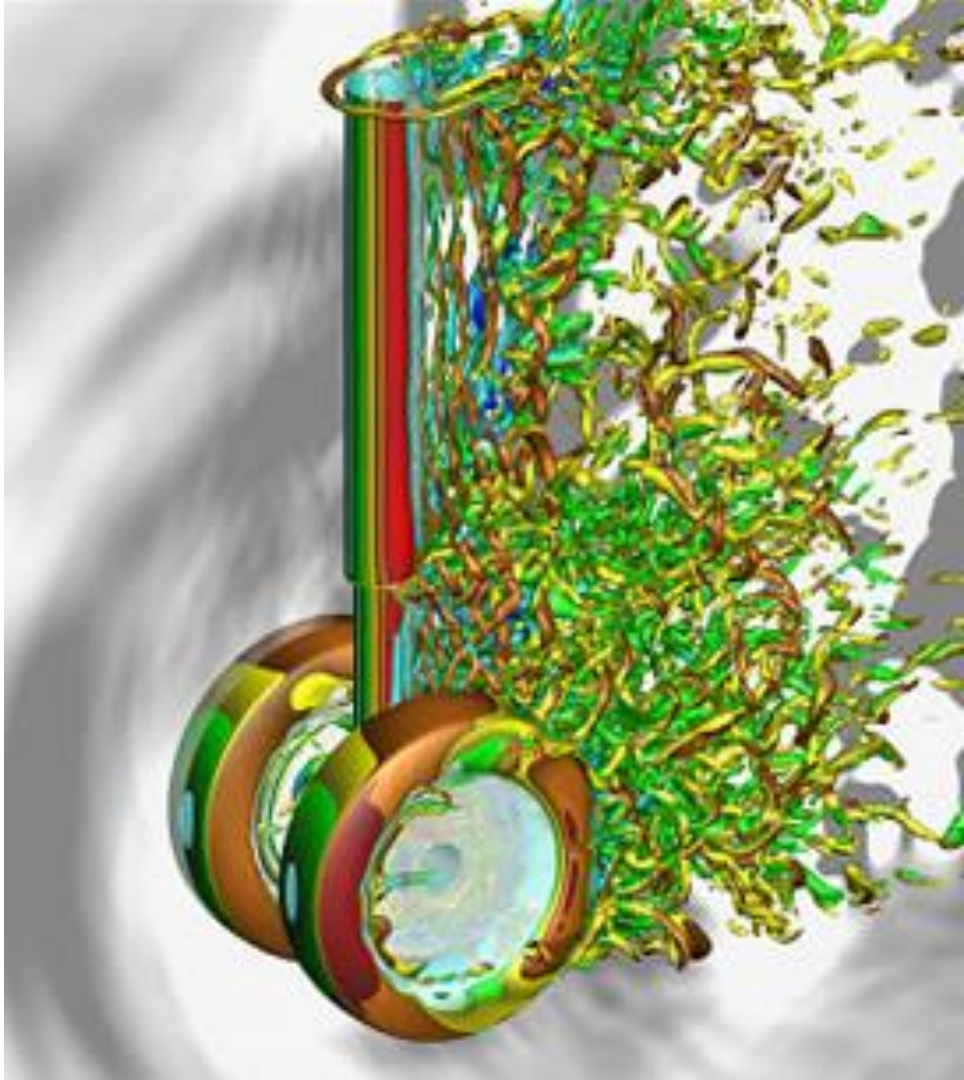
Towards geometry independent uncertainty quantification, based on deep learning

