

XFlow CFD results for the 1st AIAA High Lift Prediction Workshop

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THEME

Computational Fluid Dynamics

KEYWORDS

External aerodynamics, particle-based approach, lattice-Boltzmann method, high lift configuration, NASA trapezoidal wing, HiLiftPW, AIAA.

SUMMARY

This paper deals with the results of the CFD code XFlow for the 1st AIAA High Lift Prediction Workshop, which took place in June 2010 in Chicago, IL. The purpose was to assess XFlow accuracy in terms of drag, lift and pitching moment coefficient prediction for a complex and realistic problem such as the High Lift Prediction Workshop. Due to the particle-based fully Lagrangian approach of XFlow, the technology is mesh-less and complex wing shapes such as the NASA trapezoidal wing, which is a 3-elements airfoil, can be easily simulated. Results show good agreement with experiment from low angles of attack until high lift. The maximum lift angle and therefore the stall has been correctly predicted by XFlow.

1: Introduction

Computational Fluid Dynamics (CFD) technology allows the analysis of flow behavior in virtual environments, lowering costs and times, and being a real alternative to the analysis in experimental facilities. Furthermore, CFD analysis provides valuable information for the understanding of flow behavior, allowing the analysis and measurement of fluid magnitudes through the whole domain without interferences. Benefits from CFD analysis are nowadays clearly stated and computational simulation is providing new insights at all stages of product lifecycle management and specifically at design stage. These are not just as a replacement to the measurement of loads at experimental facilities but also in order to better understand why the performance of some models may dramatically change under slight modifications.

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Next Limit Technologies is developer and owner of the XFlow™ CFD tool, a technology that allows the simulation of complex systems and multiphysics analysis. XFlow enables the accurate computation of fluid and solid dynamics, even interacting simultaneously in arbitrarily complex environments.

The XFlow technology is able to solve a wide range of problems involving internal and external flows and it is particularly useful for the computation of transient aerodynamics and problems involving complex geometries and boundary conditions. Specifically, XFlow is able to compute overall aerodynamics loads, static and total pressure distributions over complex models as those typically used for external aerodynamics.

Unlike traditional CFD systems, XFlow provides a proprietary Fully Lagrangian particle-based kinetic approach which dramatically reduces the time to solution for a given level of solution accuracy. Being particle-based, the algorithms behind XFlow lower the requirements imposed to the CAD models, e.g. for external aerodynamics around fixed parts the software is concerned with moving or crossing surfaces as soon as these define a coherent fluid volume. Moreover, the traditionally time consuming meshing process is totally avoided and the software just requires the target scales that the user wants to resolve for the far field, the near shapes or within the wake.

The kinetic approach has been specifically designed to perform fast with accessible hardware. The scheme has been designed to provide Large Eddy Simulation analysis for external aerodynamics in times similar to most commercial software providing just RANS analysis. The kinetic approach enables the rate-of-strain tensor locally available making possible the efficient implementation of state of the art LES models. The approach to the turbulence modeling available within XFlow takes advantage of state-of-the-art LES schemes designed to work in most cases minimizing the presence of algorithmic parameters and possible arbitrariness.

Finally, the memory requirements are also much lower than those required by classic FVM/FEM solvers and XFlow innovative approach allows complex problems to be solved on standard modern desktop computers, removing the need for large clusters or HPC systems.

2: High Lift Prediction Workshop

The 1st AIAA CFD High Lift Prediction Workshop (HiLiftPW-1), sponsored by the Applied Aerodynamics Technical Committee, took place in June 2010

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in Chicago, IL. The challenge was to simulate a half aircraft configuration composed of a body and a 3-element airfoil with a plane of symmetry (as shown in Figure 1) for a range of high angles of attack. The trapezoidal wing is composed of slat, main element and flap. The latter can be in two different configurations: "Config 1" at 25 degrees and "Config 8" at 20 degrees of angle-of-attack.

