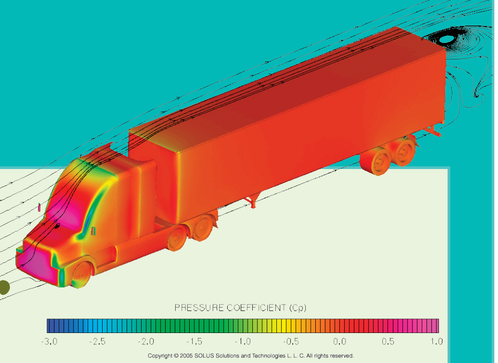
Math Matters

Apply It.

The math behind... Aerodynamic Design



Technical terms used:

Drag force, Navier–Stokes equations, computational fluid dynamics, dimensional analysis

Uses and applications:

Aerodynamic design allows all kinds of vehicles–planes, boats, cars, and trains–to be created with a fuel-efficient shape.

How it works:

Have you ever stuck your hand out of a car window to feel the breeze? If so, you have experienced the invisible force called drag! Imagine how strong this force would feel on a fast-moving plane! When any vehicle is in motion, it constantly runs into the air ahead of it, and the air pushes back to slow it down. The force from the air that opposes the motion of a vehicle is called the drag force. The faster a vehicle is traveling, the higher the drag force.

Sometimes drag is helpful. Without drag, a parachute would not slow down a skydiver. However, in transportation, the slowing effect of drag means that vehicles must work harder and consume more fuel to keep up their speed. Therefore, scientists and engineers design vehicles with aerodynamic (low-drag) shapes in order to increase fuel efficiency.

The physical principles of aerodynamic design are described by the Navier–Stokes equations, which are a famous set of nonlinear partial differential equations. In most situations, such as predicting the way air moves around a plane, these complicated equations cannot be solved by hand. However, an entire field of research called computational fluid dynamics (CFD) uses computers to tackle these difficult math problems. Sometimes it takes computers weeks of computation and terrabytes of memory to solve these CFD simulations [1]!

After the aerodynamics of a new design have been verified by CFD, a small-scale model is built for testing in a wind tunnel. Engineers must be careful, however, because a small model may interact with air pressure and wind velocity differently than a full-size model. By using a mathematical technique called dimensional analysis, engineers create a model that will accurately reflect the traits of the full-size vehicle. If the tests show that the drag force is adequately small, then the new aerodynamic design is ready to be manufactured!

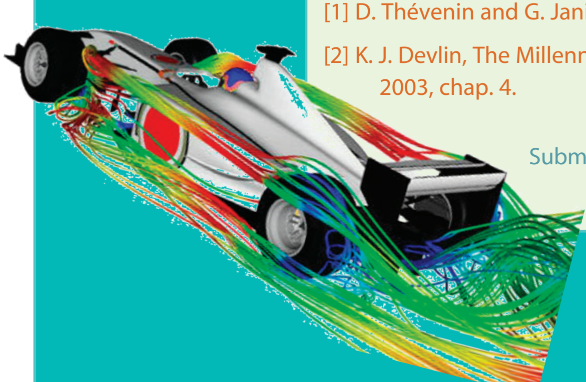
Interesting facts:

Although the Navier–Stokes equations were first written over 150 years ago, mathematicians are still working to understand some basic properties of the equations' possible solutions. In fact, the Clay Mathematics Institute named this missing theory one of the seven most important unsolved problems in mathematics and offers $1,000,000 for its solution [2].

References:

[1] D. Thévenin and G. Janiga, eds., Optimization and Computational Fluid Dynamics, Springer, 2008, chap. 1.

[2] K. J. Devlin, The Millennium Problems: The Seven Greatest Unsolved Mathematical Puzzles of Our Time, Basic Books, 2003, chap. 4.



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