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Machine Learning algorithms for Wall-model LES of high speed flow for aerospace applications.

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Project Motivation

Hypersonic regime: some cases of aerospace applications

Hypersonic regime identifies fluid flows with speed that exceeds five time the speed of sound (**Mach 5 and above)**.

Hypersonic regime is encountered in various applications relevant to the aerospace industry.

Atmospheric flights

Sub-orbital flights

Orbital flights

Planetary Re-entry

Project Motivation

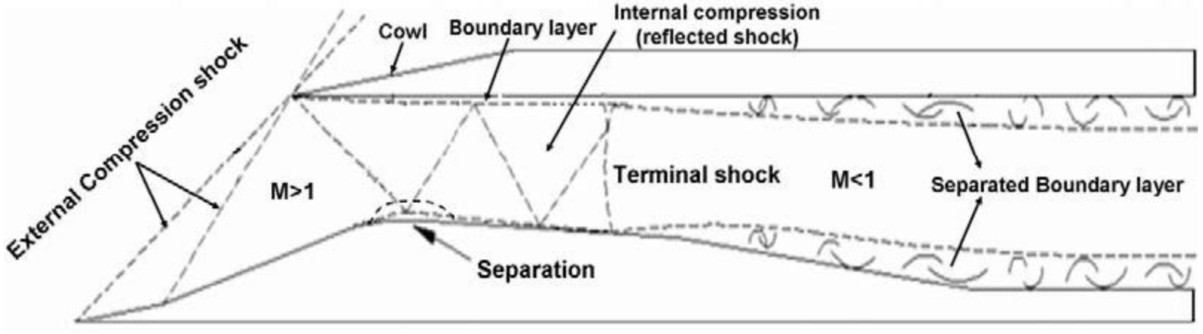
Characteristics of hypersonic flows:

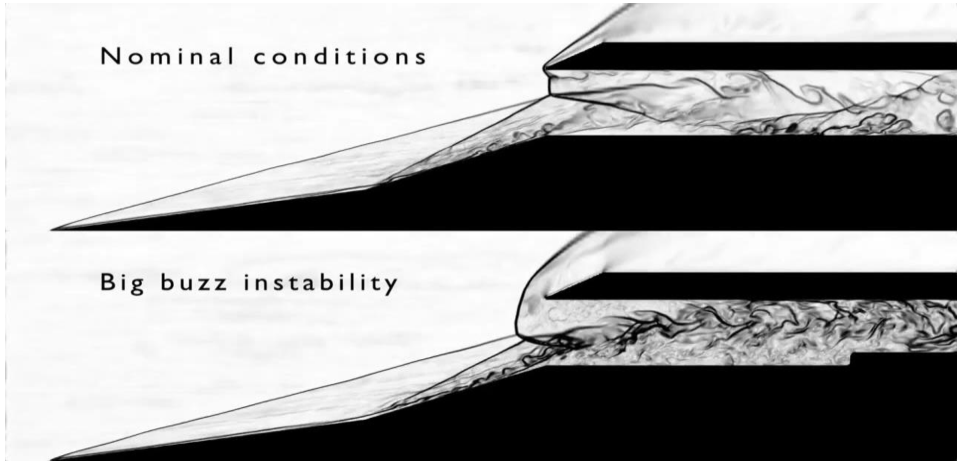
Different physics phenomena arise when the **interaction between a solid body and a hypersonic flow** happens:

- Small shock stand-off distance
- Entropy layer
- Viscous interaction
- High-temperature flow

These peculiarities lead to the **arising of various instabilities** that vary significantly the mechanical and thermal loads on the system

Hypersonic intake:

