**From IMAges 6, April 2009**

# From turbulence to biofuel

**Canadian Professor Andrew Pollard is an engineer who wears many hats. His 2009 visit was hosted by NZIMA and he spoke at the NZIMA programme workshop on energy, wind and water. He spoke to Jenny Rankine.**

Pollard occupies the Research Chair in Fluid Dynamics and Multi-scale Phenomena at Queen's University in Kingston, Ontario. He directs the university's Collaborative Programme in Computational Science and Engineering, and the Sustainable Bioeconomy Centre.

He has been the project leader for the High Performance Computing Virtual Laboratory, a cluster of powerful computers that now serves seven Ontario tertiary institutions, and president of the C3.ca Association, a national group of institutional users and providers of high performance computing.

He has been involved in computational and experimental fluid dynamics since the 1970s, focusing on turbulence, which he describes as the biggest unsolved classical problem in physics.

Earlier, he modelled combustion and radiation processes; now he simulates different flows, including airflow in the human windpipe, air bubbles in blood vessels and aerodynamics.

"In the 60s and 70s, we were very good engineers; we made approximations using models because computers were very small," he says. RANS (Reynolds averaged Navier-Stokes), which is a method for solving most fluid movement phenomena, was the discipline's most common tool until about 1980, he says. "Most of the fluid dynamics equations need computational methods, a combination of physics, chemistry, computer science and mathematics."

Large Eddy Simulation (LES) was first used in the early 1980s for engineering problems, although it had been used earlier for weather predictions. More recently, direct numerical simulation (DNS) solves fluid dynamics equations in three-dimensional space and time.

Pollard gives a building analogy: "From outside, you can see individual people going in and out; you can presume things about what happens inside. That's like RANS. LES is equivalent to seeing those people go in and out of lots of rooms."

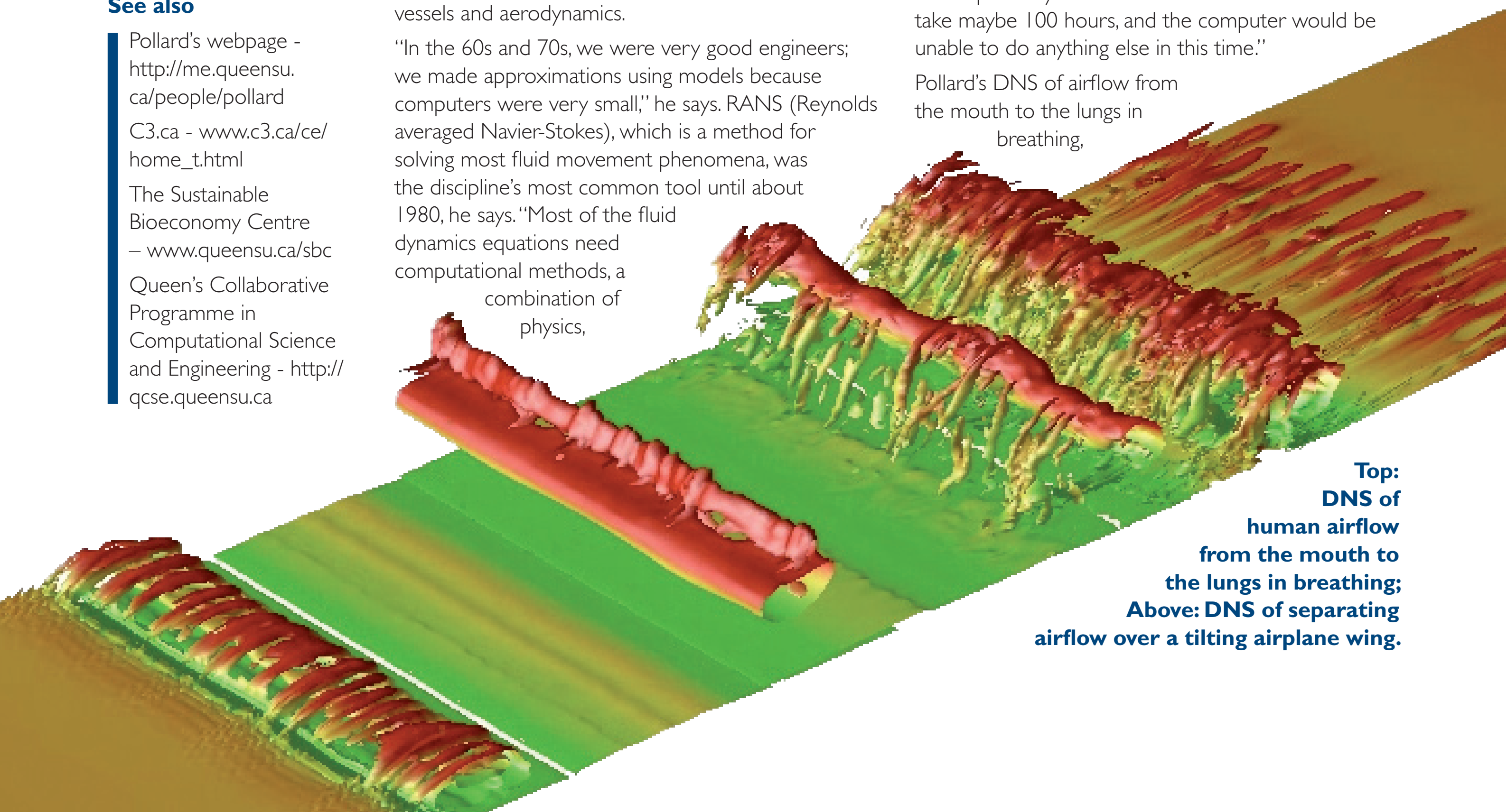
"DNS is the equivalent of following a person in and out of those rooms and floors in three dimensions and real time in milliseconds."

