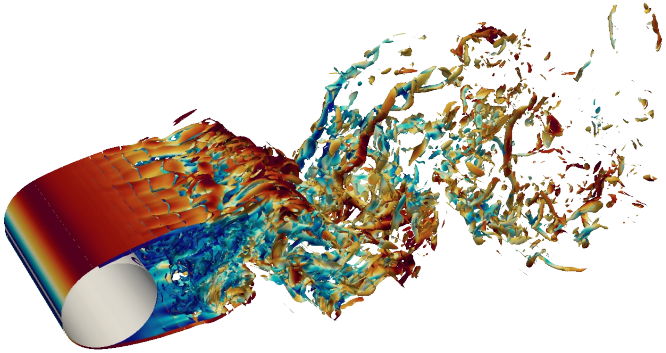
Cenaero

AS1 – LES of the cylinder at Re=3900 using ArgoDGM

4th International Workshop on High Order CFD Methods



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Fluid Dynamics Technology Leader
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Doc. ref.: PPPPPP-NS-000-00

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Convergence study Cl,Cd at t=1

- **Spatial discretisation**
  - **DG p=3,4**
  - **SLAU flux**
  - **SIPDG**
- **Temporal discretisation**
  - **BDF2: 25/50/100/200/400 time steps per convective time**
  - **ESDIRK64: 10/25/50/100 time steps per convective time**
- **Iterative strategy**
  - **Newton-GMRES with block-Jacobi**
  - **Jacobian freezing**
    - BDF2: 25 time steps
    - ESDIRK: 5 time steps
  - **Convergence 10^{-4}**
    - 3-5 Newton steps
    - 10-30 Krylov vectors

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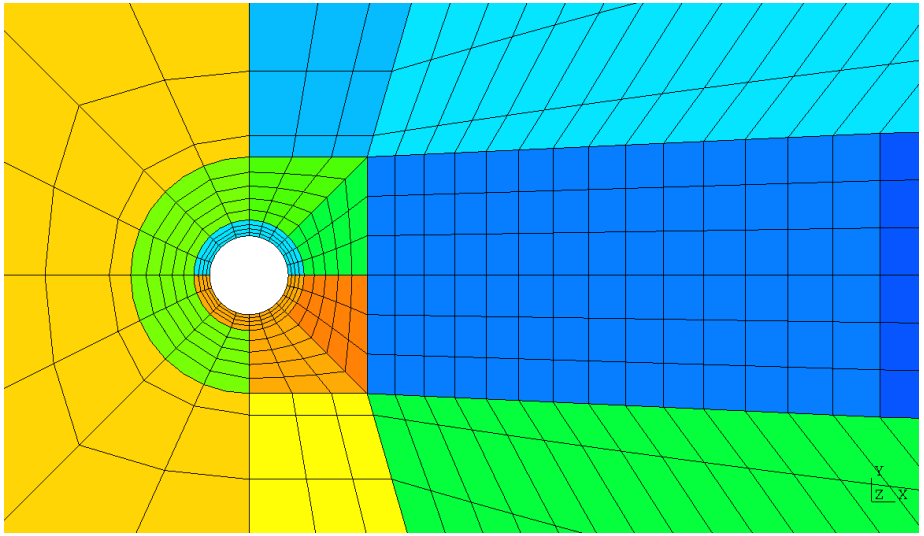
Mesh setup

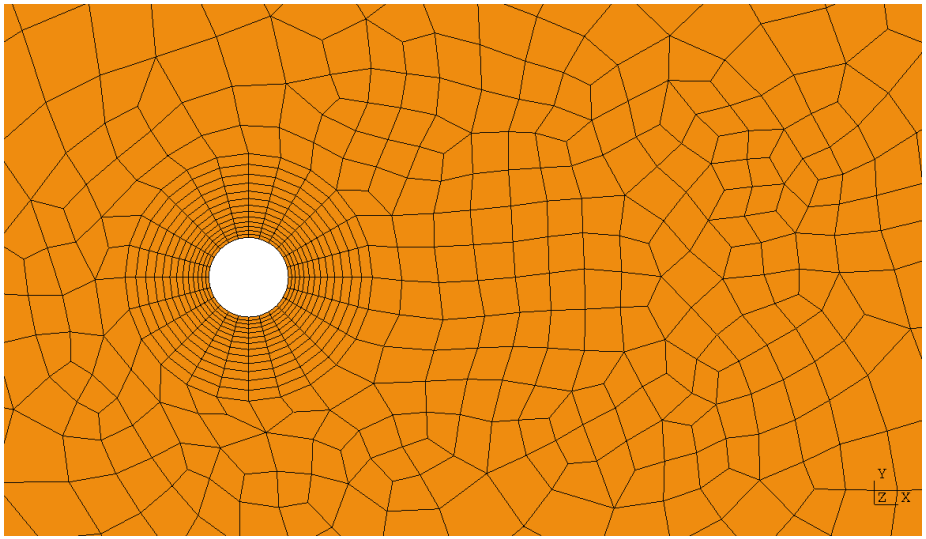
- **Block-structured (q=3)**

	elements	dof	
		p=3	p=4
coarse	4998	319872	624750
medium	53910	3450240	6738750
fine	431280	27601920	53910000



- **Unstructured (q=2)**

	elements	dof	
		p=3	p=4
coarse	8344	534016	1043000
medium	70800	4531200	8850000
fine	500430	32027520	62553750



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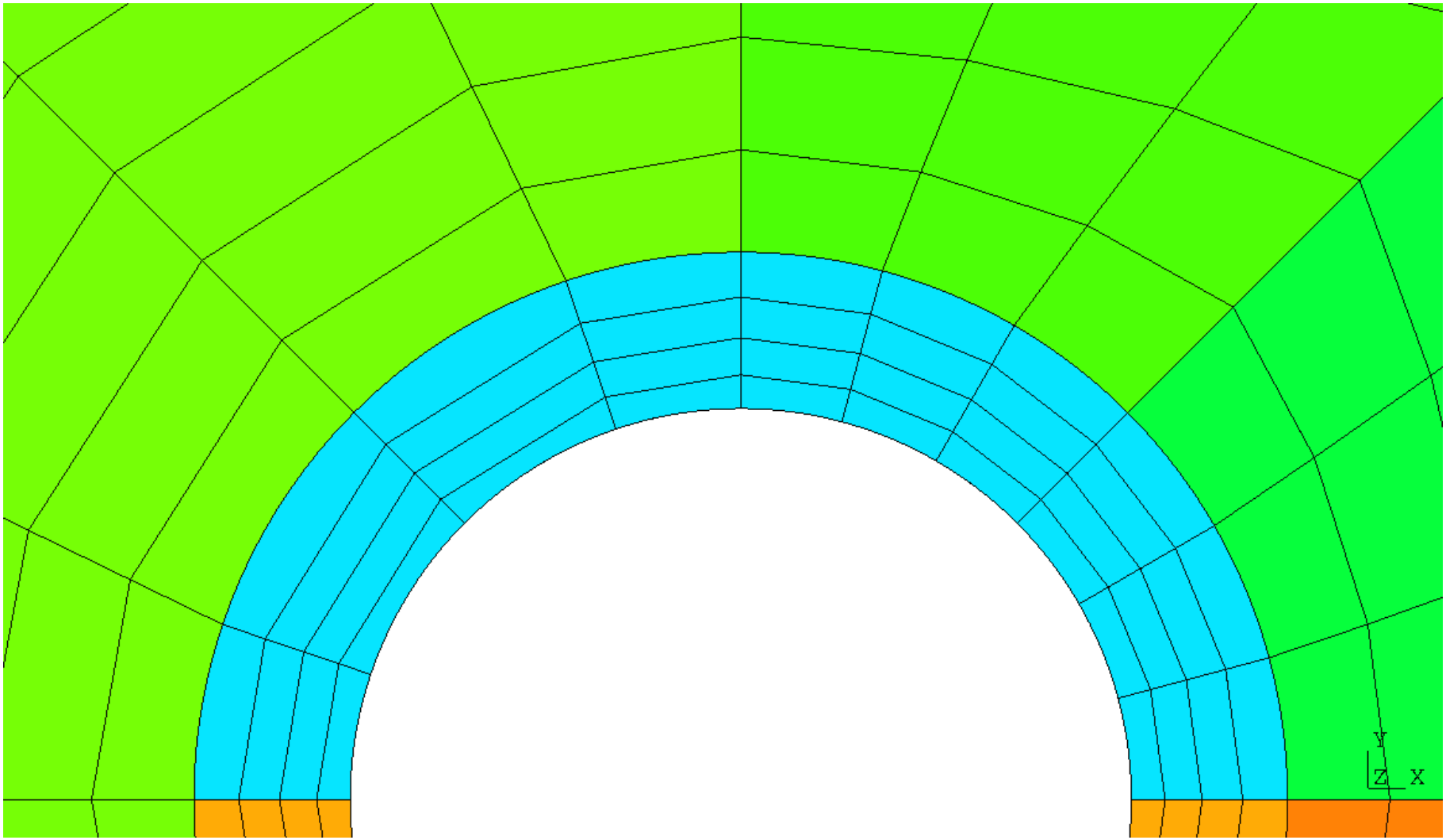
Comparison cylinder



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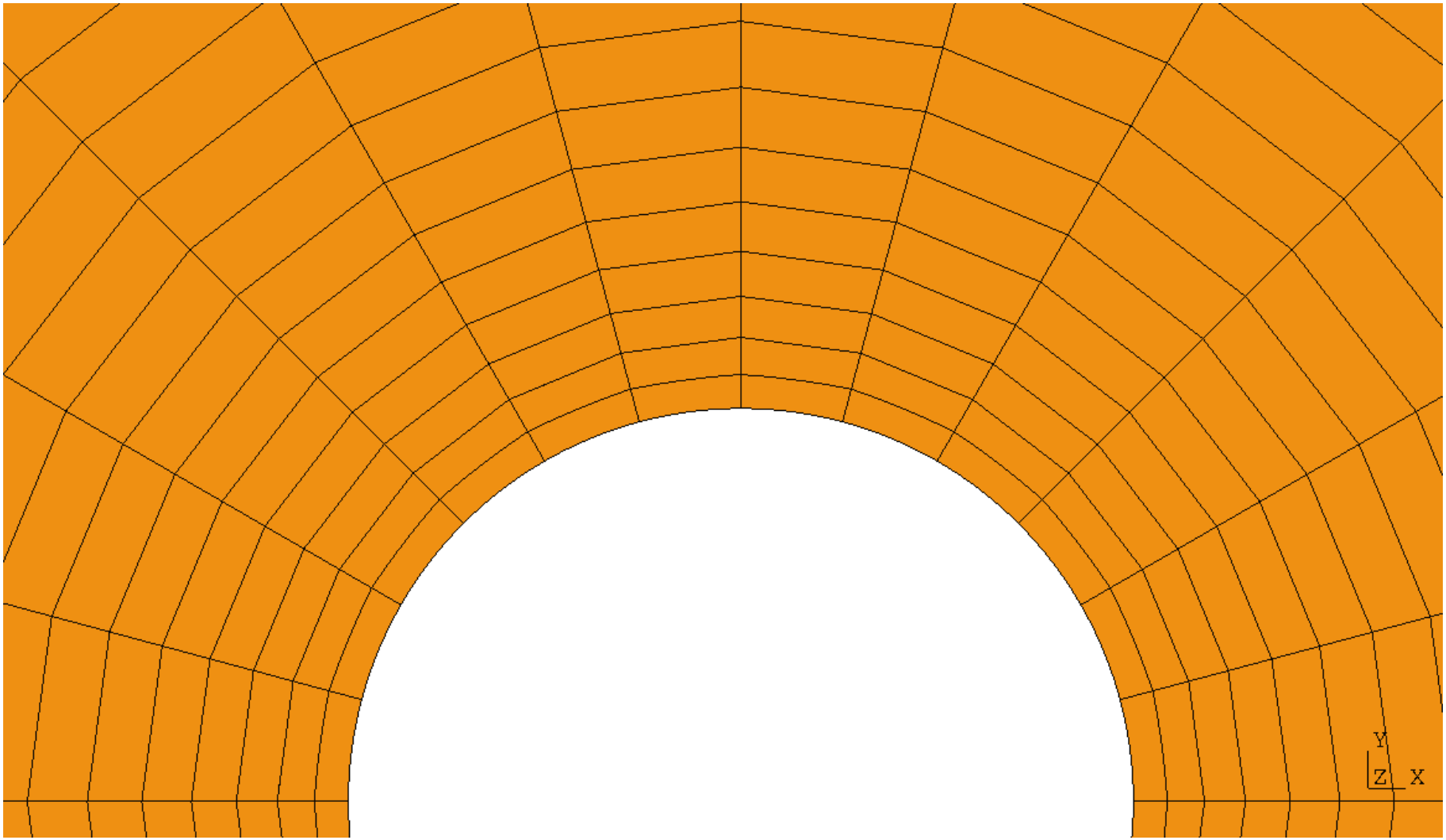
Comparison cylinder



