Turbulent flow over NACA0012 airfoil (2D)

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Overview

- Based on https://turbmodels.larc.nasa.gov/naca0012_val.html **[81]**
- References: Gregory-O'Reilly (1970) **[22]**, McCroskey (1987) **[50]**, Ladson (1988) **[35]**, Spalart-Allmaras (1994) **[72]**, and Krist et al. (1997) **[34]**
- See the **resources** section for additional data files

Flow physics:

- External flow
- Steady
- High Reynolds number
- Low Mach number, subsonic
- Newtonian, single-phase, incompressible, non-reacting

Solver:

- **simpleFoam**

Tutorial case:

- $FOAM_TUTORIALS/incompressible/simpleFoam/airFoil2D

Keywords: Reynolds-averaged Navier-Stokes, simpleFoam

Physics and Numerics

Physical domain:

- The case is a two-dimensional airfoil located around the centre of a computational domain whose dimensions are considerably larger than the chord-length of the airfoil.

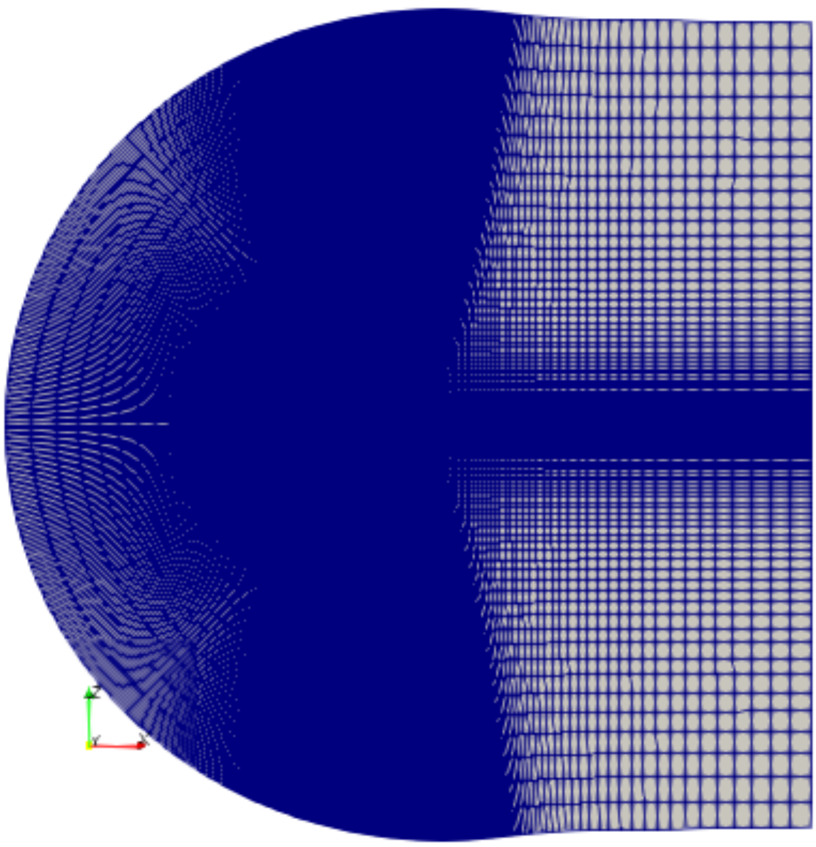
- x: Longitudinal direction (mean flow direction)
- y: Spanwise direction (statistically homogeneous direction)
- z: Vertical direction (wall-normal direction)
- O: Origin at the leading edge of the airfoil

Physical modelling:

- Reynolds number based on local chord length: $\mathrm{Re}_c = U_x \, c \, \nu^{-1} \approx 6 \times 10^6$
  - Streamwise far-field flow speed: $U_x = 51.4815$ [m·s^{-1}]
  - Characteristic length (Local chord length of the airfoil): $c = 1.0$ [m]
  - Kinematic viscosity of fluid: $\nu_{\mathrm{fluid}} = 8.58 \times 10^{-6}$ [m^2·s^{-1}]
- Mach number: $\mathrm{Ma} = U_x / U_s \approx 0.15$
  - Speed of sound: $U_s = 343.21$ [m·s^{-1}]
- Turbulence model: **Spalart-Allmaras**

Numerical domain modelling:

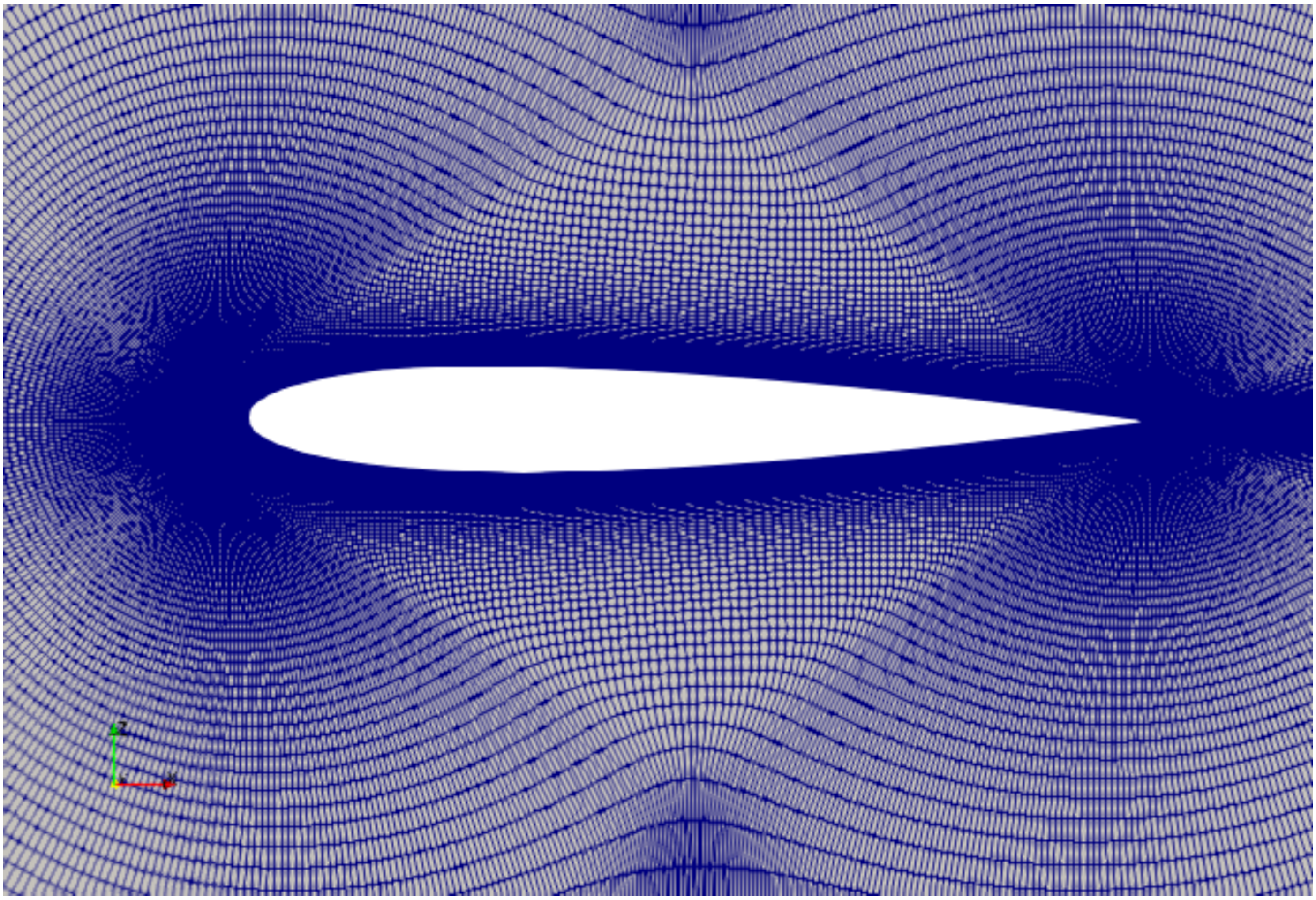
- Shape: extruded C-grid
- Dimensions: $(x, y, z) \approx (985.5, 1.0, 1015.6)$ [m]
- Sketch (View direction to y-positive):



Numerical domain

Spatial domain discretisation:

- Mesh type: hexahedral cells in *plot3d* format
- Mesh converter: plot3dToFoam
- Number of cells, N: $(N_x, N_y, N_z) = (257, 1, 897)$
- First wall-normal cell centre height: $\Delta_y^+ < 1$
- Mesh detail (View direction to y-positive):



Mesh

Equation discretisation:

Spatial derivatives and variables:

