The Mechanics of Turbulent CFD

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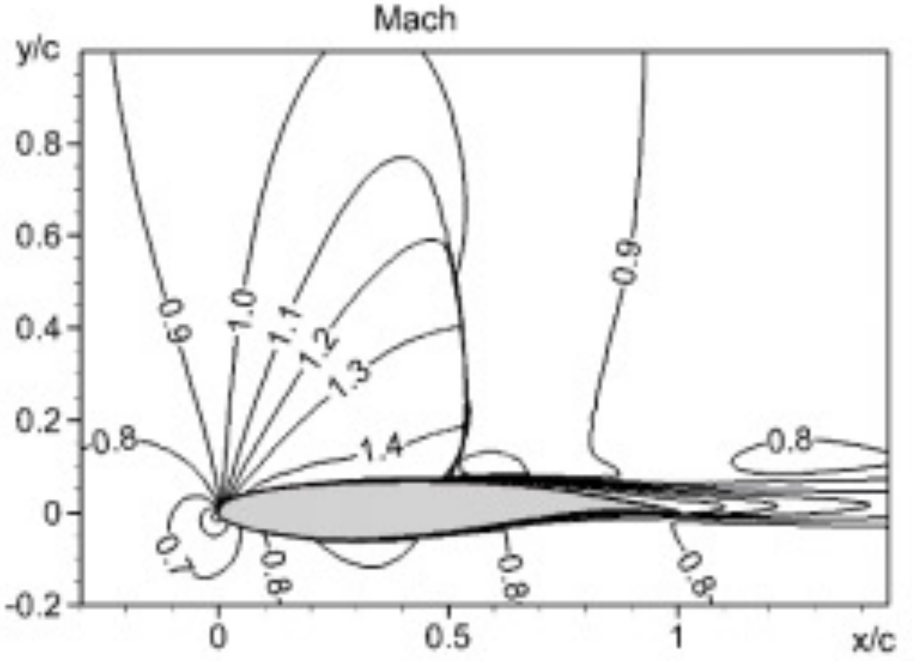
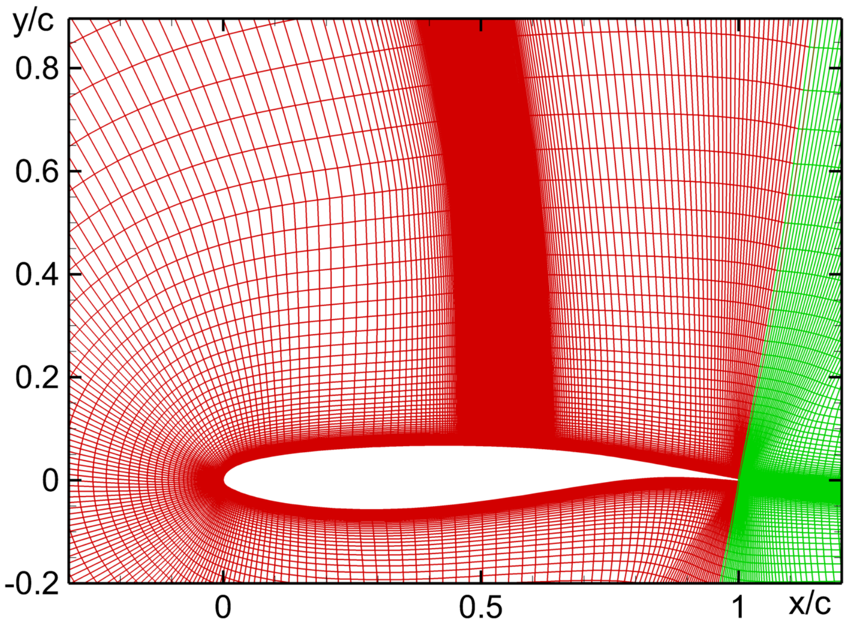
Turbulence Videos

