

# Simulating Tank-Mixer Problems Using A Time-Varying Mapped Fixed Value Approach

Jonas Müller

# Overview

1. Problem Definition
2. Approach
  - Modelling Strategy
  - File Structure and Run Script
3. Results

# Problem Definition

# Tanks in Traditional Winery



Traditional wine cellar in Germany

Photo Credit: clemens-online.com

# Tanks in Industrial Tank Farm



Modern tank farm in Western Australia

# Mixing in the Wine Industry

- ▶ mixing through bubble induced turbulence during fermentation
- ▶ non-continuous mechanical mixing after fermentation
- ▶ fast rotating propeller mixers
- ▶ goal of homogenization (blending, temperature, additives)
- ▶ high energy consumption
- ▶ minimum mixing times?



Marine Type Propeller:  
best for low-viscosity, high-speed



Pitched Blade Impeller:  
good for viscous mixtures and  
compromise for pumping and shearing

# Typical configuration in wine industry



Wine tank (6000L)



Mixer



Configuration

# Situation in the Wine Industry

- ▶ one mixer for a range of tanks
- ▶ multiple tank-mixer configurations in same winery
- ▶ usually mixing of Newtonian-fluids (must, wine) of similar viscosities
- ▶ no knowledge of mixers except for geometry and RPM
  
- **winemakers want to know the minimum mixing times to homogenize given tank with given mixer**

# Approach

# Modelling Strategy

# Problems with Traditional Strategies

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# Problems with Traditional Strategies

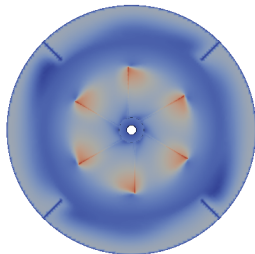
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- **Moving Reference Frame (MRF)** only calculates steady-state flowfield and lacks accuracy [Deglon and Meyer, 2006]
- **Sliding Mesh (SM)** requires too much computational power to calculate the timescales of interest [Mošťák et al., 2005]

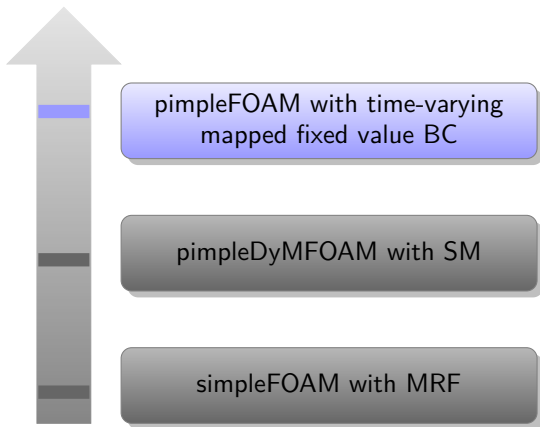
# Traditional Modelling Strategies for Rotating Propellers

Moving Reference Frame  
(steady state solution)

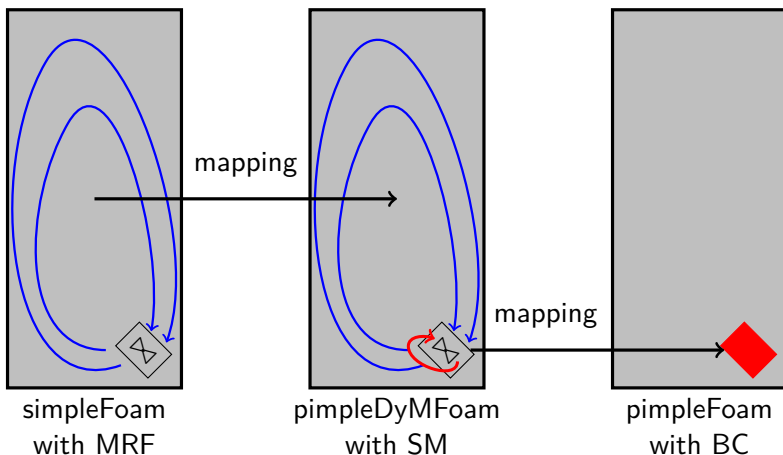


Sliding Mesh  
(transient solution)

