AC 2010-9: COURSE DEVELOPMENT EXPERIENCE ON PARTICLE TRANSPORT, DEPOSITION AND REMOVAL AND ENGINEERING OF NANO/MICRO-SCALE SYSTEMS

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Nano- and micro-particle transport, deposition and removal occur in many important processes in microelectronic, imaging, pharmaceutical and food processing industries. In addition, numerous environmental processes involve particle transport, deposition and removal. In the last decade, significant research progress in the areas of nano- and micro-particle transport, deposition and removal has been made. A series of courses was developed to make these class of new important research findings available to seniors and graduate students in engineering through developing and offering of specialized curricula. This project involved integration of numerical simulations and experiments in the developed courses. The course materials were mostly made available on the web and some courses were taught at University 1 and University 2 campuses simultaneously. Based on the course materials, a series of short courses was also offered at several countries. The first two courses on particle transport, deposition and removal are composed of four modules: i) Fundamental of particle transport, dispersion, deposition and removal. ii) Computational modeling of particle transport, deposition and removal. iii) Experimental study of particle transport, deposition and removal. iv) Industrial applications of particle transport, deposition and removal.

Based on the experience in the course of the development of these course, an undergraduate course (*Nano/Micro-scale Systems Engineering*) was developed and funds were obtained for its implementation from the NSF under the Nanotechnology Undergraduate Education program. The chief instructional objective of the proposed course is to provide instructions on the design, analysis, simulation and implementation/fabrication of nano/micro-scale engineering systems. The course consists of three main components to address a set of its well-defined educational objectives: (i) lectures developed and delivered by a multidisciplinary team at University 1, (ii) instructions on computational design/analysis and simulation tools and (iii) a hands-on workshop for experience with cleanroom and fabrication facilities. The second component has been developed with help of software companies. The third component is being realized through collaboration with the NNIN University 3 CNF facility as a hands-on workshop for the students.

Introduction

Understanding particle transport, deposition and removal is of crucial importance to many technologies that are critical for the competitiveness of the US microelectronic, imaging and pharmaceutical industries.

Nano- and micro-particles usage are 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.

Parallel to substantial scientific and technical advancements and massive public and private investments in the development of nanotechnology, the workforce in related fields has been projected to grow and, along with entrepreneurs, students from K-12 to graduate schools are exploring educational and professional opportunities in this rapidly growing field. Today significant engineering challenges exist in the design, analysis and fabrication of nano/micro-scale systems, and, therefore, a need for more engineers with the proper background has been predicted and realized.[1-4]

The main instructional objective of the course *Nano/Micro-scale Systems Engineering* is for undergraduate students to become competent in the problems faced in the design, analysis, simulation and implementation/fabrication of nano/micro-scale systems. The specific *instructional/intellectual objectives* of the proposed nano/microengineering course are determined as follows:
(1) Students will be able to link meso-scale engineering to micro/nano-scale engineering;
(2) Students will compare/contrast/evaluate nano/micro-scale engineering applications;
(3) Students will use the computational/design tools available for nano/micro-scale engineering and will know their limitations;
(4) Students will use fabrication facilities to implement micro-scale structures;