Data uncertainties matter

- Economics
- Risk assessment
- Optimization
- Measurements
- Simulations

Uncertainties in CFD

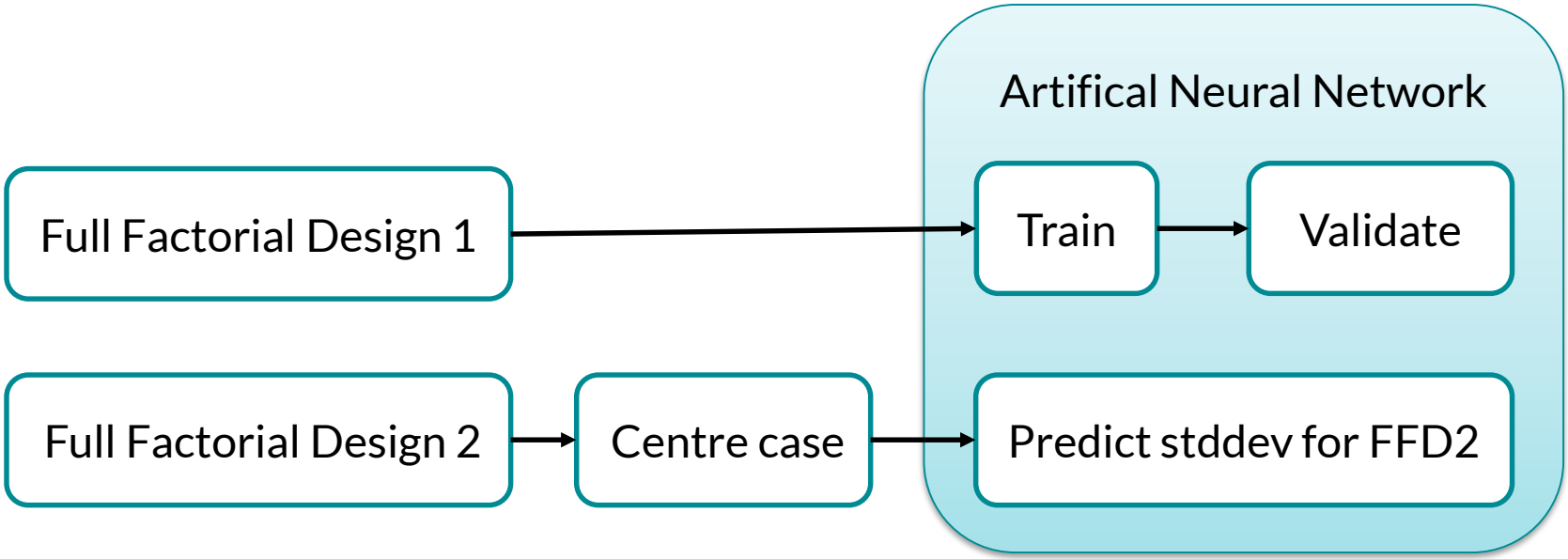
- Variations in input data
- Boundary conditions
- Discretization
- Turbulence modelling
- Solvers
- Convergence
- …



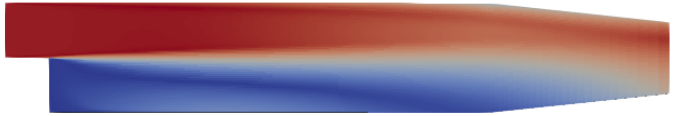
Litterature study

- Review of Uncertainty Methods for Computational Dynamics Application to Nuclear Reactor Thermal Hydraulics, NEA/CSNI/R(2016)4, OECD, https://www.oecd-nea.org/nsd/docs/2016/csni-r2016-4.pdf
- Data Driven Smart Proxy for CFD, Nov 2017, National Energy Technology Laboratory, Office of Fossil Energy, U.S. Department of Energy, NETL-PUB-21574, https://www.netl.doe.gov/sites/default/files/netl-file/NETL-PUB-21574-Data-Driven-Smart-Proxy-for-CFD-Application-of-Big-Data-Analytics.Report-1_1417305%5B1%5D.pdf
- Fluids, Special Issue “Numerical Fluid Flow Simulation Using Artificial Intelligence and Machinfe Learning”, 2019, ISSN 2311-5521 https://www.mdpi.com/journal/fluids/special_issues/Artificial_Intelligence_and_Machine_Learning

The proposed method



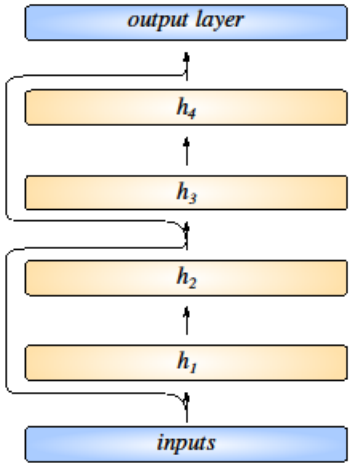
Full Factorial Design



- OpenFoam 7, pitzDaily, simpleFoam, 12765 cells, 81 cases, ~40 min
- Inlet streamwise velocity
- Initial internal field of turbulent kinetic energy
- Initial internal field of turbulent dissipation
- Kinematic viscosity
- parSim by Ola Widlund: https://gitlab.com/olwi/psm