# Workflow for mapped fixed value approach

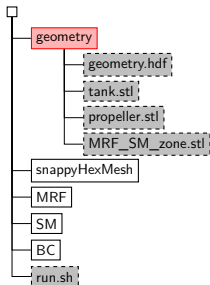


# Succession of openFOAM Simulations



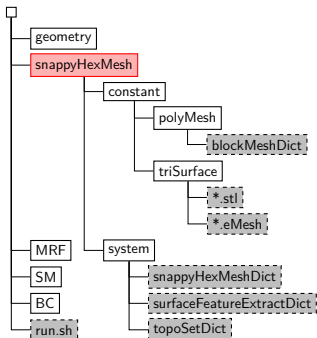
# File Structure and Run Script

# Geometry



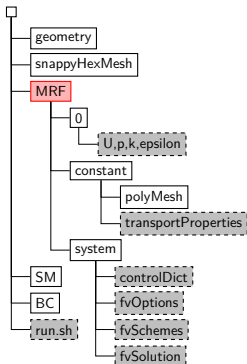
- ▶ keeping geometry simple
- ▶ create propeller, tank, rotating zone
- ▶ using Salome software
- ▶ *surfaceTransformPoints* utility on .stl files to scale for openFOAM

# Meshing



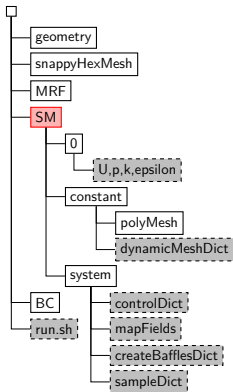
- ▶ *surfaceFeatureExtract* utility on \*.stl files to capture edges
- ▶ *blockMesh* to create background mesh
- ▶ *snappyHexMesh* to create mesh
- ▶ *renumberMesh* utility to simplify mesh
- ▶ *topoSet* to create rotating cellZone
- ▶ *checkMesh* utility to check for mesh quality

# Steady-State MRF Simulation



- ▶ copy *polyMesh* folder from *snappyHexMesh* Case
- ▶ define viscosity in *transportProperties*
- ▶ define rpm in *fvOptions*
- ▶ choose schemes in *fvSchemes*
- ▶ define convergence criteria in *fvSolution*
- ▶ run simulation: *potentialFoam*
- ▶ run simulation: *simpleFoam*

# Transient SM Simulation



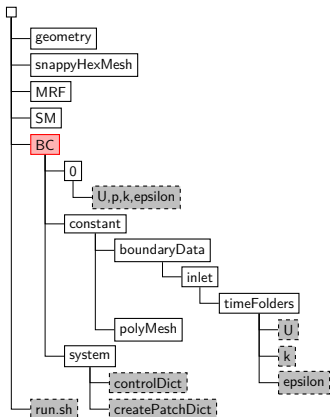
- ▶ copy *polyMesh* folder from *snappyHexMesh* Case
- ▶ define rpm in *dynamicMeshDict*
- ▶ *createBaffles* utility to create rotating surface patch
- ▶ *mergeOrSplitBaffles* to split patch in master and slave
- ▶ *splitMeshRegions* to create two cellZones
- ▶ *mapFields* utility to map converged fields of steady-state simulation to 0
- ▶ run simulation: *pimpleDyMFoam*

# Preparing the data

## Obtaining data for BC approach from SM simulation

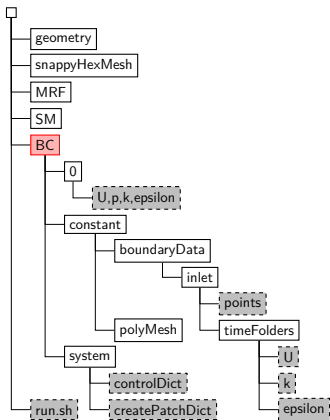
- ▶ run the transient simulation for multiple rotations
- ▶ make sure the fields on the rotating zone surface are periodic
- ▶ write out multiple flowfields during last rotation (e.g.  $36 * 10^\circ$ )
- ▶ use *sample* utility to write out U and turbulence fields during last rotation on (slave) rotating surface

# Transient BC Simulation



- ▶ copy the sampled fields from SM postProcessing into case
- ▶ rename the postProcessing folders to represent the times of the first rotation
- ▶ copy the folders containing the data for the first rotation into the `./constant/boundaryData/inlet` folder
- ▶ rename and copy the timeFolders for all subsequent rotations

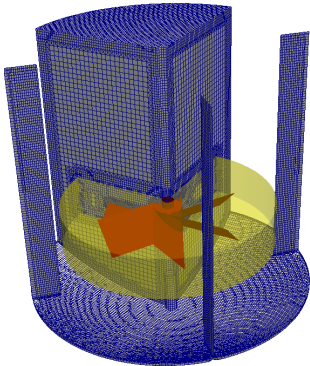
# Transient BC Simulation



- ▶ copy *polyMesh* folder from *pimpleDyMFoam* Case
- ▶ *subsetMesh* utility to remove cellRegion inside rotating zone
- ▶ *createPatch* to create inlet from slave cellZone
- ▶ apply *timeVaryingMappedFixedValue* BC to U and turbulence fields in 0 folder
- ▶ create *points* file from a postProcessing faceCentres file needed by the BC
- ▶ run simulation: *pimpleFoam*