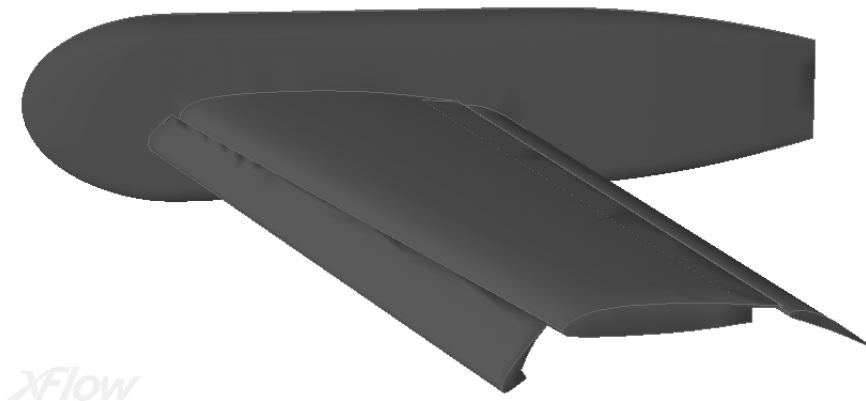


Figure 1: High Lift Prediction Geometry, Configuration 1

The objectives of the workshop are multiple [1]:

- Assess the numerical prediction capability of CFD codes in landing/take-off configuration,
- Develop practical modeling guidelines for CFD prediction of high-lift flow fields,
- Advance the understanding of high-lift flow physics to enable development of more accurate prediction methods and tools,
- Enhance CFD prediction capability for practical high-lift aerodynamic design and optimization,
- Provide an impartial forum for evaluating the effectiveness of existing computer codes and modeling techniques,
- Identify areas needing additional research and development.

This report presents the results obtained with XFlow for the High Lift Prediction Workshop. The validation has been made as close as possible to the prescribed conditions in order to ensure consistency in the analysis and comparison.

3: XFlow settings

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XFlow computations have been performed for Test Case 1:

- Trap wing "Config 1" (slat 30, flap 25)
- Mach number = 0.2
- Reynolds number = $4.3E+6$ based on mean aerodynamic chord (MAC)
- Geometry provided by the workshop [1]
- MAC = 1.0067 m
- No brackets
- Angles-of-attack: -4, 0, 6, 13, 21, 25, 28, 32, 34 and 37 degrees.

The hardware used in all the computations is a single workstation with Intel i7 2600K (quad core) processor and 16GB of RAM.

