Introduction to open source CFD

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Industrial Dust Recycling
Outline

- Introduction
- Meshing and running
- More details on running cases
- Validation test case
- Summary

Disclaimer

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INTRODUCTION

Introduction
Open source CFD

- Open source software allows the user to modify and further develop the code

- We will be using **OpenFOAM**
  - Free and open source (GPL)
  - Produced by OpenCFD Ltd. (ESI)
  - Modular C++ framework to solve PDEs (FVM)

- Other open source options, see e.g.

  www.cfd-online.com/Wiki/Codes#Free_codes

Aim of the course

- Aim: get you up to speed with OpenFOAM
  - OpenFOAM confidence
  - Linux confidence
  - C++ confidence
- Plan
  - Get used to the OpenFOAM and linux environment
  - Learn to modify OpenFOAM code
  - Learn to create your own models
  - Learn about post-processing

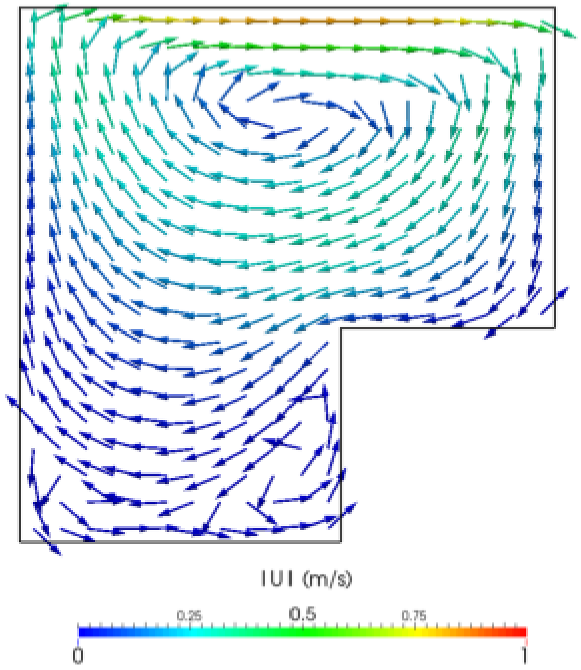
MESHING AND RUNNING

Lid-driven cavity
A basic example case

Aims:

- generate a mesh using `blockMesh`
- run a solver
- view the results in ParaView

- Incompressible, transient solver `icoFoam`
- Lid driven cavity in 2D

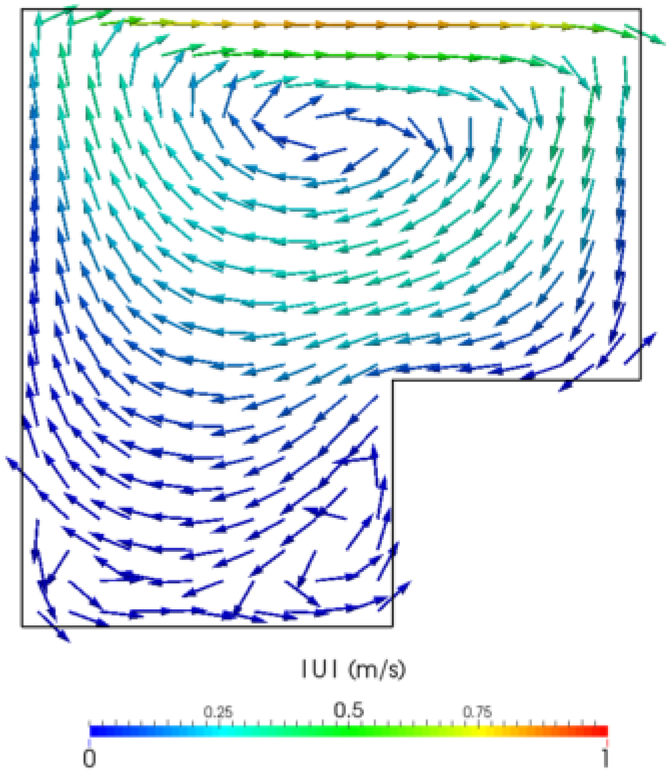


```
> run
> cp -r $FOAM_TUTORIALS/incompressible/icoFoam/cavityClipped .
> cd cavityClipped
```

Lid-driven cavity
Case structure

- Case structure

```
.
├── 0
│   ├── p
│   └── U
├── constant
│   ├── polyMesh
│   │   └── blockMeshDict
│   └── transportProperties
└── system
    ├── controlDict
    ├── fvSchemes
    ├── fvSolution
    └── mapFieldsDict
```