# Results

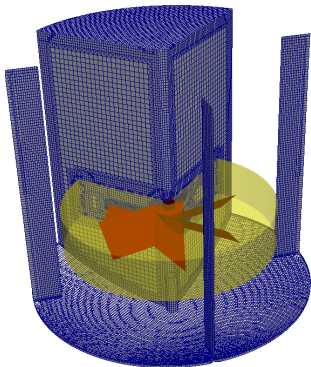
# Validation of approach with data from literature



Geometry from [Aubin  
et al., 2004] Paper

- ▶ *Modeling turbulent flow in stirred tanks with CFD: the influence of the modeling approach, turbulence model and numerical scheme* [Aubin et al., 2004]

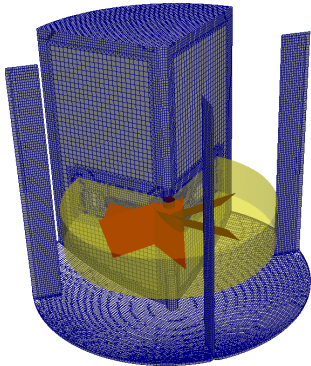
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- ▶ comparison of MRF and SM with experimental data

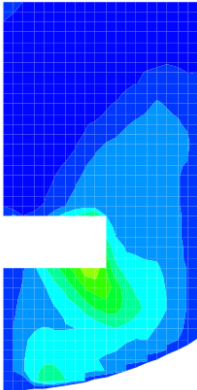
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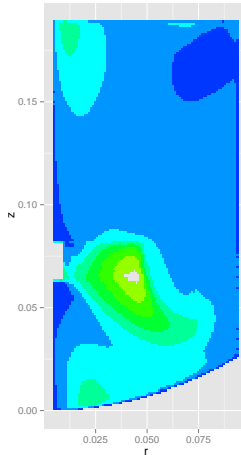
Geometry from [Aubin et al., 2004] Paper

- ▶ *Modeling turbulent flow in stirred tanks with CFD: the influence of the modeling approach, turbulence model and numerical scheme* [Aubin et al., 2004]
- ▶ comparison of MRF and SM with experimental data
- ▶ FLUENT software and results shown in dimensionless radial and tangential velocities

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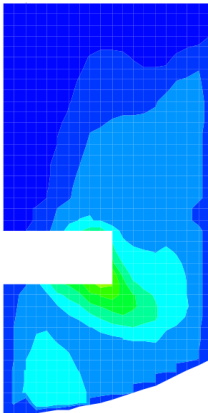
Aubin Paper, MRF



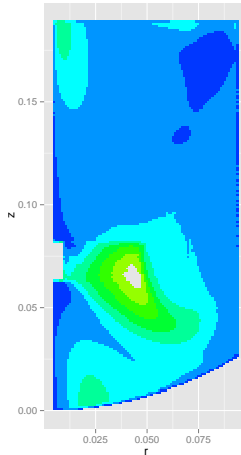
simpleFoam

- ▶ MRF
- ▶ *simpleFoam*
- ▶ ca. 40,000 iterations
- ▶ ca. 18 hrs on 18 cores

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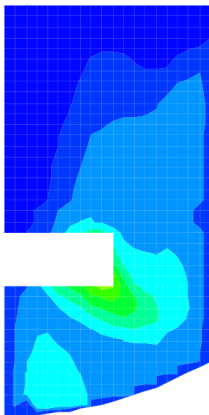
Aubin Paper, SM



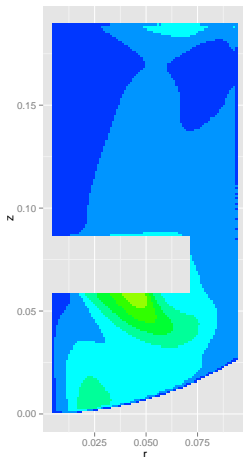
pimpleDyMFoam

- ▶ SM
- ▶ *pimpleDyMFoam*
- ▶ ca. 0.0001 sec deltaT
- ▶ ca. 6 hrs on 18 cores per rotation

