Data-Driven Transition Modeling

Position Statement and Summary

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Outline

1. Panelists and Moderators
2. Statement and Position
3. Perspectives

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Advertisement: our latest work on data-driven turbulence modeling

- X.H. Zhou, J. Han, H. Xiao. Frame-independent vector-cloud neural network for nonlocal constitutive modelling on arbitrary grids. *Computer Methods in Applied Mechanics and Engineering*. 388, 114211, 2022.
- X.L. Zhang, H. Xiao, X. Luo, G. He. Ensemble Kalman method for learning turbulence models from indirect observation data. arXiv: 2202.05122

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Disclaimer

Two papers on transition modeling (with Dr. Choudhari et al., NASA Langley):

- M. I. Zafar, H. Xiao, M. M. Choudhari, F. Li, C.-L. Chang, P. Paredes, B. Venkatachari. Convolutional neural network for transition modeling based on linear stability theory. Physical Review Fluids. 5, 113903 (21 pages), 2020.
- M. I. Zafar, M. M. Choudhari, P. Paredes, H. Xiao. Recurrent neural network for end-to-end modeling of laminar-turbulent transition, 2(e17), 2021. *Data Centric Engineering*.

(Contributed to another paper on transition)

Path to Transition

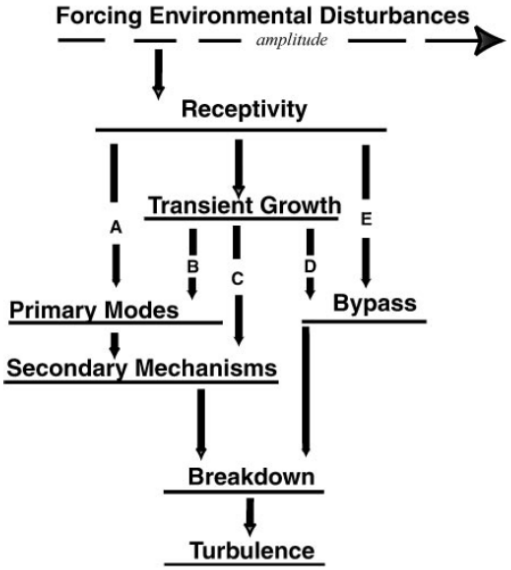

Figure from Wikipedia.

Computational methods of laminar-turbulent transition

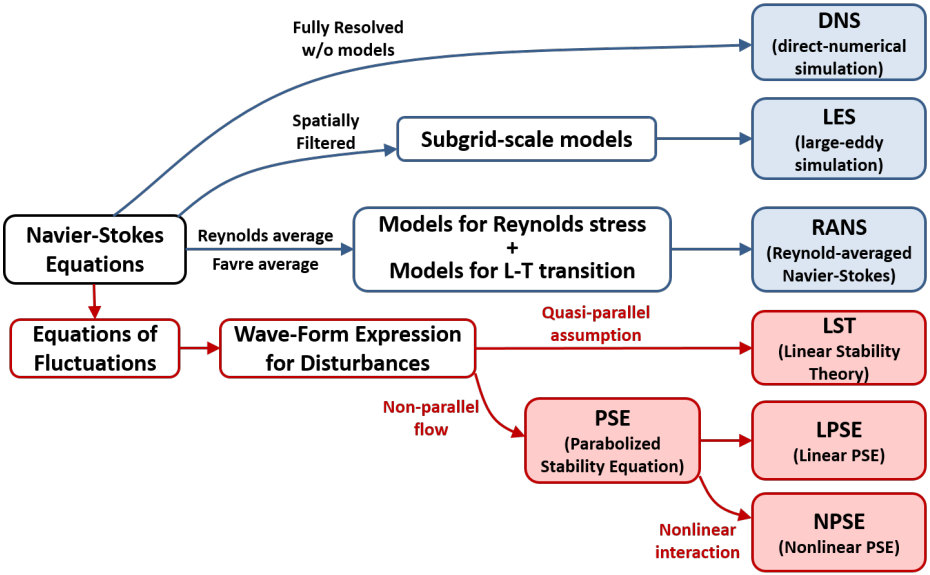

Figure courtesy of Dr. Solkeun Jee (GIST)

Position Statement – Xiao

Hierarchy of machine learning methods for physics

1. Algebraic models (empirical formulas): e.g., fully connected NN
2. Field-to-scalar mapping (e.g., velocity to growth rate): e.g., CNN
3. Neural operators: resolution-independent mapping (e.g., GNN, Vector Cloud NN)

Where do you anchor the machine learning model?

- Linear stability theory (eigenvalue problem)
- Parabolized stability equation
- Correlation-based transport PDEs (intermittency, amplification factor)
- Term based closure models for above models (N_{critical}, P, E)

What to Inherit? I

How can we adopt data-driven methods developed in turbulence modeling in transition modeling?

- Single point closure, algebraic empirical models
- Field Inversion Machine Learning or any optimization methods
- Genetic Programming / Symbolic regression
- Neural operators for PDE surrogate modeling: e.g., Vector Cloud NN, GNN, DeepONet

What to Invent?

What are the unique aspect of transition modeling (not present in turbulence modeling)?

- Mostly dealing with scalars: no tensor algebra needed.
- Turbulent constitutive model (Lumley 1973) is still an aspiration? Not for transition modeling
- Frame invariance more relaxed (intrinsic coordinate system in 2D boundary layer: CNN acceptable)
- Fewer hard/physical constraints: blessing or pitfall?

What are Easy and What are Difficult?

What are the obstacles and low-hanging fruits?

- Inevitable coupling of transition and turbulence modeling: low-Re in post-transition region. No clean minimum case possible.
- Hierarchical modeling of many factors

Other questions

- What can NASA do to accelerate data-driven transition modeling?
- ...