Addressing Turbulence Model Form Uncertainty

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ABSTRACT

The aim of the present work is to investigate different strategies to reduce RANS model form uncertainty. We investigate if using (1) accurate knowledge on the normalized Reynolds stress anisotropy tensor, (2) a double scale turbulence model that can quantify uncertainty in the dissipation, or (3) a combination of both, can improve RANS predictions of the flow around a bluff body representative of a high rise building. Our quantities of interest are the mean velocity field and the mean pressure field on the surface of the building. An LES simulation of the flow is performed to generate a high-fidelity data set that can provide information on the anisotropy tensor and serve as a reference when comparing the three RANS predictions. The results show that correctly quantifying RANS model form uncertainty requires addressing uncertainty in both the normalized anisotropy tensor and the dissipation.

Keywords: Turbulence model form uncertainty, Bluff body, High-Rise building.

1. INTRODUCTION

RANS simulations are frequently used for flow simulations of engineering complexity. However, the turbulence model required to close the RANS equations introduce a significant amount of uncertainty in the results. The ability to quantify and reduce this uncertainty is key to supporting the use of RANS as a source of information for engineering decisions. Quantifying turbulence model form uncertainty is a challenging task, as there is no straightforward way to estimate it. However, one can reduce the model uncertainty by embedding more physics into the turbulence model equations. The aim of the present work is to investigate multiple strategies for reducing turbulence model form uncertainty, focussing on the k-ω SST model. The first strategy considers informing the production term of the k-ω SST model with the LES-computed anisotropy. The second strategy considers the adoption a double scale version the k-ω SST model, which is equivalent to introducing uncertainty in the dissipation. The third and final strategy considers the combination of the two previous techniques, i.e. it informs the double scale version of the k-ω SST with the LES-computed normalized anisotropy. To perform this study, we consider the case of the flow around a bluff body representative of a high rise building. Our Quantities of Interest (QoIs) are the mean velocity field and the mean pressure field on the surface of the building. Three RANS simulations of the flow around the high rise building are performed to assess the success of the three aforementioned strategies. The results are then compared against predictions from an LES simulation of the same flow.

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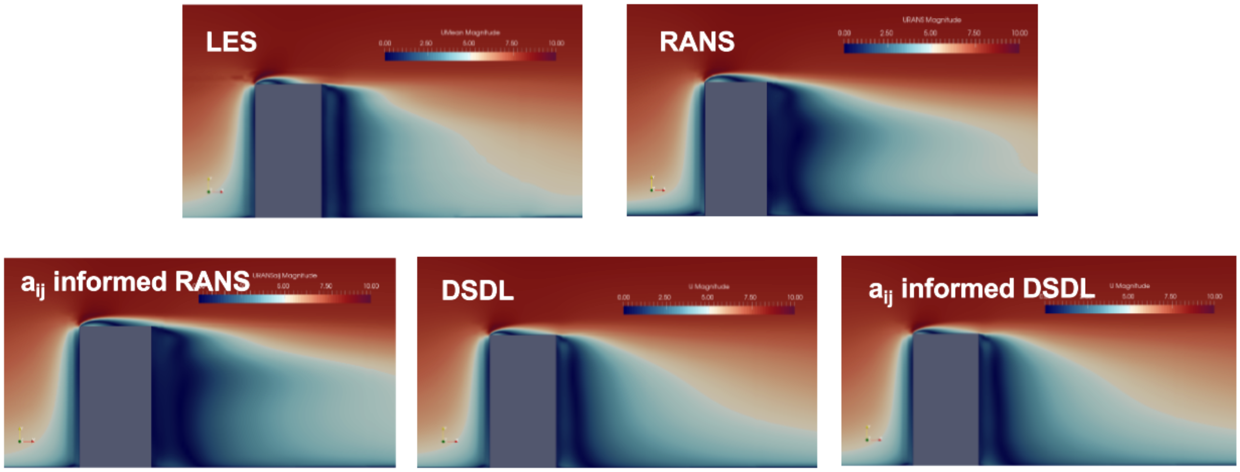

Figure 1. Comparison between the velocity field obtained computed by the LES, the informed RANS, the DSDL, and the informed DSDL.

