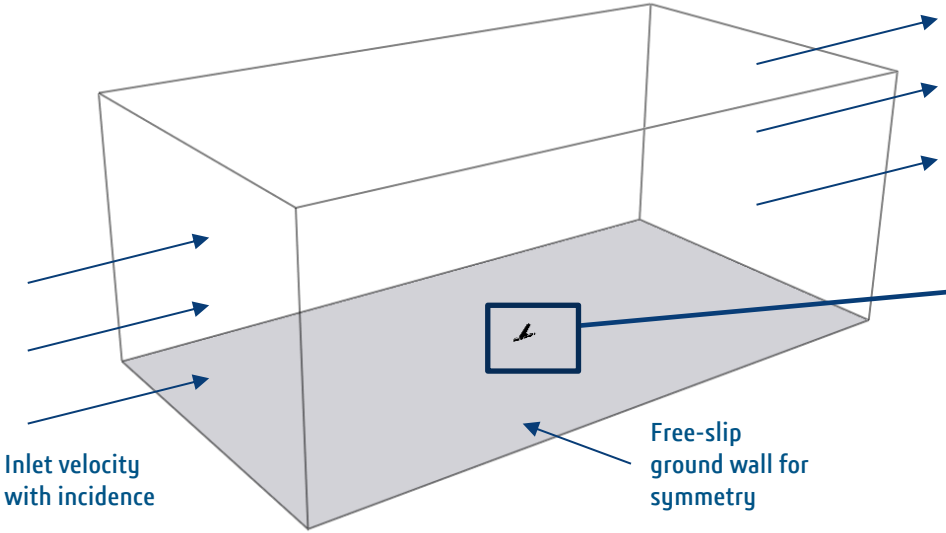
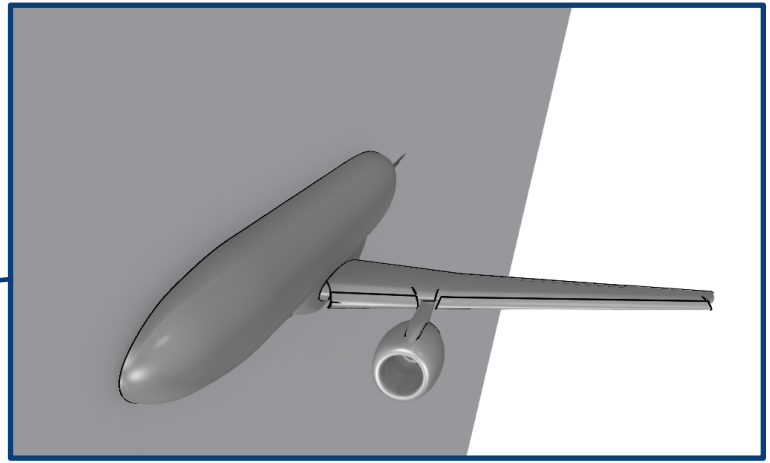
XFlow Setup





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Grids Overview

Summary

- No committee-provided grid used, since based on a Lattice-Bolzmann method
- Lattice generation is automated based on geometry and resolutions input, and took on average ~30 minutes on 6 cores

	Type	# Elements in MAC	# Elements Total	Geometry repair?
Case1a	Coarse	175	17,220,966	No
	Medium	350	49,645,160	No
	Fine	700	107,139,133	No
Case2a	Medium	350	33,169,480	Yes
Case2c	Medium	350	38,377,600	Yes

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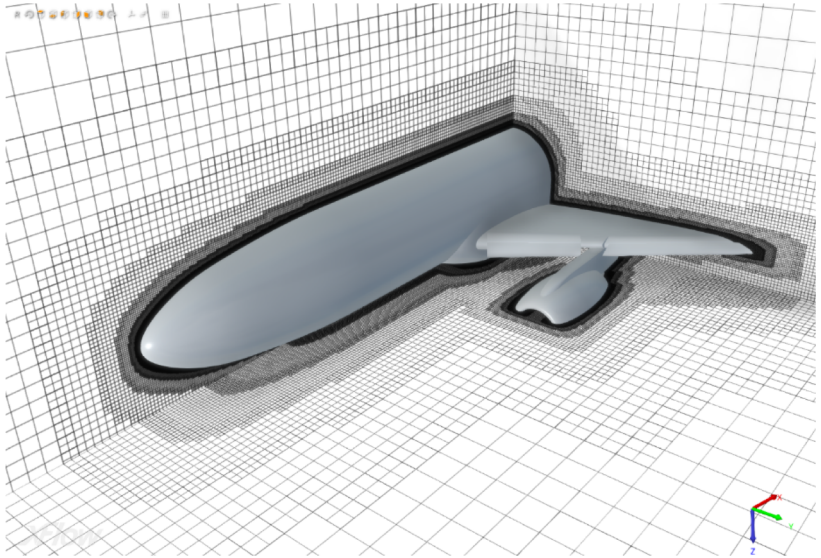
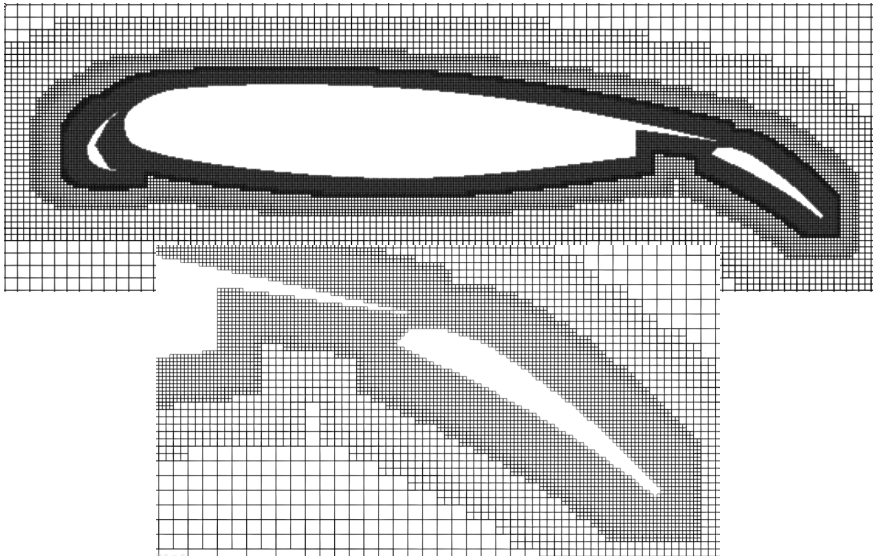
Grids Overview

Lattice structure



Case2c - Overall lattice structure



Case2c - Local refinements

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HL-CRM Results

Case1a: Computational summary

*Teide-HPC	**XFlow HPC
Intel Xeon E5-2670 @ 2.60 GHz	Intel Xeon E5-2620 v3 @ 2.40GHz
32 GB DDR-3 RAM	32 GB DDR-3 RAM
Infiniband QDR 4x to 40Gb/s	Infiniband QDR 4x to 40Gb/s

	Type	# Elements	Physical time	Cores	Wall-clock time	CPU time
AoA 8º	Coarse	17,220,966	3.00 s	60**	10 hours	600 hCPU
	Medium	49,645,160	3.00 s	96**	49 hours	4,464 hCPU
	Fine	107,139,133	**1.48 s**	512*	158 hours	86,016 hCPU
AoA 16º	Coarse	17,220,966	3.00 s	144**	5 hours	720 hCPU
	Medium	49,645,160	3.00 s	144**	34 hours	4,700 hCPU
	Fine	107,139,133	**1.30 s**	512*	168 hours	80,896 hCPU

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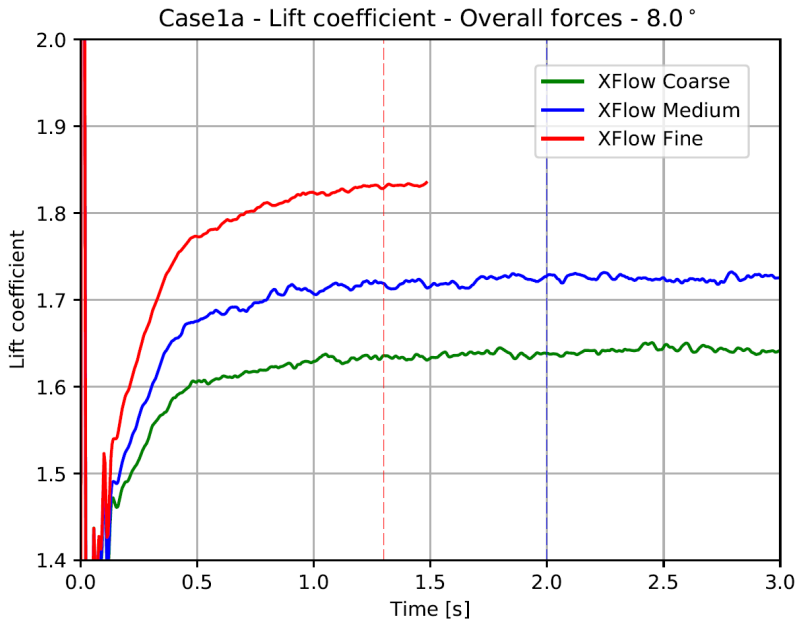
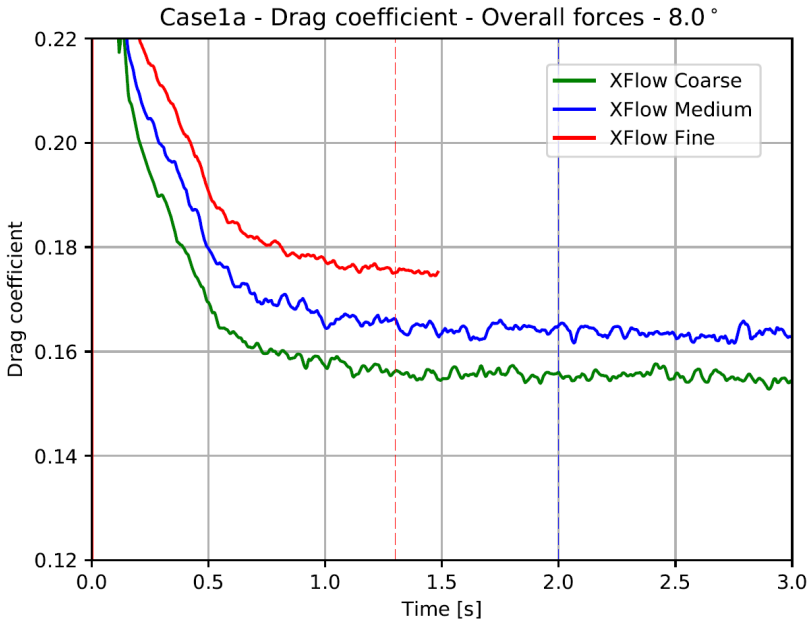
HL-CRM Results

Case1a: Forces time histories @ 8 degrees





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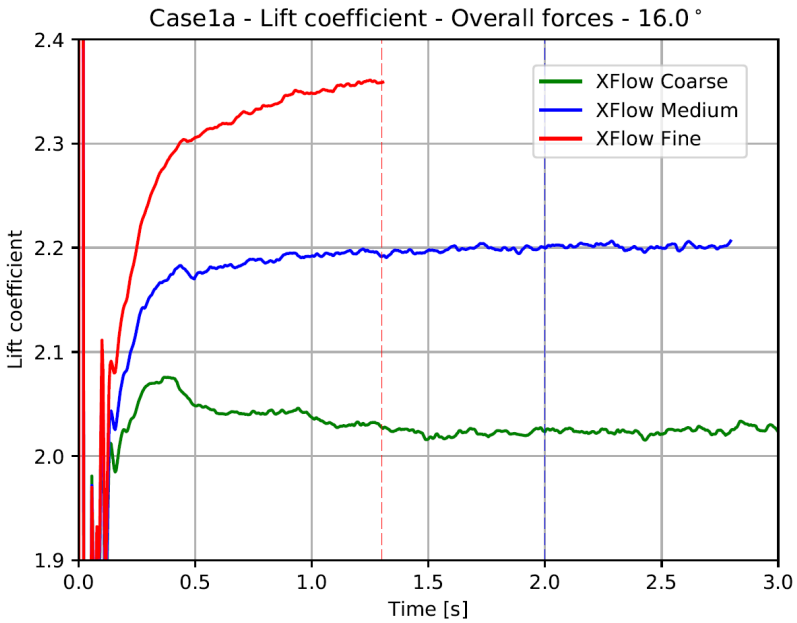
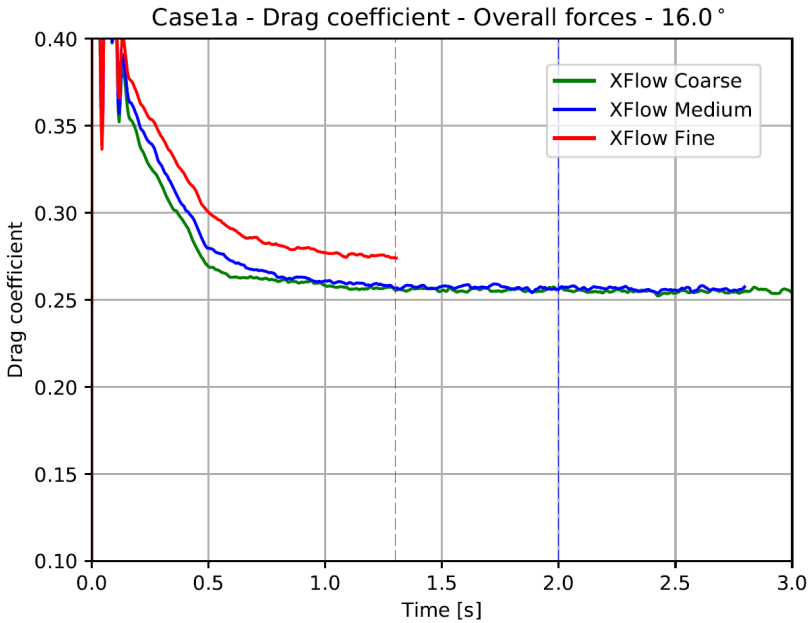
HL-CRM Results

Case1a: Forces time histories @ 16 degrees





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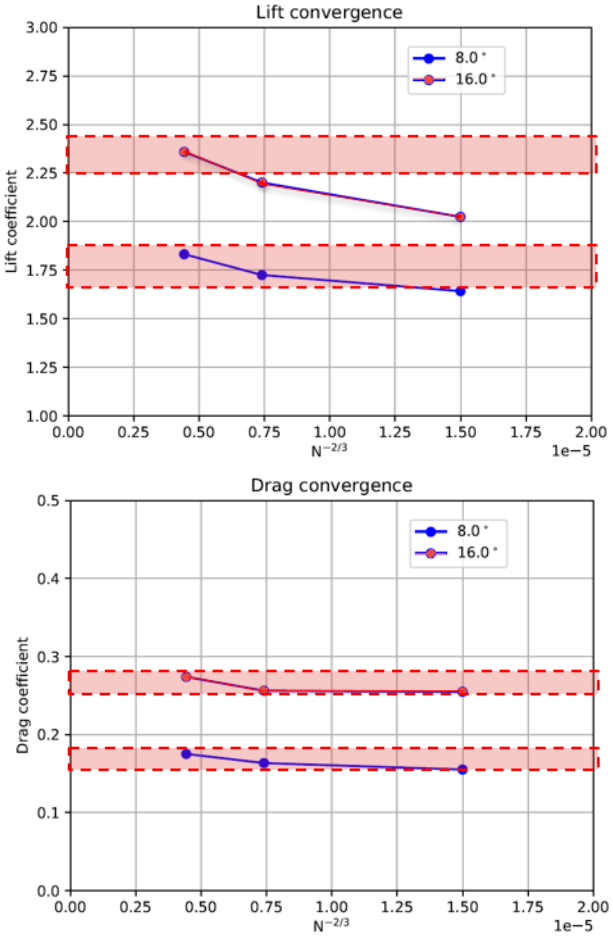
HL-CRM Results

