

CFD WITH OPENSOURCE SOFTWARE 2010

# **Implementation of an actuator disk in OpenFOAM**

**Developed for  
OpenFOAM-1.5-dev**

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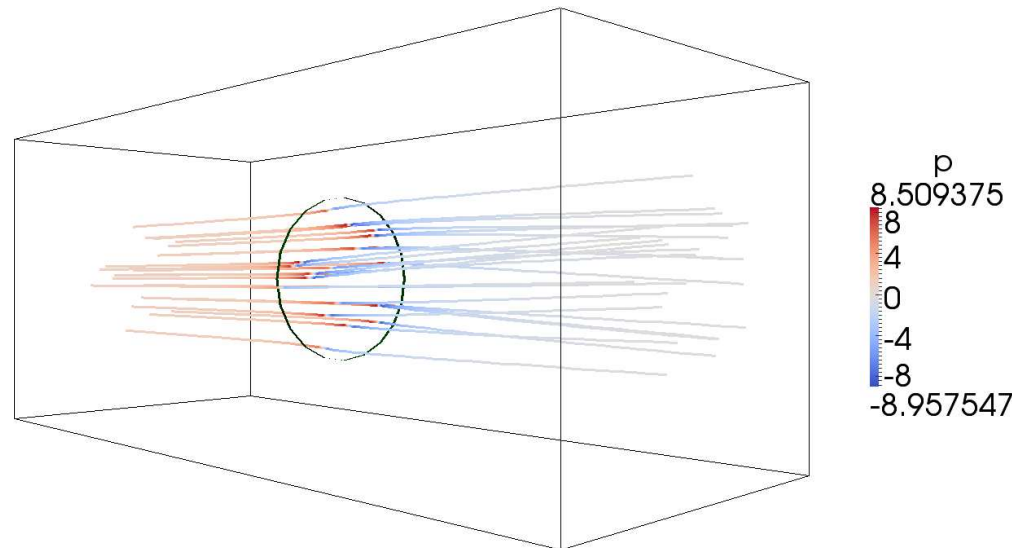
## Introduction

- What is an actuator disk?

An actuator disk model makes it possible to simulate the effect of a rotor. An actuator disk region is defined, where the rotor is accounted for by adding momentum to the fluid explicitly.

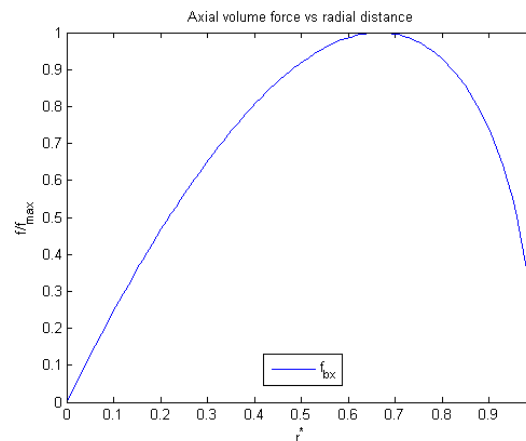
- When should it be used?

The actuator disk model can be used when we have information about how the rotor behaves on its own and we want to know how it affects its surroundings.