- Open `blockMeshDict`

```
> gedit constant/polyMesh/blockMeshDict &
```

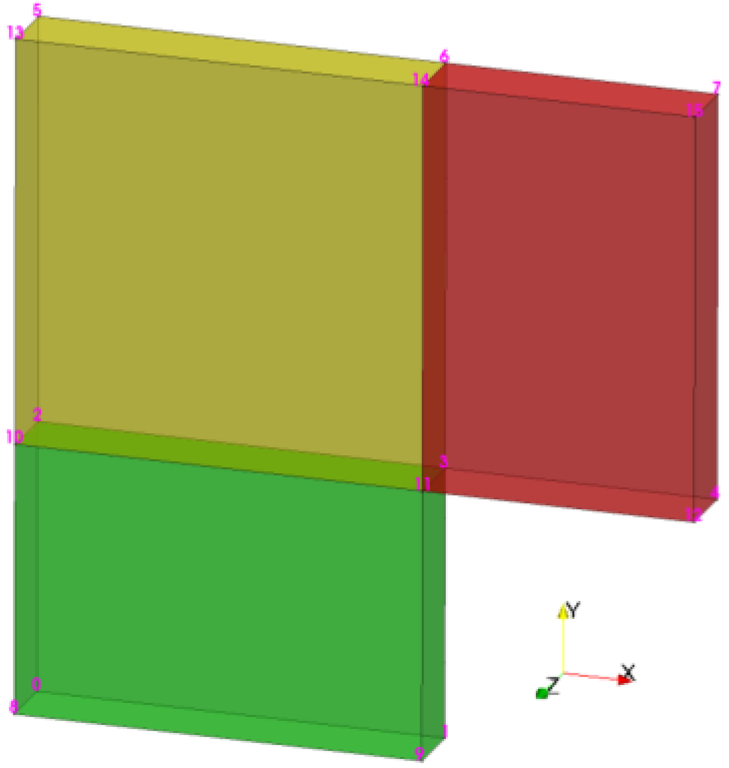
Lid-driven cavity
blockMeshDict

```
// Conversion factor to m
convertToMeters 0.1;

// List of vertices
vertices
(
    (0   0 0  ) //  0
    (0.6 0 0  ) //  1
    ...
    (0.6 1 0.1) // 14
    (1   1 0.1) // 15

);

// Block definition
blocks
(
    hex (0 1 3 2 8 9 11 10) // shape and vertices
        (12 8 1)            // nr cells in x-y-z
    simpleGrading (1 1 1)   // grading in x-y-z
    ...
);
```

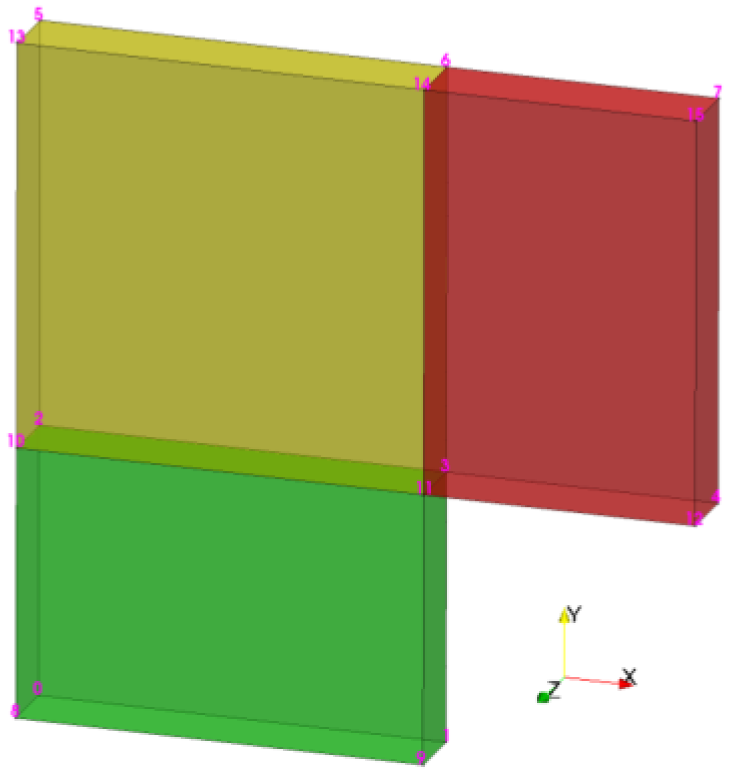


Lid-driven cavity
blockMeshDict

```
...
// List of edges for curves
edges
(
);

// Boundary definition
boundary
(
    lid                    // Patch name
    {
        type wall;         // Patch type
        faces
        (
            (5 13 14 6) // Face from vertices
            (6 14 15 7)
        );
    }
    ...
);

// Merge duplicate face pairs
mergePatchPairs
(
);
```



