Using ML to improve RANS Turbulence models

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Contents :

Turbulence :

Almost all of the turbulence theory is based on Navier Stokes equations.
Till today it is still one of the topics in classical physics problems.

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z$$

We have three common types of turbulence models :

DNS :

A direct numerical simulation is a simulation in computational fluid dynamics in which the Navier–Stokes equations are numerically solved without any turbulence model.

LES :

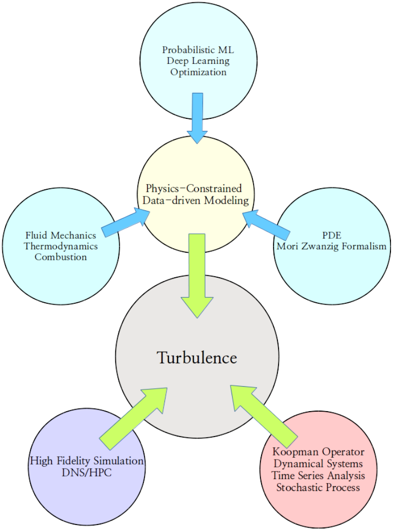
Moderately accurate and computationally costly.

RANS :

We take average usually in time.Computing this model is not expensive but it's not also that exact.

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = \frac{\partial}{\partial x_j}\left[-\bar{p}\delta_{ij} + \nu\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right) - \overline{u_i' u_j'}\right]$$

How Turbulence and Data science can be relevant :



When is it started?

Started in 2015 by joint research between NASA and University of Michigan.The most prominent paper("Turbulence Modeling in the Age of Data") published in January of 2019 in the journal of Annual Review of Fluid Mechanics(IF=14.814)

Active Research groups :

-University of Michigan-leading university
-Delft university of Technology
-Virginia Tech
-and some other universities

Data collection :

Low fidelity data by simulations(OpenFoam)

High fidelity data by experiments that is available like Johns Hopkins Dataset

Low fidelity data(Simulation Data) :

We obtain it by OpenFoam :

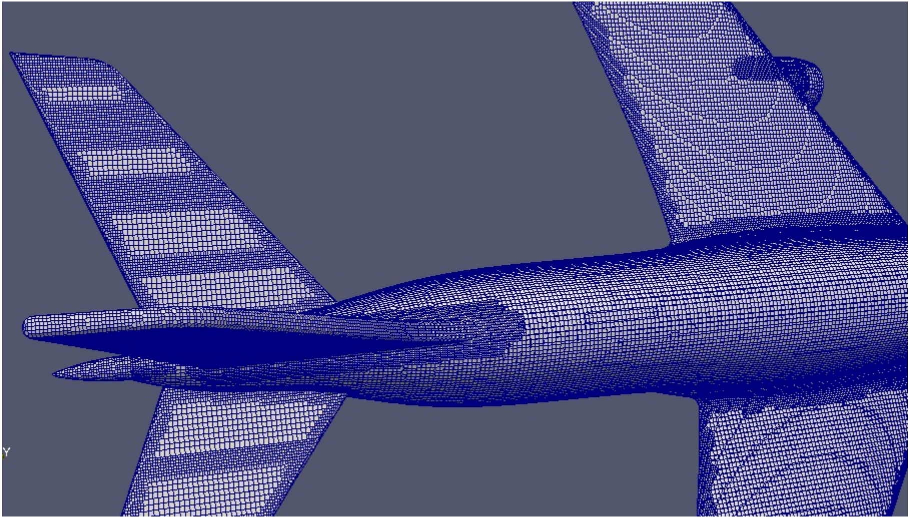
It is a C++ toolbox

It is used for continuum mechanics particularly fluid dynamic problems

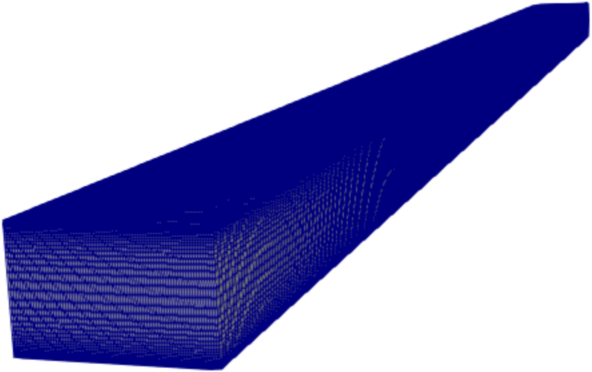
It is completely free !

