World-unique Direct FEM prediction of drag - opening new paradigm for aircraft and general design

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We show that for the first time it's possible to predict drag of a full aircraft or 3D wing, and thus general aerodynamic designs for flight, transportation, energy, architecture, etc. The computation is cheap and takes just hours, opening a new paradigm for aircraft and general design.

What causes drag of a wing or aircraft? Understanding this key scientific question is the key to designing for example efficient electric aircraft and vehicles, and our future society.

Based on the Digital Math framework and the Unicorn/FEniCS realization, we show that our Direct FEM Simulation (DFS) predictions of drag without skin friction are consistent with advanced benchmarks. This changes the design process to focus on form, where large gains from increasing lift/drag may be possible.

Abbott, Von Doenhoff and Stivers [1] already in 1945 performed advanced real flight and wind tunnel experiments, showing that drag does not depend on the Reynolds number (the velocity keeping everything else constant). We present a digitized version of their plot in Figure 1. Ladson [3] in 1988 replicate this result. We can for the first time show that this is consistent with negligible skin friction, by detailed validation of our predictions against their and other experiments. In Figures 1 and 4 we see that our DFS computations without skin friction predicts the experimental drag value for NACA0012.

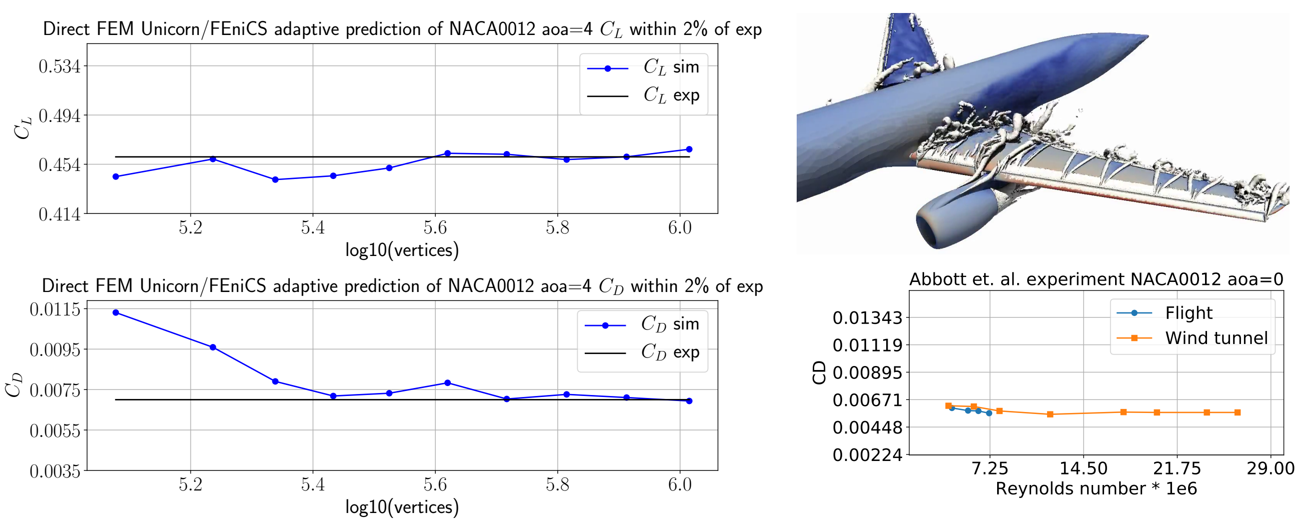

Figure 1: (Left) Adaptive DFS prediction of drag for NACA0012 at aoa=4 with slip BC - zero skin friction. (Top Right) Adaptive DFS prediction of stall in NASA HiLiftPW-3. The two key advances allow prediction and design of the full flight envelope for an aircraft, and the full range of phenomena for ground vehicles, etc.
(Bottom Right) Abbott, Van Doenhoff and Stivers real flight and wind tunnel experiment for aoa=0 showing drag CD does not depend on the Reynolds number.