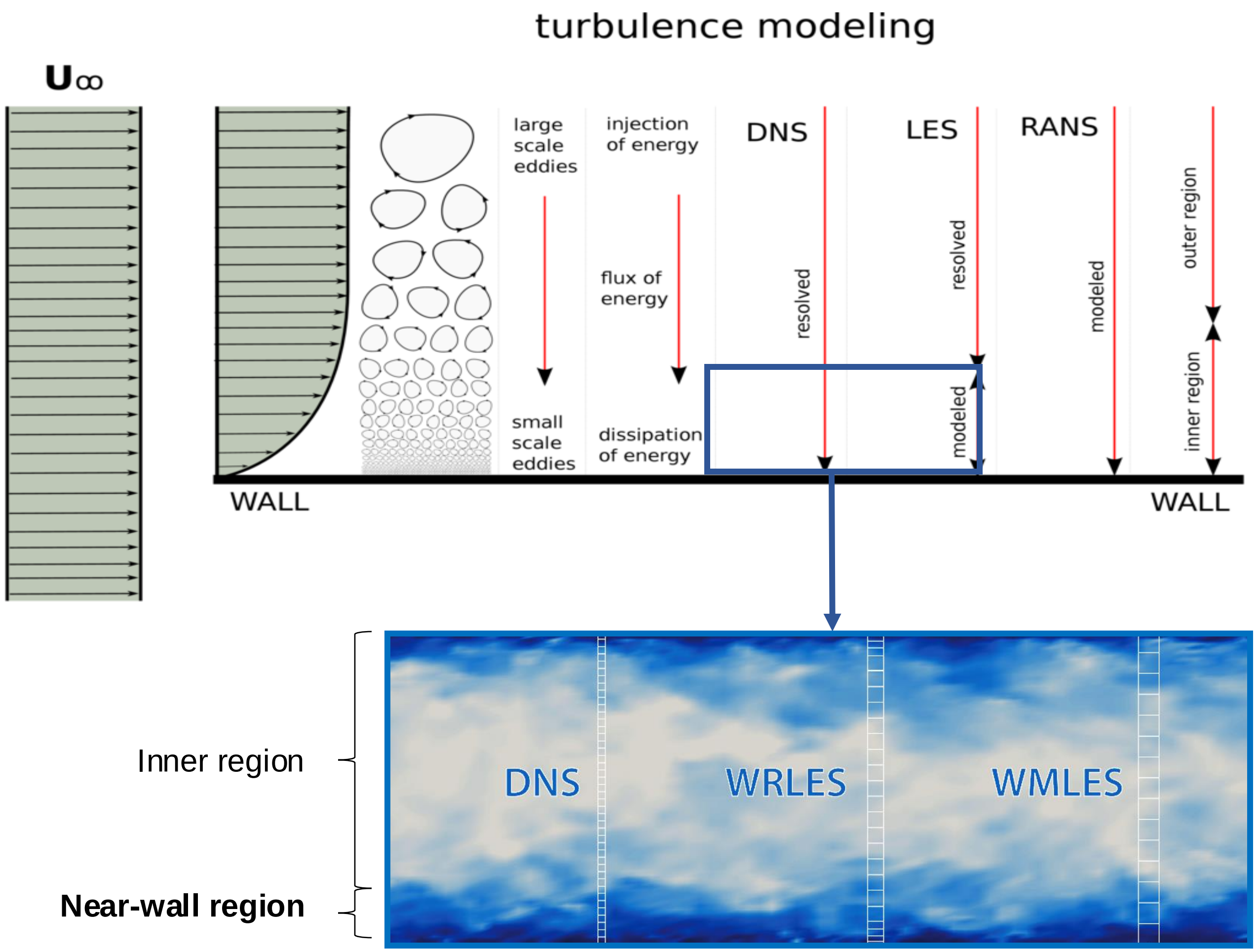




Large-Eddy Simulations of the Unsteady Behavior of a Hypersonic Intake at Mach 5, De Vanna, Picano, Benini, Quinn