"Let's assume the RANS algorithms about the building could be solved on a desktop computer with 1Gb of memory and two processors in about a minute. LES would probably take about 10 hours. DNS would take maybe 100 hours, and the computer would be unable to do anything else in this time."

Pollard's DNS of airflow from the mouth to the lungs in breathing,

### See also

- Pollard's webpage - http://me.queensu.ca/people/pollard
- C3.ca - www.c3.ca/ce/home_t.html
- The Sustainable Bioeconomy Centre – www.queensu.ca/sbc
- Queen's Collaborative Programme in Computational Science and Engineering - http://qcse.queensu.ca



**Top: DNS of human airflow from the mouth to the lungs in breathing; Above: DNS of separating airflow over a tilting airplane wing.**

at the top of the previous page, uses 140 million points of measurement, developed from scans of many people.

He has been able to explain why asthma drugs clump at the back of the throat, and a Masters student found that the normal pipe flow of air from the trachea assumed by lung modellers is not what the airway delivers.

His team has also developed an algorithm that uses existing ultrasound systems to find, count and display air bubbles in heart operations. Queen's University is seeking industry interest in this discovery.

Pollard also simulates fluid dynamics in aerodynamics. "To compute the airflow over the whole body of a plane using DNS would take approximately one billion years," he says.

"It takes 64 processors three months to do a DNS of the airflow over a wing as it tilts 20 degrees, using 15 million measurement points."

Because DNS problems are so large, mathematicians isolate and partition critical regions; the wing simulation was divided into eight regions, solved simultaneously but in parallel.

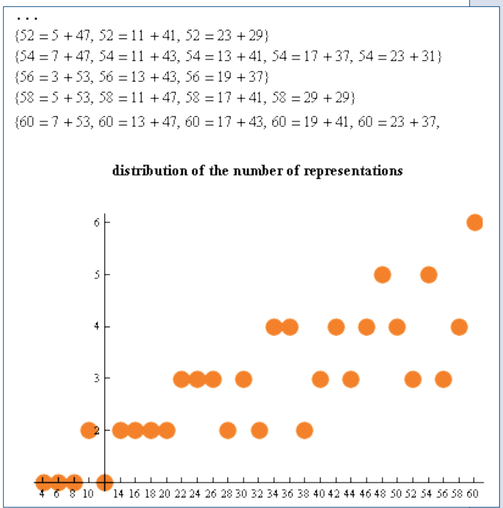
"Our hypothetical building may have 140 million rooms on 140 floors, so algorithms for each floor can be solved in parallel, because you only need to know the number of people on the stairs."

It's no wonder that Pollard became interested in high performance computing (HPC). The HPC Virtual Laboratory at Queen's is made up of more than 3,000 processors and terabytes of memory and disc space.

"The biggest ongoing costs are electricity and cooling, then support staff. In one USA installation they are building a separate power station just for the high performance computer."

Pollard says his "academic pathway has taken me in directions I hadn't anticipated". His most recent passion is the new Sustainable Bioeconomy Centre (SBC) at Queen's, which aims to help move economic reliance from 'old' oil to 'young' oil, or energy crops.

What hooked him into the issue was the question of how to transport fuel biomass in a pipeline. His team has applied for a patent for a transportable wood pellet, which doesn't have the storage and transport problems of existing pellets.




The number of ways an even number can be represented as the sum of two primes.

$$\frac{\partial r}{\partial t} + \frac{\partial r u_i}{\partial x_i} = 0$$

## NOTABLE MATHS PROBLEMS

### GOLDBACH CONJECTURE

**That every even integer greater than 3 can be written as the sum of two primes**

**Also known as**: The "strong", "even" or "binary" Goldbach conjecture because it implies the "weak", "odd" or "ternary" Goldbach conjecture that all odd numbers greater than seven are the sum of three odd primes. The conjecture does not specify that a number has to be the sum of only one pair of prime numbers.

**Discipline**: Number theory.

**Originator**: Prussian mathematician Christian Goldbach wrote to Leonhard Euler in 1742 proposing that every integer greater than two can be written as the sum of three primes. Euler replied that it follows that every even integer greater than two can be written as the sum of two primes. Euler's form has since been known by Goldbach's name.

**Incentive**: Proving one of the oldest unsolved problems in number theory and all mathematics. A $1million prize offered by publisher Faber & Faber for a proof submitted before April 2002 was never claimed.

**Examples**: 4 = 2+2, 6 = 3+3, 8 = 3+5, 10 = 5+5 = 3+7, 12 = 5+7, and so on.

**Verified results:** For smaller numbers, the strong Goldbach conjecture can be directly verified. One 1938 attempt laboriously verified up to $n \leq 10^5$, while a distributed computer search has verified the conjecture for $n \leq 10^{18}$.

**State of play**: There is little doubt among mathematicians that both conjectures are true; Euler replied to Goldbach: "That every even number is a sum of two primes, I consider an entirely certain theorem in spite of that I am not able to demonstrate it." No purported proofs are currently accepted by the mathematical community.

The weak Goldbach conjecture is fairly close to resolution, but the strong conjecture is much harder to verify. It has been shown that every even number $n \geq 4$ is the sum of at most six primes.

Statistical work on the probabilistic distribution of prime numbers presents informal evidence for the conjecture for sufficiently large integers.