Energy research Centre of the Netherlands

CFD Application on Wind Energy Problems

Hüseyin Özdemir

This presentation has been given at Yeditepe University, Istanbul, Turkey, on 28 December 2010 as an invited lecture.

ECN-L--11-010 JANUARY 2011

ECN

Energy research Centre of the Netherlands

CFD Applications on Wind Energy Problems

ECN Wind Energy - Aerodynamics
Hüseyin Özdemir

Outline

- Structure of ECN as a research institute
- Ongoing research projects within ECN Wind Energy Unit
- Possible application fields for mathematicians and engineers
- Internship options at ECN

ECN; R&D units

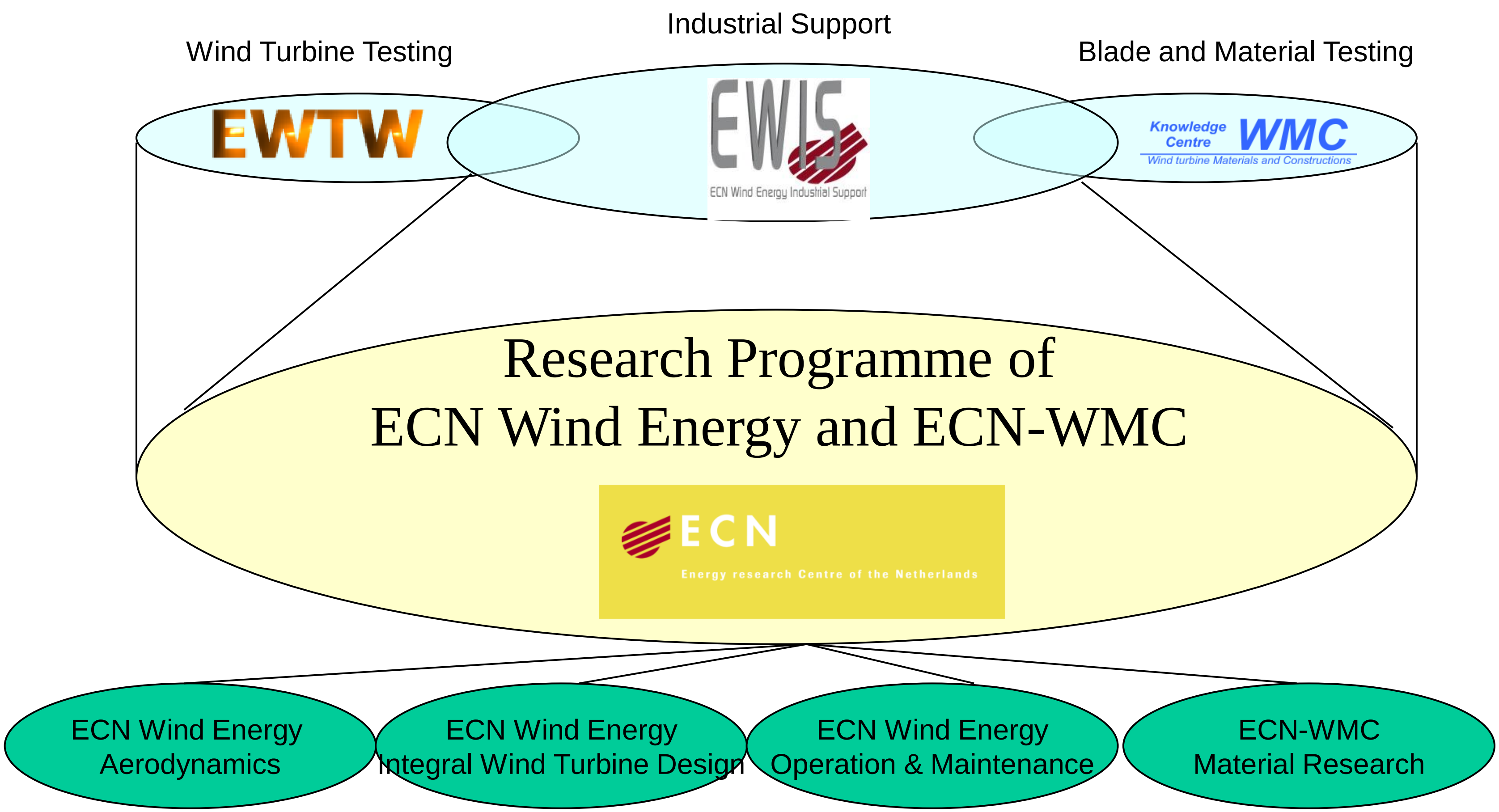
A bridge between energy research and the market