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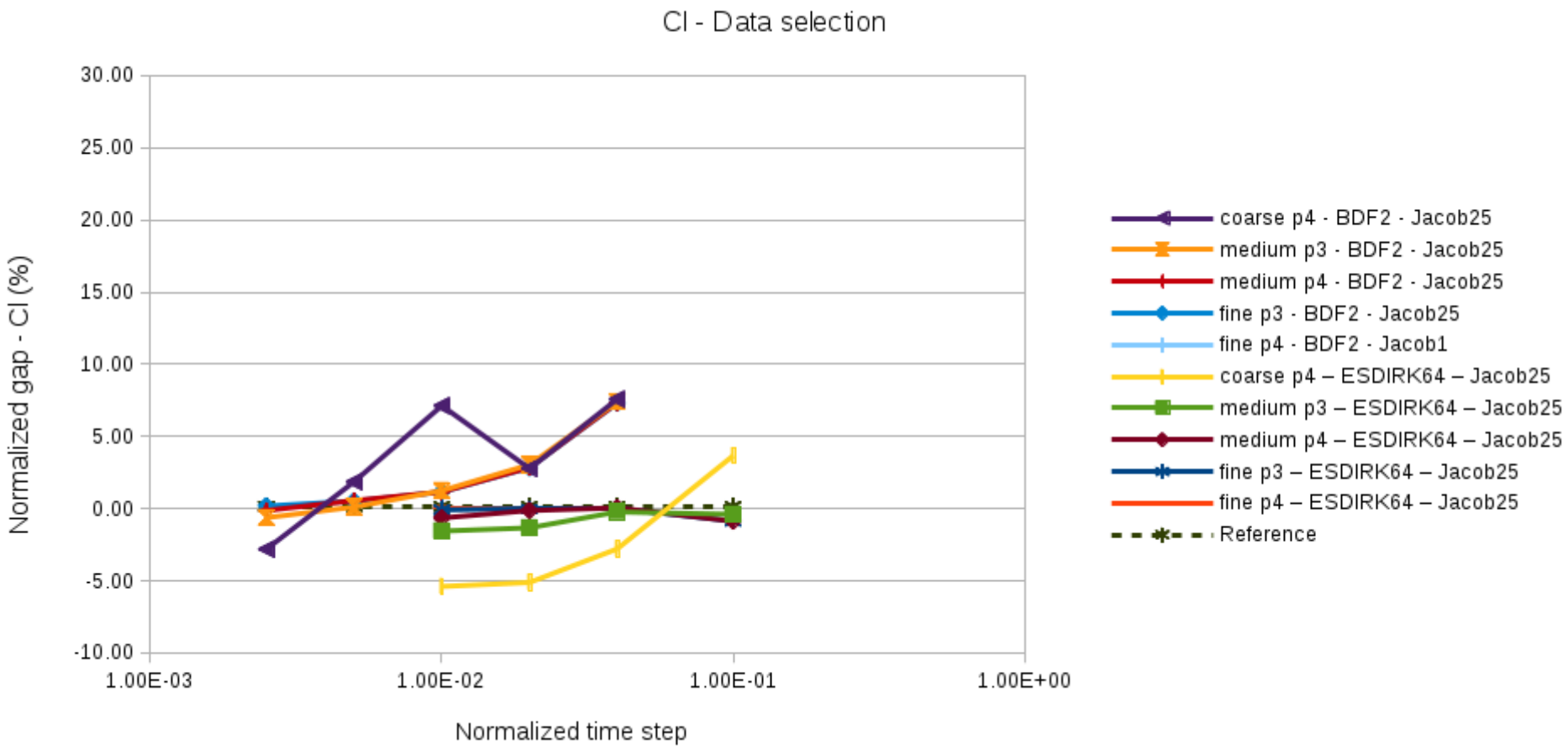
Space/time convergence of Cl
Workshop meshes



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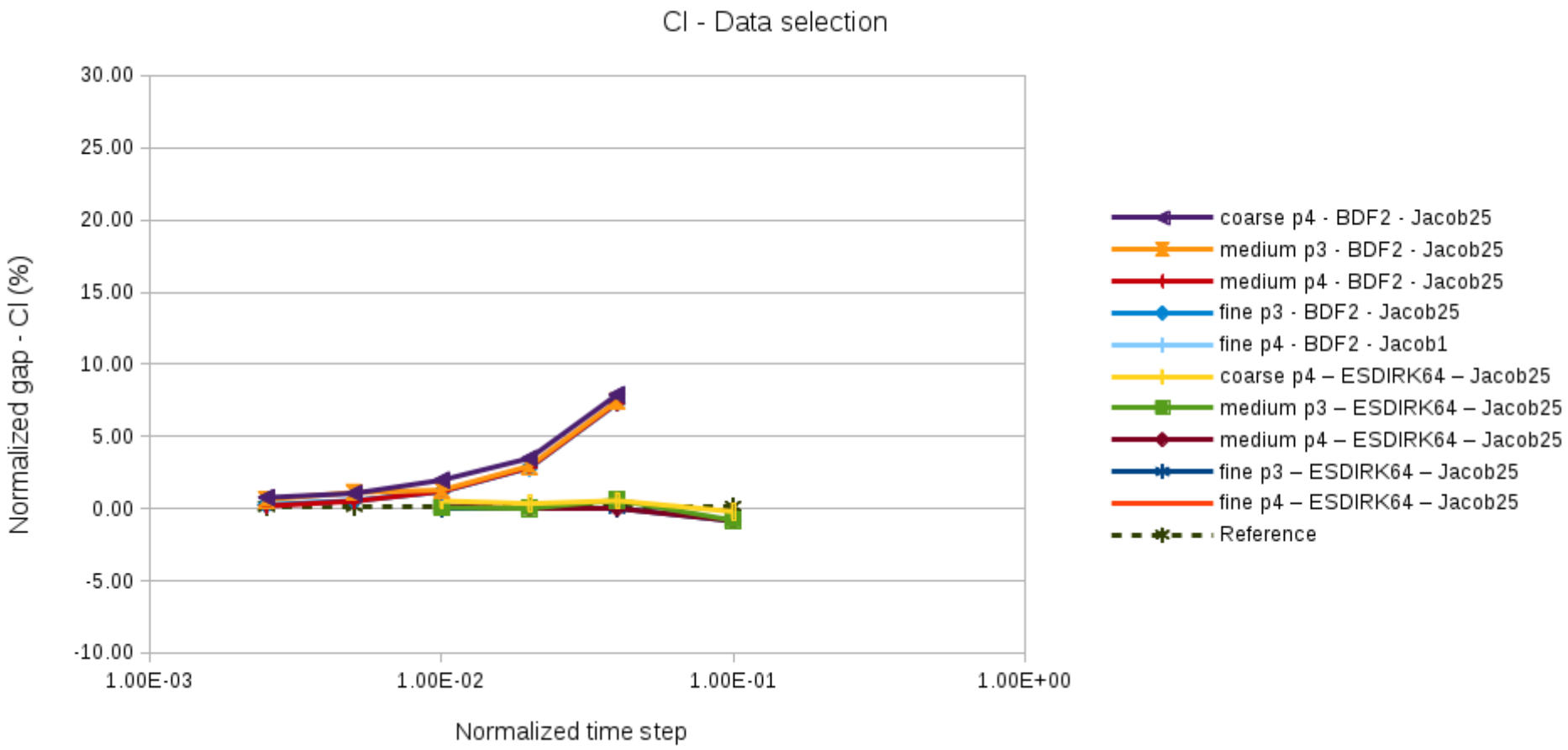
Space/time convergence of Cl
Gmsh meshes



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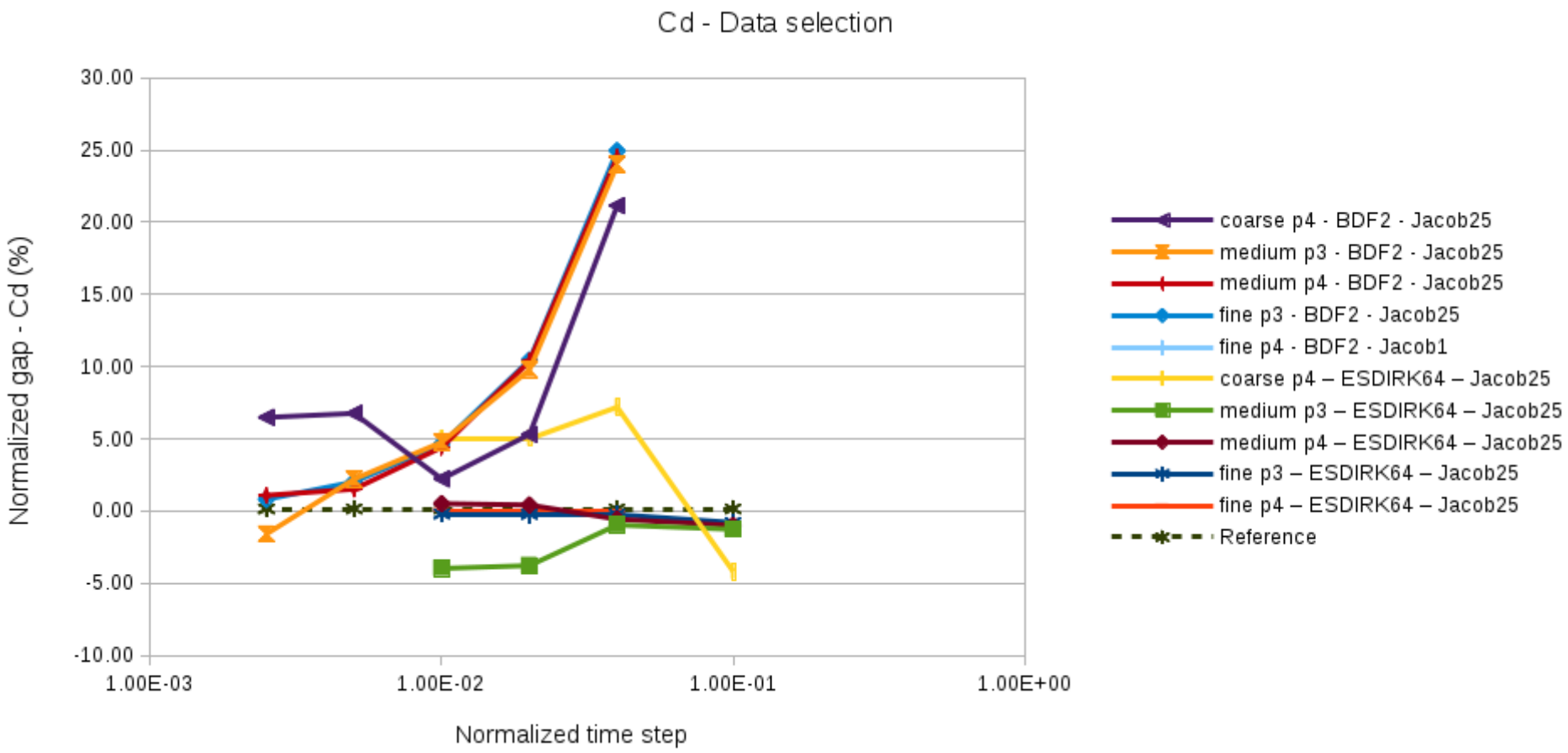
Space/time convergence of Cd
Workshop meshes



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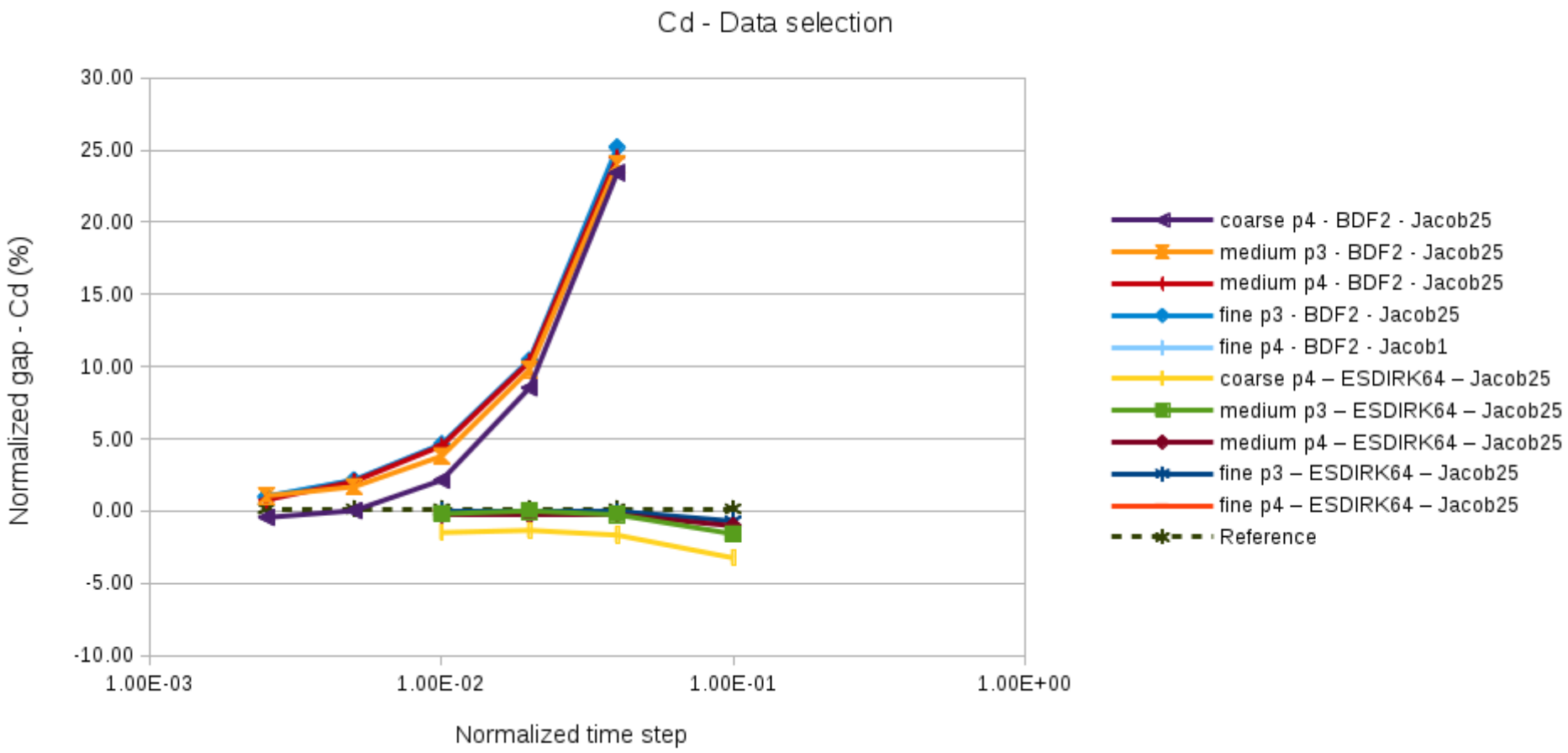
Space/time convergence of Cd
Gmsh meshes



