

Numerical Methods for Internal Aerodynamics

Historical background

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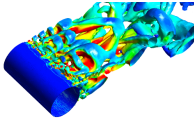
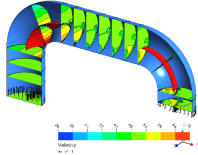
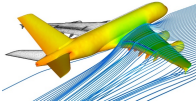
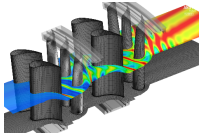
- 1 What is CFD?
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- 4 Examples

What is CFD?

- Computational Fluid Dynamics
- Objectives:
 - Design, calculation and optimization of flow components
 - Replace or extend experimental studies

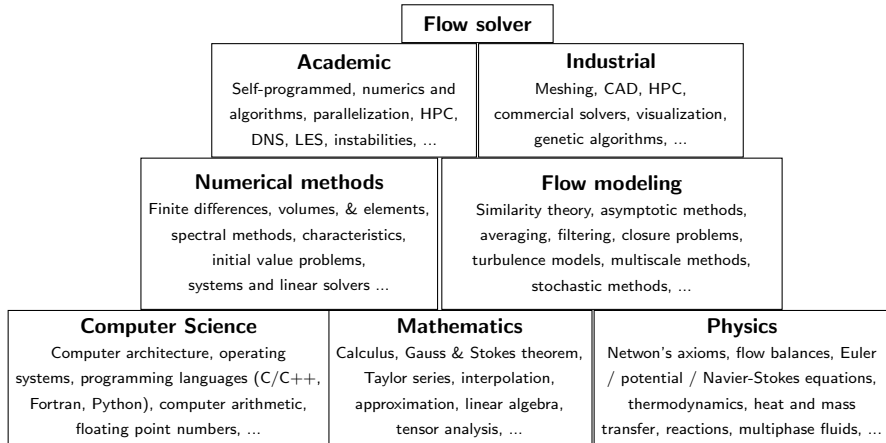
What is CFD?

■ Examples of CFD flow components

State Geometry	external	internal
simple	Plate Cylinder Wing Stair Tread 	Pipe Manifold Nozzle Diffuser 
complex	Airplane Car Wind- mill Ship 	Turbine Engine Pump Valve 

What is CFD?

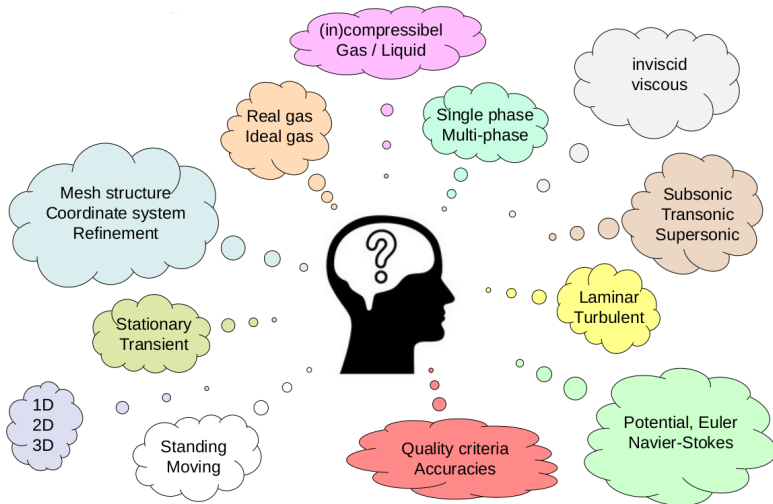
■ Complexity



CFD pyramid according to Prof. H. Schmidt (BTU)