Case1a: Convergence summary

- Drag has a lower grid dependency, and lower scattering between participants
- Lift is more sensitive to refinement, and higher scattering between participants
- Convergence seems to follow the global trend from workshop participants



Participants convergence results scattering

Source: https://hiliftpw.larc.nasa.gov/Workshop3/HiLiftPW3-Presentations/Summary_Case1.pdf

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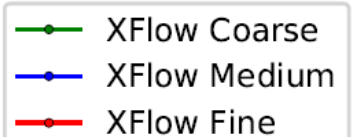
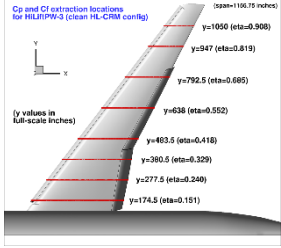
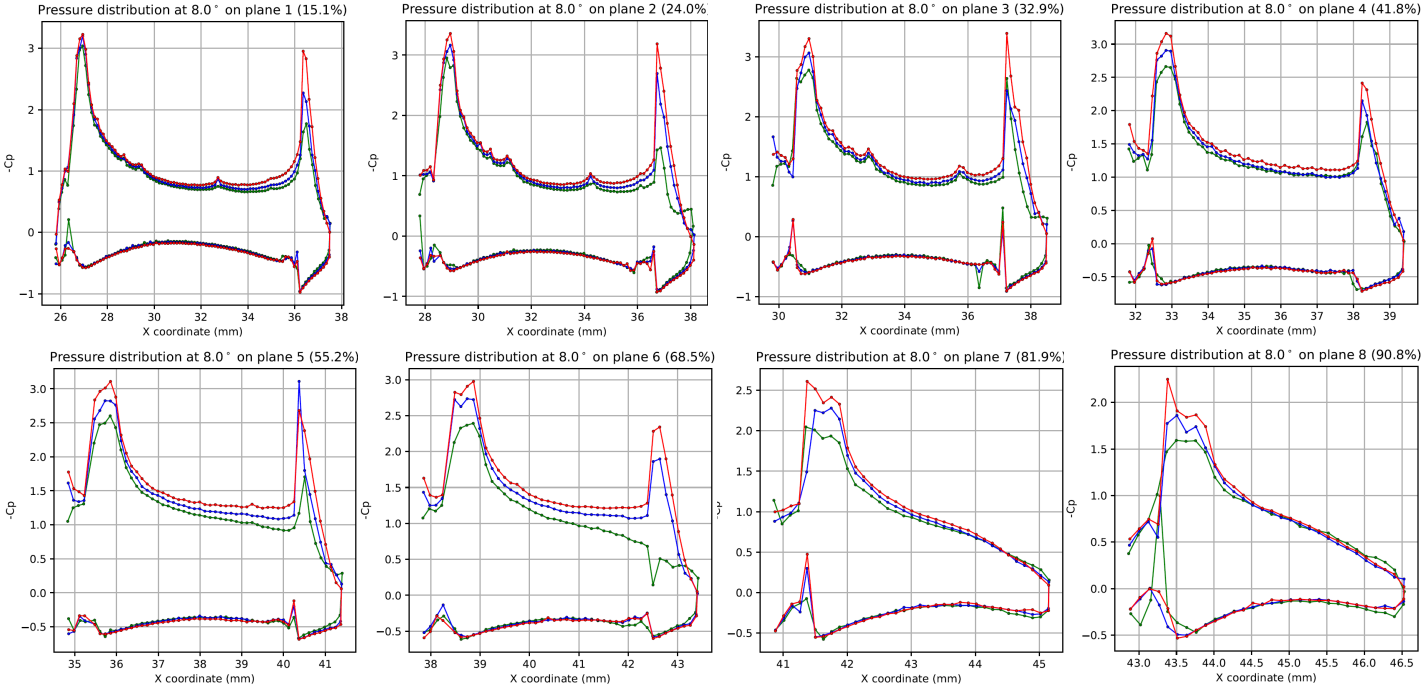
HL-CRM Results

Case1a: Pressure distribution @ 8 degrees







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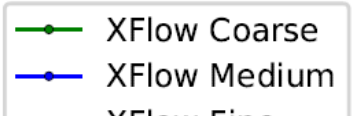
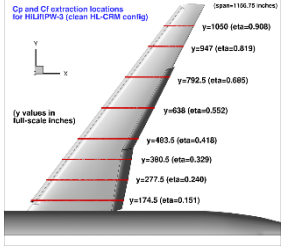
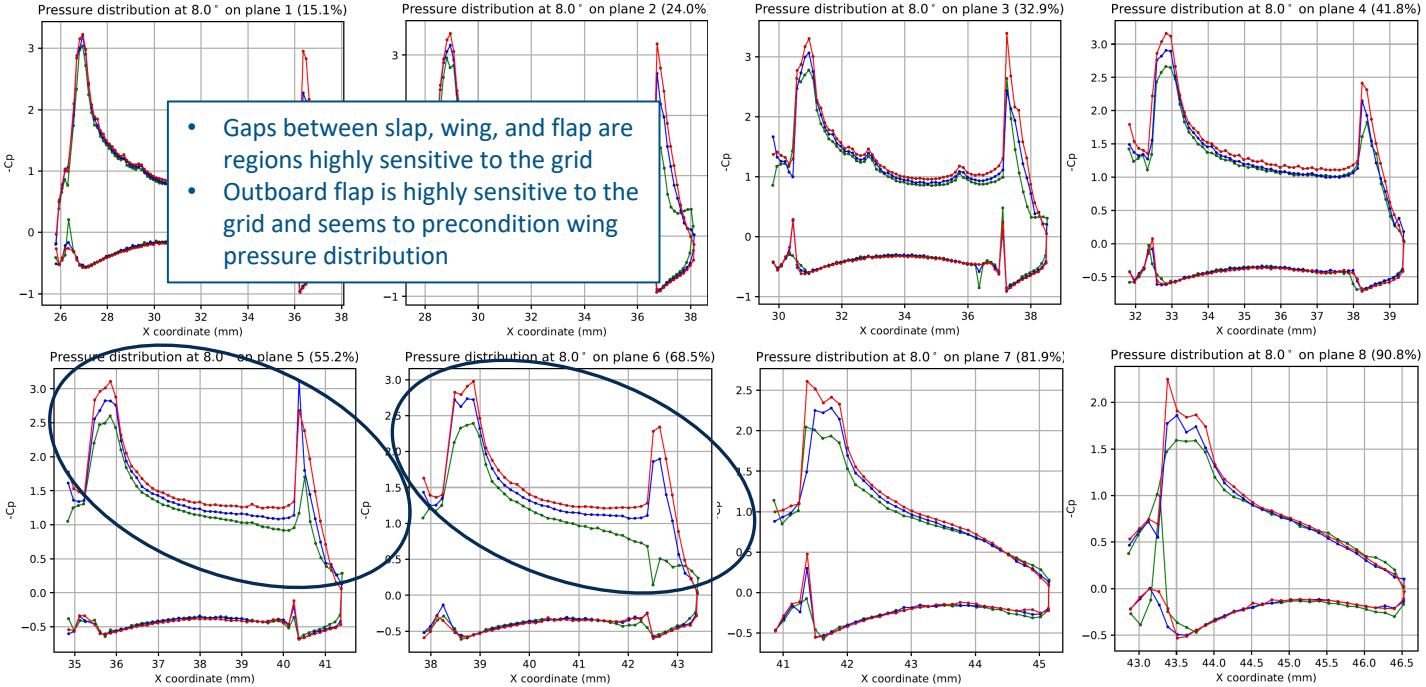
HL-CRM Results

Case1a: Pressure distribution @ 8 degrees







- Gaps between slap, wing, and flap are regions highly sensitive to the grid
- Outboard flap is highly sensitive to the grid and seems to precondition wing pressure distribution

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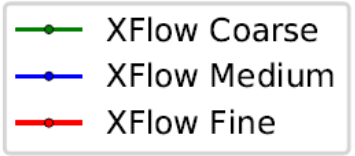
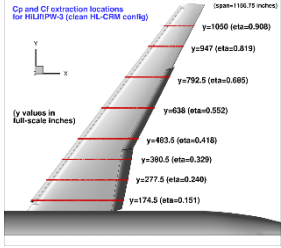
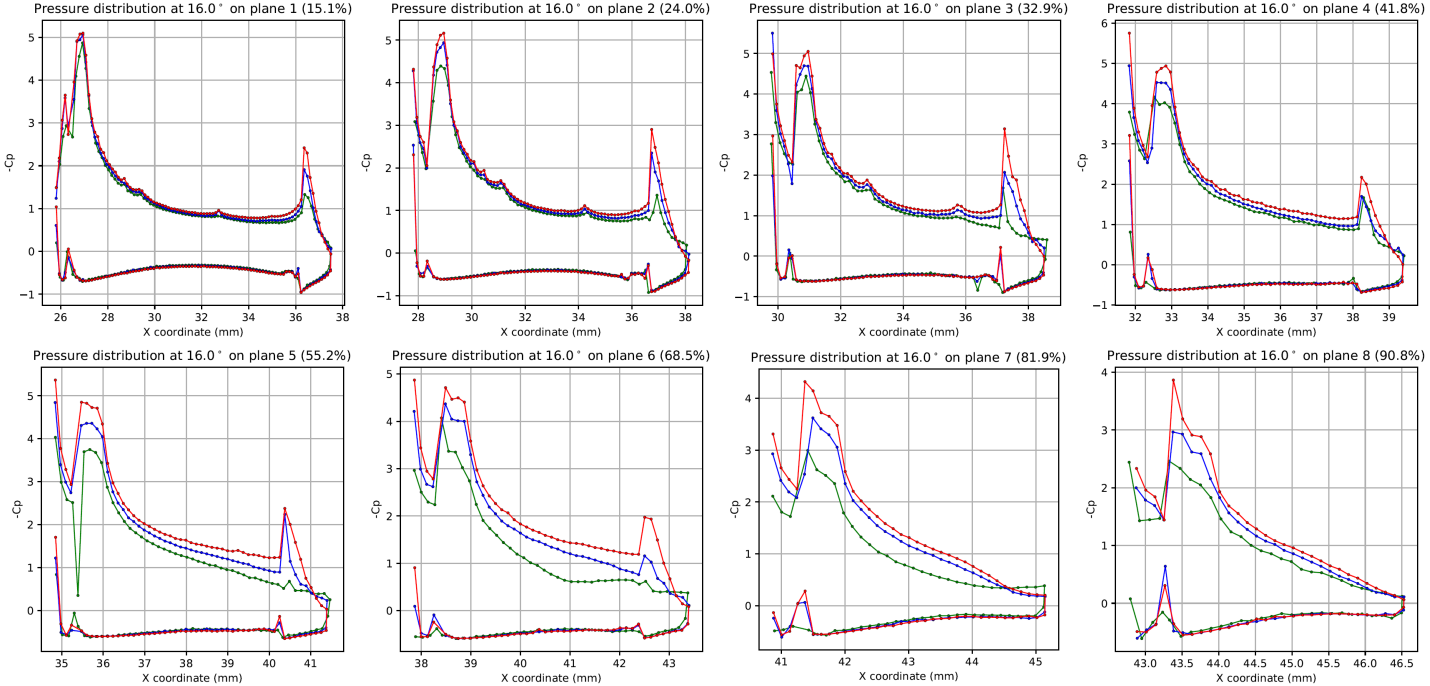
Case1a: Pressure distribution @ 16 degrees







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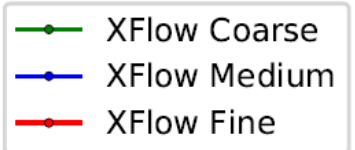
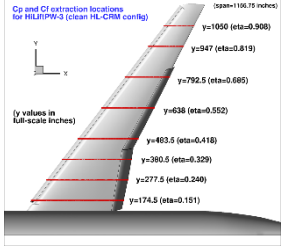
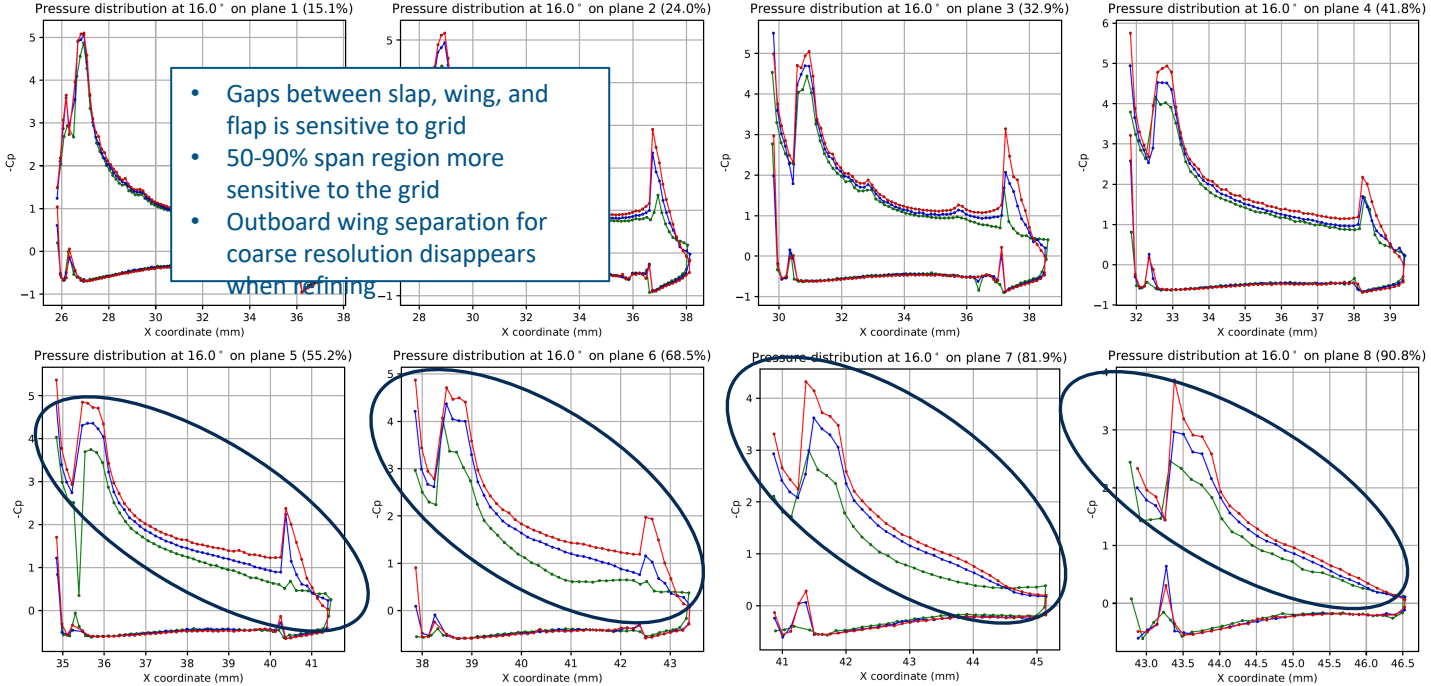
Case1a: Pressure distribution @ 16 degrees