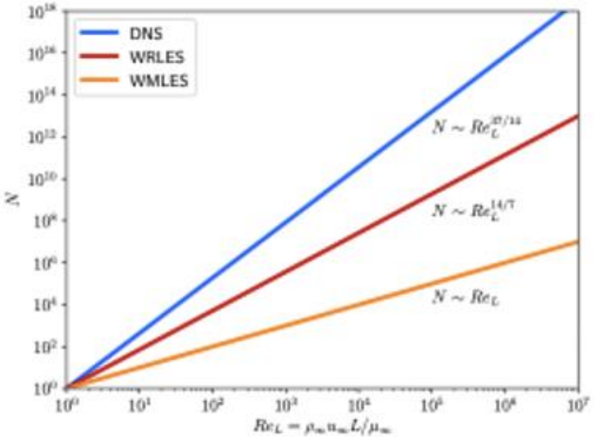
State of the art methodologies

Limitations of current numerical approach employed to simulate unsteady flow.



Simulations of turbulent flows, particularly at high Reynolds Numbers and related to complex geometry, is intractable by current CFD methodologies primarily due to **high computational cost required**.

Grid-points required for near-wall region:

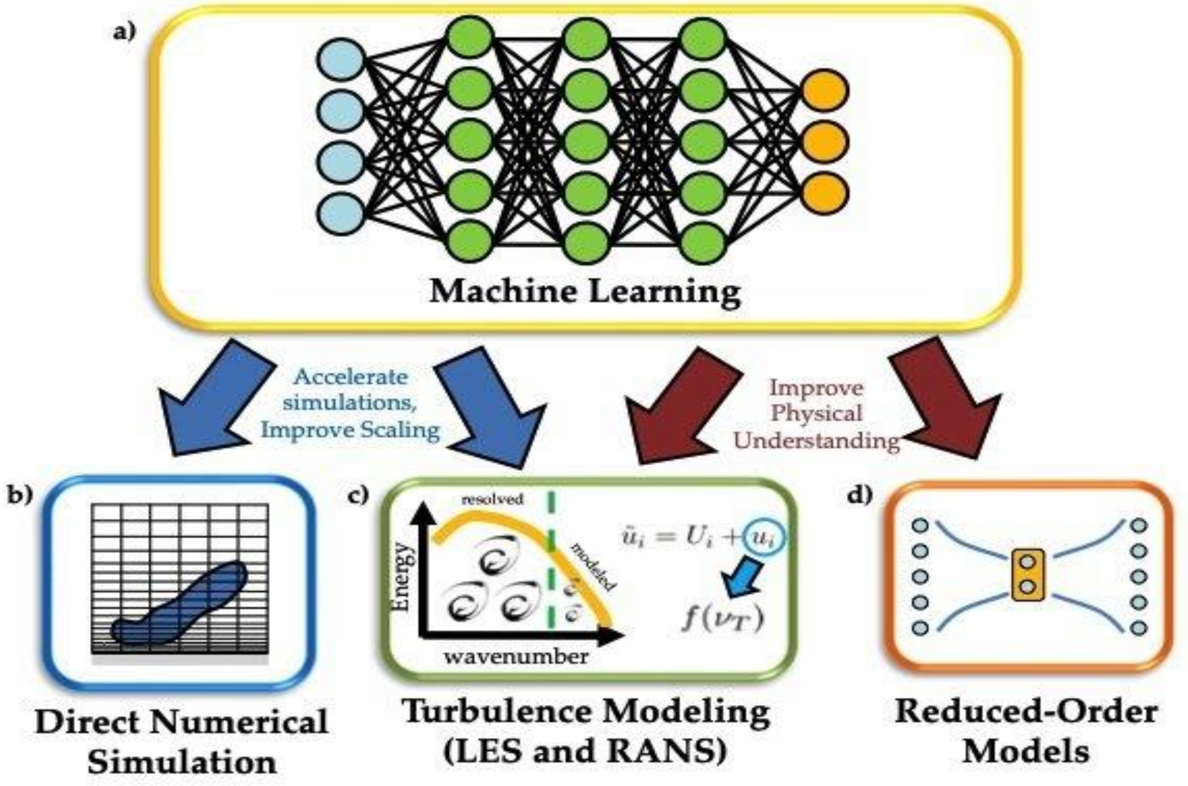


Machine Learning

Machine Learning to overcome the limitations of cutting-edge CFD methodologies:

Machine Learning (ML) is a field of study in Artificial Intelligence (AI) **able to create algorithms that can recognize patterns in data and forecast outcomes** without the need for explicit mathematical models.

