Estimation of equivalent non-uniform momentum source distribution for propeler modelling with Deep Learning model

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Grupo de Fluidos Multifásicos
Department of Mechanical Engineering and Construction
Universitat Jaume I

Outline

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2. State of the art: homogeneous momentum source

3. Methods: non-homogeneous momentum source

4. Results

5. Discussion

1. Motivation

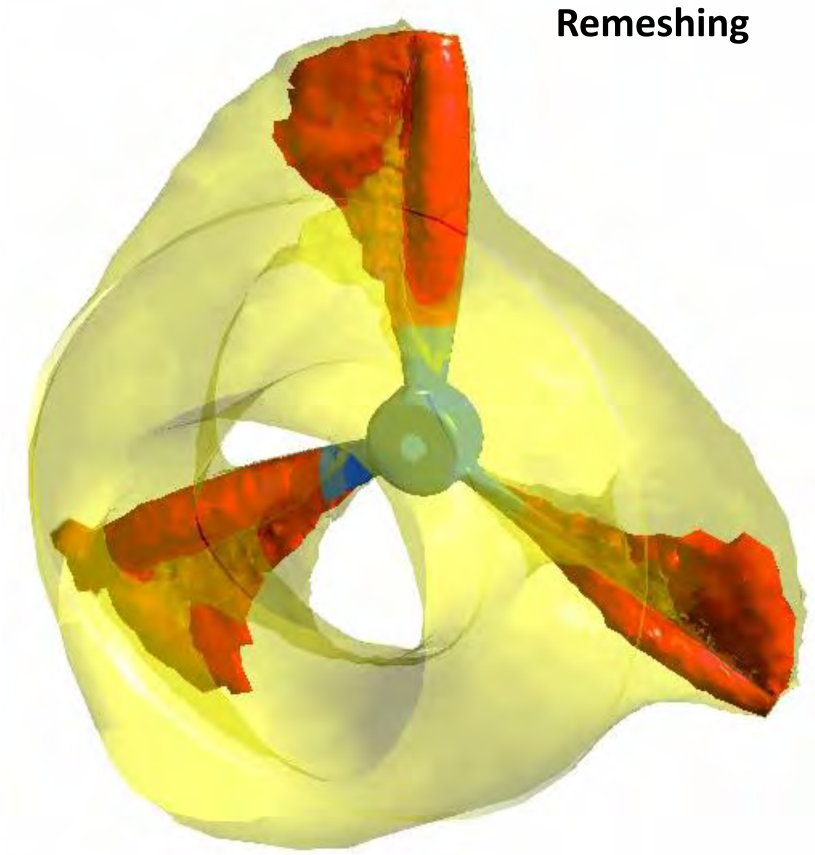
Low computational cost simulations of rotating structures (propellers, wind turbines,…)

Focus on effects **far from the rotor**

Good enough **velocity field**

Good enough **turbulence field**

2 million cells
1 millisecond
Remeshing



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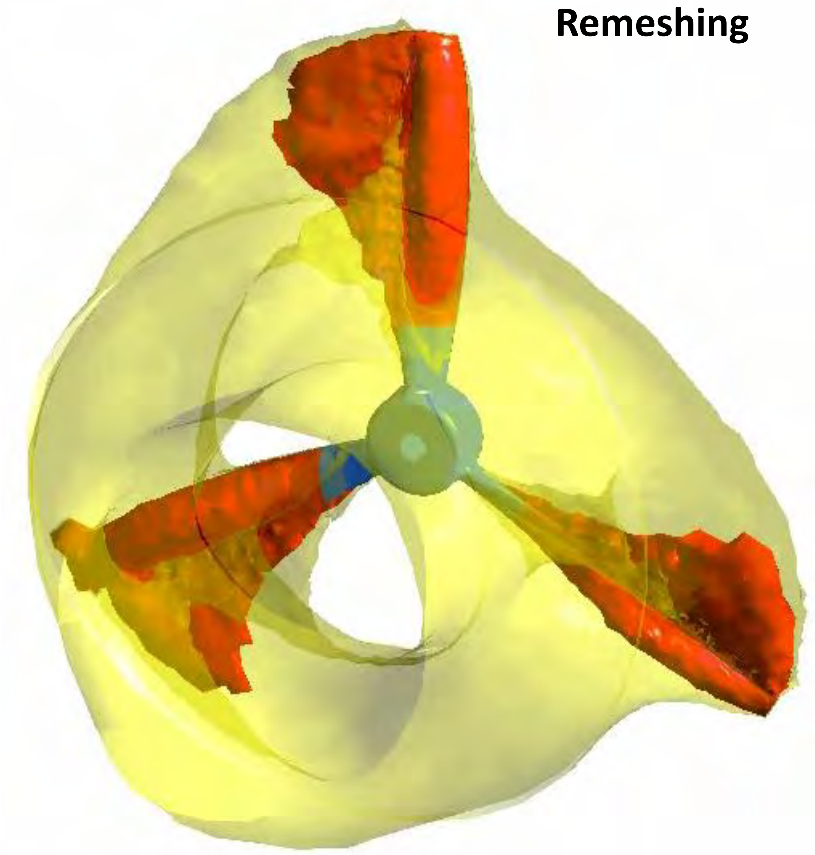

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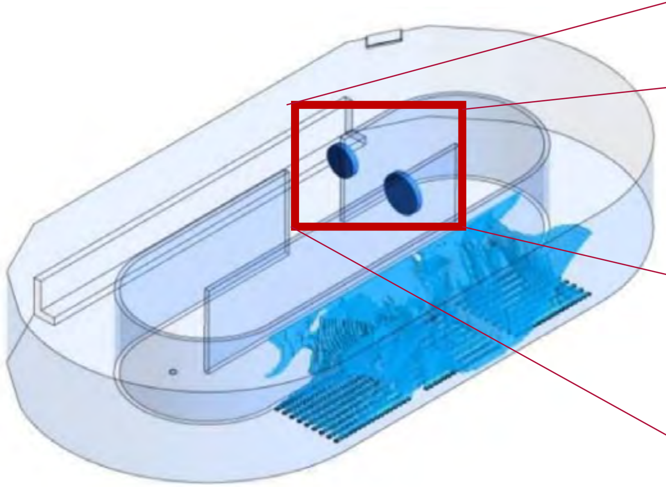

