The International Turbulence Program at Chalmers & the Need for Unique Research Facilities

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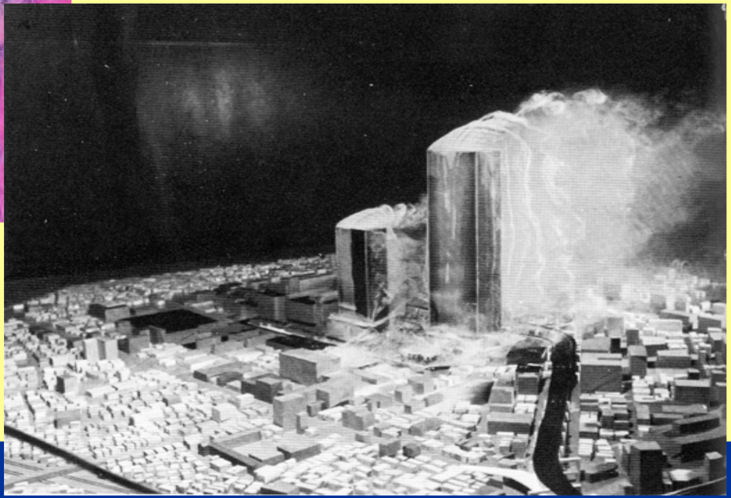
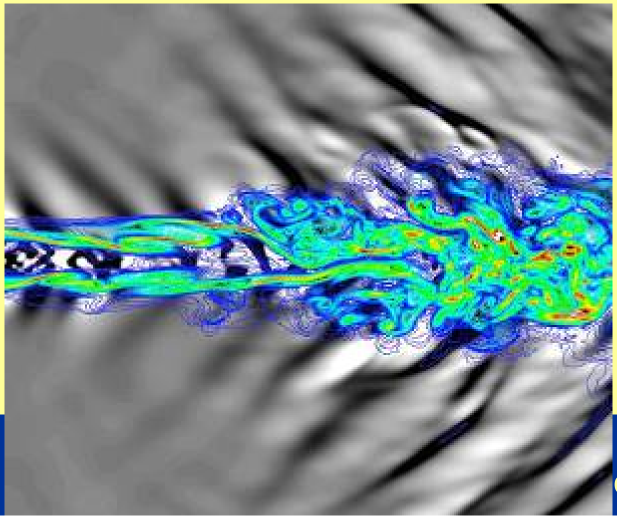
Outline

- Turbulence as a phenomenon.
- A really BIG and `CLEAN’ windtunnel.
- A new way to think about master’s education.

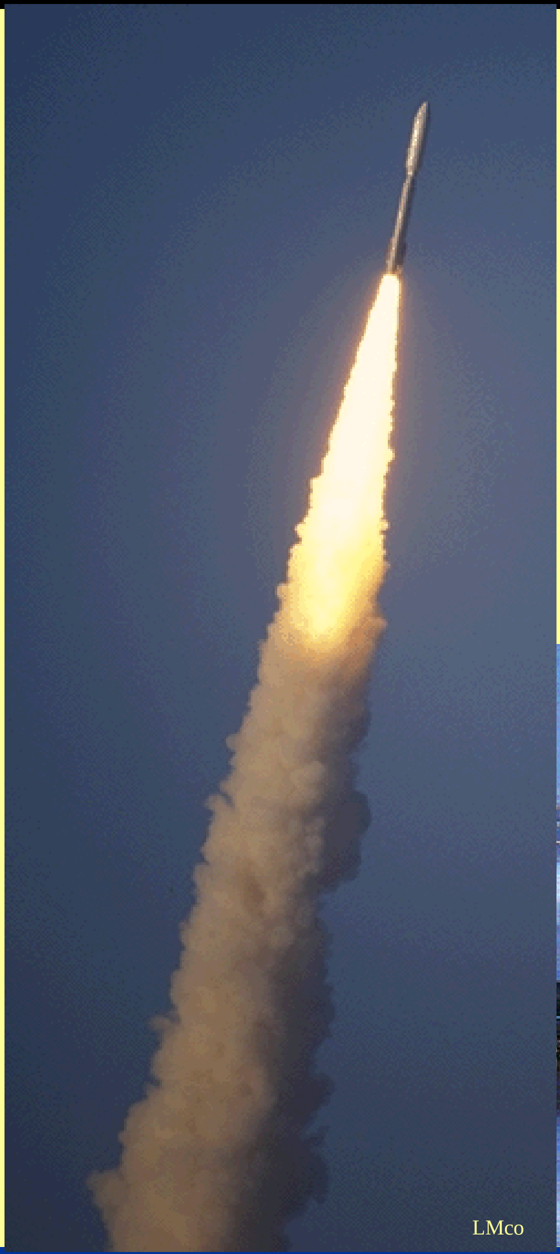
Turbulence really is everywhere.



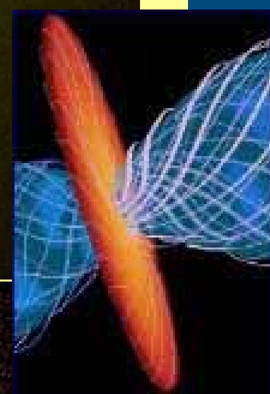




Wakes, wakes and more wakes.