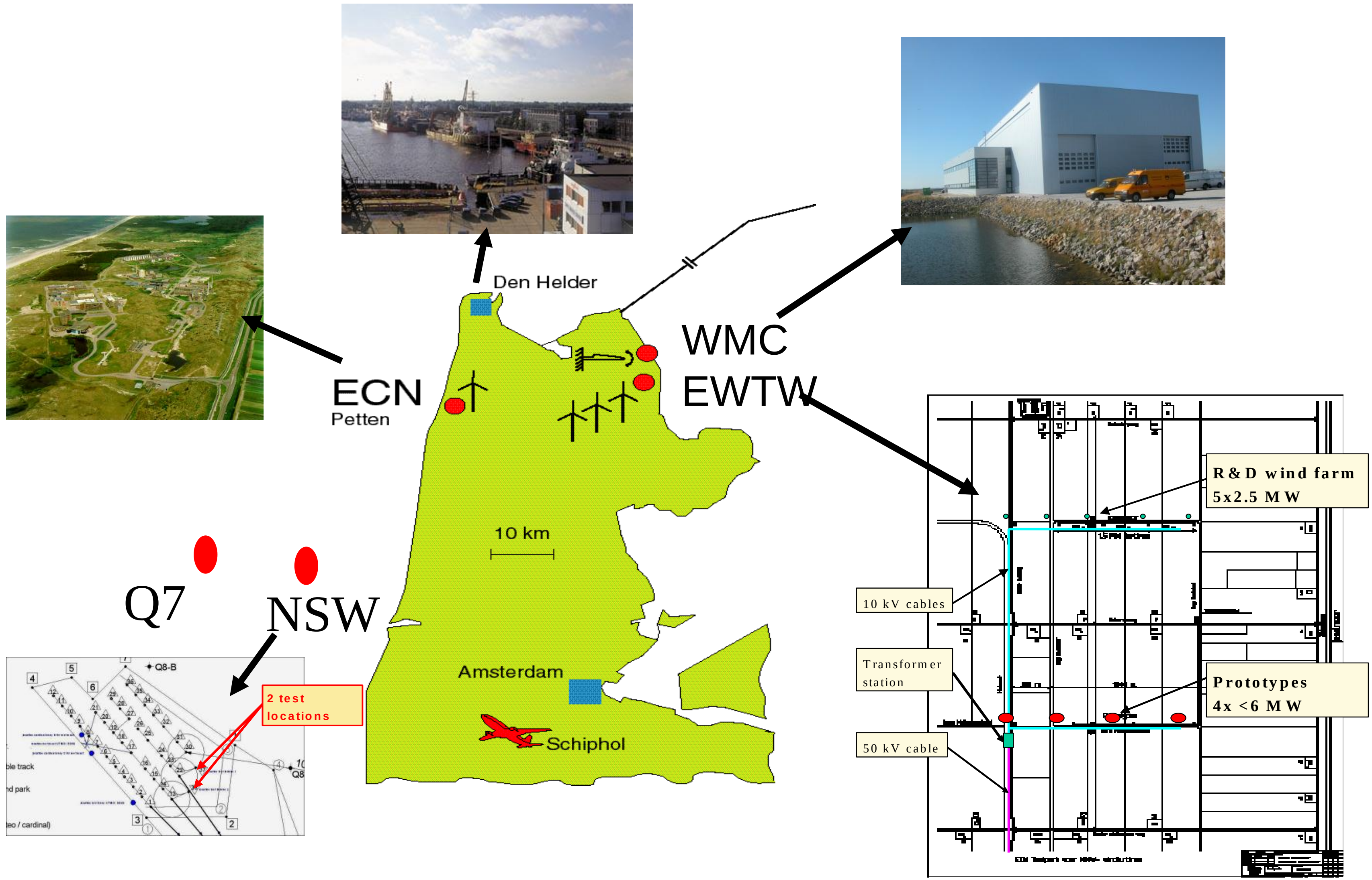
ECN develops high-quality knowledge and technology for the transition to sustainable energy management. And ECN introduces this knowledge and technology to the market.

