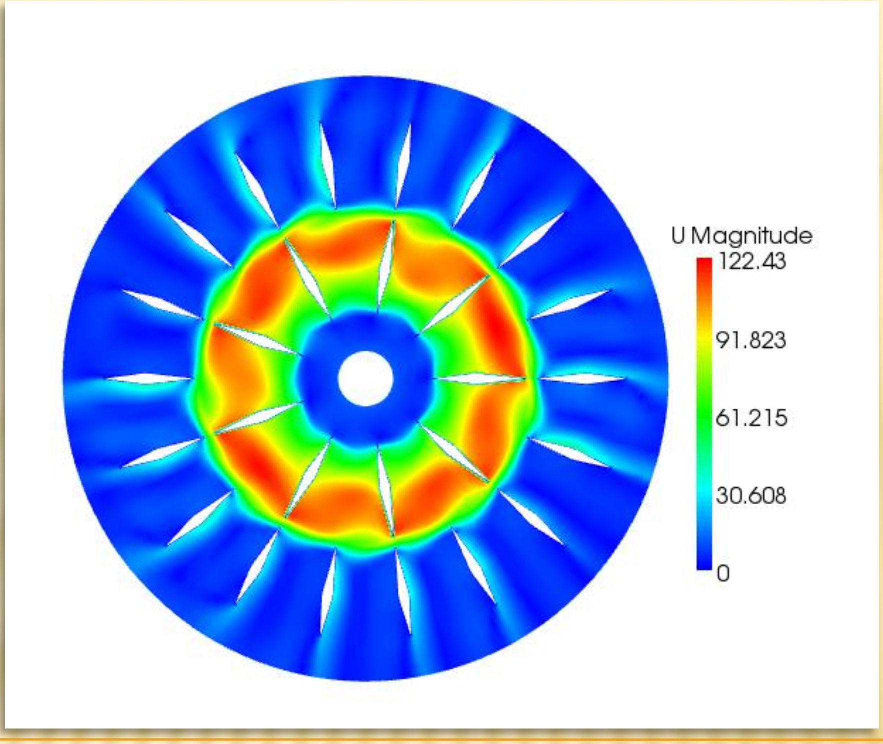
Setting up a case for turbomachinery problems



Outline

- **Pre-processing utilities**: import a mesh, mergeMesh, stitchMesh, transformPoints, creation of zones and sets.
- **MRFSimpleFoam solver**, implementation and set-up.
- **The General Grid Interface (GGI),** cyclicGgi, overlapGgi, implementation and set-up.
- **The unsteady solver, turbDyMFoam**, implementation and set-up.
- **Tools and functionObjects.**

TUTORIALS AVAILABLE

- ICEM/of5_dev: tutorials for OpenFOAM.1.5-dev
  - Pump_2D_ggi: MRFSimpleFoam, with GGI
  - Pump_2D_stitch:MRFSimpleFoam solver with stitch utility
  - Pump_2D_turbDyMFoam: unsteady simulation with GGI
- M4_blockMesh: tutorials for cyclic and cyclicGgi in OpenFoam.1.5-dev and OpenFoam.1.6.x

PROFILE1DFIXEDVALUE BOUNDARY CONDITION

- http://openfoamwiki.net/index.php/Sig_Turbomachinery_Library_OpenFoamTurbo
- The boundary condition profile1DfixedValue implements a cylindrical boundary condition field defined by a 1D fixed value profile (radial or vertical) for a typical RANS k-epsilon computation (eg. simpleFoam, turbFoam, etc).

Building the pump_2d_ggi case.

- Open the case Icem/of5-dev/pump_2D_ggi.
- Case built from 2 meshes created in Gambit format, in IcemHEXA, rotor2D.msh, stator2D.msh.
- **This tutorial is using 1.5-dev.**
- *First step*: convert the fluent mesh into foam format:
  fluentMeshToFoam meshes/rotor2D.msh - case rotor_2D
  fluentMeshToFoam meshes/stator2D.msh - case stator_2D
- *Second step*: **merge** the two meshes together.
- *Third step*: **scale** the case, if needed.
- *Last step* : Use the **GGI** to pass the informtation between the two meshes.

Importing a Gambit mesh in OpenFOAM.

- The 2 possible commands to do so:

  fluentMeshToFoam

  fluent3DMeshToFoam
- fluent3DMeshToFoam <Fluent mesh file> [-case dir] [-ignoreFaceGroups face group names] [-scale scale factor] [-ignoreCellGroups cell group names] [-help] [-doc] [-srcDoc]
- fluentMeshToFoam <Fluent mesh file> [-writeSets] [-case dir] [-writeZones] [-scale scale factor] [-help] [-doc] [-srcDoc]

- fluentMeshToFoam meshes/rotor2D.msh - case rotor_2D
  fluentMeshToFoam meshes/stator2D.msh - case stator_2D

mergeMeshes.