Structure of the research :

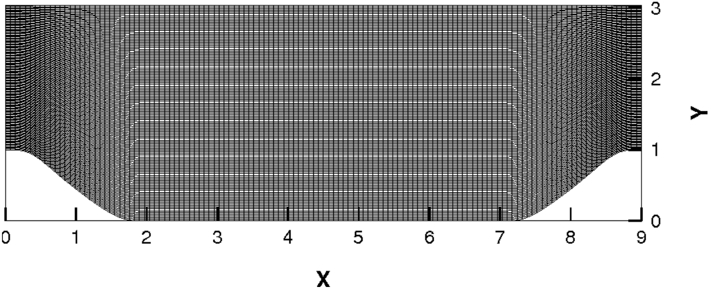
Mesh :



3D-channel flow :



Periodic hills :

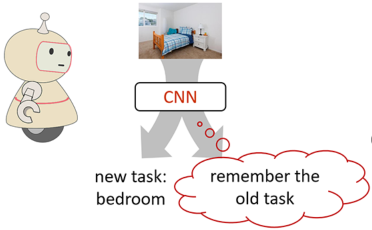


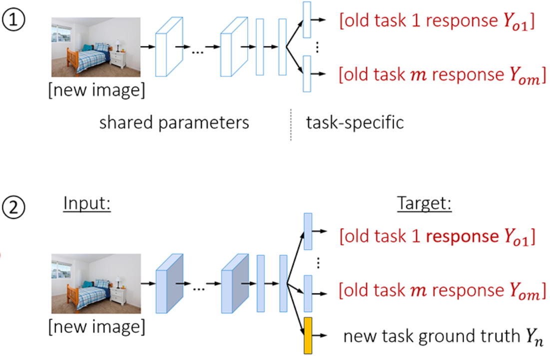
Learning Without Forgetting :

One of the biggest challenges is that we want to obtain a RANS model that is applicable for a wide range of applications.

The idea is that we won't update our training set for next training but the model will remember previous ones.

Learning Without Forgetting :





CNN :

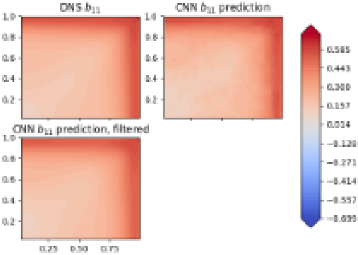
1.Getting low fidelity data by simulation from solvers like OpenFoam(=C++ toolbox for the development of customized numerical solvers)

2.Getting high fidelity data from online sources like Johns Hopkins university database or ERCOFTAC

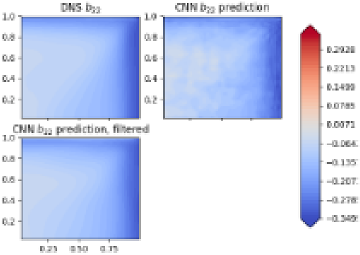
3.Improving low fidelity data(in my research RANS data) using ML methods.

4.Compare results from stage 3 with high fidelity data in stage 2 and make conclusion.

Reproduced results(Kaandorp-Delft University of Technology) :

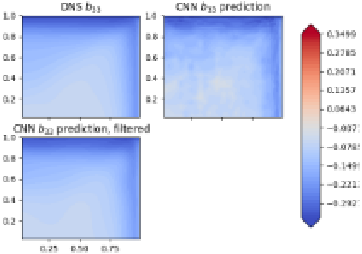


(a) b_{11}

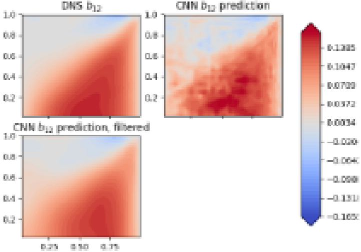


(b) b_{22}

Reproduced results(Kaandorp-Delft University of Technology) :

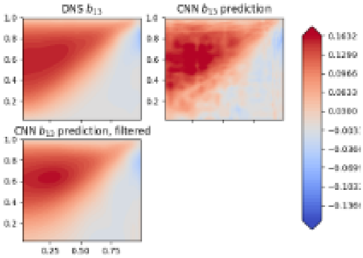


(c) b_{33}

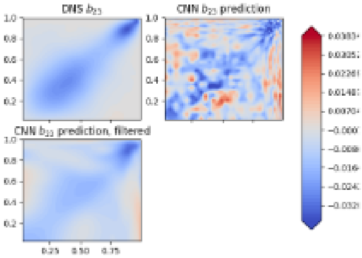


(d) b_{12}

Reproduced results(Kaandorp-Delft University of Technology) :



(e) b_{13}



(f) b_{23}

Other possible research :

Testing on similar cases. For example train for channel flow and test it on a near similar case. The goal is to see how much can we get a stable general RANS models.

References :

-"Learning without Forgetting" by Zhizhong Li, Derek Hoiem.
-Master thesis "Machine Learning for Data-Driven RANS Turbulence Modelling" by Mikael Kaandorp.

Thank you for your attention !