The Energy research Centre of the Netherlands (ECN) is the largest research centre in the Netherlands in the field of energy. At this moment ECN employs about 900 people

ECN Wind Energy

± 60 scientists



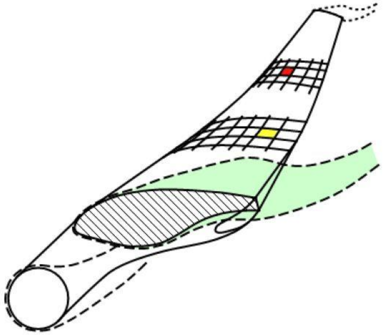

Den Helder
WMC
EWTW
ECN
Petten
10 km
Amsterdam
Schiphol
Q7
NSW
Q8-B
2 test locations
R & D wind farm
5x2.5 MW
10 kV cables
Transformer station
Prototypes
4x <6 MW
50 kV cable

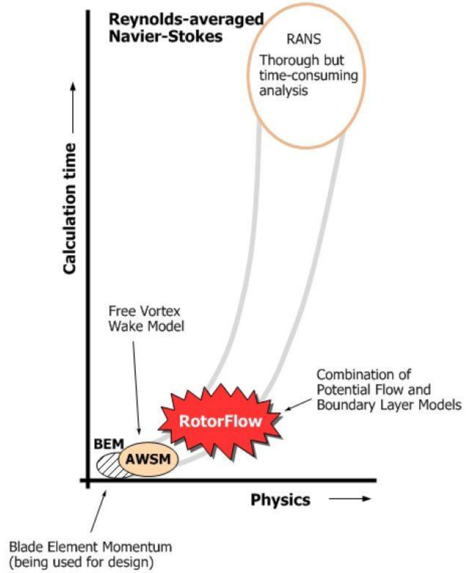
Research line 1: Aerodynamics

RotorFlow
Aerodynamics

Rotor aerodynamics

- Theoretical and experimental research
- Use of CFD
- Development of industrial codes



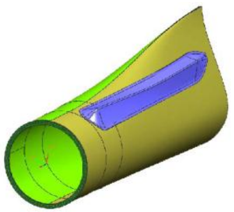


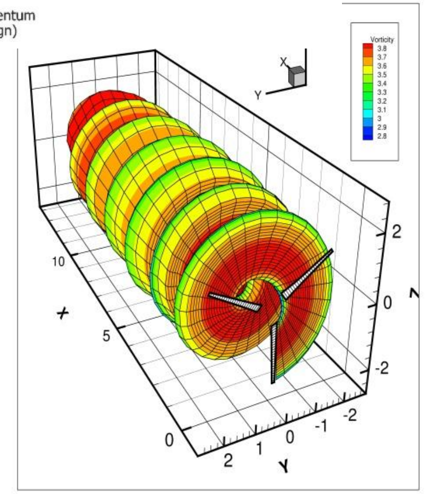
Wind farm aerodynamics

- Theoretical modelling: use of CFD
- Use of CFD
- Experiments (wind tunnels, scaled wind farm, full scale)