- Gaps between slap, wing, and flap is sensitive to grid
- 50-90% span region more sensitive to the grid
- Outboard wing separation for coarse resolution disappears when refining

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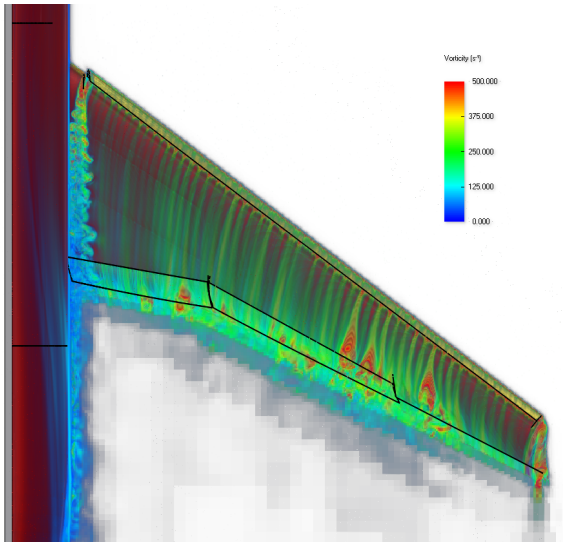
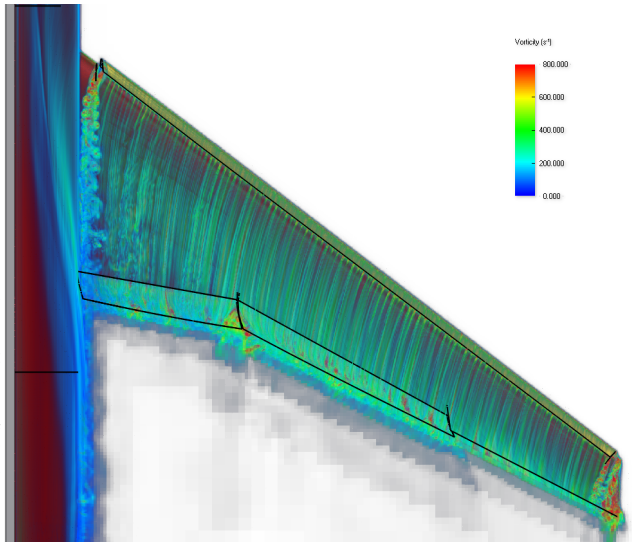
HL-CRM Results

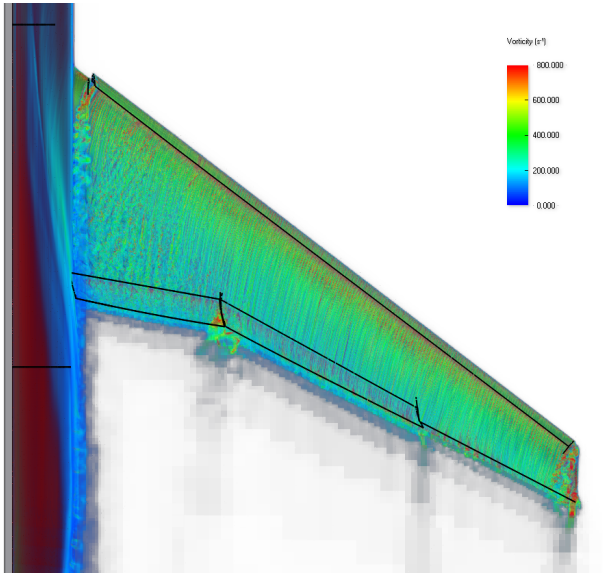
Case1a: Volumetric vorticity @ 16 degrees



Coarse



Medium



Fine

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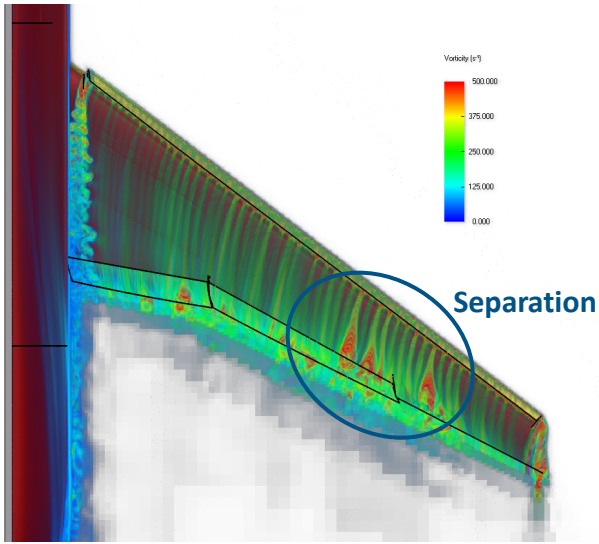
HL-CRM Results

Case1a: Volumetric vorticity @ 16 degrees



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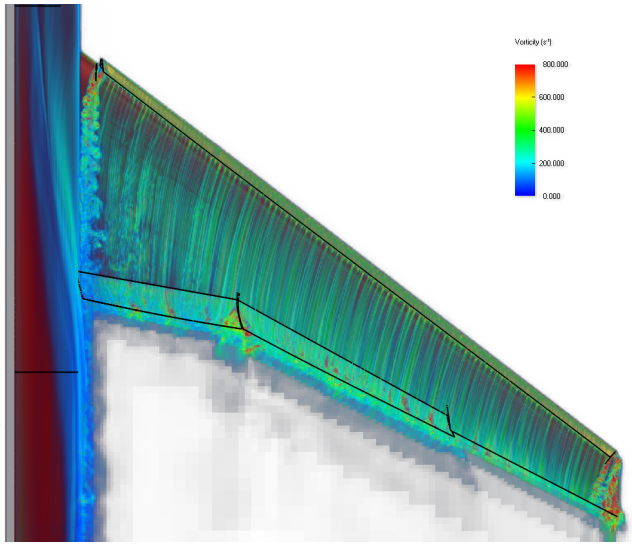

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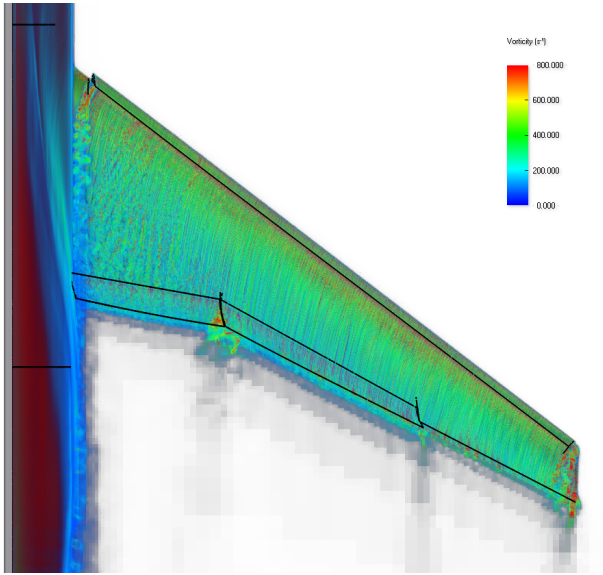

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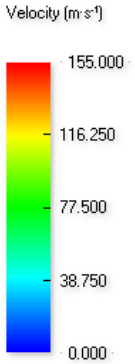
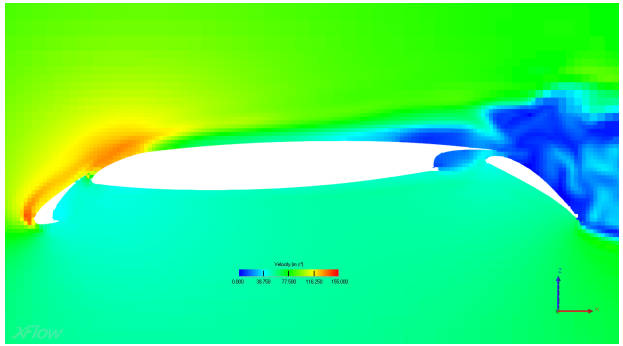
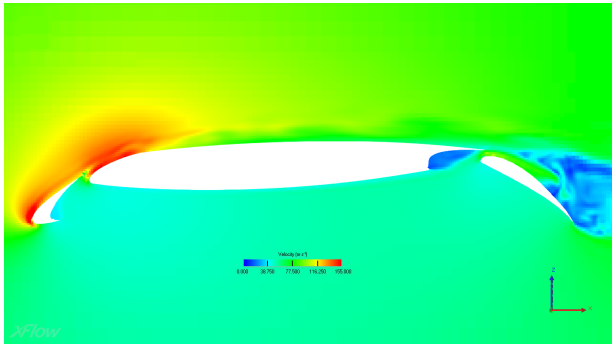
HL-CRM Results

Case1a: Instantaneous velocity on plane 6 (68.5%) @ 16 degrees





Coarse



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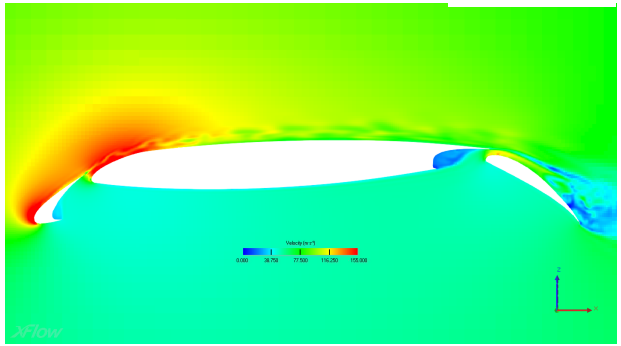

Fine

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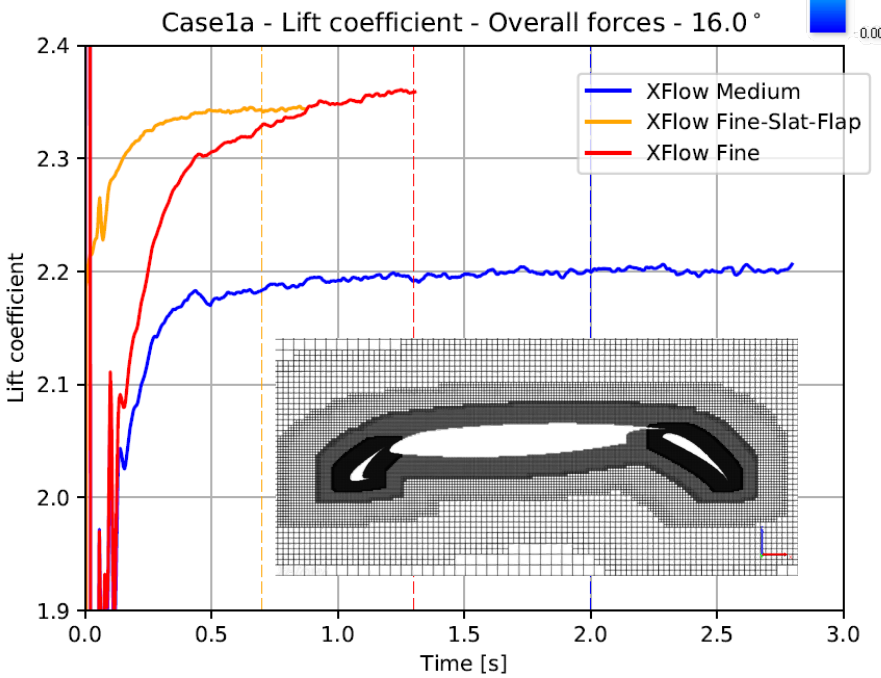
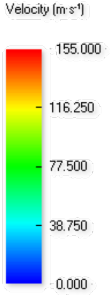
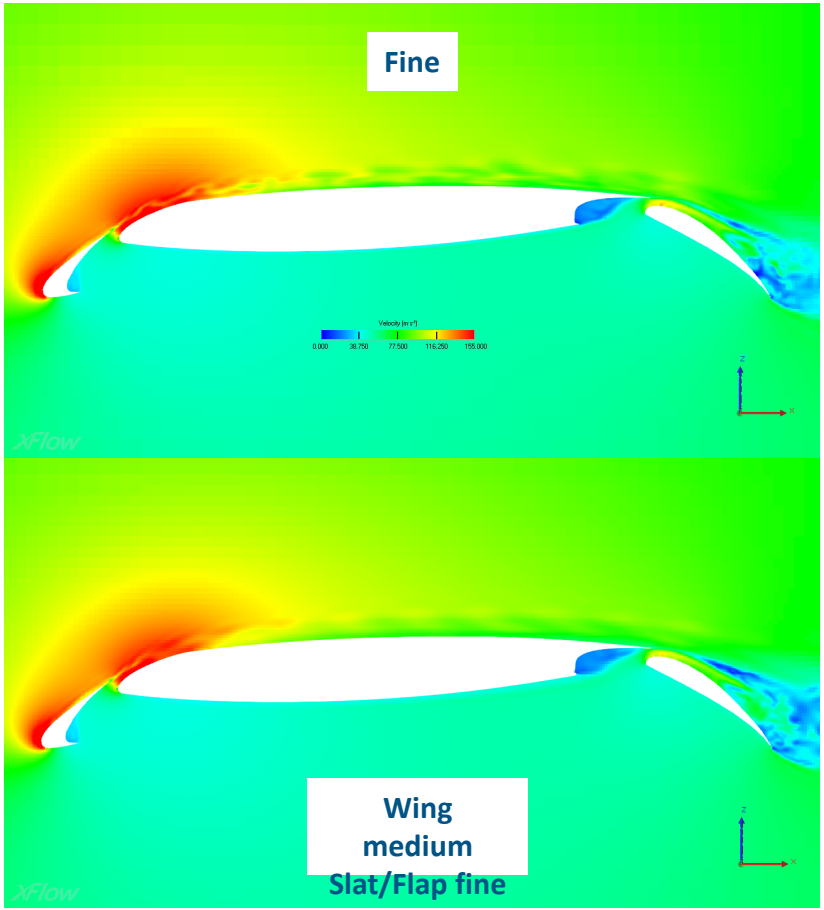
HL-CRM Results

