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Introduction to Computational Fluid Dynamics

Taygun Recep Güngör, PhD
İstanbul Teknik Üniversitesi

ncc@ulakbim.gov.tr

The CFD process

Problem identification

- What do we want?
- What do we have?

Pre-processing

- Geometry
- Grid
- Physical model
- Turbulence

Solving

- Monitoring the simulation

Post-processing

- Interpretation the results
- Report
- Update the model

Problem identification

Define the objective:

What results are you looking for? → Skin friction coefficient? Pressure drop? Mass flow rate? Vibrations on a bridge?

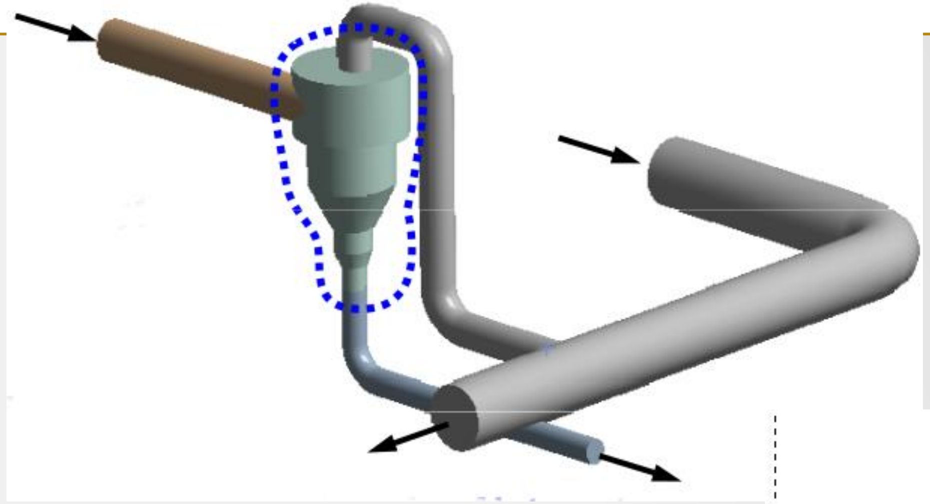
What degree of accuracy is required? → Preliminary results? Very accurate solutions:

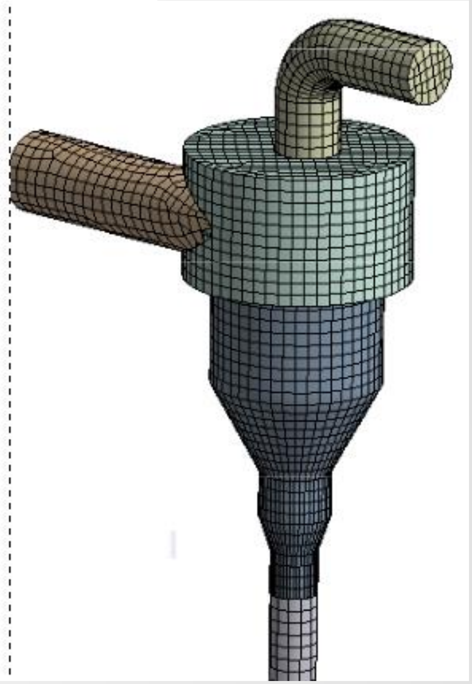
How quickly do you need the results? → 3 months or 1 week?

What sort of resources do you have? → Your personal laptop? A supercomputer?

Is a CFD a good tool for my objective?

Problem identification





Determine the domain:

How isolated will the region of interest?