Lid-driven cavity
Mesh and view results

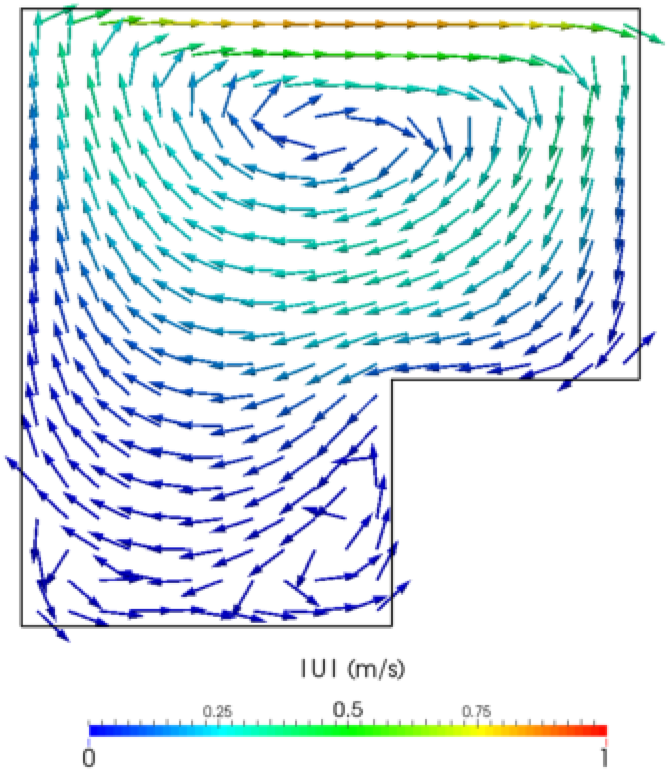
- Create the mesh and run the solver

```
> blockMesh
> icoFoam
```

- View the results with ParaView

```
> paraFoam
```

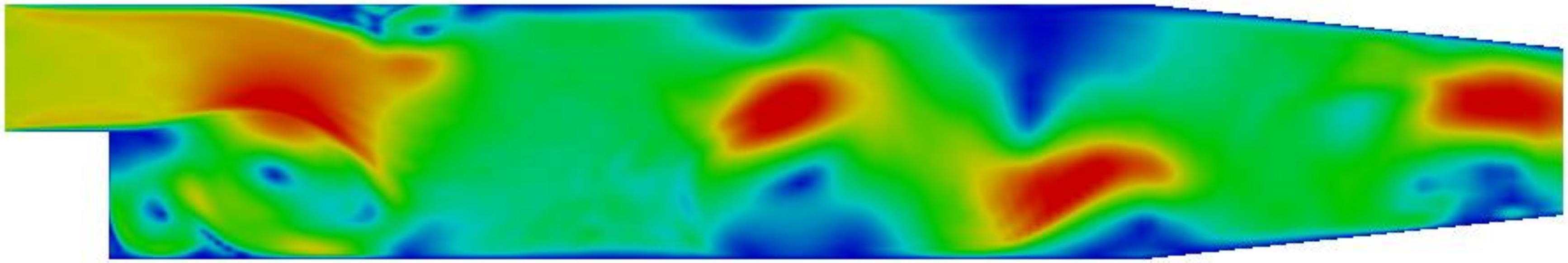
- Create a vector plot using ParaView's filters



MORE CASE RUNNING

More case details
LES pitzDaily case

- Run the incompressible LES pitzDaily case



```
> run

> cp -r $FOAM_TUTORIALS/incompressible/pisoFoam/les/pitzDaily .

> cd pitzDaily

> blockMesh

> pisoFoam |& tee log.pisoFoam
```

More case details
Solver output

```
Time = 0.03185Courant Number mean: 0.055869 max: 0.271596

smoothSolver:  Solving for Ux, Initial residual = 0.00205101, Final residual
    = 1.03065e-06, No Iterations 2
smoothSolver:  Solving for Uy, Initial residual = 0.00195554, Final residual
    = 1.10399e-06, No Iterations 2
GAMG:  Solving for p, Initial residual = 0.0342705, Final residual = 0.00260759,
    No Iterations 16
time step continuity errors : sum local = 1.57233e-07, global = 2.05609e-08,
    cumulative = -1.0282e-06
GAMG:  Solving for p, Initial residual = 0.00943142, Final residual =
    9.37652e-07, No Iterations 14
time step continuity errors : sum local = 7.25275e-11, global = 5.25955e-12,
    cumulative = -1.0282e-06
smoothSolver:  Solving for k, Initial residual = 0.000743129, Final residual =
    2.69896e-07, No Iterations 2
bounding k, min: 0 max: 9.78355 average: 0.142138

ExecutionTime = 262.76 s ClockTime = 266 s

fieldAverage fieldAverage1 output:    Calculating averages
```