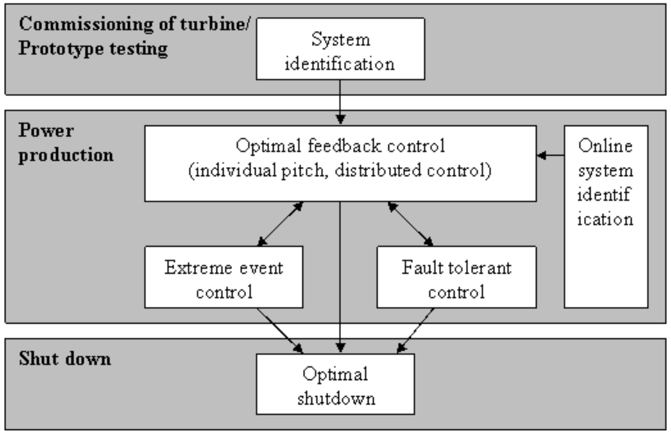
New ideas

- Strip on blade root
- Wind Farm control strategies
- Synthetic jets





Research line 2: Integrated wind turbine design



Aeroelasticity

Development of codes like Phatas and Turbu

Use of commercial multi body codes

Control

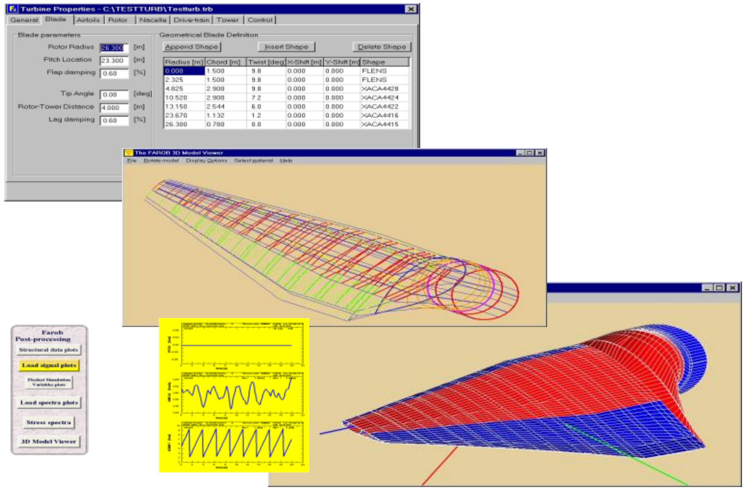
- Online System Identification
- OFC, EEC, FTC, OSC

Concepts

- Cost studies on a 20 MW turbine
- Novel turbine designs (with industry)

Design tools

- Integrated Modular Design Tool Focus (WMC)



Research line 3: Operation & Maintenance

Decision Support Tools

- O&M Tool (for planning phase)
- O&M Cost Estimator (Calculator with different building blocks)

Diagnostics and condition based maintenance

- Measuring mechanical loads on main components
  - Fibre Optic Blade Monitoring
  - Guidelines for determining, measuring and verifying loads on drive trains, pitch systems and yaw systems

•Flight leader: predicting the loads on all turbines in a farm by using the measured loads on a limited number of turbines in the same farm

Research line 4: Materials and structures (WMC)

Modelling material performance

•Fatique performance of glass- / epoxy and glass-/polyester

•fatique performance of carbon, carbon / glass hybrids, alternative resins, biodegradeble composites, thermoplatsics

Material database

• Merging FACT into the OptiDAT database (in Europe) and the DOE/MSU database in the US

Development of subcomponents

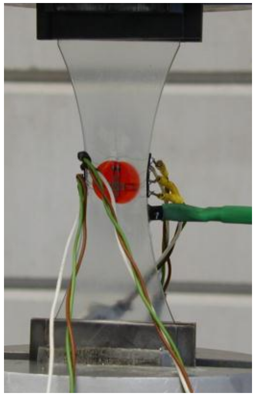
- develop specimens that are representing specific blade details
- testing
- modelling

Recommendations for testing, measurements and design

- standard development within IEC and ISO

Blade and material testing at WMC

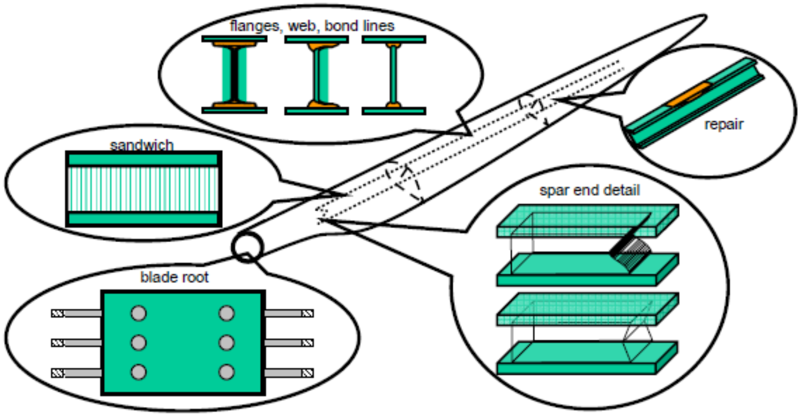
Knowledge Centre WMC
Wind turbine Materials and Constructions