- Gradient: **Gauss linear**
- Divergence:
  - `default`: **Gauss** `linear`
  - `div(phi,U)`: `bounded Gauss` **linearUpwind** `grad(U)`
  - `div(phi,nuTilda)`: `bounded Gauss linearUpwind grad(nuTilda)`
- Laplacian: `Gaussian linear corrected`
- Surface-normal gradient: **corrected**

Temporal derivatives and variables:

- `ddtSchemes`: **steadyState**

Numerical boundary conditions:

- Velocity, $\mathbf{U}$

Patch	Condition	Value [m·s-1]
Inlet	freestreamVelocity	$\mathbf{U}_\alpha$
Outlet	freestreamVelocity	$\mathbf{U}_\alpha$
Sides (y-dir)	empty	-
Aerofoil	fixedValue	(0.0, 0.0, 0.0)

α	U α
$\alpha = 0^o$	(51.4815, 0.00, 0.0000)
$\alpha = 10^o$	(50.6994, 0.00, 8.9397)
$\alpha = 15^o$	(49.7273, 0.00, 13.3244)

- Kinematic pressure, $\mathtt{p}$

Patch	Condition	Value [m^2·s^{-2}]
Inlet	freestreamPressure	0.0
Outlet	freestreamPressure	0.0
Sides (y-dir)	empty	-
Aerofoil	zeroGradient	-

- Turbulent kinematic viscosity, `nut` (i.e. ν_t)

Patch	Condition	Value [m^2·s^{-1}]
Inlet	freestream	$8.58e^{-6} \approx \nu_{\text{fluid}}$ [82]
Outlet	freestream	$8.58e^{-6} \approx \nu_{\text{fluid}}$ [82]
Sides (y-dir)	empty	-
Aerofoil	fixedValue	0.0 [82]

- Spalart-Allmaras model modified viscosity, `nuTilda` (i.e. $\tilde{\nu}$)

Patch	Condition	Value [m^2·s^{-1}]
Inlet	freestream	$3.432e^{-5} \approx 4\nu_{\text{fluid}}$ [82]
Outlet	freestream	$3.432e^{-5} \approx 4\nu_{\text{fluid}}$ [82]

Sides (y-dir)	empty	-
Aerofoil	fixedValue	0.0 [82]

Solution algorithms and solvers:

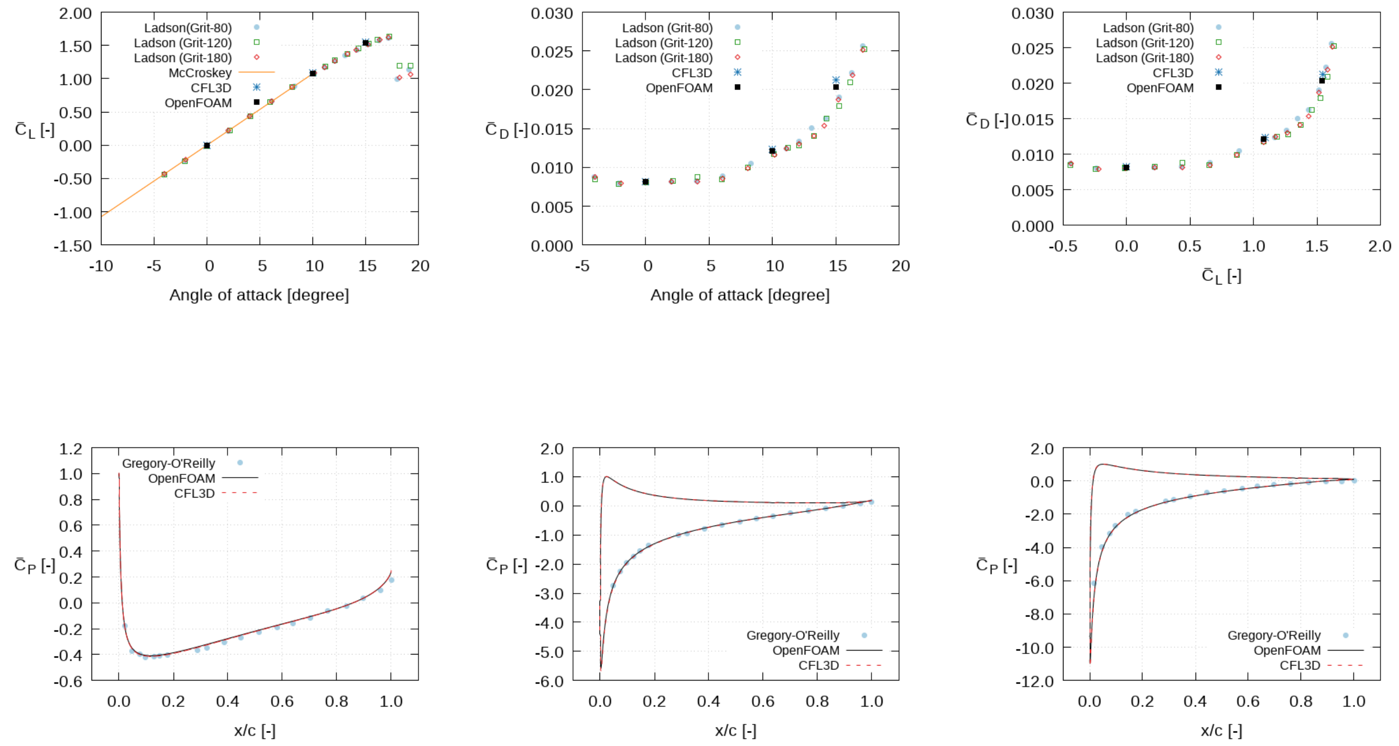
- Pressure-velocity: **SIMPLE algorithm**
- Parallel decomposition of spatial domain and fields: Not applicable
- Linear solvers:

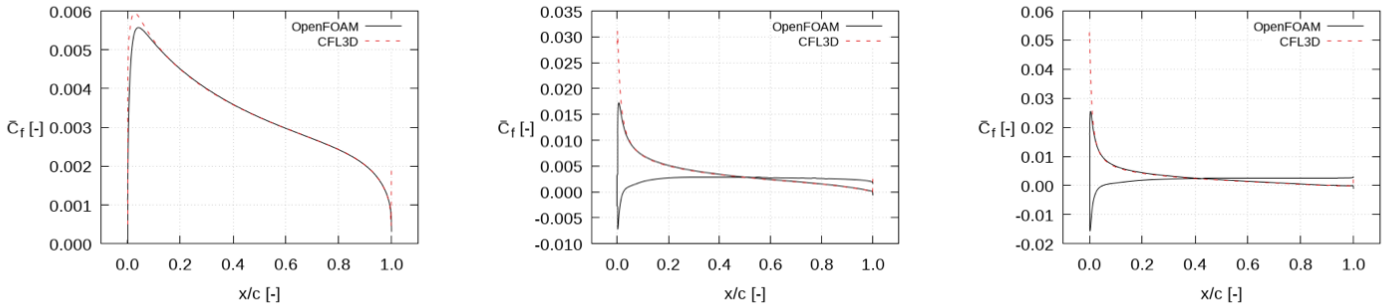
Field	Linear Solver	Smoother	Tolerance (rel)
`U`	**Smooth solvers**	**Gauss Seidel Smoother**	0.01
`p`	**GAMG Solver**	**Gauss Seidel Smoother**	0.01
`nuTilda`	**Smooth solvers**	**Gauss Seidel Smoother**	0.01

Results

List of metrics:

- Lift coefficient $\mathrm{C_L}$ vs. Angle of attack α
- Drag coefficient $\mathrm{C_D}$ vs. Angle of attack α
- Drag coefficient $\mathrm{C_D}$ vs. Lift coefficient $\mathrm{C_L}$
- Surface pressure coefficient C_p vs. Normalised chord length x/c
- Surface skin friction coefficient C_f vs. Normalised chord length x/c
- $\{\bar{\cdot}\}$ is the time-averaging operator





Resources

Note: Links will take you to the NASA website

Mesh

- Mesh description
- Mesh: (3-D) 2 x 897 x 257 with 2 x 513 points on airfoil surface (gzipped, 5.1 MB)

Datasets for verifications (plain text)

Lift and drag coefficients vs angle of attack

- [Experiment] (https://turbmodels.larc.nasa.gov/NACA0012_validation/CLCD_Ladson_expdata.dat) **[35]**
- Numerical (CFL3D software) **[34]**

Pressure distribution vs local chord length

- Experiment **[35]**
- Numerical (CFL3D software) **[34]**

Lift coefficient vs angle of attack

- Theoretical **[50]**

Skin friction coefficient vs local chord length

- Numerical (CFL3D software) **[34]**