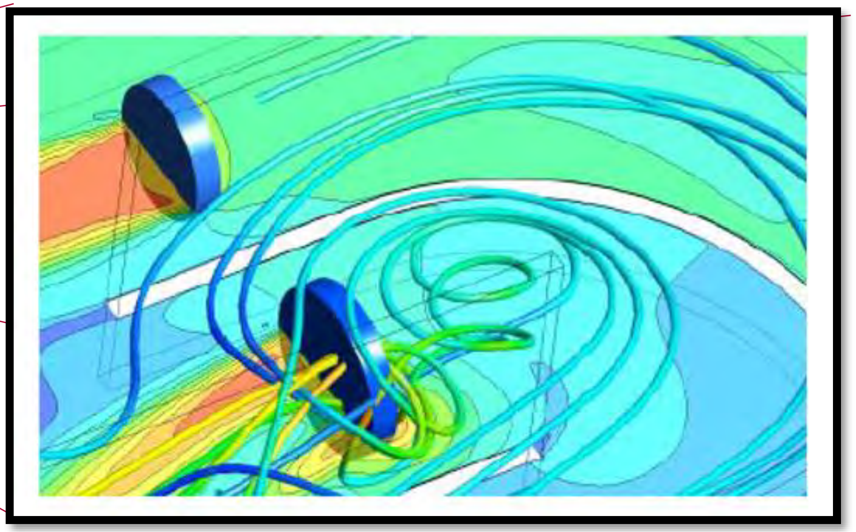

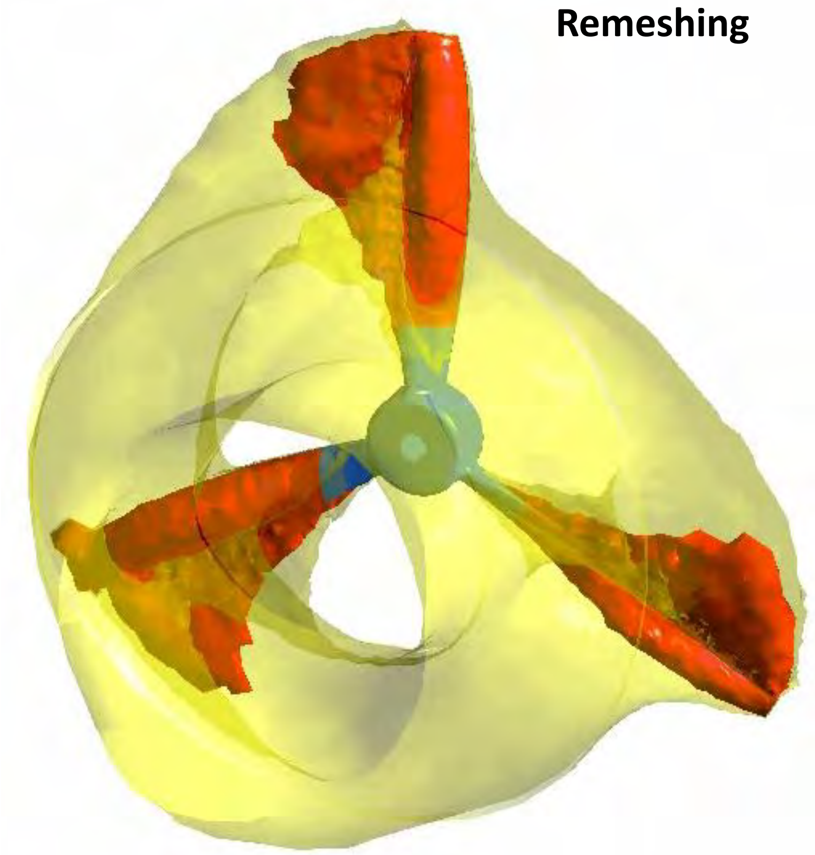

1. Motivation

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Low computational cost simulations of rotating structures (propellers, wind turbines,...)

- Dynamic Meshing
  Complete blades´ geometry
  Rotation of the body: remeshing

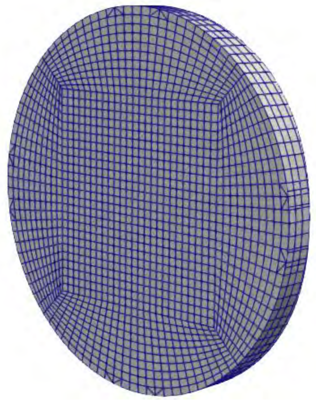
- Sliding Mesh
  Internal region rotates while external is fixed
  Algorithm to couple both regions

- Multiple Reference Frame
  Two regions, both stationary, one has non-inertial reference frame
  Algorithm to couple regions

- Momentum Source Term
  No explicit geometry
  Same reference

Resolving interaction wall-fluid

Computational cost



Adding equivalent momentum source

$$\frac{DU_i}{Dt} = -\frac{\partial p}{\partial X_i} + \frac{\partial}{\partial X_i}\left[(\mu + \mu_t)\left(\frac{\partial U_i}{\partial X_j} + \frac{\partial U_j}{\partial X_i}\right)\right] + \boxed{M_i}$$

Low accuracy

Equivalent momentum source term?

2. Methodology: momentum source approach

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Mechanistic approaches:

- Mainly for axial component, based on simplistic assumptions
- Lack of experimental information for validation
- Specifications available (torque, rotational regime, thrust, etc.)

Machine learning based:

- Three components of momentum source
- Assumes uniform momentum source components
- Needs for new specifications of commercial rotors

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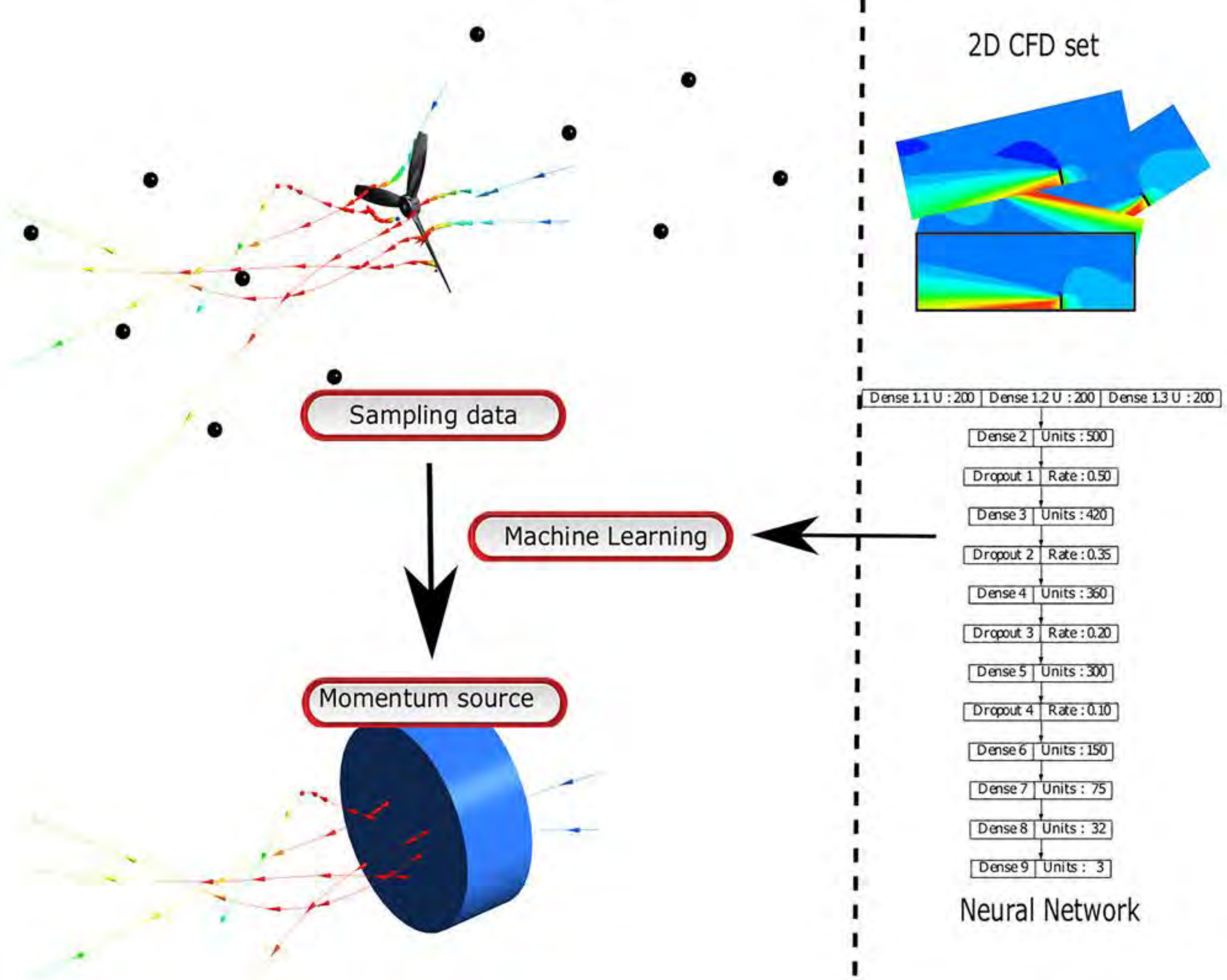
On the use of deep learning and computational fluid dynamics for the estimation of uniform momentum source components of propellers

