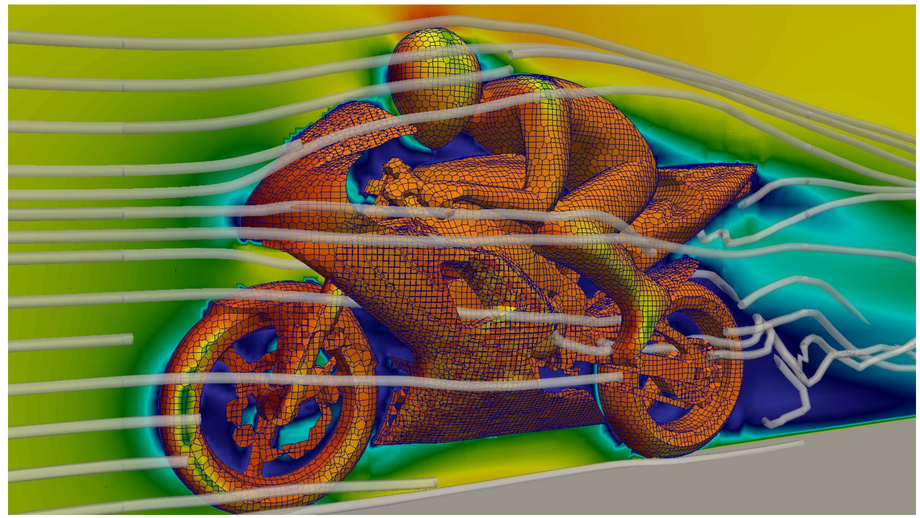
Open Source Computational Fluid Dynamics



An MSc course to gain extended knowledge in Computational Fluid Dynamics (CFD) using open source software.

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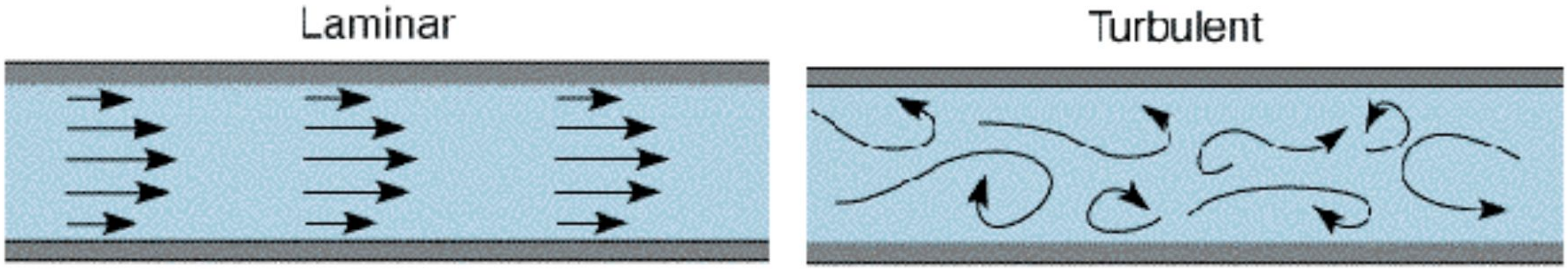
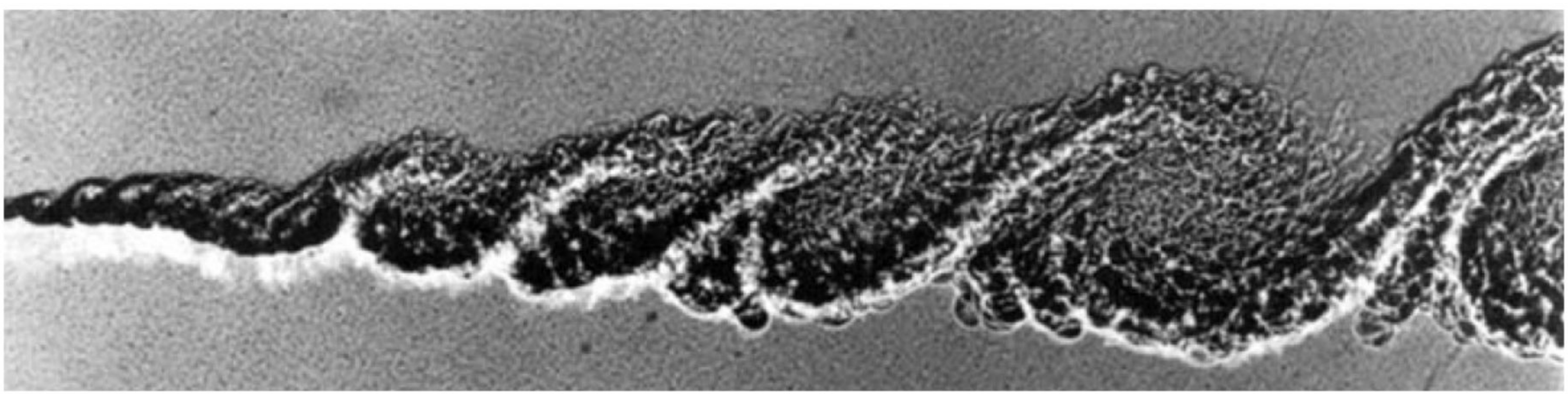
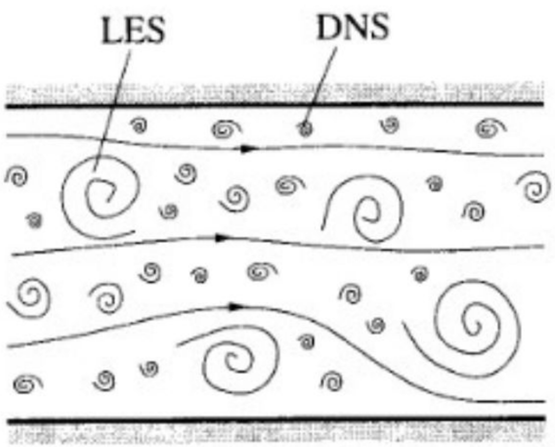
Turbulent flows

