# ME 637 PARTICLE TRANSPORT, DEPOSITION, AND REMOVAL-II
## Spring 2023

**INSTRUCTOR:** Goodarz Ahmadi, Room 267 CAMP and SC 304(325-268-2322)
gahmadi@clarkson.edu
Office Hours: Tuesday and Thursday 12:30 - 3:30 pm
(Zoom meeting as needed https://clarkson.zoom.us/j/761986404)

**TEXT:** None. Lectures notes are available on the web.
http://webspace.clarkson.edu/projects/crcd/
https://sites.clarkson.edu/gahmadi/courses/me637/

**TA:** Tony Abrantes, abrantaj@clarkson.edu

### Course Description

Review of viscous flow theory. Creeping flows around a sphere. Introduction to turbulent flows and turbulent modeling. Algebraic, one, and several equation models. Drag, lift, virtual mass, and Basset forces acting on particles. Wall effects and nonspherical particles. Aerosol transport and dispersion in turbulent flows. Turbulent diffusion and wall deposition of aerosols. Particle charging mechanisms and electrostatics forces. Thermophoretic and electrophoretic effects. Introduction to colloids and electrokinetic phenomena. Computational aspects of aerosol dispersion and deposition in turbulent flows. Sublayer model approach. Approximate simulation of turbulence and turbulence transport. DNS simulation methods. Nonspherical particle transport in turbulent flows. Coagulation of aerosols due to shear and turbulence. Experimental techniques for turbulent flow measurements. Hot-wire anemometry, Isokinetic sampling. Particle concentration and velocity measurements with Phase-Doppler, and PIV. Applications to micro-contamination control, air pollution, combustor, spray, particle deposition in human lungs, respiratory viruses spread, clean room equipment, xerography, and surface cleaning in microelectronic and imaging industries.

### Delivery Method

The course is offered in blended mode, both in-person in the class as well as online (asynchronous). The lectures will be captured by Echo 360 and will be available to students on Moodle.

## COURSE WEB SITE:

https://webspace.clarkson.edu/projects/crcd/public_html/me637/index.php
https://sites.clarkson.edu/gahmadi/courses/me637/

### Course Objectives

1. To provide a fundamental understanding of aerosol/particle transport and removal in turbulent flows.
2. To provide a fundamental understanding of the computational modeling of dilute two-phase flows.
3. To provide a fundamental understanding of the industrial applications of dilute multiphase gas-solid turbulent flows.
4. To familiarize the students with the modern experimental techniques in aerosol transport and deposition.
5. To provide a fundamental understanding of the industrial, environmental, and biomedical applications of aerosol transport processes.

## Course Learning Outcomes

### Objective 1:

- Students will be able to formulate and solve aerosol transport and deposition in turbulent flows.

### Objective 2:

- Students will be able to formulate and analyze charged particle transport and deposition.

### Objective 3:

- Students will be able to perform computational fluid dynamics and particle trajectory analysis in turbulent flows.
- Students will demonstrate using the ANSYS-Fluent Code for solving particle transport in turbulent flows.
- The student will be able to perform an experimental study of aerosol transport and deposition processes.

### Objective 4:

- Students will be able to analyze the industrial gas cleaning and separation processes.
- Students will demonstrate the application of aerosol transport and dispersion in industrial, environmental, or biomedical applications in pollution transport and respiratory deposition

