AC 2009-33: PARTICLE TRANSPORT, DEPOSITION, AND REMOVAL: INTEGRATION OF SIMULATION AND EXPERIMENT

Goodarz Ahmadi, Clarkson University

Particle Transport, Deposition and Removal - Integration of Simulation and Experiment

Particle transport, deposition and removal occur in many important processes in microelectronic, imaging and pharmaceutical industries. In addition, numerous environmental processes involve particles and particle processing. In the last decade, significant research progress in the areas of particle transport, deposition and removal has been made. A sequences of courses was developed to make the results of these of new important research findings available to seniors and first year graduate students in engineering through developing and offering of specialized curricula. This project involved integration of numerical simulations and experiments in the developed courses that are taught regularly at Clarkson University. The course materials were made available on the website and the course was also taught it at two campuses simultaneously on some occasions. The developed courses are composed of four modules:

- Fundamental
- Computational Modeling
- Experimental Study
- Industrial Applications

Short courses were also offered to industries, universities and research centers in the U.S. and abroad.

Introduction

Nano- and micro-particle transport, deposition and removal are of critical interest to many modern technologies, as well as in a number of environmental processes. The last decade has seen development of significant computational as well as experimental tools for studies of particle transport, deposition and removal. The primary objective of this combined research and curriculum development project is to make these new important research findings available to seniors and first year graduate students in engineering through developing and offering of sequence of specialized courses. Another objective was to integrate the simulation and experimentation into these courses, as well attract industrial interactions. In these courses, the processes of particle transport, deposition and removal and re-entrainment were described. Computational simulation methods as well laboratory experiments are integrated into the curriculum. In addition, a comprehensive website was developed for these courses, and the courses were taught at two universities simultaneously on several occasions.

Course Modules

Four course modules are included into these combined research and curriculum development (CRCD) courses. These are:

- Fundamentals of particle transport, deposition and removal.

- Computational modeling of particle transport and Dispersion.
- Experimental study of particle transport, deposition and removal.
- Industrial applications.

The home page of the course website is shown in Figure 1. The lecture notes and the calculations models are uploaded to the course website and are available in both pdf format as well as html format.