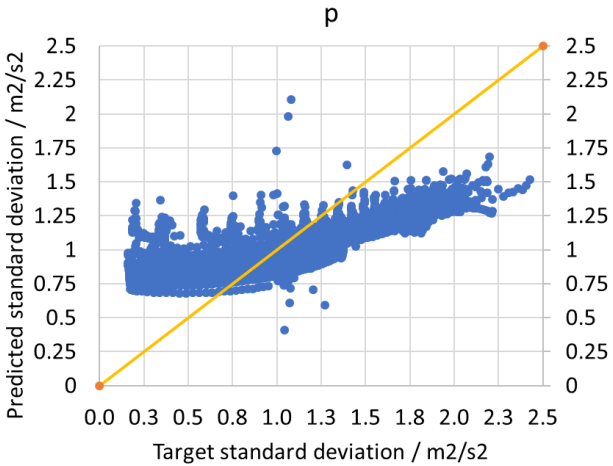
3^4

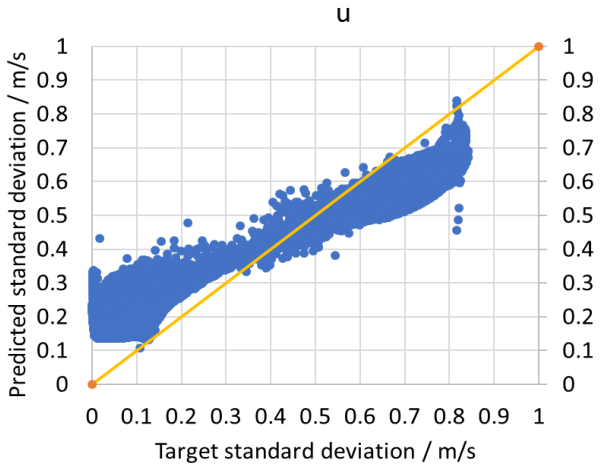
Deep Learning

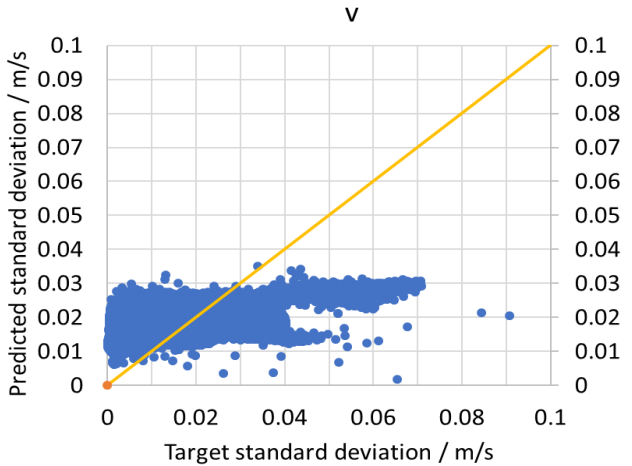


- Activation function hidden layers: tanh
- Activation output layer: linear
- Early stopping
- Dimension inputs: 29 features
- Dimension hidden layers: 200
- Dimension output layer: 4 (3 presented)
- Back propagation and the Adam optimizer
- Training: ~24 min, Prediction: ~0.3 s