- This utility takes the meshes from two different cases and merges them into the master case.
- The two meshes will keep all their original boundary conditions, so they are not automatically coupled.
- mergeMeshes reads the system/controlDict of both cases.

- Usage: **mergeMeshes <master root> <master case> <root to add> <case to add>.**

- The result of the mergeMesh is saved into the first time step folder according to system/controlDict (in this tutorial, 1/).

transformPoints.

- **Usage: transformPoints [-translate “(vector)”] [-rotate “(vector vector)”] [-scale “(vector)”]**
- Useful to rotate, scale, translate a mesh.
- The transformPoints utility overwrite the mesh in constant/polyMesh, no folder is created.

The GGI implementation

- Coupling interface used to join multiple non-conformal regions where the patches nodes on each side of the interface **do not match.**
- Non-conformal meshes can be designed separately, and joined together using one of many GGI alternatives:
- Ggi CyclicGgi OverlapGgi mixingPlane (in progress, not implemented yet)
- Weight factors is used to know how much information should be transferred from one side of the ggi to its neighbour cells on the other side of the ggi.
- The GGI is user developped and is a part of **of-XX-dev ONLY**. It is not available in the OpenCFD versions.

GGI interface, basic setup

constant/polyMesh/boundary

```
GGI_INT
{
  type          ggi;
  nFaces        707;
  startFace     374119;
  shadowPatch   GGI_EXT;
  bridgeOverlap false;
  zone          GGI_INT_ZONE;
}
```

```
GGI_EXT
{
  type          ggi;
  nFaces        756;
  startFace     374826;
  shadowPatch   GGI_INT;
  bridgeOverlap false;
  zone          GGI_EXT_ZONE;
}
```

0/[U p k epsilon] boundaryField

```
GGI_INT
{
  type ggi;
}
GGI_EXT
{
  type ggi;
}
```

- Additional step for serial/parallel computing:

```
setBatch file: faceSet GGI_INT_ZONE new patchToFace GGI_INT
               faceSet GGI_EXT_ZONE new patchToFace GGI_EXT
               quit
setSet –batch setBatch
setsToZones -noFlipMap
```

MRFSimpleFoam: implementation.

- MRFSimpleFoam means Multiple Reference Frame simpleFoam.
- Steady-state solver, for incompressible, turbulent flow, using the SIMPLE solver.
- When a frame is rotating, the flux equation is solved using an extra term, the Coriolis term:

Frame	Convected velocity	Steady incompressible Navier-Stokes equations
Inertial	Absolute velocity	$\begin{cases} \nabla\cdot(\vec{u}_I\otimes\vec{u}_I) = -\nabla(p/\rho)+\nu\nabla\cdot\nabla(\vec{u}_I) \\ \nabla\cdot\vec{u}_I = 0 \end{cases}$
Rotating	Relative velocity	$\begin{cases} \nabla\cdot(\vec{u}_R\otimes\vec{u}_R)+2\vec{\Omega}\times\vec{u}_R+\vec{\Omega}\times\vec{\Omega}\times\vec{r} = -\nabla(p/\rho)+\nu\nabla\cdot\nabla(\vec{u}_R) \\ \nabla\cdot\vec{u}_R = 0 \end{cases}$
Rotating	Absolute velocity	$\begin{cases} \nabla\cdot(\vec{u}_R\otimes\vec{u}_I)+\vec{\Omega}\times\vec{u}_I = -\nabla(p/\rho)+\nu\nabla\cdot\nabla(\vec{u}_I) \\ \nabla\cdot\vec{u}_I = 0 \end{cases}$

MRFSimpleFoam: compilation.

- Can be found in $FOAM_TUT/MRFSimpleFoam/MRFSimpleFoam for **1.5-dev** or $FOAM_TUT/incompressible/MRFSimpleFoam/MRFSimpleFoam/ for **1.6.x.**

  Cp –r $FOAM_TUT/MRFSimpleFoam/MRFSimpleFoam $WM_PROJECT_USER_DIR

  Cd $WM_PROJECT_USER_DIR/MRFSimpleFoam

  wmake.

- The executable is MRFSimpleFoam.

MRFSimpleFoam: set-up in OF5-dev.

- The set-up changes between 1.5-dev and 1.6.x, but the steps are similar:
  - Define a region where the Coriolis force will be added, when calculating the flux.
  - Define the rotating parameters. Those are defined in constant/MRFZones.