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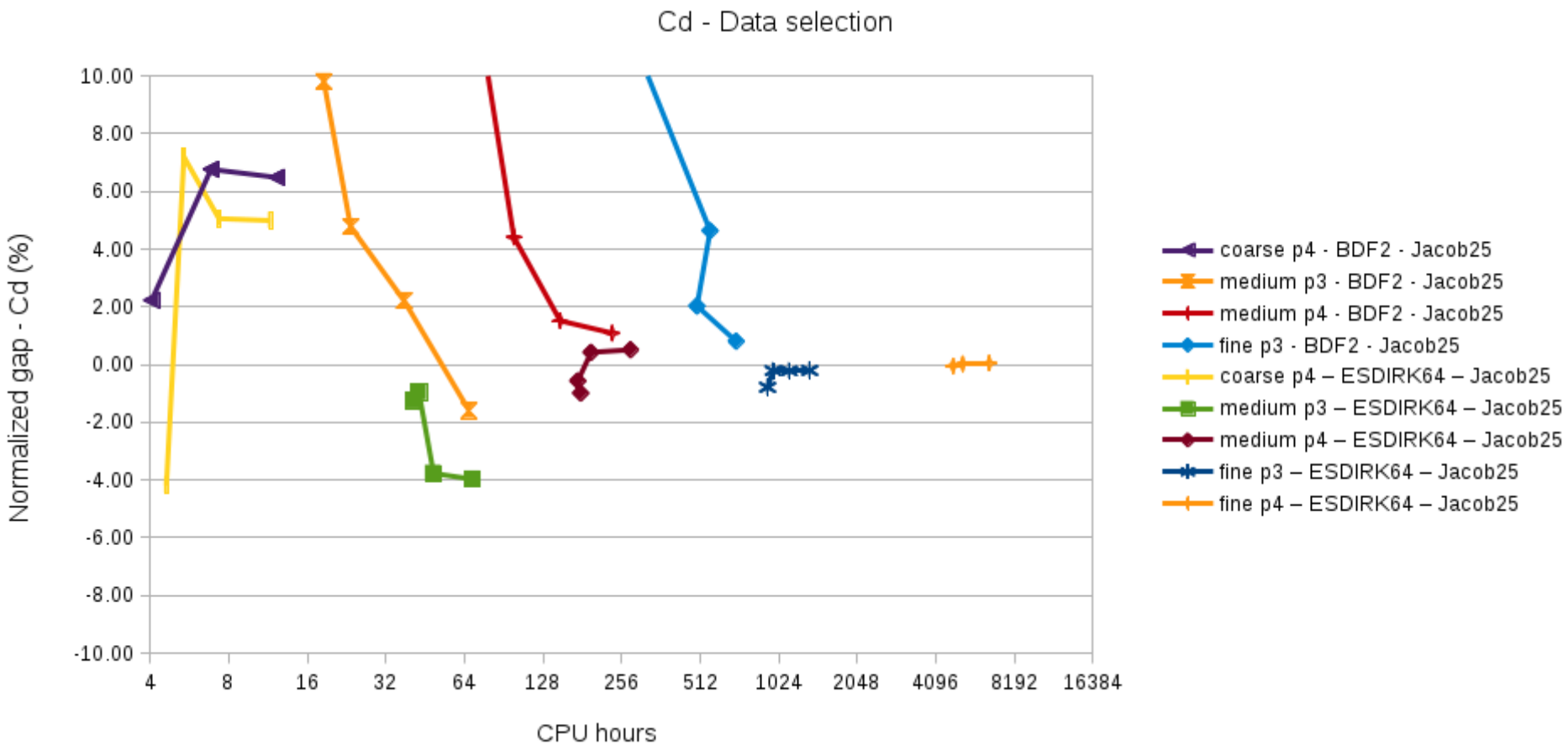
Effort convergence of Cd
Workshop meshes



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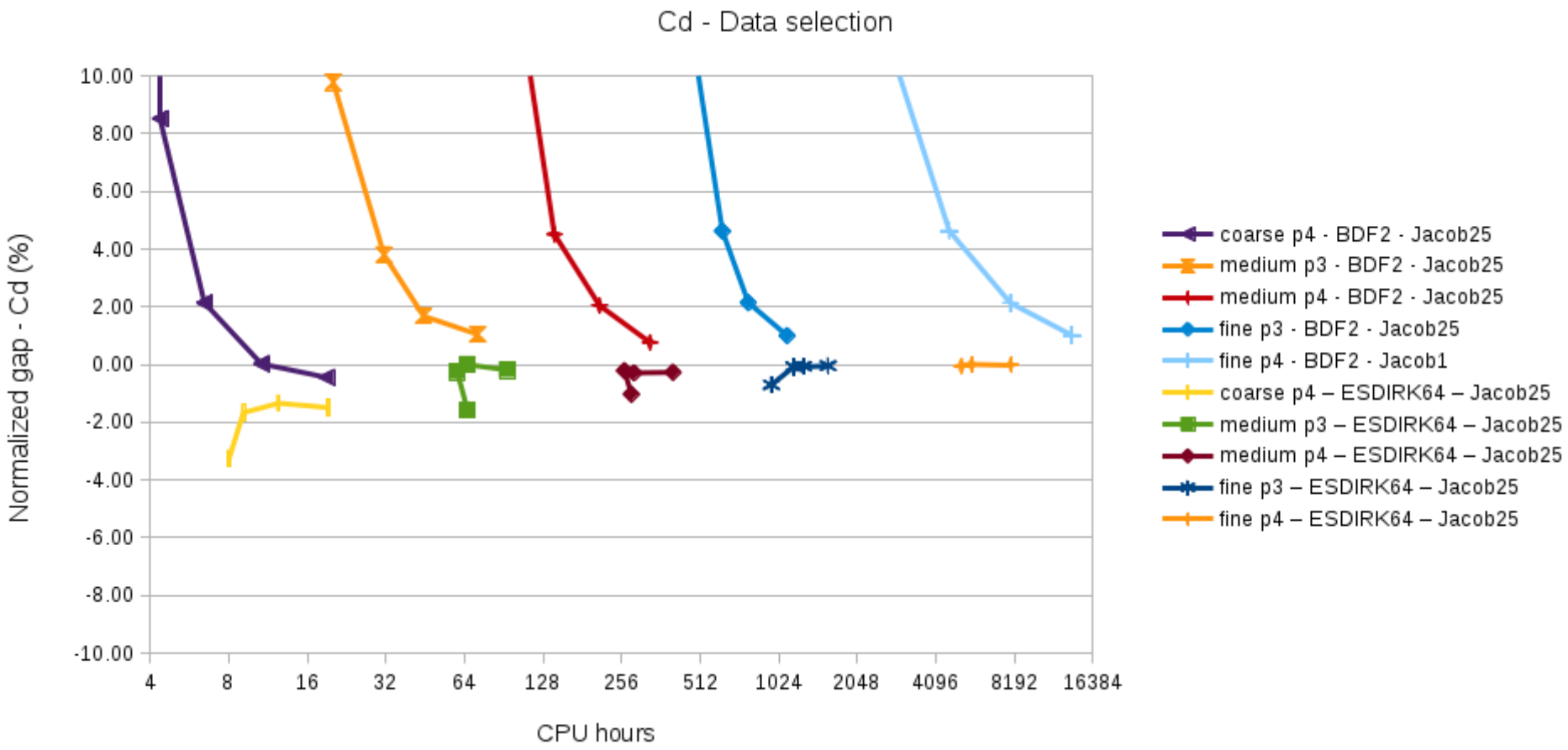
Effort convergence of CI
Gmsh meshes



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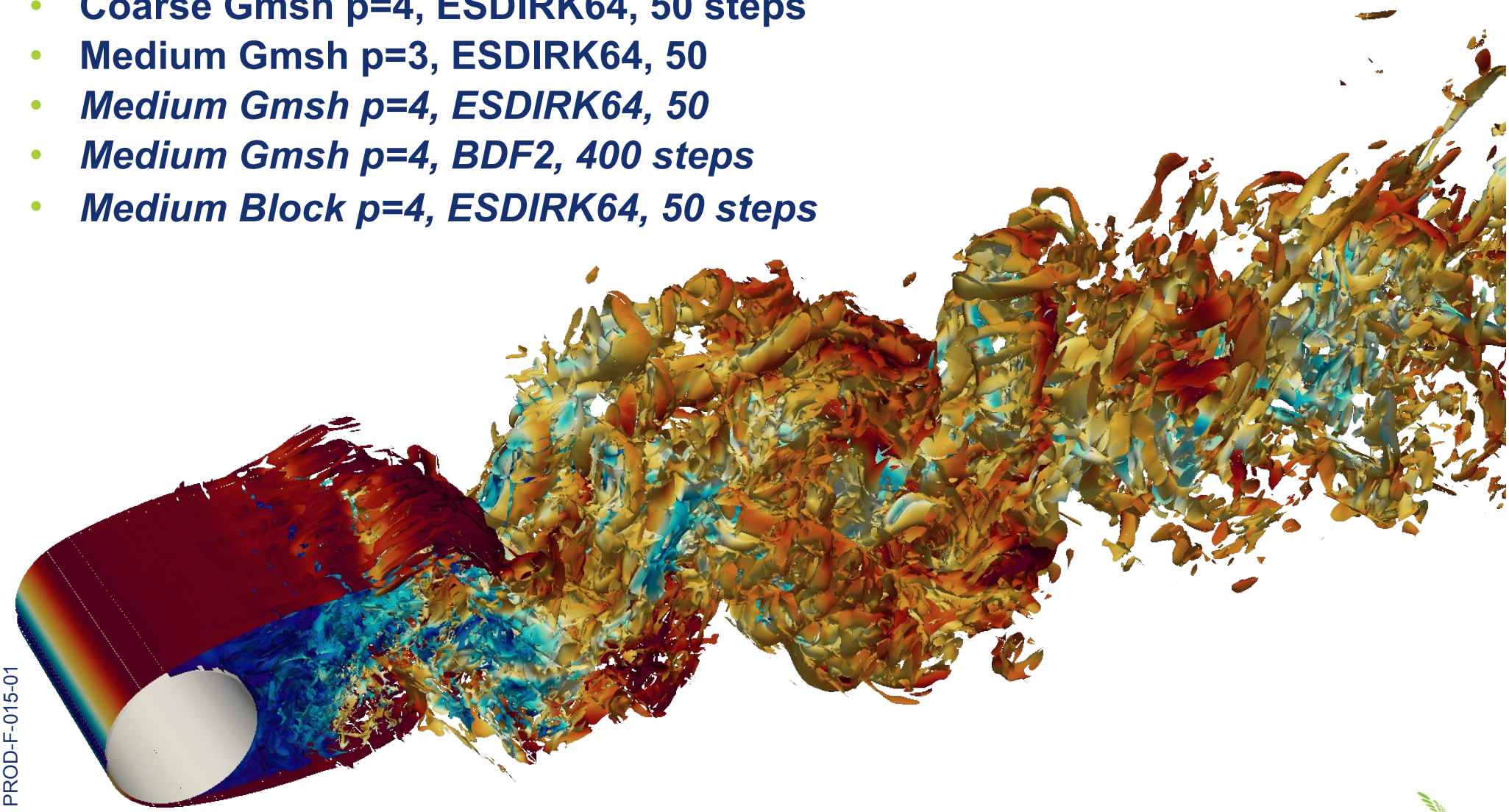
Computational configurations

Within 1% of reference Cd

- **Coarse Gmsh p=4, ESDIRK64, 50 steps**
- **Medium Gmsh p=3, ESDIRK64, 50**
- ***Medium Gmsh p=4, ESDIRK64, 50***
- ***Medium Gmsh p=4, BDF2, 400 steps***
- ***Medium Block p=4, ESDIRK64, 50 steps***



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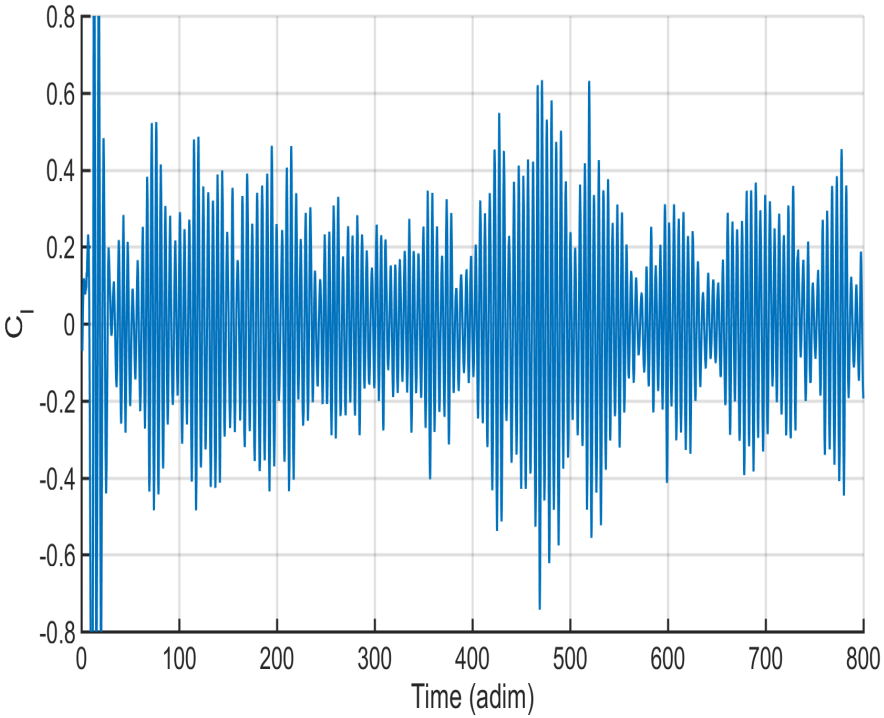
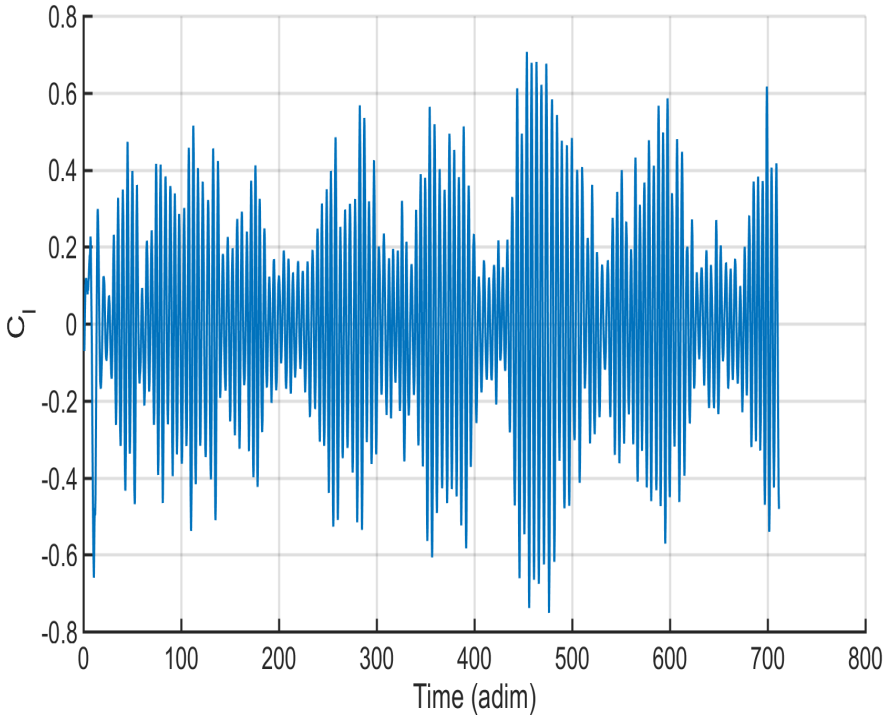
Statistical convergence
Lift force



