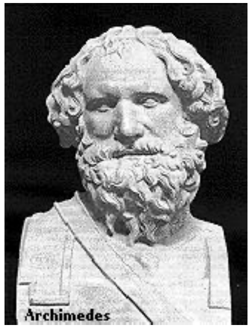
Física dos Meios Contínuos

Margarida Telo da Gama

Rodrigo Coelho

History

Faces of Fluid Mechanics



Archimedes
(C. 287-212 BC)

Newton
(1642-1727)

Leibniz
(1646-1716)

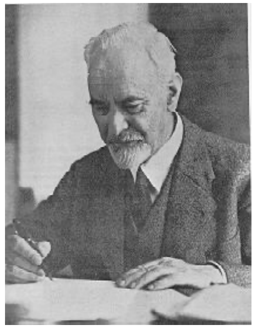
Bernoulli
(1667-1748)

Euler
(1707-1783)

Navier
(1785-1836)

Stokes
(1819-1903)

Reynolds
(1842-1912)



Prandtl
(1875-1953)

Taylor
(1886-1975)

Significance

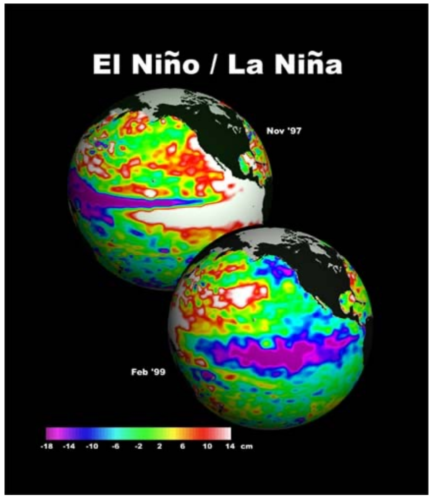
- Fluids everywhere
  - Weather & climate
  - Vehicles: automobiles, trains, ships, and planes, etc.
  - Environment
  - Physiology and medicine
  - Sports & recreation
  - Many other examples!