Rivers et. al. [5] perform experiments of a full aircraft - the NASA Common Research Model. The experiments show that the drag does not depend on the Reynolds number. They say: “Typically, as Reynolds number increases, the skin friction drag decreases, which in turn means the total drag should decrease and effective camber increases. This typically results in an increase in lift at a given angle-of-attack, and at a given CL, the pitching moment should be more negative. None of the data at any of the three temperatures presented follow these trends. This break in trend may be explained by a greater extent of laminar flow at the lower Reynolds numbers, which in turn could cause a thinner boundary layer at the trailing edge of the upper surface than the higher Reynolds numbers. This behavior is being investigated further. “

In Figures 2 and 3 we show detailed DFS validation of the advanced NASA HiliftPW-2 experiment. We see that our DFS computations without skin friction predicts the experimental drag value, and lift as well.

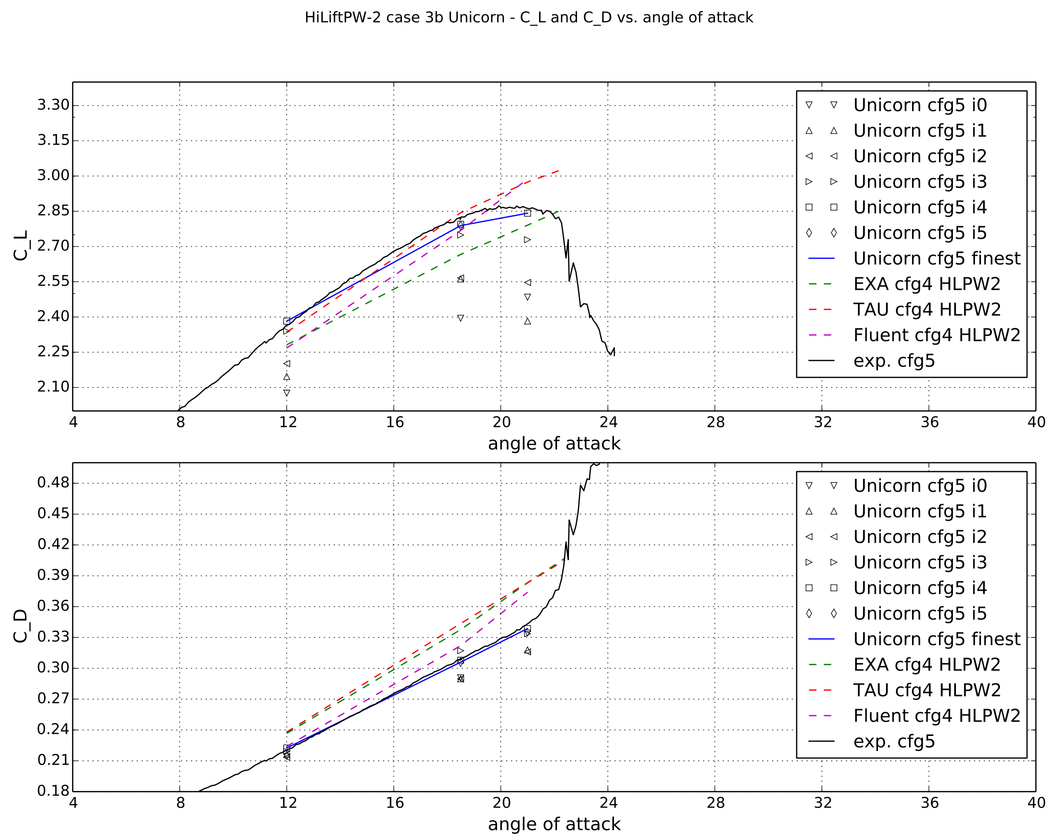

Figure 2: Adaptive DFS prediction of lift and drag for a full aircraft in NASA HiLiftPW-2 with slip BC - zero skin friction.

1 Digital Math Software

The simulations in this article have been computed using the Unicorn solver in the FEniCS automated FEM software framework [2, 4], and are available for reproducibility and applications from the Icarus Digital Math team at [7].

2 Conclusion and outlook

We present the realization that negligible skin friction is consistent with the state of the art real flight and wind tunnel experiments of wings and full aircraft. We show that based on this realization, coupled with our predictive simulation technology, it's for the first time possible to predict drag of full aircraft, wings, and thus general aerodynamic designs.