Raúl Martínez-Cuenca [1,3] · Jaume Luis-Gómez [1] · Sergio Iserte [2] · Sergio Chiva [1]

Affiliations & Notes · Article Info

2. Methodology: momentum source approach

Procedure:

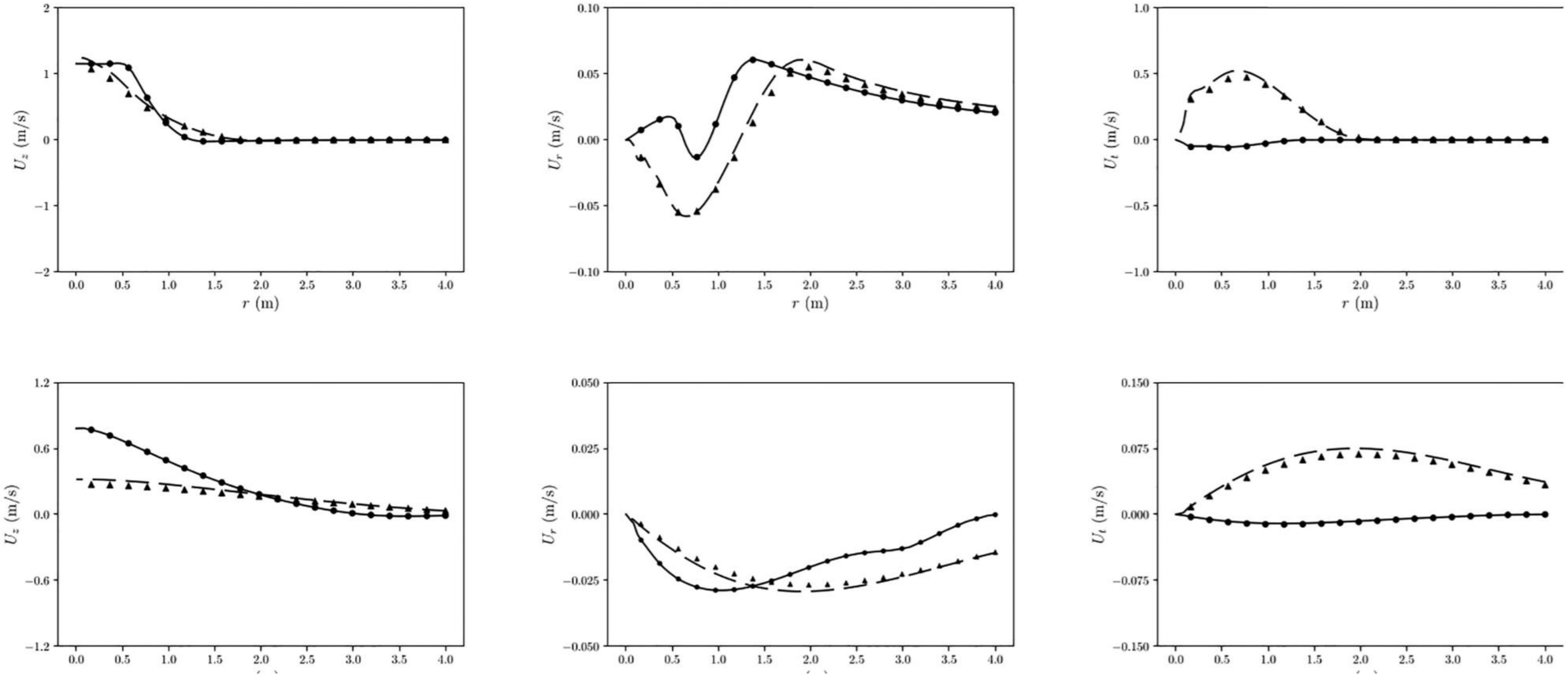


500 CFD simulations with

$$\vec{M} = M_z \vec{u}_z + M_r \vec{u}_r + M_\theta \vec{u}_\theta$$

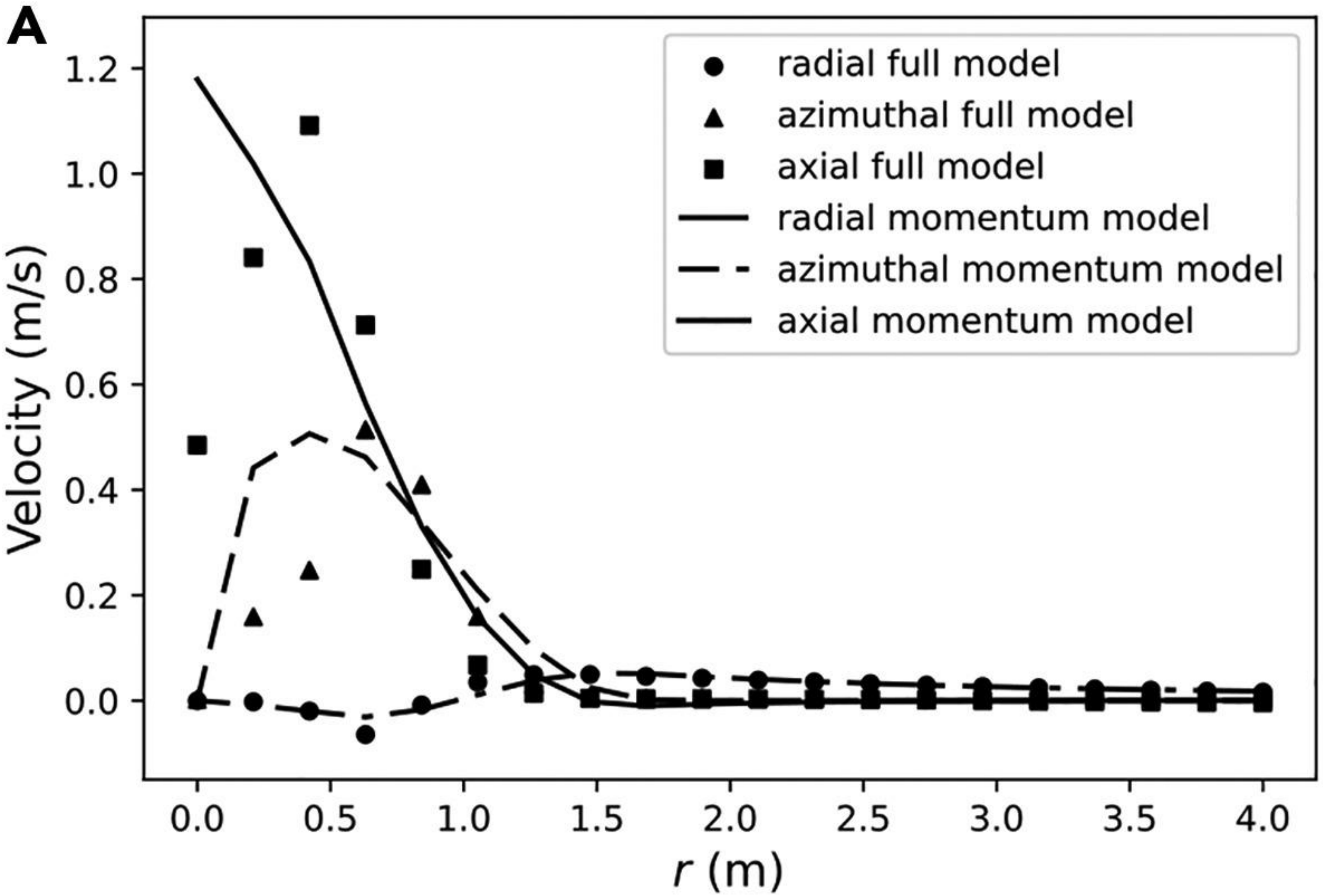
2. Methodology: momentum source approach