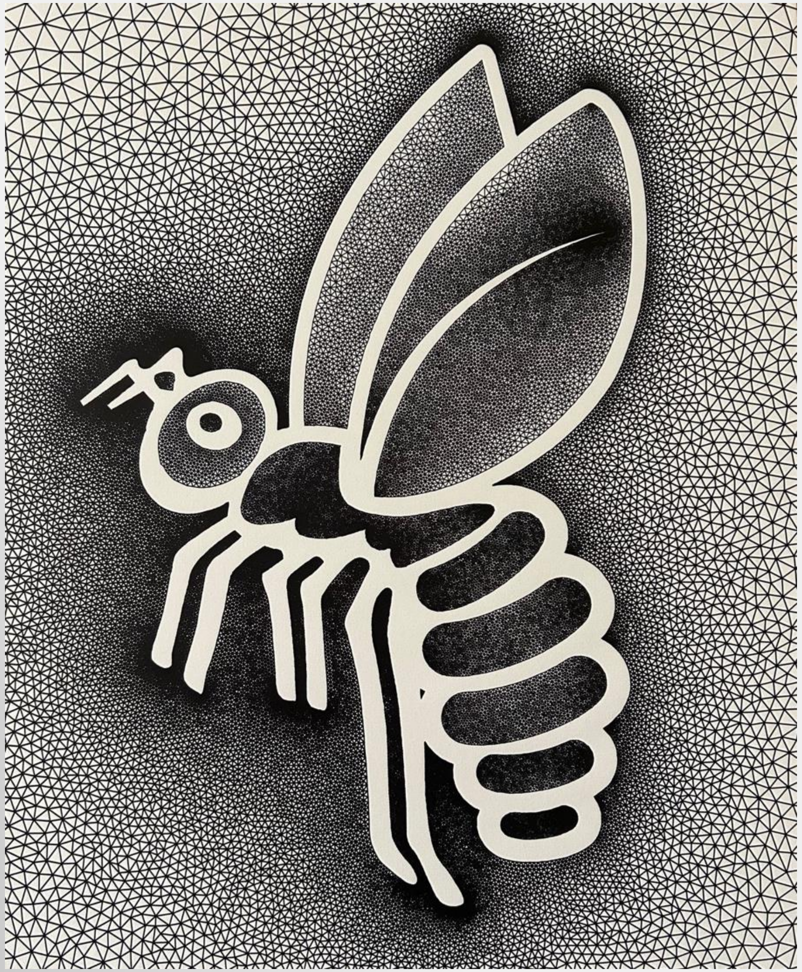
What is the extent of the computational domain?

- Are there any boundaries the conditions are known?
- Are there boundaries with more precise information?

Can it be simplified?

- Can we solve the problem as with a 2D domain?
- Is there any symmetry?

The grid generation



Mesh is one of the most important aspect of CFD.

A good mesh might not lead to the ideal solution, but a bad mesh will always lead to a bad solution.

GARBAGE IN GARBAGE OUT!

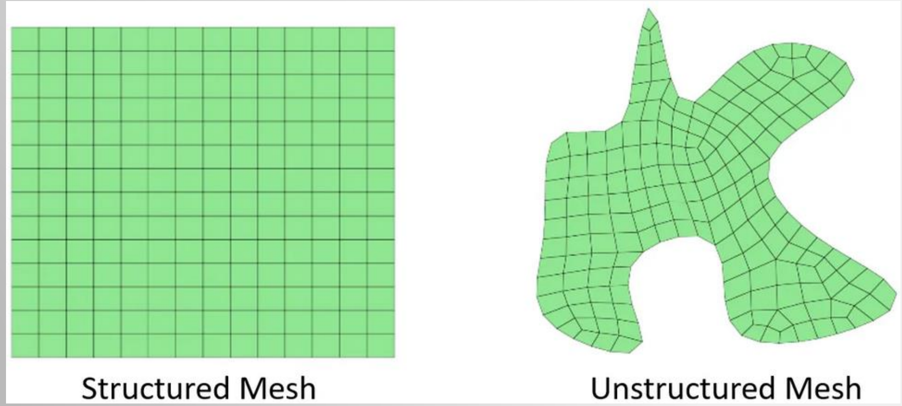
The grid generation

Structured

- Memory efficient
- Fast to solve
- Very difficult to generate the mesh
- Sometimes cannot catch the shape properly
- Weeks to months

Unstructured

- Complex geometries easier to mesh
- Arbitrary positions
- Hours to days
- Greater memory requirement
- Slower to solve
- Fluent, openFOAM, etc are unstructured