Case1a: Slat/Flap refinement







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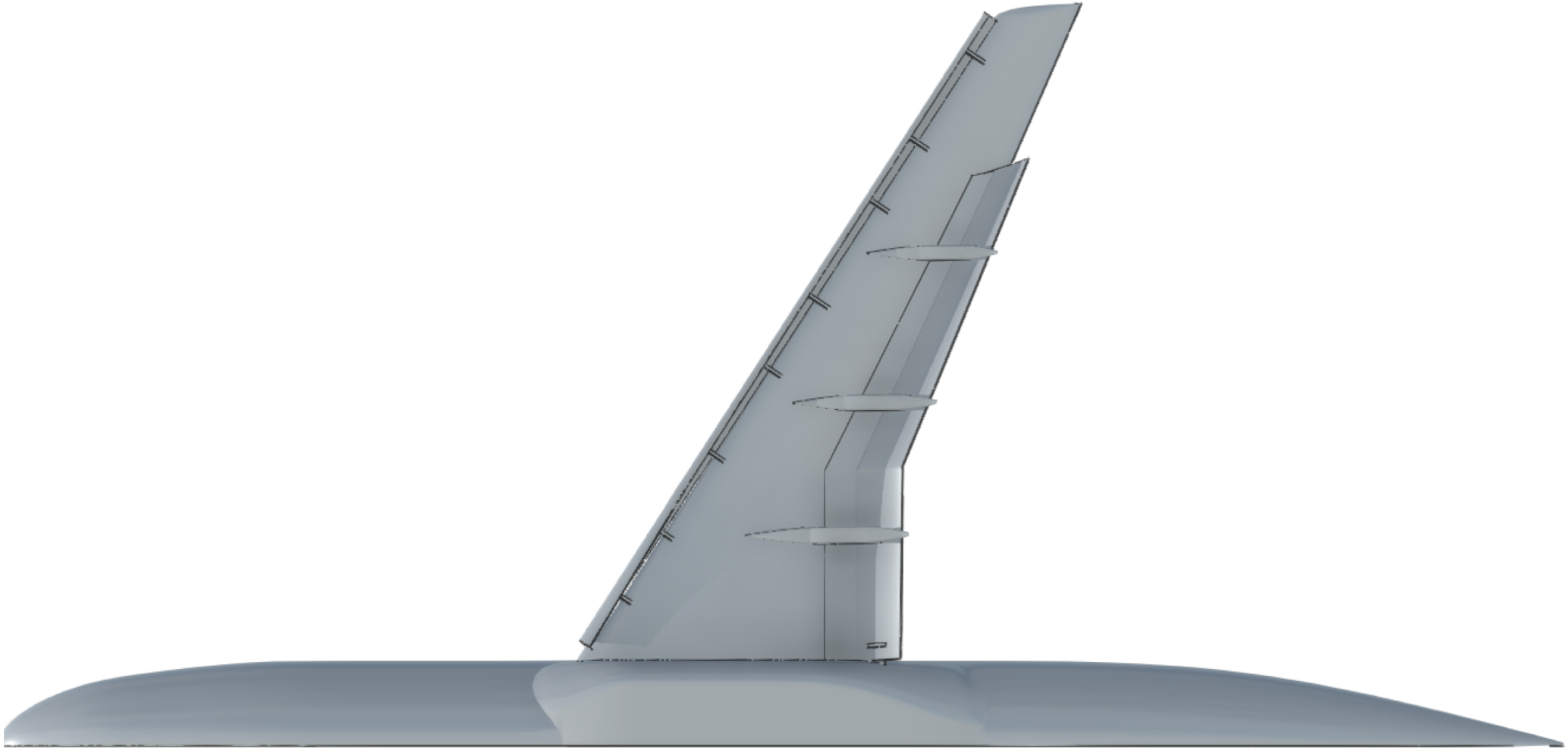
Case2a - No Nacelle



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Case2a: Computational summary

XFlow HPC
Intel Xeon E5-2620 v3 @ 2.40GHz
32 GB DDR-3 RAM
Infiniband QDR 4x to 40Gb/s

Alphas	# Elements	Physical time	Cores	Wall-clock time	CPU time
4.37º	33,169,480	0.20 s	144	47 hours	6,768 hCPU
10.47º	33,169,480	0.25 s	96	90 hours	8,640 hCPU
18.58º	33,169,480	0.30 s	192	59 hours	11,328 hCPU
21.57º	33,169,480	0.30 s	72	117 hours	8,424 hCPU
23.50º	33,169,480	0.40 s	96	118 hours	11,328 hCPU

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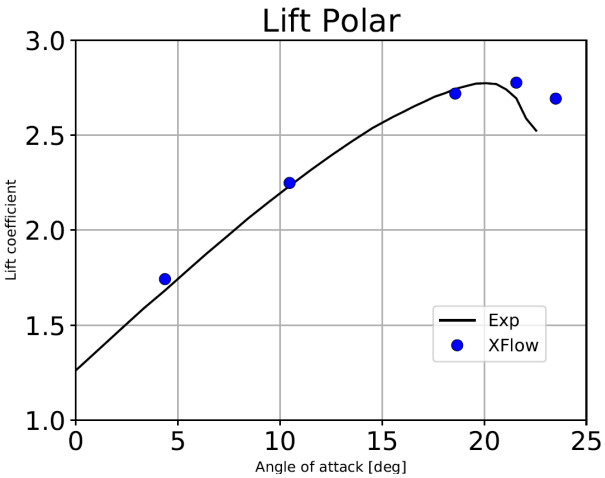
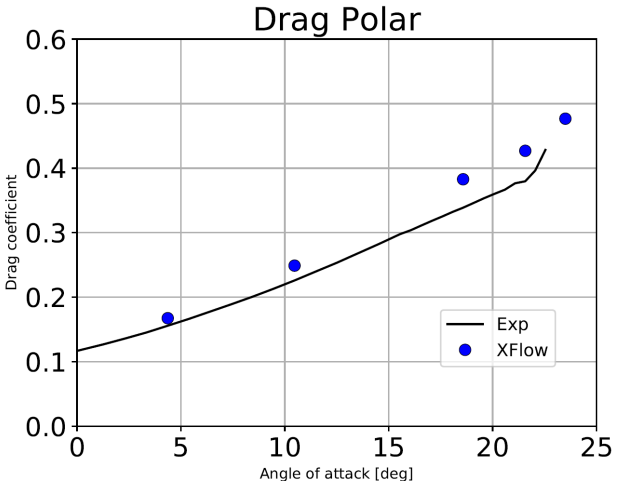
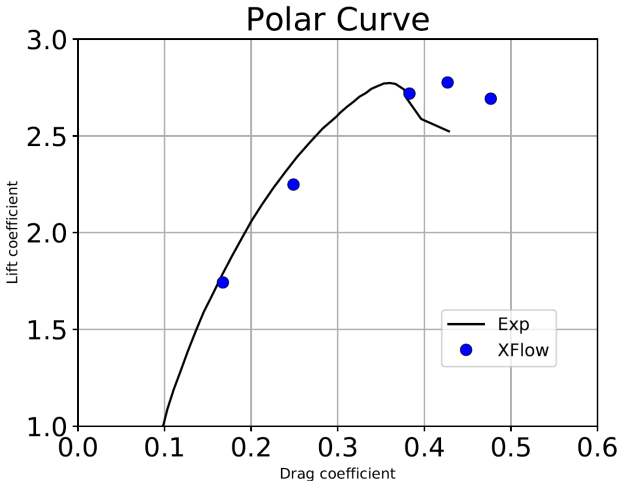
Case2a: Polar curves

Experimental stall angle = 20.09º
XFlow stall angle = 21.58º

Experimental max CL = 2.740
XFlow max CL = 2.776







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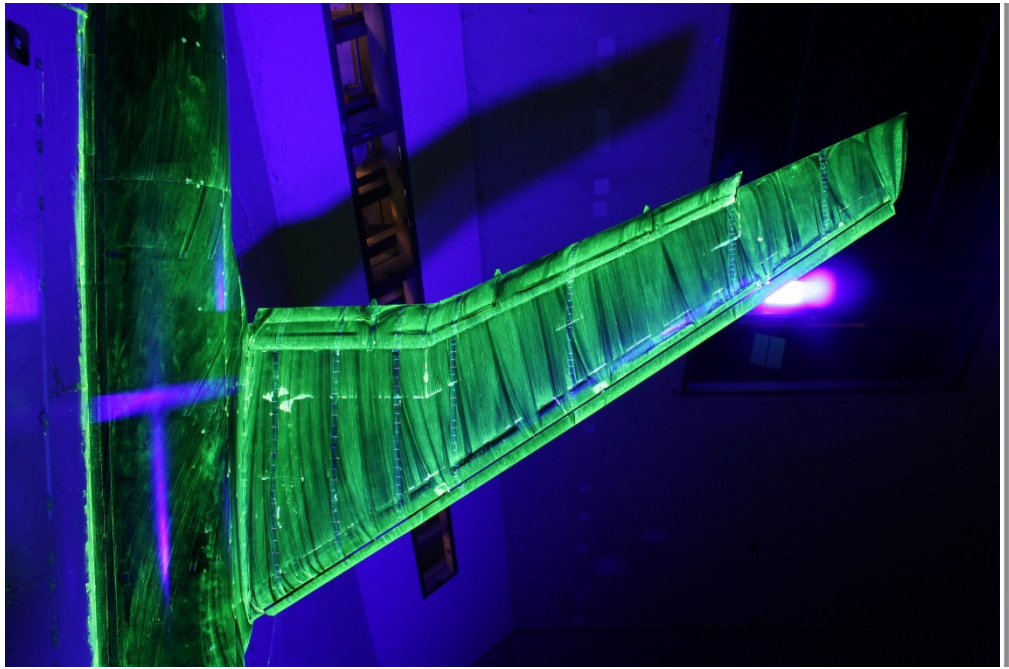
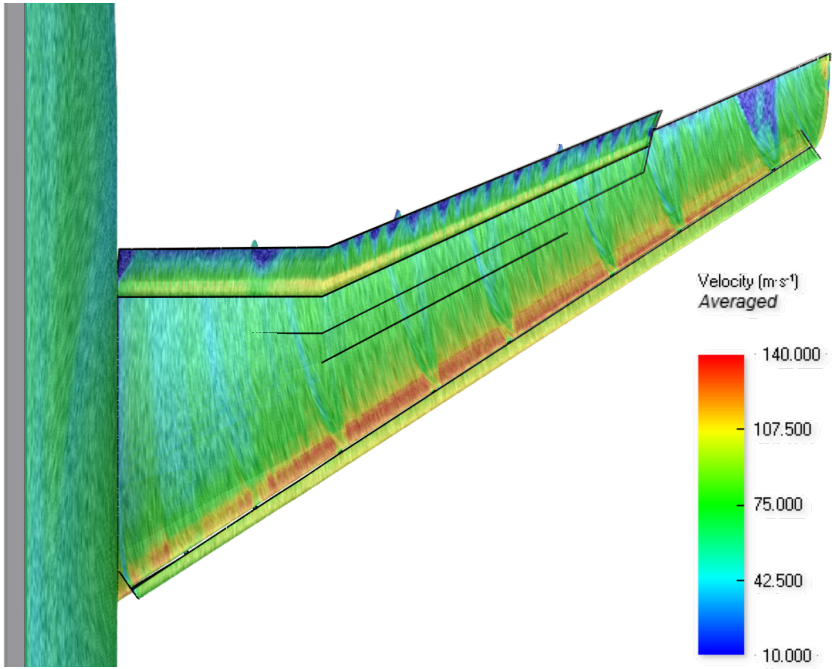
Case2a: Oil flow images @ 10.48º

Line integral convolution + near-wall velocity





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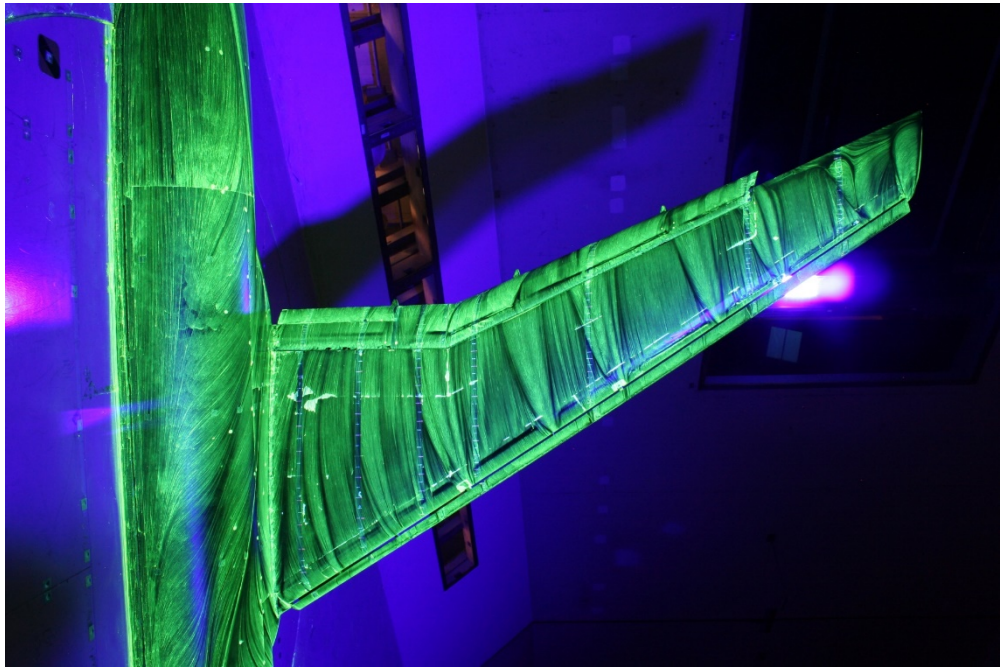
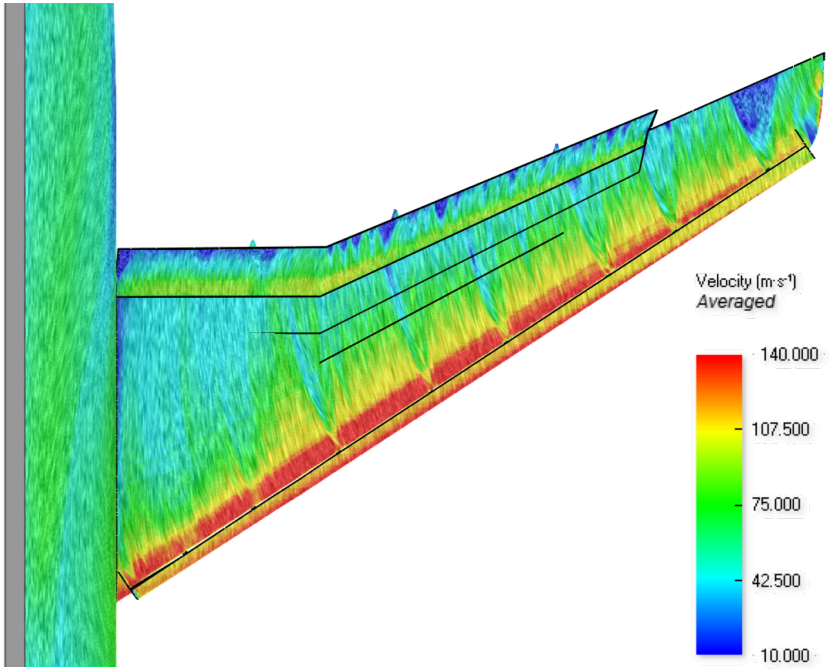
Case2a: Oil flow images @ 18.58º