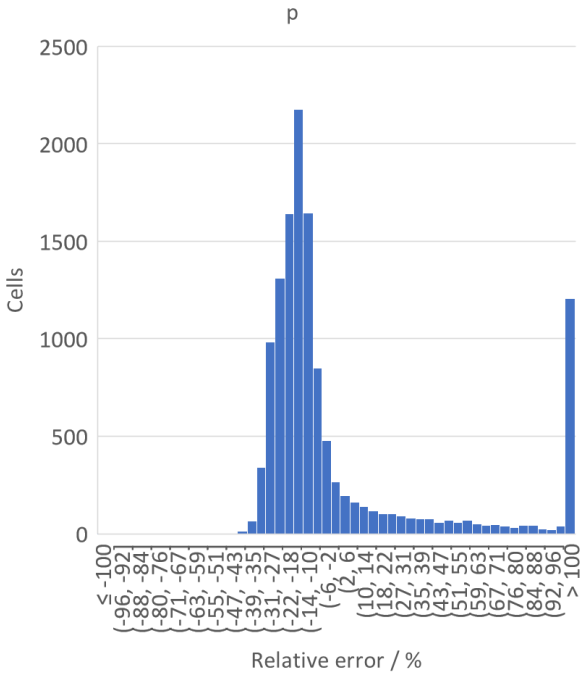
Preliminary findings



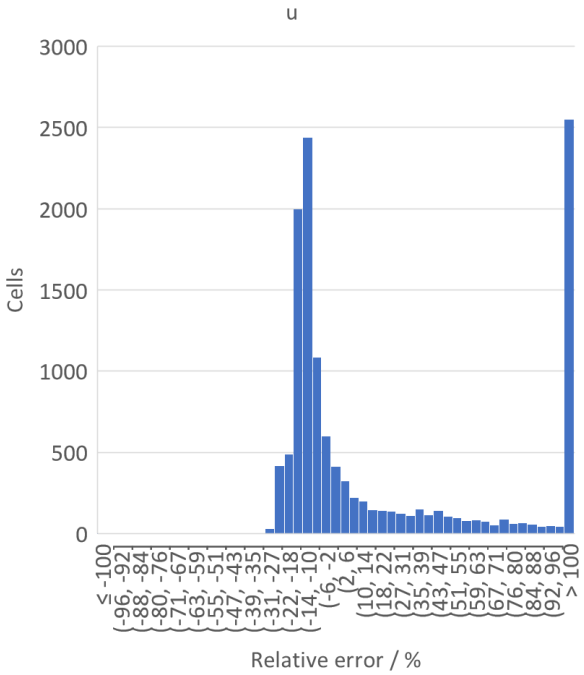




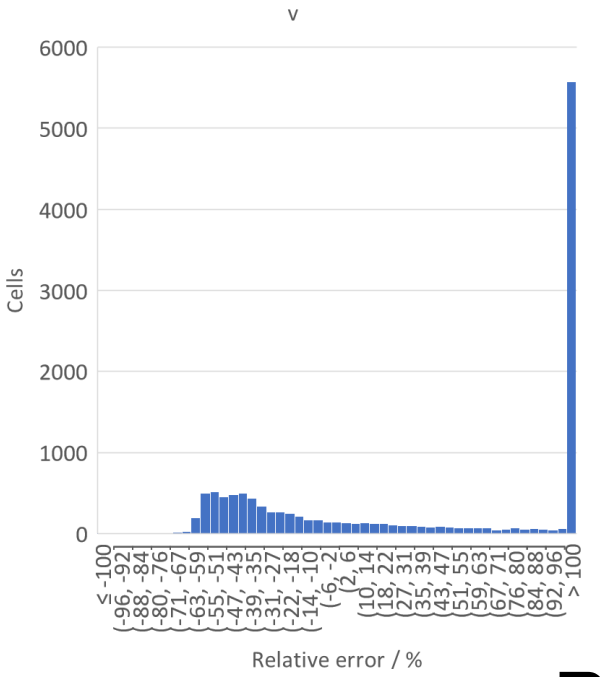
Preliminary findings (normalized with local target)