Medium p=3



Coarse p=4

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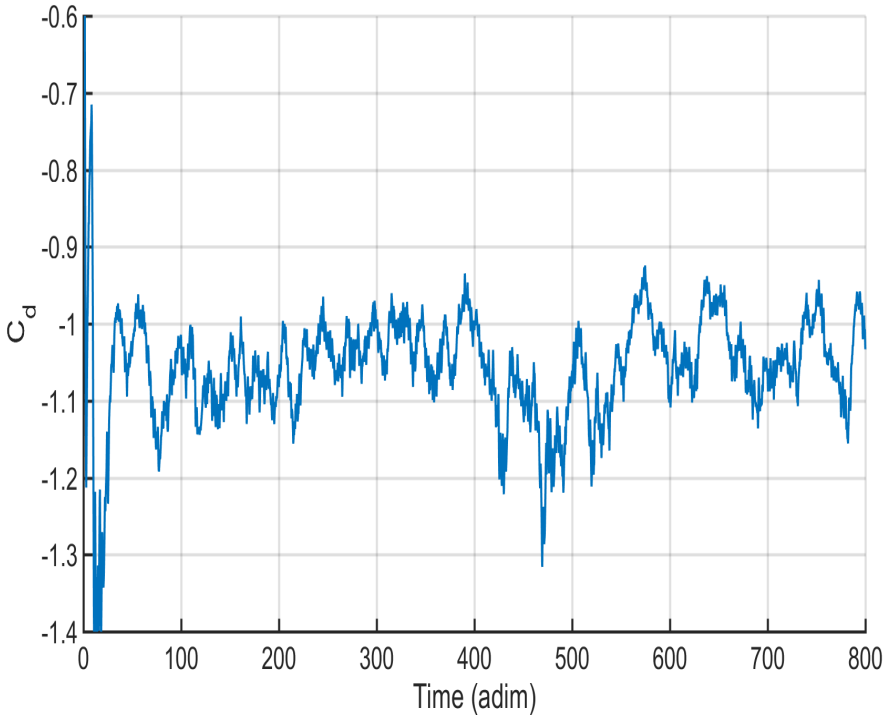
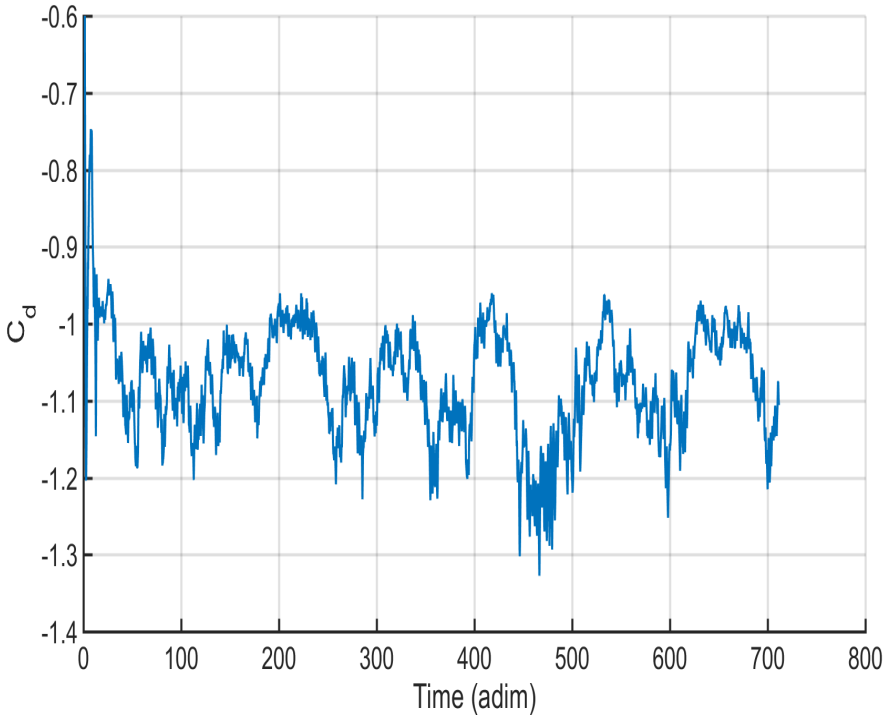
Statistical convergence
Lift force



Medium p=3



Coarse p=4

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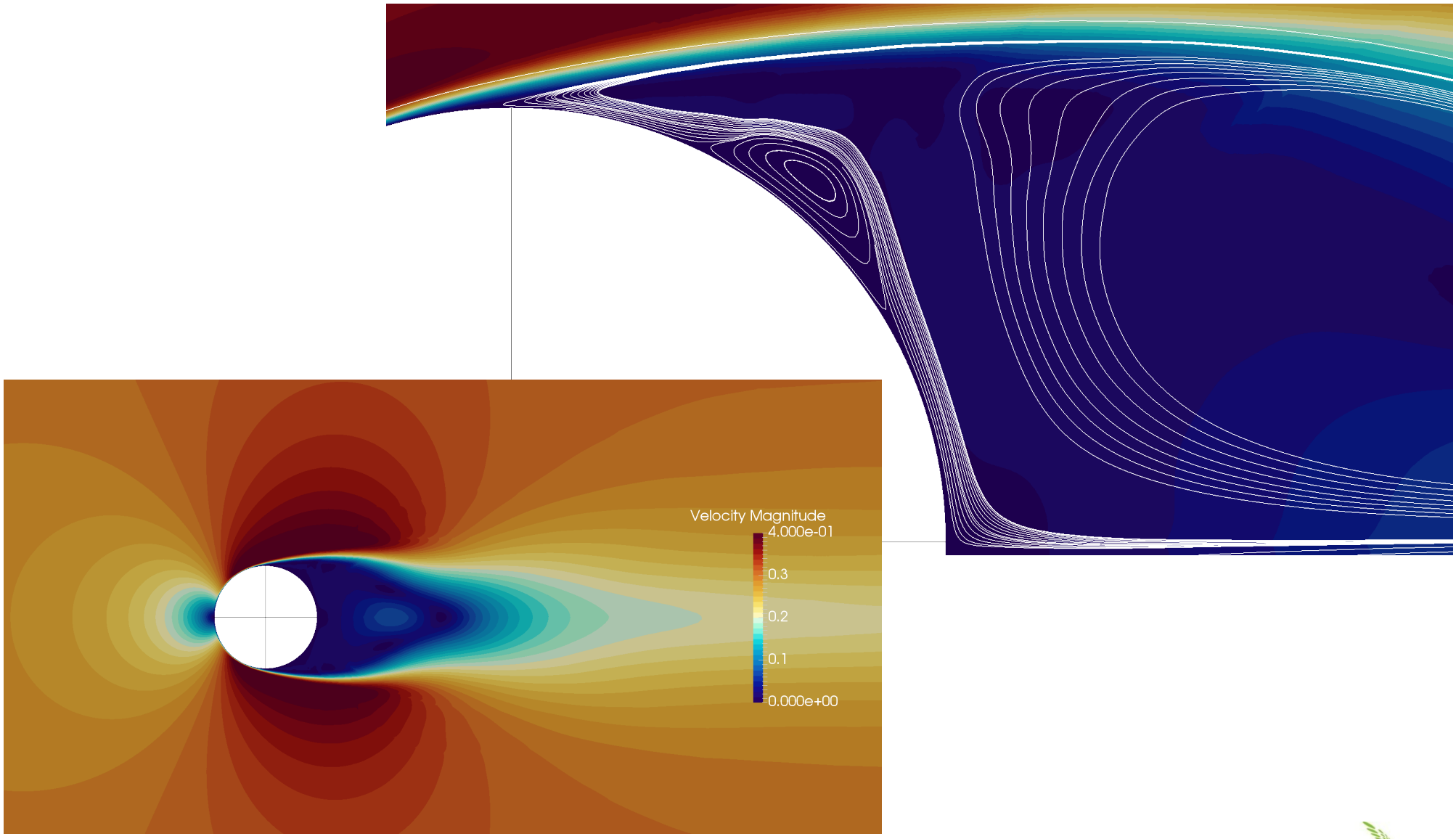
Global recirculation pattern – coarse p=4



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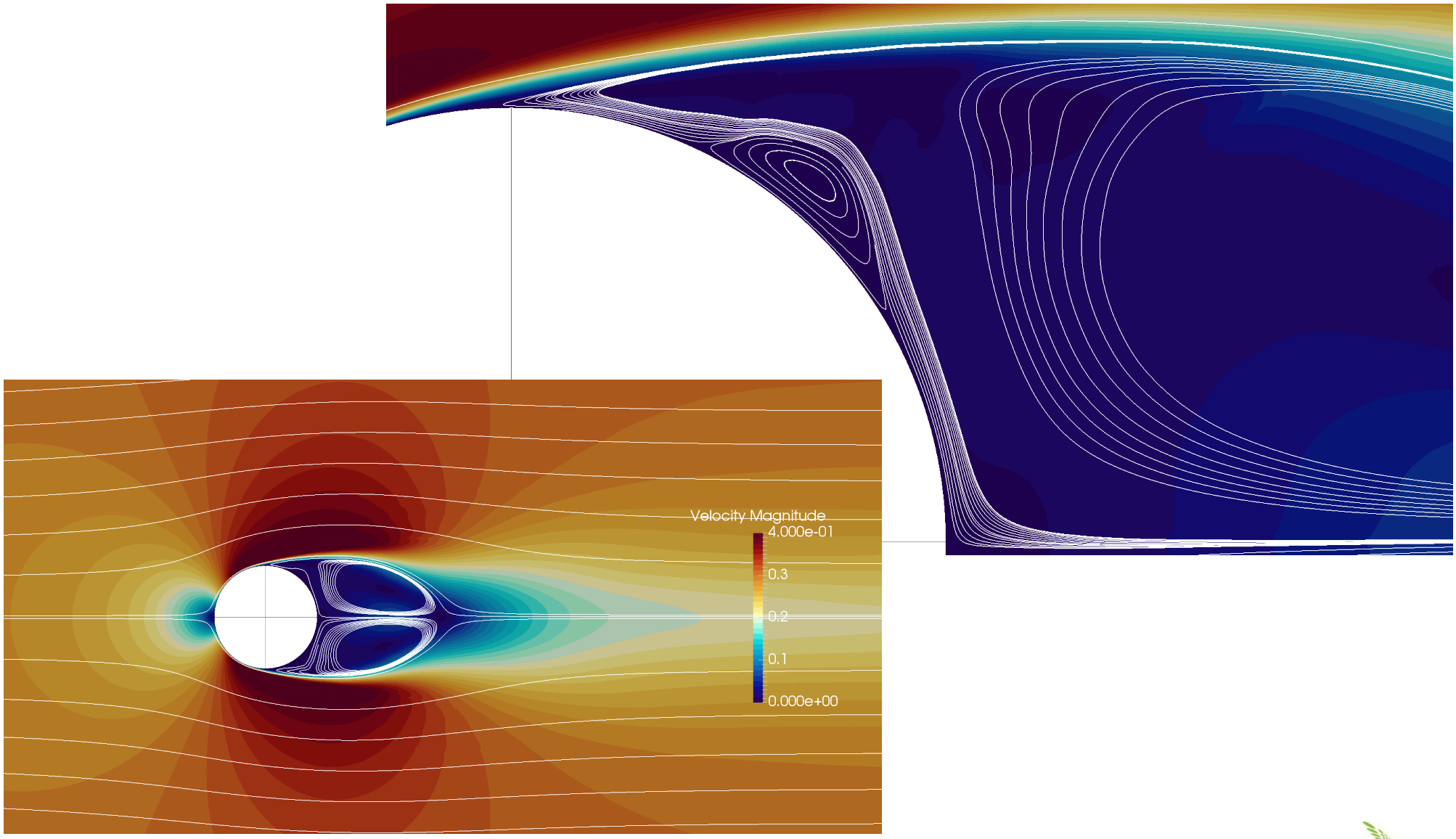
Global recirculation pattern – coarse p=4