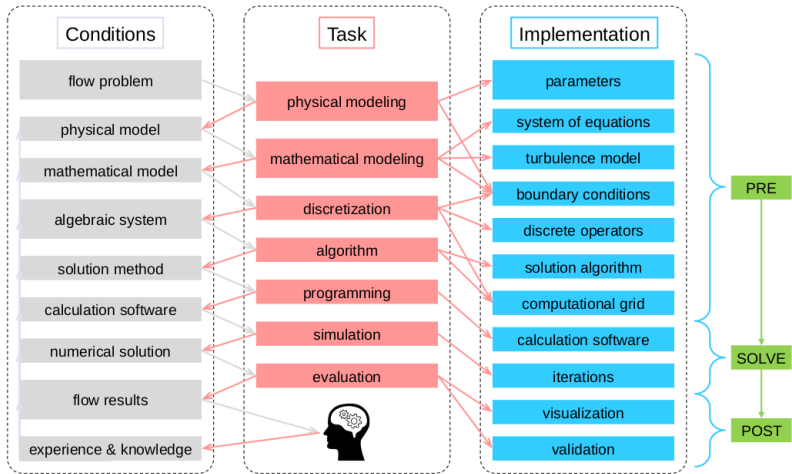
What is CFD?

■ Brainstorm



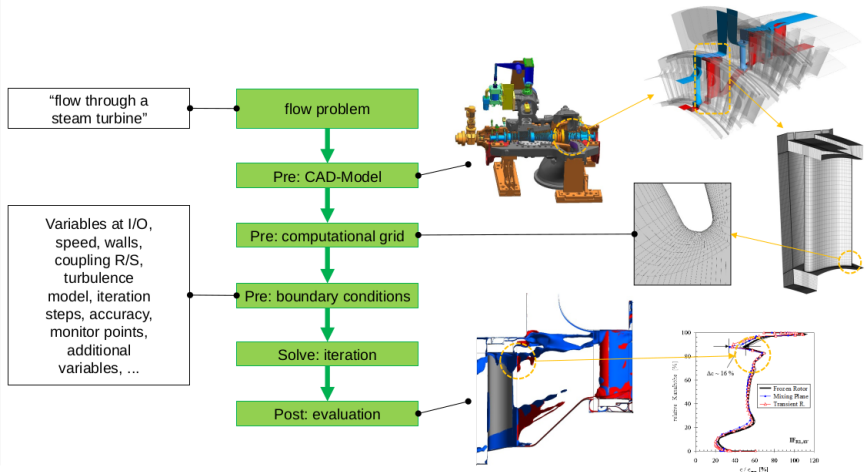
What is CFD?

■ Overview of a numerical solution



What is CFD?

■ Procedure from a user point of view



What is CFD?

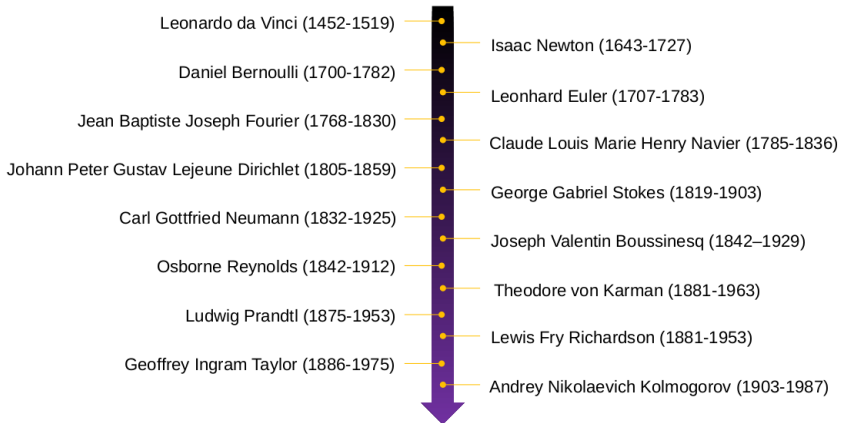
- Reasons for the use of CFD
 - Numerical methods have become increasingly important in the course of the last 60 years or so, both in research and in industry.
- Why?
 - Numerical methods are continuously improved
 - Increasing performance of computers
 - Computing time and memory become cheaper (relatively speaking)
 - Computers / software become more user-friendly and versatile
 - Increasing accuracy of geom., phys. and math. Approximations
 - Parallel computers / parallel processes open up new perspectives
 - Calculation of complex geometries (3D)
 - Calculation of unsteady flows
 - GPU instead of CPU for parallel processes