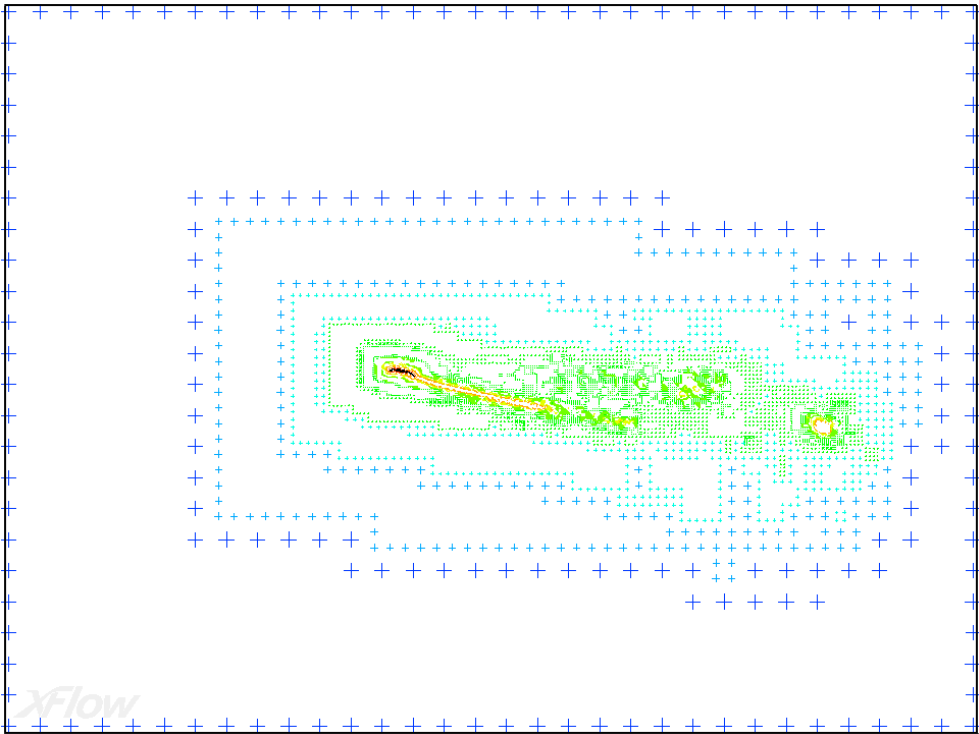
Two different spatial resolutions have been used depending on the level of lift. Resolution 1 (explained in Table 1 and shown in Figure 2) leads to very large number of elements at high angles-of-attack, which could not be computed with our resources. This is due to a large number of elements generated for the wake refinement, since separation starts to occur and detached eddies leave the airfoil. For this reason Resolution 2, with a coarser refinement for the wake, has been used for the angles-of-attack 34 and 37 degrees (where the stall starts to happen) and Resolution 1 for the other angles.

	Walls	Wake	Far Field	Max. # of Particles
Resolution 1	0.005 m	0.01 m	1.28 m	25 E+6
Resolution 2	0.005 m	0.02 m	1.28 m	10 E+6

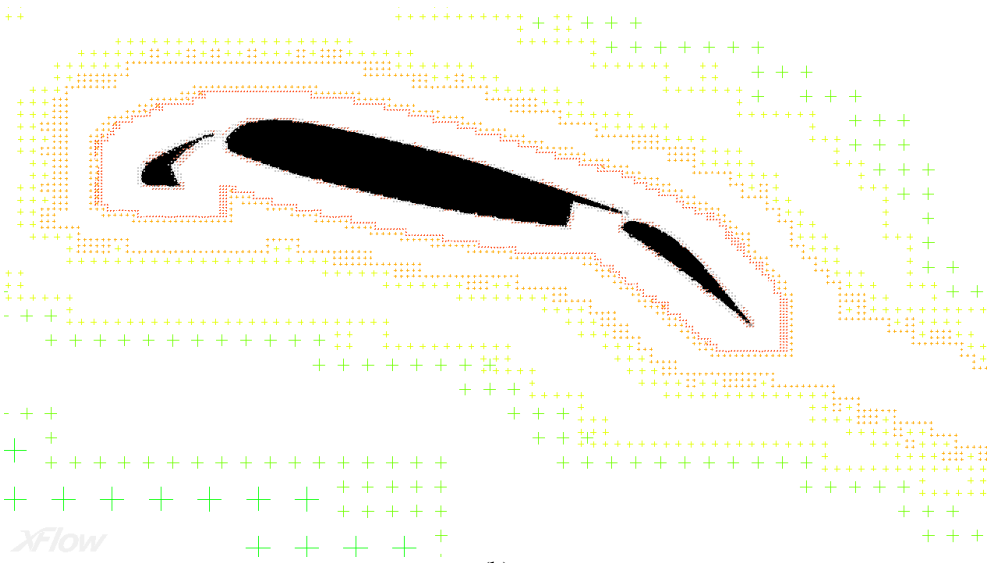
Table 1: Resolutions

Workshop attendees were asked to run all the simulation as "free air" (no wind-tunnel walls or model support systems are to be included) and fully turbulent. Since there is a symmetry axis on the geometry model, the airfoil has been placed in the XFlow virtual wind tunnel with the ground wall enabled as a free-slip wall, which has been used as the plane of symmetry.