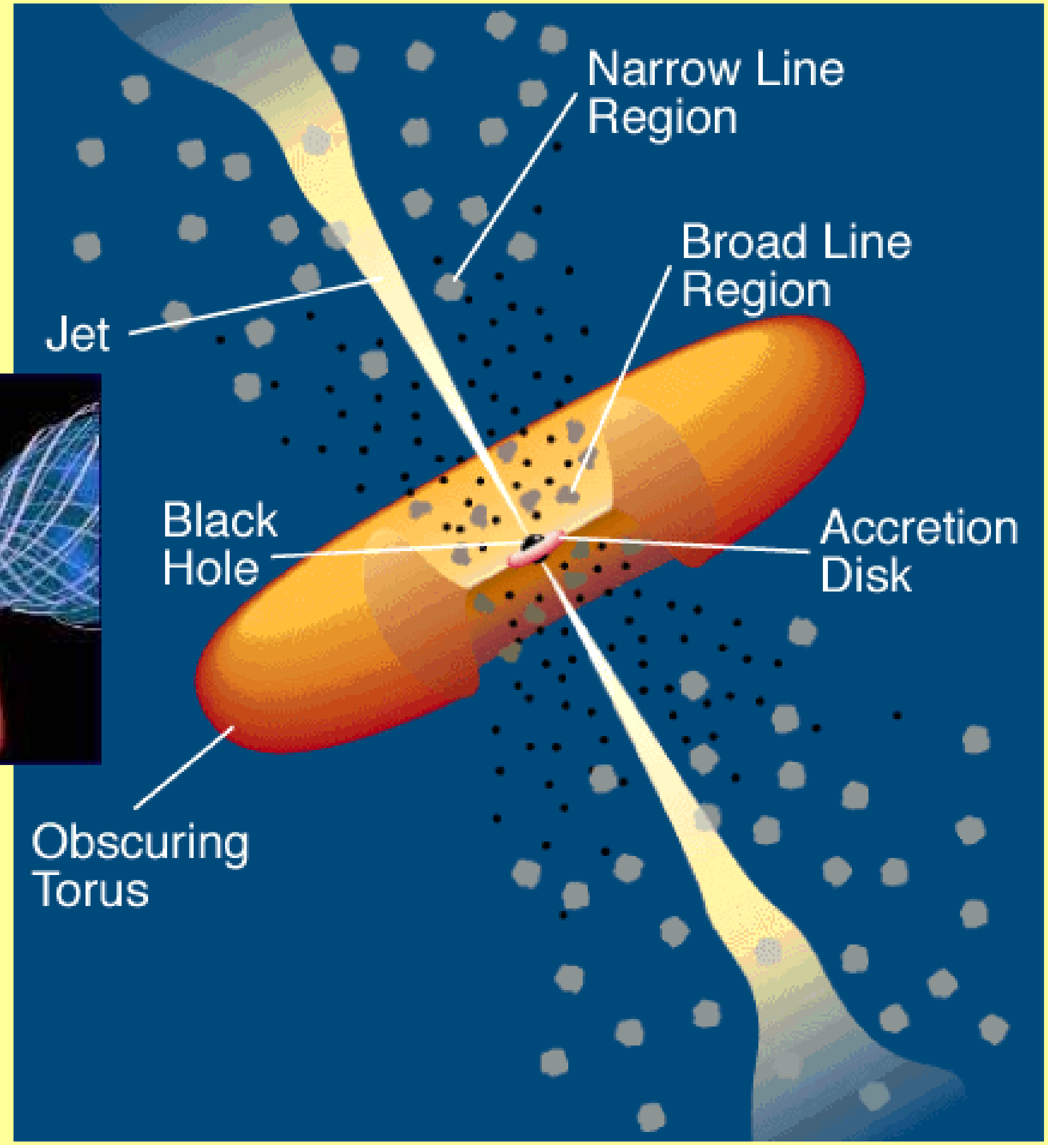
Jets



Galactic jet in the M 87 Galaxy



Pictor A galaxy



And our lack of understanding does matter!