Line integral convolution + near-wall velocity





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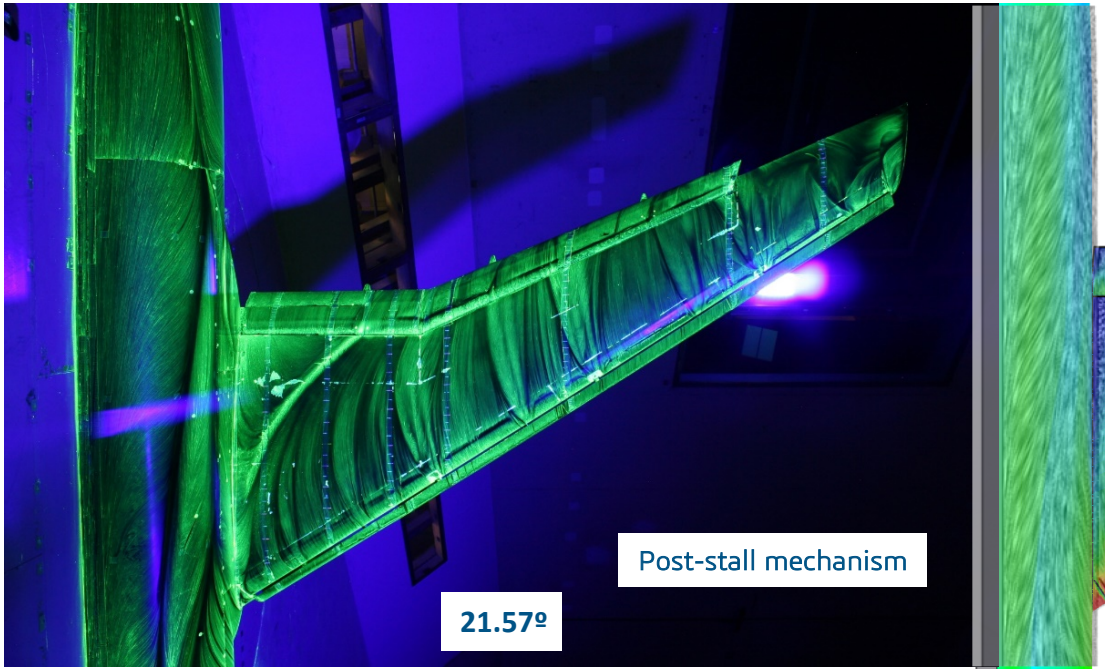
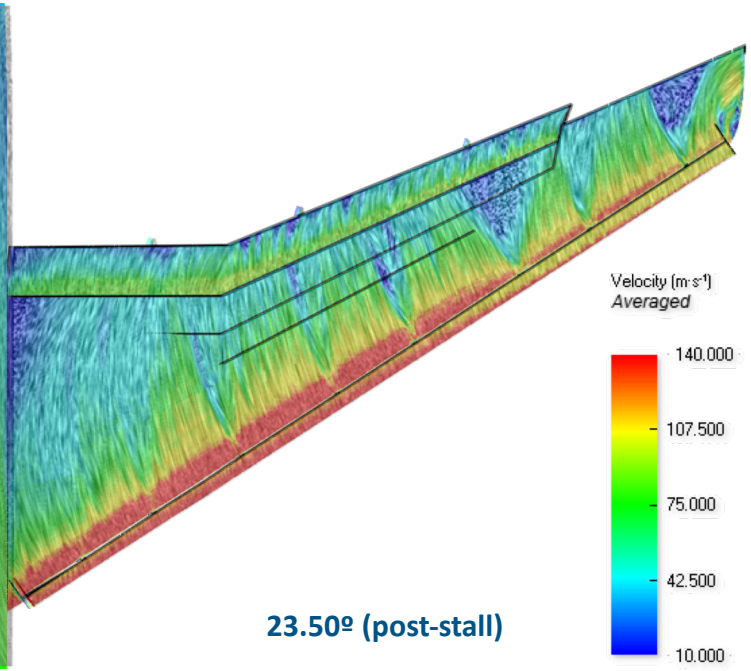
Case2a: Oil flow images @ 21.57º

Line integral convolution + near-wall velocity





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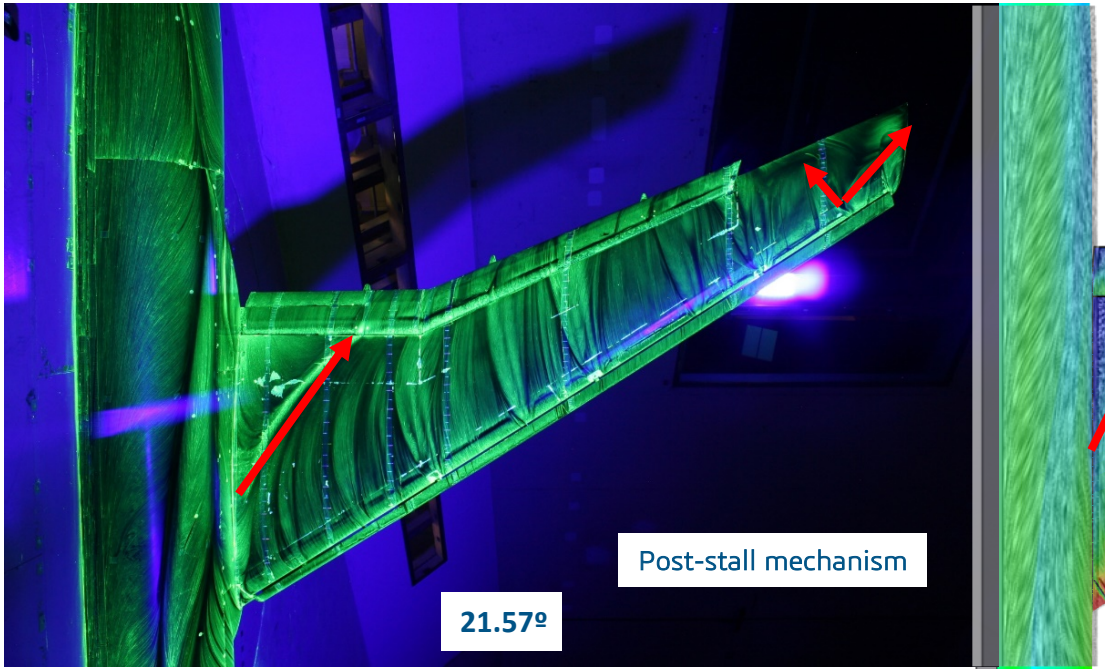
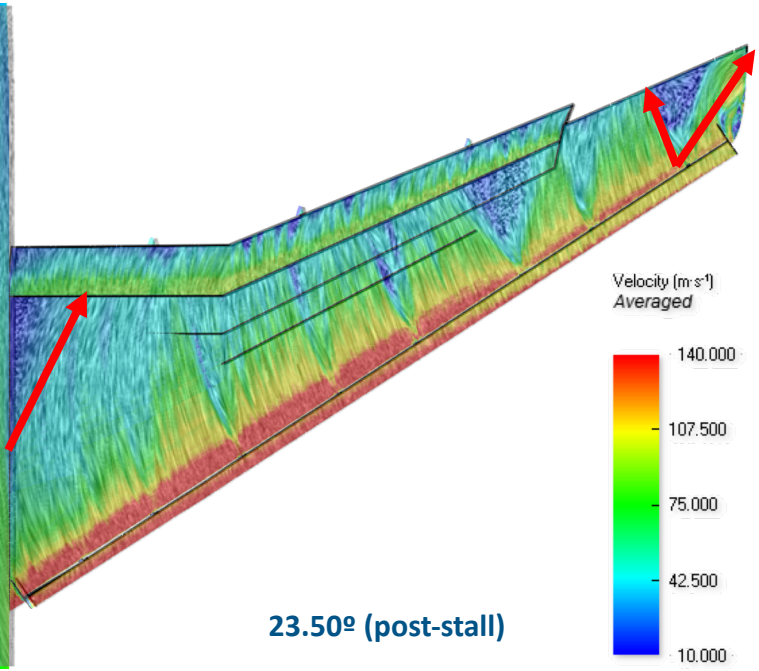
Case2a: Oil flow images @ 21.57º

Line integral convolution + near-wall velocity





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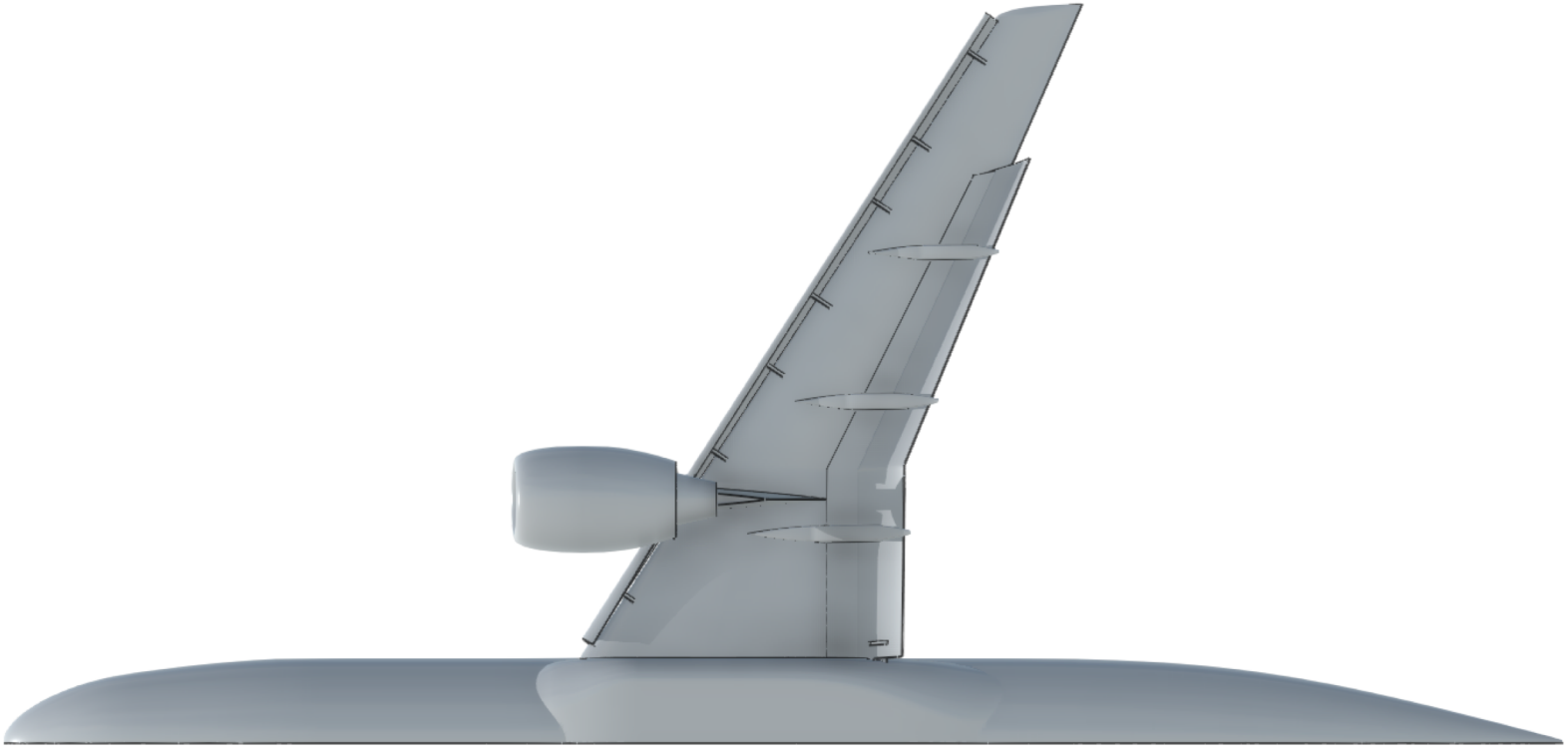
Case2c - Engine Pylon & Nacelle



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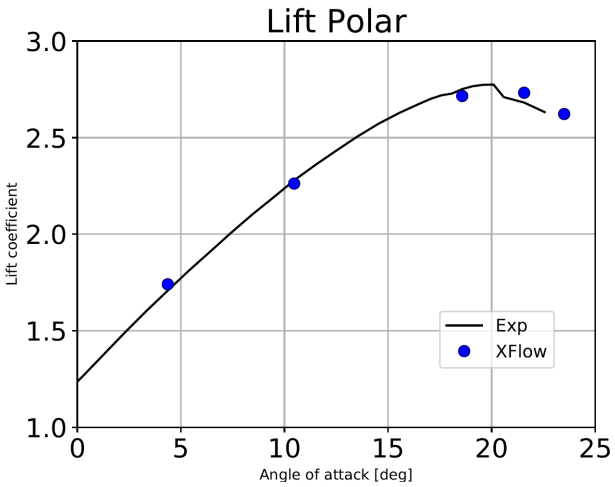
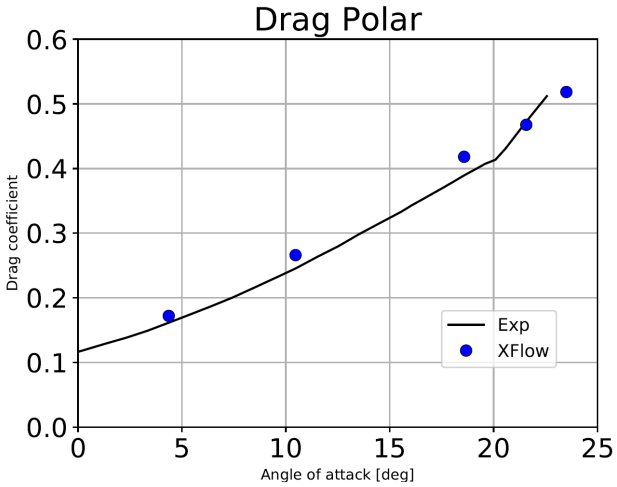
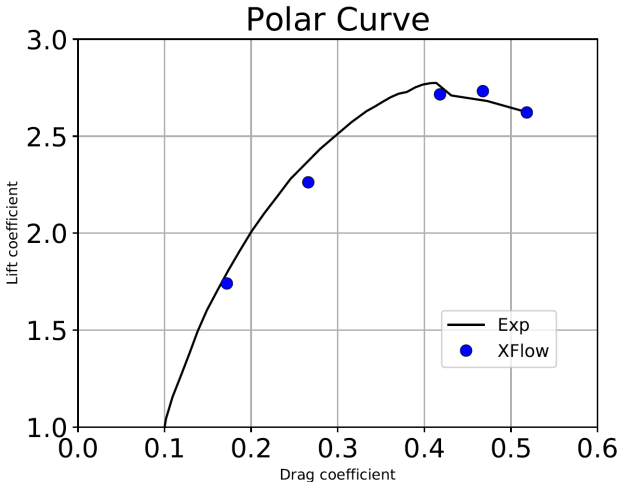
Case2c: Polar curves