Axial / Torsion 250kN / 4kNm

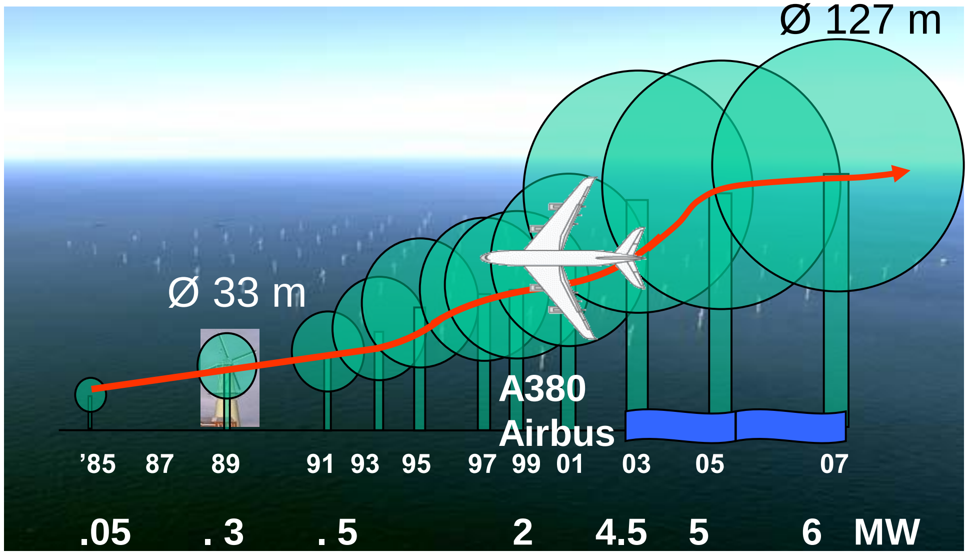
Static / Fatigue 400kN

Static / Fatigue 1000kN



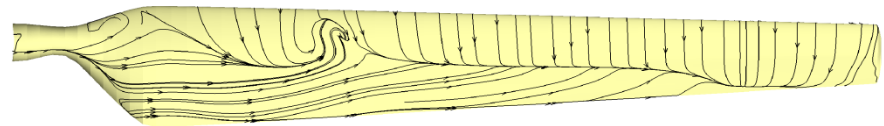
CFD Applications: Wind Farm CFD

CFD Applications: RotorFlow Project

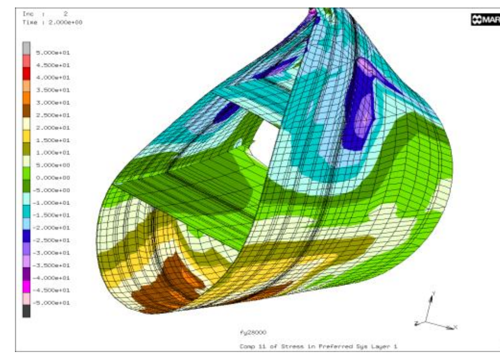


Van Kuik, 2007

- Detailed wind turbine dynamics simulation



- Local aerodynamic forces, structural stresses and deformations



Equations of motion for fluid dynamics

Navier-Stokes equations:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0,$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_j u_i + p\delta_{ij} - \tau_{ij}) = 0,$$

$$\frac{\partial \rho E}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_j E + u_j p + q_j - u_i \tau_{ij}) = 0.$$

Werner Heisenberg
"When I meet God, I am going to ask him two questions: Why relativity? And why turbulence? I really believe he will have an answer for the first."

Horace Lamb
"I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."

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News > Science > Matt's mathematical mind mash

NOTES&THEORIES
DISPATCHES FROM THE SCIENCE DESK

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Win a million dollars with maths, No. 3: The Navier-Stokes equations

Fluids move in mysterious ways. Mathematicians aren't even sure the equations that describe them will work in every situation

The Navier-Stokes equations attempt to describe the fiendishly complex movement of fluids. Photograph: Matt Parker

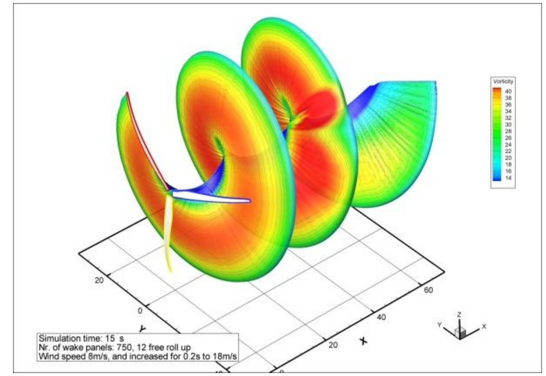
A million dollars in cash (£640,000) awaits anyone who can develop a rigorous mathematical model for how fluids flow – this week's Millennium Prize Problem.