Fuel consumption

Thrust

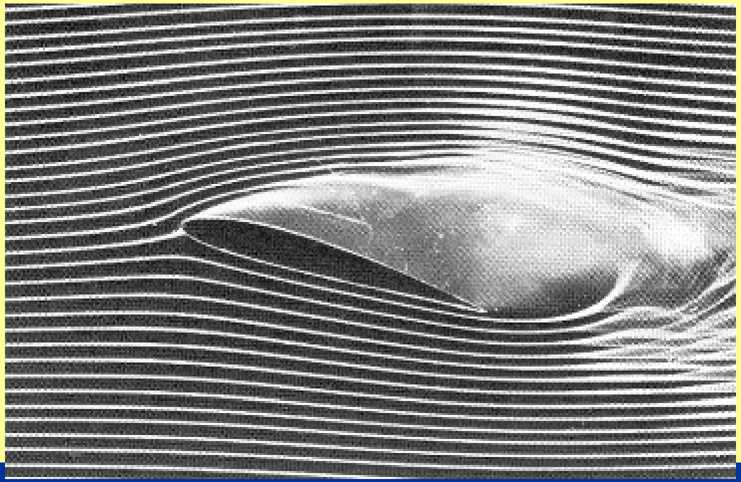
Noise

Safety

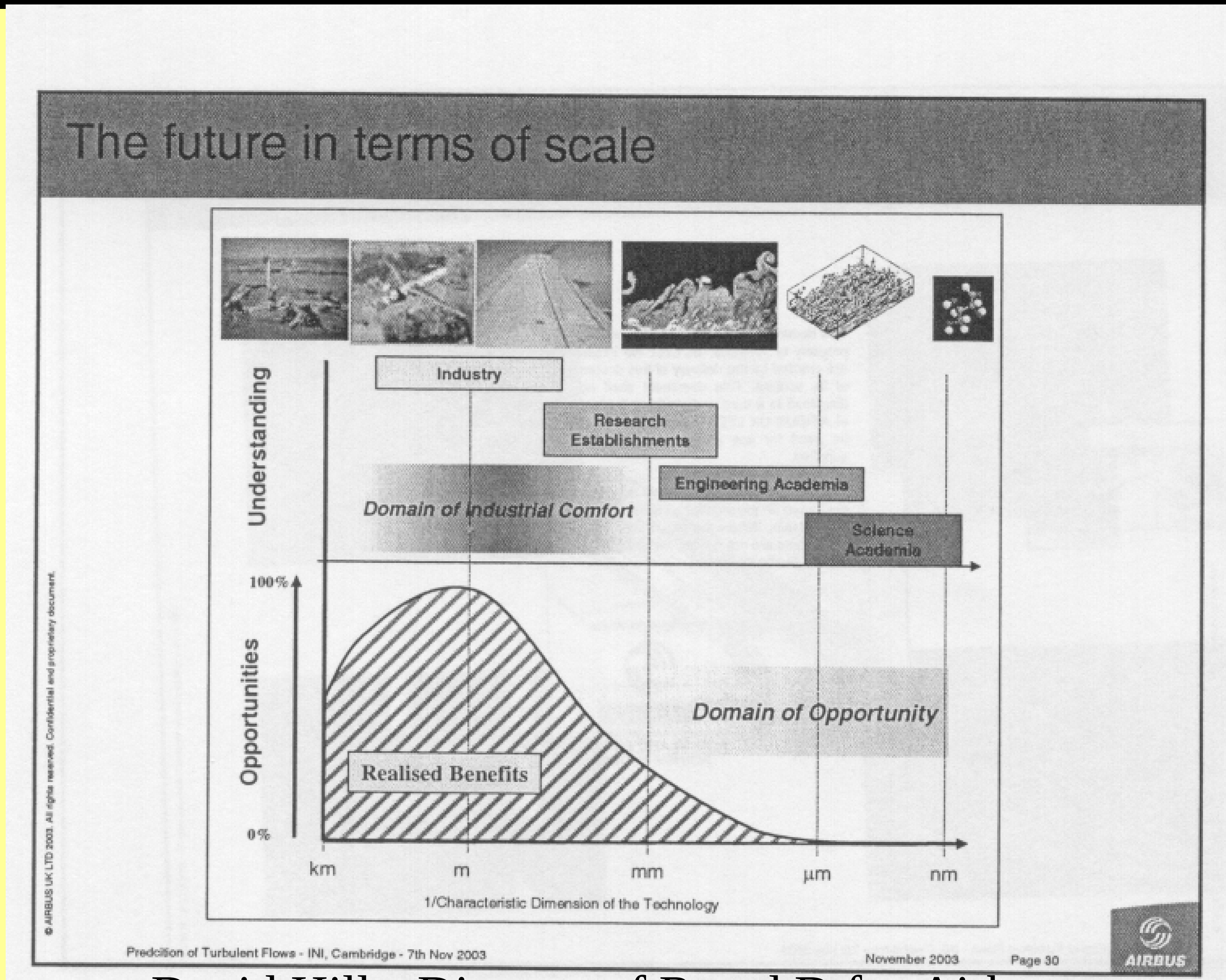
Power output

Wind loads

Design Cost



It matters a lot to some.



David Hills, Director of R and D for Airbus

But we often know the equations, so why not just compute?

$$\frac{\partial U}{\partial x}+\frac{\partial V}{\partial y}+\frac{\partial W}{\partial z}=0$$