## Theoretical background

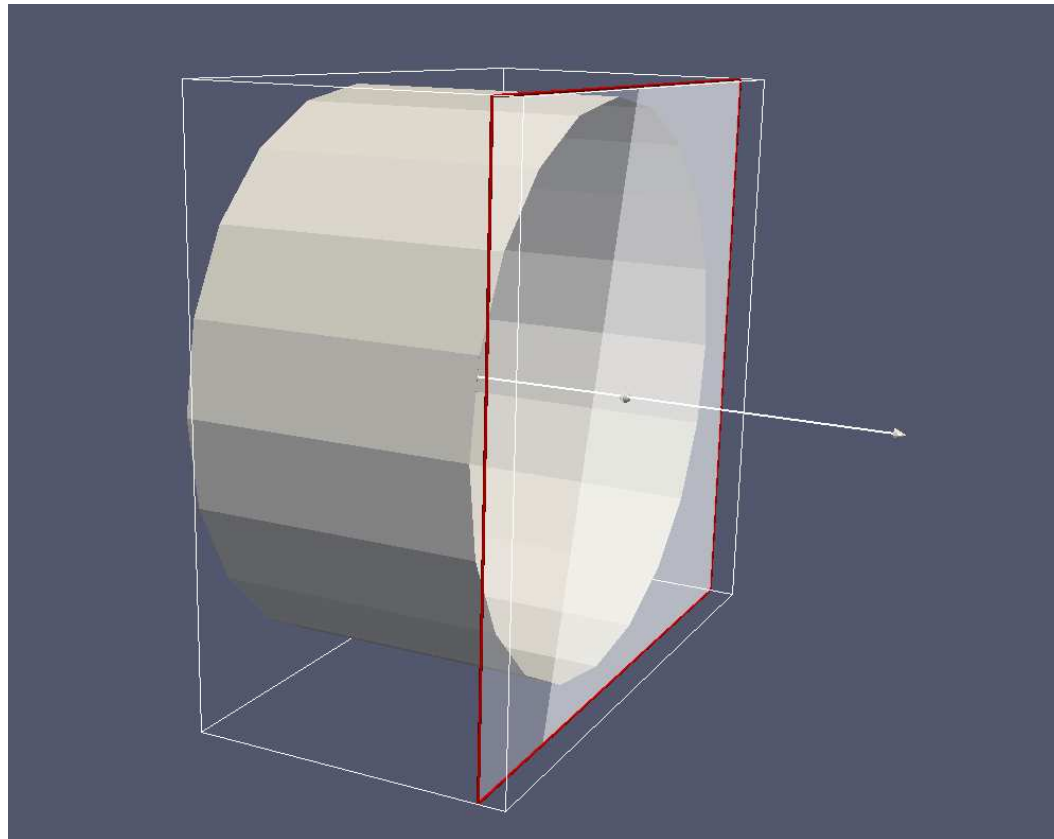
- We need some kind of model for the behavior of the propeller. We could use:
  - uniform force distribution
  - non-uniform force distribution
  - structural dynamics simulation
- The following approach is chosen:
  - Assume that the total torque and thrust is known.
  - Assume Goldstein optimum distribution.



## Geometry of an actuator disk

Cylindrical actuator disk region:

- Centerline: start point and end point
- Exterior radius and possibly also interior radius



## The fan tutorial

- Start by downloading and extracting the fan tutorial

[http://www.tfd.chalmers.se/~hani/kurser/OS\\_CFD/fan.tar.gz](http://www.tfd.chalmers.se/~hani/kurser/OS_CFD/fan.tar.gz)

- *0/U:*

```
fan
{
    type          cyclic;
}
```

- *0/p:*

```
fan
{
    type          fan;
    patchType     cyclic;
    f List<scalar> 2 (10.0 -1.0);
    value         uniform 0;
}
```

## The fan BC

```
$FOAM_SRC/finiteVolume/fields/fvPatchFields/derived/fan/fanFvPatchFields.C:  
    for(label i=1; i<f_.size(); i++)  
    {  
        jump_ += f_[i]*pow(Un, i);  
    }
```

The pressure jump is computed according to  $\Delta p = \sum_{i=0}^n f_i \cdot U^i$