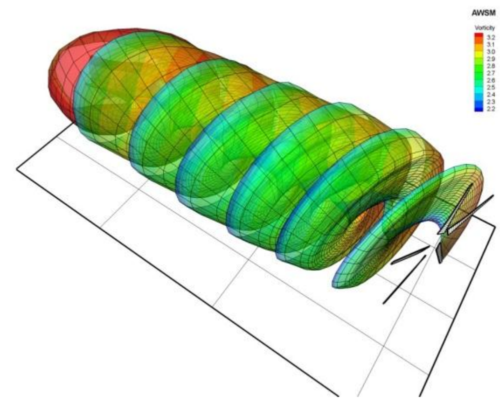
Numerical Approach

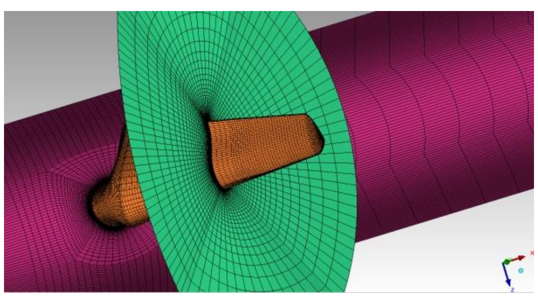
- Simplify Navier-Stokes equations under certain assumptions
  - Compressible / incompressible
  - Viscous / inviscid
  - Steady / time dependent
  - etc.
- Discretize the resulting equations with a suitable numerical method
- Apply a suitable turbulence model depending on the problem
- Implement in to a computer code
- Verification
- Validation

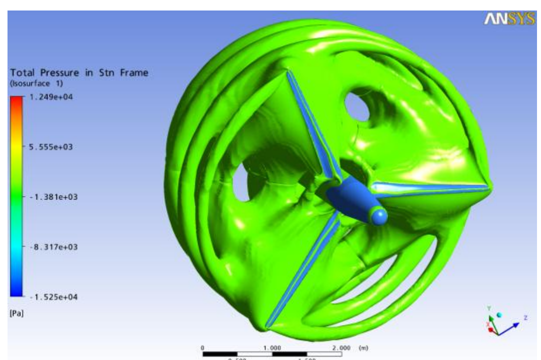
EXAMPLE: RotorFlow Project

- Engineering tools: ***not accurate enough***
  - 1D-2D, steady state methods: Blade Element Momentum (BEM), Vortex line method (AWSM), XFOIL, RFOIL
- CFD tools (CFX): ***too expensive, too much time***
  - Axial-symmetric (1/3rd of the domain)
  - 2.7 M elements
  - ~2 weeks on 16 node cluster







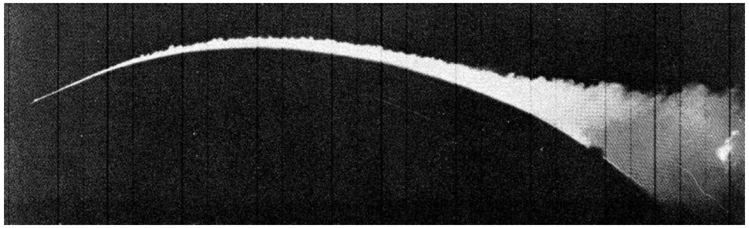


Numerical Approach: Modelling

Navier-Stokes equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0,$$
$$\frac{\partial \rho u_i}{\partial t} + u_j \frac{\partial \rho u_i}{\partial x_j} = \frac{\partial \sigma_{ij}}{\partial x_j} + \rho f_n,$$
$$\frac{\partial \rho E}{\partial t} + \frac{\partial \rho E u_i}{\partial x_i} = \rho u_i f_n + \frac{\partial u_i \sigma_{ij}}{x_j} - \frac{\partial q_i}{\partial x_i},$$

Full N-S solvers (RANS, LES, DNS, etc.)