Results: simulations with homogeneous momentum source components



2. Methodology: momentum source approach

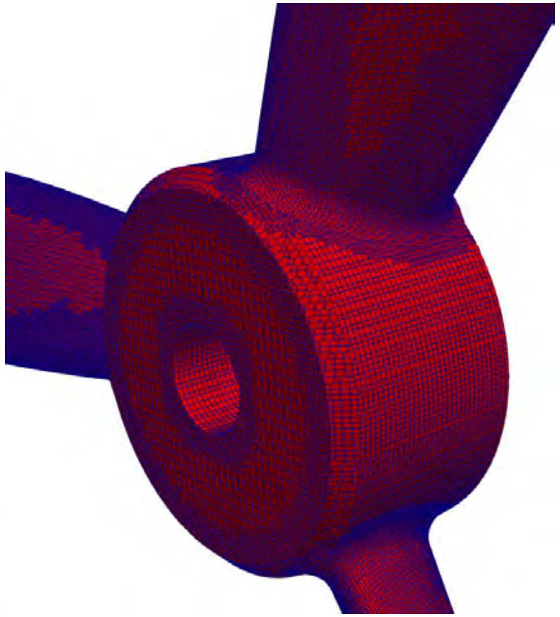
Results: inference for a real propeller



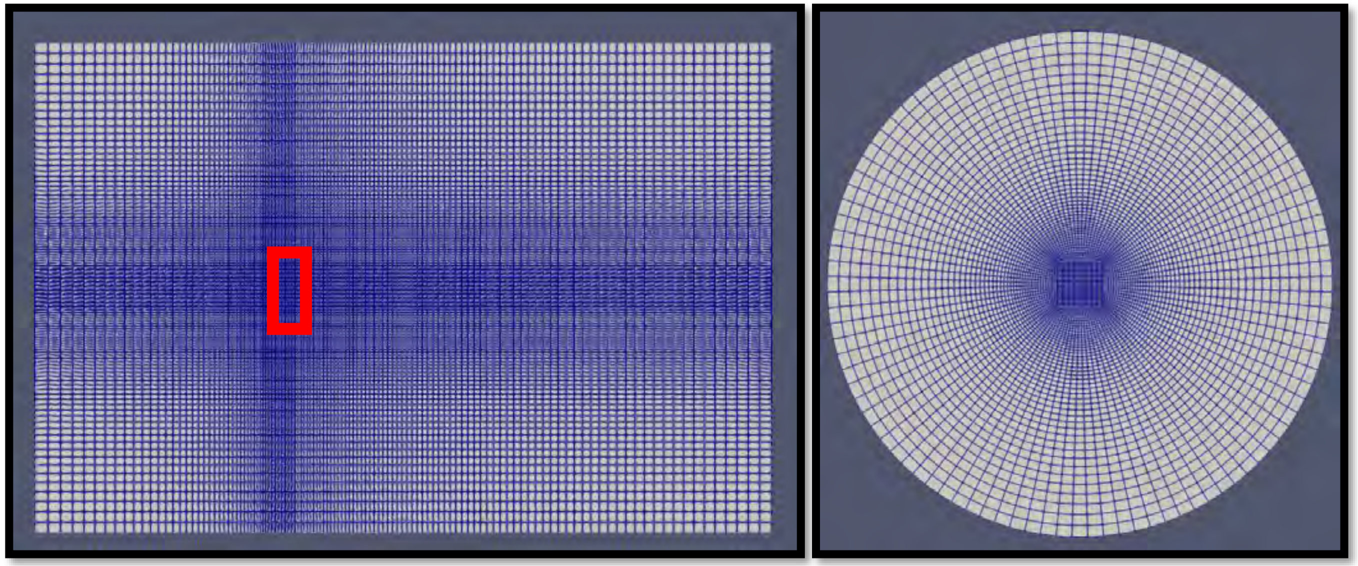
3. Methods: non-homogeneous momentum source

CFD simulation: ***Sliding mesh VS nonm-homogeneous momentum source***

- Openfoam mesher (SnappyHexMex)
- pimpleFoam (35 seconds, time step $2 \cdot 10^{-5}$s)
- SST turbulence model



3,5M nodes



6,4k nodes

3. Methods: non-homogeneous momentum source

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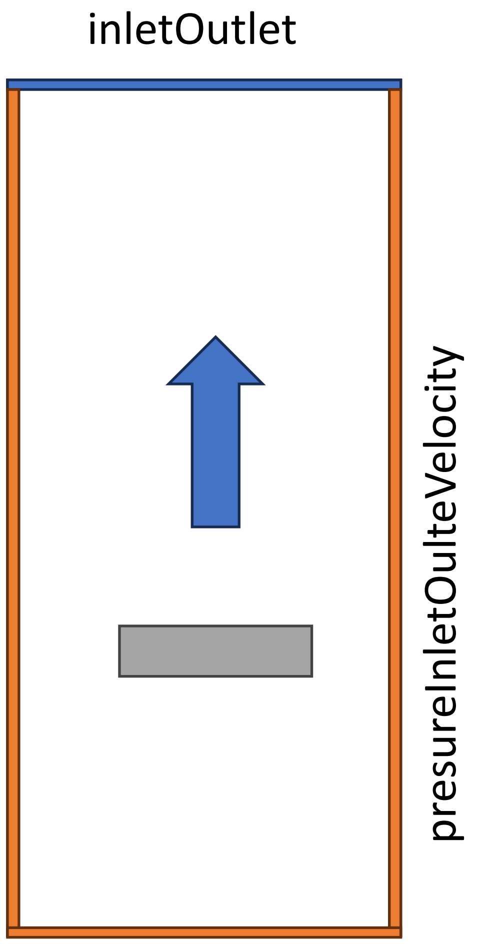
- Boundary conditions
- Velocity fields initialized at 0,1 m/s axial speed