## The fan BC: modelling possibilities and limitations

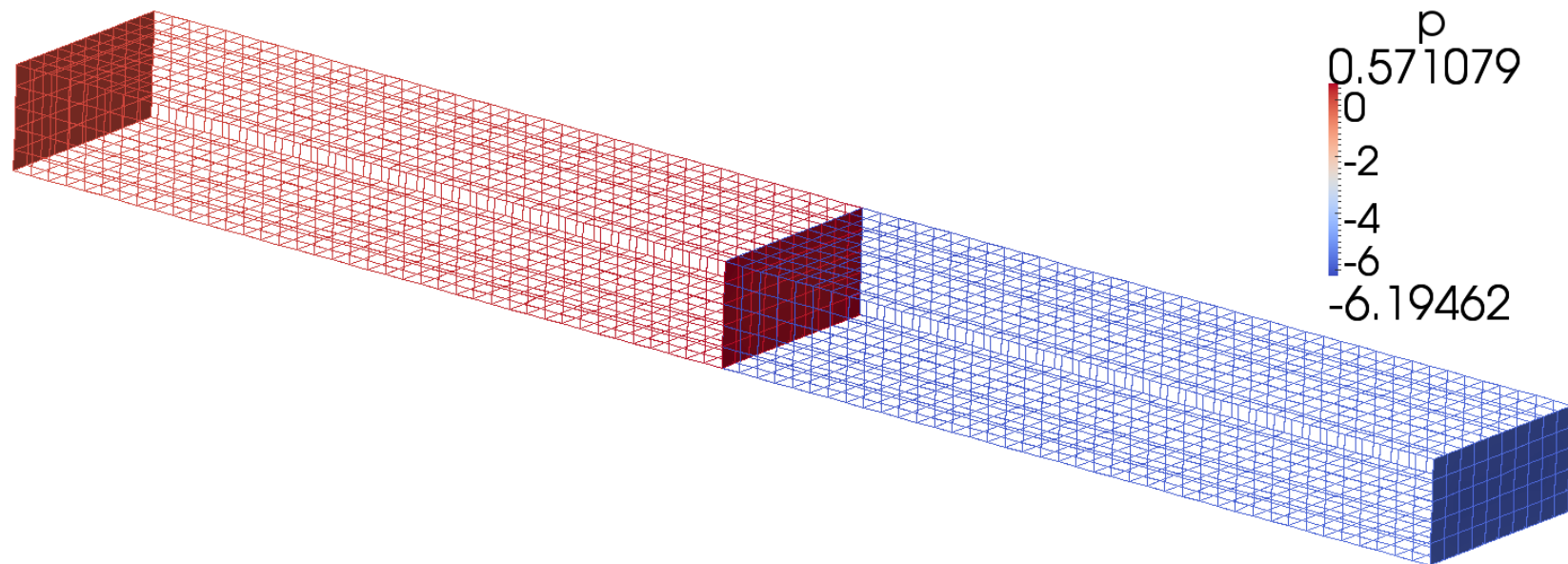
- Thrust can be modelled
- Torque can not be modelled
- The thrust may depend on the velocity
- Only uniform thrust can be modelled (if the freestream velocity is uniform)

## The fan BC: running the case

- cd fan
- blockMesh
- simpleFoam
- paraFoam



## The fan BC: pressure



## Actuator disk: requirements

- Possibility to add non-uniform axial force (thrust)
- Possibility to add non-uniform tangential force (swirl)
- Possibility to define an actuator disk region without changing the mesh

## Actuator disk: strategy

- Copy the *simpleFoam* solver and modify it
- Implement an actuator disk class
  - Read geometry and settings from a dictionary
  - Find all cells in the actuator disk region
  - Add volume force
  - Visualize in Paraview
- Validate

## Actuator disk: structure

- *actuatorDiskExplicitForceSimpleFoam*
  - Call functions for computing and visualizing the volume force
  - Add the computed volume force to the right hand side of the momentum equations
- *class actuatorDiskExplicitForce*
  - Compute the volume force
  - Read the actuator disk definition
  - Write actuator disk geometry to VTK file

## Actuator disk: geometry definition

The actuator disk parameters are defined in system/fvSolution

```
actuatorDisk
{
    startPoint          (4.9 0.5 0.5);
    endPoint            (5.1 0.5 0.5);
    thrust              5;
    torque              0.5;
    density              1.2;
    interiorRadius      0.05;
    exteriorRadius      0.2;
}
```

