CFD on HPC – OpenFOAM

03 – Advanced usage

Aleksander GRM – June, 2025

Content

Introduction

- **Templates**: use templates to start case
  `$> cp $FOAM_ETC/templates/... case_dir`
- **Dictionaries**: use `foamGet` to copy templated dictionary files
  `$> foamGet forcesIncompressible`
- **Information**: use `foamInfo` to get help on foam item
  `$> foamInfo incompressibleFluid`
- **Dictionary manipulation**: use `foamDictionary` to edit dictionary files
  `$> foamDictionary [OPTIONS] <dictionary file>`

Nice example in folder

- `day_02/02_test_case-cavity_with_hole/snappyHexMesh/steadyState/` look into `readme.txt` file

Example

```
Fancy corrections of constant/polyMesh/boundary file symmetryPlane -> empty

- foamDictionary constant/polyMesh/boundary -keywords
- foamDictionary constant/polyMesh/boundary -entry entry0 -keywords

Front:
- foamDictionary constant/polyMesh/boundary -entry entry0/front -keywords
- foamDictionary constant/polyMesh/boundary -entry entry0/front/type -value
- foamDictionary constant/polyMesh/boundary -entry entry0/front/type -set empty

here are two choices, both works
- foamDictionary constant/polyMesh/boundary -entry entry0/front/inGroups -set "List<word> 1(empty)"
- foamDictionary constant/polyMesh/boundary -entry entry0/front/inGroups -remove
```

Hydrofoil case

- describe basic case philosophy
- describe two different meshing approaches
  - OpenFOAM foil `blockMesh`: change angle of attack with velocity vector rotation
  - GMSH foil `mesh`: change angle of attack with geometry rotation
- Describe two different solutions (OF module `foamRun`)
  - steady state – `SIMPLE` algorithm
  - transient – `PIMPLE` algorithm
- show mesh generation for different angles of attack (compare with fixed mesh),
- solution initialization with `potentialFoam` integrated in `foamRun`,
- compare solutions of the case for angle of attack 20° (turbulent and laminar solver).

Simple mixer case

Problem: mixing `dye` with `paint`

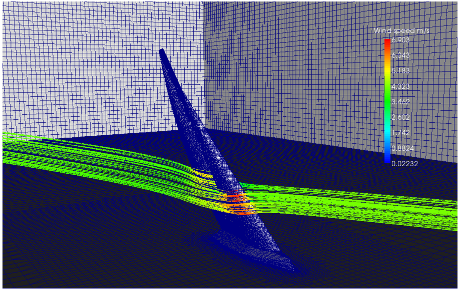
- steady state – `SIMPLE` algorithm – show run without the dye, only paint flow
- transient – `PIMPLE` algorithm – run complete case with dye inflow until 300s

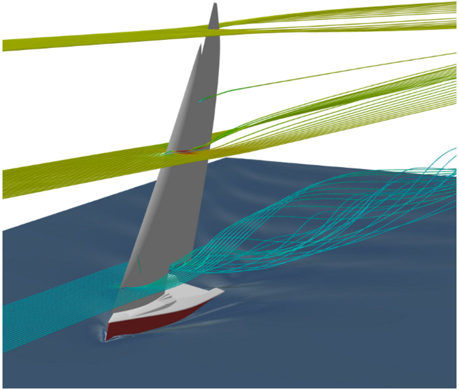
Meshing procedure

- `blockMesh`: background mesh procedure
- `snappyHexMesh`: steps to generate computational mesh
  - `baffles` objects in OpenFOAM mesh (2D object in 3D space)
  - `surfaceFeatures` detect featured edges
  - set `refinement` levels
  - use `snappyHexMeshConfig` to generate automatically dictionary files
  - edit all generated dictionary files