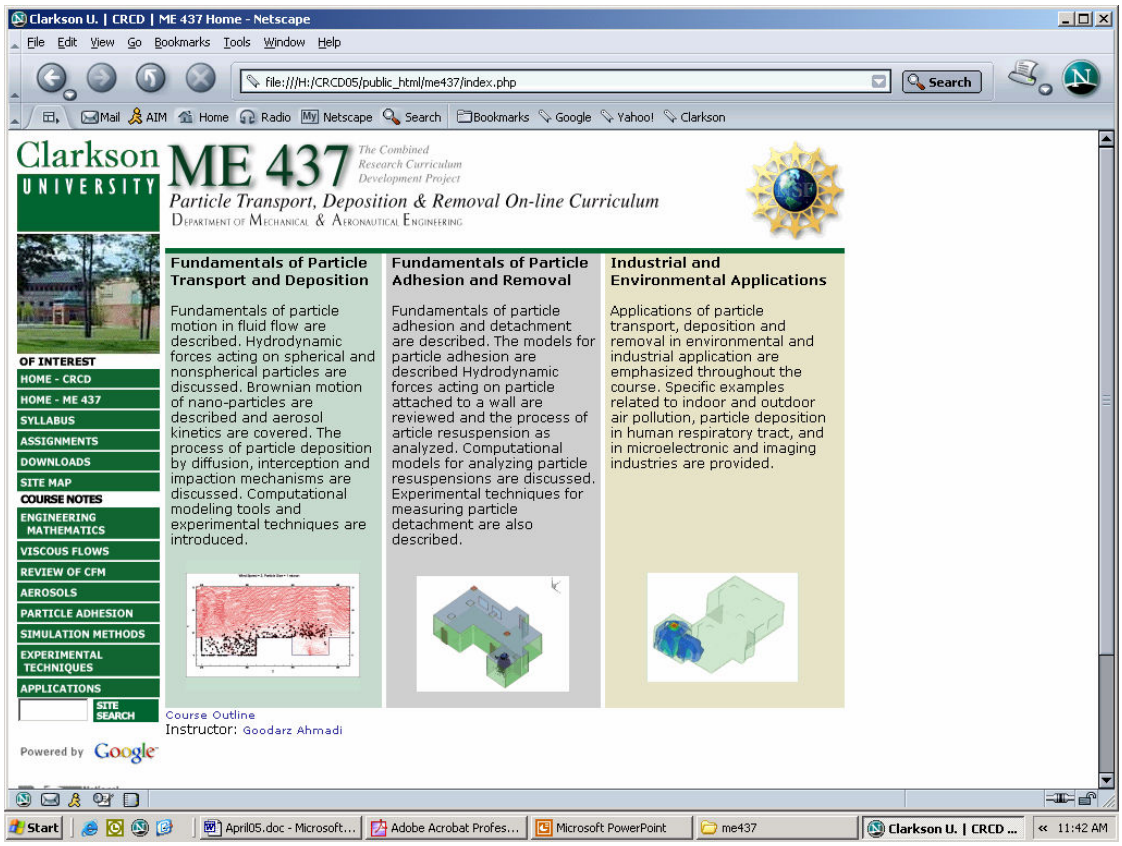

Figure 1. Home page of one of the CRCD courses.

Module I, Fundamentals

In Module I the descriptions of fundamentals of aerosols including hydrodynamic forces (drag, lift), and adhesion forces were described. The nature of particle adhesion and removal was also discussed. This module also contains the description of particle interaction with laminar flow, Brownian motion, and particle deposition by diffusion, interception and impaction.

The sections on interactions of particles with turbulence and turbulent deposition are normally taught in the second course. Computational modeling of turbulent flows was discussed, and classical models of turbulent deposition were described. In addition the process of aerosol charging and transport under the action of electrical forces and turbulence were presented.

A number of computational modules were added to make the course presentations of the materials more interactive. The plan was to have sufficient number of calculation modules for the student to experiment with. As a result the student could develop a physical understanding of some of the more complex concepts. Figure 2 shows a sample of the fundamental module dealing with comparison of the predicted lift force acting on a particle in a shear flow with the experimental data.