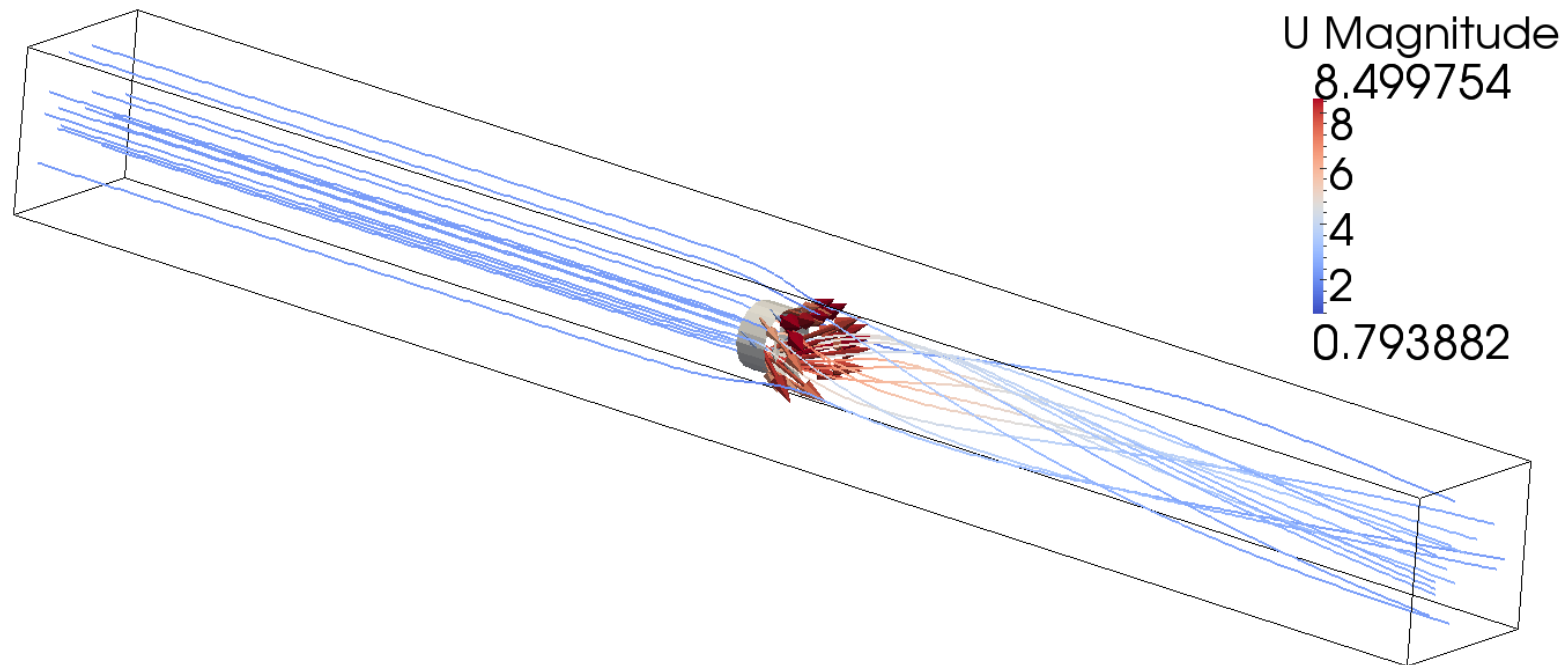
## Actuator disk: download and compile

- Download and extract *actuatorDiskExplicitForce*. Put it in erik-1.5-dev/applications
- `cd actuatorDiskExplicitForce`
- `wmake`