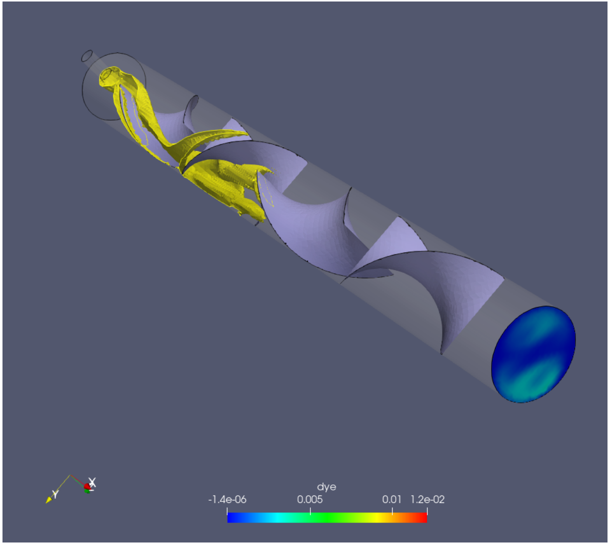
OpenFOAM baffle mesh element

Typical is simulation of sail performance. It is a 2D object in 3D space



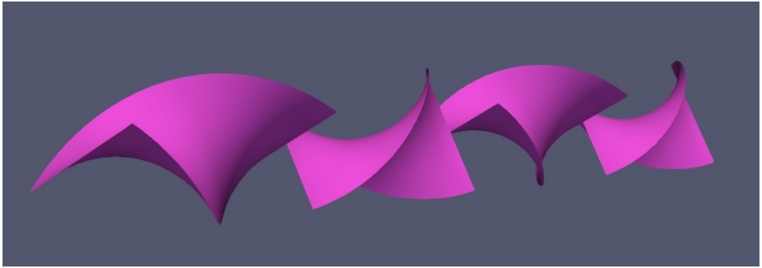


Static mixer case



For 2D geometry embedded into 3D space in OpenFOAM snappyHexMesh use **baffle** element type.

In mixer baffles are static curved surfaces installed in pipe to mix dye with paint.



Generate **baffles** with snappyHexMesh

- `snappyHexMeshConfig -help`
- Set baffles from file `constant/geometry/baffles.obj`
  `$> snappyHexMeshConfig -baffles '(baffles)'`

Surface geometry files are automagically recognised; look at the output

```
+ pipe
+ File: "pipe.obj"
+ Bounding box: (0 -0.05 -0.09) (1 0.05 0.05)
+ Closed surface
+ External boundary surface
+ Inlet regions: inletMain, inletSide
+ Outlet regions: outlet

+ baffles
+ File: "baffles.obj"
+ Bounding box: (0.1 -0.05 -0.05) (0.9 0.05 0.05)
+ Open surface
+ Baffle wall surface
```

`snappyHexMeshConfig` generates 3 system mesh files

- `blockMeshDict`
- `surfaceFeaturesDict`
- `snappyHexMeshDict`

blockMeshDict

geometry file `pipe.obj` forms an external boundary so,
it is possible to clear the boundary

```
$> snappyHexMeshConfig -baffles '(baffles)' -clearBoundary
```

Comment on blockMeshDict file

Generate `baffles` with snappyHexMesh

surfaceFeaturesDict file containing surface feature capturing information
generates additional geometry files with extension `*.eMesh`

```
$> snappyHexMeshConfig -baffles '(baffles)'
     -clearBoundary -explicitFeatureSnap
```

- `implicitFeatureSnap`: automatically identifies surface features
  - may not pickup specific features, like ends, edges, ...
- `explicitFeatureSnap`: features defined in a file
  - user must specify a file
  - complete control over features identification and refinement

Surface Features dictionary


```
surfaces                    <-- list of surface geometry files
(
    "pipe.obj"
    "baffles.obj"
);

includedAngle   150;        <-- feature identification parmeter

subsetFeatures
{
    nonManifoldEdges yes;    <-- edges connected to more than 2 edges
    openEdges        yes;    <-- edges connected to 1 face
}

trimFeatures

{
    minElem         0;       <-- minimum number of edges in feature
    minLen          0;       <-- minimum length of feature
}
writeObj        yes;        <-- write additional obj files to visualise features
```

Generate computational mesh

Generate all mesh dictionaries

```
snappyHexMeshConfig \
  -baffles '(baffles)' \
  -clearBoundary \
  -explicitFeatures \
  -refinementLevel 1 \.            <-- default level
  -surfaceLevels '((pipe 2))' \      <-- pipe refinement level
  -refinementRegions '((pipe 1))' \  <-- internal region
  -nCellsBetweenLevels 1           <-- cells between refinement levels
```

To create the mesh, must run

- `blockMesh`
- `surfaceFeatures`
- `snappyHexMesh -overwrite` (overwrite creates polyMesh)

Transport properties are set in dictionaries

- `constant/physicalProperties`:
  transport material properties: viscosity, density, ...
- `constant/momentumTransport`:
  fluid flow momentum transport properties: flow type, turbulence model, viscosity model, ...
- `constant/thermophysicalTransport`:
  energy transport properties: specific conduction, enthalpy, ...