- 1: A Visual Introduction to Turbulence and its Prediction in CFD
- 2: The Basics of Turbulence Modeling
- 3: Steady Turbulence Modeling versus Turbulence-Resolving Simulations
- 4: The Mechanics of Turbulent CFD
    - Pre-processing
    - Generate grids
    - Obtain Solutions
    - Understand Solutions

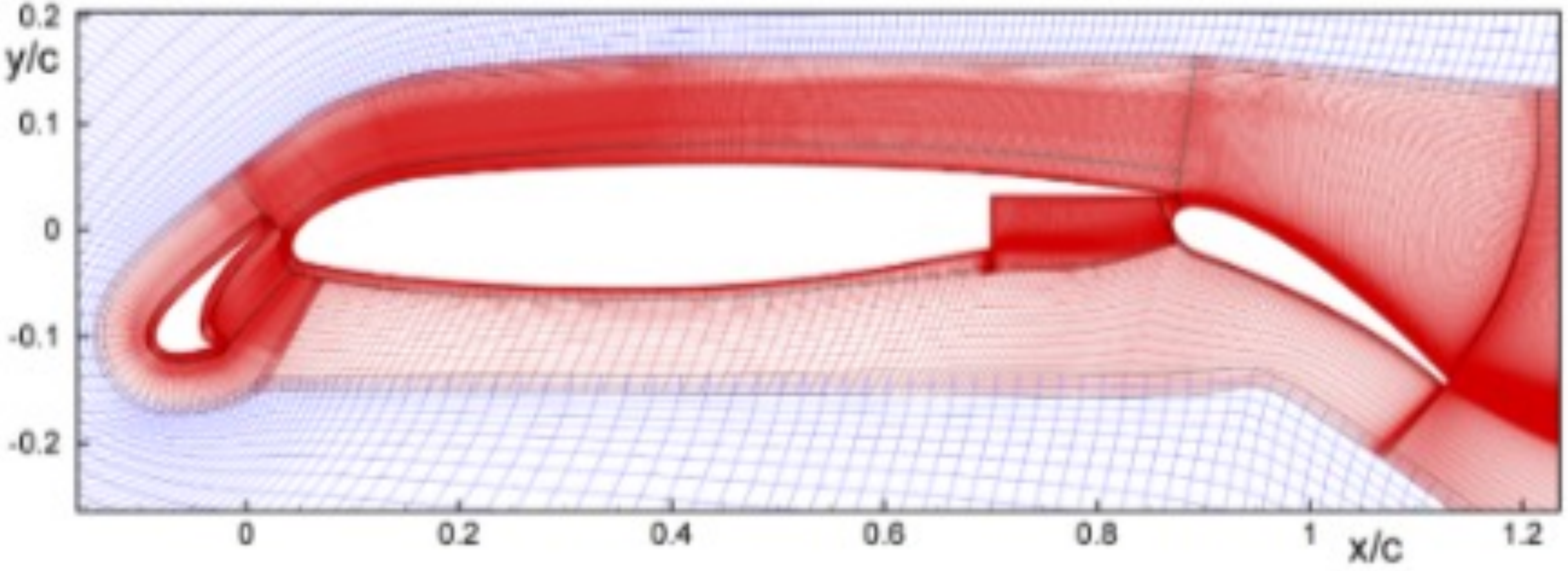
Manual Grids

- Transonic airfoil:
  - C grid
  - Refinement at shock, boundary layer, and wake





- Multi-element airfoil:
  - Overset grid blocks
  - Combination of C and H blocks
  - Refinement in recirculation regions, shear layers, and boundary layers