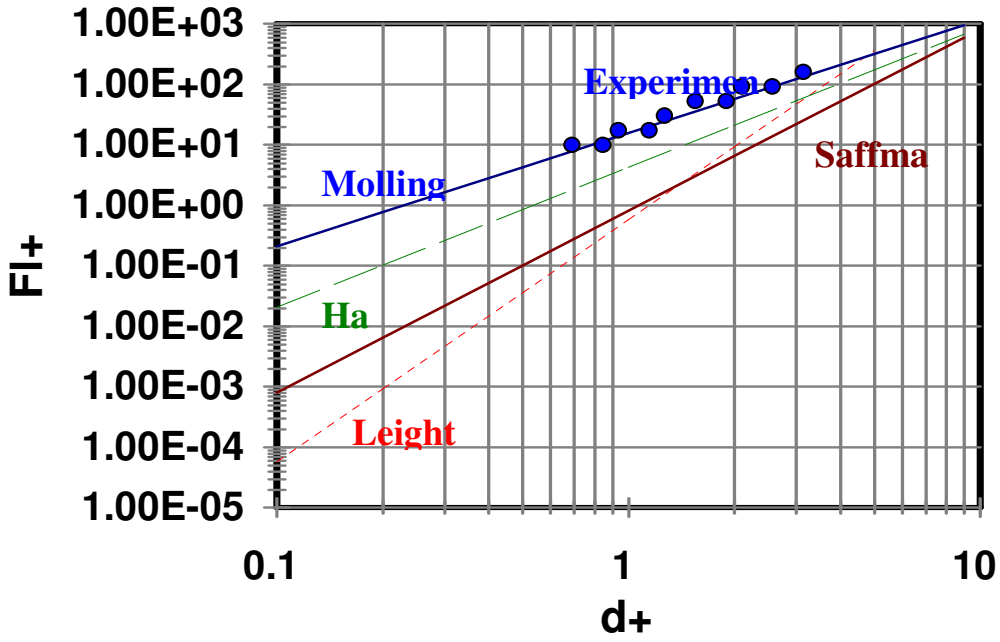

Figure 2. A sample page of the fundamental module on comparison of model predictions with the experimental data.

Module II, Computer Simulations

Several computer modules were developed, refined and were incorporated into the course sequence. One class of examples was concerned with exploring the flow and particle transport in a variety obstructed ducts. FORTRAN simulation programs that were developed earlier were converted to JAVA. These programs were incorporated into the modules dealing with the motion of aerosol particles in duct flows. The students will be able to use the JAVA Applet programs interactively to explore the effects of various forces (gravity, drag, lift, Brownian), materials properties (particle density), and the flow geometry on the motion and deposition of particles.

A module was developed for illustrating Brownian particle motion in cross flows. The flow field in this module is a parabolic velocity profile between two parallel plates. The particle equation of motion includes Brownian motion, drag, lift, and gravity. Figure 3 shows the user interface for this module. Here, particles are injected from a nozzle in

the middle of the channel. The dispersion of the Brownian particles can be seen from this figure. The module can also be used to illustrate the effects of the lift force on larger particles. Student can select values of the particle diameter and density, the number of particles, and the centerline fluid velocity.

