What is CFD?

- The Physical aspects of any fluid flow are governed by three fundamental principles: Mass is conserved; Newton's second law and Energy is conserved. These fundamental principles can be expressed in terms of mathematical equations, which, in their most general form, are usually partial differential equations.

- The role of CFD in engineering predictions has become so strong that today it may be viewed as a new third dimension of fluid dynamics, the other two dimensions being the above stated classical cases of pure experiment and pure theory.

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What is CFD? – Cont.

- Fluid flows are modeled by a set of partial differential equations, the Navier--Stokes equations. Except for special cases, no closed-form solutions exist to the Navier--Stokes equations, and this fact was one of the motivations John Von Neumann provided for the development of electronic computers.

- Solving a particular problem generally involves first discretizing the physical domain that the flow occurs in. This discretization is straightforward for very simple geometries, but is a difficult problem for more complicated objects.

- On the discretized mesh, the Navier-Stokes equations take the form of a large system of nonlinear equations; going from the continuum to the discrete set of equations is a problem that combines both physics and numerical analysis.

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What is CFD? – Cont.

- The system of nonlinear equations is typically solved by a Newton-like method, which in turn requires solving a large, sparse system of equations on each step. Scarcity here means that the matrix of coefficients for the linear system consists mainly of zeros, with only a few nonzero entries. Storing the coefficients requires development of efficient data structures that require little overhead storage but allow the necessary manipulations to be performed efficiently.

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What is CFD? – Cont.

- Methods for solving large sparse systems of equations are a hot topic right now, since that is often the most time-consuming part of the program, and because the ability to solve them is the limiting factor in the size of problem and complexity of the physics that can be handled.
  - Direct methods, which factor the matrices, require more computer storage than is permissible for all but the smallest problems.
  - Iterative methods use less storage but suffer from a lack of robustness: they often fail to converge. The solution is to use preconditioning; that is, to pre-multiply the linear system by some matrix that makes it easier for the iterative method to converge.

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What is CFD? – Cont.

- CFD problems are at the limits of computational power, so parallel programming methods are used. That brings in the research problem of how to partition the data to assign parts of it to different processors; usually domain decomposition methods are applied.

- Once the solution is found, analyzing, validating, and presenting it calls into play visualization and graphics techniques.
  - Visualization can help with understanding the nature of the problem, the interaction of algorithms with the computer architecture, performance analysis of the code, and, most importantly, debugging! This example of CFD indicates where computer science comes into play: graph theory and algorithms, computational complexity, numerical analysis, parallel programming, graphics and visualization are all needed here.

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CFD for Ship Design

- Merchant Ships
  - Very Large Custom-made Product (100 ~ 320 m)
  - Price : US$ 10 ~200 million
  - All Ships are different
    - Cargo volume/weight, Speed
    - Cargo type (container, oil, grain, ore, passenger)
    - Route, sea roughness, port, canal
    - Engine/machinery, registry/insurance
    - Owner's preference
  - L, B, T, CB : DWT, Harbor depth, Canal width
  - Hull Form : Designer's task

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Why Hull Form Important?

- Based on various factors, determine the best possible combination of size and speed.
- Importance of speed
  - Acceptable up to 0.2 kt difference from desired speed
  - Penalty of $100K per 0.1 kt difference
  - Denied if more than 0.5 kt difference (2% of 25 kts)
  - Why? For 25 years of life, it takes 10 – 15 years. In 10 - 15 years, owner needs to save operation costs.