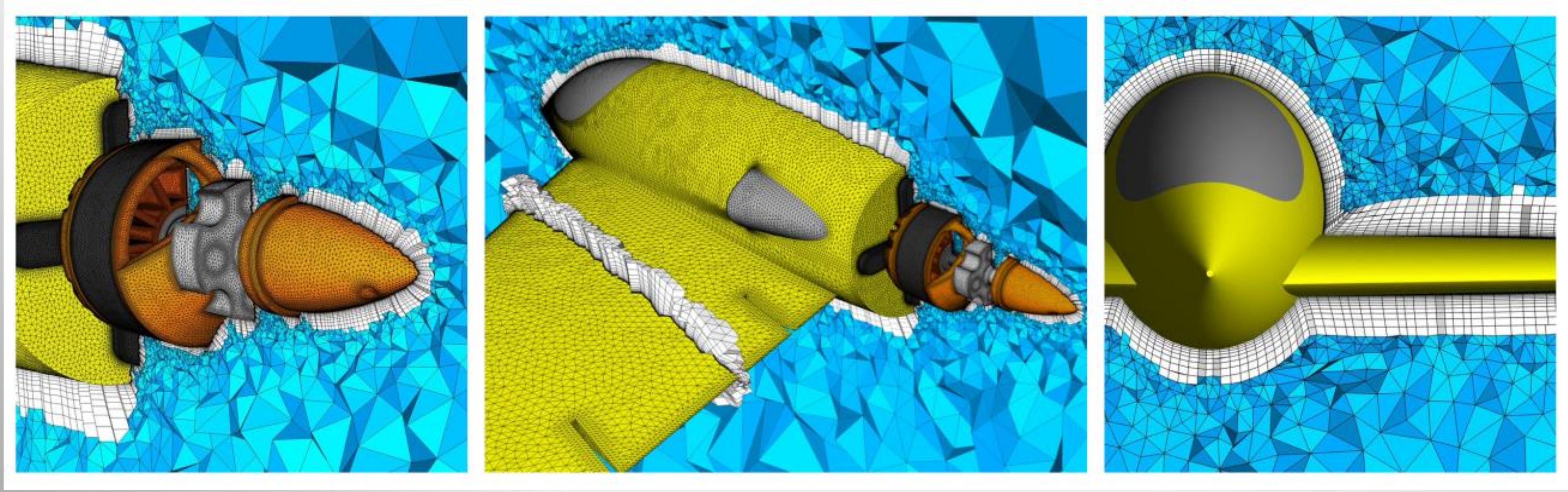
onscale.com

It is not about the shape of the mesh but how the information is stored.

The grid generation

There is unfortunately **NO** written rules for grid generation.

It highly depends on user experience besides some metrics.



