M. ENG. AND UNDERGRADUATE PROJECT ANNOUNCEMENT

LARGE-SCALE NUMERICAL SIMULATION PROJECTS IN THE COMPUTATIONAL THERMOFLUIDS LAB

Thermofluids processes are key in many engineering systems as well as in nature. Our group focuses on using large-scale computational resources ($10^4$ compute cores on top 10 supercomputers in the world) to explore the complex physics of multiphase turbulent reacting flows in complex geometries. This document describes a variety of projects available to MAE students in our lab – these are typically targeted for two semesters, with a clear objective of complementing our daily research activity by exploring novel ideas that could ultimately become integral part of our research.

Faculty Sponsor: Olivier Desjardins (olivier.desjardins@cornell.edu)

Office: 250 Upson

Needed Skills: Background in fluid mechanics, strong programming skills (Fortran, Matlab), familiarity with Unix/Linux environment, prior CFD experience desirable.

Time Frame: Typically two semesters, typically 6-8 hours/week (3-4 credits/semester)

Application: Please contact Prof. Desjardins by email with a CV, a short paragraph describing which project is of interest to you and why, and how many credits you are looking for.
1- **Computational Investigation of Particle-laden Flows**

**Project 1a – Simulation of cluster formation in turbulent risers**

Circulating fluidized bed reactors were developed to improve the performance of traditional fluidized beds by using higher airflows to move the bed material resulting in a significant increase in the contact efficiency between phases. This increased kinetic energy causes the flow to become unsteady with large particle concentration fluctuations. Regions of densely packed particles called clusters form (see Fig. 1), which greatly affect the overall flow behavior and mixing properties. In this project, the simulation code NGA (developed in Dr. Desjardins’ research group) will be employed to investigate cluster formation and dynamics (see Fig. 2). The student will focus first on learning to use large-scale computational resources and the NGA code. Then, numerical simulation of the experimental setup of He et al. (2008) will be performed. Simulation results will be compared with experimental data, and appropriate methodology for studying cluster formation and dynamics will be devised.

![Figure 1: Experimental visualization of a particle cluster (He et al., 2008)](image1)

![Figure 2: NGA simulation of cluster formation in a turbulent riser.](image2)

**Project 1b – Electrostatic effects in dense fluidized bed reactors**

Bubbling dynamics in dense fluidized bed reactors are controlled by particle-particle interactions, typically in the form of collisions. However, it is common for particles to interact through other forces, such as electrostatic forces. This project aims at implementing electrostatic interactions between particles, and assessing their impact on bubbling dynamics of a simple fluidized bed configuration (see Fig. 3 for example).

![Figure 3: NGA simulation of a 2D fluidized bed.](image3)
Project 1c – Computational modeling of slurries

Slurries are commonly found in chemical engineering, and correspond to a thick suspension of solid particles in a liquid. They exhibit interesting properties, but tend to be difficult to model. By combining the particle-tracking capabilities of NGA with its capability to handle liquid-gas flows, a model slurry composed of glass beads in oil will be modeled computationally. This model will be validated on various experiments such as flows on inclined planes (shown on Fig. 4). We will make use of what we learn in these simple flows to understand what is would take to model slurry injection, which is commonly used in coal gasification processes.

2- Computational investigation of liquid-gas flows

A significant fraction of our research activity is focused on turbulent gas-liquid flows, which play a critical role in many systems. For example, any liquid-fueled air-breathing propulsion device relies on liquid atomization to generate a fuel spray suitable for faster evaporation and combustion.

Project 2a – Making a computational splash (a milk crown simulation)

When a droplet falls in a shallow pool, it forms a milk crown (see Fig. 5). While fairly well understood, this classical feature of liquid-gas flows remains extremely challenging to simulate. Following prior computational studies of this phenomenon, a series of increasingly realistic and refined simulations will be conducted. In particular, the impact of turbulence in the liquid and in the gas on the milk crown topology will be investigated. Focus of this project will be on very-large scale simulation of this phenomenon, scaling of numerical methods on very large number of processors, and high-quality visualization (including stereoscopic – 3D – rendering and physically accurate ray tracing).

Project 2b – Droplet break-up in a turbulent shear layer

High Weber number droplets tend to break catastrophically into much smaller droplets. While this has been studied in laminar flows (see Fig. 6) as well as in homogeneous isotropic turbulence, droplet break-up in turbulent shear layers remains to be investigated. A canonical turbulent mixing layer will first be simulated, then a droplet will be super-imposed on this flow and allowed to break-up. Different conditions will be investigated, and the simulation outcome will be classified. In particular, size distribution of the children drops will be extracted.
3- Computational combustion

Project 3a – Differential diffusion effect in the presence of a strong recirculation region

It was recently postulated by combustion experimentalists that differential diffusion effects (the fact that “smaller” molecules diffuse faster than “large” ones) could significantly modify the local equivalence ratio in a flame provided it is anchored by a strong recirculation zone, as can be expected in bluff-body-stabilized flames. This could have a noticeable impact in both simulations and experiments, and therefore should be further investigated. This project will aim at investigating this effect in a 2D bluff-body-stabilized hydrogen flame through direct numerical simulation.

4- Turbulent flows and other topics...

Project 4a – Accounting for realistic terrain in large-eddy simulations of wind farms

This project aims at using a conservative immersed boundary algorithm to represent realistic terrain in a turbulent neutral atmospheric boundary layer simulation. An algorithm will be devised to transfer topographical data to the NGA code, and then various wall models will be implemented in the context of the immersed boundary technique. Wind turbines will be modeled using a simple actuator disk approach. Such an approach has the potential to allow for large-eddy simulation of complete wind farms on realistic terrain, which could in turn enable the utilization of optimization algorithm for determining optimal wind turbine placement.