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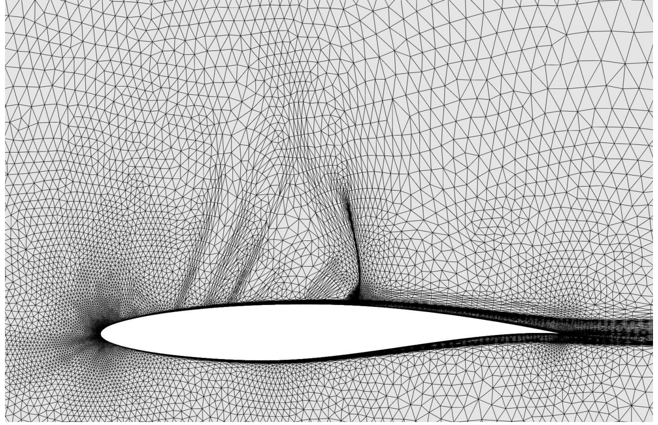
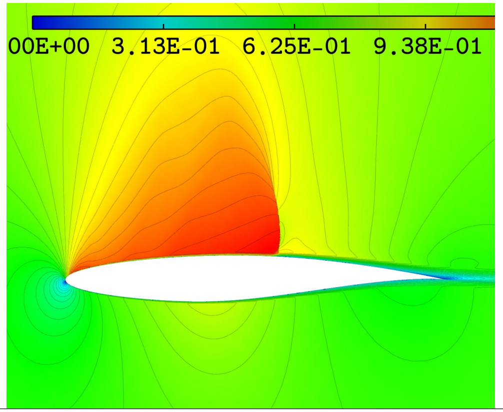
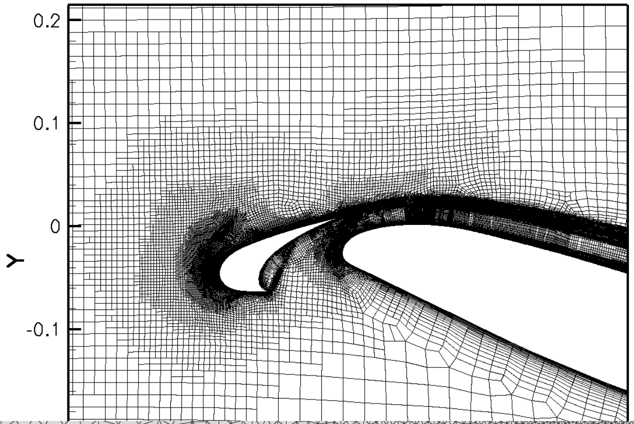
Adapted Grids

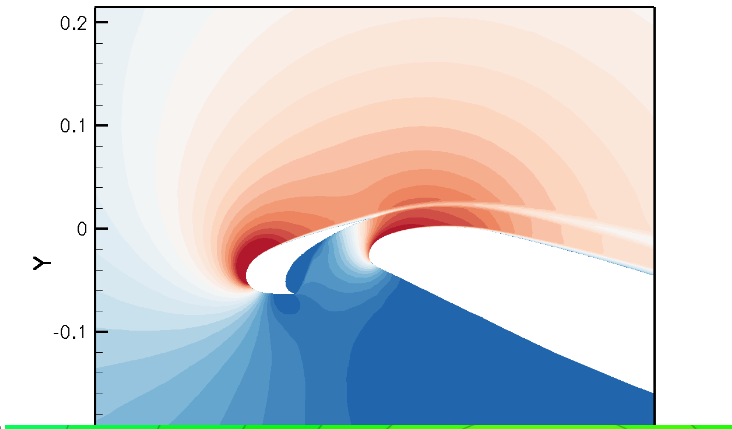
- Transonic airfoil:
  - Unstructured single grid
  - Anisotropic refinement at shock, Mach waves, and boundary layer
  - Substantial improvement in user load/expertise AND accuracy
  - Cost of creating a series of grids
  - As of 2023, limited to steady flows!