Historical background



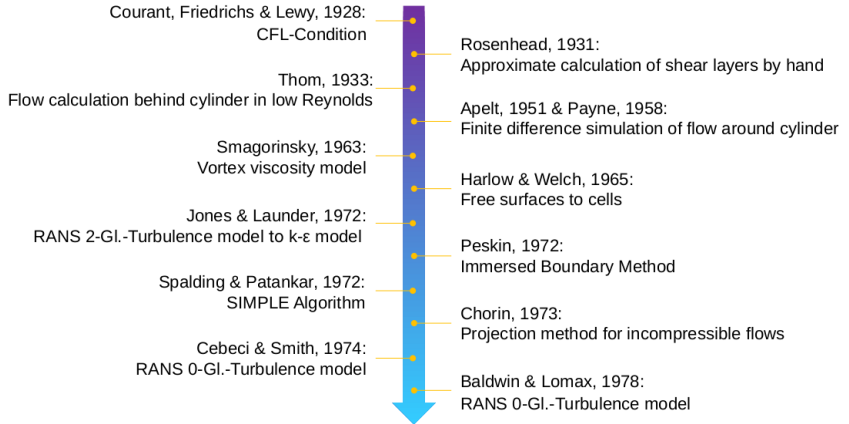
Historical background

■ Personalities and milestones



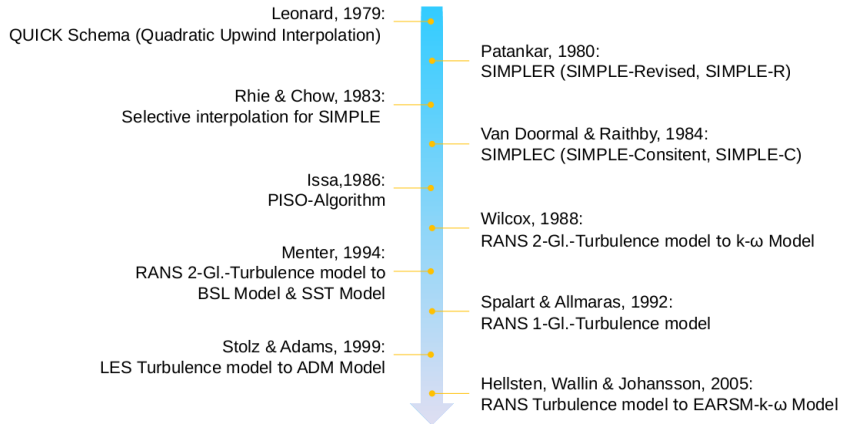
Historical background

■ Personalities and milestones

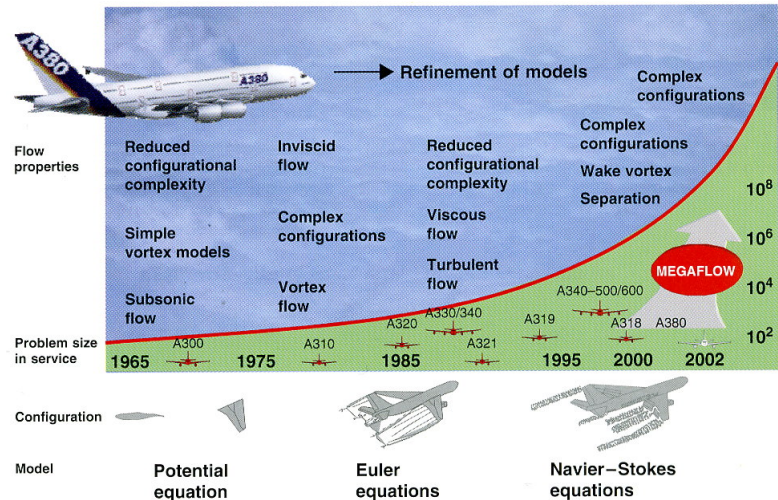


Historical background

■ Personalities and milestones



- 40 years of CFD development at Airbus

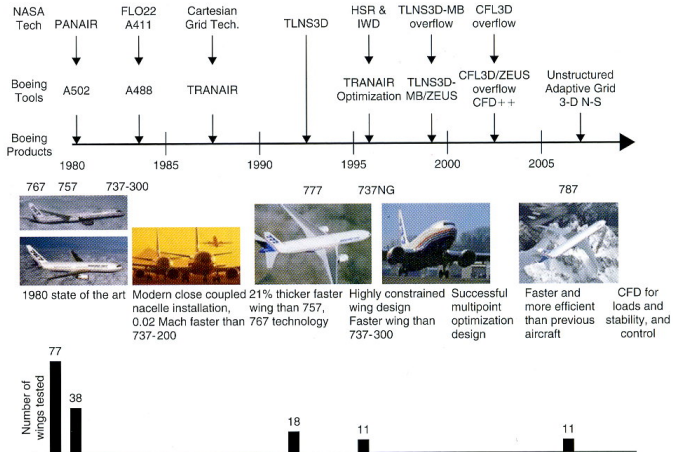


from Hirsch, vol.1, 2007

Historical background