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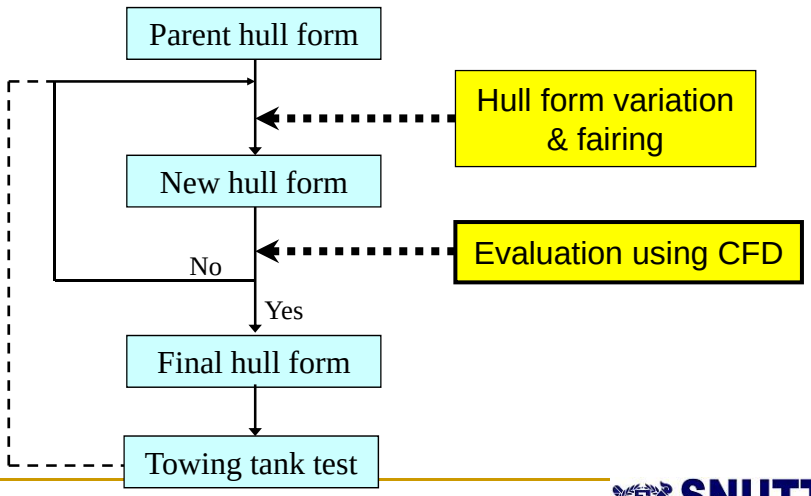
How a New Hull Form is Designed?



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How a New Hull Form is Designed?

- Estimate hydrodynamic performance
  - Model tests
    - Towing tank, cavitation tunnel, square basin
    - Large cost and time
  - CFD
    - Less cost and time
    - Ease of use
    - Consistency & accuracy

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Hydrodynamics Performance

- Resistance, propulsion, maneuvering, seakeeping
  - Resistance
    - Bare hull in calm water

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Hydrodynamics Performance – Cont.

- Resistance, propulsion, maneuvering, seakeeping
  - Propulsion
    - Bare hull + propulsor in calm water

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Hydrodynamics Performance – Cont.

- Resistance, propulsion, maneuvering, seakeeping
  - Maneuvering
    - Bare hull + propulsor + rudder in calm water

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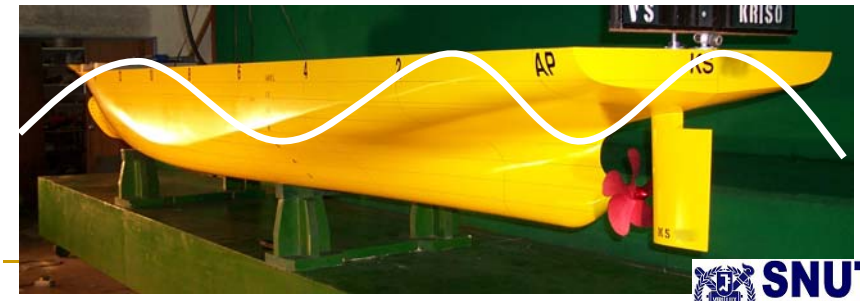
Hydrodynamics Performance – Cont.

- Resistance, propulsion, maneuvering, seakeeping
  - Seakeeping
    - Bare hull + propulsor + rudder in ambient waves



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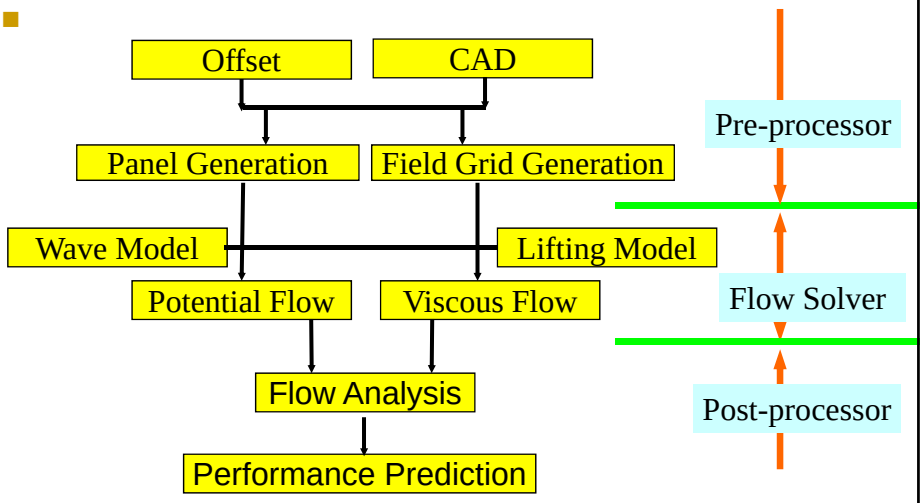
Typical CFD Procedure



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