Particle Transport 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.
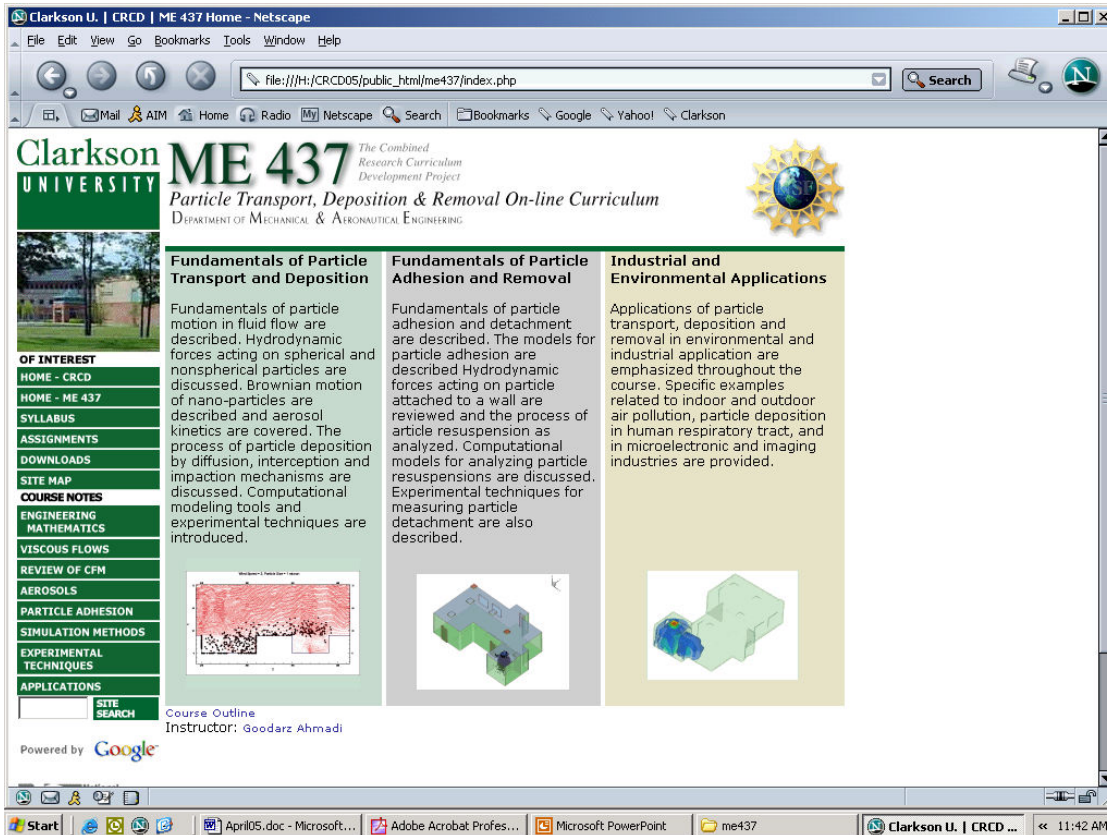
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Figure 1. Home page of one of the particle transport courses.

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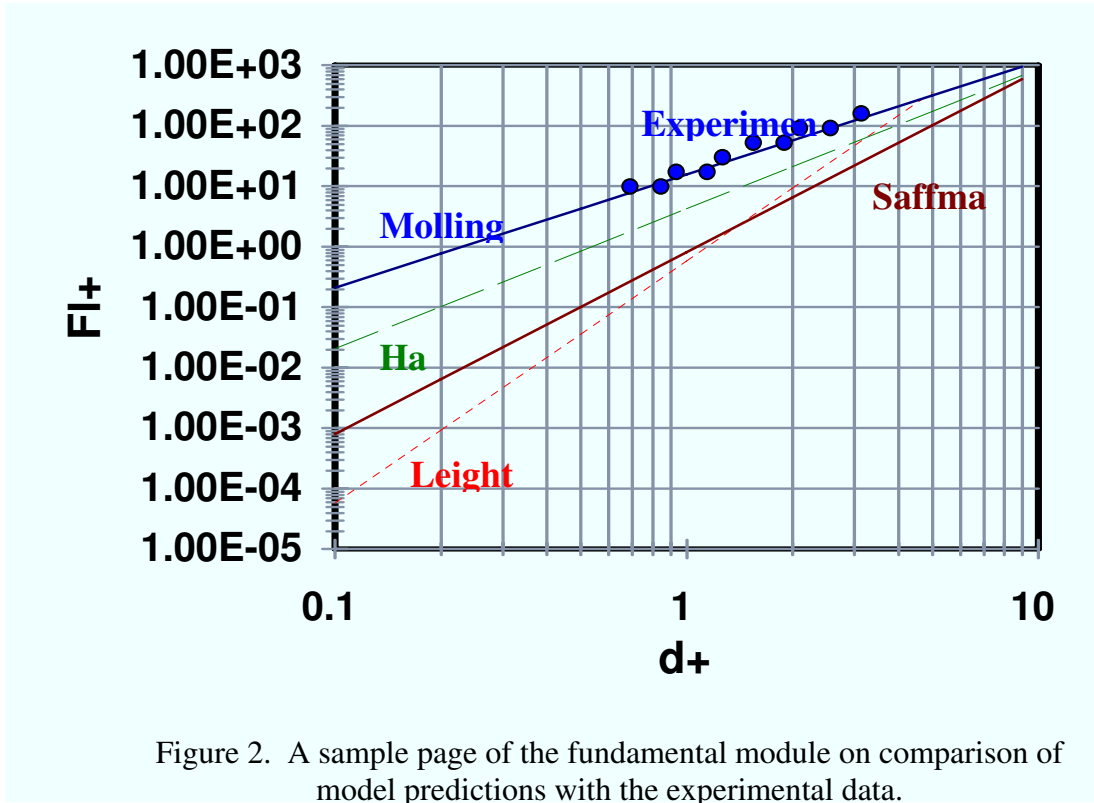
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Figure 2. A sample page of the fundamental module on comparison of model predictions with the experimental data.