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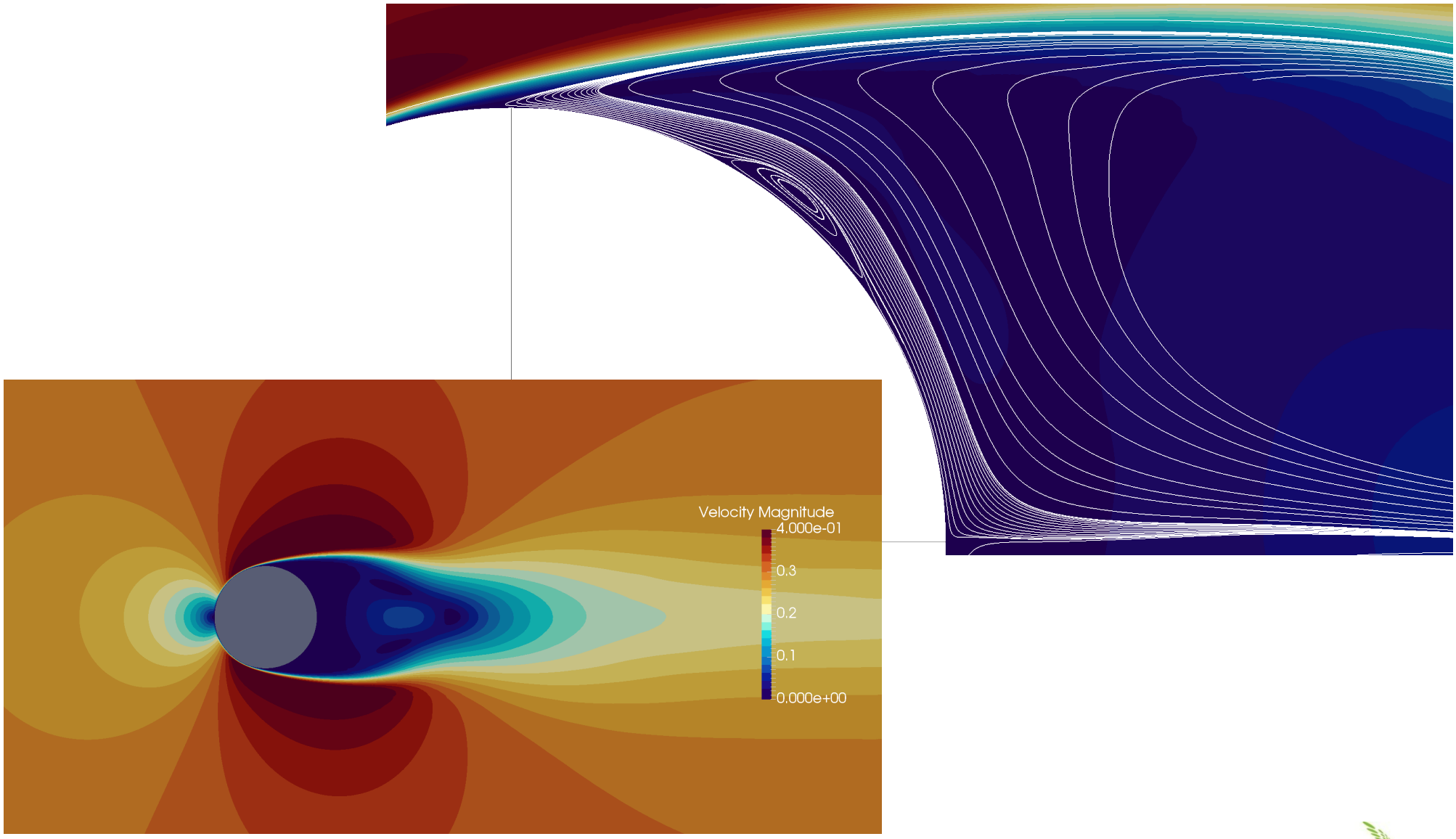
Global recirculation pattern – medium p=3



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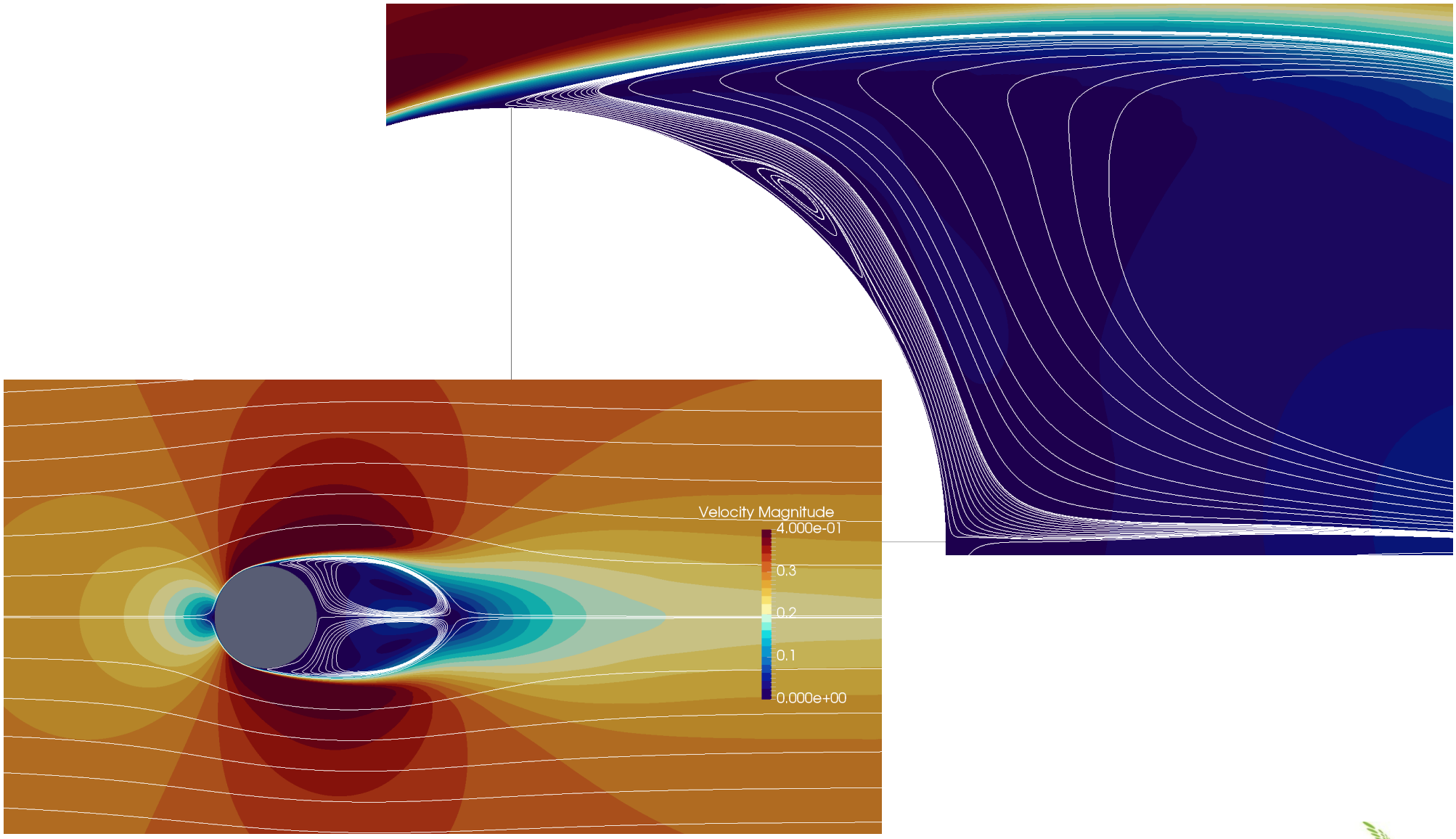
Global recirculation pattern – medium p=3



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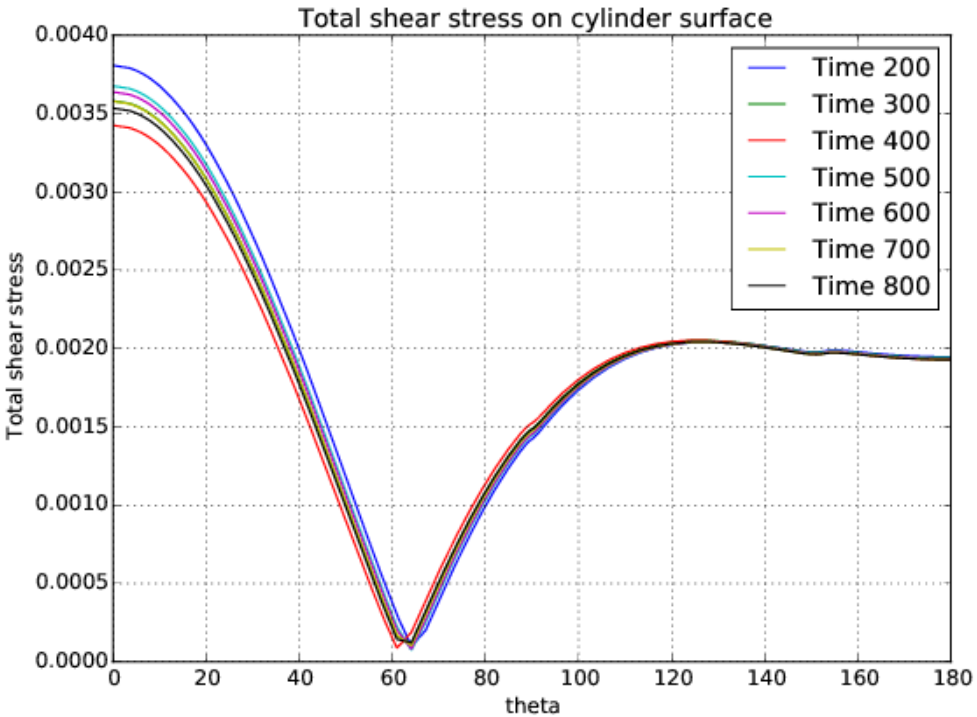
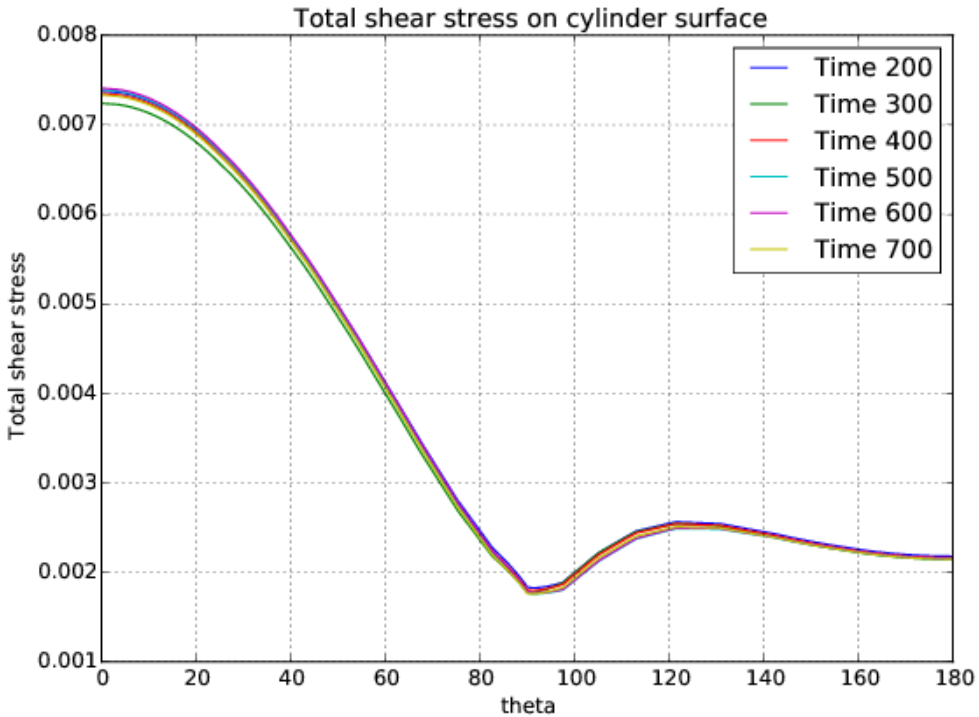
Statistical convergence
Surface shear stress distribution



Medium p=3



Coarse p=4

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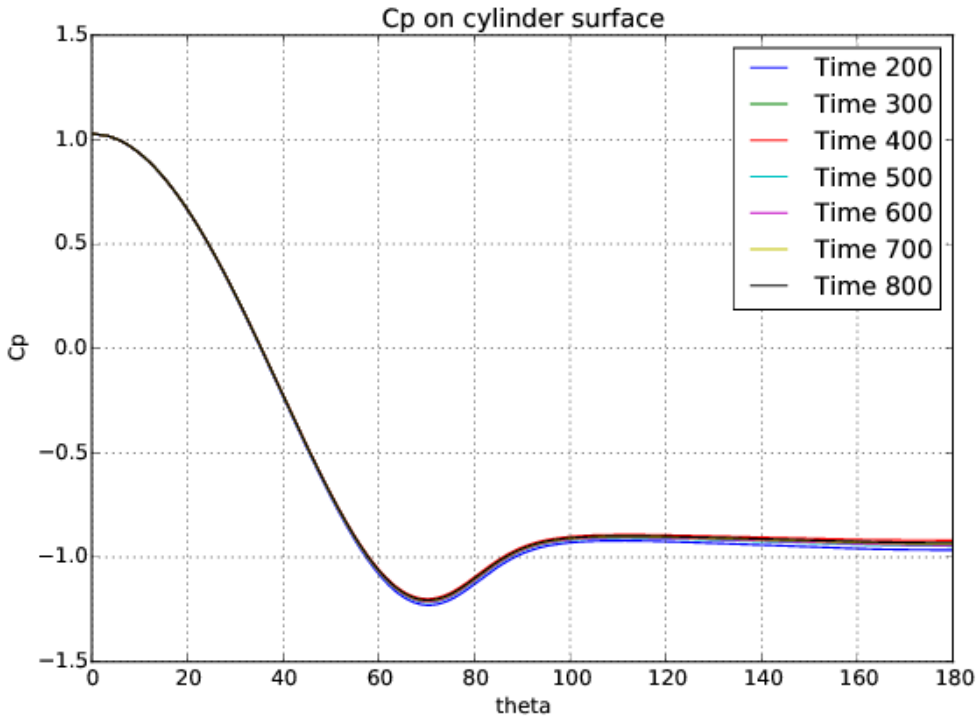
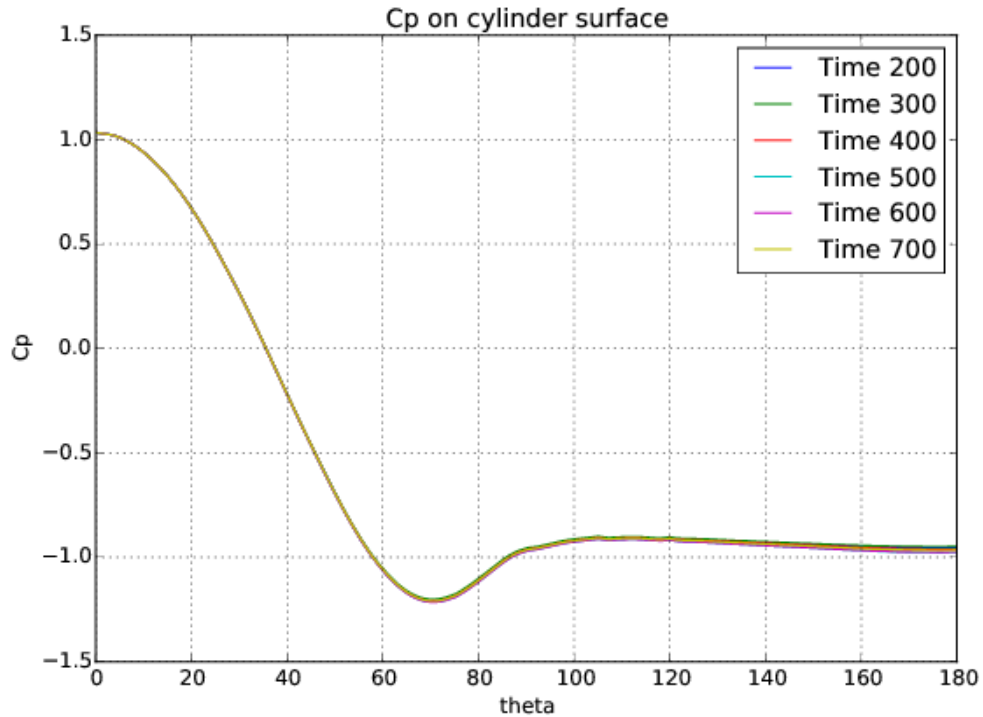
Statistical convergence
Surface pressure distribution