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(a)



(b)

Figure 2: Example of lattice refinement - Resolution 1
(a) virtual wind tunnel and far field resolution, (b) resolution near walls and wake refinement

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4: XFlow results

The experimental data have been produced at the 14x22 wind-tunnel at NASA Langley. Forces, moments, and C_p distribution have been provided with free transition [2]. Data are provided as lower and upper values which are assumed to be the range of uncertainty in the wind tunnel measurements.

In Figures 3 and 4 one can observe the drag and lift coefficients against the angle-of-attack α . XFlow shows good agreement within the range [1, 28] degrees, predicting accurately both slope and values of the aerodynamic coefficients. The polar curve in Figure 5 is hence matching the experimental results, especially in the pre-stall region. The pitching moment coefficients have been calculated for the range [6, 34] degrees and also lay between the upper and lower limits of the experimental results, as shown in Figure 6.

Some snapshots of the flow field are presented in Figures 7-10.

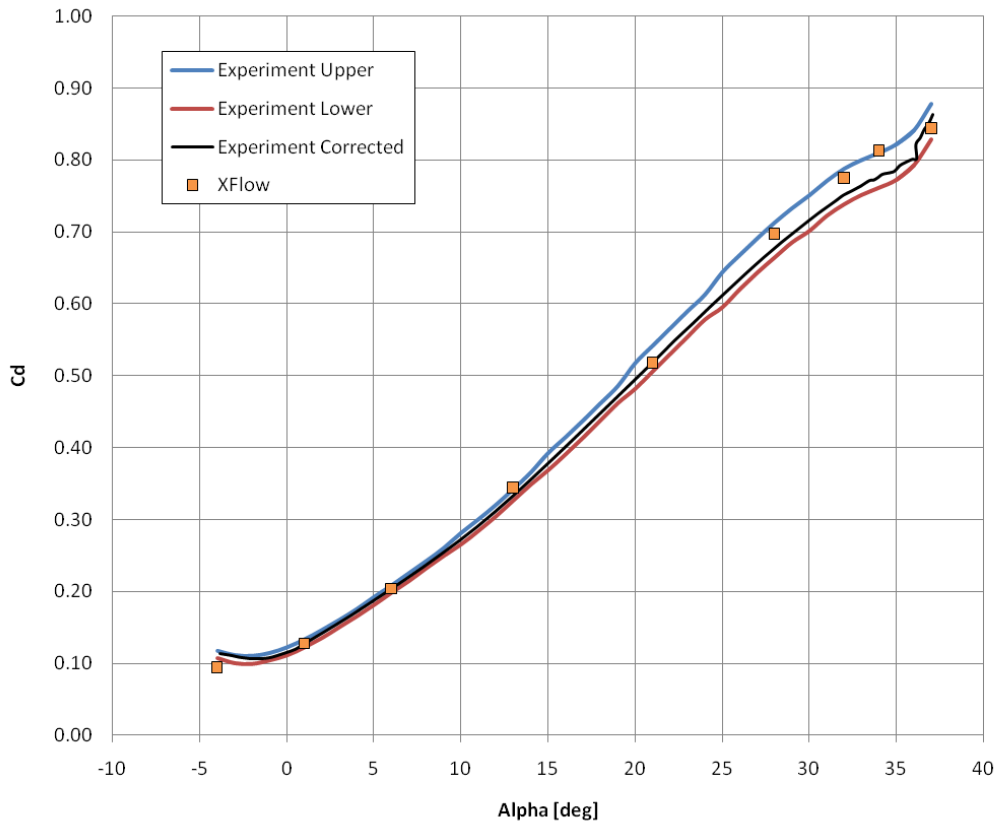


Figure 3: Drag coefficient versus angle-of-attack

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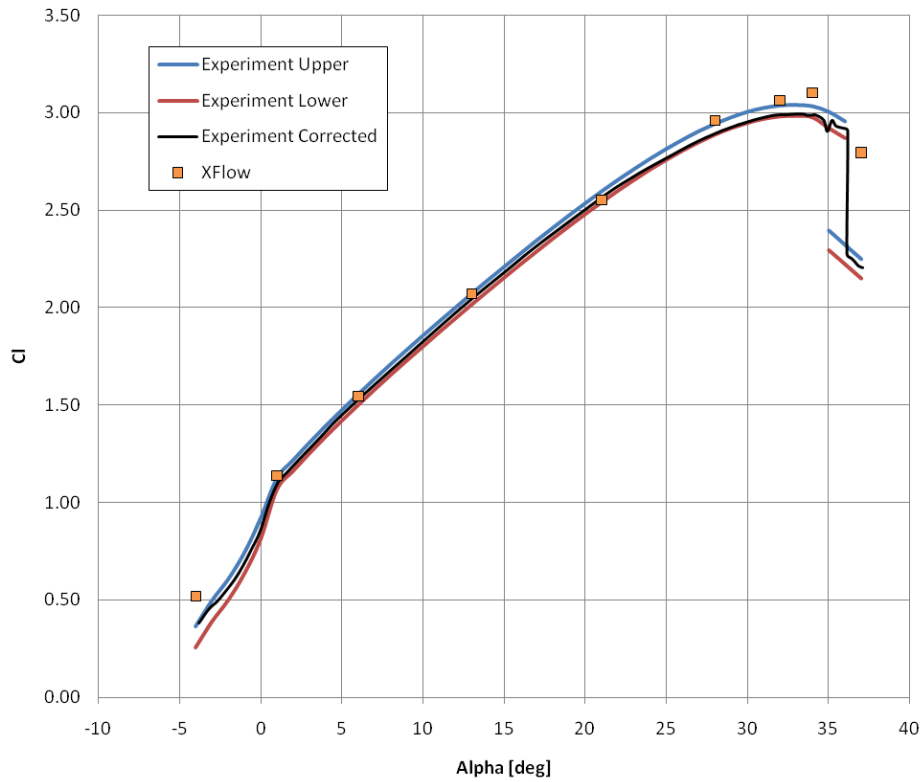