## Actuator disk: basic test case

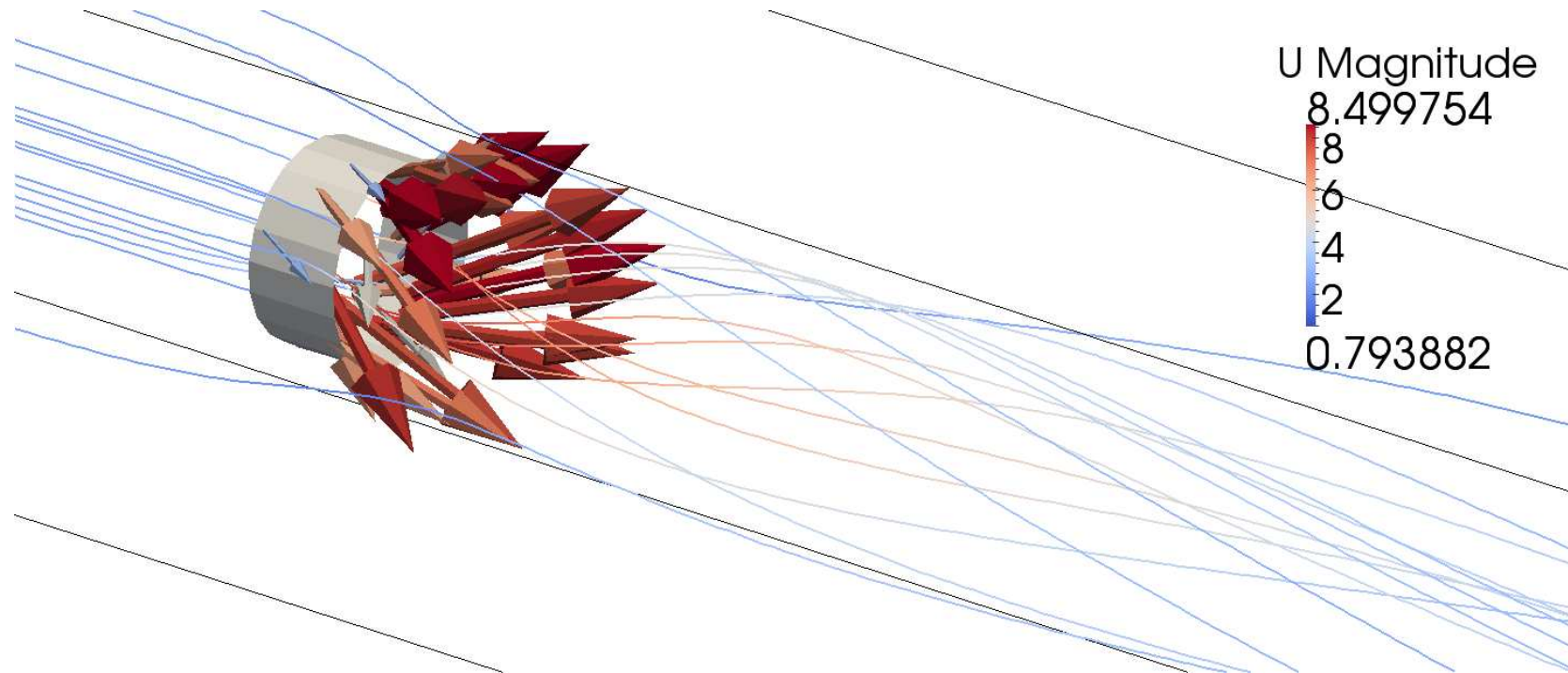
- Download and extract *cavityActuatorDisk*. Put it in the *run* directory.
- `blockMesh`
- `actuatorDiskExplicitForceSimpleFoam >& log &`