More case details
Solver output

```
Time = 0.03185Courant Number mean: 0.055869 max: 0.271596

smoothSolver:  Solving for Ux, Initial residual = 0.00205101, Final residual
    = 1.03065e-06, No Iterations 2
```

- Controlled by the U entry in system/fvSolution

```
"(U|k|B|nuTilda)„
{
    solver          smoothSolver;
    smoother        GaussSeidel;
    tolerance       1e-05;
    relTol          0;
}
```

More case details
Solver output

```
GAMG:  Solving for p, Initial residual = 0.0342705, Final residual = 0.00260759,
    No Iterations 16
time step continuity errors : sum local = 1.57233e-07, global = 2.05609e-08,
    cumulative = -1.0282e-06
```

- Controlled by the p entry in system/fvSolution

```
P
{
    solver          GAMG;
    tolerance       1e-06;
    relTol          0.1;
    ...
}
```

More case details
Solver output

```
Time = 0.03185Courant Number mean: 0.055869 max: 0.271596

smoothSolver:  Solving for Ux, Initial residual = 0.00205101, Final residual
    = 1.03065e-06, No Iterations 2
smoothSolver:  Solving for Uy, Initial residual = 0.00195554, Final residual
    = 1.10399e-06, No Iterations 2
GAMG:  Solving for p, Initial residual = 0.0342705, Final residual = 0.00260759,
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ExecutionTime = 262.76 s ClockTime = 266 s

fieldAverage fieldAverage1 output:    Calculating averages
```
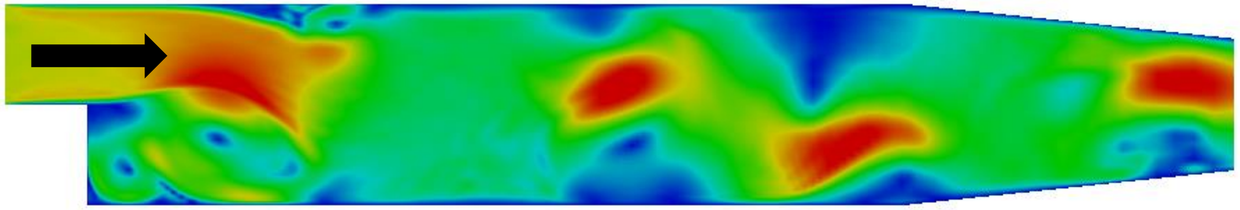

More case details
A quick look at the boundary conditions

- The boundary and initial conditions can be found in 0/<fieldName>
- In essence the boundary conditions are

$U = 10$
$\nabla p = 0$



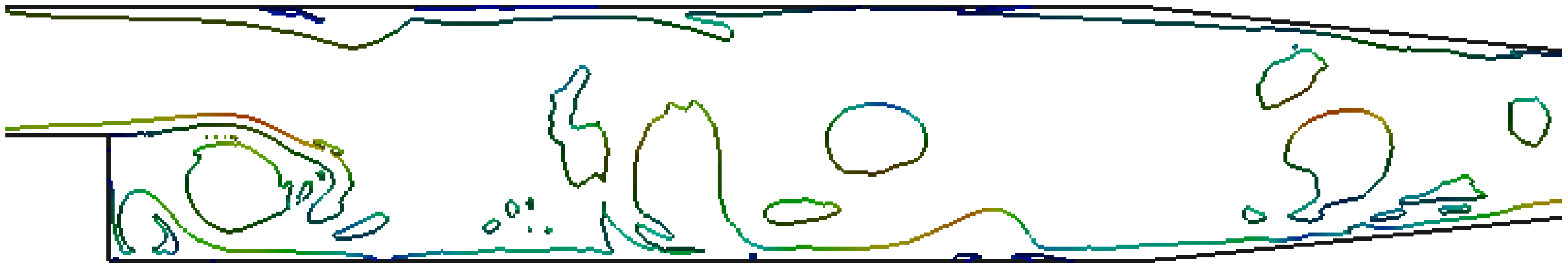
$\nabla U = 0$
$p = 0$

... with some sofistication ...