Figure 4: Lift coefficient versus angle-of-attack

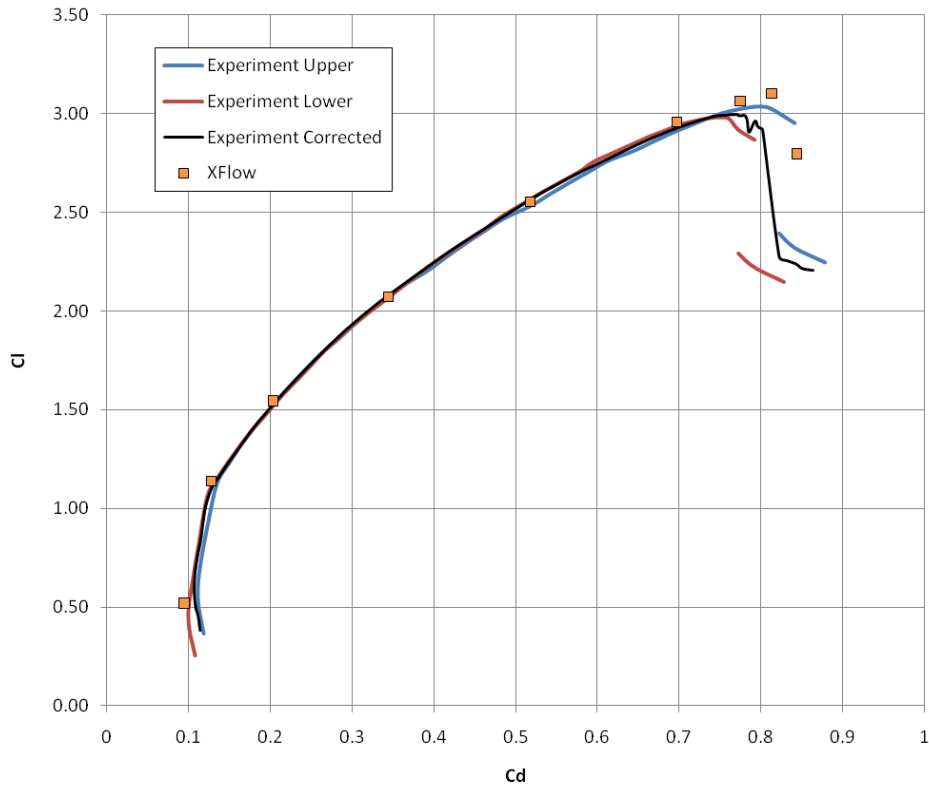


Figure 5: Polar curve

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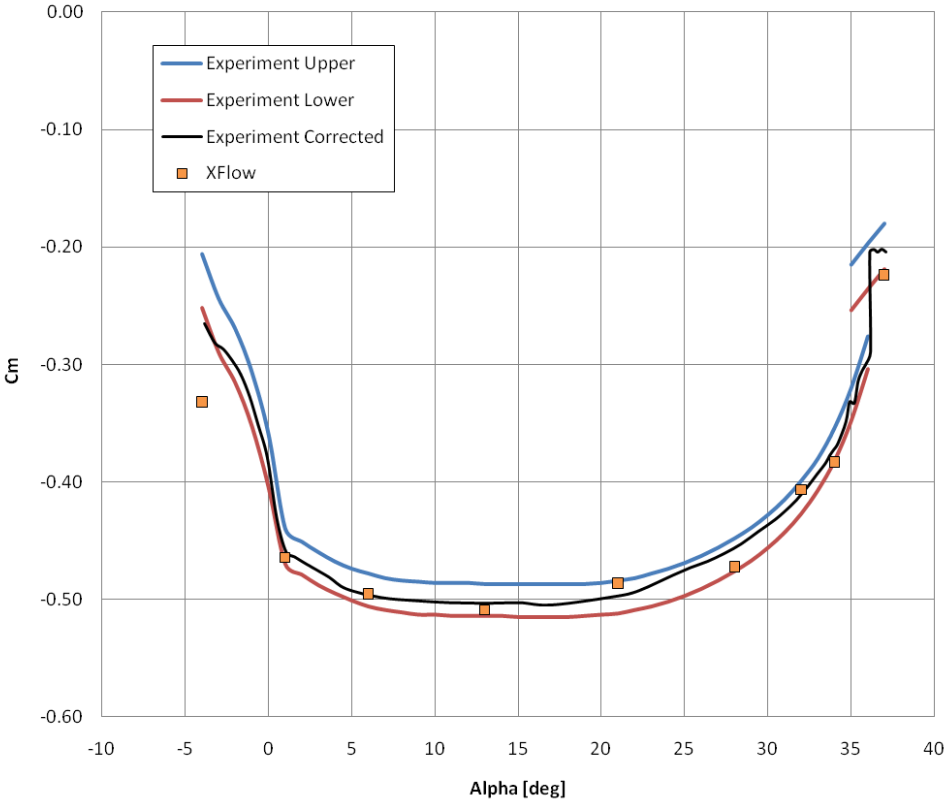