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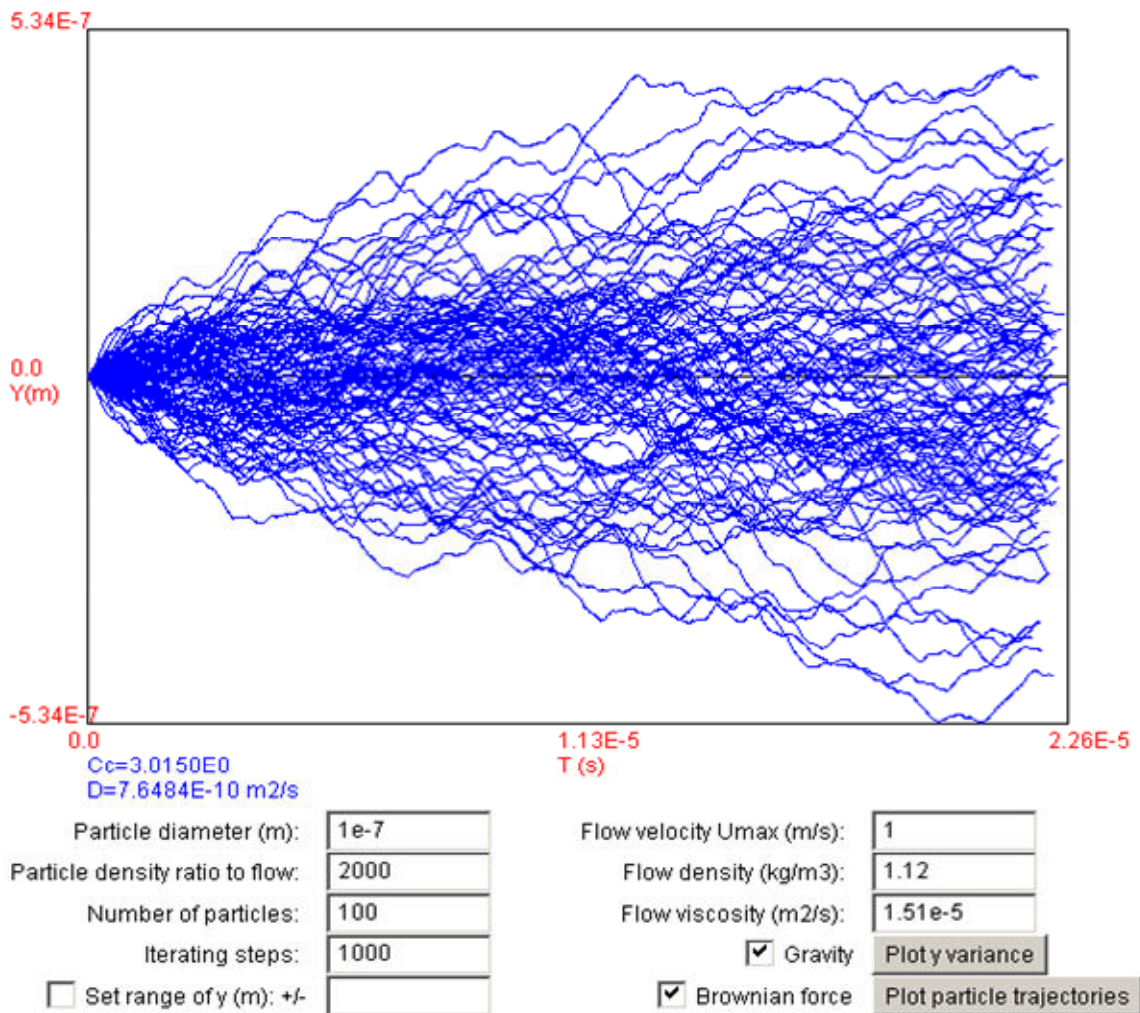
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Figure 3. User interface for the module for Brownian particle motions in cross flows.