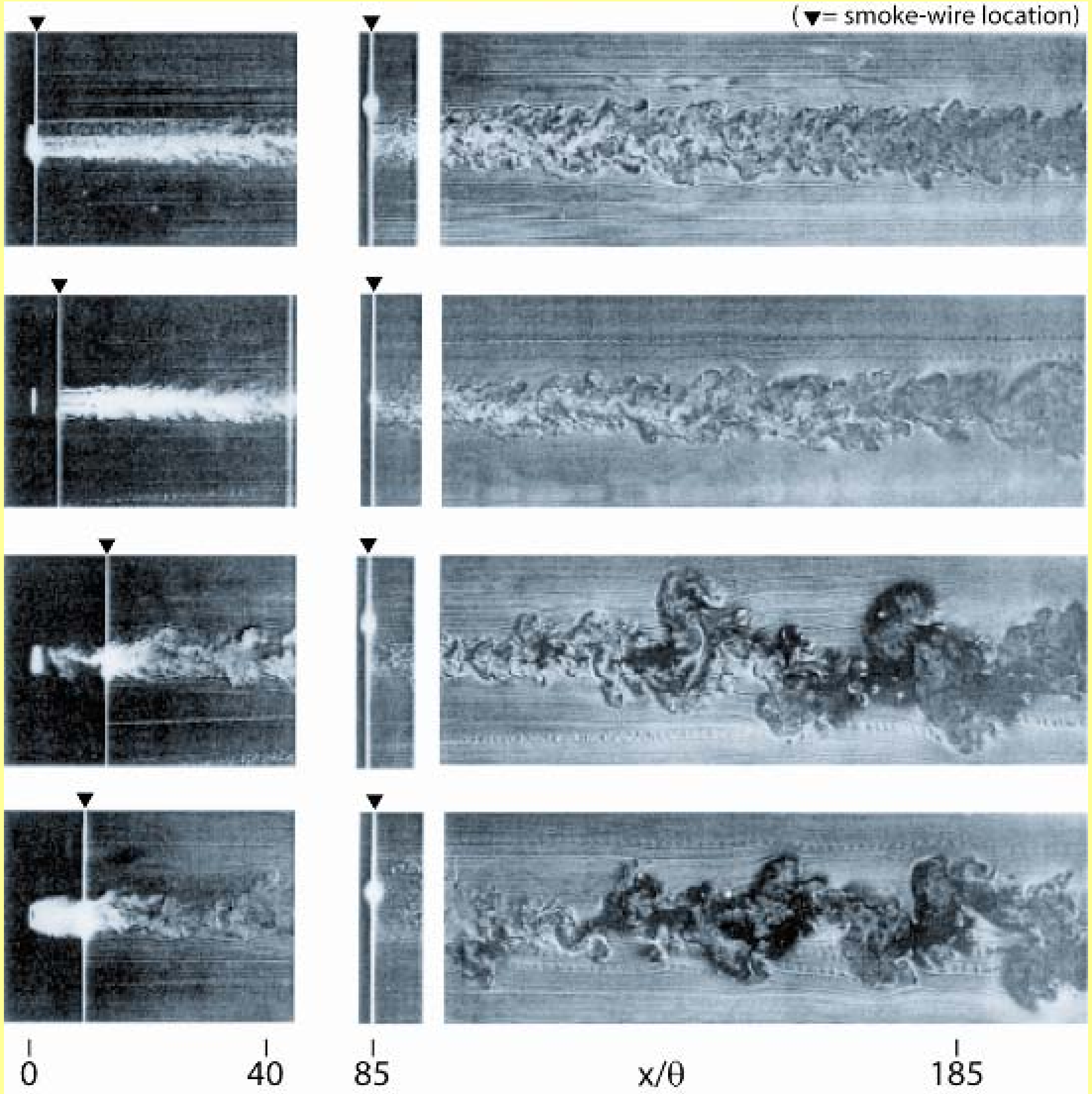
$$\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+V\frac{\partial U}{\partial y}+W\frac{\partial U}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\nu\left(\frac{\partial^2 U}{\partial x^2}+\frac{\partial^2 U}{\partial y^2}+\frac{\partial^2 U}{\partial z^2}\right)$$