22rd IMR Meshing Maestro Contest Winner

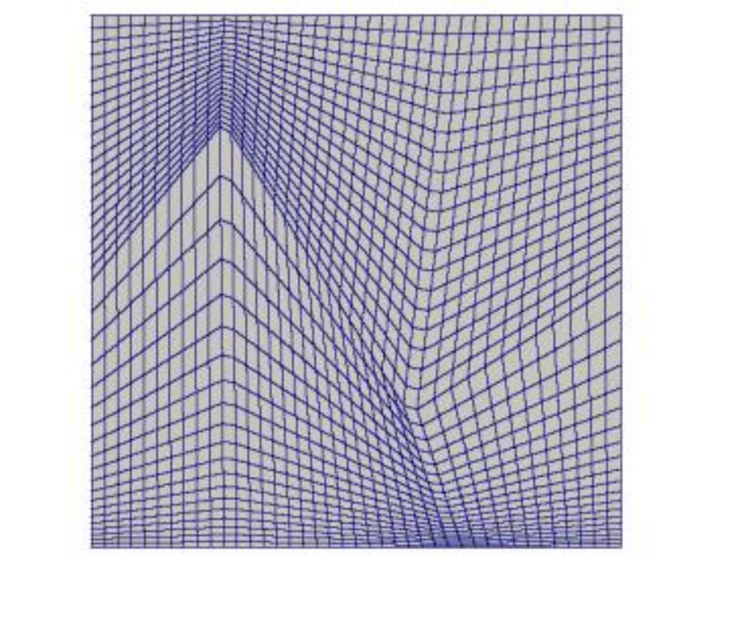
The grid generation

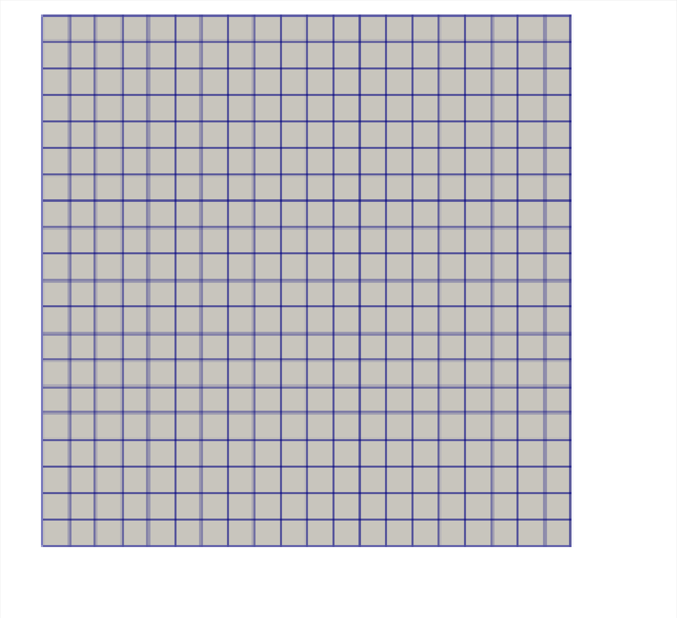
Four metrics that can help us to evaluate the quality of our grid.

You can usually check this with the grid generator or the solver.