Experimental stall angle = 20.09º
XFlow stall angle = 21.58º

Experimental max CL = 2.775
XFlow max CL = 2.732







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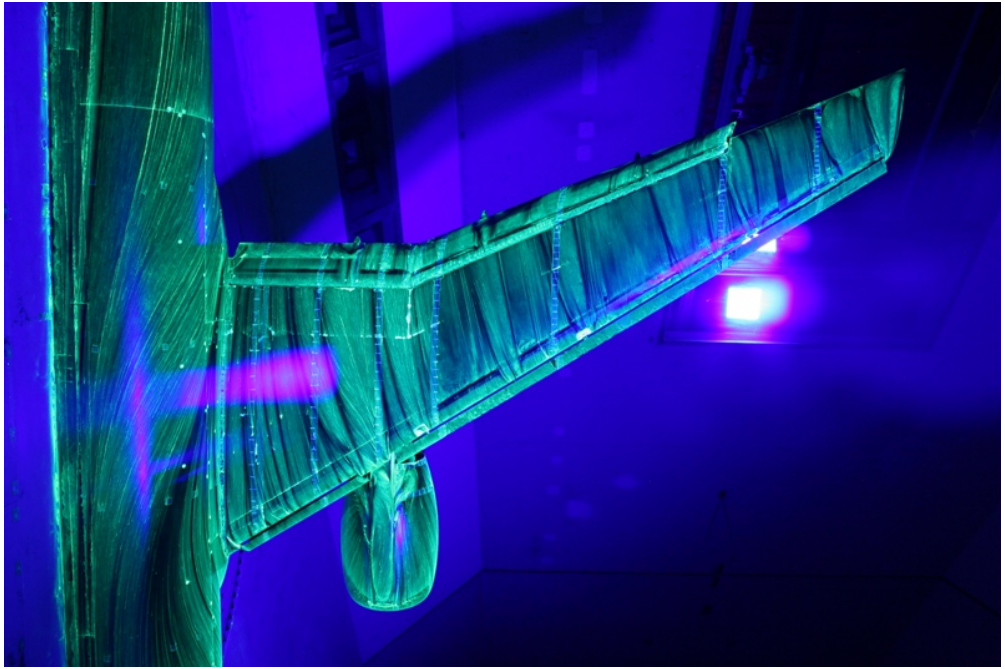
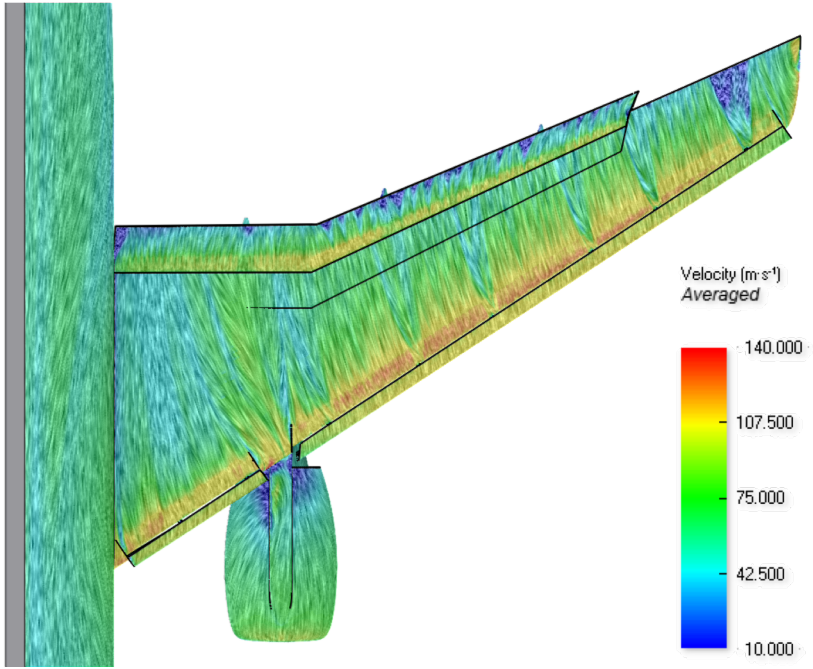
Case2c: Oil flow images @ 10.47º



Line integral convolution + near-wall velocity



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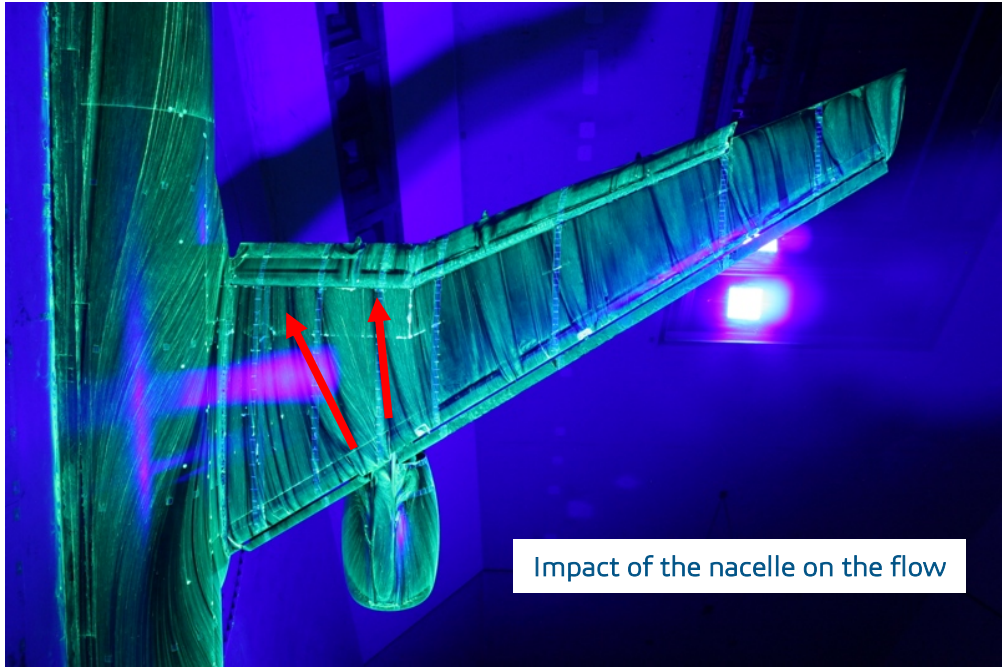
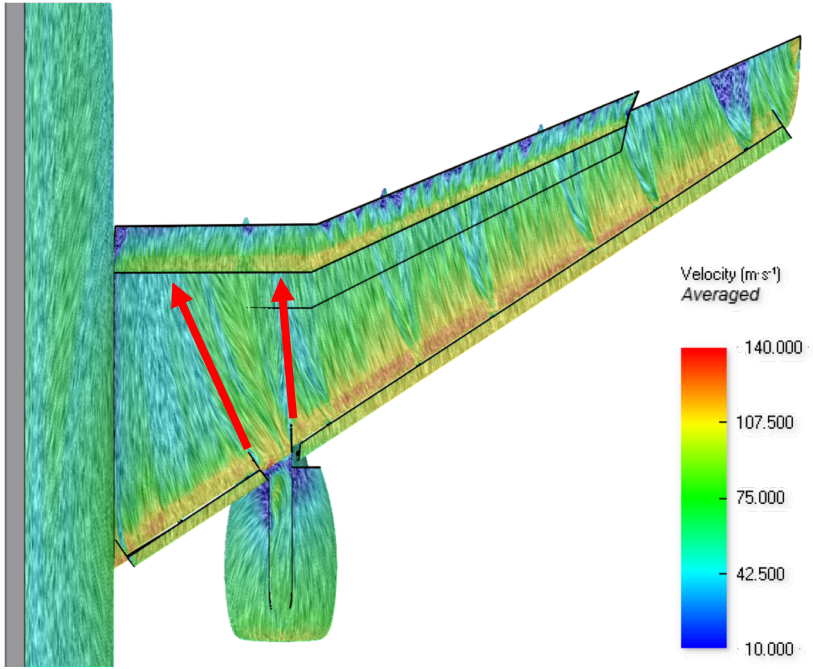
Case2c: Oil flow images @ 10.47º



Line integral convolution + near-wall velocity



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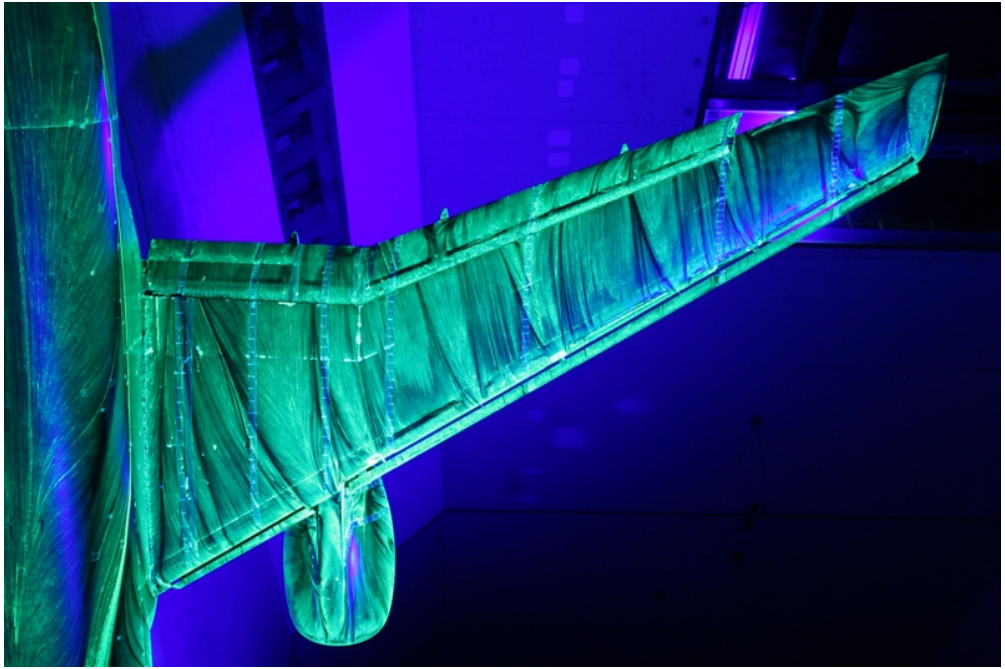
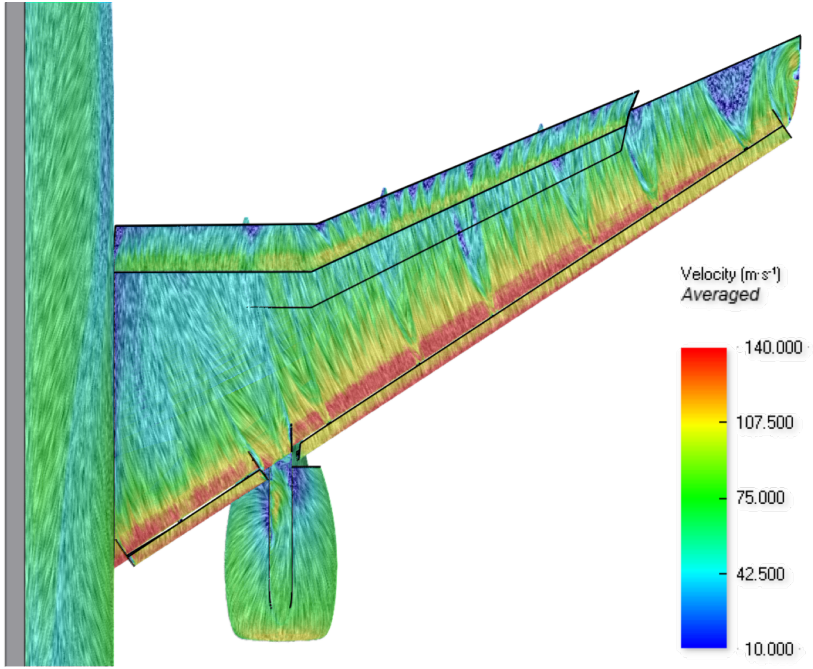
Case2c: Oil flow images @ 18.58º



Line integral convolution + near-wall velocity



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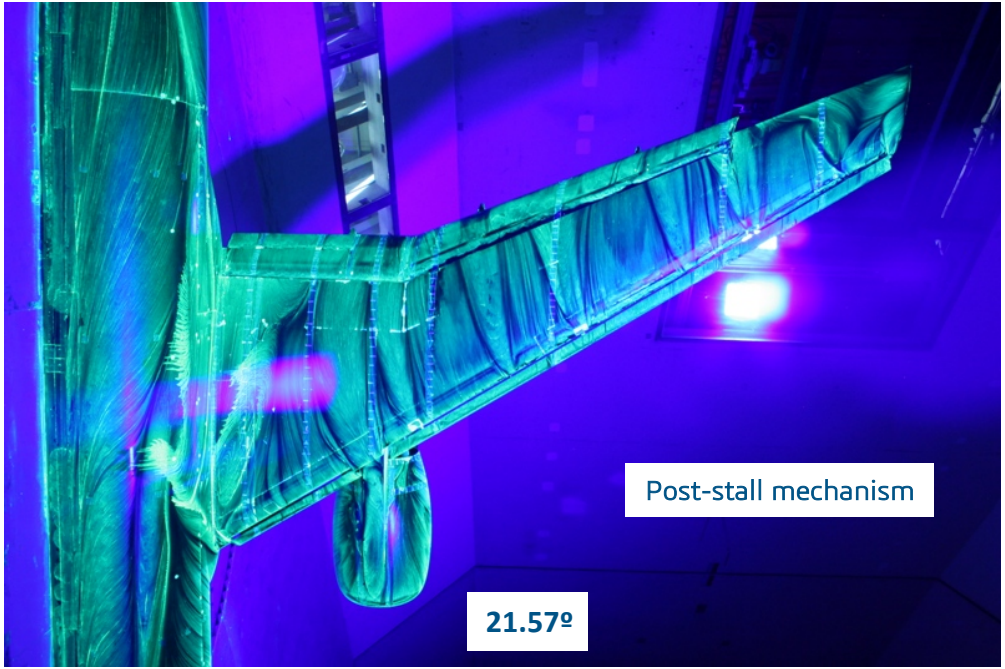
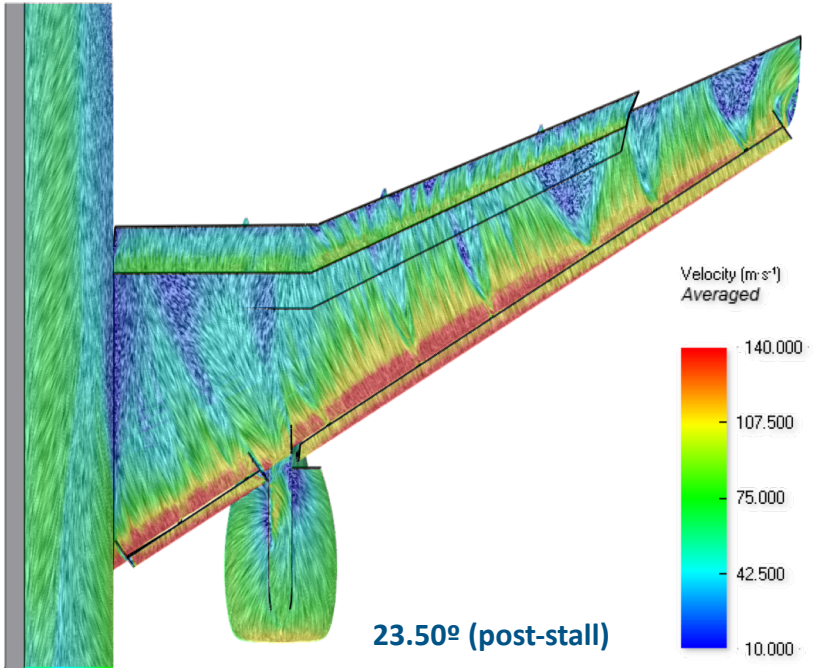
Case2c: Oil flow images @ 21.57º