## COURSE OUTLINE

Course Schedule & Graded Activities

| Dates | Module Title | Learning Materials (readings, videos, etc.) | Activities |
|---|---|---|---|
| Week 1-2 | **I. REVIEW OF VISCOUS FLOWS** | − Navier-Stokes Equation<br>− Simple Flows<br>− Creeping Flows<br>− Drag on Spherical Particles | Homework |
| Weeks 2-3 | **II. REVIEW OF COMPUTATIONAL FLUID MECHANICS** | − Finite Difference and Finite Volume Methods<br>− Introduction to ANSYS-Fluent Code | Homework |
| Weeks 4-8 | **III. REVIEW OF TURBULENCE MODELING** | − Algebraic Models<br>− Two-Equation Models<br>− Stress Transport Model<br>− Rate-Dependent Models<br>− PDF Models | Homework |
| Weeks 9-10 | **IV. AEROSOLS** | − Review of Drag, Lift, Virtual Mass and Basset Forces, BBO Equation<br>− Review of Nonspherical Particles<br>− Review of Brownian Motions<br>− Review of Particle Deposition Mechanisms<br>− Aerosol Transport in Turbulent Flows<br>− Wall Deposition in Turbulent Flows | Computer Projects |

| | | | |
|---|---|---|---|
| | | − Inertia Impaction<br>− Particle Charging Mechanisms<br>− Electrostatic Forces<br>− Thermophoretic Forces<br>− Aerosol Coagulation<br>− Coagulation by Turbulence and Shear Fields | |
| **Exam 1** | **March 10 (Friday) 4:00-5:30** | **Exam 1, CAMP 175 (Friday) 4:00-5:30** | **Exam 1** |
| Weeks 11 | **V. COLLOIDS** | − Introduction to Colloids<br>− Double Layer Forces<br>− Electrokinetic Phenomena | Computer Projects |
| Weeks 12-15 | **VI. SIMULATION METHODS** | − Sublayer Model of Turbulence<br>− Particle Deposition on Smooth and Rough Wall<br>− Sublayer Simulation of Charged Particle<br>− Approximate Simulation of Instantaneous Turbulent Flows<br>− DNS and Large Eddy Simulation of Turbulence<br>− Particle Transport and Deposition in Turbulent Flows<br>− Brownian Motion of Nano-particles in Turbulent Flows<br>− Nonspherical Particle Transport in Turbulent Flows | Homework |
| Weeks 15 | **VII. EXPERIMENTAL TECHNIQUES** | − Turbulent Flow Measurement (Hot-Wire, PIV, Laser-Doppler)<br>− Particle Concentration and Velocity Measurements (Phase-Doppler, PIV)<br>− Particle Production<br>− Aerosol Sampling Techniques and Aerosol Instrumentation<br>− Advanced Surface Cleaning Techniques (laser, cryogenic, ultrasonic) | Homework |
| Weeks 16 | **VIII. APPLICATIONS** | − Micro-contamination Control and Clean Room Operation<br>− Xerography<br>− Indoor Air Quality<br>- Transmission of respiratory viruses<br>− Computational Methods for Indoor Air<br>− Lung Deposition and Inhalation Drug Delivery<br>− Filtration Processes and Gas Cleaning<br>− Combustors and Boilers<br>− Spray formation | |
| **Final Exam** | | **Final Exam week** | **Final Exam** |

## COURSE TOPICS

### I. REVIEW OF VISCOUS FLOWS
- Navier-Stokes Equation
- Simple Flows
- Creeping Flows
- Drag on Spherical Particles

### II. REVIEW OF COMPUTATIONAL FLUID MECHANICS
- Finite Difference and Finite Volume Methods
- Introduction to ANSYS-Fluent Code

### III. REVIEW OF TURBULENCE MODELING
- Algebraic Models
- Two-Equation Models
- Stress Transport Model
- Rate-Dependent Models
- PDF Models

### IV. AEROSOLS
- Review of Drag, Lift, Virtual Mass and Basset Forces, BBO Equation
- Review of Nonspherical Particles
- Review of Brownian Motions
- Review of Particle Deposition Mechanisms
- Aerosol Transport in Turbulent Flows
- Wall Deposition in Turbulent Flows
- Inertia Impaction
- Particle Charging Mechanisms
- Electrostatic Forces
- Thermophoretic Forces
- Aerosol Coagulation
- Coagulation by Turbulence and Shear Fields