- Orthogonality
- Skewness
- Aspect Ratio
- Smoothness

The grid generation

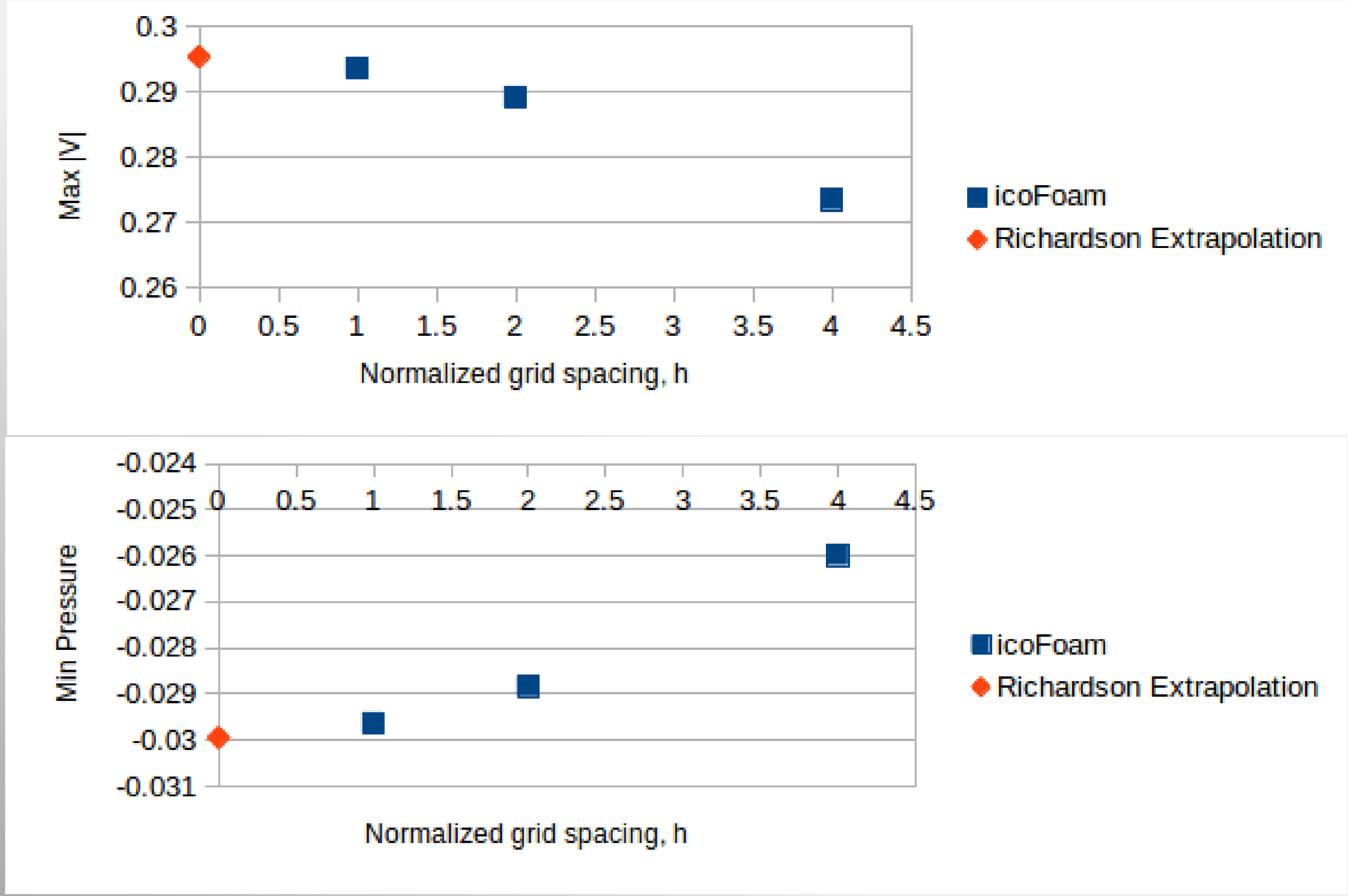




These metrics do not guarantee a good mesh

Both meshes are good in terms of these metrics

The grid generation



(curiosityfluids.com)

The most important thing about grid is grid independence.

Your solution must be independent of the grid.

Numerical scheme

Another important point is what kind of discretization scheme are used. This is something can be cheatable easily, but you should not.

- First order methods are bounded and stable but diffusive.
- Second order methods are accurate, but they might become oscillatory.
- At the end of the day, we always want at least second order accurate solution.
- Higher level accuracy is more difficult with FVM. Therefore, FEM or FDM can be more useful, especially you do academic research.

Boundary and Initial Conditions

Defining boundary conditions involves:
- Finding the location of the boundary condition in the domain.
- Determining the boundary condition type.
- Giving the required physical information.

The choice of the boundary conditions depend on:
- Geometrical considerations.
- Physics involved.
- Information available at the boundary condition location.
- Numerical considerations.

And most important, you need to understand the physics involved.

Boundary and Initial Conditions

Initial conditions (IC) can be divided into two groups:

- Uniform initial conditions.
- Non-uniform initial conditions.