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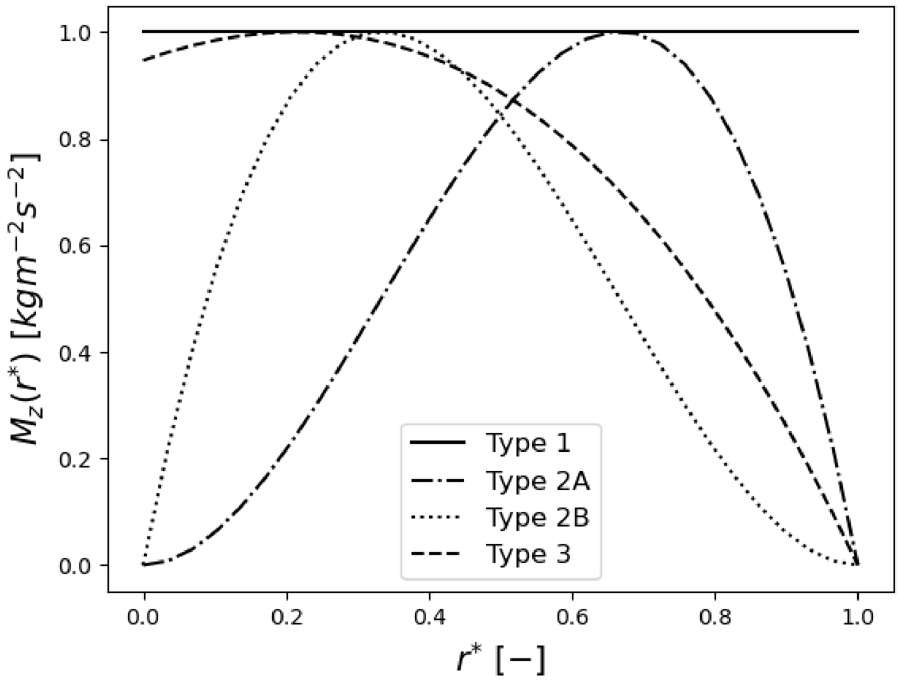
- Velocity fields initialized at 0,1 m/s axial speed
- Non-homogeneous axial component,

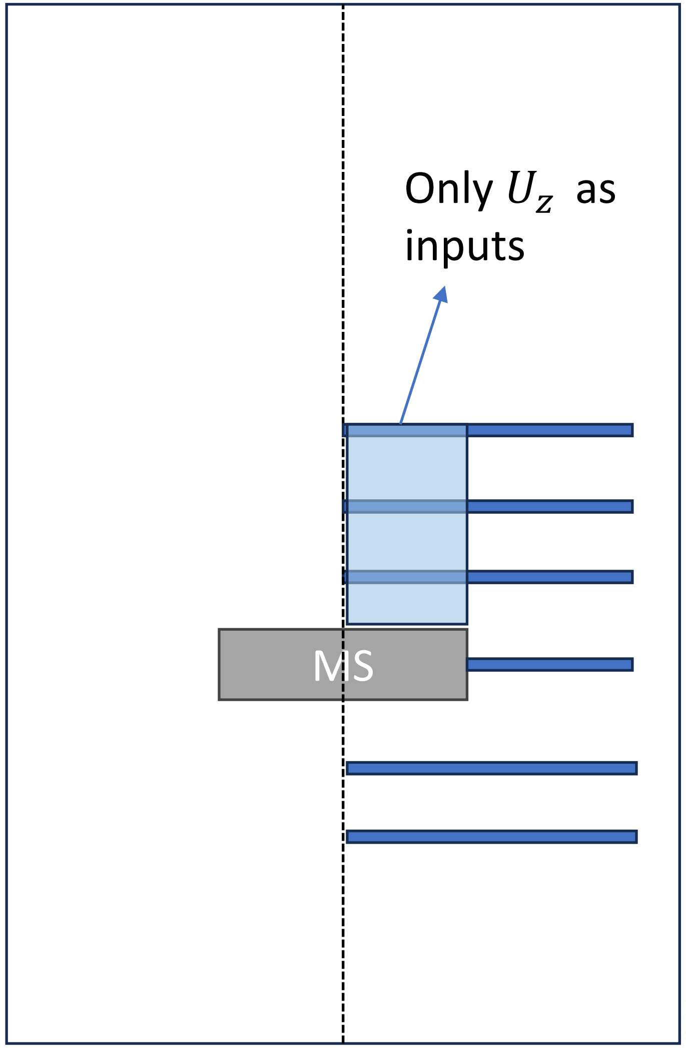
  rest of components homogeneous



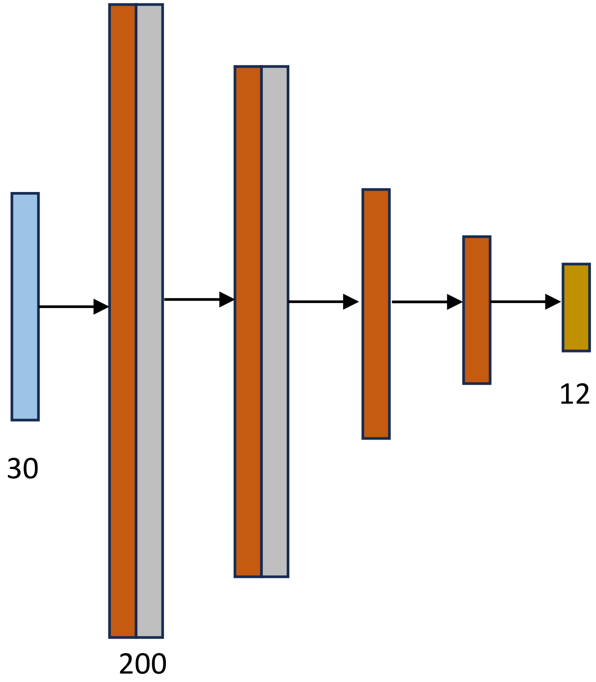
$$M_z\left(\frac{r}{R}\right) = \underbrace{S_z}_{\text{Modulus}}\, \underbrace{K(a_1, a_2, a_3, b_1, b_2)}_{\text{Normalization}} \underbrace{\left[a_1 + a_2\left(a_3 + \frac{r}{R}\right)^2\right]}_{\text{Parabolic}} \cdot \underbrace{\left(b_1 + b_2\frac{r}{R}\right)}_{\text{Asymmtery}}$$

3. Methods: non-homogeneous momentum source

Neural network 1: classify constant/parabolic



$$M_z\left(\frac{r}{R}\right) = S_z\, K(a_1, a_2, a_3, b_1, b_2)\left[a_1 + a_2\left(a_3 + \frac{r}{R}\right)^2\right] \cdot \left(b_1 + b_2\,\frac{r}{R}\right)$$



Velocity profile inputs

Fully connected layer

Dropout layer

Classification layer for radial distribution coefficients

Hyperbollic tangent used as activation function for every layer except last one (sigmoid)