Weather & Climate

Tornadoes

Thunderstorm

Global Climate



Hurricanes

Vehicles

Aircraft

Surface ships

High-speed rail

Submarines

Environment

Air pollution

River hydraulics

Physiology and Medicine

Blood pump

A BVS blood pump

Ventricular assist device

Sports & Recreation

Water sports

Cycling

Offshore racing

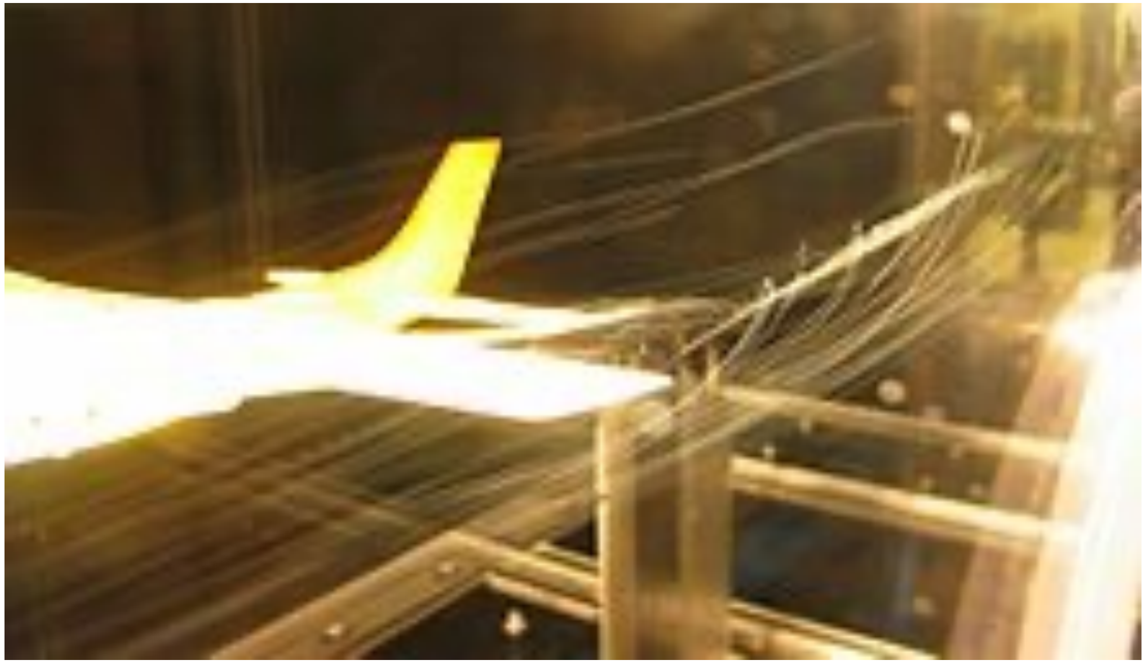
Auto racing

Surfing

Analytical Fluid Dynamics

- Mathematical physics problem formulation
- Control volume & differential analysis (RTT)
- Exact solutions exist ONLY for simple geometry and conditions
- Approximate solutions for practical applications
  - Linear
  - Empirical relations using EFD data

Full and model scales: wind tunnel



- Scales: full-scale and model
- Selection of the model scale: governed by dimensional analysis and similarity

Computational Fluid Dynamics

- CFD is use of computational methods for solving fluid engineering systems, including modeling (Mathematics & Physics) and numerical methods (solvers, finite differences, grid generations, etc.).
- Rapid growth in CFD technology since advent of computer

ENIAC 1, 1946

IBM WorkStation

Purpose

- The objective of CFD is to model the continuous fluids with Partial Differential Equations (PDEs) and discretize PDEs into an algebra problem, solve it, validate it and achieve simulation based design instead of "build & test"
- Simulation of physical fluid phenomena that are difficult to be measured by experiments: scale simulations (full-scale ships, airplanes), hazards (explosions, radiations, pollution), physics (weather prediction, planetary boundary layer, stellar evolution).

Modeling

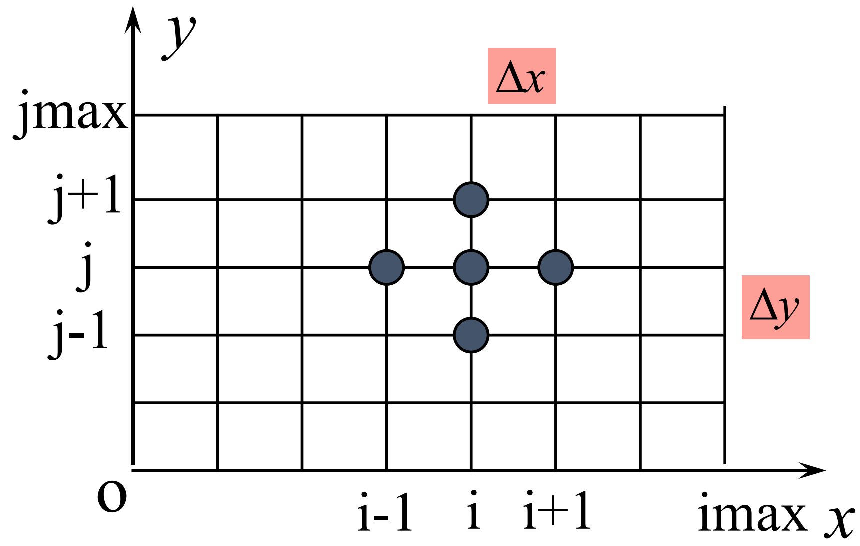
- Mathematical physics problem formulation of fluid engineering system
- Governing equations: Navier-Stokes equations (momentum), continuity equation, energy equation, ideal gas law, combustions (chemical reaction equation), multi-phase flows and turbulent models (RANS, LES, DES)
- Coordinates: Cartesian, cylindrical and spherical coordinates result in different forms of governing equations
- Initial conditions (initial guess of the solution) and Boundary Conditions (no-slip wall, free-surface, zero-gradient, symmetry, velocity/pressure inlet/outlet)
- Flow conditions: Geometry approximation, domain, Reynolds Number, and Mach Number, etc.