Deep Learning and so Neural Networks are able to develop hierarchical representation of data suitable to hierarchical structures of turbulence scales.

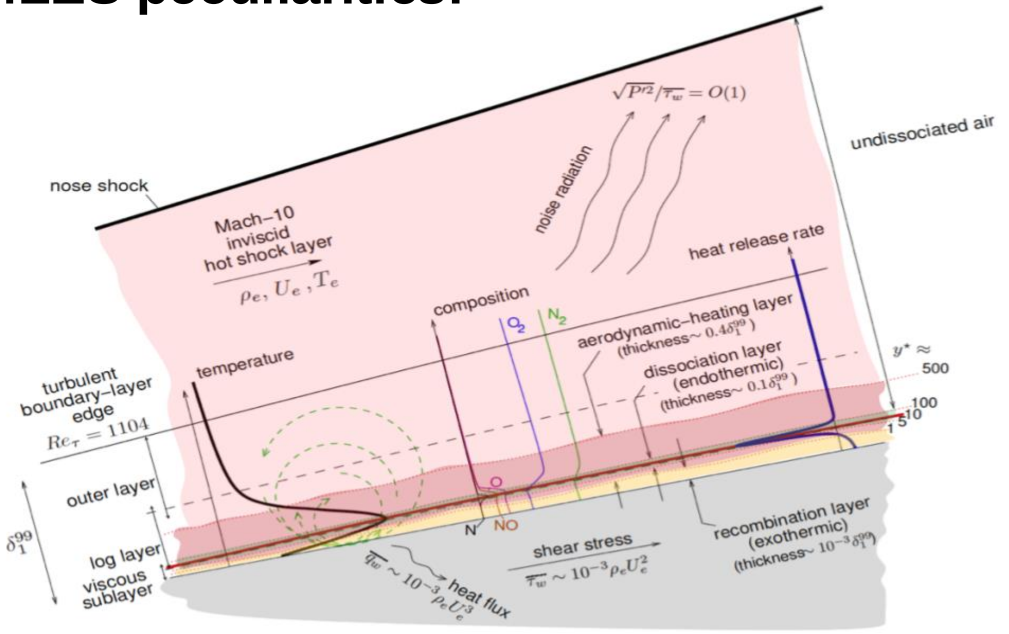


Enhancing computational fluid dynamics with machine learning by Ricardo Vinuesa & Steven L. Branton

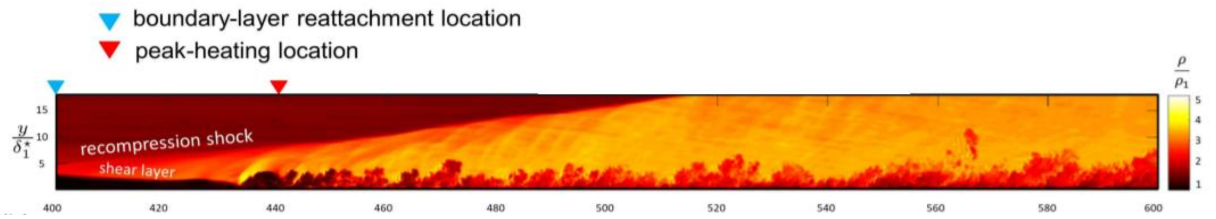
Activity Breakdown: Task #1

Understand the effects of compressibility and WMLES peculiarities:

- Understanding of the physical aspects of highly compressible flows.
- Implementation of wall-model in the LES framework for simple geometry (flat plate).
- Validating model using DNS data already available.
- Assess the adaptability of the model to different scenarios.
- Assess performance of WMLES on flat plate with zero pressure gradient. Considerations for more complex scenarios (shock wave – boundary layer interactions)



Schematics of the structure of the hypersonic turbulent boundary layer. Adapted from Urzay et al., Annual Research Briefs, CTR [2020]



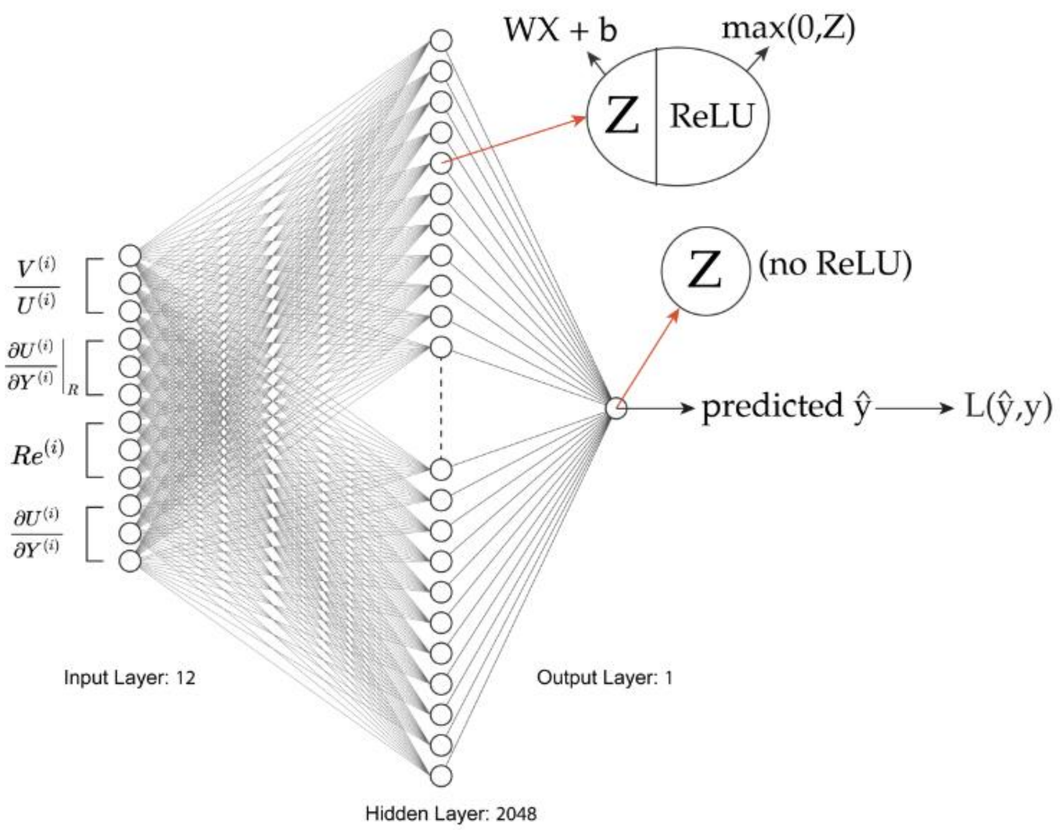
Density contours of shock wave – boundary layer interaction at Mach 6. Fu et al. [2021] JFM

Activity Breakdown: Task #2

Develop a Machine Learning algorithm :

- Understanding of the Machine Learning environment.
- Collect data available from DNS and LES simulations.
- Develop a suitable Machine Learning algorithm.
- Couple the ML algorithm with CFD solver.
- Apply the blended model on a simple case (flat plate, zero pressure gradient).
- Compare results with DNS and LES ones.
- Assess the gaining in accuracy reached , time and computational cost required.