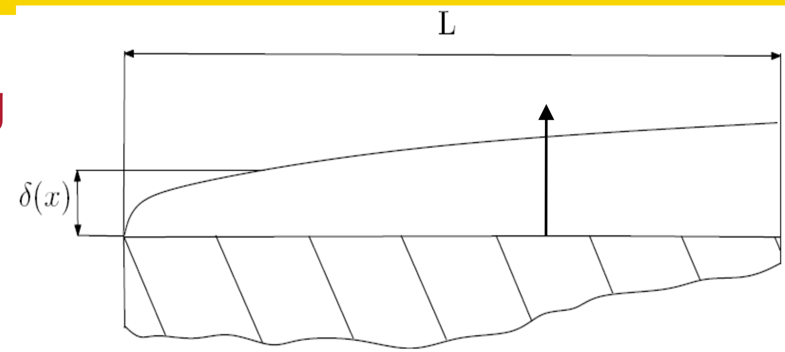


boundary layer assumptions

Boundary layer equations

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0$$
$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + w \frac{\partial u}{\partial z} \right) = -\frac{\partial p}{\partial x} + \mu \frac{\partial^2 u}{\partial z^2},$$
$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} \right) = -\frac{\partial p}{\partial y} + \mu \frac{\partial^2 v}{\partial z^2},$$

Numerical Approach: Modelling



Integration through boundary layer

$$\int_0^{y_e} [\text{Continuity equation}] \times \left(u^{n+1} - u_e^{n+1}\right) + [\text{Momentum equation}] \times (n+1) u^n \, dy$$

↓

Integral Boundary Layer (IBL) equations + closure set

Integral momentum eqn.: $$\frac{\partial \delta^*}{\partial t} + \frac{\partial (\theta u_e)}{\partial x} = \frac{C_f}{2} u_e - (\delta^* + \theta) \frac{\partial u_e}{\partial x} - \delta^* \frac{1}{u_e} \frac{\partial u_e}{\partial t}$$

Kinetic energy eqn.: $$\frac{\partial (\delta^* + \theta)}{\partial t} + \frac{\partial (u_e \theta H^*)}{\partial x} = C_D u_e - 2\theta H^* \frac{\partial u_e}{\partial x} - 2\theta \frac{1}{u_e} \frac{\partial u_e}{\partial t}$$

Unsteady entrainment eqn.: $$\frac{\partial (\delta^* + \theta H_1)}{\partial t} + \frac{\partial u_e \theta H_1}{\partial x} = C_E u_e$$

Numerical Approach: Modelling

$$\frac{\partial \mathcal{F}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{S},$$

$$\mathcal{F} = \begin{bmatrix} \delta^* \\ \delta^* + \theta \end{bmatrix},$$

$$\mathbf{F} = \begin{bmatrix} u_e\theta \\ u_e\delta^k \end{bmatrix},$$

$$\mathbf{S} = \begin{bmatrix} \frac{C_f}{2}u_e - (\delta^* + \theta)\frac{\partial u_e}{\partial x} - \delta^* \frac{1}{u_e}\frac{\partial u_e}{\partial t} \\ C_D u_e - 2\delta^k \frac{\partial u_e}{\partial x} - 2\theta \frac{1}{u_e}\frac{\partial u_e}{\partial t} \end{bmatrix}.$$

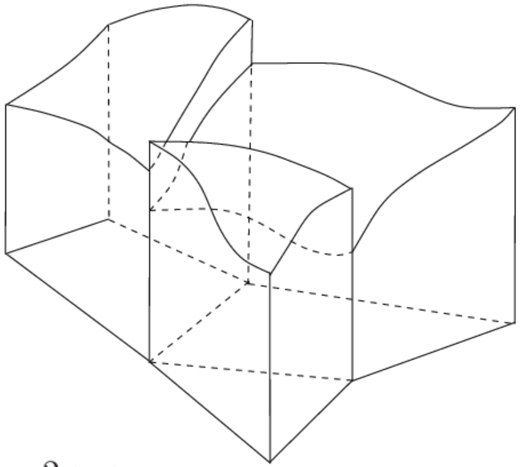
$$\begin{aligned} H &= \frac{\delta^*}{\theta}, \\ H^* &= \frac{\delta^k}{\theta}, \\ C_f(H,\theta) &= \overline{C_f}(H)\frac{2\nu}{u_e\theta}, \\ C_D(H,\theta,H^*(H)) &= \overline{C_D}(H)H^*(H)\frac{\nu}{u_e\theta}, \end{aligned}$$