Medium p=3



Coarse p=4

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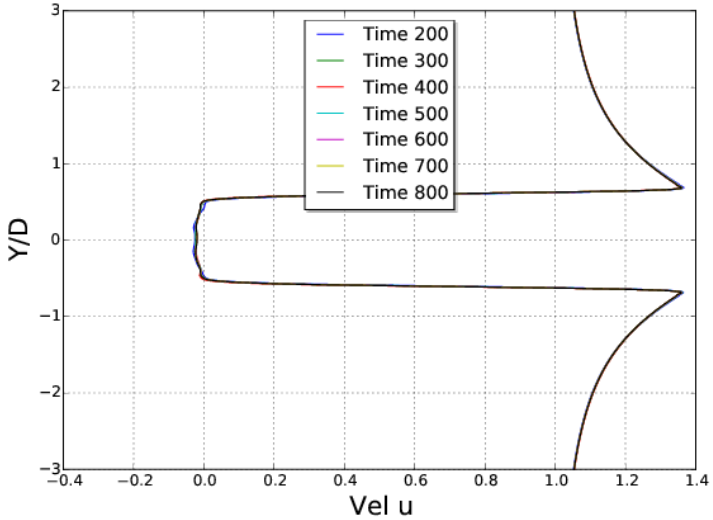
Velocity in the wake

Medium p=3



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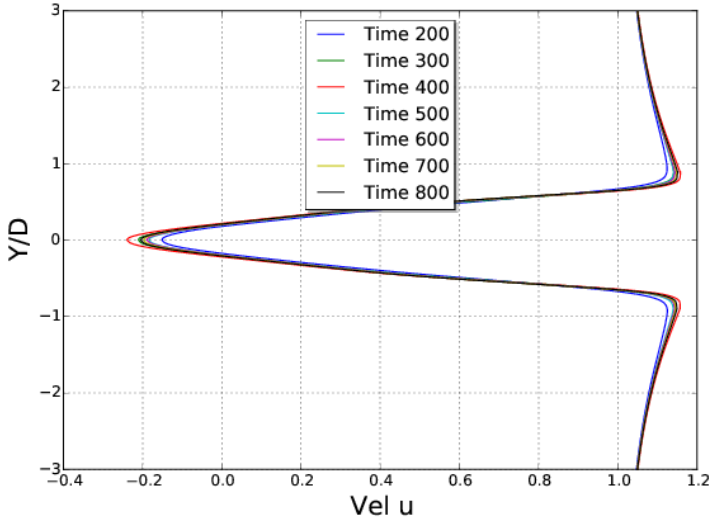

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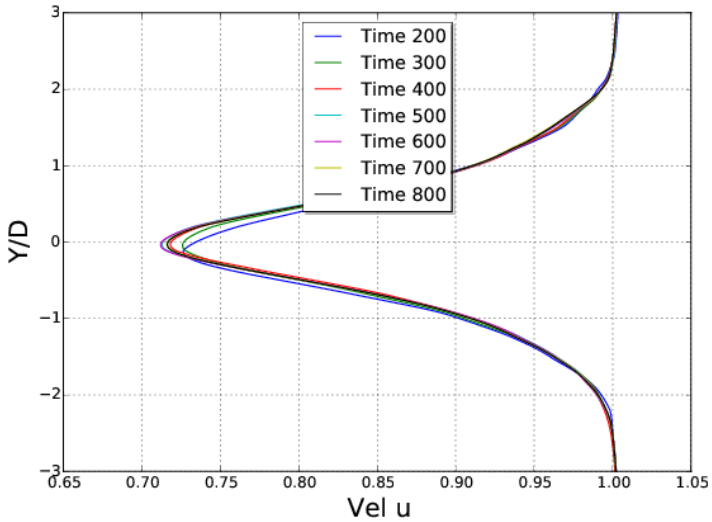
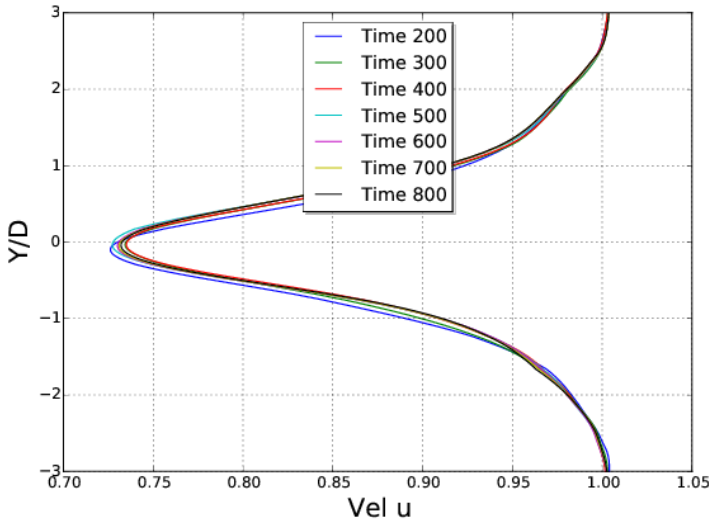


x=5D



x=10D

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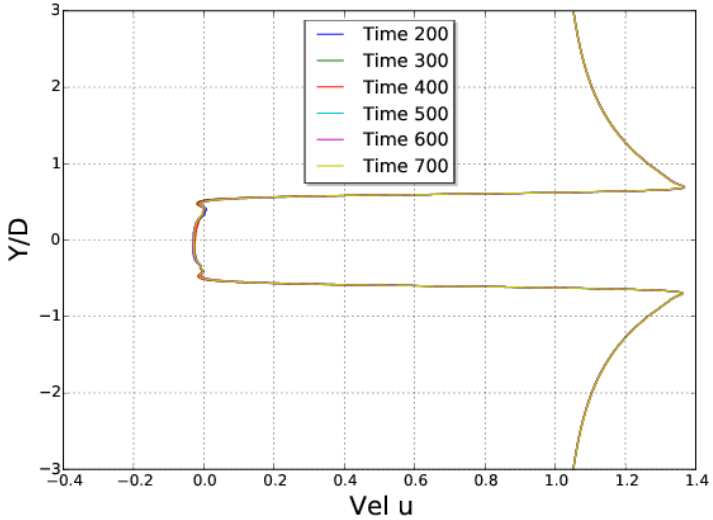
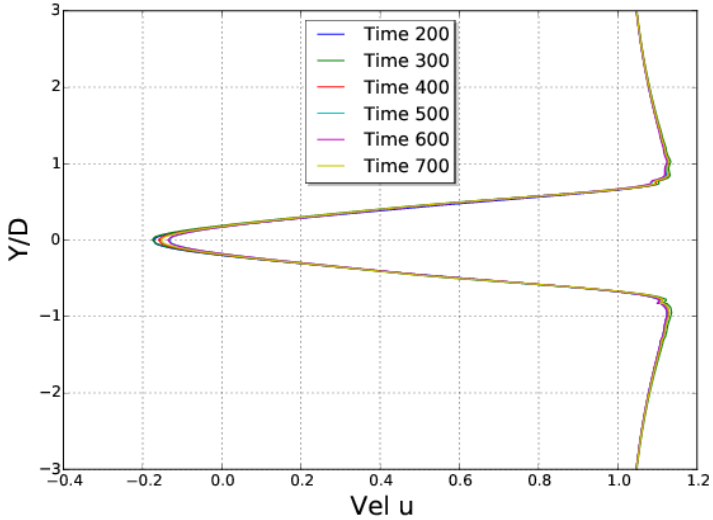
Cenaero

Velocity in the wake

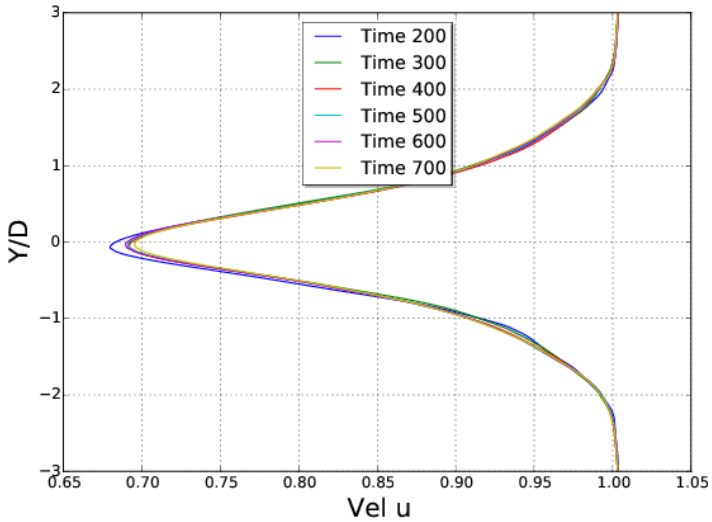
Coarse p=4



x=1D



x=1.54D



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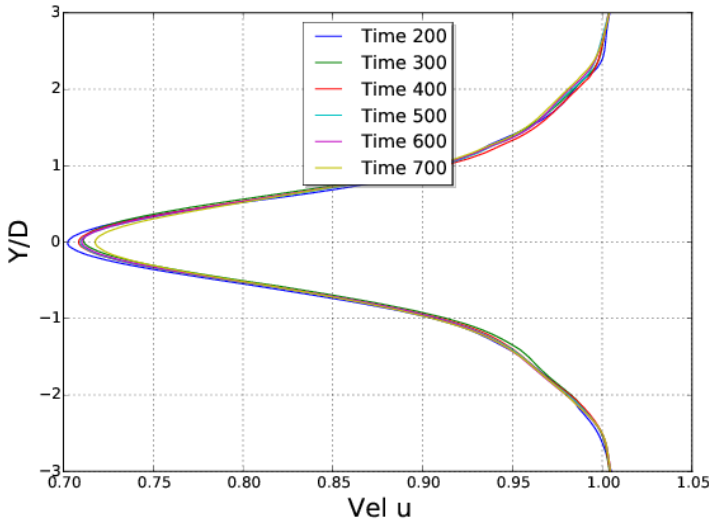

x=10D

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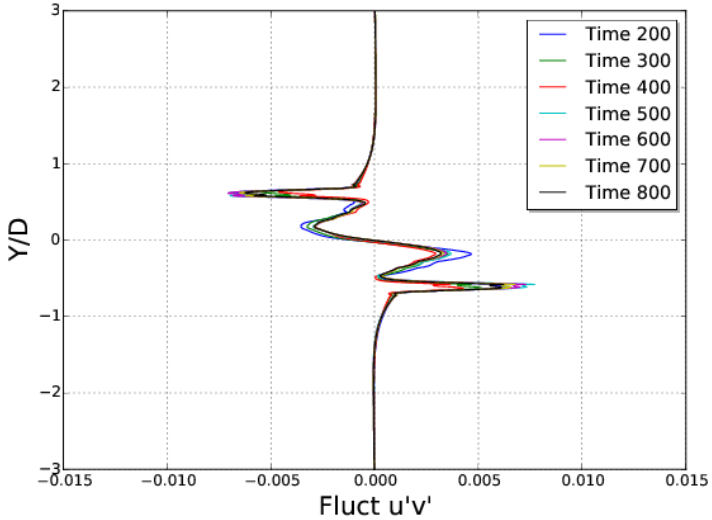
Turbulent shear stress <u'v'> in the wake

Medium p=3



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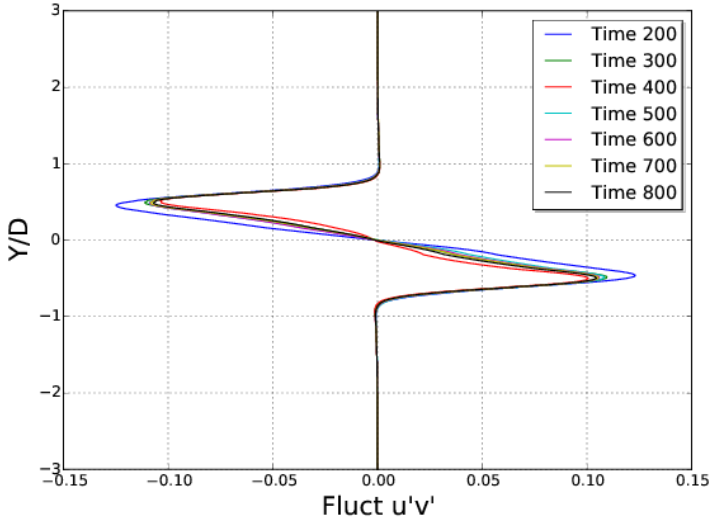