Creation of the rotating region.

- Use of sets and zones.
  - Creation of a set of cells that define the rotating region, using the many operations available in topoSetSource.
  - Creation of a set of faces from the previous set to get the Coriolis term for those faces for the flux equation.
  - Convert the set of cells (and faces for of-1.5-dev) into cellZones and faceZones using setsToZones.

Creation of the rotating region.

- The created zones can be checked in paraFoam, to be sure that the rotating region was chosen properly.
- The exact steps to perform for of-1.5-dev can be found among other tutorials in **http://openfoamwiki.net/index.php/Sig_Turbomachinery_/_ERCOFTAC_centrifugal_pump_with_a_vaned_diffuser.**

Definition of the rotating parameters.

- Defined in constant/MRFZones.
- Differ from of-1.5-dev to of-1.6.x.
- OBS! The rotating velocity is in rad/s, not in rpm.

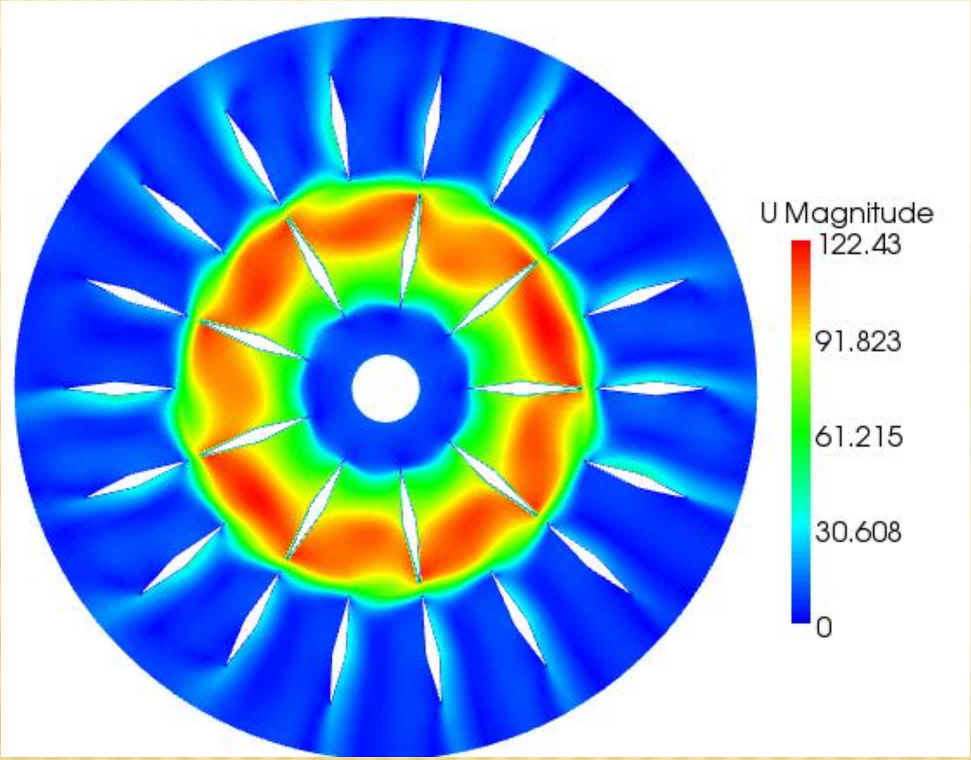
Boundary conditions

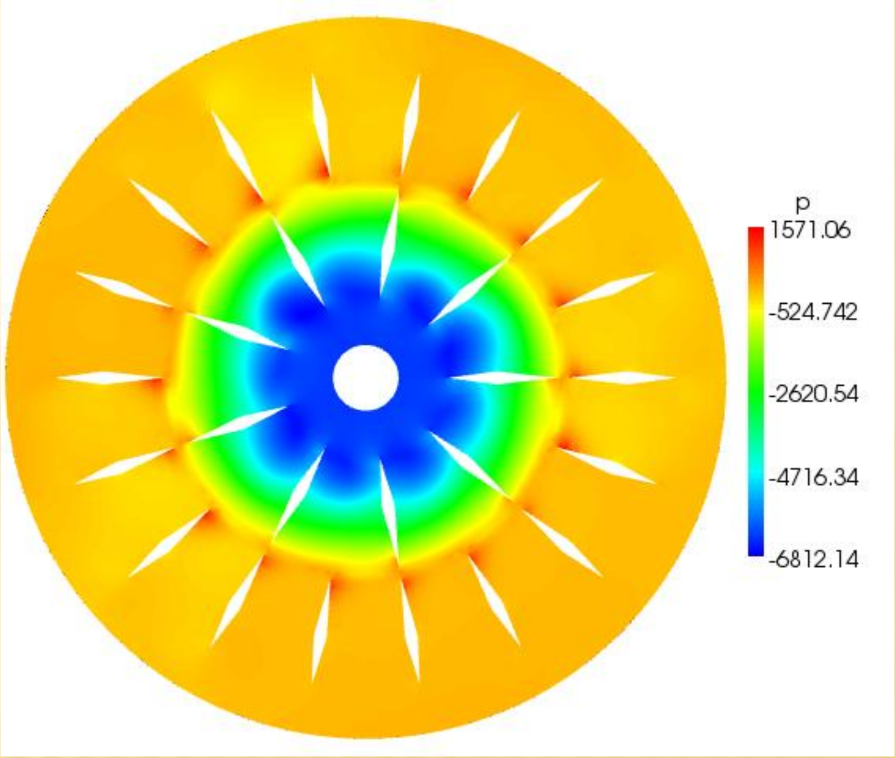
- Usage:
```
type            profile1DfixedValue;
fileName        "rotor2d_abs.csv";
fileFormat      "turboCSV";
interpolateCoord "Z";
fieldName       "Velocity";
```
- Need a file called in this case rotor2d_abs.csv in constant. In this file the header should be as mentionned on the wiki.
- Need to link the library libOpenFoamTurbo.so at the end of system/controlDict.

Writting a script to automatically run a case.

- It is possible to create an executable that will do all operations automatically.
- Here, it is called Allrun.
- To use it, the command is ./Allrun.
- When a simulation is finished, and one wants to start over, ./Allclean removes everything that wasn't there at start.

Results


U Magnitude
122.43
91.823
61.215
30.608
0


p
1571.06
-524.742
-2620.54
-4716.34
-6812.14

Unsteady simulation: turbDyMFoam

- Transient solver for incompressible, turbulent flow of Newtonian fluids with **moving mesh**.
- Uses both PISO and SIMPLE to couple U and p.
- There are many ways a mesh can move, and some of the basics move are coded as **dynamicFvMesh**:
  - LinearValveFvMesh
  - MovingConeTopoFvMesh
  - MixerFvMesh
  - MixerGgiFvMesh (only available in of-1.5-dev)

TurbDyMFoam set-up

- The tutorial is located in Icem/ pump_2D_ggi_turbDyMFoam.
- All the definition of the moving mesh is gathered in a dictionnary called dynamicMeshDict, located in constant/.
- A cellZone called movingCell needs to be generated.