3. Methods: non-homogeneous momentum source

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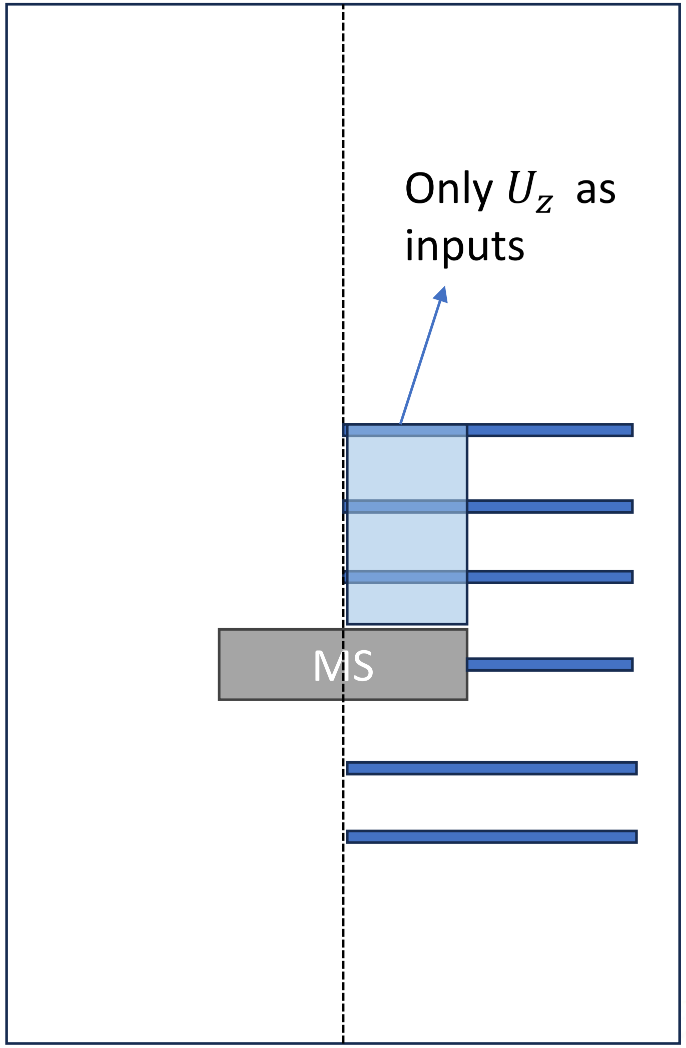
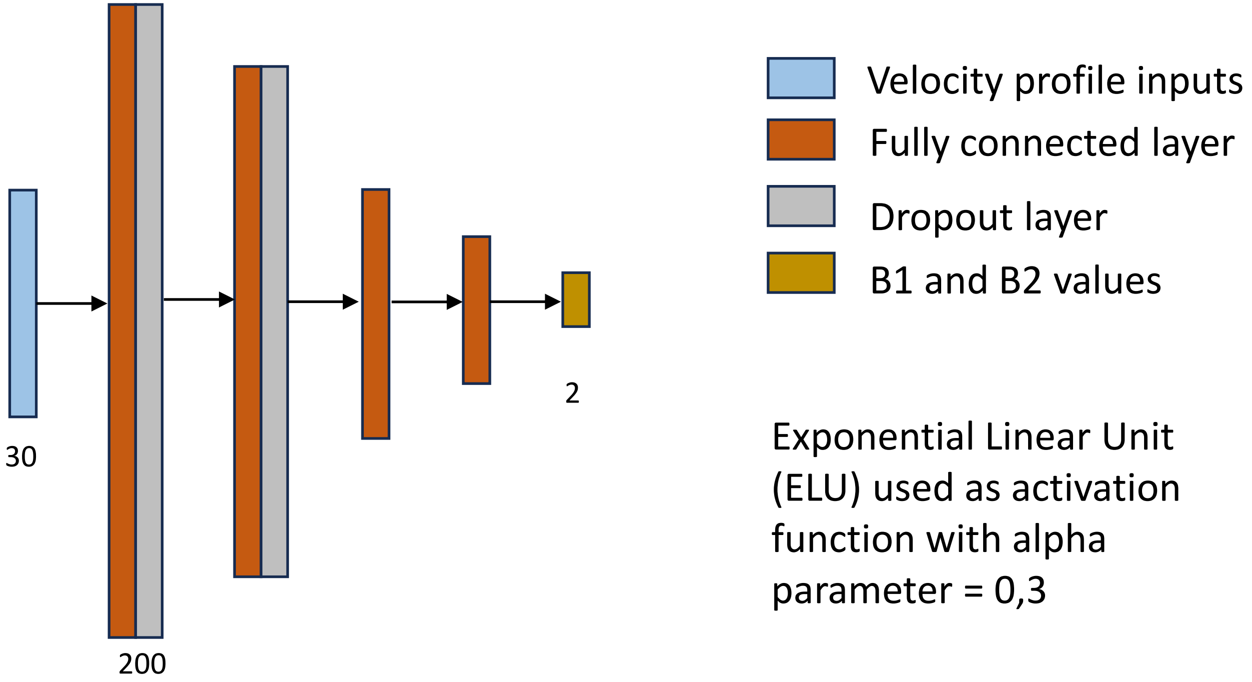
Neural network 2: inference of assymmetry (only if parabolic)



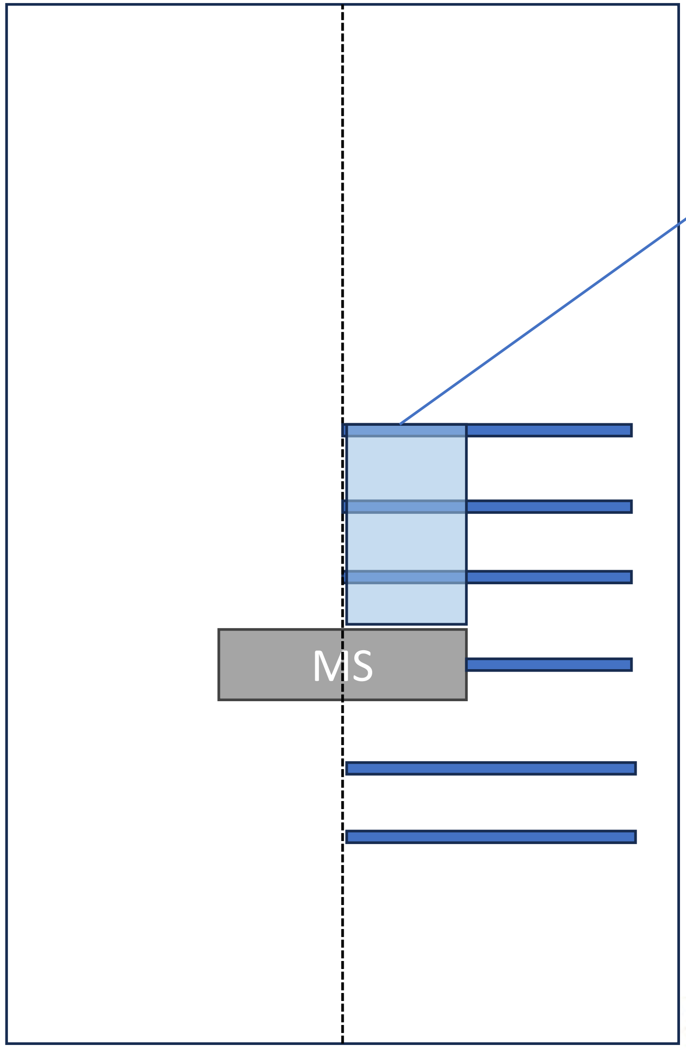
$$M_z\left(\frac{r}{R}\right) = S_z\, K(a_1, a_2, a_3, b_1, b_2)\left[a_1 + a_2\left(a_3 + \frac{r}{R}\right)^2\right] \cdot \left(b_1 + b_2\frac{r}{R}\right)$$



Exponential Linear Unit (ELU) used as activation function with alpha parameter = 0,3

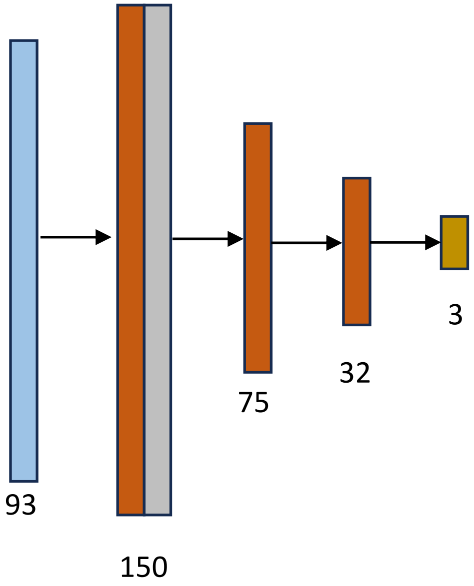
3. Methods: non-homogeneous momentum source

Neural network 3: momentum source components



$$M_z\left(\frac{r}{R}\right) = S_z\, K(a_1, a_2, a_3, b_1, b_2)\left[a_1 + a_2\left(a_3 + \frac{r}{R}\right)^2\right] \cdot \left(b_1 + b_2\frac{r}{R}\right)$$ and M_r, M_θ

