AI-DRIVEN TUNING OF RANS TRANSITION MODELS

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Summary

This study introduces a novel framework that harnesses the capabilities of deep neural networks to optimize the coefficients of a transition model, ensuring alignment with existing experimental data. Our approach has been validated using the widely recognized Gamma transition model developed by Menter et al. [1] and the comprehensive ERCOFTAC T3 flat plate experiment series [2]. The process entails the construction of an extensive database by adjusting the transition model coefficients, which then informs a fully connected neural network designed to predict wall shear stress. After training, the neural network tackles the inverse problem of identifying the coefficient set that yields the closest match to experimental wall shear stress measurements.

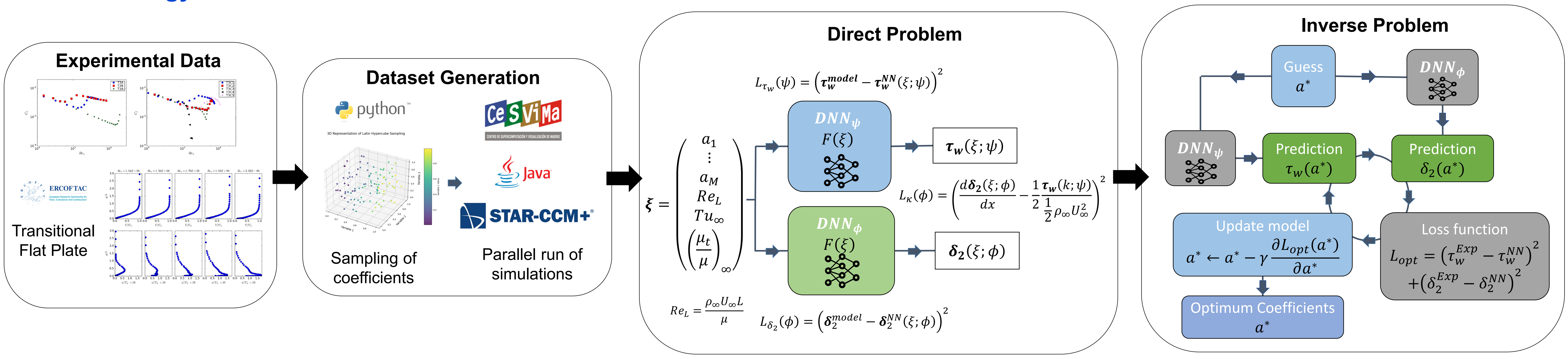
The application of our method to a zero-pressure gradient transitional flat plate (T3A) resulted in an accurate prediction of the transition location. However, achieving a precise match for the entire wall shear stress distribution was challenged by factors not included as neural network inputs, such as freestream velocity, turbulence intensity, and turbulence viscosity ratio.

Our results not only demonstrate the potential of our framework, but also establish a foundation for a tool that could revolutionize how researchers and industry professionals calibrate transition model coefficients. This tool aims to provide valuable insights into performance through cost-effective RANS simulations, reducing the reliance on manual intervention and more expensive alternative methods.

Objective

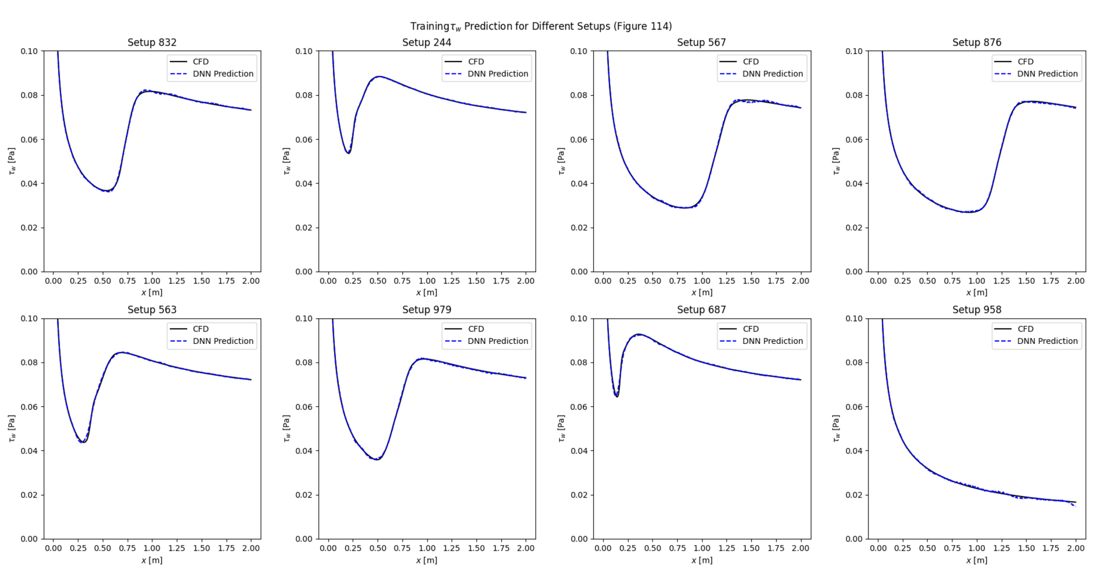
"Develop a computational tool to automatically calibrate the coefficients of a RANS transition model to match experimental data accurately".