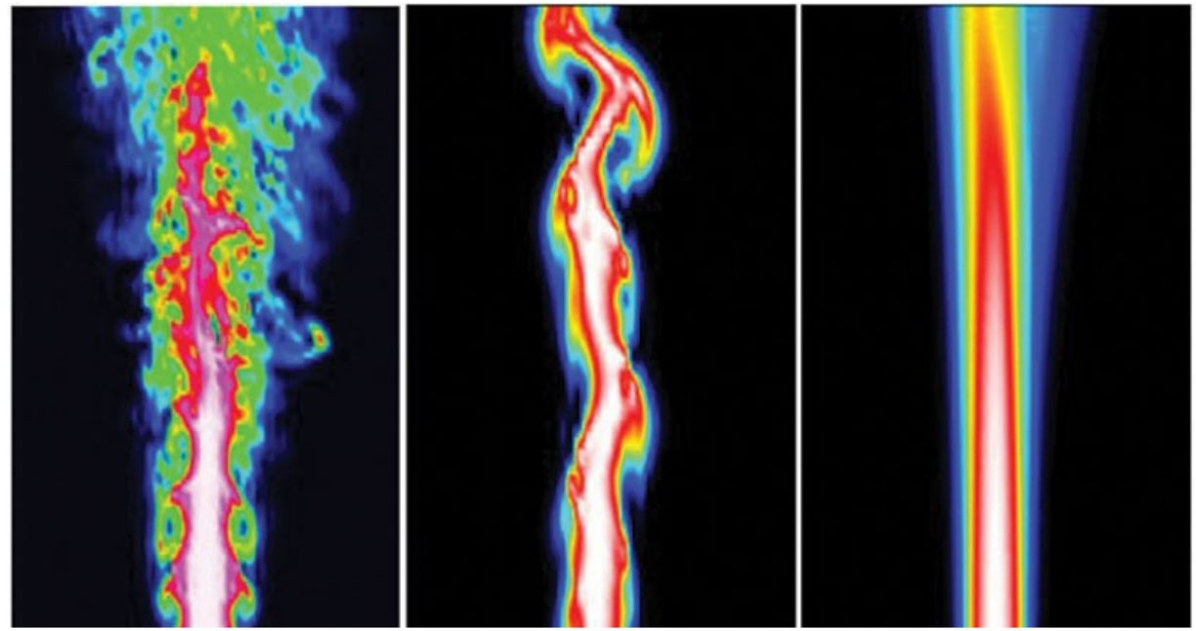


$$\mathrm{Re} = \frac{\rho V L}{\mu} = \frac{V L}{\nu} = \frac{\text{total momentum transfer}}{\text{molecular momentum transfer}}$$