$$\frac{\partial V}{\partial t}+U\frac{\partial V}{\partial x}+V\frac{\partial V}{\partial y}+W\frac{\partial V}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial y}+\nu\left(\frac{\partial^2 V}{\partial x^2}+\frac{\partial^2 V}{\partial y^2}+\frac{\partial^2 V}{\partial z^2}\right)$$

$$\frac{\partial W}{\partial t}+U\frac{\partial W}{\partial x}+V\frac{\partial W}{\partial y}+W\frac{\partial W}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\nu\left(\frac{\partial^2 W}{\partial x^2}+\frac{\partial^2 W}{\partial y^2}+\frac{\partial^2 W}{\partial z^2}\right)$$

One huge problem: The solutions are extremely sensitive to minute disturbances, and solutions are chaotic and **turbulent**.

ALL turbulence books tell you these pictures should be the same…



Wakes behind four different axisymmetric generators ... suggesting strongly that far wakes retain dependence on initial conditions. (Cannon 1991).

Great CFD! But what does it mean?

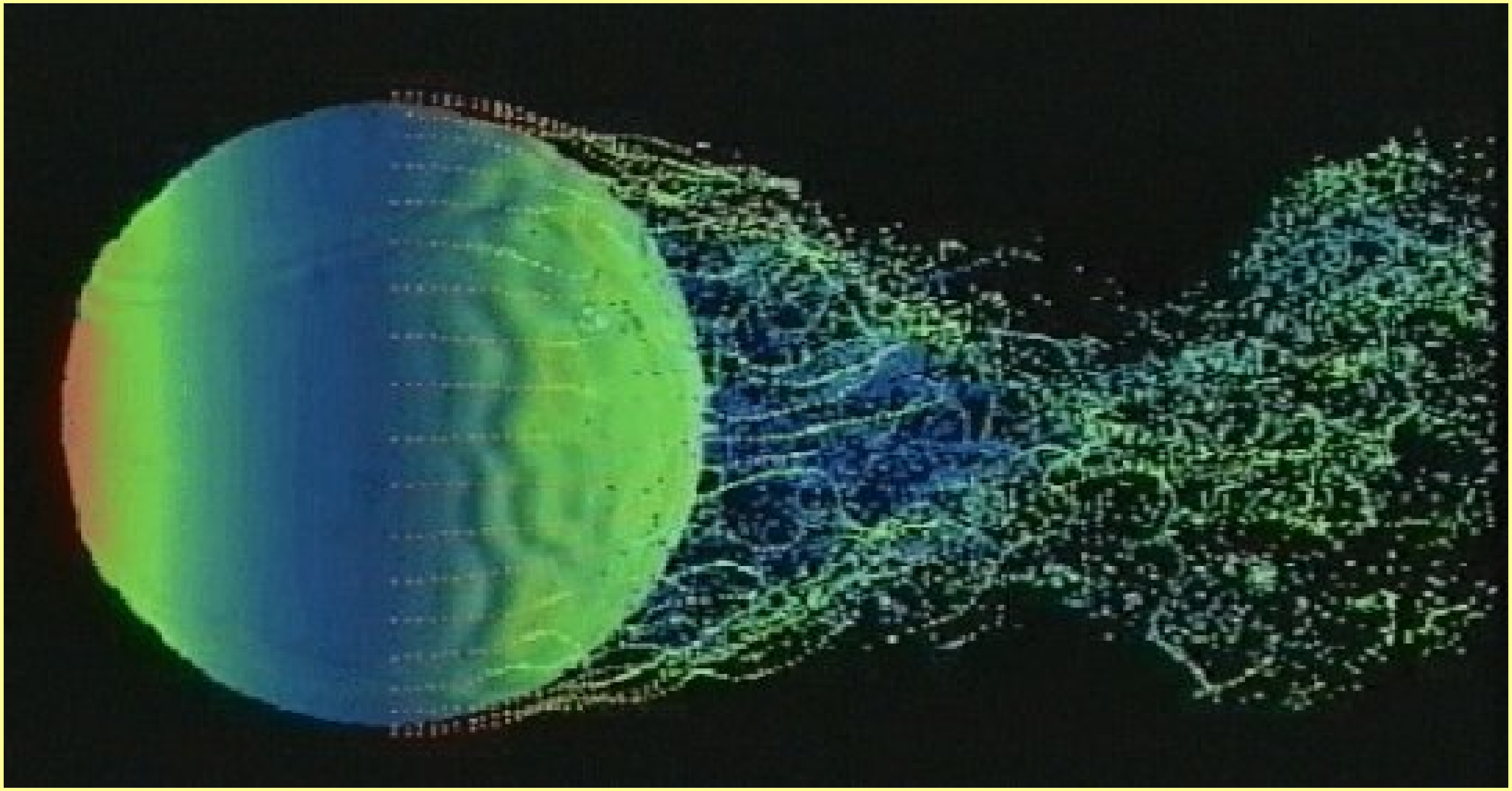
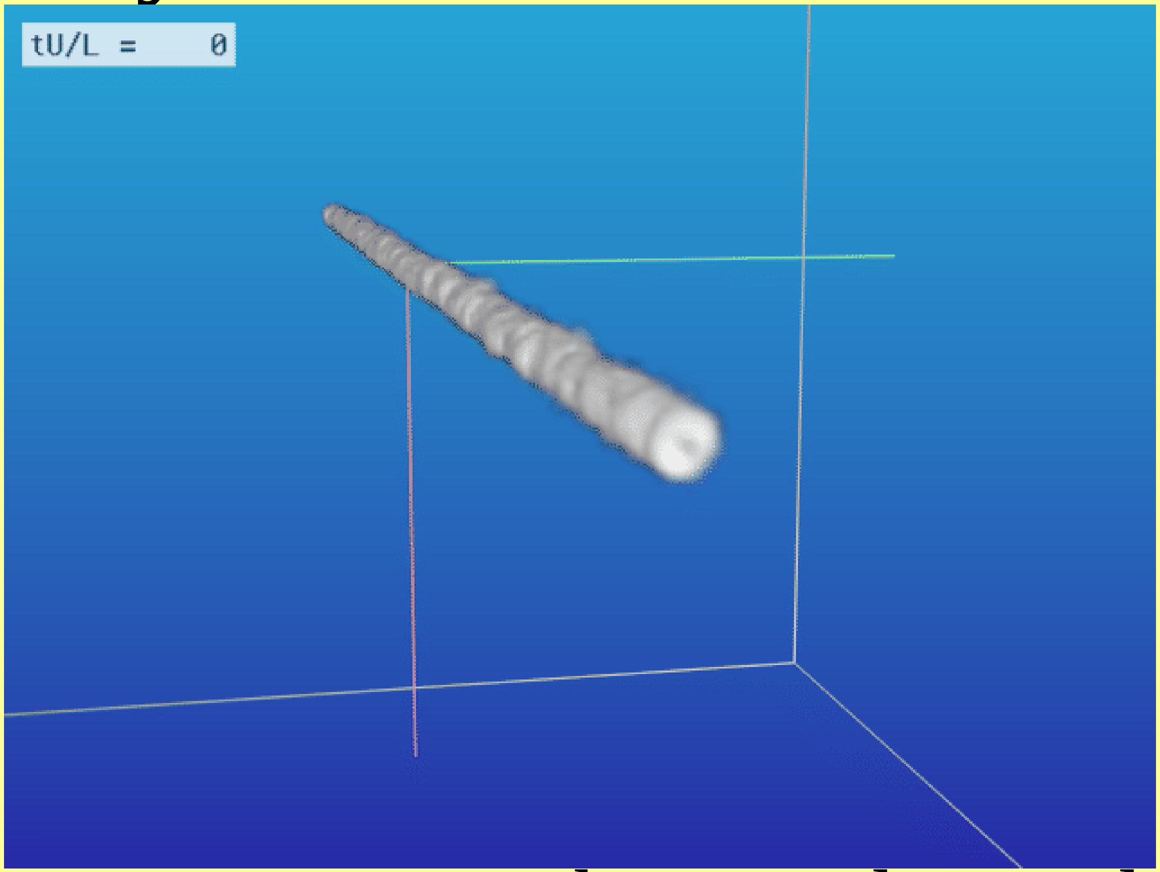


Image from www.efluids.com

Near sphere wake – transients or determinants of far wake?

We can use computers, but not at Reynolds numbers that matter



DNS of axisymmetric wake, Gourlay et al. (2001)

Our biggest problem:

The REYNOLDS NUMBER

Large scales: energy containing eddies

Small scales: dissipation

$$\mathrm{Re} = \frac{inertia}{viscous}$$

High Re → Large separation of scales

Re = 10,000,000 or higher for most applications.

What about CFD…

Why can't a super-computer do the job *(yet)*?

- The computational box required to duplicate the capabilities of the proposed wind tunnel is (based on test section width of 3 m):