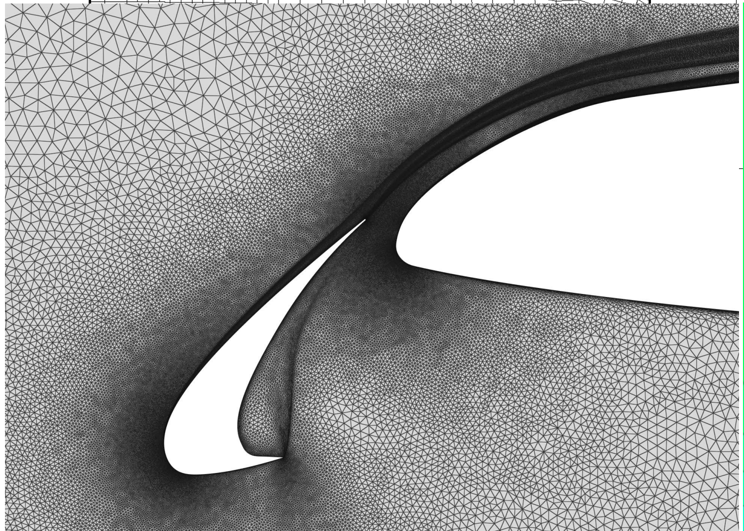
- Multi-element airfoil:
  - Refinement at various shear layers and boundary layers
  - Major improvement in user load/expertise AND accuracy