### V. COLLOIDS
- Introduction to Colloids
- Double Layer Forces
- Electrokinetic Phenomena

### VI. SIMULATION METHODS
- Sublayer Model of Turbulence
- Particle Deposition on Smooth and Rough Wall
- Sublayer Simulation of Charged Particle
- Approximate Simulation of Instantaneous Turbulent Flows
- DNS and Large Eddy Simulation of Turbulence
- Particle Transport and Deposition in Turbulent Flows
- Brownian Motion of Nano-particles in Turbulent Flows
- Nonspherical Particle Transport in Turbulent Flows

### VII. EXPERIMENTAL TECHNIQUES
- Turbulent Flow Measurement (Hot-Wire, PIV, Laser-Doppler)
- Particle Concentration and Velocity Measurements (Phase-Doppler, PIV)
- Particle Production

- Aerosol Sampling Techniques and Aerosol Instrumentation
- Advanced Surface Cleaning Techniques (laser, cryogenic, ultrasonic)

## VIII. APPLICATIONS

- Microcontamination Control and Clean Room Operation
- Xerography
- Indoor Air Quality
- Transmission of respiratory viruses
- Computational Methods for Indoor Air
- Lung Deposition and Inhalation Drug Delivery
- Filtration Processes and Gas Cleaning
- Combustors and Boilers
- Spray formation

## EVALUATION METHOD

Exam 1 (March 10, CAMP 175, (4:00-5:30) 25%
Final Exam (Final Exam week) 35%
Computational Projects and Lab 30%
Homework 10%

## Grading

### Grade Ranges

**Graduate Letter Grades**

| Course Average | Grade | Quality Points |
|---|---|---|
| 97+ | A+ | 4.0 |
| 93-96 | A | 4.0 |
| 90-92 | A- | 3.667 |
| 87-89 | B+ | 3.334 |
| 84-86 | B | 3.0 |
| 80-83 | B- | 2.667 |
| 76-79 | C+ | 2.334 |
| 70-75 | C | 2.0 |
| <70 | F | 0 |

## Course Policies

### Etiquette Expectations & Learner Interaction

Educational institutions promote the advancement of knowledge through positive and constructive debate--both inside and outside the classroom. Please visit and follow: Netiquette and Electronic Learner Interaction Guidelines.

## Institutional Policies

## Institutional Policies & Regulations

### Academic Integrity

Students are expected to abide by the standards of academic honesty, as described in the Clarkson Regulations. The work or words of others must be properly cited. Please refer to Clarkson Library's Guide to Plagiarism and Citing Sources.

## Students with Disabilities Policy

**Clarkson University welcomes inquiries and applications** from individuals who have disabilities. Information relating to disabling conditions is not a determining factor in admission decisions. The University strives to make all facilities and programs accessible to students with disabilities by providing appropriate academic adjustments and other appropriate modifications (accommodations), as necessary. Timely notification of any need for accommodations due to a disability is encouraged so that the Office of Accommodative Services (OAS) may provide for students in an efficient manner.

For more information or other appropriate campus referrals, contact:

Director of Accommodative Services
Clarkson University
P.O. Box 5645
Potsdam, NY 13699-5635
Phone: 315-268-7643
**Fax**: 315-268-2400
**Email**: oas@clarkson.edu
Office of Accessibility Services Website

### Instructor Participation

During this course, as your instructor, you can expect me to

- Respond to emails and voicemails within 1 day
- Grade activities and assessments within 3 days
- Be an active participant on the discussion board

## REFERENCES


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- M. Soltani, H. Ounis, G. Ahmadi, and J.B. McLaughlin, Direct Numerical Simulation of Charged Particle Deposition in a Turbulent Flow, Int. J. Multiphase Flow, Vol. 24, pp. 77-94, (1988).
- M.R. Spina and W.W. Nazaroff, Particle deposition from turbulent flow: Review of published research and its applicability to ventilation ducts in commercial buildings, http://repositories.cdlib.org/lbnl/LBNL-51432/