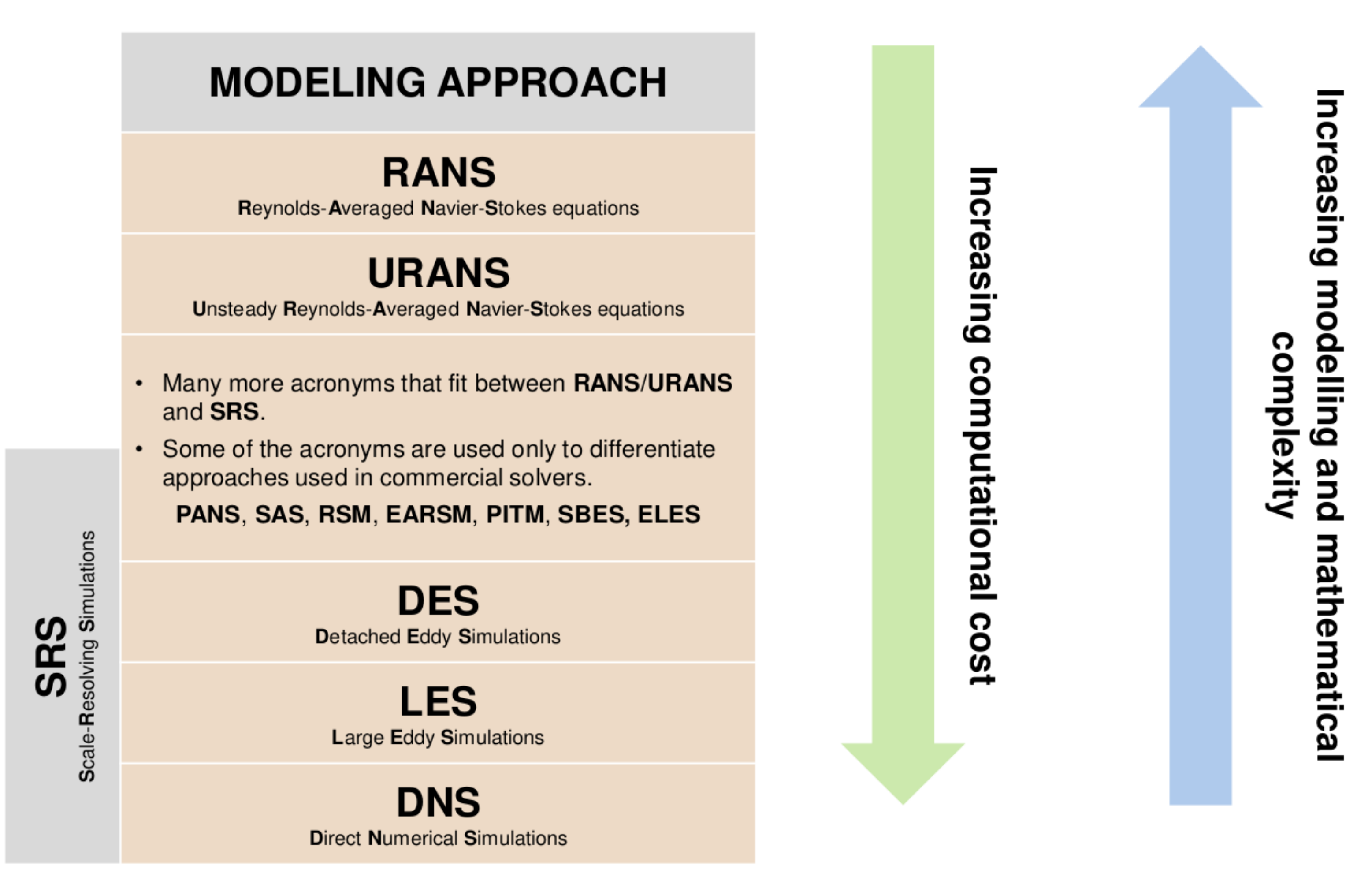
For non-uniform IC, the value used can be obtained from:
- Another simulation (including a solution with different grid resolution).
- A mathematical function
- A potential solver.
- Reduced order models.
- Experimental results.

And most important, you need to understand the physics involved.

Turbulence modelling

Modelling turbulence is one of the most challenging part of preparing a CFD simulation.

You are lucky if your flow is laminar.



(www.wolfdynamics.com)