## Actuator disk: basic test case





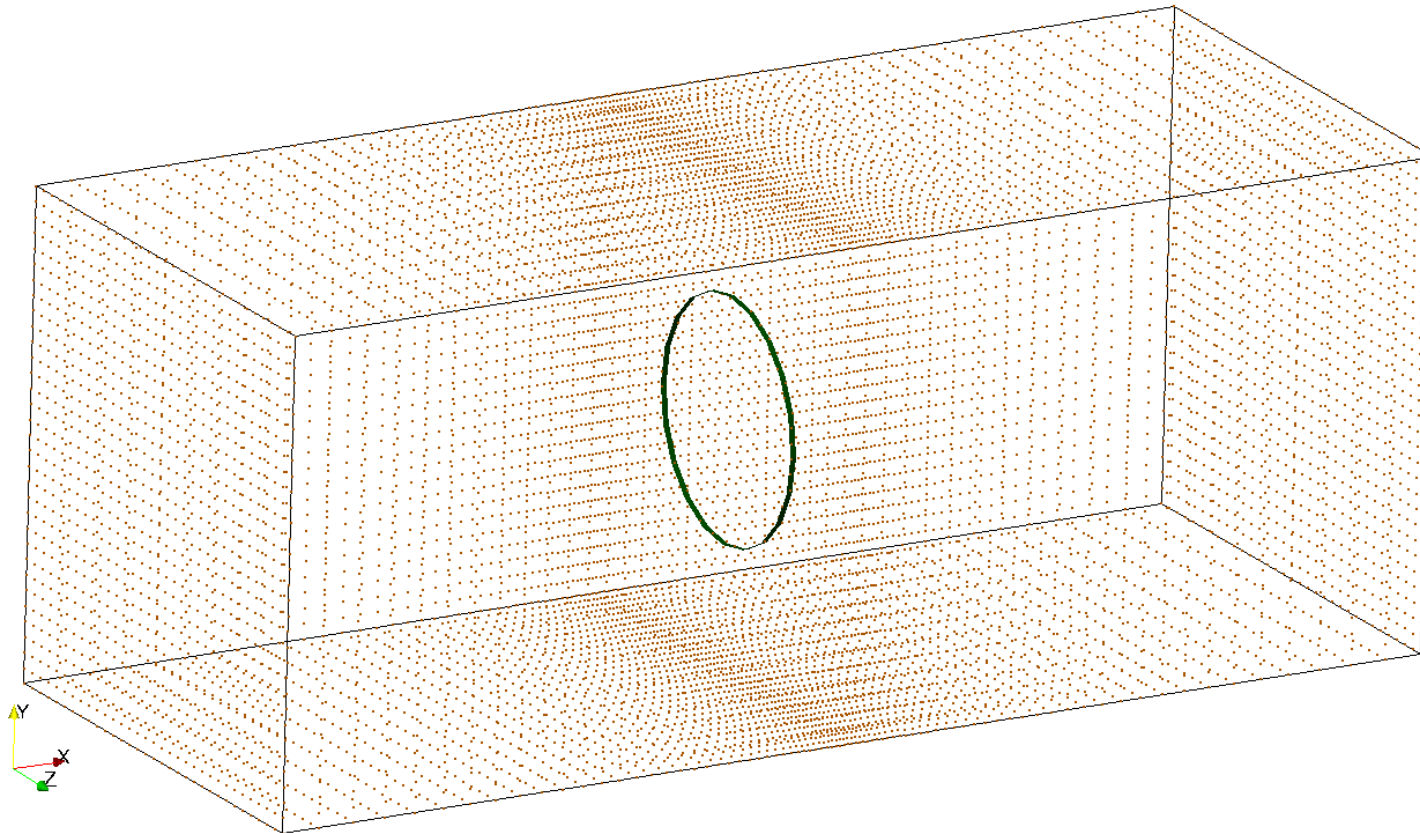
## Actuator disk: basic test case



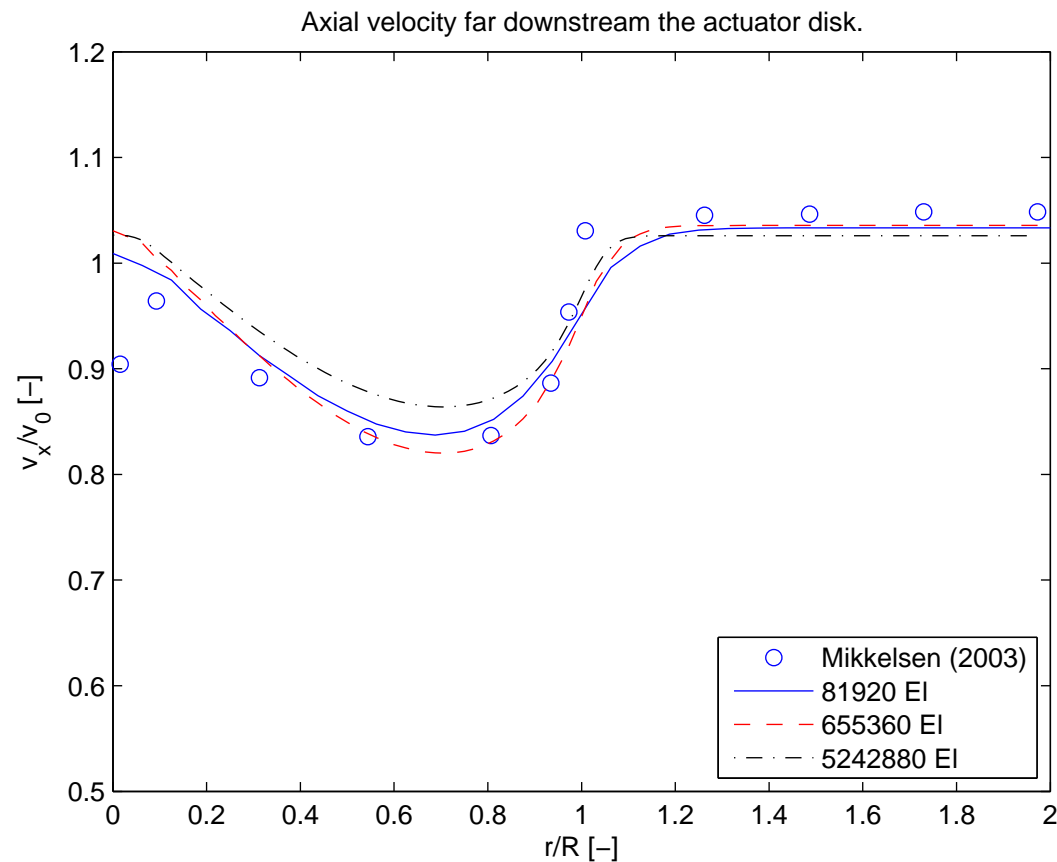
## Actuator disk: comparison with Mikkelsen (2003)

- Tunnel blockage: simulation of a wind turbine rotor in a tunnel with inviscid walls
- $V_0 = 10 \text{ m/s}$
- $R = 20.5 \text{ m}$
- The axial velocity profile downstream is studied.

## Actuator disk: comparison with Mikkelsen (2003)



## Actuator disk: comparison with Mikkelsen (2003)



## Actuator disk: references

### References

- [1] Goldstein, S: 'On the Vortex Theory of Screw Propellers', Proceedings of the Royal Society of London. Series A, Containing Papers of a Mathematical and Physical Character, Vol. 123, No. 792 (1929), pp. 440-465
- [2] Hough, G. R. and Ordway, D. E: 'The generalized actuator disk', Technical Report TAR-TR 6401, Therm Advanced Research, Inc. (1964)
- [3] Mikkelsen, R: 'Actuator Disc Methods Applied to Wind Turbines', Dissertation, Technical University of Denmark (2003), ISBN 87-7475-296-0
- [4] The Visualization Toolkit (VTK): <http://www.vtk.org>  
See especially <http://www.vtk.org/VTK/img/file-formats.pdf>