Methodology

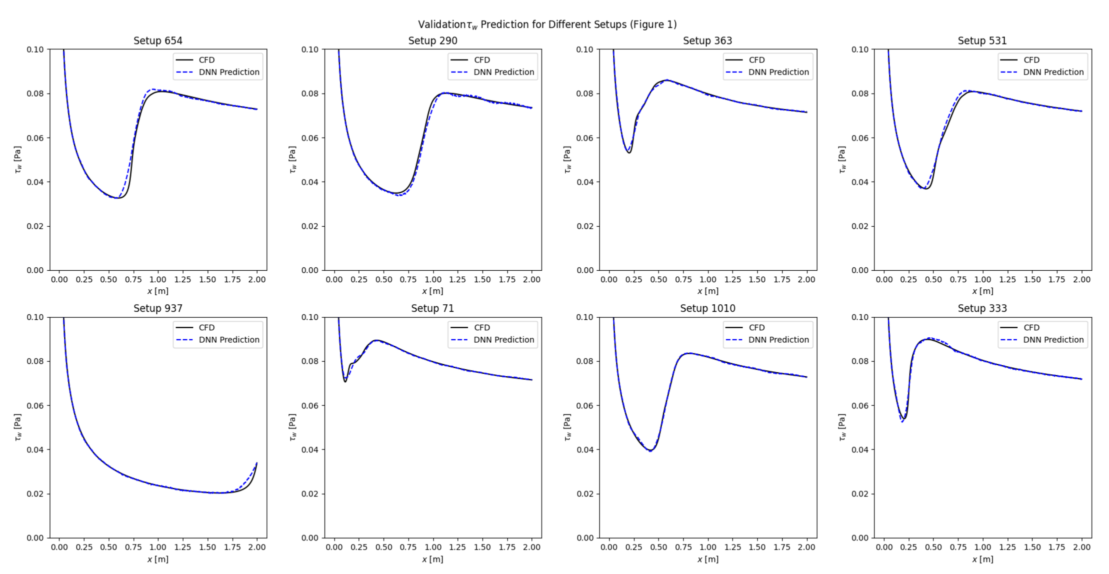


Results – 2D ZPG Flat Plate (T3A)