- The boundary condition of the rotorblades for the velocity is

```
ROTORBLADES
{
type            movingWallVelocity;
value            uniform ...;
}
```

Unsteady simulation: hints

- In unsteady simulation, the Courant number is important and directly linked to the time step.
- Time step should be small, and a lot of SIMPLE loops should be done inside the PISO loop.
- This is done by playing with the parameters nCorrectors, and nOuterCorrectors in system/fvSolution.
- The more PISO and SIMPLE loop , the bigger the time step.
- Start from a steady simulation (done with MRFSimpleFoam for exemple).

Useful tools.

- **PyFOAM.** Simplifies a lot the creation of a case, allow to follow in real-time the simulation, and reduce the errors when building a case.
- **trackDictionnary.**
- **ggiCheck.**

Trackdictionnary

- trackDictionary functionObject writes the value of all the known simulation switches (DebugSwitches, InfoSwitches, OptimisationSwitches, Tolerances, DimensionedConstants) and named dictionnary.
- It is user developped, and works for of-XXX-dev only.
- Available at http://openfoam-extend.svn.sourceforge.net/svnroot/openfoam-extend/trunk/Breeder_1.5/libraries/simpleFunctionObjects/
- Needs some lines to be added at the end of system/controlDict.
- If specified in system/controlDict but not installed, the simulation will not start.

GgiCheck

- functionObject pre-installed in OpenFOAM-1.XX-dev.
- Allow the user to see whether the flux across the GGI interface is balanced or not.
- At the end of system/controlDict:

```
   ggiCheck
{
 type ggiCheck;
  phi phi;
  functionObjectLibs ("libsampling.so");
}
```

GgiCheck

- During the computation, the ggiCheck functionObject will show this information at each time step:

Initializing the GGI interpolator between master/shadow patches: GGI_INT/GGI_EXT
Evaluation of GGI weighting factors:
Largest slave weighting factor correction : 0 average: 0
Largest master weighting factor correction: 4.4408921e-16 average: 4.9960036e-17

Conclusions

- Important to understand the differences between of-xxx and of-xxx-dev.
- Setting up a case can be easier when using the different tools available.
- Doxygen, forum, wiki are treasure chests if you know what you are looking for.
- http://openfoamwiki.net/index.php/Sig_Turbomachinery_/_Validation_test_cases is a webpage with a lot of informations to simulate a case the best way possible.