More case details
Post-processing

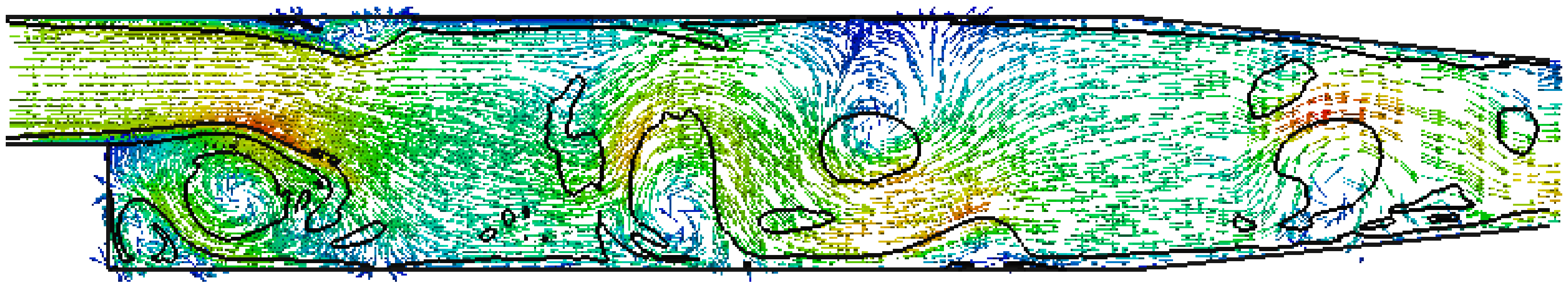
- OpenFOAM provides a ton of utilities, see $FOAM_UTILITIES
- For example, visualize vortex shedding using the vorticity and/or Q utilities and ParaView‘s Countour filter

```
> vorticity
> Q
```



More case details
Post-processing

- Use the Extract Edges filter on the Countour filter results to show the edges of vorticity contours in 2D
- Optionally, show flow vectors using the Glyph filter



BUICE-EATON DIFFUSER

Buice-Eaton diffuser
Introduction

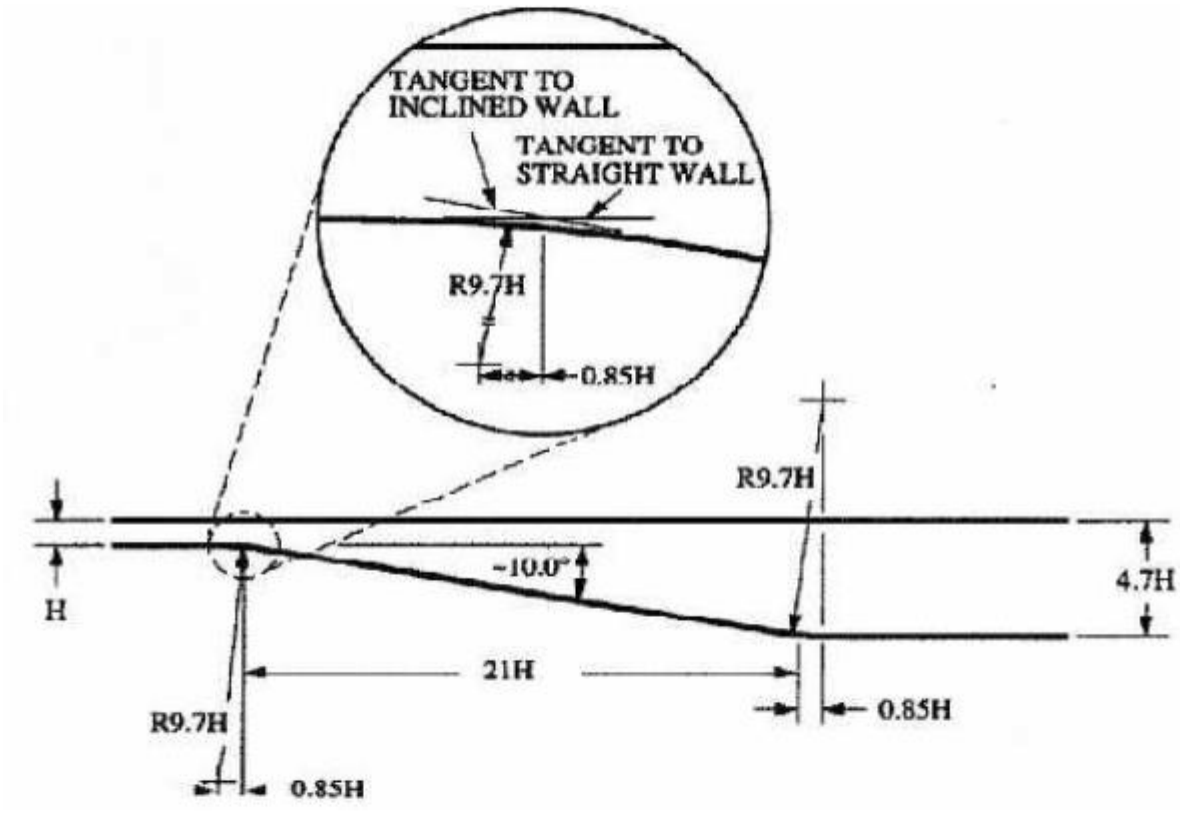
- Buice-Eaton[1] diffuser is a 2D validation case to study predicition of flow separation
  - behaviour of wall functions and turbulennce models
  - numerical settings

- NASA[2] published the mesh, case set-up, experimental data and an analysis of results

[1] Buice, C.U. & Eaton, J.K., "Experimental Investigation of Flow Through an Asymmetric Plane Diffuser", *Journal of Fluids Engineering*, Vol. 122, pp. 433-435, June 2000.