■ 40 years of CFD development at Boeing

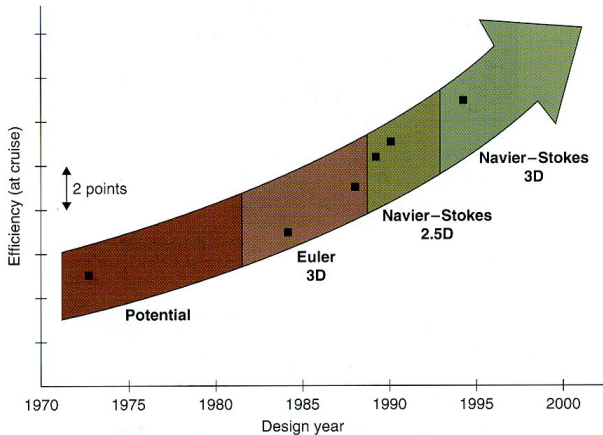
Chronology and impact



from Hirsch, vol.1, 2007

Historical background

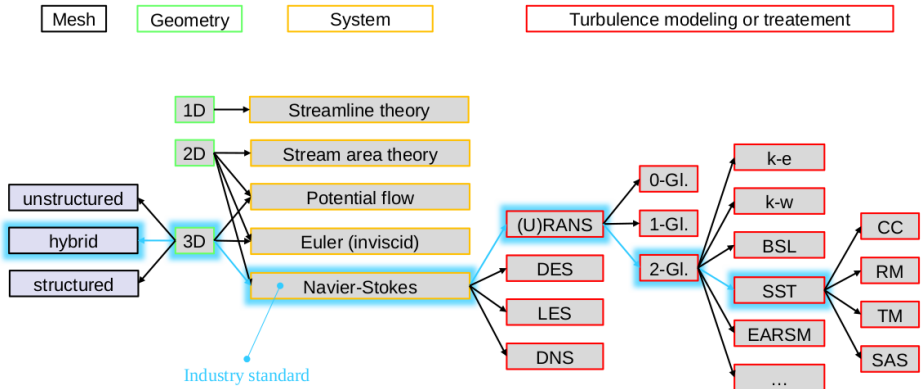
- 30 years of CFD development at SNECMA



from Hirsch, vol.1, 2007

Historical background

■ Components of CFD simulation



Historical background

- Examples of commercial CFD solvers



CFX, FLUENT



FINE/Turbo



T-Block



Star CCM+ (Siemens)