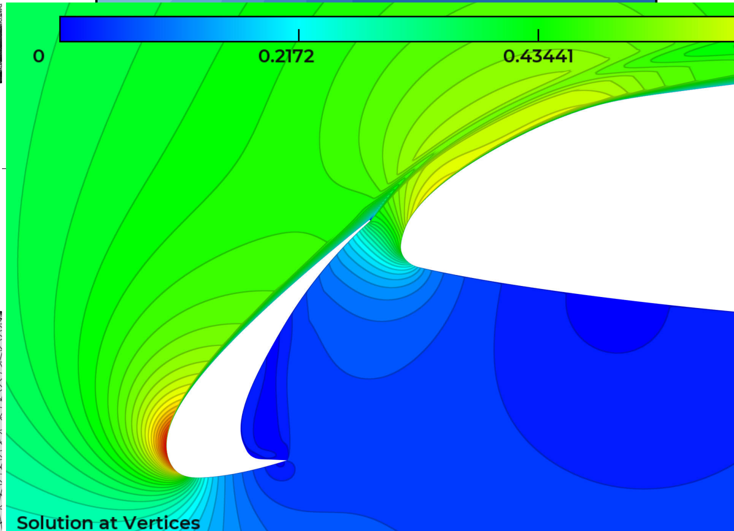






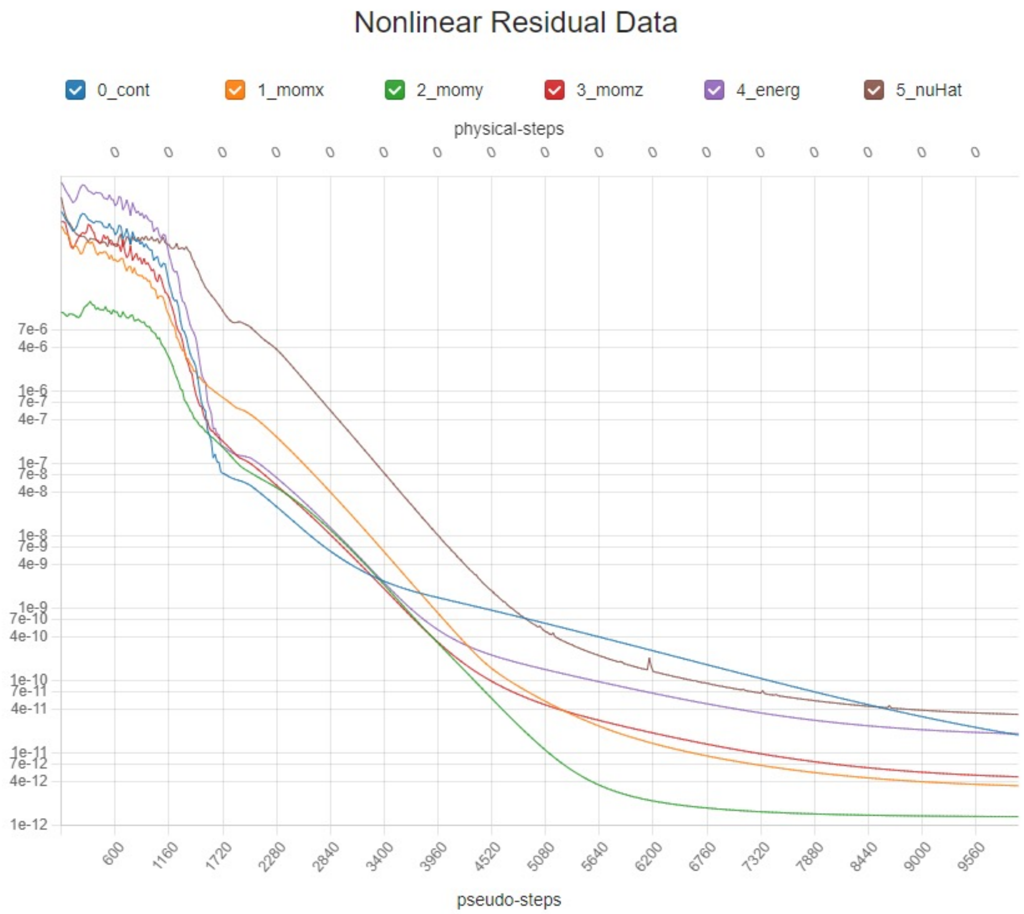






INRIA and CNRS

Grid Generation and Solution for Tu

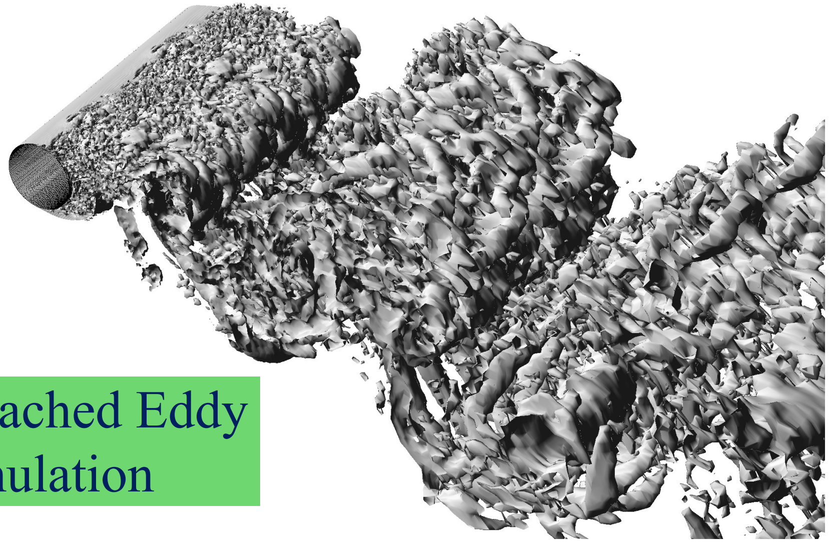


- Obtain geometry file
  - This involves much checking and often "repair" (s
- Generate grids
  - Often, define grid blocks, which might be moving
  - Unless adaptation is used, generate grid manuall
  - This involves many rules related to turbulent bou
  - Flow features such as shock waves and vortices
- Run solver
  - Decide between steady and unsteady RANS, DE
  - Impose correct flow conditions. Possibly use "cor
  - Carefully monitor convergence of residuals durinç
    - If convergence is poor, DO NOT average the iterations. These are not valid flow fields
    - If possible, continue simulation as time-accurate, therefore URANS (and **then** average!)
- Explore solution
  - Compare results on different grids and with different turbulence models, if this is a new geometry or conditions
  - Visualize flow. Plot pressure, skin friction, and so on. Not just the forces and moments