Stitch tutorial: pump_2D_stitch.

- Open the case Icem/of5-dev/pump_2D_stitch.
- Case built from 2 meshes created in Gambit format, in IcemHEXA, rotor2D.msh, stator2D.msh.
- **This tutorial is using 1.5-dev.**
- *First step*: convert the fluent mesh into foam format:
  fluentMeshToFoam meshes/rotor2D.msh - case rotor_2D
  fluentMeshToFoam meshes/stator2D.msh - case stator_2D
- *Second step*: **merge** the two meshes together.
- *Third step*: **stitch** the merged meshes together.
- *Last step*: **scale** the case, if needed.

stitchMesh.

- stitchMesh couples two uncoupled parts of the mesh that belong to the same case.
- You should have a patch in one part of the mesh (masterPatch) that fits with a corresponding patch on the other part of the mesh (slavePatch).
- MasterPatch and slavePatch are important, as the face and cell numbers will be renamed after the master patch.
- Usage: **stitchMesh <masterPatch> <slavePatch>.**
- For pump_2D_stitch case:

```
cd pump_2D_stitch
stitchMesh GGI_INT GGI_EXT
```

- Remember to delete the empty patches in constant/polyMesh/boundary, or the simulation will not start.

Boundary conditions for pump_2D_stitch.

- the boundary condition at the inlet is called **profile1DfixedValue**.
- It is user developped and can be found at http://openfoamwiki.net/index.php/Sig_Turbomachinery_Library_OpenFoamTurbo
- The boundary condition profile1DfixedValue implements a cylindrical boundary condition field defined by a 1D fixed value profile (radial or vertical) for a typical RANS k-epsilon computation.
- Limitations: The rotation axis is forced to the Z axis.

MRFSimpleFoam in of-1.6.x

- Source OpenFOAM-1.6.x.
- The tutorial is located in m4_blockMesh/of6x.
- To create the cellZone, a manipulation called **cylinderToCell** is used. Select all the cell inside the described cylinder.
- The boundary condition used for the velocity is called **surfaceNormalFixedValue**, create a uniform radial velocity.
- This tutorial introduces the patch cyclic. It allows to take into account rotation periodicity.
- Limitation: cyclic needs to be 1 to 1 cell periodic, so that the mesh can not change from one side of the patch to an other.

Tutorial using the cyclicGgi:

m4_blockMesh/of5-dev/ mixer_2D_MRF_m4

- Source of-1.5-dev
- Geometry created via m4 and blockMesh.
- Instead of the cyclic patch, cycliGgi is used to allow a non matching mesh between the two periodic patches.
- The normal Ggi is used as well between the rotor and the stator parts.

CyclicGgi interface, basic setup

constant/polyMesh/boundary

```
ROTOR_CYCLIC_LEFT
  {
    type          cyclicGgi;
    nFaces        13;
    startFace     3514;
    shadowPatch   ROTOR_CYCLIC_RIGHT;
    zone          ROTOR_CYCLIC_LEFT_ZONE;
    bridgeOverlap off;
    rotationAxis  (0 0 1);
    rotationAngle -40;
    separationOffset (0 0 0);
  }
```

```
ROTOR_CYCLIC_RIGHT
  {
    type          cyclicGgi;
    nFaces        13;
    startFace     3540;
    shadowPatch   ROTOR_CYCLIC_LEFT;
    zone          ROTOR_CYCLIC_RIGHT_ZONE;
    bridgeOverlap off;
    rotationAxis  (0 0 1);
    rotationAngle 40;
    separationOffset (0 0 0);
  }
```

0/[U p k epsilon] boundaryField

```
ROTOR_CYCLIC_LEFT
{
  type cyclicGgi;
}
ROTOR_CYCLIC_RIGHT{
  type cyclicGgi;
}
```

setBatch file: faceSet ROTOR_CYCLIC_LEFT_ZONE new patchToFace ROTOR_CYCLIC_LEFT
faceSet ROTOR_CYCLIC_RIGHT_ZONE new patchToFace ROTOR_CYCLIC_RIGHT
quit
setSet –batch setBatch
setsToZones -noFlipMap

OBS: The rotation angle in the definition of the cyclicGgi patches is very important. If you do not get it right, an error message of type flotation point error will occur.