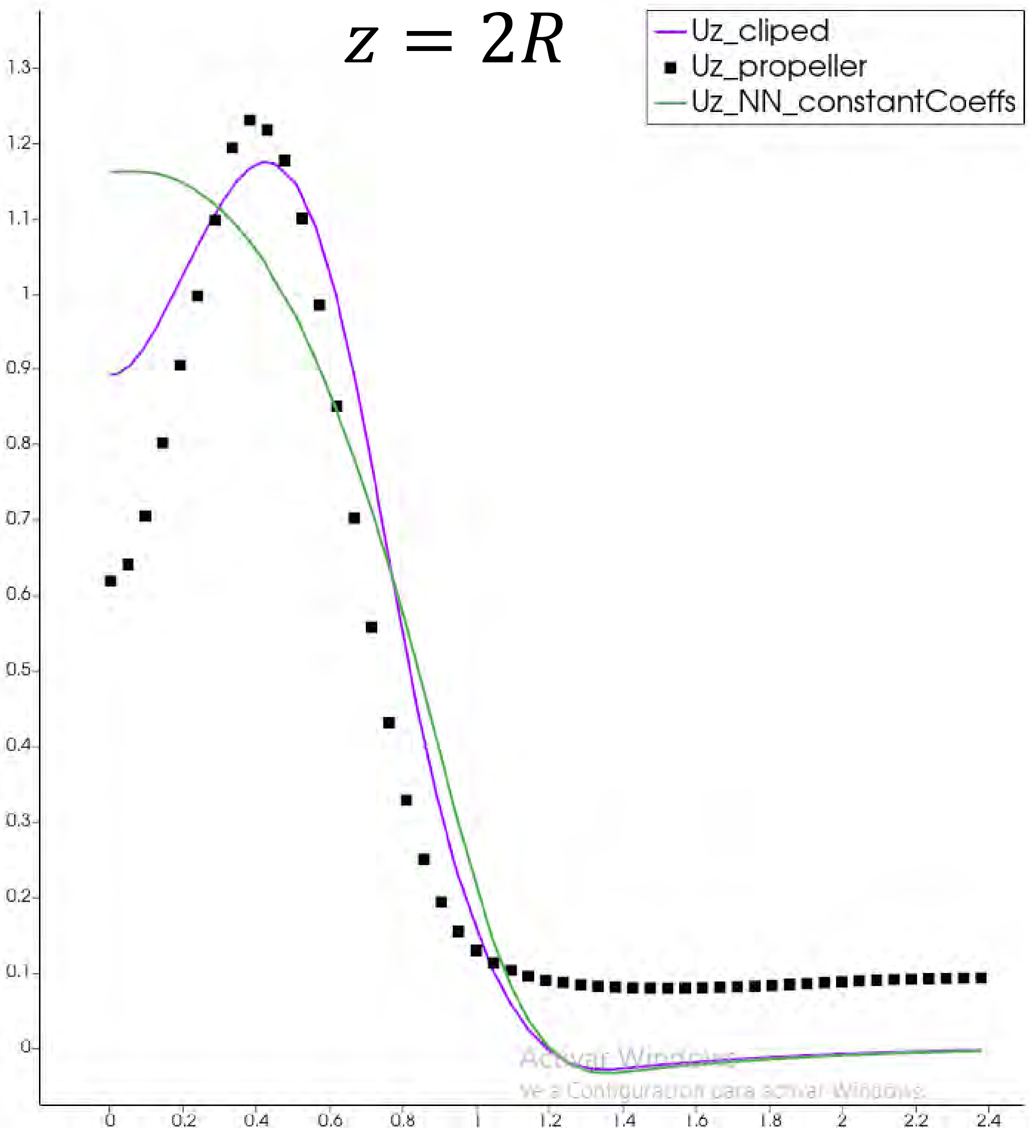
All velocity components (90 points) + maximum value of U_z at each row

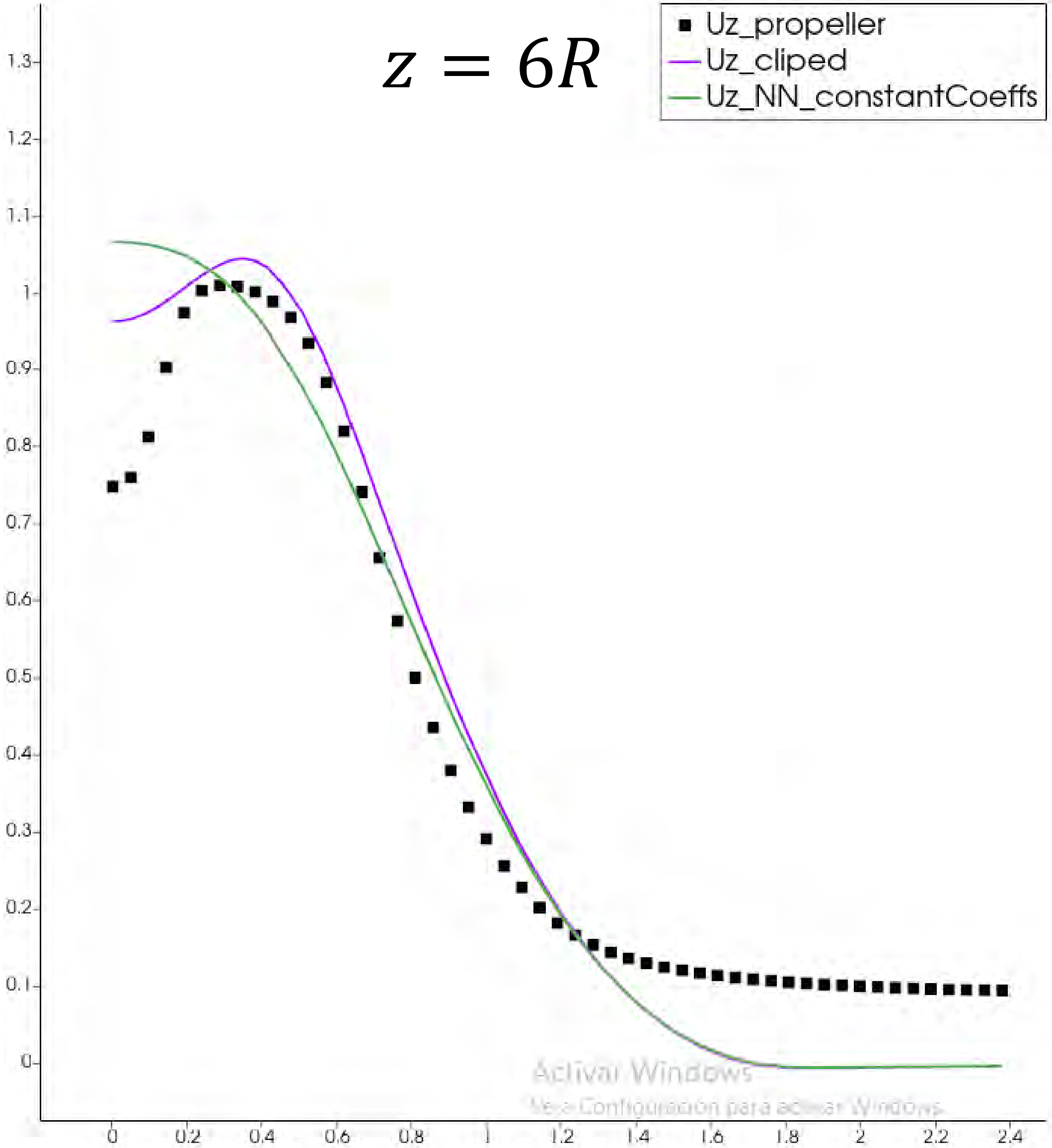


Velocity profile inputs
Fully connected layer
Dropout layer
Momentum term values

Exponential Linear Unit (ELU)
alpha parameter = 0,3

4. Results


$z = 2R$
Uz_cliped
Uz_propeller
Uz_NN_constantCoeffs
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
2.2
2.4