[2] http://www.grc.nasa.gov/WWW/wind/valid/buice/buice01/buice01.html

Buice-Eaton diffuser
Geometry

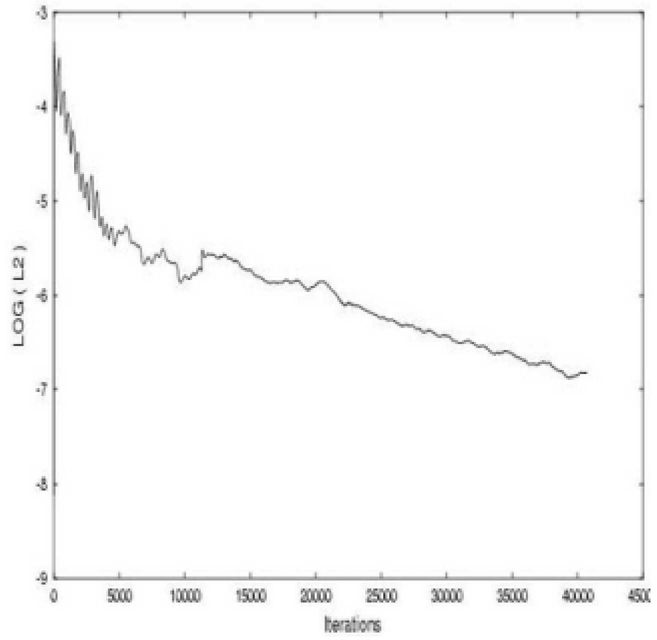


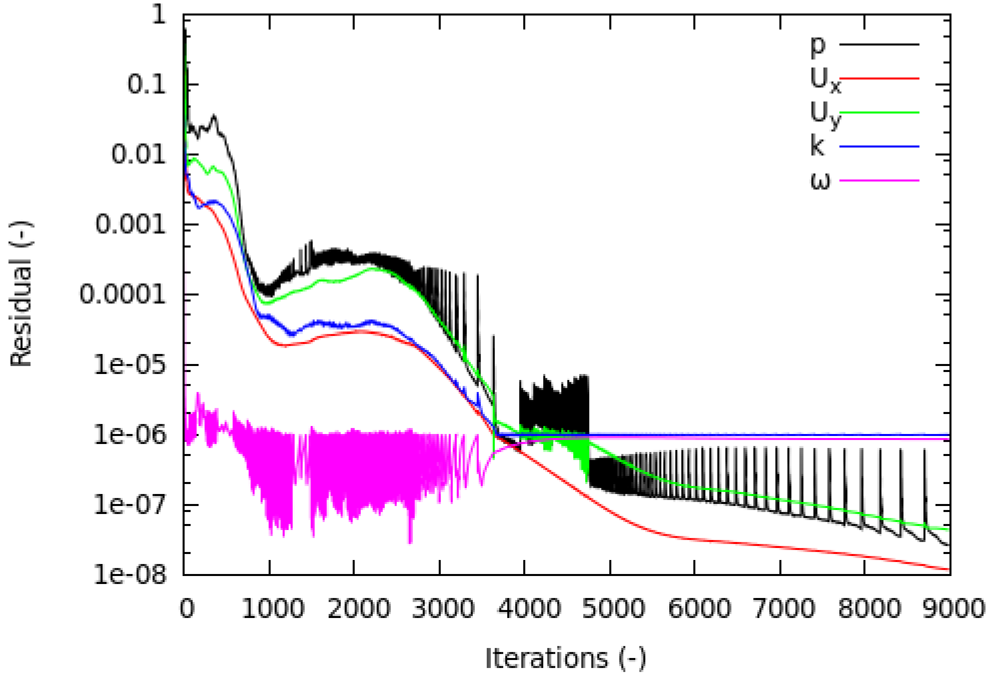
http://www.grc.nasa.gov/WWW/wind/valid/buice/buice01/buice01.html

Buice-Eaton diffuser
Residuals and convergence

NASA results[1] (40,000 iterations)

This course results (9,000 iterations)