Line integral convolution + near-wall velocity



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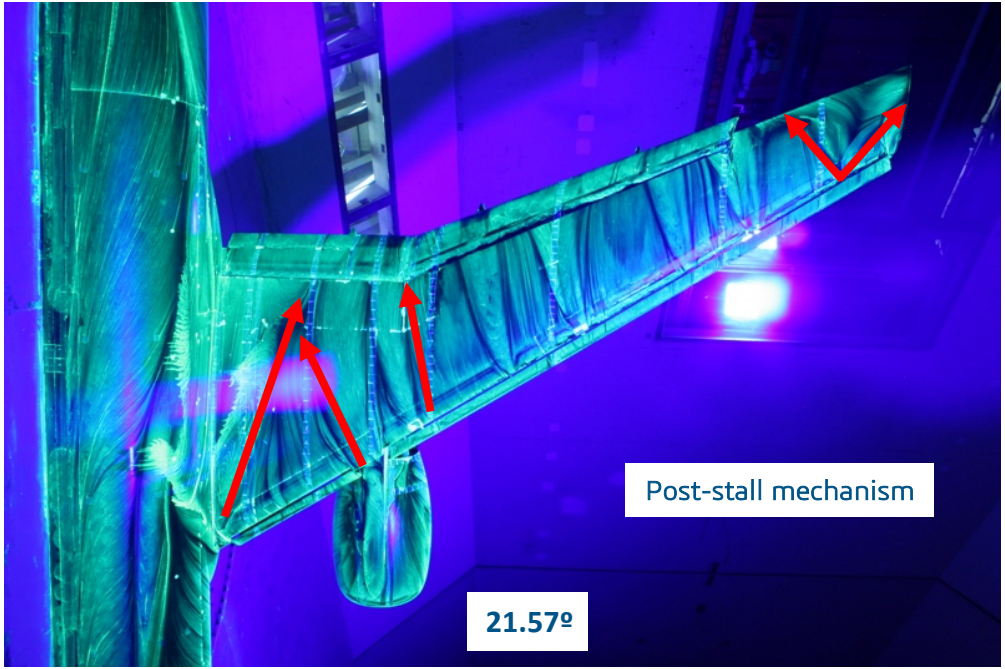
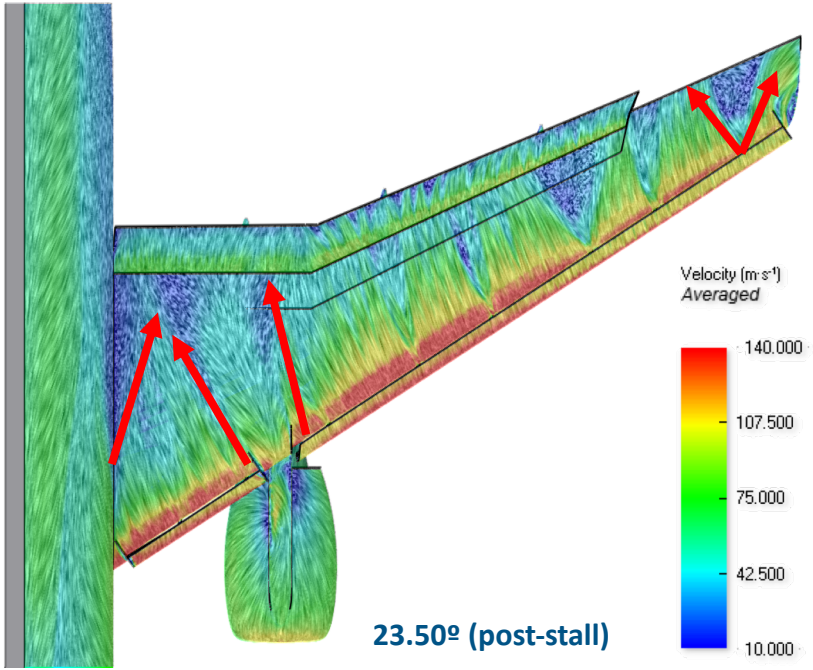
Case2c: Oil flow images @ 21.57º



Line integral convolution + near-wall velocity



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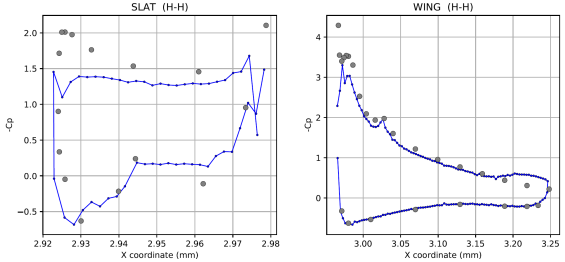
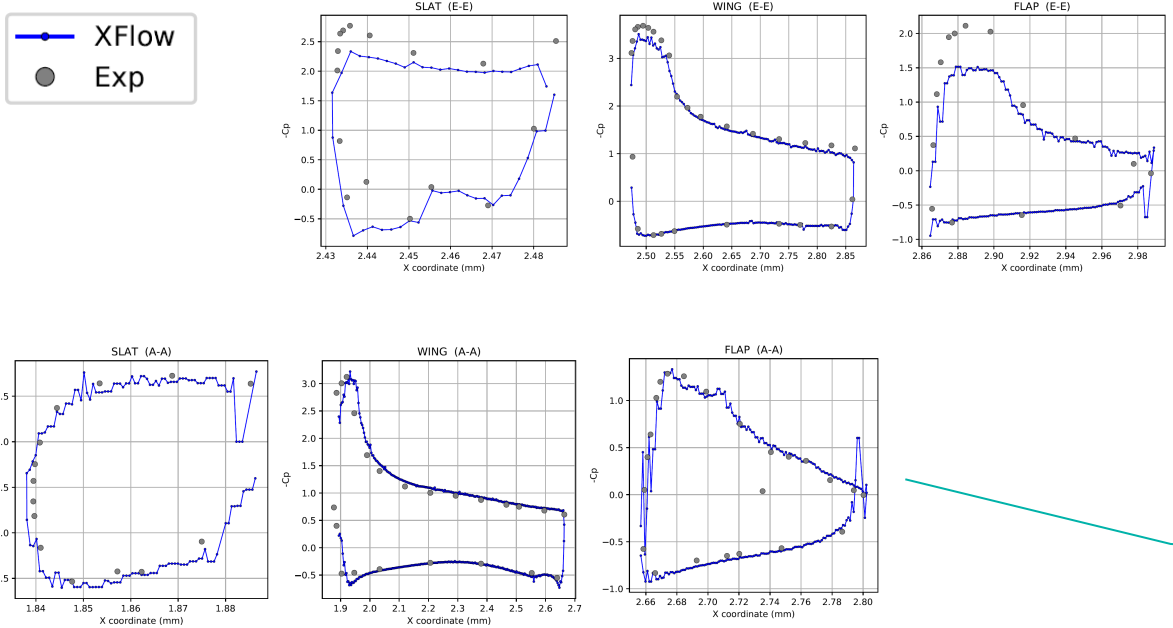
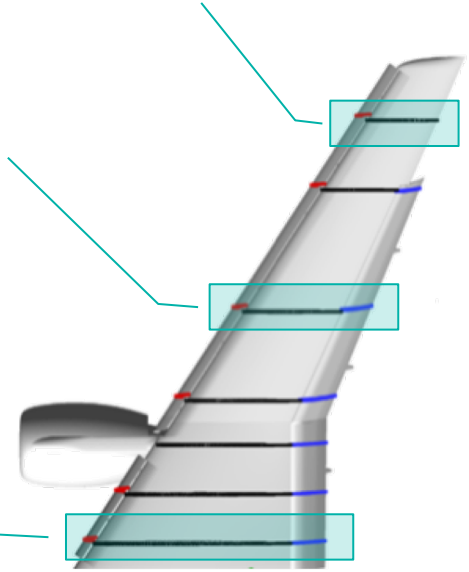
Case2c - AoA 10.47







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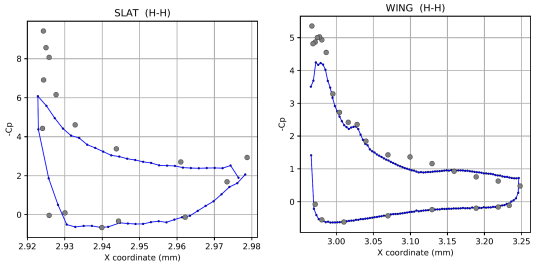
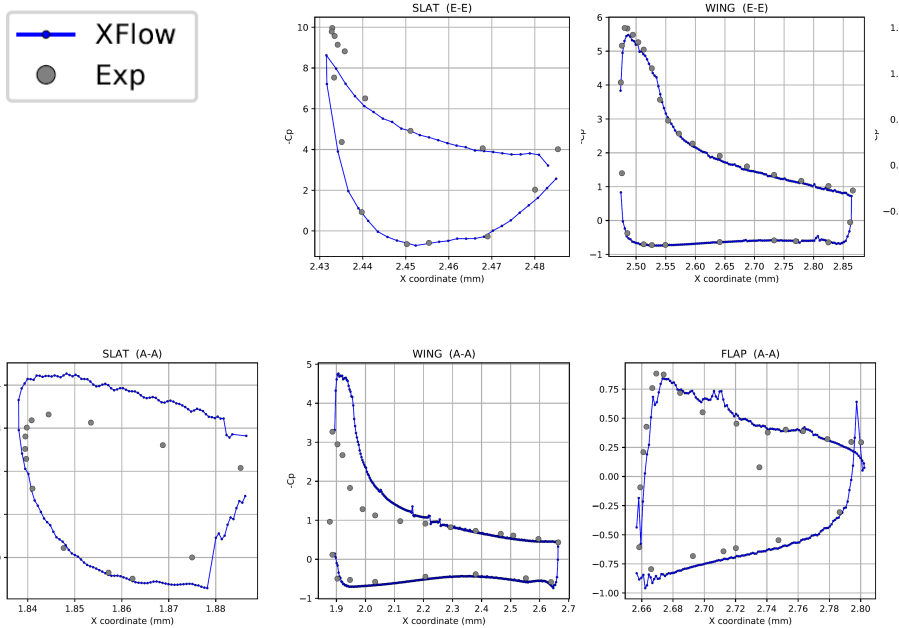
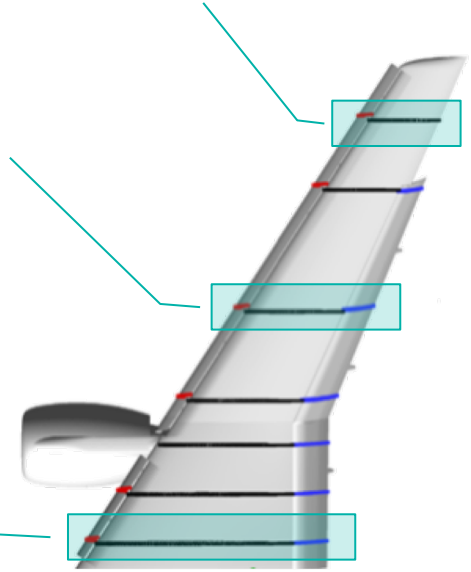
Case2c - AoA 21.57







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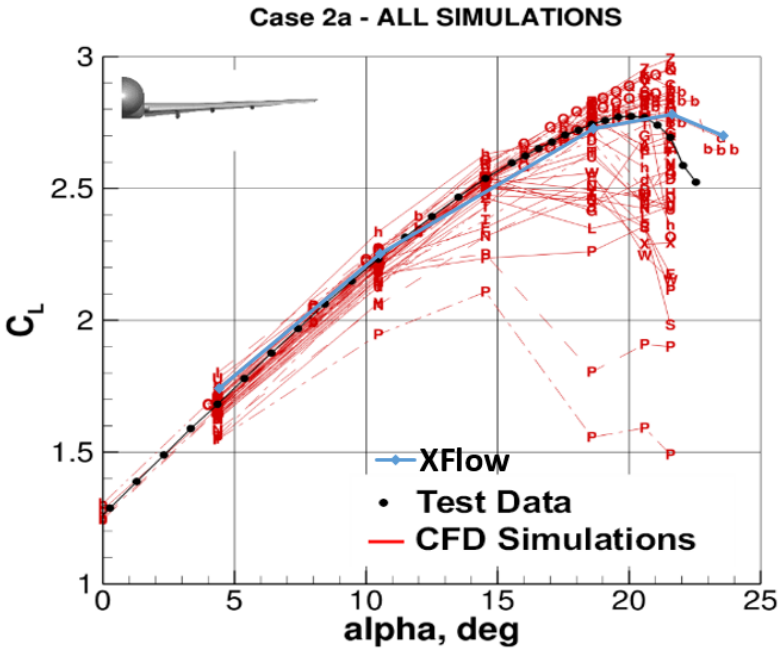
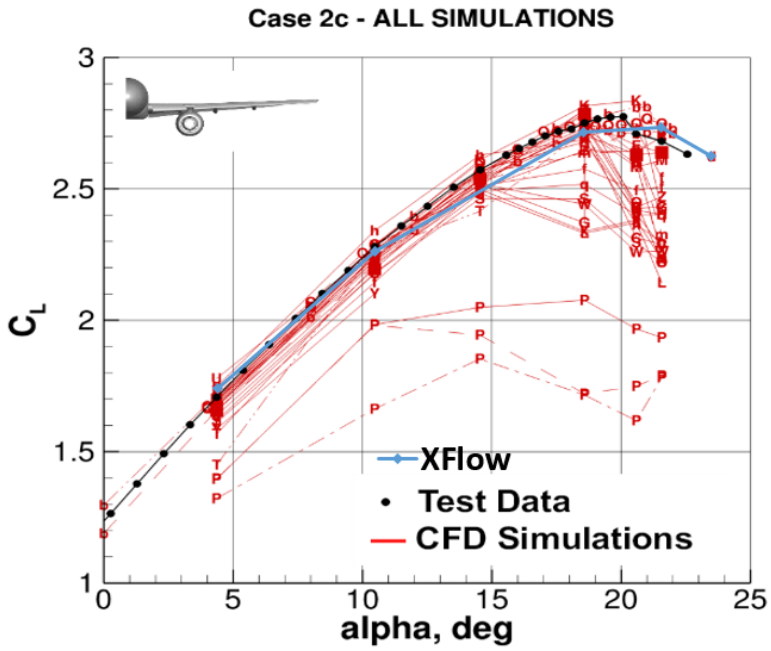
Case2a/Case2c summary and comparison with other participants





Source: https://hiliftpw.larc.nasa.gov/Workshop3/HiLiftPW3-Presentations/Summary_Case2.pdf

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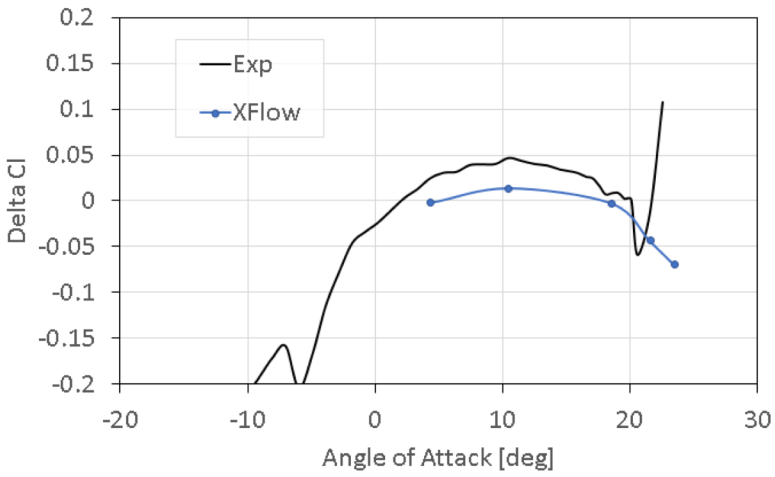
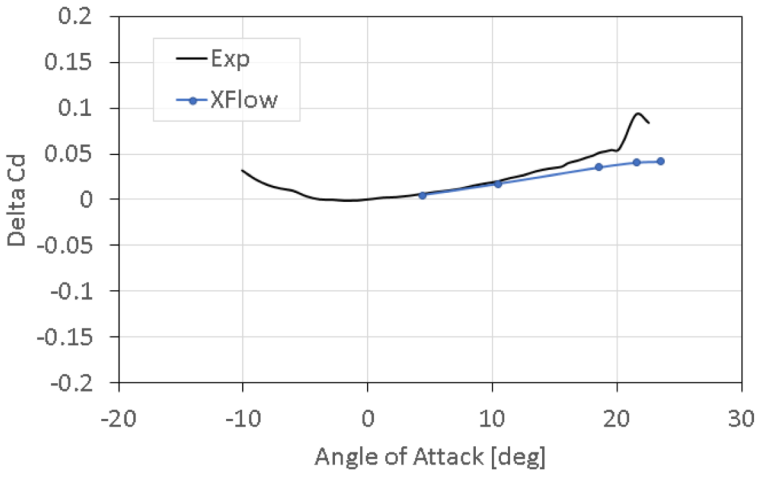
Engine Installation Effects