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 University 1. 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.
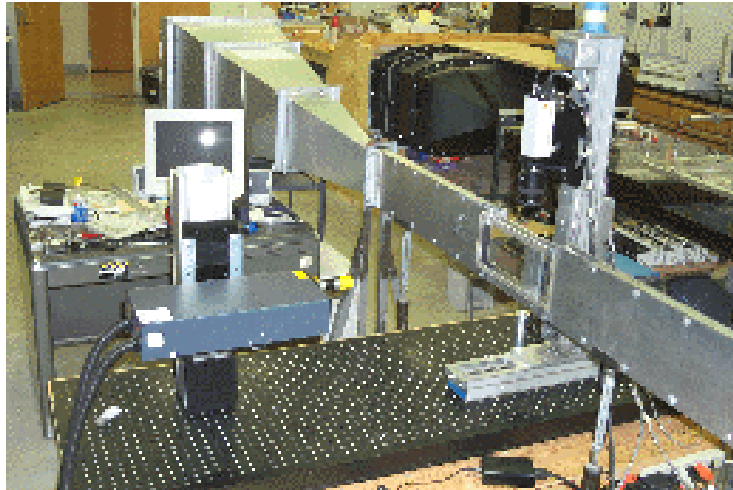
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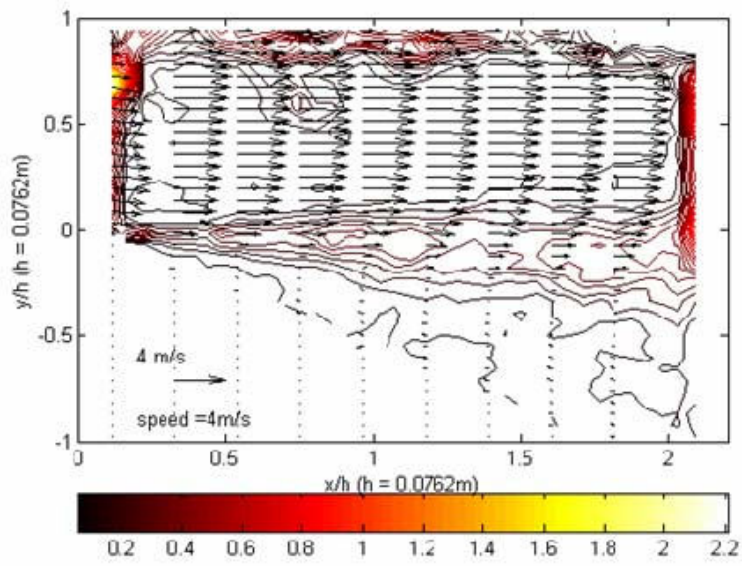Figure 4. A picture of the aerosol wind tunnel.

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

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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.

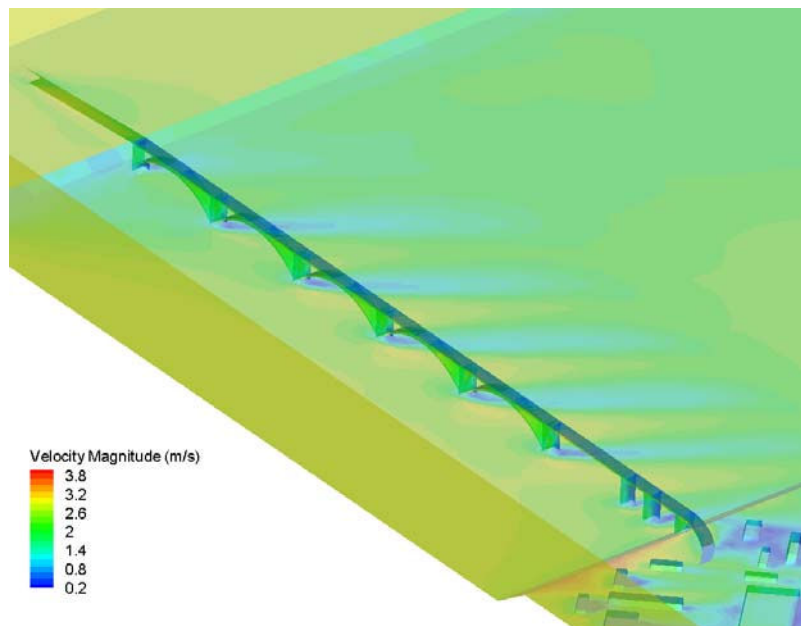Figure 6. A picture of Peace Bridge area and city of Buffalo.