[1] http://www.grc.nasa.gov/WWW/wind/valid/buice/buice01/buice01.html

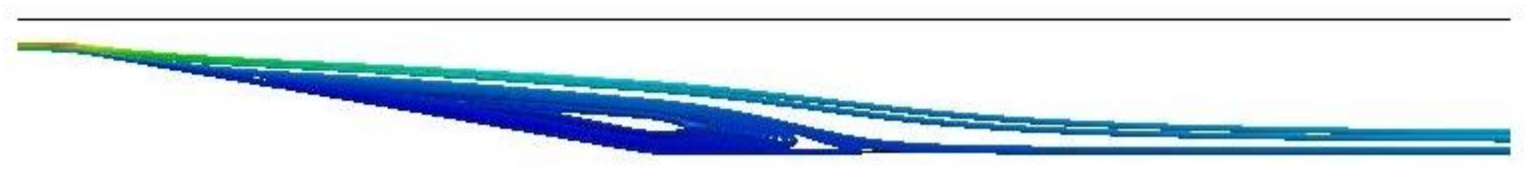
Buice-Eaton diffuser
Residuals and convergence

- Use OpenFOAM‘s foamJob and foamLog utilities to monitor residuals
- Use gnuplot to plot the residuals

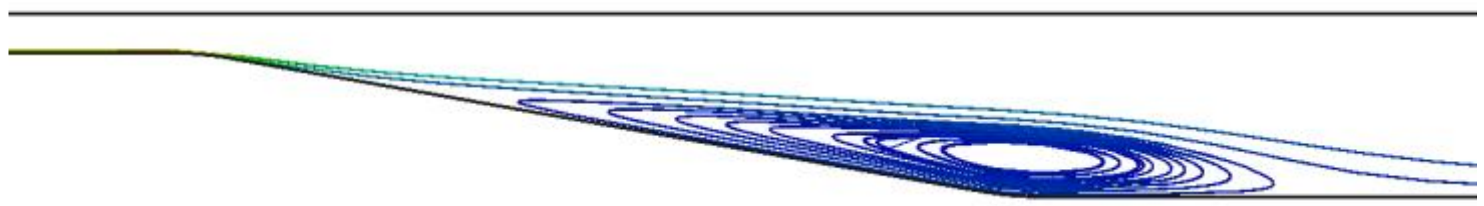
```
> foamJob simpleFoam

> foamLog

> gnuplot

gnuplot > plot 'logs/p_0' using 1:2 with lines notitle
```

Buice-Eaton diffuser
Separation point

NASA results[1] (20,000 iterations)



This course results (9,000 iterations)