2. A HIGH-FIDELTY ANISOTROPY TENSOR INFORMED MODEL

The first strategy informs the turbulence model with accurate knowledge on the Reynolds Stress tensor anisotropy. Specifically, the normalized anisotropy tensor

$$a_{ij} = \frac{R_{ij}}{k} - \frac{2}{3}\delta_{ij} \tag{1}$$

computed from an LES simulation is used to compute the production term of the k-ω SST model. The comparison of the prediction of the informed model with the standard k-ω SST and the LES predictions indicates that this approach is not sufficient to increase RANS model accuracy; Figure 1 shows that the size of both the separation region on the roof and the building wake remain significantly overpredicted.

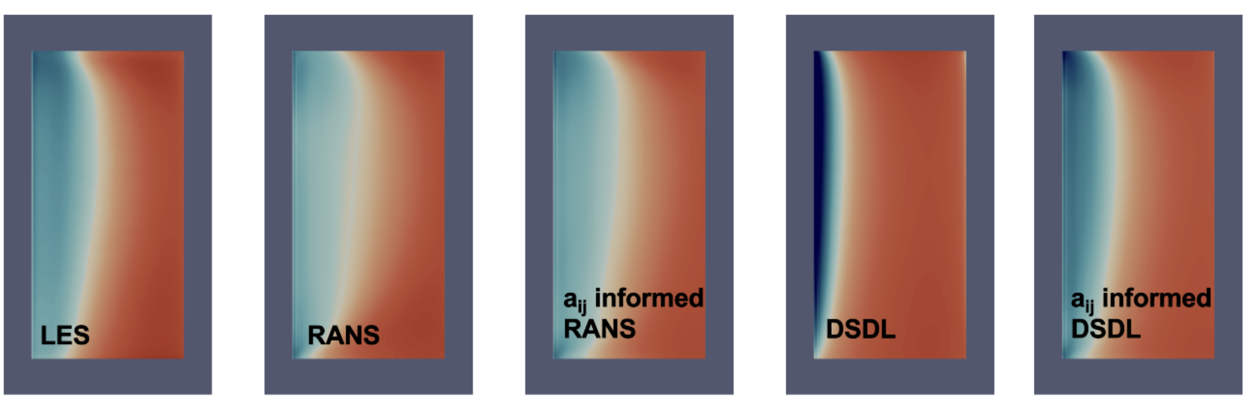

Figure 2. Comparison between the pressure over the surface of the building predicted by the LES, the informed RANS, the DSDL, and the informed DSDL.

3. A DOUBLE SCALE APPROACH TO TURBULENCE MODELING

The second strategy adopts a double scale (DSDL) version of the k-ω SST model. As noted by many authors, the existent of coherent structures (CS) within a stochastic turbulence field (ST), such as vortex shedding or VITA events, exposes an important problem with traditional RANS modeling, i.e. the existence of multiple length and velocity scales within the same flow field. To address this problem, a double scale approach as proposed by Hao 2020 can be explored. This approach consists in splitting the contribution to the velocity fluctuations between different length scales, i.e. CS and ST, and model their associated turbulent kinetic energy (TKE) separately. The TKE associated to the larger length scales (i.e. CS) flows to the smaller length scale (i.e. ST) according to a modelled energy transfer rate. In a fashion similar to the turbulence cascade, dissipation only acts on the TKE stored at the smaller length scales. In this model, uncertainty can be introduced in the energy transfer rate, which is equivalent to introducing uncertainty in the dissipation rate. The results show that the DSDL can generate remarkably good predictions for the velocity field; Figure 1 visualizes the improved predictions of the separation region on the roof and the building wake. However, when considering the pressure, the model does not provide an accurate representation of the LES solution.

4. INFORMING A DOUBLE SCALE TURBULENCE MODELING

The third strategy combines the two aforementioned techniques by informing the DSDL model with the LES-computed anisotropy tensor. This strategy provides a similar prediction for the mean velocity field as the DSDL model, with a more accurate prediction of the separation and wake region. However, it also significantly improves the prediction of the pressure on the building surface.

5. SUMMARY AND FUTURE WORK

The results of this study indicate that quantifying and reducing turbulence model form uncertainty requires an uncertainty estimate or more accurate information on both the normalized anisotropy tensor and the dissipation rate. In ongoing work we are performing this analysis for additional wind directions, and we are using the insights obtained from this study to develop multi-fidelity simulation strategies that can reduce turbulence model form uncertainty.

ACKNOWLEDGEMENTS

This research has been funded by a CIFE seed award.

REFERENCES

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