$$H^*(H) = \begin{cases} 1.528 + 0.0111\frac{(H-4.35)^2}{H+1} - 0.0278\frac{(H-4.35)^3}{H+1} & \\ -0.0002[(H-4.35)H]^2 & \text{if } H < 4.35, \\ 1.528 + 0.015\frac{(H-4.35)^2}{H} & \text{if } H > 4.35, \end{cases}$$

$$\overline{C_f}(H) = \begin{cases} \frac{1}{2}\left[-0.07 + 0.0727\frac{(5.5-H)^3}{(H+1)}\right] & \text{if } H < 5.5, \\ \frac{1}{2}\left[-0.07 + 0.015\left(1 - \frac{1}{(H-4.5)}\right)^2\right] & \text{if } H > 5.5, \end{cases}$$

$$\overline{C_D}(H) = \begin{cases} 0.207 + 0.00205(4-H)^{5.5} & \text{if } H < 4, \\ 0.207 - 0.0016\frac{(H-4)^2}{1+0.02(H-4)^2} & \text{if } H > 4, \end{cases}$$

Numerical Approach: Modelling



Unknowns

$$\mathbf{u}(\cdot,t) \in U^5, \quad U \equiv L^2(\Omega),$$

Weak formulation

$$(L(\mathbf{u}(\cdot,t)),\mathbf{v}) = (\mathbf{s},\mathbf{v})$$

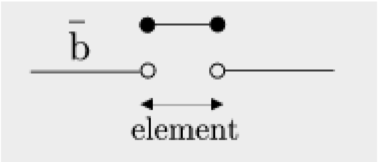
Approximate solution

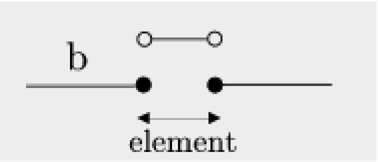
$$\mathbf{u}_h(\cdot,t) \in U_h^5, \quad U_h = span\{b_{jk}\} \subset U, \forall \mathbf{v} \in U^5,$$

$$\mathbf{u}_h(\mathbf{x},t) = \mathbf{u}_{jk}(t) b_{jk}(\mathbf{x}), \quad \mathbf{u}_{jk}(t) \in L^2(I_t), \quad b_{jk} \in L^2(\Omega),$$

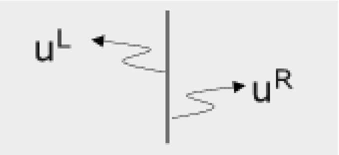
Discrete equation

$$\int_{\Omega_j} L\left(\mathbf{u}(\mathbf{x},t)\right) b_{jm} d\Omega_j = \int_{\Omega_j} \mathbf{s} b_{jm} d\Omega_j$$





$$\int_{\Omega_j} \frac{\partial \mathbf{u}_{jk}}{\partial t} b_{jk} b_{jm} d\Omega - \int_{\Omega_j} \mathbf{f}_i \frac{\partial b_{jm}}{\partial x_i} d\Omega + \int_{\partial\Omega_j} b_{jm} \mathbf{f}_i n_{ji} dS = \int_{\Omega_j} \mathbf{s} b_{jm} d\Omega.$$



Challenges

- Mathematical modelling
  - Analytical derivation of the equations
  - Re-writing in various forms
  - Determining the type of the equations
  - etc.
- Numerical modelling
  - Finding suitable numerical method
  - Improving/modifying numerical schemes / algorithms
  - Implementing computer codes

Furthermore:

- Application with commercial CFD package CFX
  - Steady/unsteady flow over 2D airfoils / 3D wind tubine blades
  - Boundary layer flows
  - Turbulence modelling, etc.

Short / long term internship possibilities for students

ECN offers:

- Short term trainee programs for 3rd and 4th year undergraduate students (3 to 6 months)
- Long term internship programs for MSc students (6-12 months)
- Short or long term programs for PHd students

via:

- Project announcements at www.ecn.nl
- Individual applications to the appropriate units/groups

selects:

- Depending on the ***grades / ambitions / aims*** of the student
- Depending on the current budget status of the research groups

cont'd

supports:

- Housing for the students (flats for 2-3 student)
- Free transportation
- Additional scholarship upto 400 Euros per month

procedure:

- Initial contact and interviews by the research group
- Student must apply via HR department
- Residence and working permit should be obtained via ECN
- Whole procedure takes about 3 months for Turkish citizens

Thank you for your attention