$z = 6R$
Uz_propeller
Uz_cliped
Uz_NN_constantCoeffs
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
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4. Results

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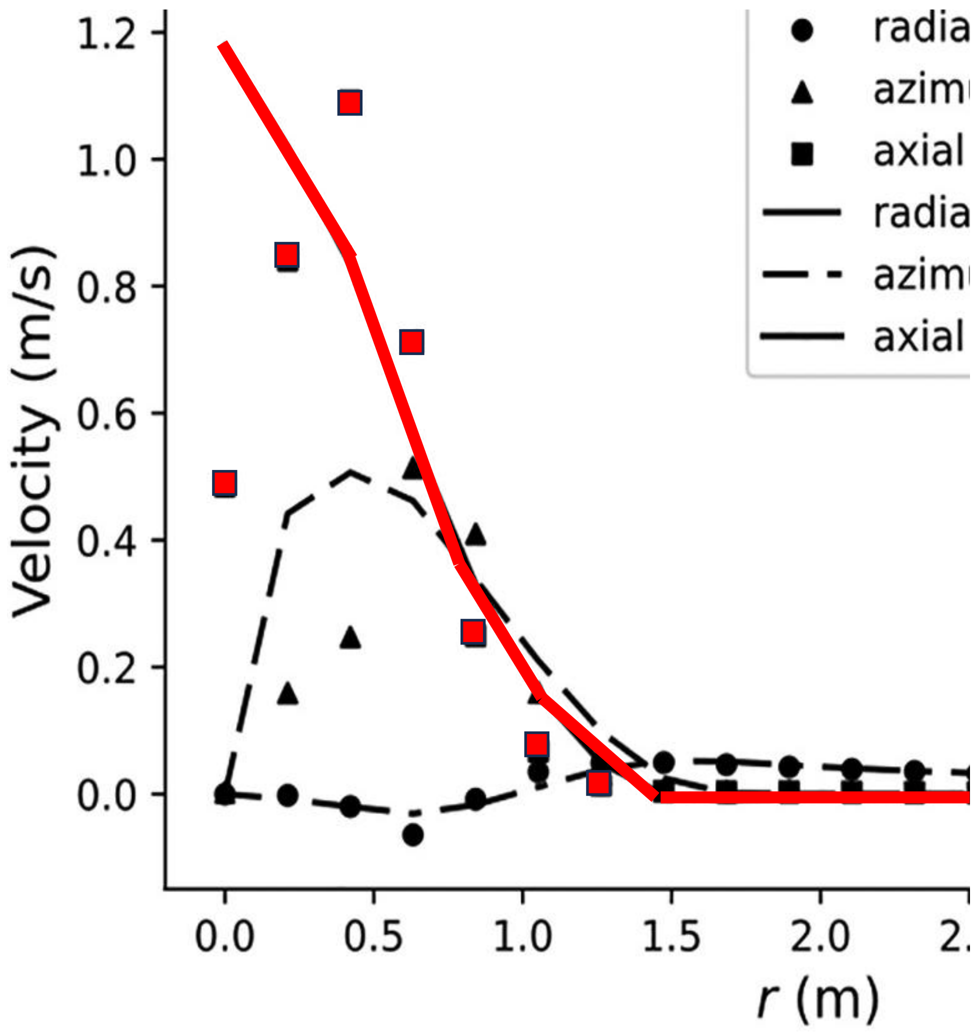

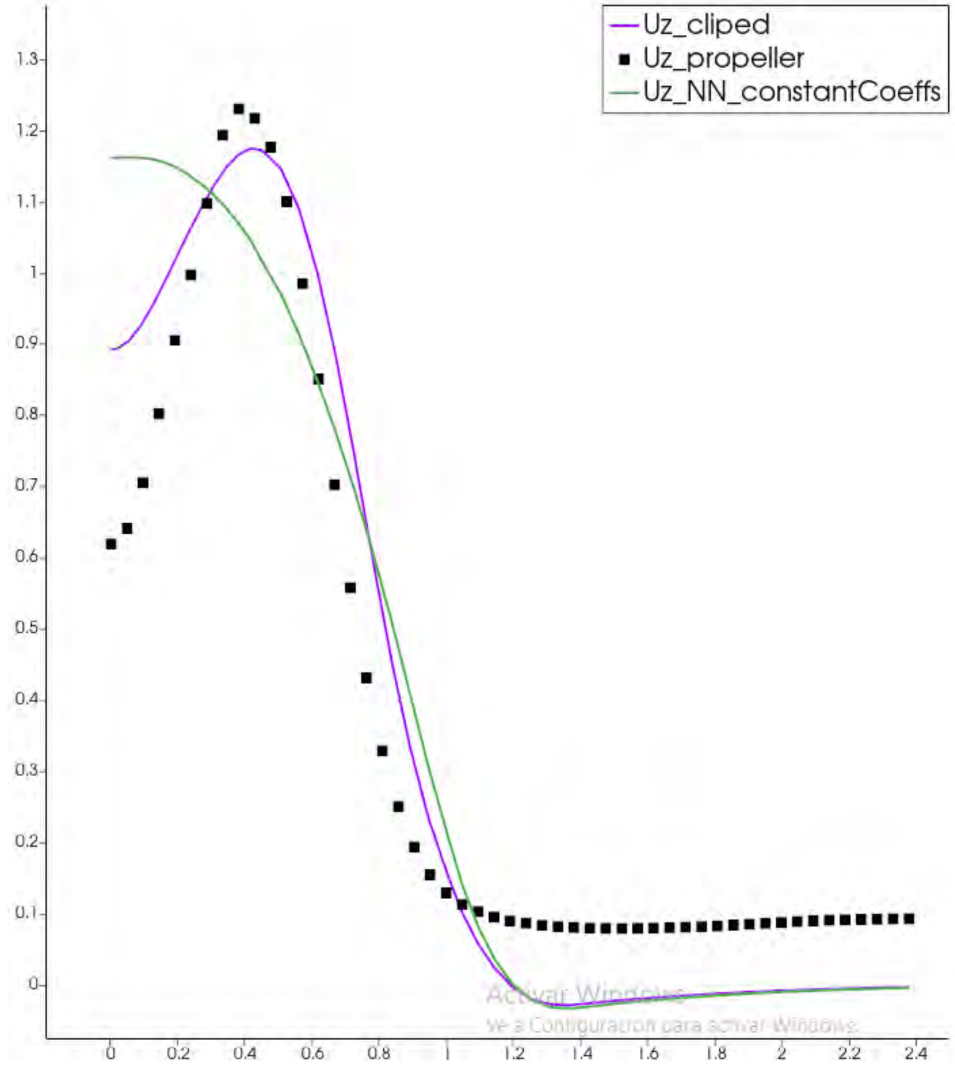

5. Discussion

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Conclusions

- Improved performance with just axial non-homogeneous component
- Reduction of a factor 6 in number of nodes
- Steady state

Future work

- Extend the non-homogeneity to all the components
- Work with simpler representations (Hermite, Zernike, etc)
- Transient effects

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