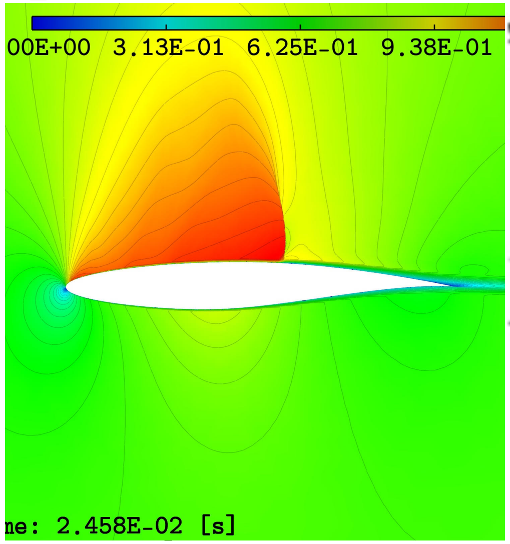
Turbulence Treatments for Unsteady/Separated Flows

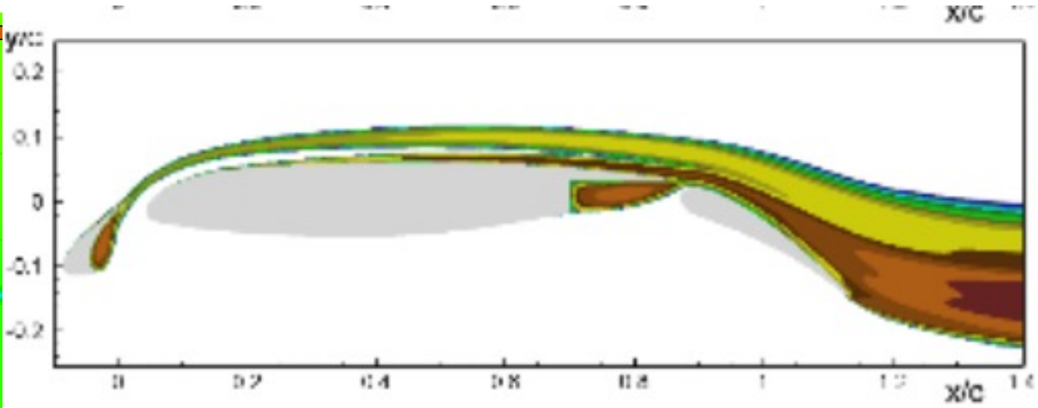
Steady RANS

Unsteady RANS

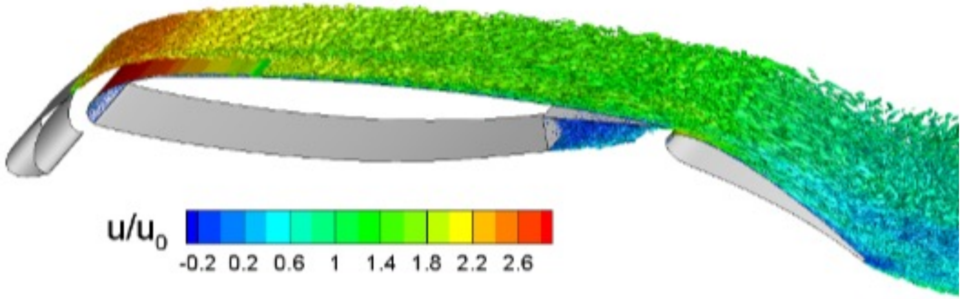


Detached Eddy Simulation





Steady RANS



Detached Eddy Simulation / MWLES

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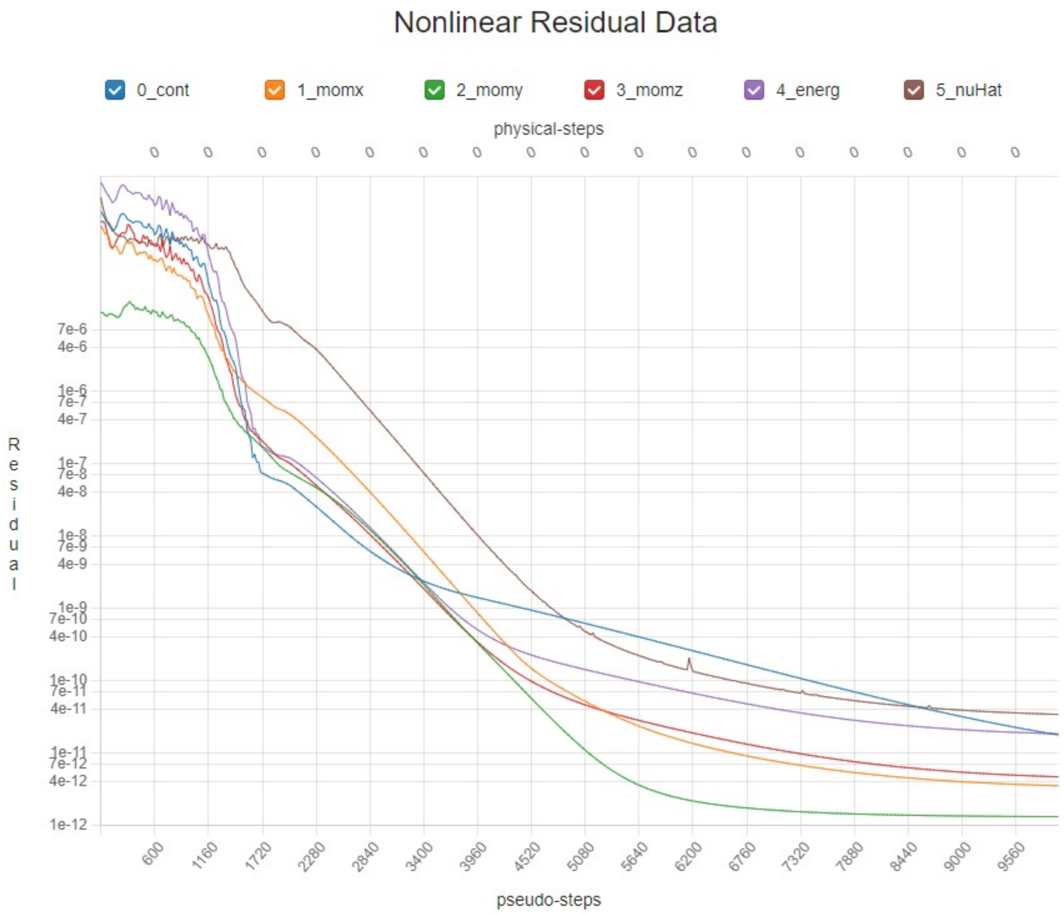

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Manual Grid Generation for Turbulent Flows, 2

- Distinguish inviscid regions, shock waves, free shear layers and vortices, and boundary layers
- Inviscid regions:
  - Grid cells are fairly isotropic except at shocks, and density loosely follows the distance from the walls
- Free turbulent layers:
  - The best grids are nearly aligned with the streamlines
  - We have guidelines for the transverse resolution:
    - How many points for each shear layer, how many points in a vortex core
    - These tend to ∞ at grid convergence
- Boundary layers:
  - Much more quantitative
  - 1) First grid spacing:
    - Δy^+ <~ 2 for SA model, <~ 0.5 for SST
    - This depends on estimating the friction velocity u_τ. Find the peak skin friction
    - $\Delta y/L$ strongly depends on the Reynolds number in order to keep Δy^+ correct
  - 2) Stretching ratio:
    - $r \equiv \Delta y_{j+1}/\Delta y_j$ sets the spacing in the bulk of the boundary layer
    - $r < \sim 1.2$, and $r \to 1$ for grid convergence
  - 3) This is sustained up to $y \geq \delta$
    - δ is far more difficult to estimate than u_τ!