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.
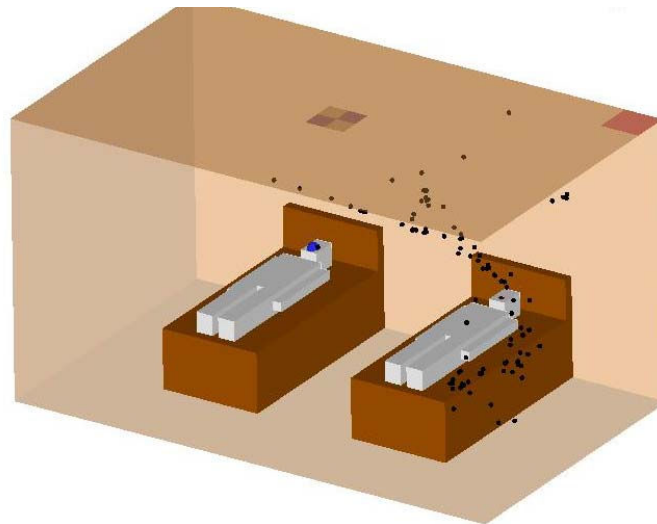

Figure 8. Sample computational result for virus transport in a hospital room.

Nano/Micro-scale Systems Engineering
The course *Nano/Micro-scale Systems Engineering* consists of three main components to address its well-defined educational objectives (discussed below): (i) lectures developed and delivered by a multidisciplinary team at University 1, (ii) instructions on computational design/analysis and simulation tools and (iii) a hands-on workshop for experience with cleanroom and fabrication facilities. The third component is realized through collaboration with the NNIN University 3 CNF facility as a hands-on workshop for University 1 students (the CNF Workshop). A video clip reporting the activities of the CNF Workshop and University 1 visit is available at the CNF website.[5] See Ref. 6 for information on the NNIN.

The following outlines the proposed activities and topics covered in a 16-week semester:

Weeks 1-4: Introduction to nano/micro-scale engineering: Students submit their weekly homework assignments based on lectures and reading assignments.
Topics:
   Engineering process in the nanoscale
   Scaling laws for length and time and its effect on modeling
   Nano-scale materials and systems (Man-made systems vs. biological systems)
   Nanoparticles, Nanotubes, Nanowires, Quantum Dots
   Fabrication and testing fundamentals; Fabrication of Semiconductor/IC circuits (chips, switches)
   MEMS Devices: Design/Analysis Principles, Sensors, Switches, and Mirrors
   Sensing and actuation in nano/micro-scale
   Analysis and design tools for nano/micro-scale systems

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MEMS: MEMS vs. NEMS
    Overviews: CNF project and trips, and computational project

Week 5: CNF Nanocourses Videos - Basics (Part 1). These videos are watched in class. Before starting the videos, brief discussions are made to answer/address questions/concerns from previous video sessions. If needed, teleconferences are scheduled with the CNF staff. The CNF workshop schedule and trip planning:
Topics:
    Fabrication of cantilever beam arrays
    Cleanroom and Fab Procedures
    Photolithography: Processes, Design, E-Beam lithography

Week 6: Basic Training: (CNF Workshop 1 at Ithaca, New York)
Topics :
    Safety training
    Cleanroom operation and training
    Basic tools operation and training
    Metrology training

Week 7-8: Software workshop/instructions [with support from Nanorex]
Topics:
    Principles of molecular mechanics with Nanorex/NanoEngineer-1
    Overview of Molecular dynamics methods and simulations
    Brief Overview of FE (finite element methods) and DEM (Discreet element method)
    Project: Goal/Objective/Function: Develop a nano-mechanism to transfer rotational motion from a motor driven nanogear to a free-spinning nanogear through the use of a middle component.Requirements: The gear assembly must be stable for a simulation of 25,000 total frames, 10 steps/frame, at 300K. Restrictions: No jig or anchor can be connected directly for covalent bonding of the middle component.

