WHY IT IS POSSIBLE TO FLY AND SAIL

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How can you prove that a butterfly in the Amazonas cannot set off a Tornado in Texas? Well, take away the butterfly and notice that tornados anyway develop.

I will present the same approach in a new resolution of the basic problem of fluid mechanics of flying and sailing: How is it possible that the flow around a wing or sail can generate a lift to drag quotient in the range 10 - 20 (up to 70 for long thin wings at low speeds), which allows flying at affordable power for both birds and airplanes, and allows sailing against the wind?

The accepted truth of fluid mechanics, formulated by the father of modern fluid mechanics Ludwig Prandtl, is that both lift and drag result from the presence of a thin boundary layer caused by a no-slip boundary condition, which generates transversal vorticity which changes the global features of the flow from the zero lift and drag and lift of potential flow to the non-zero lift and drag of real turbulent flow.

We show that Prandtl's explanation is insufficient by computationally solving the Navier-Stokes equations with slip boundary condition, which eliminates the boundary layer, and observing turbulent solutions with lift and drag in accordance with observation. We thus observe tornados without any butterfly: Lift and drag do not originate from a thin boundary layer. The central thesis of Prandtl underlying modern fluid mechanics cannot be correct.

The slip boundary condition models the small boundary friction force of slightly viscous flow, understanding that Navier-Stokes equations can be solved with (small) friction force boundary conditions or no-slip velocity boundary conditions, and that the former choice is computationally more advantageous since there is no no-slip boundary layer to resolve. This allows accurate computation of both lift and drag for complex geometries using millions of mesh point, which is possible today, instead of the quadrillions required for boundary layer resolution, which may never be possible.

The computations use the G2 (General Galerkin) finite element method with residual stabilization as automatic turbulence model with automatic a posteriori error control of mean-value quantities such as lift and drag [1]. A variety of computational results are presented including wings, cars and fluid-structure interaction, on single and multi-processor computers [4, 5]

We also present a mathematical analysis of the computed solutions showing that lift and drag result from a specific 3d instability mechanism generating low-pressure rolls of streamwise vorticity attaching at separation. This analysis gives a new resolution of d'Alembert's paradox of zero drag in inviscid flow [2], which is fundamentally different from the accepted resolution by Prandtl based on boundary layer effects.

A previous talk on the subject can be downloaded from my home page at http://www.csc.kth.se/ cgjoh/ under News: The Mathematical Secret of Flight, BAIL 2010.

I will also report on my blog under the category Svenska Mekanikdagar 2011 at http://claesjohnson.blogspot.com/ .

For more information and some movies, see the home page of Computational Technology Laboratory at http://ctl.csc.kth.se/index.php/Research .

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