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Summary

- Case1a:
  - Convergence is highly sensitive to refinement in slat and flap gaps, especially at the outboard flap
  - Extra fine mesh may be required to confirm discretization-independent solution

- Case2a/Case2c:
  - XFlow predicts both lift and drag performance with good correlation with wind tunnel measurements:
    - Stall is captured with good accuracy (CLmax, stall angle)
    - Flow patterns are similar to oil flow images (STF separation, etc.), despite the inboard wing-fuselage separation being under-estimated
    - Engine Pylon & Nacelle installation effects are easily estimated and match reasonably well the experimental values

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Giuseppe.TRAPANI@3ds.com

Thank you for your attention

teideHPC

XFlow

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Back-up

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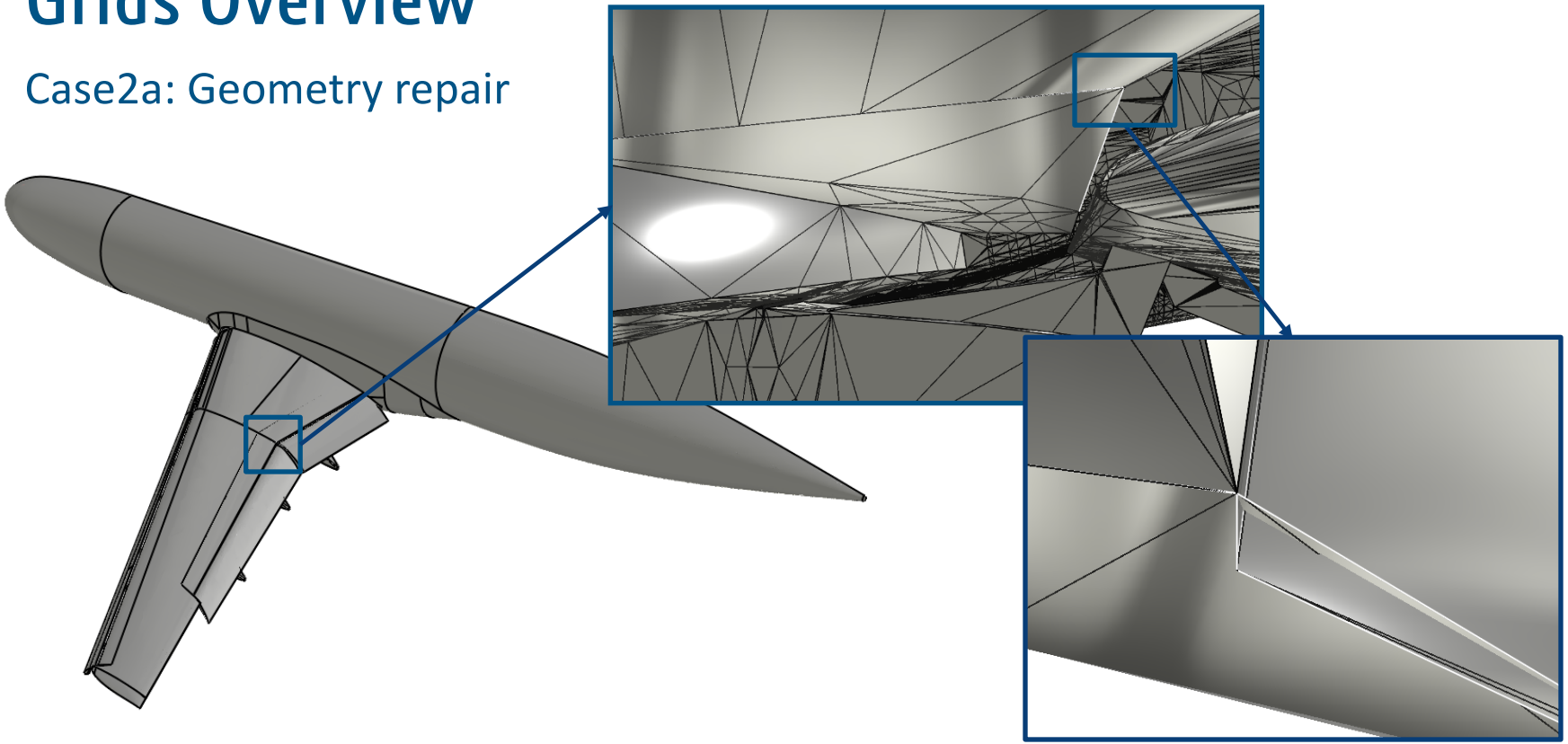
Grids Overview

Case2a: Geometry repair



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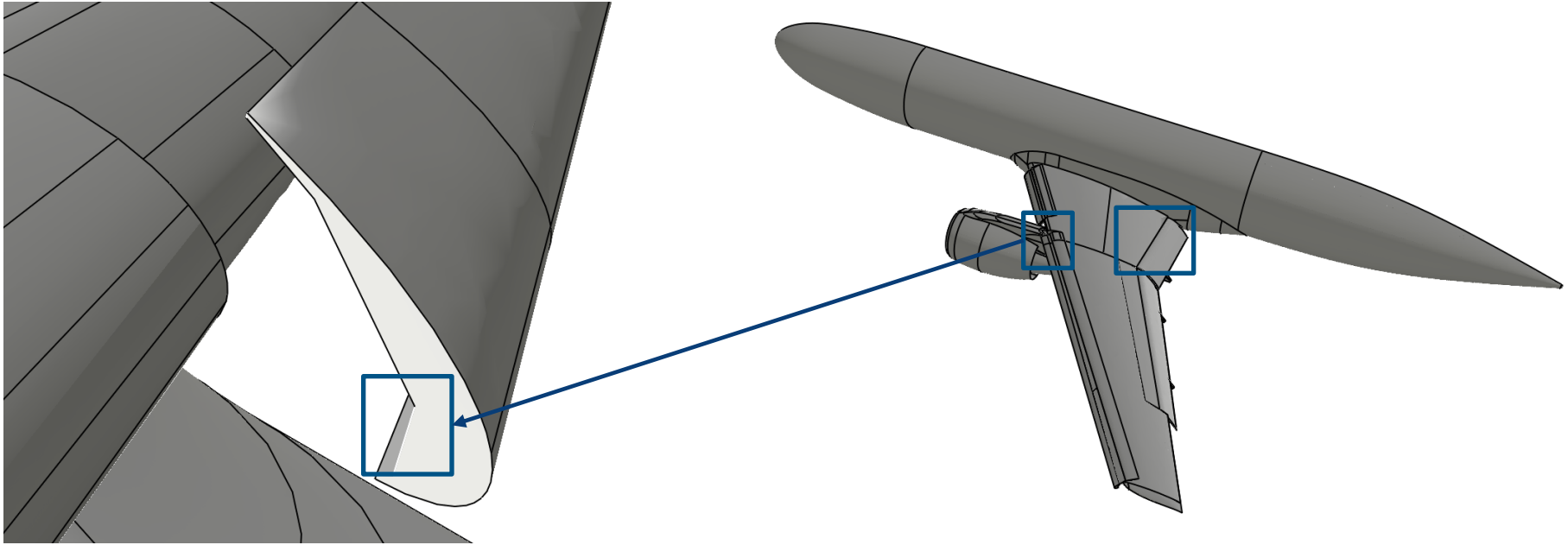
Grids Overview

Case2c: Geometry repair



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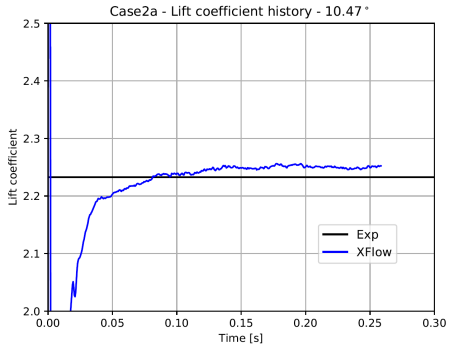
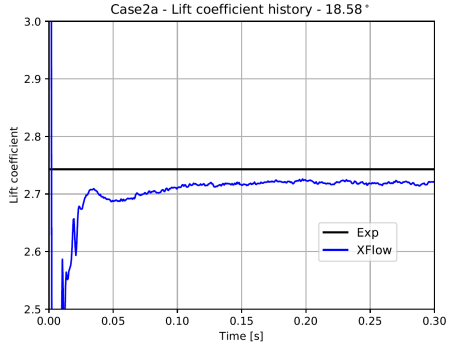
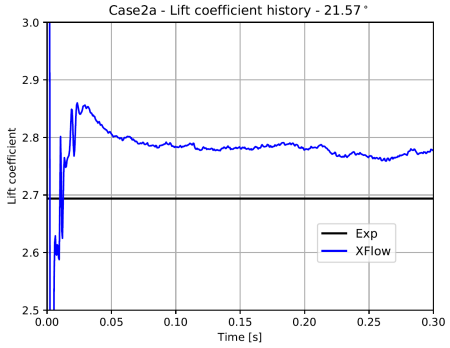
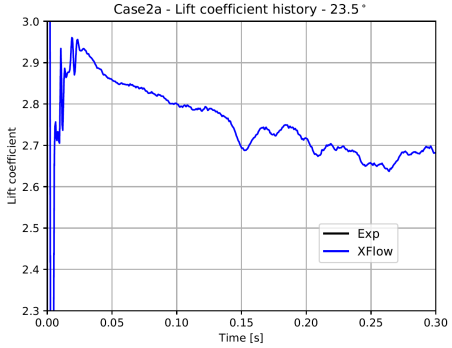
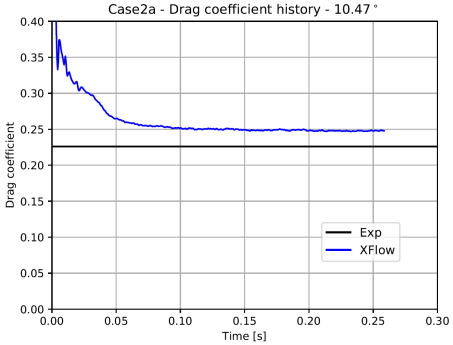
Case2a: Forces time histories

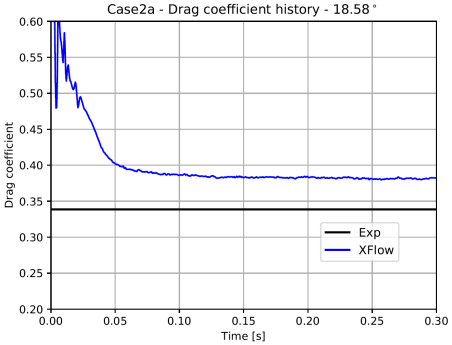


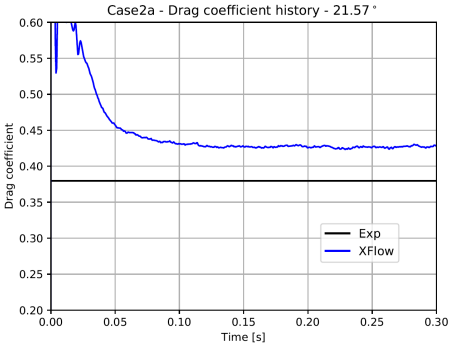


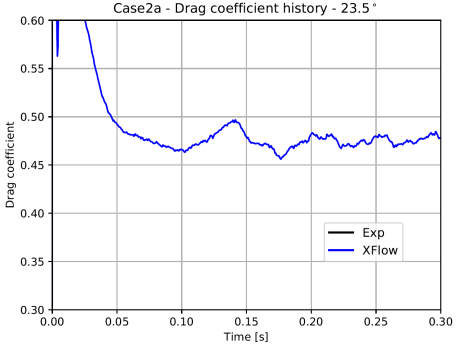












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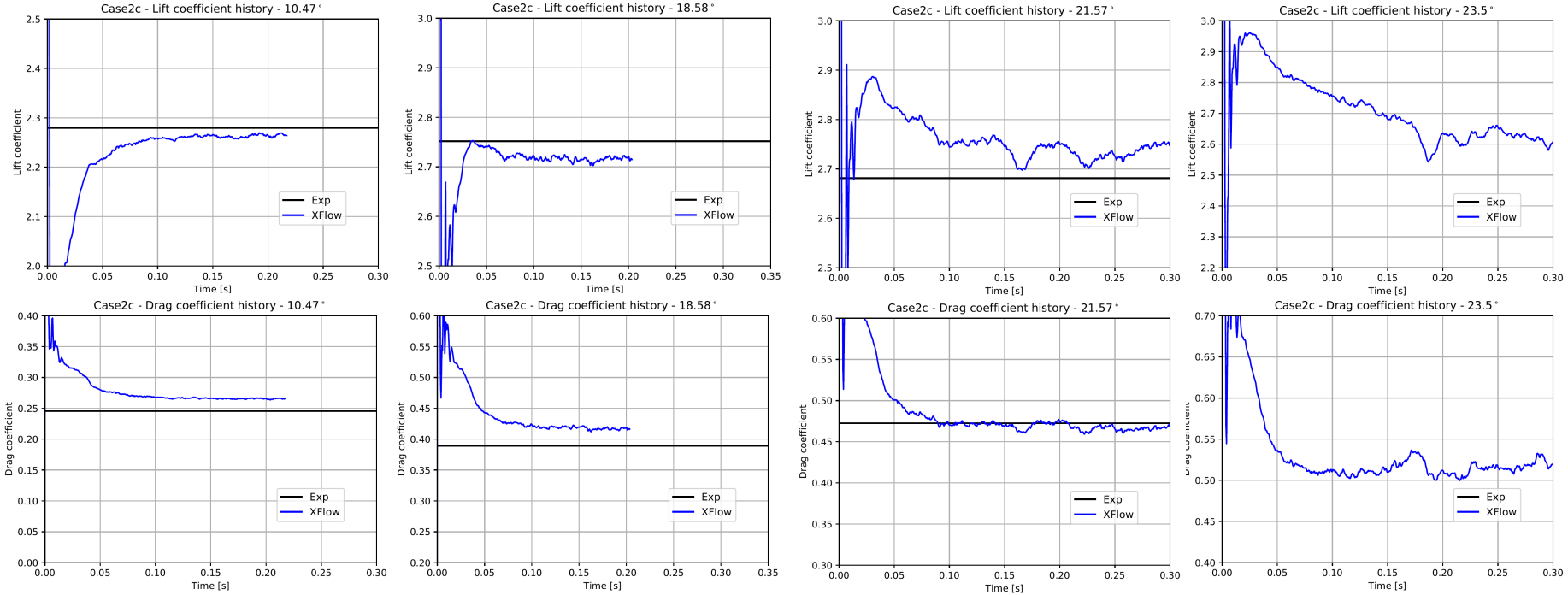
Case2c: Forces time histories



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