Turbulence modeling





	DNS	LES	RANS
Mathematical method:	brute-force solution	filtering small scales	averaging all scales
Modeled turbulent scales:	no modeling	sub-grid	all
Resolved turbulent scales:	all	just large scales	none
Memory needed (ratio):	10^9-10^{10}	10^2-10^5	1
CPU time needed (ratio):	10^{14}	10^6-10^9	1

RAS turbulence models in OpenFOAM

- laminar: Dummy turbulence model for laminar flow
- kEpsilon: Standard $k{-}\epsilon$ model
- kOmega: Standard $k{-}\omega$ model
- kOmegaSST: $k{-}\omega$ SST model
- RNGkEpsilon: Re-Normalisation Group $k{-}\epsilon$ model
- LaunderSharmaKE: Launder-Sharma low-Re $k{-}\epsilon$ model
- LRR: Launder-Reece-Rodi RSTM
- LaunderGibsonRSTM: Launder-Gibson RSTM
- realizableKE: Realizable $k{-}\epsilon$ model
- SpalartAllmaras: Spalart-Allmaras 1-eqn mixing-length model

LES turbulence models in OpenFOAM

- Smagorinsky: Smagorinsky model
- dynSmagorinsky: Dynamic Smagorinsky
- oneEqEddy: k-equation eddy-viscosity model
- dynOneEqEddy: Dynamic k-equation eddy-viscosity model
- locDynOneEqEddy: Localised dynamic k-equation eddy-viscosity model
- DeardorffDiffStress: Deardorff differential stress model
- scaleSimilarity: Scale similarity model

Note

For a more complete list, consult with OpenFOAM User Guide and source code.

Wall functions for RAS turbulence

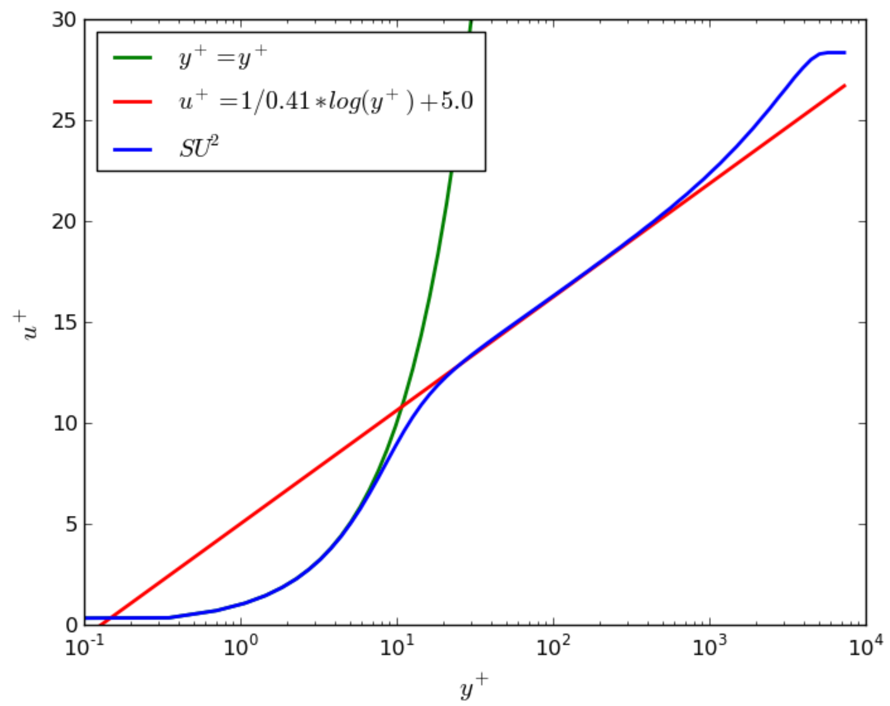
- alphatWallFunctions: turbulent thermal conductivity
- epsilonWallFunctions: turbulence dissipation
- fWallFunctions: turbulence damping function
- kqRWallFunctions: turbulence kinetic energy
- nutWallFunctions: turbulent kinematic viscosity
- omegaWallFunctions: turbulnce specific dissipation
- v2WallFunctions: turbulence stress normal to streamlines