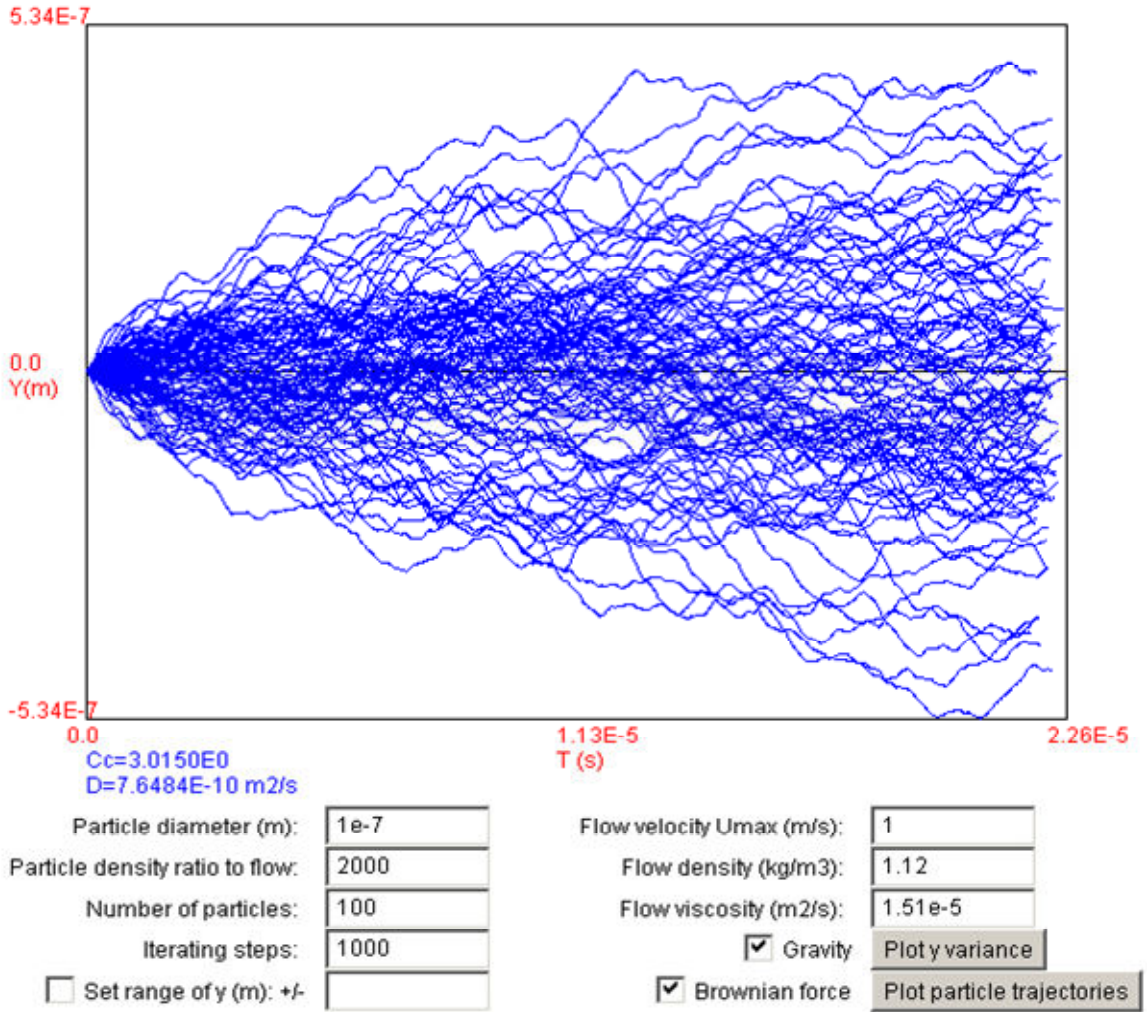

Figure 3. User interface for the module for Brownian particle motions in cross flows.

Module III, Experimental

The course sequence includes several experimental modules. One main experiment is the measurement in the aerosol wind tunnel with the use of Particle Image Velocimeter (PIV). The aerosol wind tunnel is located in the Turbulence and Multiphase Flow Laboratory at Clarkson University. The laser used was a 120mJ Nd:YaG laser with a 20° adjustable width sheet generator. In this experiment, the sheet width was 0.5 mm. The digital camera that was used was a Kodak ES1.0 MegaPlus camera. The camera had a resolution range of 1008x1008pixels. The pixel size was 25 micrometers

and the interframe delay between pictures was 12 microseconds. A picture of the experimental setup is shown in Figure 4. A sample PIV measurement of the velocity field behind a step is shown in Figure 5.

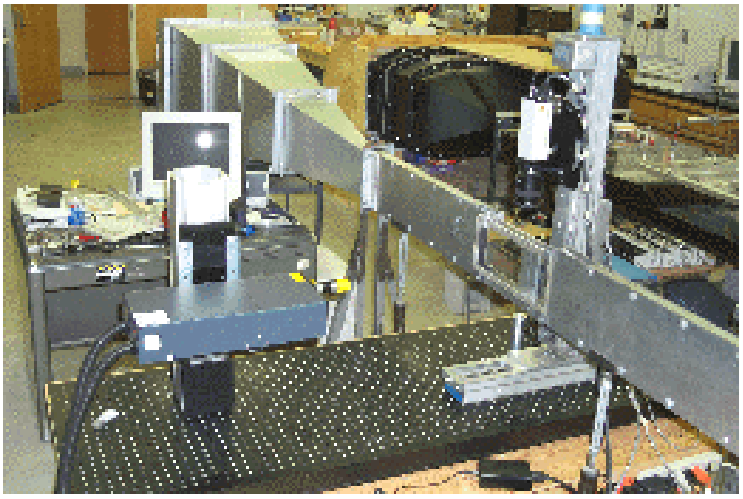

Figure 4. A picture of the aerosol wind tunnel.