Figure 6: Pitching moment coefficient versus angle-of-attack

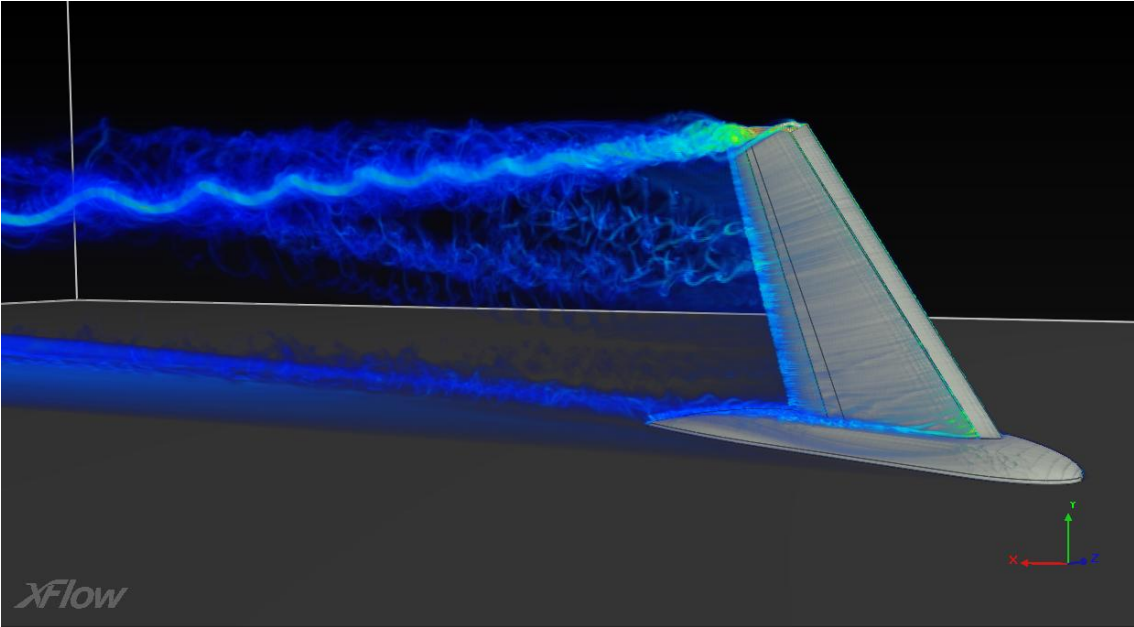


Figure 7: Volumetric rendering of vorticity - AoA = 13 - Upper side

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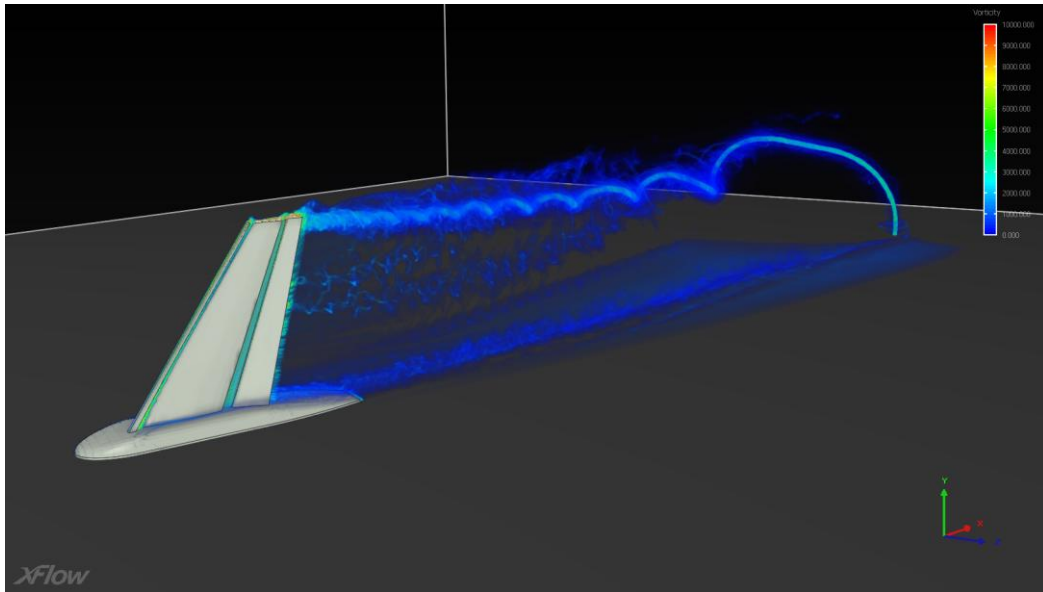