Note

You can list available wall functions:

```
ls $FOAM_SRC/turbulenceModels/*/RAS/derived*/wall*/*
```

Wall functions for RAS turbulence

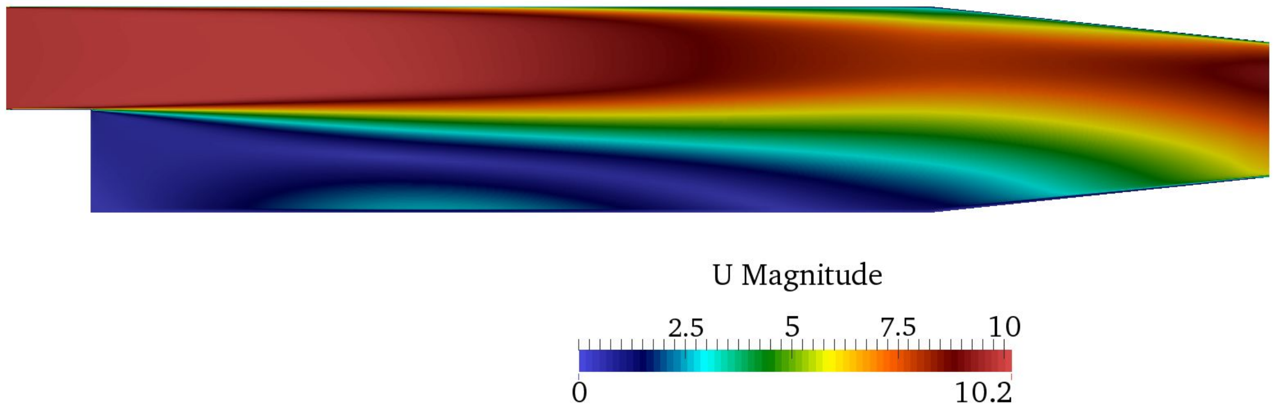


Standard wall functions: $y^+ < 5$ or $30 < y^+ < 300$

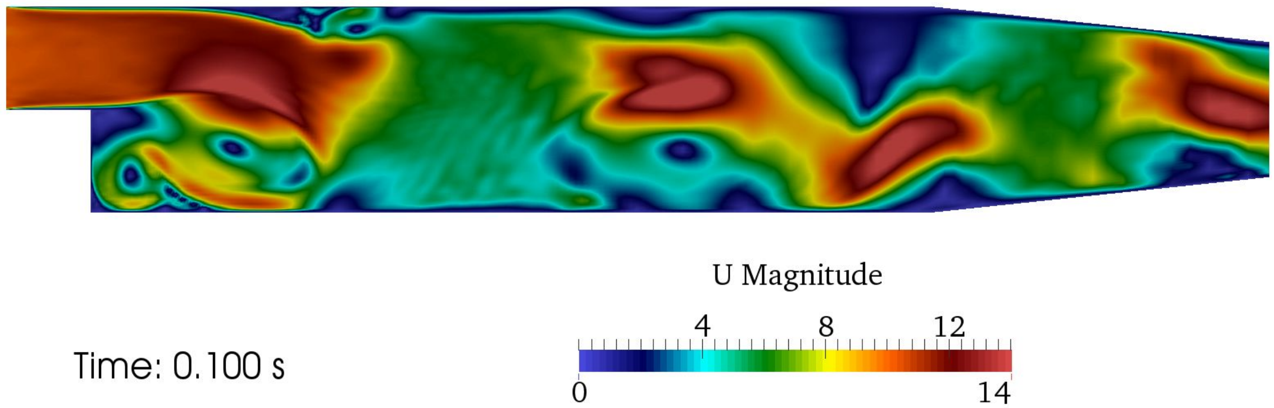
Important: in wall adjacent cells, proper settings are necessary for turbulence parameters (e.g. nut, k, epsilon, omega).