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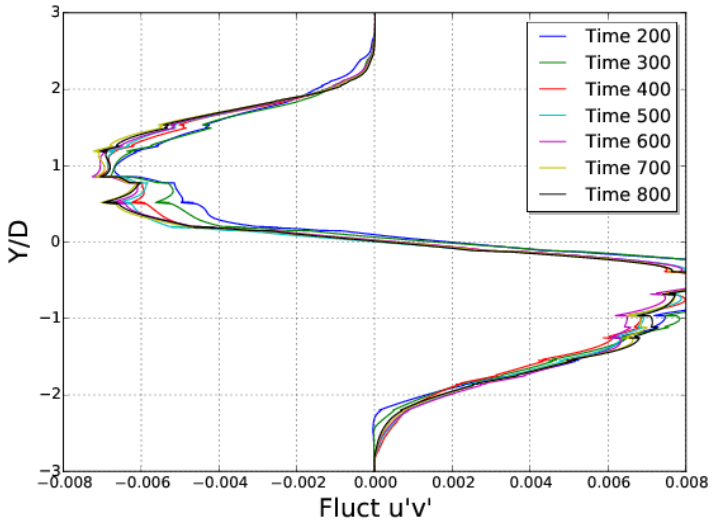
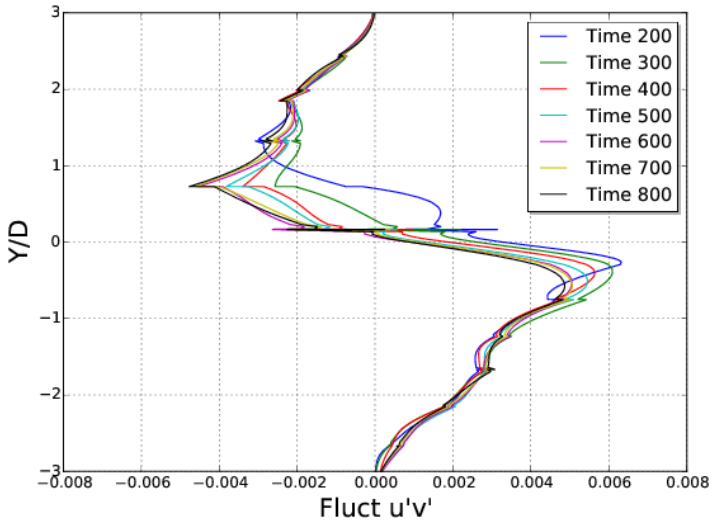


x=5D



x=10D

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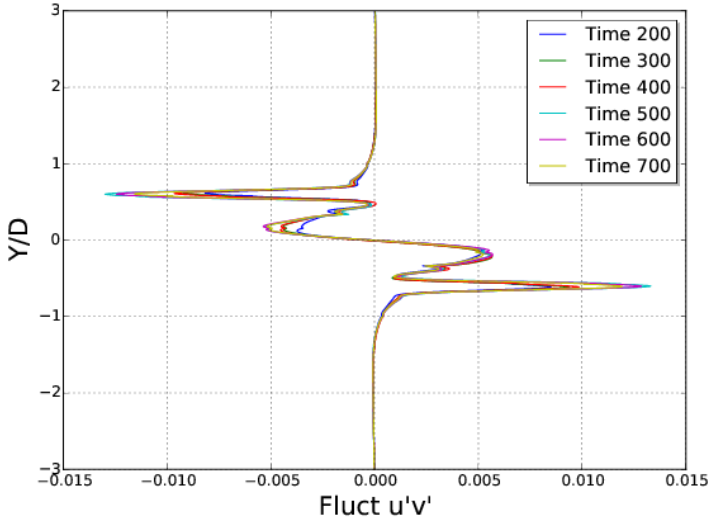
Cenaero

Turbulent shear stress <u'v'> in the wake

Coarse p=4



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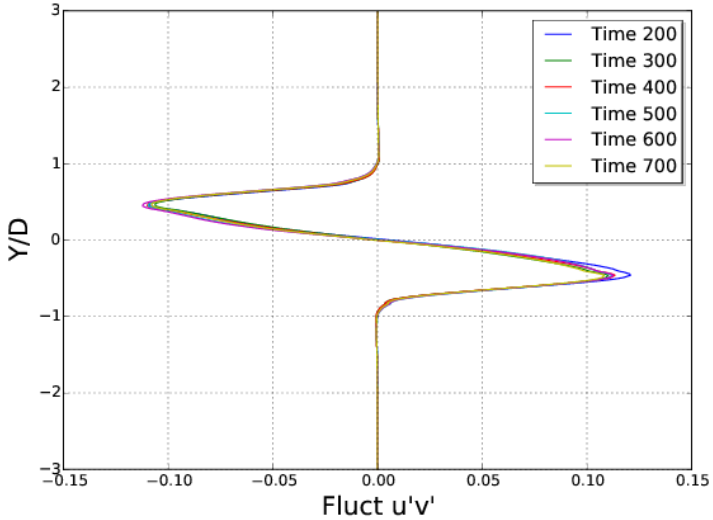

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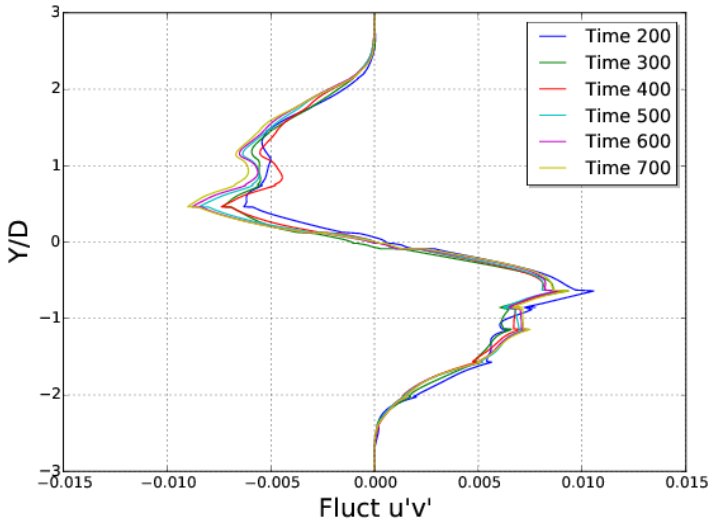

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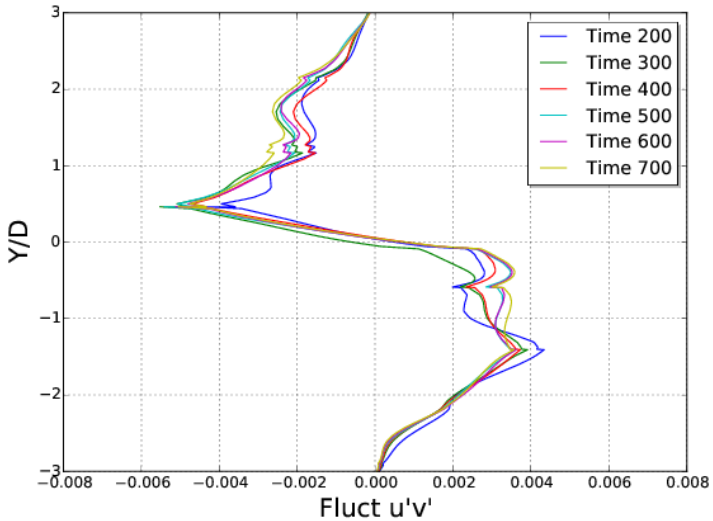

x=10D

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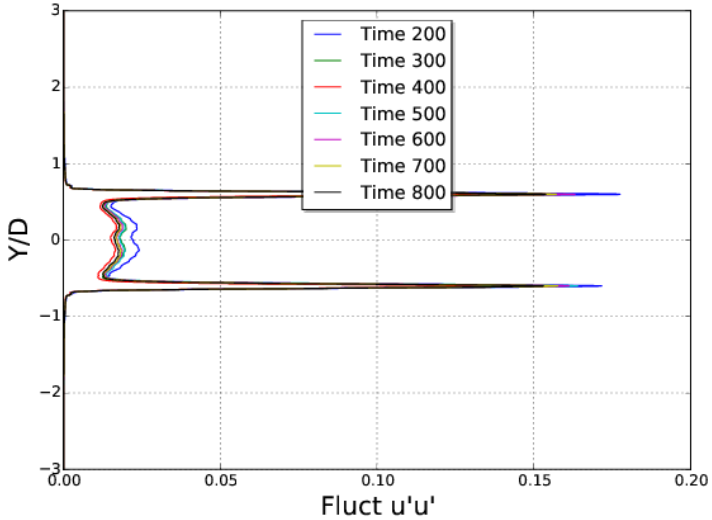
Turbulent main stress <u'u'> in the wake

Medium p=3



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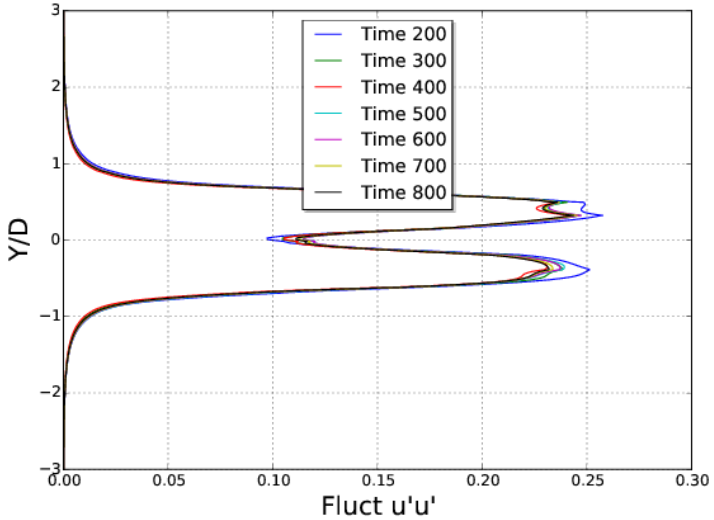

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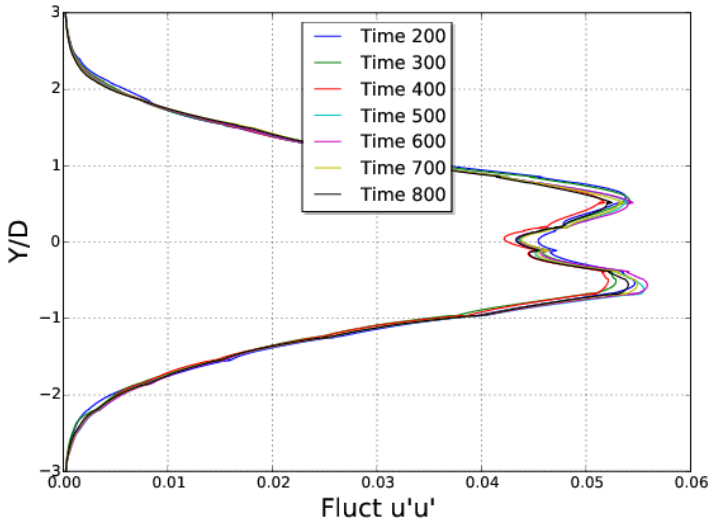
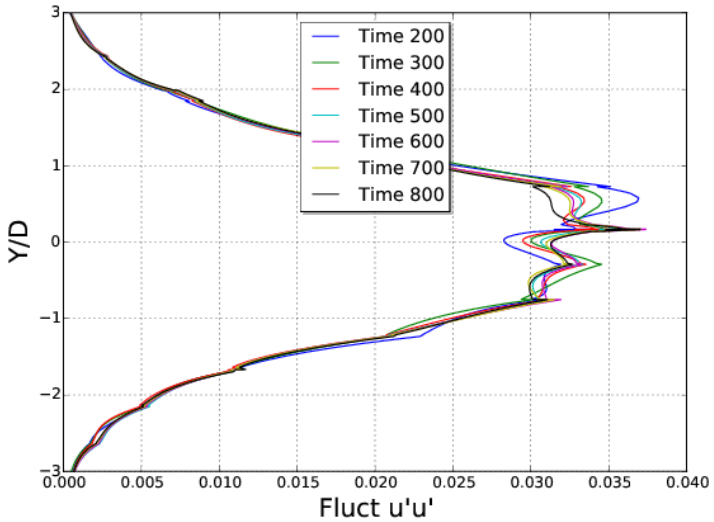


x=5D



x=10D

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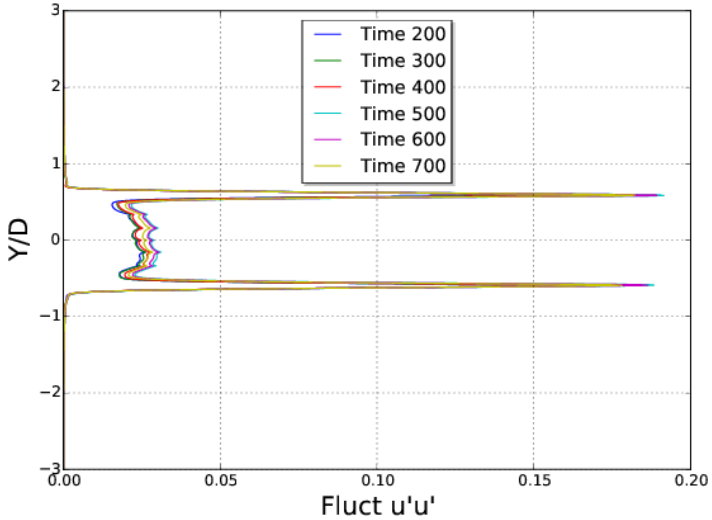
Cenaero