Neural Network model as reference:

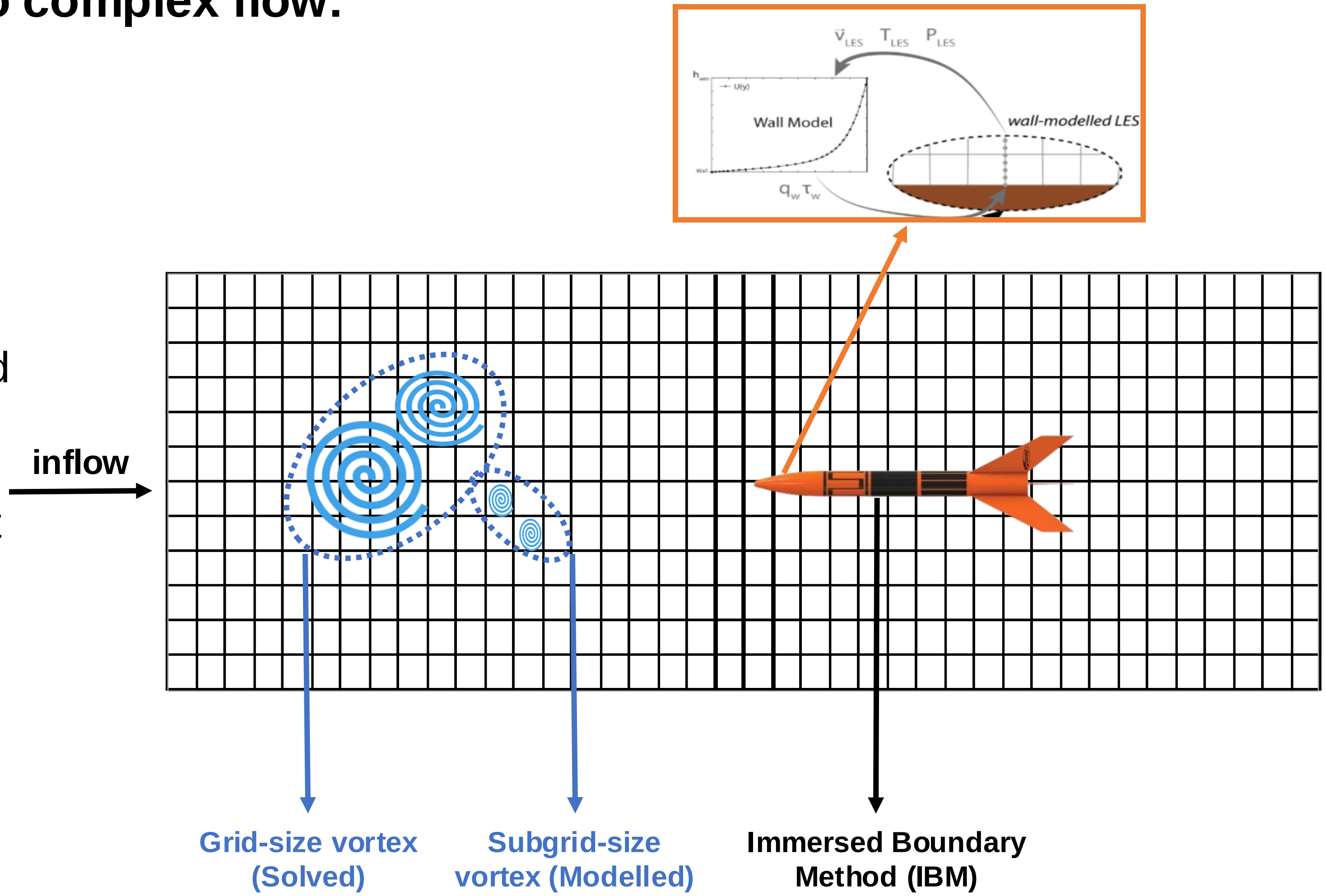


Neural Network and Deep Learnin presentation. Michele Cogo

Activity Breakdown: Task #3

Application of ML based wall-model to complex flow:

