Verifying and applying LES-C turbulence models for turbulent incompressible flow and fluid-fluid interaction problems

Mustafa Aggul*, Yasasya Batugedara†, Alexander E. Labovsky‡, Eda Onal§ and Kyle J. Schwiebert‖

* Department of Mathematics
Hacettepe University
Ankara 06800, Turkey
email: mustafaaggul@hacettepe.edu.tr

† Department of Mathematical Sciences
Michigan Technological University
Houghton, MI 49931, USA
email: bbatuged@mtu.edu

‡ Department of Mathematical Sciences
Michigan Technological University
Houghton, MI 49931, USA
email: aelabovs@mtu.edu - Web page: https://pages.mtu.edu/ aelabovs/

§ Department of Mathematics
Hacettepe University
Ankara 06800, Turkey
email: edaonal@hacettepe.edu.tr

‖ Department of Mathematical Sciences
Michigan Technological University
Houghton, MI 49931, USA
email: kjschwie@mtu.edu

ABSTRACT

The large eddy simulation (LES) models for incompressible flow have found wide application in computational fluid dynamics (CFD), including areas relevant to aeronautics such as computing drag and lift coefficients and fluid-structure interaction problems [1, 2]. LES models have also found application in climate science through modeling fluid-fluid (atmosphere-ocean) problems. Large eddy simulation with correction (LES-C) turbulence models, introduced in 2020, are a new class of turbulence models which rely on defect correction to build a high-accuracy turbulence model on top of any existing LES model [3, 4, 5]. LES-C models have two additional benefits worth serious consideration. First, LES-C models are easy to run in parallel: One processor can compute the defect (LES) solution, while the other processor computes the LES-C solution. Thus, if one has access to a machine with more than one computational core (essentially ubiquitous in modern architectures), the improved solution comes at nearly no cost in terms of the "wall time" it takes a simulation to complete. Second, LES-C models readily lend themselves to coupling with other defect correction approaches including the several options in numerical ordinary differential equations as in [2].

In this presentation, we will first discuss five LES-C models applied to several well-known benchmark problems such as flow over the backward-facing step and flow around a cylindrical obstacle. Notably, this section will conclude with first-ever numerical evidence that the LES-C models out compete their LES counterparts in a truly turbulent setting by resolving turbulent channel flow on a coarse mesh.

Finally, we will build upon a prior result in which the LES model Navier-Stokes omega was adapted

to fluid-fluid interaction problems, representing the first unconditionally stable and optimal order turbulence model for such problems. It will be shown that expanding this model into its corresponding LES-C model produces a yet more accurate solution, improving accuracy in time as well as in the LES model parameter. The numerical results are backed by a full numerical analysis, showing that, like its LES-C counterpart, Navier-Stokes omega with correction is unconditionally stable and of optimal order accuracy [5].

REFERENCES

[1] A. Labovsky, *Approximate Deconvolution with Correction: A Member of a New Class of Models for High Reynolds Number Flows*, SIAM Journal on Numerical Analysis, vol. 58(5), pp. 3068–3090, 2020.

[2] Y. Batugedara, A. Labovsky and K. Schwiebert, *Higher temporal accuracy for LES-C turbulence models*, Computer Methods in Applied Mechanics and Engineering, vol. 377, 113696, 2021.

[3] M. Aggul and A. Labovsky, *Approximate Deconvolution Models for Turbulent Fluid-Fluid Interaction Problems*, Computers & Mathematics with Applications, vol. 117, pp. 113-126, 2022.

[4] M. Aggul, A. Labovsky and K. Schwiebert, *NS-ω Model for Fluid-Fluid Interaction Problems at High Reynolds Numbers*, Computer Methods in Applied Mechanics and Engineering, vol. 395, 115052, 2022.

[5] M. Aggul, A. Labovsky and K. Schwiebert, *Fluid-Fluid Interaction Problems at High Reynolds Numbers: Reducing the Modeling Error with LES-C*, To Appear: SIAM Journal on Numerical Analysis. pp. 3068–3090, 2020.