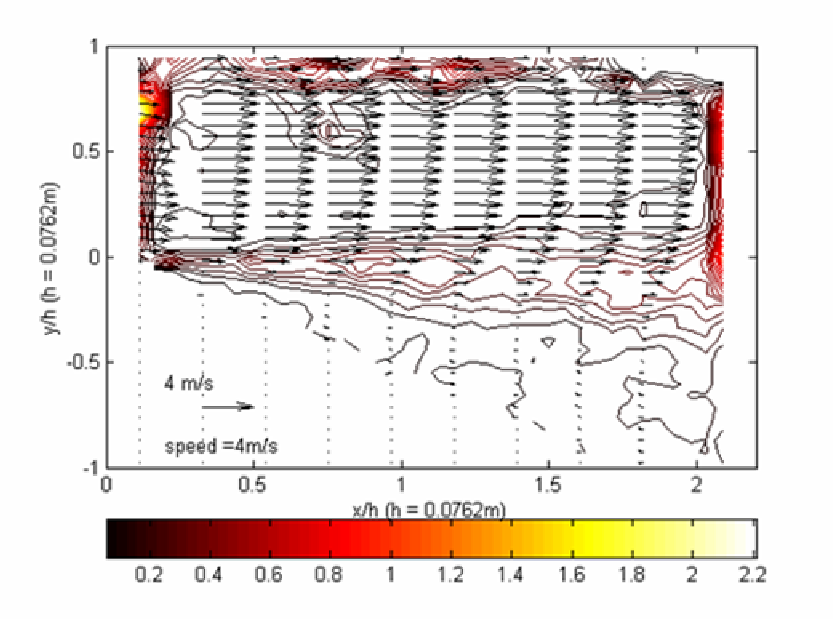

Figure 5. Sample PIV measurement behind a step in the aerosol wind tunnel.

Module IV, Applications

The applications module concerns with a number of examples from air pollutions to xerography. Figure 6 shows the photo of the Peace Bridge area in South West Buffalo, NY. Figure 7 shows a sample computational result for flow field near the Peace Bridge. Transport and dispersion of particulate pollutant emitted form the traffic on Peace Bridge and Peace Bridge Plaza were also analyzed.

Figure 6. A picture of Peace Bridge area and city of Buffalo.

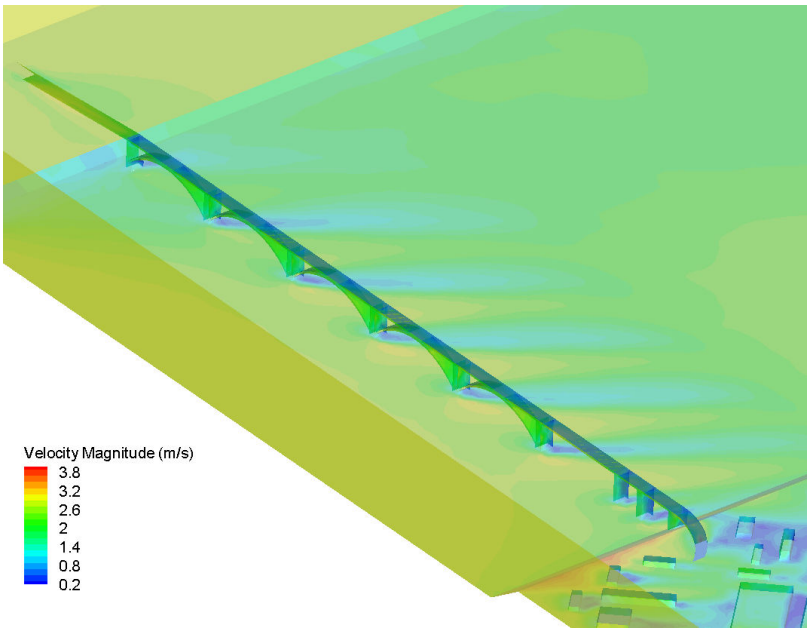

Figure 7. Sample computational result for the airflow velocity near Peace Bridge.