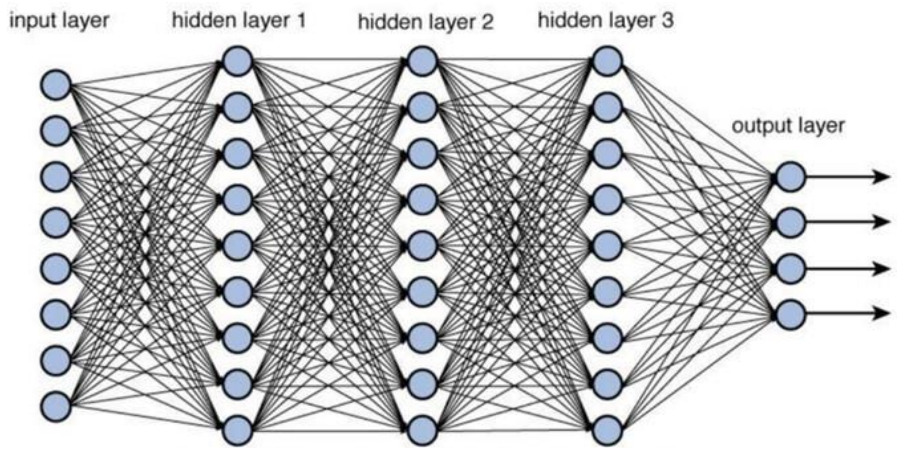
- Simulation set-up.
- Implement the ML algorithm.
- Perform the simulation with the ML based model.
- Assess the performance reached against the model without ML algorithm.
- Evaluate the characteristics of generality and scalability of the blended model.



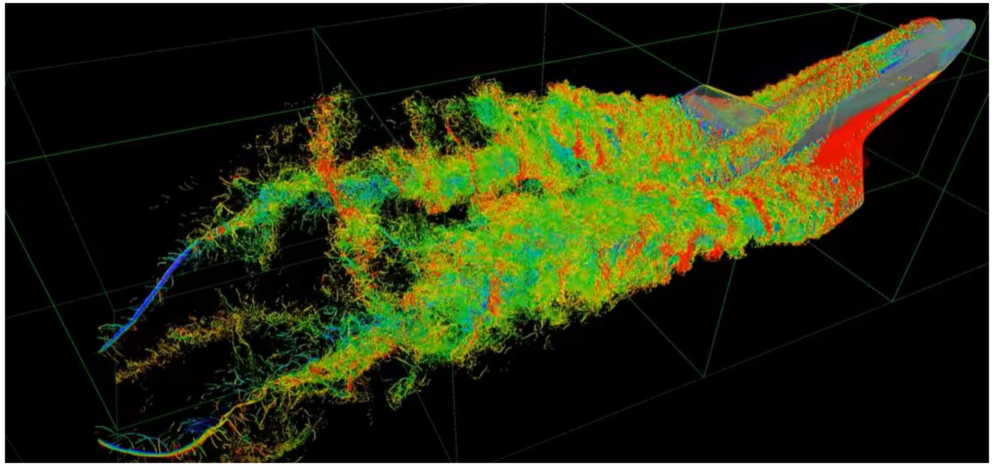
Final Remarks

Summary of the proposed activity:

- Investigation of physics phenomena related to high-speed turbulent flows and development of WMLES applied on simple geometries.
- Investigation of different Machine Learning techniques and development of a suitable algorithm to enhance turbulence model in near-wall region.
- Implementation of Machine learning algorithm in the WMLES and application of the combined method to a more complex case.



Deep Learning: a comprehensive guide, Iakshya Ruhela



Space Shuttle 10 bilion voxel CFD on 8x64 GB GPUs, Dr. Moritz Lehmann

Thanks for the attention

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