Numerical methods

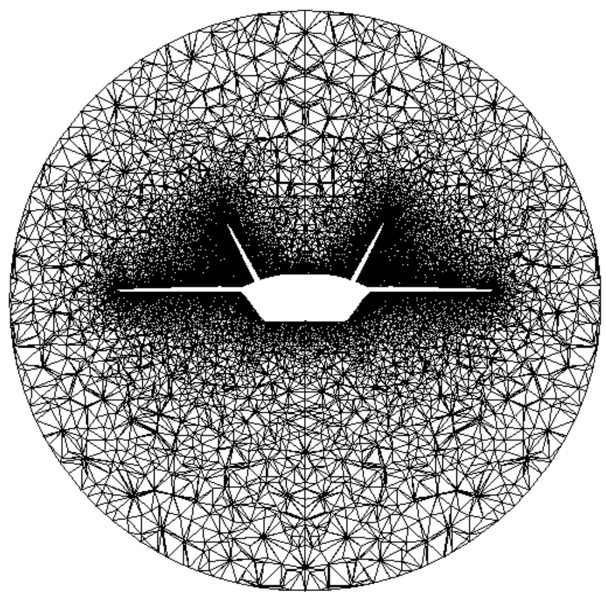
- **Finite difference methods**: using numerical scheme to approximate the exact derivatives in the PDEs

$$\frac{\partial^2 P}{\partial x^2} = \frac{P_{i+1} - 2P_i + P_{i-1}}{\Delta x^2}$$

$$\frac{\partial^2 P}{\partial y^2} = \frac{P_{j+1} - 2P_j + P_{j-1}}{\Delta y^2}$$