The established models in the aerospace community state that appx. 50% of the drag comes from skin friction [6]. We see that the experimental data, coupled now with our simulation results without skin friction matching experiments, indicates that skin friction is on the order of 10%. This changes the design process to focus on form, where large gains from increasing lift/drag may be possible,

The DFS Digital Math technology and new realization opens up completely new possibilities for design of efficient aircraft and vehicles, which may be the key for unlocking long-range electric transport.

We believe that the realization shows such potential that it should be investigated thoroughly, and leveraged as much as possible, in the aerodynamics industry for meeting the challenges of our future society.

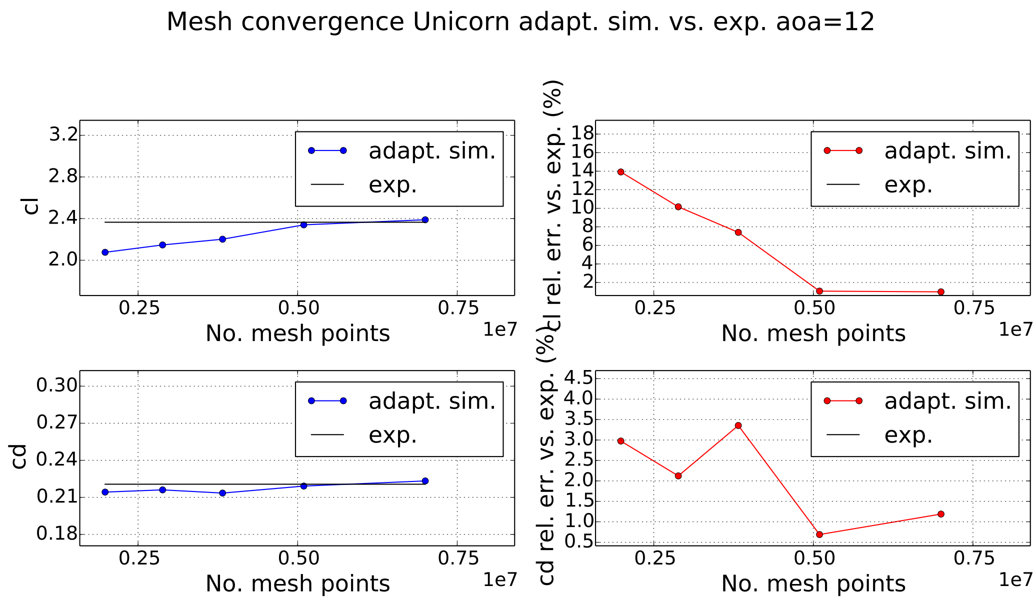

Figure 3: Adaptive DFS prediction of lift and drag for a full aircraft in NASA HiLiftPW-2 with slip BC - zero skin friction., here highlighting mesh convergence ana aoa=12.

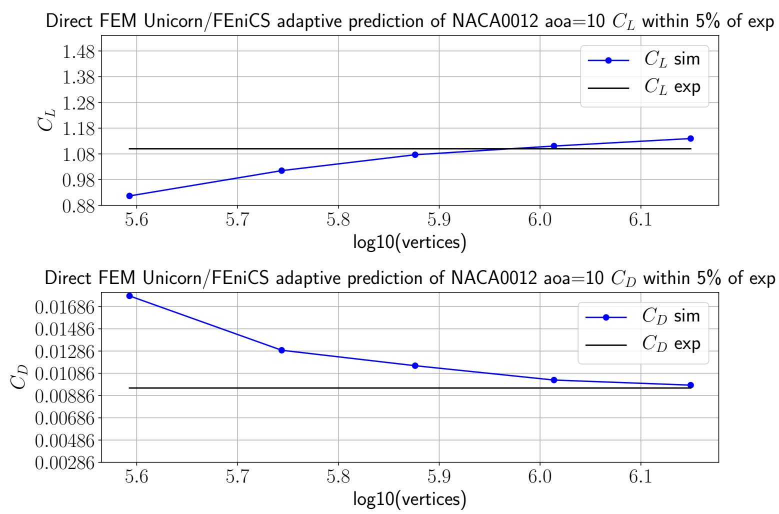

Figure 4: (Left) Adaptive DFS prediction of drag for NACA0012 at aoa=10 with slip BC - zero skin friction, with an older version of the framework.

References

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