Week 9: Module 1 (Ian Suni): Principles and Applications of Nanobiosensors
Topics:
    Principles and operation of nanobiosensors (including practical aspects)
    Effects of mass transport on nano-sensor performance
    Lab: Development of multilayers of alternating nanoscale films for sensing elements

Week 10: Module 2 (W. Ding): Micro/nano-scale Mechanics in Sensor Development
Topics:
    Mechanics of micro/nano-scale structure
    Structure of cantilever beam-based sensors
    Lab: Experimental mechanics of cantilevered beams in sensor application: Force-deflection curves

Week 11: Module 3 (F. Hua): Engineering of Sensor Nanomaterials
Topics:
    Methods of engineered nanomaterials
    Electronic, thermal, optical and mechanical properties of materials in micro/nano-scales
    Lab: Nanoprinting with particles and films

Week 12: CNF Nanocourses Videos – Fabrication (Part 2)
Topics:
    Vacuum: Vacuum systems, pumps and gauges
    Thin Film Processes: Evaporation, dry and wet etching, sputter deposition, chemical mechanical planarization (CMP), bonding and embossing
    Characterization: Optical techniques and microscopy, SEM, optical and electrical properties, Auger and thin film analysis, atomic force microscopy (AFM)
Week 13: Fabrication Training: (CNF Workshop 2 at Ithaca, New York)
Topics:
    Development of fabrication steps
    Fabrication of sensor elements (beams and disks with nano- and micro-scales
    Characterization and imaging of sensor elements
Week 14: Testing and Characterization of Sensor Elements (University 1)
Topics:
    Mechanical modeling and characterization of sensor elements fabricated at CNF
    Instructions on the use of the air-coupled/interferometer set-up for micro-structure testing
    Lab: Hands-on testing and characterization experiments with the cantilever beams and rotational oscillators.
Week 15: Computational project reports (oral and written reports); preparation and corrective feedback for the final report. (University 1)
Activities:
    Oral peport presentation
    Final written reports
Week 16: Final exams week: final project report and presentations due finals week.

The contents of the proposed modules are included and discussed in detail below:

Module 1 Principles and Applications of Nanobiosensors (Prof. Ian Suni): Creation of nanoscale protein films on cantilever for sensor applications
Lecture 1: Self-assembly techniques for attachment of biomolecules to cantilever surfaces
For many sensor applications, biosensors offer the promise of superior selectivity due to their biological specificity. For example, through the use of enzymes or receptor proteins that interact specifically with glucose, the concentration of glucose can be measured independently of the presence of other sugars that are quite chemically similar. As for industrial catalysis, practical sensor applications require that enzymes and receptor proteins be immobilized onto a solid surface. The chemical scheme most commonly employed on the laboratory scale involves the use of Au-S self-assembly chemistry. This allows both direct immobilization of proteins that contain cysteine residues, and indirect attachment of proteins to surfaces through linker chemistries. As will also be discussed, protein immobilization can also be made directly onto Si for integration into MEMS devices. Protein films created in Prof. Suni's laboratory range from 5-15 nm in thickness.
Lecture 2: Effects of Mass Transport on Nano-Sensor Performance

For many sensor applications, rapid analysis is of critical importance. For glucose biosensors, patients with diabetes or hypoglycemia need real time information on blood glucose levels. However, many traditional biosensor methods are quite slow and incapable of providing real-time information. When the sensing element is arrayed as one monolayer onto a solid surface, or when the sensing element is confined to nanoscale geometries within a porous surface, rapid measurements are possible. On the other hand, distribution of the sensing element throughout longer length scales within a porous surface will increase the time constant of the sensor, and prevent real-time measurements. Students from all engineering disciplines can learn to do both back-of-the-envelope calculations of transport rates and solve simple transport models. Valuable lessons can include, for example, the large difference in effective diffusion coefficients between small molecules (glucose) and large molecules (proteins, including antibodies).

