Simulating complex flows in energy systems by resolving turbulent structures

Michael J. Acton, Giancarlo Lenci, Jingyong Zhang, Emilio Baglietto
Massachusetts Institute of Technology - Department of Nuclear Science and Engineering

Objective
Assess the performance of a new hybrid turbulence model in simulating complex turbulent flows, which are typical of many energy systems.

Desirable features:
- Accuracy and low cost
- Robustness
- Ease of use
- Level of description
- Numerical convergence
- Suitability for complex flows

Consequences of our limitations in turbulence simulation
Improved tools for simulating turbulence could be used to design more efficient energy systems, to obtain more accurate weather forecasts, and to prevent several causes of failure of engineering components.

The STRUCT Approach
The strategy of STRUCT is to overcome the lack of robustness of other hybrid turbulence models by leveraging URANS in regions of the flow in which such a model is suitable, and switching to hybrid models in high-turbulence regions.

Resolved flow frequency: $f_r = \sqrt{f_{URANS}}$
Modelled flow frequency: $f_{URANS} = \frac{f_r}{f_{URANS}}$

Controlled model:
- $f_r = f_{URANS}$
- $f_{URANS} = f_{URANS}$

Complete model:
- $f_r = \min\left(f_{URANS}, f_{LES}\right)$

Thermal Stripping
Turbulent flow of fuel streams at different temperatures can cause thermal stripping material degradation. This process has caused failures in sodium fast nuclear reactors.

Nuclear Fuel Assembly
Coolant flow through a nuclear reactor encounters mixing variables which generate turbulence. The accurate prediction of this turbulence is necessary to understand forces causing vibration.

Swirl Combustor
Reproducing flow behind a sudden expansion and downstream a swirl is used to improve the stability of pre-mixed combustion. The ability to effectively predict flow features in a swirl combustor is important to understand the underlying dynamics.

External Aerodynamics
External aerodynamics applications include flows around vehicles. Prediction of turbulence is important in the design process for fuel efficiency.

Conclusions: observed performance
- Compared to URANS:
  - Higher accuracy in mean flow predictions
  - Wider range of applicability, including unsteady cases
  - Increased information on unsteadiness (i.e. suitable for applications such as FSI, vibration, thermal fatigue, noise)
  - Comparable computational cost (approximately 20% increase)
  - Compared to LES:
    - Strongly reduced computational cost (10x-100x reduction)
    - Improved robustness in complex flows
    - Reduced sensitivity to inlet boundary conditions

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