Turbulence modelling

A: Steady RANS

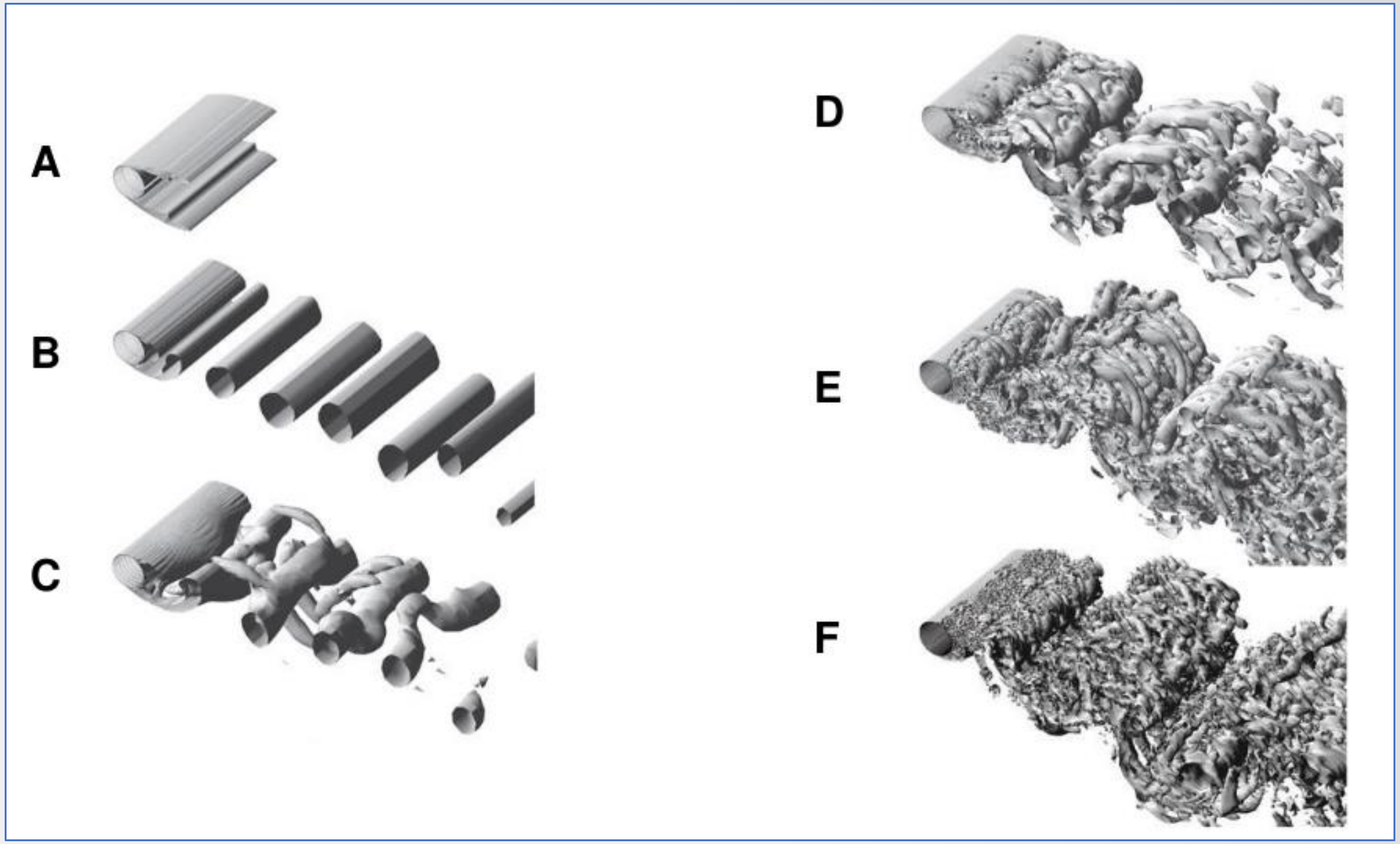
B: 2D URANS

C: 3D URANS

D: Spalart-Allmaras DES coarse grid

E: Spalart-Allmaras DES fine grid

F: SST DES fine grid



(Spalart, 2009)

(curiosityfluids.com)

Verification and Validation

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Verification is the process of checking whether the simulation is correctly implemented, by assessing the mathematical model against analytical results, and detecting programming and user errors.

Validation, on the other hand, is the process of comparing the numerical results of the simulation to the physical world and experimental data. In other words, validation determines if the simulation results agree with those obtained from experiments.

It is important to note that a simulation cannot be considered physically accurate until it is thoroughly validated against experimental results.

- Aerodynamics-based CFD simulations are typically validated using wind tunnels, which employ various measurement techniques, including force measurements, pressure taps, velocity probes, and visual methods such as PIV (Particle Image Velocimetry).
- It is strongly recommended that all CFD results be critically evaluated and validated before use.

Thanks

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