avg: 14%
median: -15%
stddev: 82%

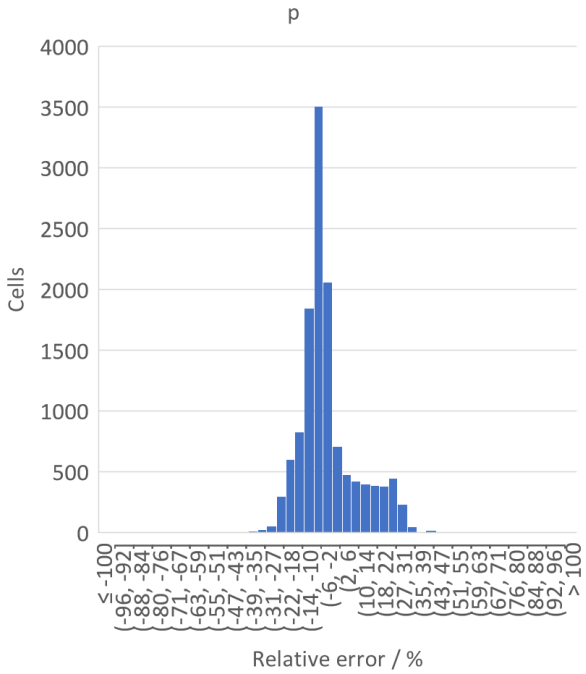


avg: 274%
median: -6%
stddev: 1662 %

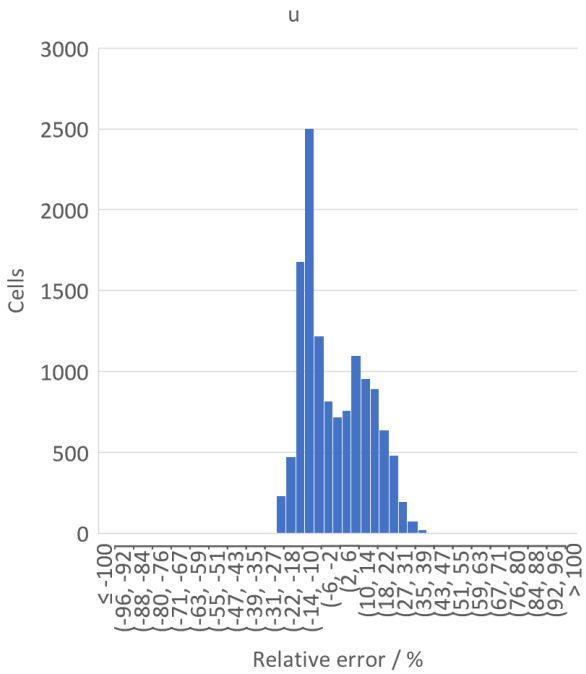


avg: 215%
median: 48%
stddev: 896%

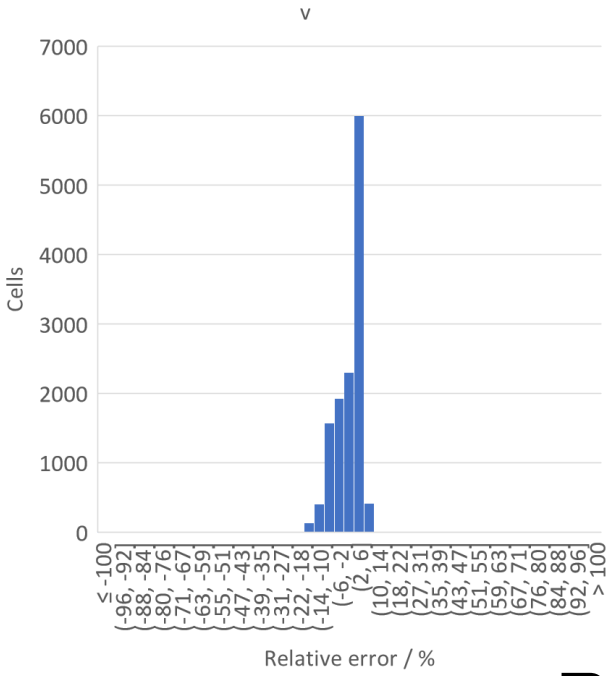
Preliminary findings (normalized with maximum target)



avg: -3.9%
median: -7.0%
stddev: 12%

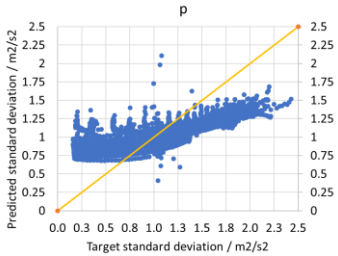


avg: -1.1%
median: -4.7%
stddev: 14%



avg: -0.1%
median: 2.1%
stddev: 5.4%

Preliminary findings

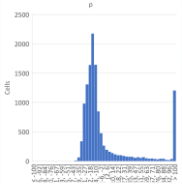


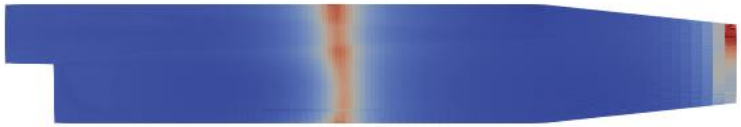
$\sigma(p_{target})$ / m^2/s^2

0.0 0.5 1.0 1.5 2.0 2.4

$\sigma(p_{predicted})$ / m^2/s^2

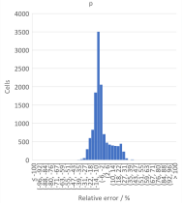
0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.1