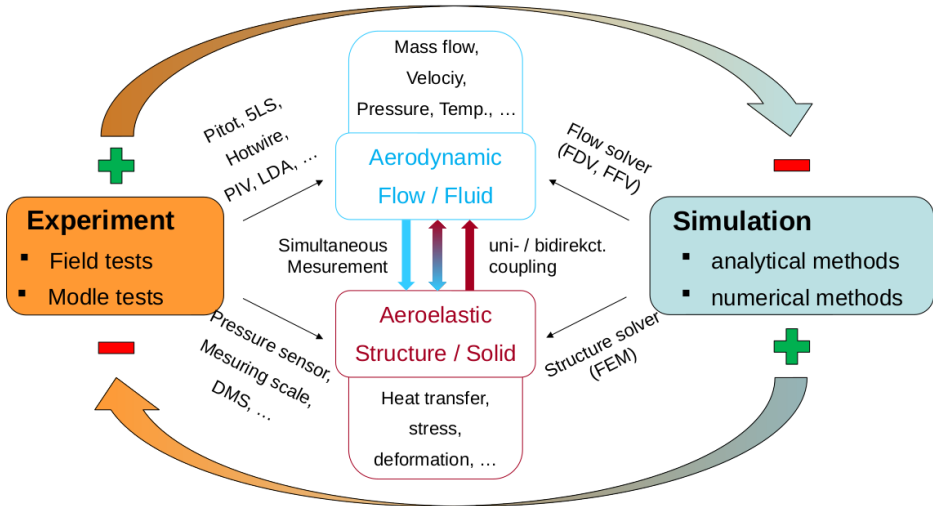


TRACE

OpenFOAM®



Experiment vs simulation



Experiment vs simulation

■ Advantages and disadvantages experiment

Advantages:

- Measurements generally reflect reality (with correctly selected measurement method), not a mathematical model.
- Often only the experiment offers insight into the flow conditions, because numerical methods are still too complex for these cases. (e.g. aircraft engine with compressor, combustion chamber, turbine and nozzle)
- Validation, verification and improvement of numerics (benchmark, test cases, own exp.)

Disadvantages:

- Model tests are usually very expensive (test stand / expensive measurement technology / personnel deployment)
- Measurements on real objects are often not possible or too expensive (e.g. airplane in wind tunnel)
- Field tests to Model tests: difficulty of transferability
- flammable or toxic fluids, hot surfaces, risk of explosion
- Measurement inaccuracies

Experiment vs simulation

■ Advantages and disadvantages simulation

Advantages:

- Application is often faster and less expensive than the experiment
- More complete information about the flow field (also in areas that are not accessible for measurement technology)
- extensive studies possible: parameter variations (Re , Ma , T , ...), geometry variations

Disadvantages:

- Limitations due to computer hardware / computation time (e.g. turbulence, multiphase flow).
- Inaccuracies in mathematical modeling or numerical approximation
- high frustration tolerance of the user / programmer necessary

Instead of "either experiment or simulation", we use both in combination. Experiments and simulations must complement each other.

Experiment vs simulation

■ Example cost comparison

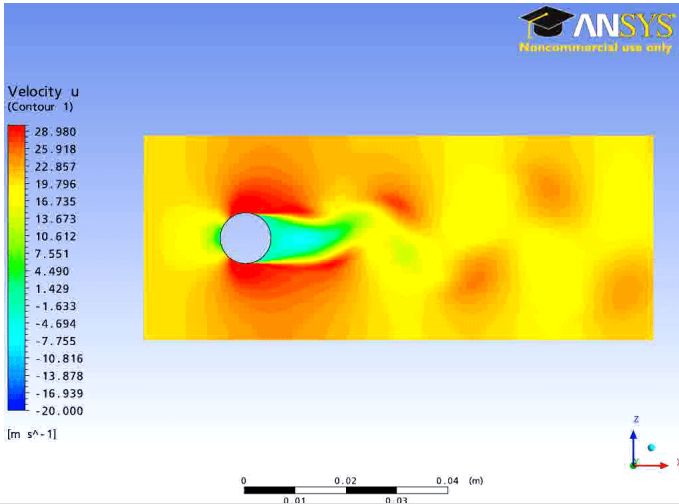
Simulation:

- PC / Workstation: 2.500€
- Computing cluster: 10.000€
- CFD license costs: 10.000€ p. year
- Investment: 12.500€
- ongoing: 10.000€ p. year