Figure 8 shows the sample computational results for transmission of viruses in a hospital room from one patient to another.

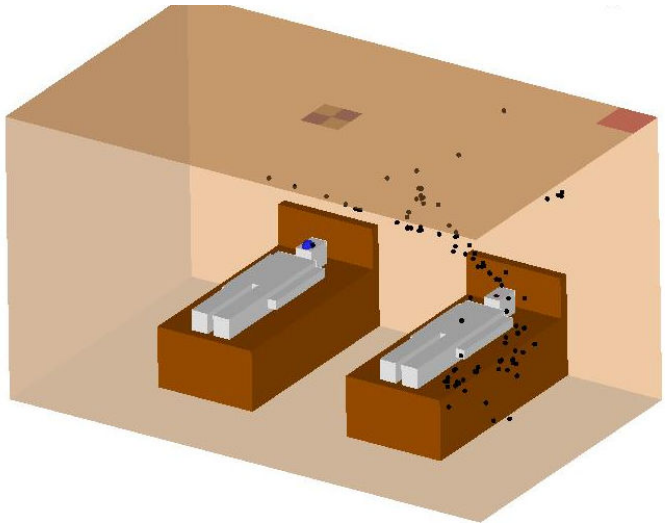

Figure 8. Sample computational result for virus transport in a hospital room.

Course Website Effectiveness

The effectiveness of the course (ME 437/537) website was assessed in two ways:

1. Usability tests were conducted on an early version of the site and conducted again on a revised version of the site. In both tests, participants were given tasks to find course material and use the calculation model available on the site. The purpose of these tests was to determine how efficiently the participants could complete each task.

2. A survey questionnaire was administered to students enrolled in the courses to assess the students' satisfaction with the website.

Usability Tests

The Usability Testing Lab in the Eastman Kodak Center for Excellence in Communication at Clarkson University was set up to record users testing out the website. In the first test on the early version of the website twelve student volunteers participated: six Mechanical Engineering majors and six Information Technology majors. Information from these tests was communicated to the website designers. A year later after the website had been redesigned a second usability test was conducted with two Mechanical Engineering majors and three Information Technology majors

For both test sessions a list of twelve tasks was devised that would cover a variety of possible uses of the website. All tasks required the students to search the site for course-related information. One task asked the students to do a calculation using the calculation model currently embedded into the site. The results indicate that the participants using the revised site completed the tasks more efficiently.

Original Site
Average number of clicks, searches, scrolls to complete each task per user: **3.70**
Revised Site
Average number of clicks, searches, scrolls to complete each task per user: **2.56**

Original Site
Average number of failed or incomplete completions of the task per user: **1.41**
Revised Site
Average number of failed or incomplete completions of the task per user: **0.60**

Survey Questionnaire

Twenty-two students, who used the website to assist their learning, completed a questionnaire after completing the course. Overall, these students found the website useful for their needs:

1. The website was used to access information and employ calculation models:

- 77% used the website to read the course syllabus
- 86% used the website to read homework assignments
- 77% used the website to download course notes
- 54% used one or more of the calculation models

2. Students found the availability of course notes to be useful:

- 86% found the course notes to be easy to moderately easy to find.
- 96% found the course notes helpful to moderately helpful to their coursework.
- 86% found the course notes to be easy to moderately easy to understand.

3. Students found the calculation models to be useful:

- 81% found the calculation models to be helpful to moderately helpful.
- 81% found the calculation models to be easy to moderately easy to use.

4. Overall, 86% found the website to be very to moderately helpful to their coursework.

Conclusions

The development of a sequence of web-based courses on particle transport, deposition and removal was described. Different modules of the course are outline and the integration of the simulation and experiment into the curriculum was described. The suitability of the course website in helping the student learning was assessed. The results showed that the availability of the course material and computational module on the website was very helpful to student learning, and students at multiple campuses could take the course simultaneously.

References

http://www.clarkson.edu/projects/crcd/