Turbulent main stress <u'u'> in the wake

Coarse p=4



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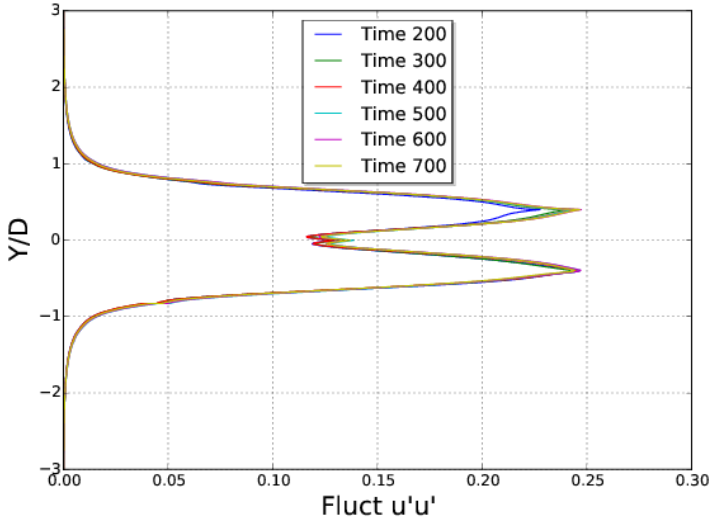

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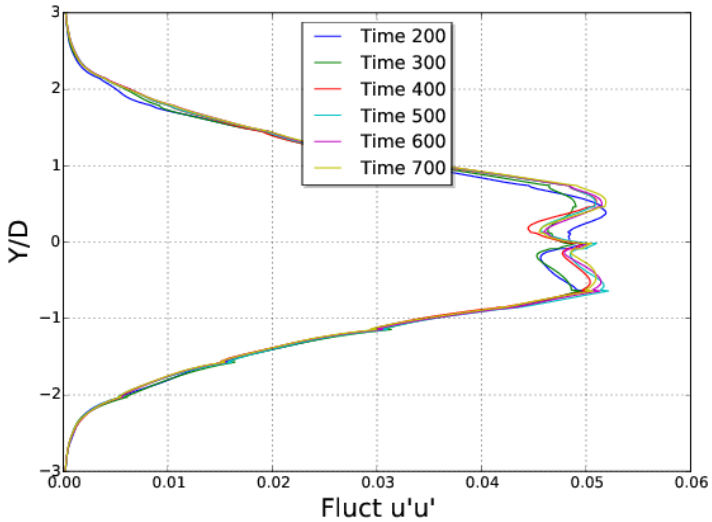
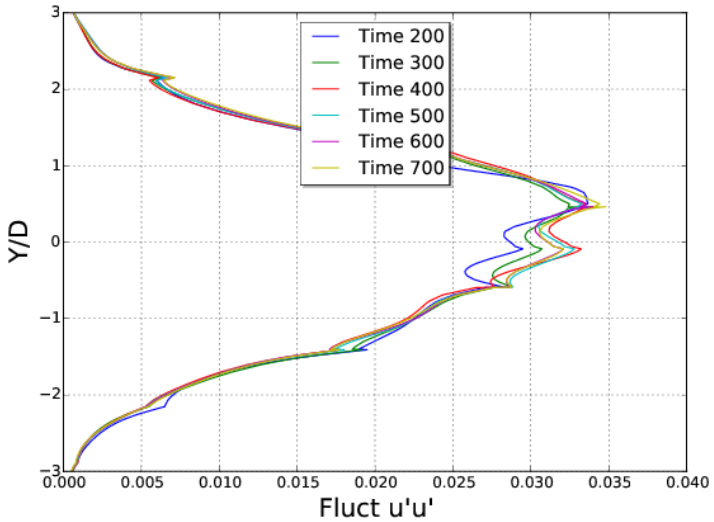


x=5D



x=10D

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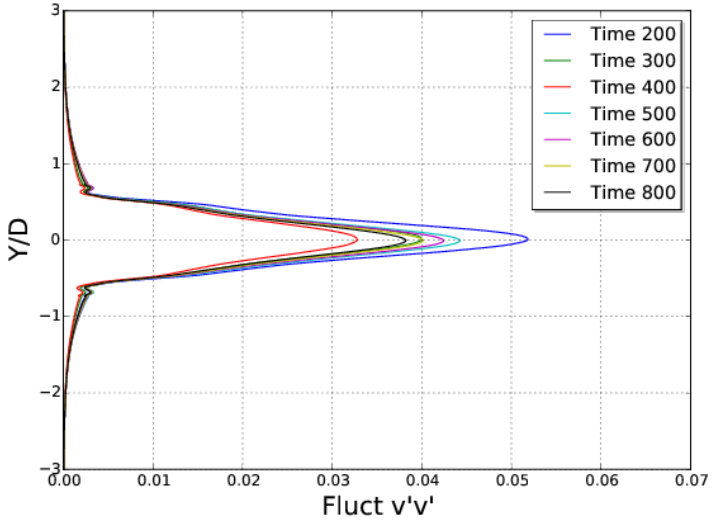
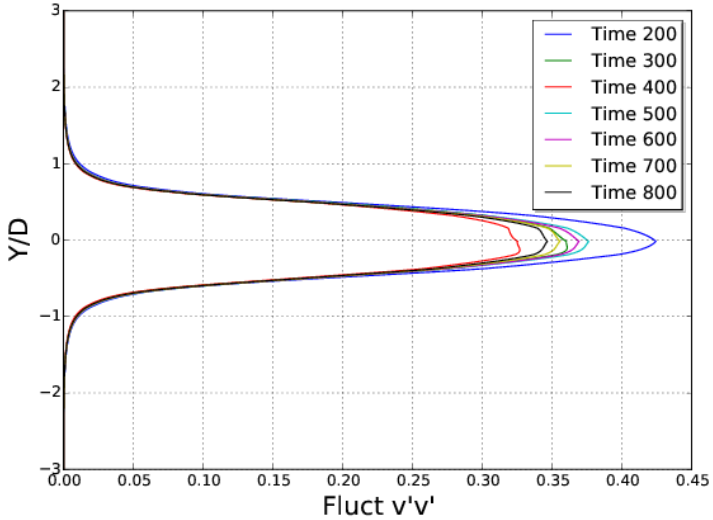
Turbulent main stress <v'v'> in the wake

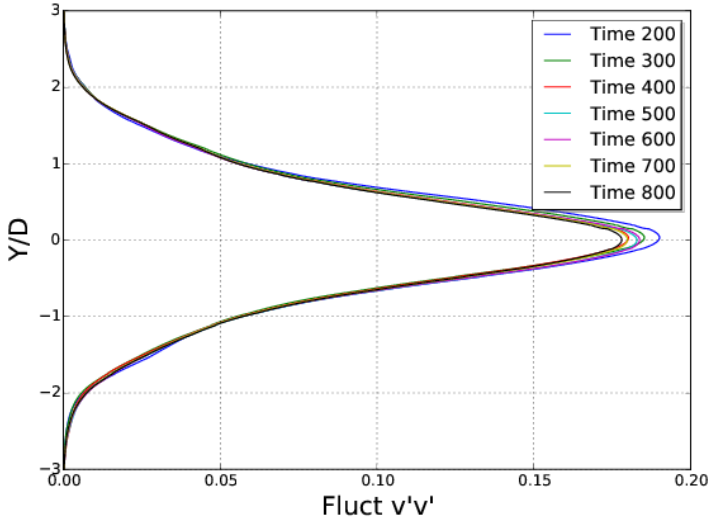
Medium p=3



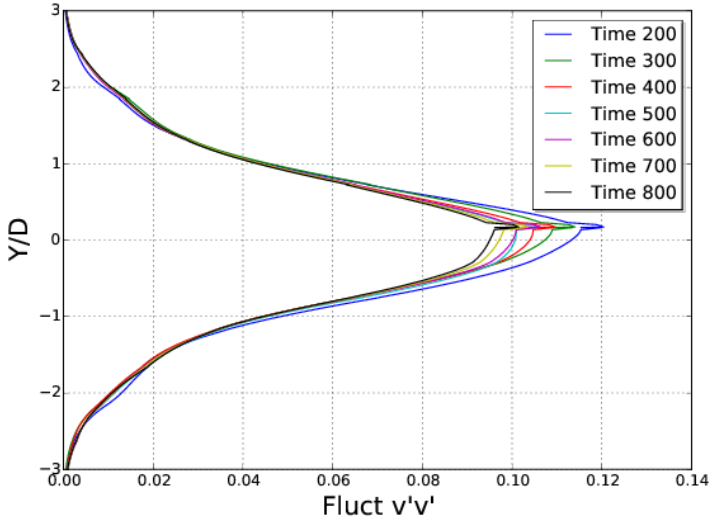
x=1D



x=1.54D



x=5D



x=10D

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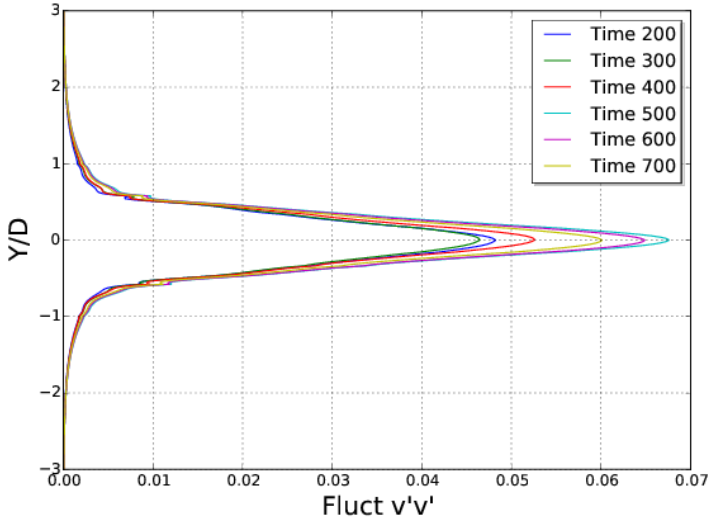
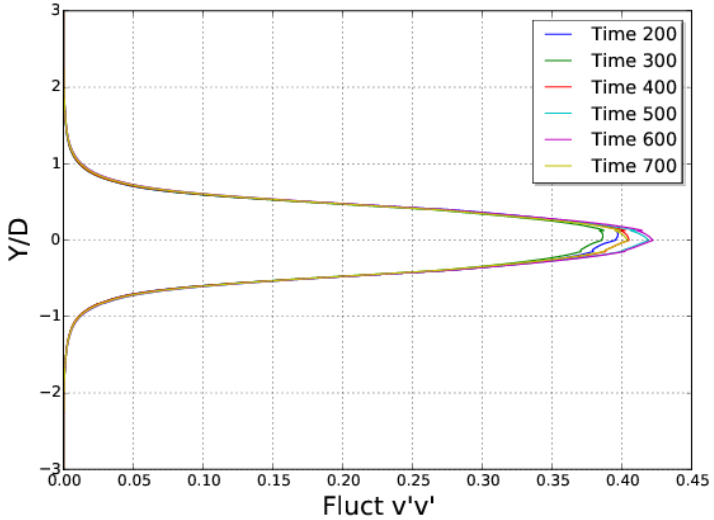
Turbulent main stress <v'v'> in the near wake

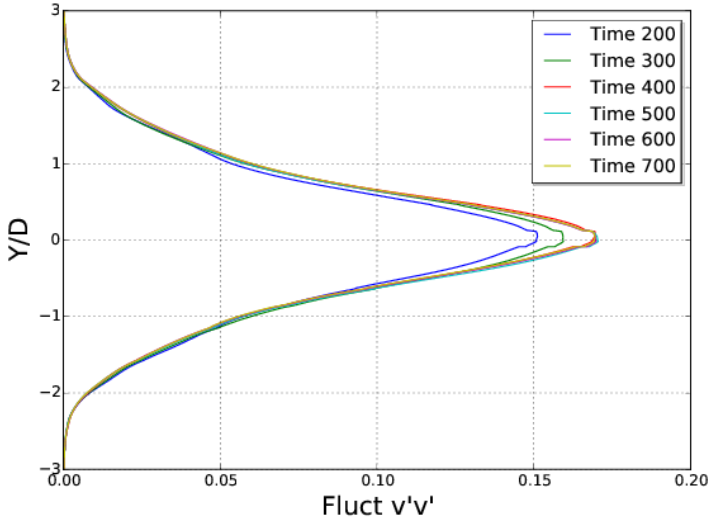
Coarse p=4



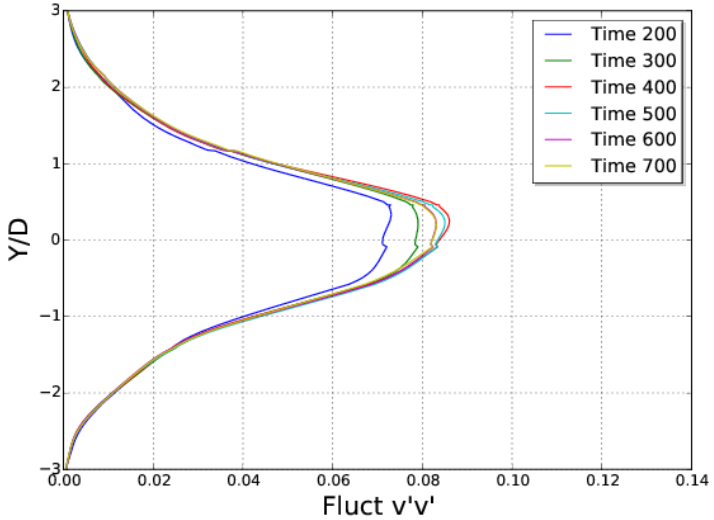
x=1D



x=1.54D



x=5D



x=10D

PROD-F-015-01

Cenaero

Conclusions

- **Convergence studies**
  - **No regular convergence on structured meshes**
    - Coarse front resolution → capture of the LBL ? Grid continuity ?
    - Lack of internal curving → badly conditioned elements
    - Meshes provided on the web site
  - **ESDIRK64 more efficient for (very) low errors**
  - **Identified coarse p=4, medium p=3,4 as promising**

- **Long term simulation**
  - **Beat is present in the signal, notable on fluctuations**
  - **Decent statistical convergence of velocity < t=800**
  - **Differences between coarse p=4 and medium p=3, coarse p=4 seems less accurate**
  - **Grid independence → ongoing computations**