Paint Transport Model

Paint can be described as **generalized newtonian fluid**, viscosity is not constant, but strain rate $\dot{\gamma}$ dependant

$$\nu = f(\dot{\gamma}), \quad \dot{\gamma} = \sqrt{2}|\boldsymbol{D}|, \quad \boldsymbol{D} = \mathrm{sym}\,(\nabla \boldsymbol{v})$$

where: $\dot{\gamma}$ is strain rate, $\boldsymbol{D}$ is symmetric part of velocity gradient

Shear stress

$$\boldsymbol{\tau} = 2\rho\nu\boldsymbol{D}$$

Listing models

```
$> foamToC -table generalisedNewtonianViscosityModel
$> foamInfo BirdCarreau
```

Surface Features dictionary

```
Contents of table generalisedNewtonianViscosityModel:
    BirdCarreau                                  libmomentumTransportModels.so
    Casson                                       libmomentumTransportModels.so
    CrossPowerLaw                                libmomentumTransportModels.so
    HerschelBulkley                              libmomentumTransportModels.so
    Newtonian                                    libmomentumTransportModels.so
    powerLaw                                     libmomentumTransportModels.so
    strainRateFunction                           libmomentumTransportModels.so
```

Bird-Carreau viscosity model

For **paint** use the **Bird-Carreau** strain rate $\dot{\gamma}$ dependant viscosity model

$$\nu = \nu_\infty + (\nu_0 - \nu_\infty)[1 + (k\,\dot{\gamma})^a]^{(n-1)/a}$$

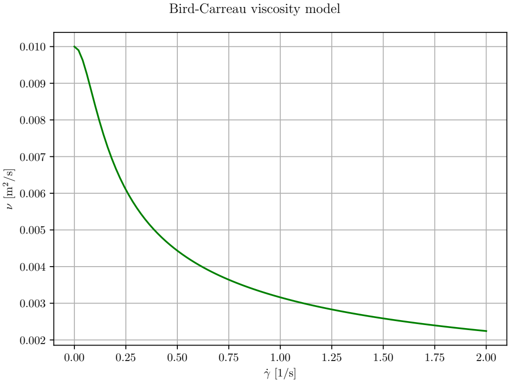
$$\nu_0 = 0.01\,\mathrm{m}^2/\mathrm{s}$$

$$\nu_\infty = 0.000\,01\,\mathrm{m}^2/\mathrm{s}$$

$$k = 10$$

$$n = 0.5$$

$$a = 2 \quad \text{(by default)}$$



Transport model

Choice of two transport models

- **laminar**: slow fluid flow, minimal vorticity
- **turbulent**: when not laminar

All transport models are set in the `constant/momentumTransport` file.

Laminar transport model


```
simulationType  laminar;

laminar
{
  model          generalizedNewtonian;

  viscosityModel  BirdCarreau;
  nuInf           1e-5;
  k               10;
  n               0.5
}
```

```
simulationType RAS;

RAS
{
  model           kOmegaSST;
  turbulence        on;
  printCoeffs       on;

  viscosityModel  BirdCarreau;
  nuInf             1e-5;
  k                 10;
  n                 0.5
}
```

Simulate flow of paint only. Test laminar and turbulent transport model.

Transport model

- **laminar**: iterate until 250 steps
- **turbulent**: iterate until 250 steps

Inlet velocity

- **main**: $1.0\,\mathrm{m/s}$
- **side**: $0.5\,\mathrm{m/s}$ (dye inflow is zero!)

Comment on constant and system files!

Include dye flow at side inlet. Test laminar and turbulent transport model.

Transport model

- **laminar**: iterate until 2.0 s
- **turbulent**: iterate until 2.0 s

Scalar inlet – Dye source

- **main**: 0.0
- **side**: 1.0

Dye (scalar field) dimension is arbitrary. Normally dimension less.

Comment on constant and system files!

- for transient simulation **PIMPLE** solver is used
- for steady-state simulation **SIMPLE** solver is used

Courant number or **CFL** number

- **definition**:

$$\mathrm{CFL} = \frac{U_x\,\Delta t}{\Delta x}$$

  - U_x: velocity in cell
  - Δt: time step
  - Δx: cell size in flow direction

- **explicite** solver: $\mathrm{CFL} < 1$
- **implicite** solver: CFL is more an accuracy consideration

Use some rough approximations in the estimation

- use `checkMesh` to find cell size Δx

  `Min volume = 1.7680364e-09` $\Delta x = \sqrt[3]{2e-9} \approx 1.3\,\mathrm{mm}$

- steady state max velocity $\approx 2.0\,\mathrm{m/s}$

- estimated initial **time step**:

$$\Delta t = \mathrm{CFL}\frac{\Delta x}{U_x} = 1.0\frac{1.3\,\mathrm{mm}}{2.0\,\mathrm{m/s}} \approx 0.6\,\mathrm{ms}$$

CFL condition

Try to play with `maxCo` (max CFL) in `system/controlDict`.

