ME EN 7960-003 Large-Eddy Simulation of Turbulent Flows

Class Project: An *a postiori* study of LES SGS models

1 *a postiori* studies of LES SGS models

The ultimate test of the ability of an LES SFS model is to examine its performance in actual turbulent flow simulations. Many different types of flows have been used for this purpose. Particularly popular is to use homogeneous turbulent flows (e.g., Lu et al., 2008). These flows include homogeneous shear flow, rotating turbulence, forced isotropic turbulence (e.g., Overholt and Pope, 1998) and decaying isotropic turbulence. These flows are chosen for many reasons including lack of difficulties associated with filtering and modeling at boundary conditions and the relative ease (compared to more complex flows) in analyzing the resulting turbulent flow fields.

In addition to these traditional flows used to study the performance of LES SFS models, researchers have also used simplified mathematical models of the Navier-Stokes equations to test models (and in general study the physics of turbulence). One method of particular interest is the use of the stochastic Burgers equation (or Burgulence) to test models (e.g., Basu, 2009). This offers the advantage of simple model implementation and overall low computational costs (even for DNS).

2 project description

The class project will be to conduct your own *a postiori* study of SGS models. You will do this using the Matlab based (see me if you have no matlab experience) Burgers turbulence code provide to you by me (through the generosity of S Basu). The minimum requirement will be to examine three SGS models (see Lecture 9 for a rough summary of different types of SGS models). You will submit the assignment in the form of a short report (4-5 pages max including references and figures). In this project, you will need to implement the models in the provided stochastic 1D Burgers equation code. Note, that I expect that you will not simply implement the two easiest model that you can find (the code already includes constant coefficient Smagorinsky model) but will instead choose models based on their properties that make them idea for your problem of interest (questions you want to explore in this project or in your own research). Don't feel confined to the limited description given here and contact me if you want to do something closer to your research topic but are unsure of how to proceed. The project report is due by Tuesday November 18th.

The report should contain the following components (or equivalent) noting that structurally you don't need to think of this list as defining the sections of your paper, only that it defines some key elements I will be looking for:

- A brief introduction explaining the general idea of LES and the goal of your study. You don't have to show all the LES equations but you must include at least a description of the LES methodology, i.e., scale separation using a low-pass filter and what the closure problem is (i.e., the SGS stress term that must be modeled). You should also briefly describe the rationale of using the 1D filtered Burgers equation as a model for the full LES equations.

- A description of the three models you have chosen to evaluate including at least their general basis, any key assumptions they make and any interesting model coefficients etc. that they use.

- A short description of the numerical implementation (e.g., pseudospectral methods, etc.). The matlab code that you will be using is the one used in Basu (2009) and was discussed in class during lecture 13. You should make sure to mention:

– numerical methods used to solve the equation

– initial conditions

– simulation parameters that govern the evolution and initial velocity field.

– grid resolution and time step that you used for each case and the total execution time on (also specify the type of computer used and version of matlab).

You should cite references when possible but citing a reference does not completely get you off the hook from describing the code you are using. The requirement is that an informed reader (in numerical methods and turbulence) doesn't have to check the references just to get a basic idea of your numerical treatment (I expect your description to be as brief as possible).

- Key results (statistical) from your study. See below for a description of the minimum stats to calculate.

- A summary of the major finding from your study. It is fine if these are similar results to what has been found previously or are not completely conclusive. Still, your summary should demonstrate knowledge of the models you tested and their strengths, limitations and any differences.

- Any references you used in your report

Your report should give as a minimum the following statistics. Note, you are encouraged to calculate other relevant turbulence and SGS statistics depending on your application/interests and the models that you choose to study. Feel free to talk to me about this as you go. What is listed here are minimum requirements. All statistics should be compared to statistics calculated from the provided DNS data or your own DNS run.

- Evolution of the kinetic energy (KE) for the entire flow field and how it adjusts with time for each model and for at least two filter widths Δ (see Basu figure 6).

- The second order structure function and energy spectrum of the velocity both averaged over 100 time increments for each model and for at least two filter widths Δ (see Basu figure 7). Note you can calculate the spectrum using Fourier transforms (instead of Haar wavelets used by Basu, 2009).

- A plot of the temporal evolution of the mean SGS, molecular, and total energy dissipation for each of your chosen models for at least two filter widths Δ (see Basu figure 8).

- The centralized skewness and flatness factors of the velocity increments as functions of the separation distance for each tested SGS model for at least two filter widths (see Basu figures 3 and 10).

Procedurally, you will calculate to calculate your DNS statistics by first separating the velocity field into resolved and SGS components by calculating $\tilde{u}$ and $\widetilde{u^2}$ where the tilde (˜) is a filter at scale Δ. Note, calculating $\widetilde{u^2}$ means filtering the product u^2. Use one of the common filters discussed in class (and that you used in homework #2) that is appropriate for the model you are comparing to. Once you have the filtered fields you can calculate the exact SGS stress tensor $\tau^\Delta = \widetilde{u^2} - \tilde{u}\tilde{u}$ and the exact filtered strain rate tensor (simply the filtered velocity derivative in this context). You will also need to calculate the other statistics listed above to compare with. This is an important step when comparing LES to DNS data to make sure that the effect of filter shape is included in the analysis (e.g., for spectra) and that you are comparing the same statistics.

The project report is due by Tuesday November 18th. Please don't hesitate to contact me with any questions or problems.