Experiment (two lectures, one week): Undergraduate students can easily construct multilayers of alternating nanoscale films of streptavidin and biotin. Streptavidin is a 60,000 dalton tetrameric protein purified from the bacterium *Streptomyces avidinii*. It finds wide use in molecular biology through its extraordinary affinity for the vitamin biotin, and streptavidin-biotin binding is often used as a model system for testing biosensor strategies. The dissociation constant (K_d) of the biotin-streptavidin complex is on the order of $\sim 10^{-15}$ mol/L, one of the strongest known non-covalent interactions. Numerous methods have been developed to immobilize nanoscale films of streptavidin and biotin. In addition, electrochemical methods can easily measure the increased electrical isolation from the surface as the thickness of the streptavidin-biotin multilayer increases. Thus students can indirectly measure the thickness of the nanoscale protein film. Detailed characterization of the nanoscale protein films will be done at the CNF facility.

Module 2 Micro/nano-scale Mechanics in Sensor Development (Prof. Weiqiang Ding): Two lectures will be given on the mechanics aspect of micro/nanoscale sensing structure and system:

Lecture 1: Micro/nano-structure Mechanics

This lecture will cover experimental nanomechanics studies of micro/nano-scale structures. To provide essential nanomaterials background, several nanostructure synthesis techniques such as vapor-phase, vapor-liquid-solid, electro-spinning and template-directed methods will first be briefly reviewed. Then a number of micro/nano-scale mechanical characterization techniques, including atomic force microscopy, nanoindentation, tensile testing, bending and mechanical resonance methods, will be presented. The underlying principles of each technique will be addressed, and corresponding experimental studies from the recent literature will be presented. While a number of related testing instruments such as STM, AFM and FIB are not available at University 1, the students will get a chance to see demonstrations of these instruments at CNF. As a homework assignment, the students will be asked to compare the performance of different nanoscale mechanical characterization techniques based on the literature.

Lecture 2: Mechanics of Cantilever Beam-based Sensors

This lecture will be an in-depth discussion on microsize cantilever beam sensor mechanics studied by nanomanipulation inside an SEM. First the principle of SEM imaging will be briefly introduced. Then two techniques to characterize the cantilever

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beam mechanics, the bending method and the mechanical resonance method, will be presented. Mechanical characterization examples from Dr. Ding's previous and ongoing research projects will be presented, including tensile and resonance studies of carbon nanotubes, boron nanowires and carbon nanofibers. Several important issues in beam mechanics study such as the boundary condition and beam nonlinearity will be discussed. The student will get a homework assignment to analyze the resonance frequencies of silicon cantilever beams that they will fabricate at CNF.

Hands-on Lab Session on Beam Sensor Mechanics:
In addition to the two lectures, a hands-on lab session of microfabricated cantilever beam stiffness determination inside the SEM will be given. The experiments will be carried out with a custom-made SEM nanomanipulator from Dr. Ding's group inside the vacuum chamber of a JEOL 7400F SEM in the Center for Advanced Materials Processing at University 1. The nanomanipulator is composed of two positioning stages driven by piezoelectric actuators. AFM cantilever probes are mounted on top of the stages for nanostructure manipulation and mechanical testing. An AFM cantilever of known force constant will be used to determine the force constant of a microfabricated silicon cantilever beam with the bending method. Through nanomanipulation, the AFM cantilever will be pushed against the silicon cantilever beam. The deflection of both cantilevers will be monitored in the SEM, and the force constant of the silicon cantilever beam will be obtained from its bending response. As a comparison, the force constant of this microfabricated silicon beam will also be determined with the mechanical resonance method. The students will observe the entire testing process on the SEM monitor. They will also learn the data analysis process. Through the lectures and the lab demonstration, the students are expected to develop a general understanding of current techniques in characterizing the mechanical properties of micro/nano-scale structures.

Module 3 Engineering of Sensor Nanomaterials (Prof. Feng Hua)
Two more lectures will be given on the design, formation and function of micro/nano systems using nanostructured materials as the building block. Furthermore, the macroscopic properties of the system will be correlated to those of the nanomaterials from which they are made. One lab session will be implemented at CNF's cleanroom to offer both the hands-on experience and practical link to the contents of the lectures.
Lecture 1: Sensor Surface Modification by Nanomaterials
This lecture will first briefly introduce the concept of surface tension, and its relation with the hydrophobic and hydrophilic properties of the surface. Then various nanomaterials that have been used to modify the surface property will be introduced, including self-assembled monolayers (SAMs) of hydrophobic and hydrophilic molecules and layer-by-layer self-assembled polyions and nanoparticles. The nanofabrication techniques that manipulate those nanomaterials will be reviewed. Eventually, different patterning techniques to generate surface wetting function will be covered. In an attempt to attract the student interest, many pictures of an alternate wetting/dewetting pattern on one surface will be shown in class. One homework assignment will be given asking students to design a simple approach to modify the wetting properties of a glass window.
Lecture 2: Strength Enhancement
This lecture will review a class of layer-by-layer self-assembled nanoparticle thin films and their unique properties. Then the nanostructure, property and self-assembly of the