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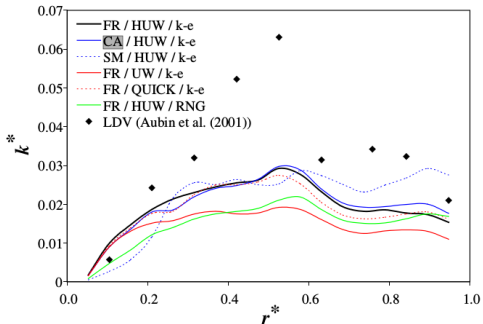
Aubin Paper, SM



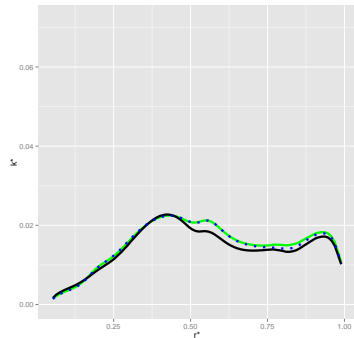
Time-Varying Mapped  
Fixed BC

- ▶ BC
- ▶ *pimpleFoam*
- ▶ 2 sec real-time  
(10 rotations)
- ▶ ca. 20 min on 18  
cores per rotation

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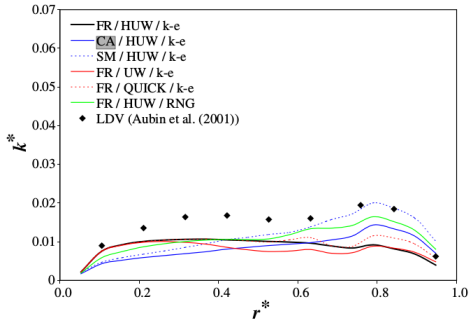


$k^*$  below propeller ( $z^*=0.30$ )

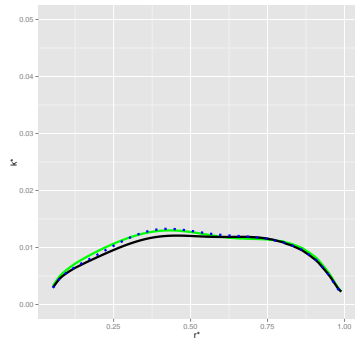


$k^*$  below propeller ( $z^*=0.30$ )

# Validation of approach using data from literature



$k^*$  above propeller ( $z^*=0.60$ )



$k^*$  above propeller ( $z^*=0.60$ )

# Summary & Outlook

- ▶ BC approach recreates flowfields of SM approach in much shorter time



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- ▶ BC approach recreates flowfields of SM approach in much shorter time
- ▶ automatization with run scripts is possible (meshing!)
- ▶ need to run the approach with larger tanks



# Summary & Outlook

Thank you very much  
for your attention!

Questions?



# References

- J. Aubin, D. F. Fletcher, and C. Xuereb. [Modeling turbulent flow in stirred tanks with CFD: the influence of the modeling approach, turbulence model and numerical scheme](#). *Experimental thermal and fluid science*, 28(5): 431–445, 2004.
- D. Deglon and C. Meyer. [CFD modelling of stirred tanks: Numerical considerations](#). *Minerals Engineering*, 19(10): 1059–1068, 2006.
- M. Dhainaut, P. Tetlie, and K. Bech. [Modeling and experimental study of a stirred tank reactor](#). *International Journal of Chemical Reactor Engineering*, 3(1), 2005.
- W. Huang and K. Li. [CFD simulation of flows in stirred tank reactors through prediction of momentum source](#). INTECH Open Access Publisher, 2013.
- M. Moštek, A. Kukukova, M. Jahoda, and V. Machoň. [Comparison of different techniques for modelling of flow field and homogenization in stirred vessels](#). *Chem. Pap.*, 59(6a):380–385, 2005.

# Create Graphs for axial and tangential velocity

1. use postProcessing utility to create scalar fields  $\rho$ ,  $\theta$ ,  $U_\rho$ , and  $U_\theta$  from the given scalar fields Xcoord and Ycoord and U vector field in time folder
  - ▶  $\rho = \sqrt{(Xcoord^2 + Ycoord^2)}$
  - ▶  $\theta = atan(Ycoord / Xcoord)$
  - ▶  $U_\rho = U_x * cos\theta + U_y * sin\theta$
  - ▶  $U_\theta = -U_x * sin\theta + U_y * cos\theta$
2. use bash script (*createSampleDict.sh*) to create a *sampleDict* file which samples all fields along circles over whole domain
3. use R script (*graphs.R*) to round  $\rho$  and z values and create  $U_\rho$  and  $U_\theta$  means