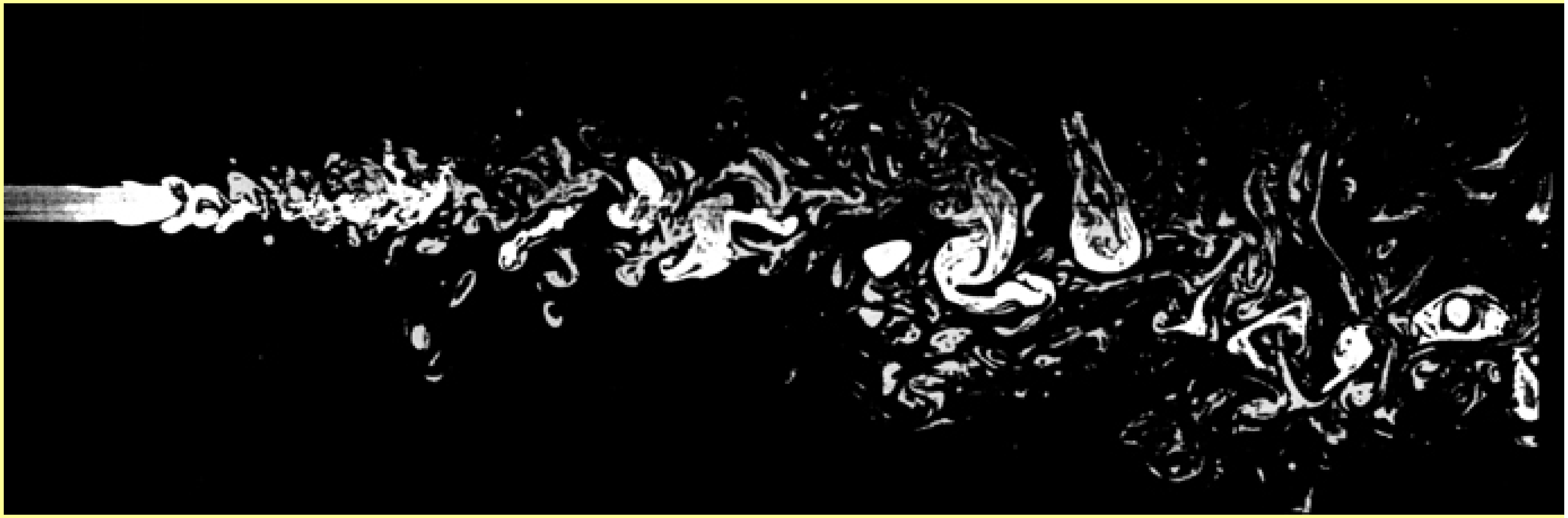
$$(3 \times 10^5)^3 = 27 \times 10^{15} \text{ for each time step}$$

- If the largest turbulence simulation (DNS) to-date is only $1024^3 \simeq 10^9$, then the *simplest* computer experiment (*non-decaying* (forced) isotropic turbulence) *of this scale* can be done in **37 years!**

- For effect of "box size" on DNS of turbulent flow see talk by H.Wang, APS-DFD'01, session **DC.010**, Sunday 17:47

Reynolds numbers really do matter.

Low
Reynolds #
2 300



High
Reynolds #
65 000

Turbulence modeling has also been less than a total success. **Fluent's Stefan Olovsson** sums the situation up quite well:

• No major breakthrough in turbulence modeling for industrial flows.

• Numerous models, mostly *ad hoc*, spawned over the last two decades.

• Hard to find a single, dominantly superior, universally reliable engineering turbulence model. .

Some think the emphasis should be on better models to match our increasing computer power

… algebraic stress, Reynolds stress, and the latest cure-all: LES.

All *assume* we understand already the essential physics on which to base such models.

BUT DO WE?

Part II: The Nordic Wind Tunnel

A very large turbulence research facility

by

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A Large *Turbulence Research Facility* should be:

- *large enough* to remove the effect of side walls on the energetic turbulence scales.

- *fast enough* and *large enough* to get the necessary high Reynolds numbers, yet still resolve the dissipative scales.

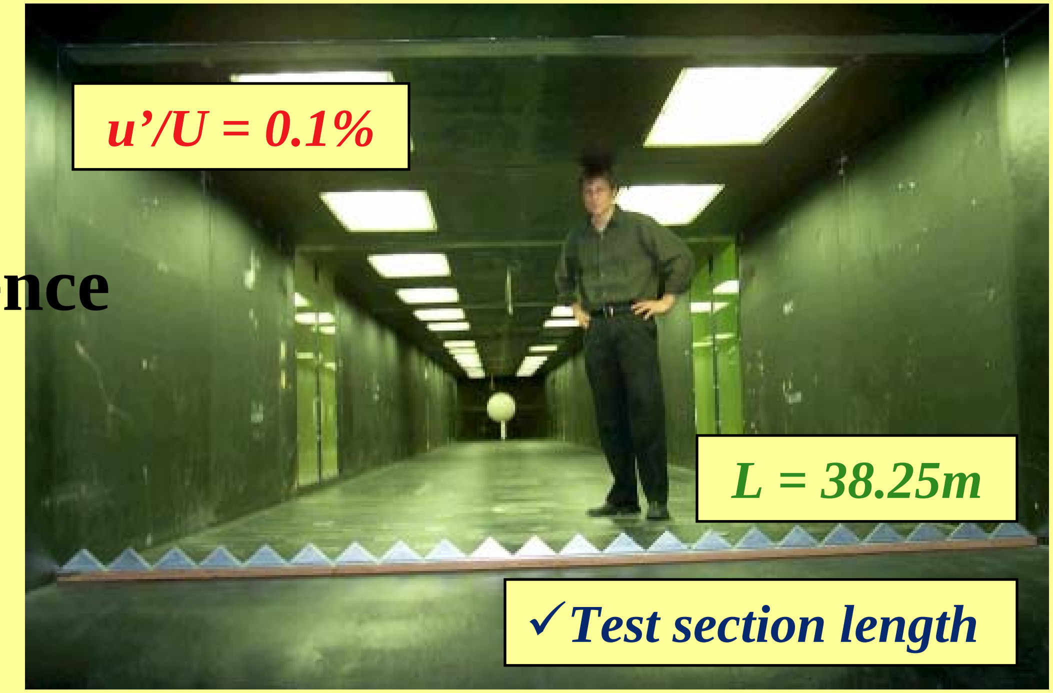
- *long enough* and with *low enough background disturbances* to obtain the necessary downstream development times.