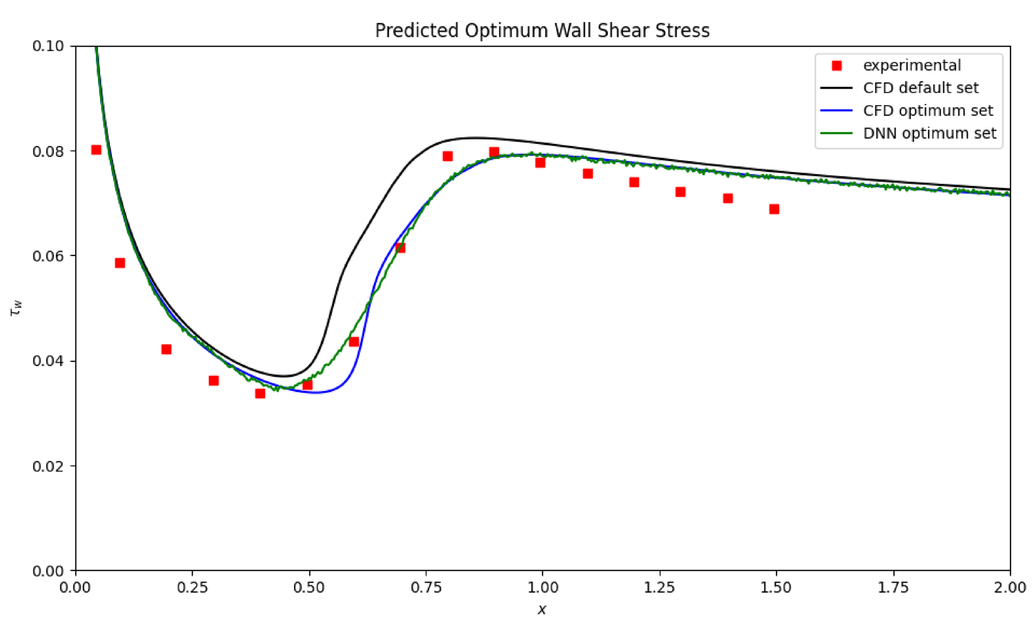
Training



Validation



Optimization

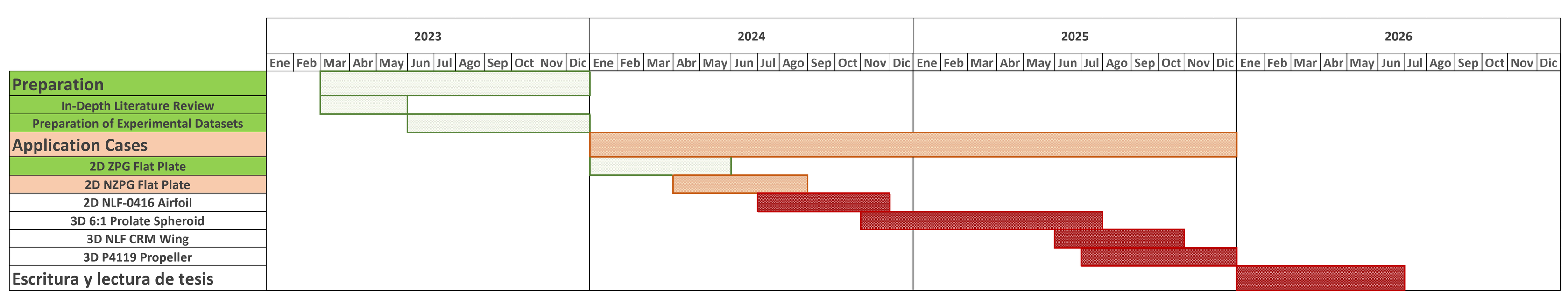


- Multi-Layer Perceptron with 3 hidden layers, 128 neurons/layer, learning rate of 1e-3, Z-score normalization, ADAM optimizer. 1024 simulations dataset, (80% training, 10% validation, 10% testing).
- The results show the applicability of the framework and the capability of finding an optimum set of coefficients for a given case.

	σ_γ	$Ca2$	$Ce2$	γ_{min}	$CTU1$	$CTU2$	$CTU3$	$Conset1$
Default	1	0.06	50	$1e-10$	100	1000	1	2.2
Optimized	1.23	0.08	74.94	$1e-10$	91.59	1074.77	0.97	1.97
Difference	23.3%	38.3%	50%	0%	−18.4%	7.4%	−2.8%	−10.22%

Vectorization of flow visualization showing the structure of the transitional flow due to a laminar separation bubble over a flat plate due to an imposed negative pressure gradient [3].

Planning



Publications and Presentations

Ponencias en congresos internacionales: ECCOMAS24 (June 2024, Lisbon)

Conclusions and Future Work

- Determine the minimum required dataset size for the neural network to achieve meaningful and accurate predictions.
- Develop a model capable of predicting and optimizing wall shear stress for every transitional flat plate case, including both zero-pressure gradient (ZPG) and non-zero-pressure gradient (NZPG)
- An implemented hyperparameter optimization is expected to enhance the neural network predictions.
- A comprehensive statistical validation is currently underway.
- Evaluate the possibility of implementing a recurrent neural network (RNN) to capture spatial correlations in 2D setups.
- Explore the use of reinforcement learning to address the inverse problem.
- Implement a convolutional neural network for 3D setups.

Bibliography

[1] Menter, F. R.; Smirnov, P. E.; Liu, T.; Avancha, R. A One-Equation Local Correlation Based Transition Model. Flow Turbulence Combust 95, 583-619 (2015).
[2] Coupland, J. ERCOFTAC special interest group on laminar to turbulent transition and retransition: T3A and T3B cases. A309514 (1990).
[3] Jagadeesh, C. S.; Balthazar, M.; Gross, A.; Fasel, H. Experimental Investigation of the Structure and Dynamics of Laminar Separation Bubbles at the Onset of Bursting. 31st AIAA Applied Aerodynamics Conference (2013).