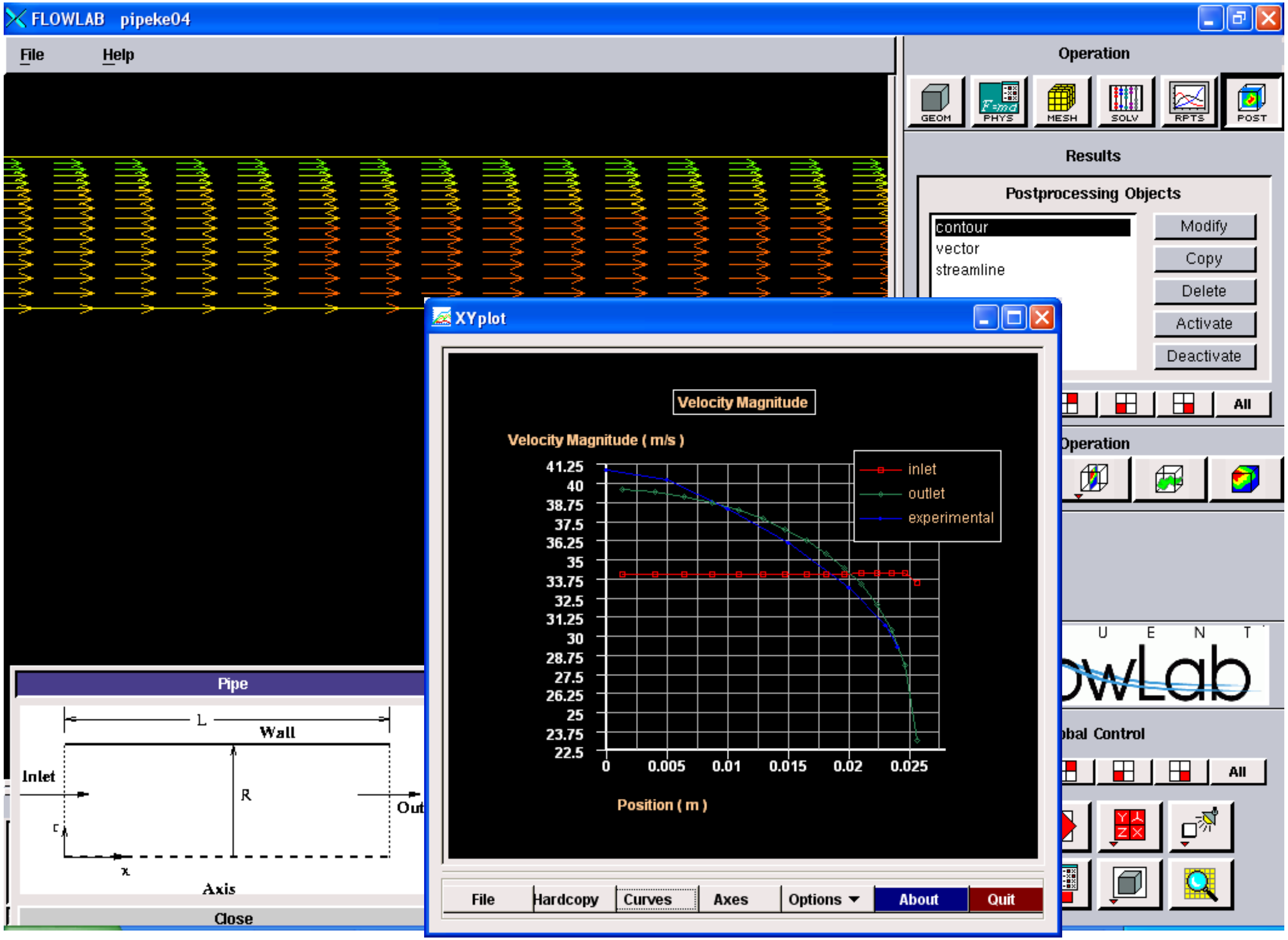


- **Finite volume methods**
- **Grid generation:** conformal mapping, algebraic methods and differential equation methods
- **Grid types**: structured, unstructured
- **Solvers**: direct methods (Cramer's rule, Gauss elimination, LU decomposition) and iterative methods (Jacobi, Gauss-Seidel, SOR)