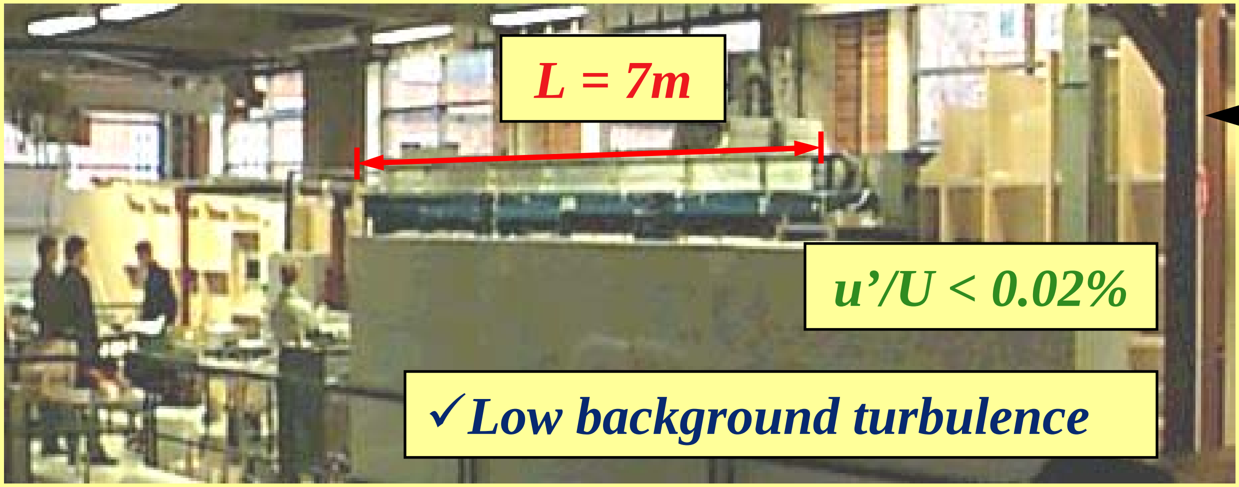
- an experimental facility capable of resolving some of the oldest questions in turbulence while also testing conclusively new ideas.

Existing Facilities are either:

Too much background turbulence

BLWT2 (Boundary Layer Wind Tunnel)
University of Western Ontario
London, Ontario, Canada





Or too small

MTL low-speed wind tunnel
Royal Institute of Technology
Stockholm, Sweden

Design criteria:

• What length and time scales *need* to be resolved to conduct "meaningful" measurements?

• What Reynolds numbers do we need in the experiments we want to perform to resolve fundamental questions and sort competing theories? (of course length and time scale and Reynolds number criteria depend on the flow being measured!)

---> A catalog of requirements for different ***benchmark experiments*** has been developed.

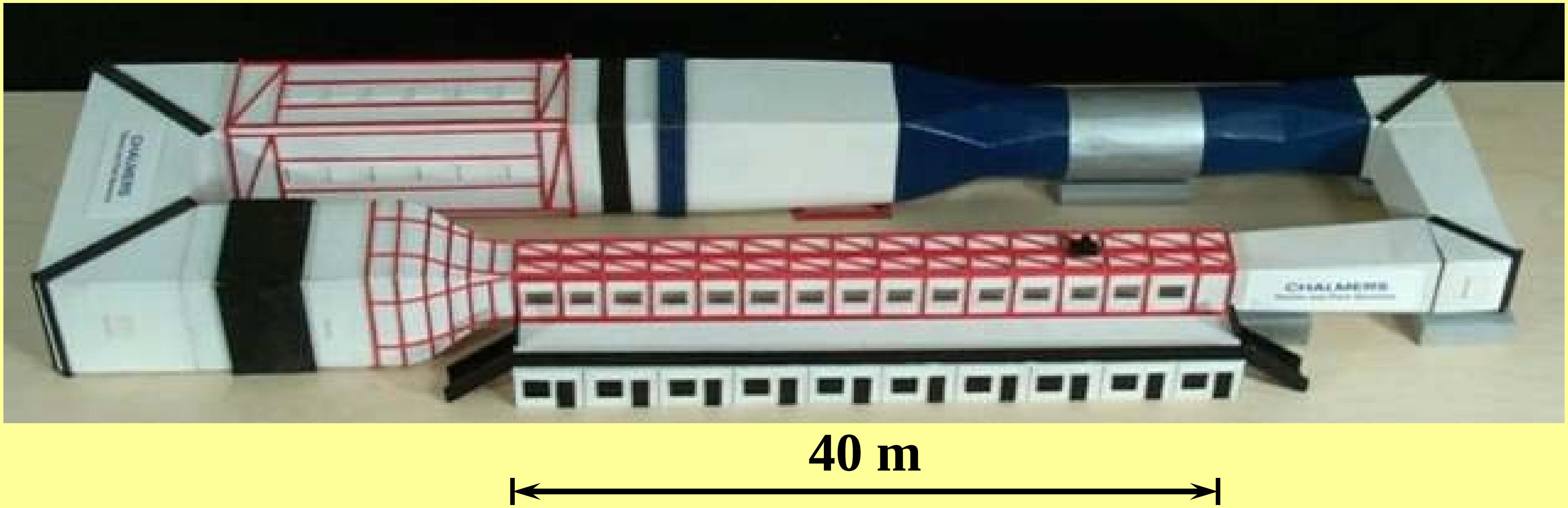
• **Design limitation: smallest currently available probes, 10 μm**

The proposed “Nordic Wind Tunnel”:

test section length:	**40 m**
cross-section*:	3 m X 3 m
max. speed (test section):	40 m/s
background disturbance level:	< 0.02% (0.01% possible)
overall dimensions:	80 m X 21 m X 7 m

*after contraction **from design to operation excluding building

(1:100 scale model of proposed facility)



The "*Nordic Wind Tunnel*"

The Large Wind Tunnel Facility would:

- be the largest and longest *turbulence research tunnel* in the world with very low background disturbance level.

- be large enough for all present and foreseeable fundamental research wind tunnel experiments.

- have an estimated useful life of 50-100 years

- be suitable for eventual commercialization for a variety of atmospheric, wind engineering and sporting applications — including urban building design testing, Olympic winter sports training, and racing yacht design.