Relative error / % (local normalization)

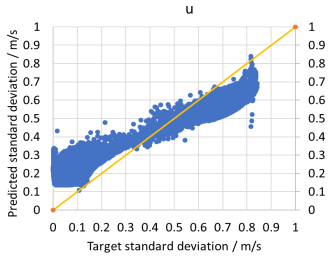
-60.6 100.0 200.0 300.0 400.0 560.0

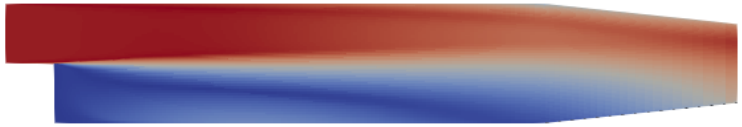


Relative error / % (normalized with max)

-38.9 -20.0 -10.0 0.0 10.0 20.0 30.0 46.9

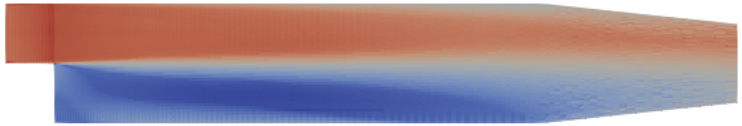
Preliminary findings





$\sigma(u_{target})$ / m/s

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

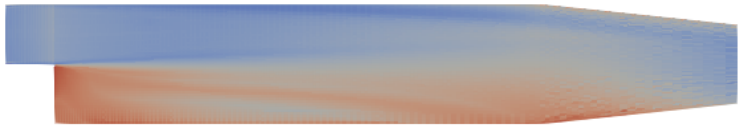


$\sigma(u_{predicted})$ / m/s

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

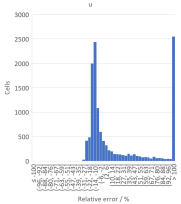
Relative error / % (local normalization)

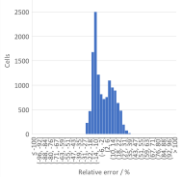
-44.0 1.e+4 2.e+4 3.e+4 4.e+4 5.e+4 6.e+4 76944.5



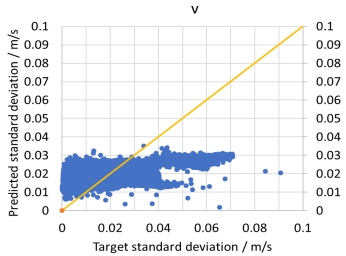
Relative error / % (normalized with max)

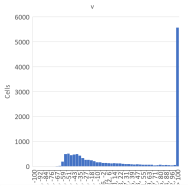
-42.7 -30.0 -20.0 -10.0 0.0 10.0 20.0 30.0 40.0 49.3

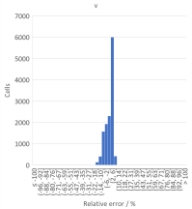




Preliminary findings







$\sigma(v_{target})$ / m/s

0.0 0.1 0.1 0.2 0.2 0.2

$\sigma(v_{predicted})$ / m/s

-0.006 0.0 0.005 0.01 0.01 0.02 0.02 0.03 0.04 0.043

Relative error / % (local normalization)

-112.9 1.e+4 2.e+4 3.e+4 4.e+4 5.e+4 62784.6

Relative error / % (normalized with max)

-91.8 -80.0 -60.0 -40.0 -20.0 0.0 10.4

RI. SE

Preliminary findings

- Approx. 80 x speedup, considered ANN training is performed in background
- Possibilities to reach correlation between CFD and deep learning
- Geometry independence need further investigations
- Conservative ANN
- Test dataset outside of training and validation region
- Small standard deviations – large relative errors

Future work

- Apply for external funding
- Test on real cases, preferably 3D
- Test on various geometries
- Investigate more extensive data where training and test sets overlap
- Improvement of the deep learning algorithms

Purpose for being here

- Show current activities within RISE
- Raise and scan for interest
- Getting valuable input from experts and stakeholders
- Looking for partners or letter of support for upcoming calls

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