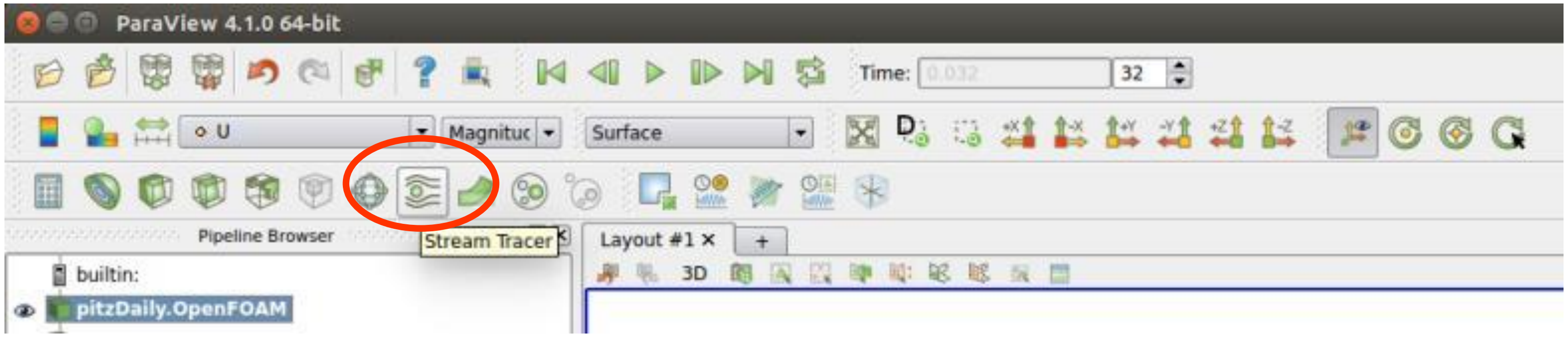


- Use ParaView‘s streamline and tube filters to generate streamlines

[1] http://www.grc.nasa.gov/WWW/wind/valid/buice/buice01/buice01.html

Buice-Eaton diffuser
Separation point

- Use ParaView‘s streamline and tube filters to generate streamlines



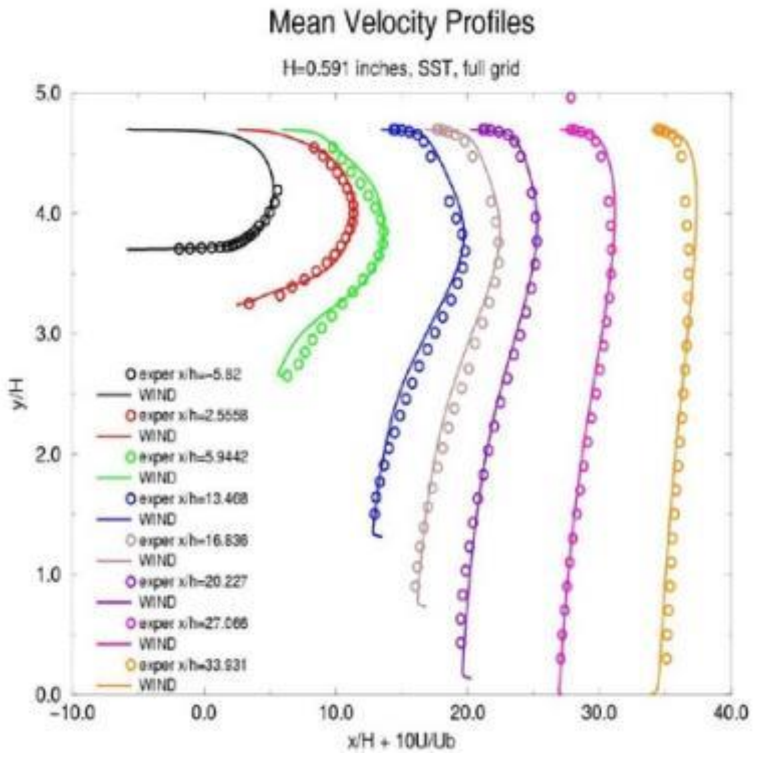
- ... or use the Filters menu:

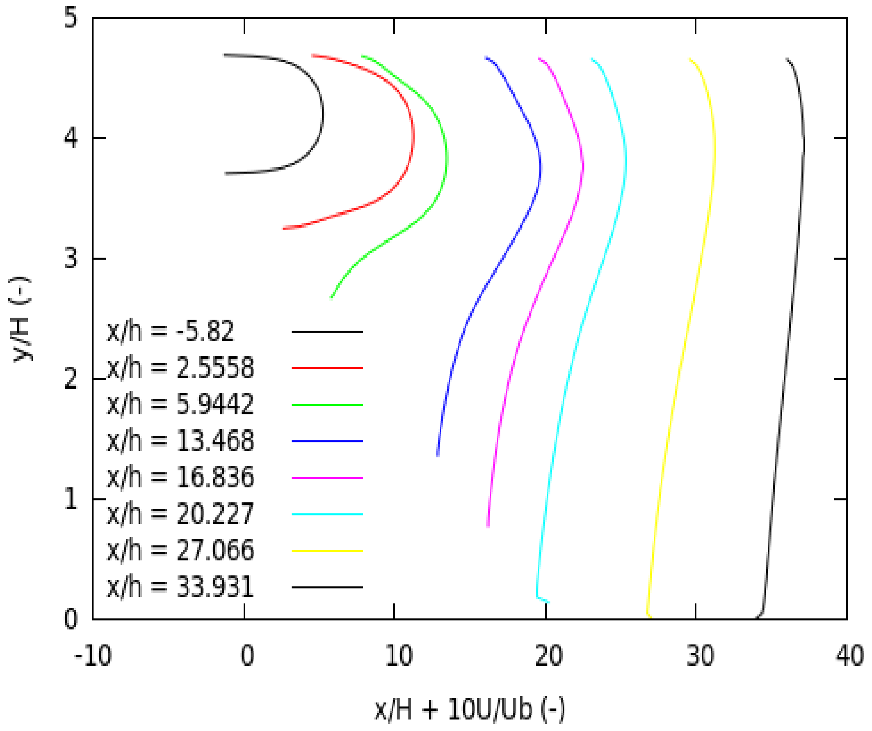
Filters > Alphabetical > Stream Tracers

Buice-Eaton diffuser
Sampling velocity

NASA results[1] (20,000 iterations)

This course results (9,000 iterations)





[1] http://www.grc.nasa.gov/WWW/wind/valid/buice/buice01/buice01.html

Buice-Eaton diffuser
Sampling velocity

- Create a sampleDict file in the system directory with the following content

```
interpolationScheme cellPointFace;

setFormat raw;

sets
(
    sampleLine
    {
        type face;
        axis y;
        start   ( 0.2022 0.0199 0 );
        end     ( 0.2022 0.0706 0 );
        nPoints 100;
    }
);

fields ( U );
```

- Plot using e.g. gnuplot

```
plot 'postProcessing/sets/<time>/sampleLine_U.xy' using 2:1 with lines notitle
```

Summary
Recap

- Basic meshing strategy
- Case structure
- Running of cases and viewing results
- Basic post-processing methods

Summary
Up next

- More advanced meshing techniques
- Creating our own post-processing utility
- Creating our own libraries
    - Boundary conditions
    - Physics library
- Using macros, expansion and `codeStream`
- Bit deeper look at C++ and linux
- Overview of physics
- Parallel computation