Outlook: It will not be built in Sweden

Leading scientists (mostly from Stockholm) say country is too small for such a facility.

Current efforts to build support for it are underway in New Hampshire, **Puerto Rico** and Denmark.

Part III: Education:

The real reason we are in business.

What about education?

I really like the "**Dark side of CFD**"
(from Ferit Boysan, Fluent CEO)

- "It is now possible for more people to get bad results from CFD faster and cheaper than ever before."
- "Ability to **do** cfd does not imply the ability to interpret cfd results."

"An educated consumer is our best customer."

- motto for Syms clothing stores in USA.

If this is true for Syms, it certainly is even more true for Fluent, or for that matter any other fluids company.

At what levels in the education should the student acquire the different skills?

Most never acquire them in turbulence, at least in school.

Academic career or Industrial research

Industrial career

Ph.D. level education
Expert knowledge.

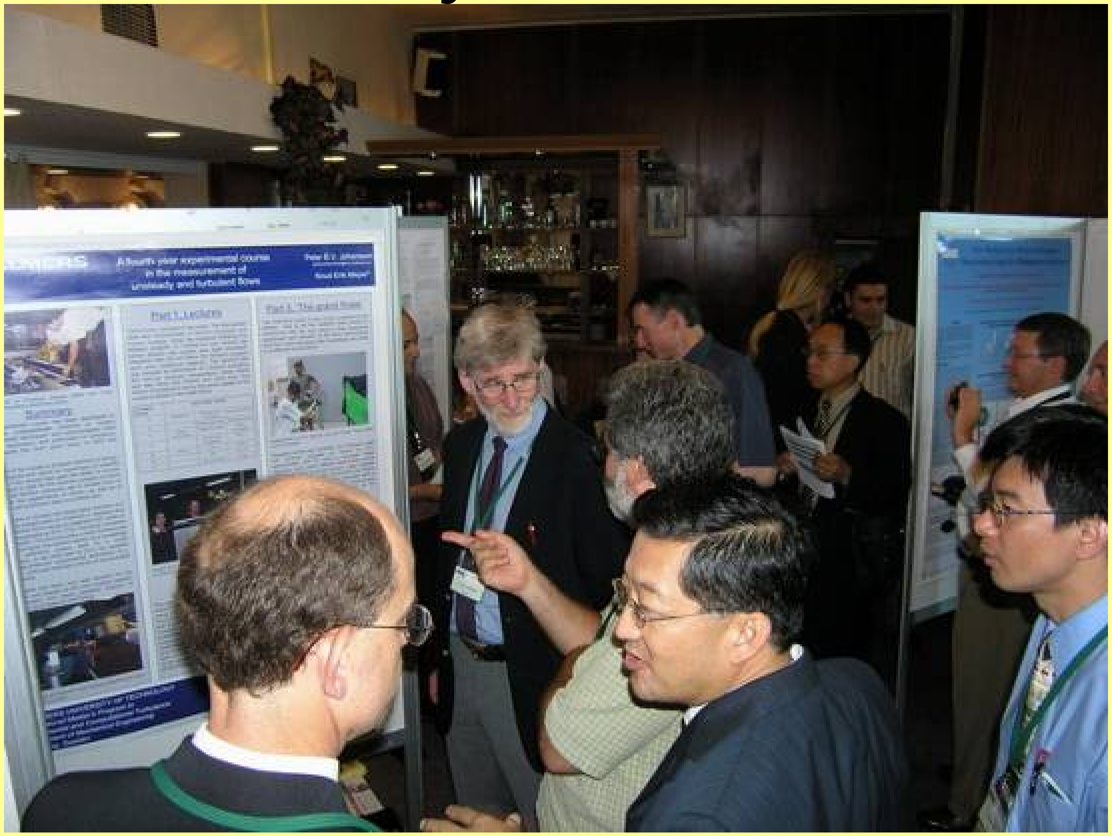
Industrial career

Higher level engineering education.
Specialized, deepened knowledge in a chosen sub-field.
Know how to proceed in the absence of specific knowledge.

Industrial career

Basic level engineering education.
Broad base in all relevant engineering subjects.

A new kind of master's education – focused and global, both in whom it attracts and what happens to the graduates after they finish.



Details in several conference papers.

The International Master's Program in Turbulence at Chalmers.

Goals:

- To teach students to continue to learn about turbulence.
- To provide a mechanism for efficient international exchange of students.

All courses are taught in English.

Courses (8 in all, 4 required)

Specialized courses In turbulence (compulsory)	Required broadning in fluid mechanics	Elective courses in areas of special interest (examples)
Introduction to turbulence	Adv. fluid mechanics	Fourier analysis
Experimental fluid dynamics	Applied fluid mechanics	Road vehicle aero. des. Fourier and wavelet anal.
Turbulence theory	Comput. fluid dynamics	Gas turbine technology Partial diff. equations
Turbulence modelling	Heat transfer	Internal combustion eng. Functional analysis

Thesis project (preferably in industry or at another university)

A few keys to our success

- Twice as many students as we can possibly absorb ourselves (20 – 25/ year) – some on ’loan’.
- Focused program, mandated courses in theory, cfd and experimental methods.
- Limited duration. 10 months courses, 4-6 months thesis project.
- No tuition.
- We care a lot about what happens to them.
- Active social program so they get to know us and each other.

Students from six continents = food from six continents.

Our Ph.D. students assume leadership.

We share local traditions

Teaching the Swedish frog dance

Learning new and useful skills.

Changing the world.

They really do learn to like each other.

The Grande Finale: In Denmark (DTU and Dantec)…almost ready to face an exciting world

- Some like it so much they stay around…

The baby-sitters: a final moment together

And friendships that will never end.

Finishing the job – making them part of an international network.

ETC 10, Trondheim, Norway