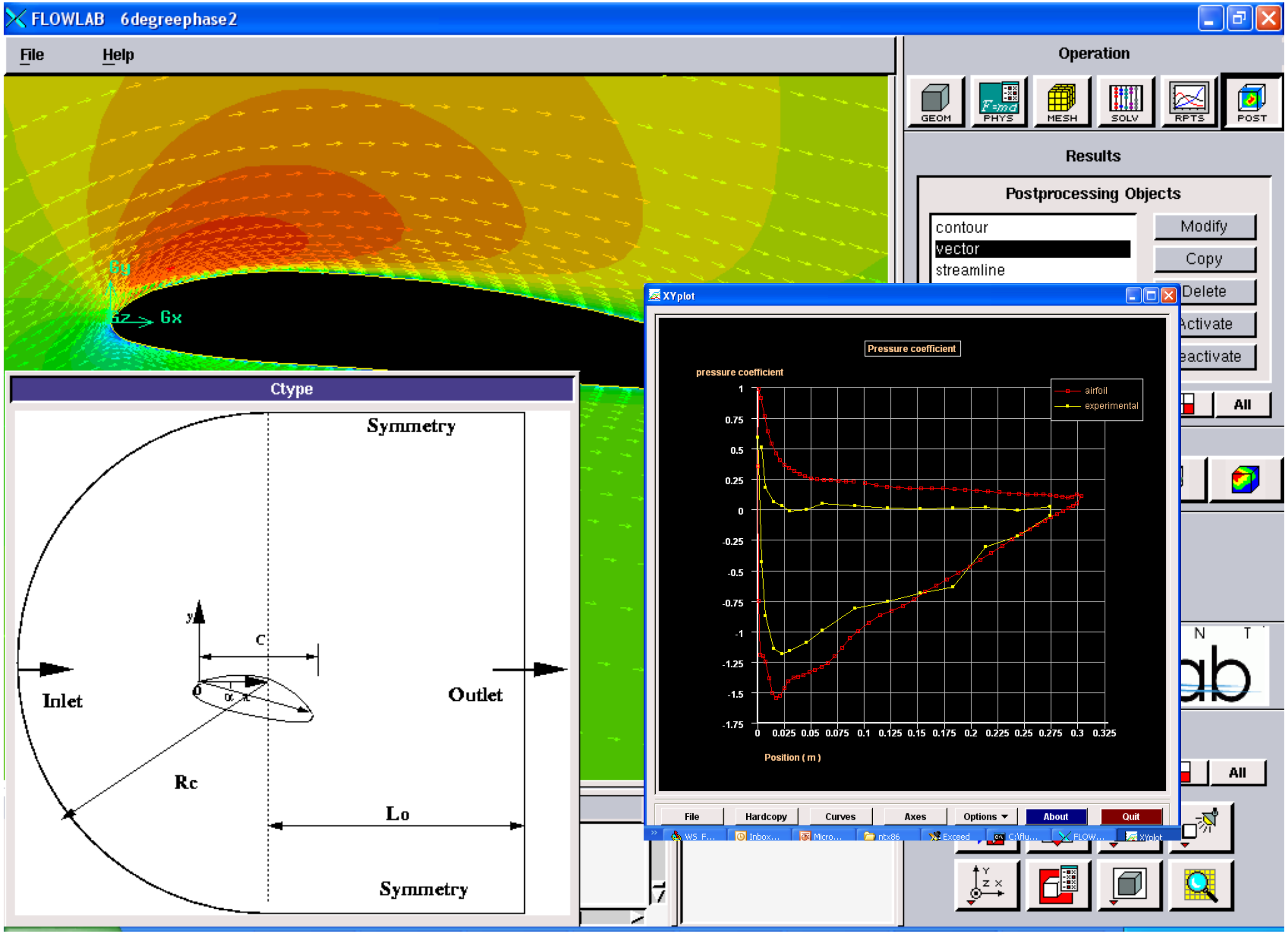


Slice of 3D mesh of a fighter aircraft

“Hands-on” experience using CFD Interface (pipe template)



“Hands-on” experience using CFD Interface (airfoil template)



Designing, building and operating a submarine

SSPA Your Maritime Solution Partner

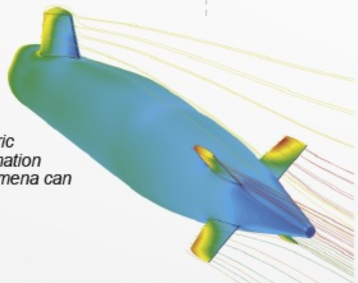
Designing the submarine

1 Concept evaluation

- Hull main parameters
- Location and size of the sail and control surfaces
- Choice of propulsion arrangement

2 Basic hydrodynamic design

- Hull
- Sail
- Control surfaces

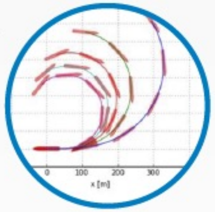


CFD calculation of a generic submarine. Detailed information about different flow phenomena can be obtained.

Verifying the design – model tests and simulations

3 Power Requirement

- Resistance and self-propulsion tests in the towing tank
- Wake flow distribution
- Rudder forces and moments



Simulation of turning circle manoeuvre in Submo. The interface to Submo can be entirely web server-based either in-house or in the cloud.

4 Propeller design

- Cavitation tunnel tests
- High efficiency
- Good cavitation properties
- Low radiated noise

Model of the IZAR P650 tested at SSPA. The same model was used in all SSPA facilities.

5 Manoeuvring performance

- Captive tests in wave basin, hydrodynamic coefficients for simulation model
- Simulations of standard manoeuvres and depth change
- Autopilot and depth controller design
- Stability in the horizontal and vertical planes

TOWING TANK

CAVITATION TUNNEL

MARITIME DYNAMICS LABORATORY

In operation

A submarine in a simulator environment. The crew can practise repeat manoeuvres and practise operations which are not easy to perform on a real submarine.

6 Simulator

- Crew training
- Development of hardware for a submarine's bridge

In operation

- Depth keeping in periscope conditions under a seaway
- Simulation of emergency recovery manoeuvres
- Compensation and trimming
- Safe operation envelopes