clay nanosheet will be introduced. The multilayer assembly of nanoparticles and clay will be demonstrated. The students will find that the mechanical strength of the self-assembled thin film is significantly improved with the integration of the clay nanosheet. The improved strength will be correlated to the properties and structure of the clay nanosheet. Relative pictures and videos will be shown in class. One homework assignment will be given, asking students to sketch a multilayer with clay and nanoparticles.

Hands-on Lab Session:

In order to solidify the class knowledge, one hands-on module is designed. The lab module will be implemented after the homework from the first lecture is due because it is the lab version of this homework assignment. The purpose is to demonstrate to students the modification of the surface wetting based on nanomaterials' properties. The module will be not only demonstrated by the lecturer, but also allow student participation. This includes (i) the self-assembly of a hydrophobic SAM over the surface, (ii) the fabrication of a silicon mold, (iii) the fabrication of a polydimethylsiloxane (PDMS) mold which is derived from the silicon mold, (iv) printing of the hydrophobic group onto the surface, and (v) observing the wetting/dewetting pattern on the surface. This lab will take advantage of the cleanroom and facilities at CNF for photomask fabrication, photolithography, etc.

Through the lectures and the lab, the students are expected to develop a general concept of nanomaterials, as well as the nanofabrication techniques that manipulate them. They should also gain the basic idea of the design and fabrication of micro/nano systems with appropriate nanomaterials for a specific application.

Methods of Evaluation

The final grade of the student is based on the following tasks and associated percentage weights:

Project: Computational Analysis/Design of a Nanosystem	20%
Project: Nanosystem Simulations	25%
Homework Assignments	20%
Final Written/Oral Report on Micro-oscillators (Team)	35%

The homework assignments will include (i) problems based on materials covered in lectures and (ii) open-ended research problems based on reading assignments.

Students were presented with post-course instrument items that asked them to answer questions about the instructional elements. Items were answered using a five-point scale in which one signified a strong negative response and five signified a strong positive response (e.g., 1 = strongly disagree and 5 = strongly agree). Overall mean ratings and percent distributions are provided in Table 1.

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Table 1. Summary of course evaluation data on the instructional elements

Instructional Elements	Strongly Disagree	2	Neutral	4	Strongly Agree	Mean	n
The reading assignments were relevant to the course objectives.	0%	0%	0%	0%	100%	5.0	7
The assigned readings were at an appropriate level for me.	0%	0%	0%	43%	57%	4.6	7
The reading assignments were interesting.	0%	0%	0%	71%	29%	4.3	7
I spent an appropriate amount of time completing reading assignments for this course.	0%	0%	0%	57%	43%	4.4	7
The instructor generally used computer-based instructional materials effectively.	0%	0%	14%	57%	29%	4.1	7
The computer-based instructional materials used in this course helped me learn.	0%	0%	29%	71%	0%	3.7	7
The use of the CNF Workshop enriched my learning experience in this class.	0%	0%	0%	14%	86%	4.9	7
The instructor clearly explained expectations for use of the CNF Workshop in this course.	0%	0%	0%	29%	71%	4.7	7
The instructor effectively used the CNF Workshop as a basis for group work in class.	0%	0%	0%	0%	100%	5.0	7
The CNF Workshop has been a valuable part of this course.	0%	0%	0%	0%	100%	5.0	7

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 University 1 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

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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 the 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.

One challenge in developing and implementing experimental aspects of the course *Nano/Micro-scale Systems Engineering* at CU, a small research-intensive university, has been the unavailability of needed on-site cleanroom and fabrication facilities and required support staff. This is a common limitation for several small universities, and we have demonstrated that this limitation can be overcome by teaming up with a larger institution where nano/micro-scale fabrication facilities with trained staff are available. We believe that our experience will play a key role developing such a course in other similar small universities. As the reports from the independent assessor of the course indicate, the student satisfaction with the course and the instructors was high in the first year of the program (Spring 2009).

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