Figure 8: Volumetric rendering of vorticity - AoA = 13 - Lower side

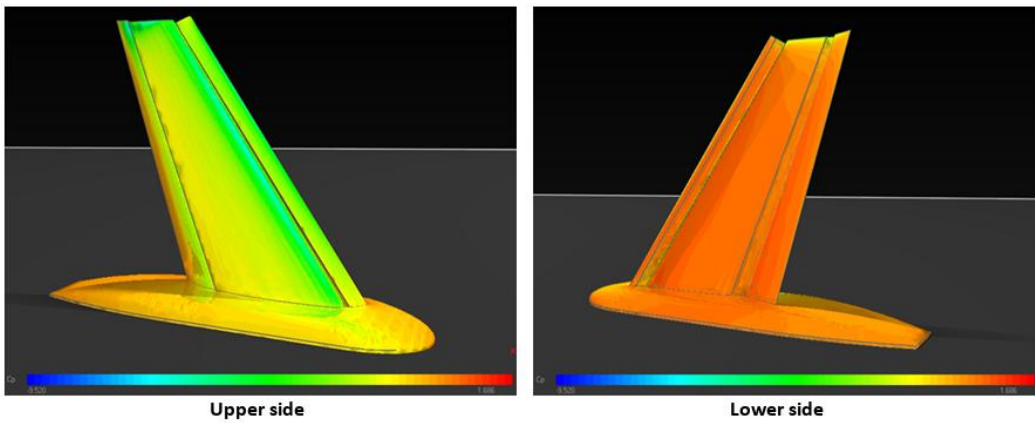


Figure 9: Pressure coefficient - AoA = 13

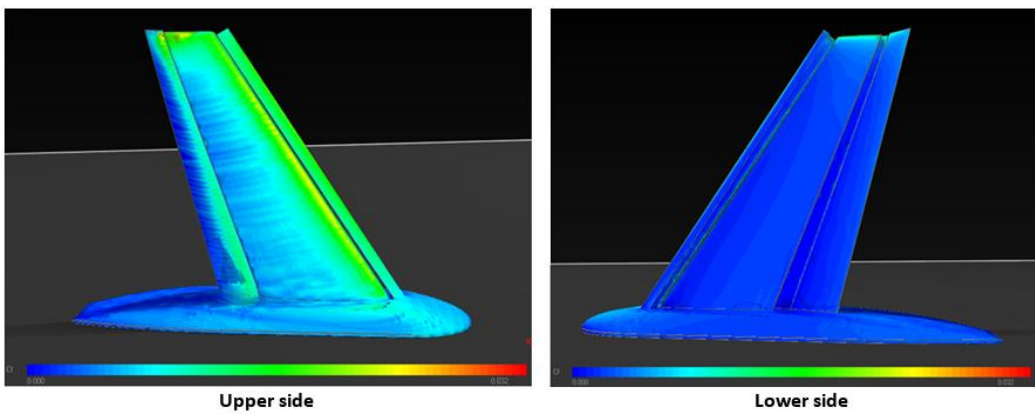


Figure 10: Skin friction coefficient - AoA = 13

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REFERENCES

[1] Christopher Rumsey, NASA Langley Research Center, *The 1st AIAA CFD High Lift Prediction Workshop (HiLiftPW-1)*, <http://hiliftpw.larc.nasa.gov/index-workshop1.html>.

[2] Mc Ginley C.B., Jinkins L.N., Watson R.D., and Bertelrud A., *3-D High-Lift Flow-Physics Experiment - Transition Measurements*, AIAA Paper, 2005-5148, 2005.