Experiment:

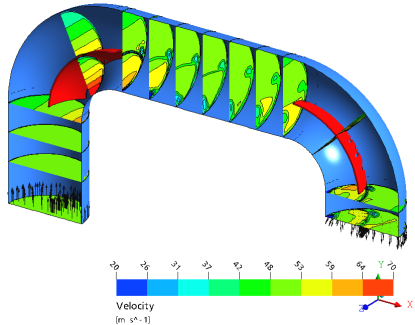
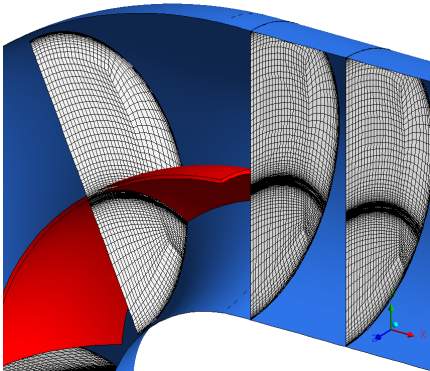
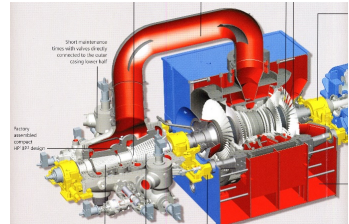
- Air supply: 200.000€
- Metrology: 150.000€
- Electricity costs: 5.000€ p. measuring day
- Investment: 350.000€
- ongoing: 50.000€ p. year (10 measurement days)

- Cylinder recirculation
 - unsteady, incompressible flow
 - orthogonal coordinate system



Examples

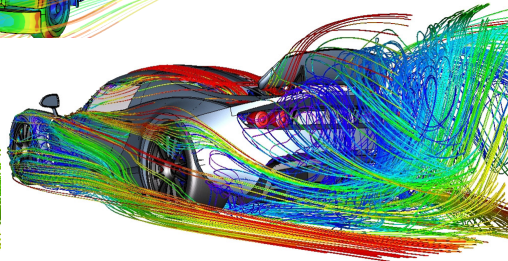
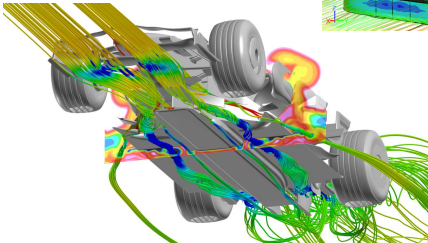
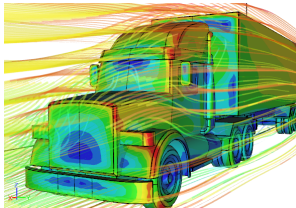
- Overflow pipe in a steam turbine
 - stationary, compressible flow
 - non-orthogonal coordinates



Examples

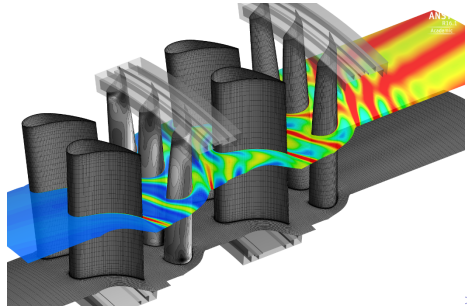
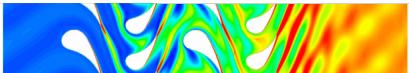
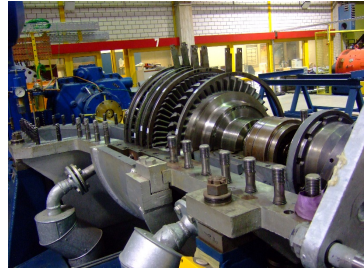
■ Vehicles

- unsteady, compressible flow
- orthogonal/non-orthogonal coordinates



Examples

- 4-stage axial turbine
 - non-orthogonal coordinates
 - rotor - stator exchange



Examples

- Speedboat
 - Free surface

Thanks for your attention!

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