Warning: change in CFL is related to simulation accuracy.
Test dye travel distance for concentration 0.05!

Run simulation with different CFL and measure time of simulation

- use `maxCo` $= 1.0$
- use `maxCo` $= 2.0$
- use `maxCo` $= 4.0$

Use `foamLog` utility to extract simulation step data and plot using `GnuPlot`!

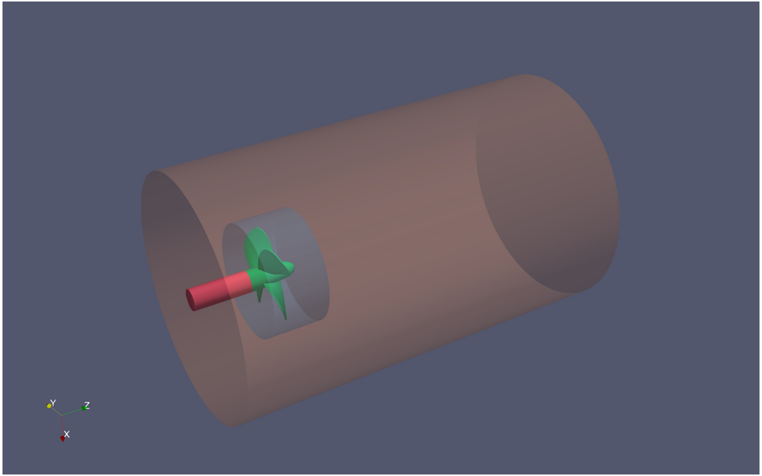
```
File: system/controlDict

adjustTimeStep  yes; // time adaptive scheme ON (use CFL limit)
maxCo           1;   // max CFL number {1,2,4}

Follow:
 - time of execution
 - number of iterations in U and p
```

Ship resistance case

Case: Calculation of ship resistance force

- describe basic case philosophy
- describe meshing approach
  - `blockMesh`: anisotropic background mesh
  - `refineMesh`: different refinement mesh regions
  - `snappyHexMesh`: addition of boundary layer
  - `additional feature`: mesh refinement in bow and stern region (TODO)
- compute quasi steady state
  - steady state – `PIMPLE` algorithm with `localEuler` – pseudo transient
  - `setFields`: set air and water region
  - `incompressibleVoF`: solver module for 2 incompressible, isothermal immiscible fluids using a VOF (volume of fluid) phase-fraction based interface capturing approach

Propeller – Open water test case



case zones: external, rotating, shaft, propeller

MRF approach.

- **velocity**
  velocity is composed of two terms: **relative** and **rotating**

$$\boldsymbol{v} = \boldsymbol{v}_{\text{rel}} + \omega \times \boldsymbol{r}$$

$\boldsymbol{v}_{\text{rel}}$ - relative velocity (inlet flow)
ω - angular velocity (propeller rotation)
$\boldsymbol{r}$ – radius vector in rotating zone

- **momentum** convection
  use of a relative velocity for convective flux

$$\left(\boldsymbol{v} \cdot \nabla\right)\boldsymbol{v} = \left(\boldsymbol{v}_{\text{rel}} \cdot \nabla\right)\boldsymbol{v} + \omega \times \boldsymbol{v}$$

Case: Calculation of ship propeller thrust/moment.

- describe basic case philosophy
- describe meshing approach
  - `blockMesh`: radially symmetric background mesh
  - `rotatingZone`: define rotating mesh regions
  - `snappyHexMesh`: rotating zone
  - `additional feature`: mesh refinement only in blade region and boundary layer (TODO)
- compute steady state
  - steady state – `PIMPLE` algorithm with `MRF` source
  - `movingWallVelocity`: set as velocity BC at rotating surface (propeller) to obtain rotationžđ
  - `incompressibleVoF`: solver module for 2 incompressible, isothermal immiscible fluids using a VOF (volume of fluid) phase-fraction based interface capturing approach

Sponsorship

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Thank you for attention!

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