Example: pitzDaily cases

RAS turbulence: U field (Reynolds-averaged velocity)



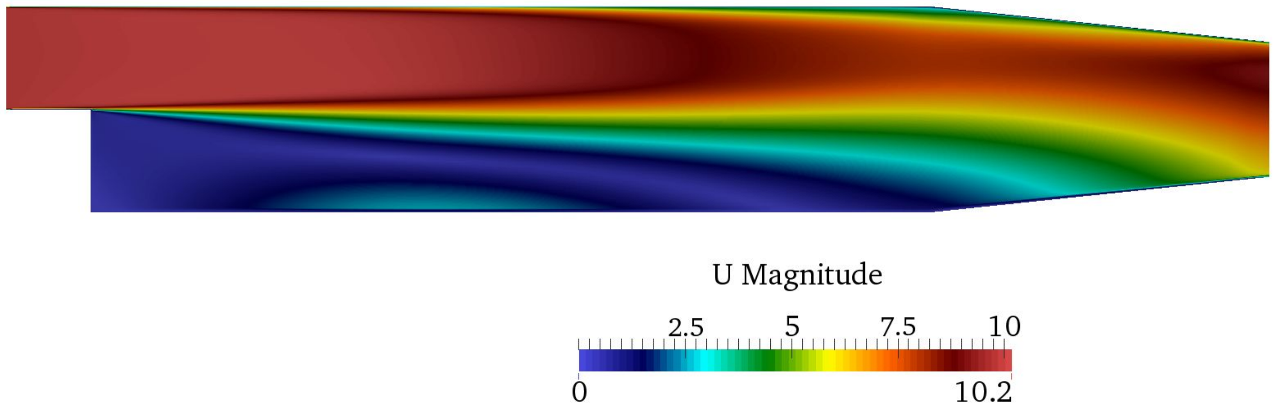
LES turbulence: U field (instantaneous velocity)



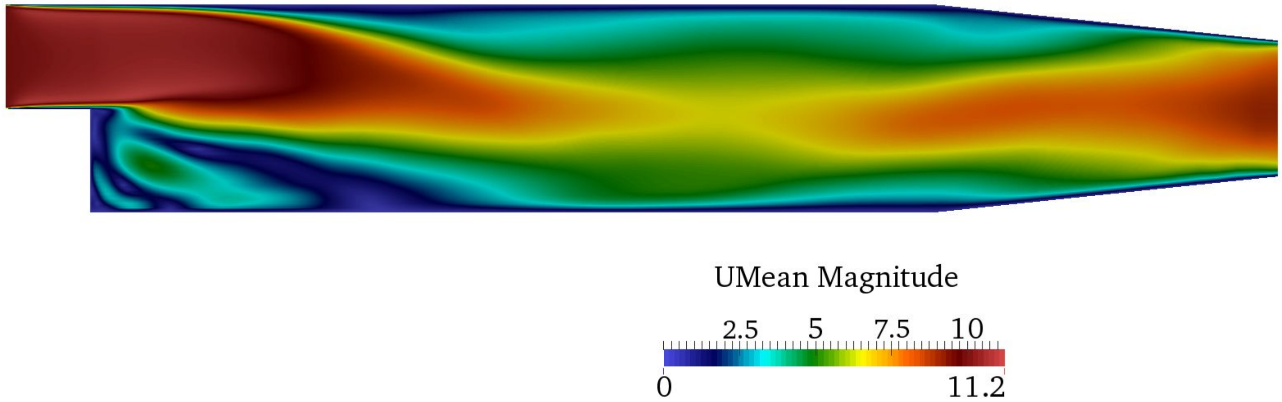
Note: This is just 2D, so not strictly LES. Turbulence: always 3D.

Example: pitzDaily cases

RAS turbulence: U field (Reynolds-averaged velocity)



LES turbulence: UMean field (time-averaged velocity)



Compressible flows

- Incompressible model: $\rho = \text{constant} \rightarrow$ kinematic equations, e.g. Pa $\rightarrow$ m^2/s^2
- Compressible model: ρ is based on equationOfState, e.g. perfectGas: $\rho = p/RT$
- Constant temperature air:
  - If $\Delta\rho/\rho = 0.05 \rightarrow$, $\Delta p/p = 0.05 \rightarrow$ then Δp = 5000 Pa
  - 5000 Pa dynamic pressure $\rightarrow$ 92 m/s air speed
  - If Ma < 0.27, then incompressible model for air is 5% accurate!
- Historically: pEqn for incompressible, rhoEqn for compressible.

Example: supersonic forward facing step