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TENTATIVE SYLLABUS

Mechanics of locomotion in air, water and on land

Course hours and credit: Tue-Thu: 1-3:00pm. Credit: 4 units

Description: This graduate course focuses on the mechanics of locomotion of biological and bio-inspired systems operating in aerial, underwater, and terrestrial environments. The approach will rely on project-based learning, and will involve: (1) identifying mathematically and experimentally tractable questions in animal and robotic locomotion; (2) formulating a scientifically-sound approach for addressing these questions by integrating tools from diverse research areas, such as fluid and solid mechanics, rigid-body dynamics, control and dynamical systems, statistical mechanics, and machine learning. To assist with these projects, the class will be divided into five modules or topics consisting of weekly lectures and hands-on computational work.

List of topics: The following is a tentative outline of the topics to be covered.

1. **Overview of continuum mechanics and tensor calculus** (2 weeks)
   - Review of vector calculus, linear algebra and tensor calculus
   - Continuum mechanics: conservation of mass and momentum, constitutive relations.
   - Navier-Stokes equation. The stress tensor.
   - Rigid body motions. The rotation tensor.

2. **Viscosity-driven locomotion and the Stokes equations** (3 weeks)
   - The Stokes equations. The energy-dissipation theorem. Uniqueness of Stokes flow. Lorentz reciprocal theorem.
   - Green's function and the Stokeslet solution as the fundamental solution of the Stokes equations for exterior problems. Integral representation of solutions. Multipole expansion.
   - Resistive force theory. Slender-body theory.
   - Locomotion and pumping by cilia and flagella.

3. **Inertia-driven locomotion and inviscid fluid models** (3 weeks)
   - Navier-Stokes equation. Incompressible and inviscid flows. Potential flows.
   - Vorticity formulation. Velocity from vorticity and the Biot-Savart law.
   - Lighthill's theory for slender fish. The energy method for small-amplitude swimming. Large amplitude theory of slender fish by momentum balance.
   - The wake structure and vortex shedding. Bound versus free vorticity. The Kutta-Joukowsky condition. Wu's inviscid theory for waving plates.
   - Application to undulatory swimming and flapping flight.

4. **Nonlinear control and motion planning using geometric mechanics** (2 weeks)
   - Decomposition of configuration space into shape and locomotion variables.
   - Locomotion by cyclic shape changes. Control and motion planning. Optimization methods.

5. **Numerical algorithms for solving fluid-structure interactions** (2 weeks)
   - Boundary element methods for potential flows. Vortex sheet methods for inviscid fluid-structure interactions.
   - Boundary element methods for Stokes flows. Regularized Stokeslet methods.

- Finite difference methods. Immersed boundary method for viscous fluid-structure interactions.

Pre-requisites: Dynamics AME 301, Fluid dynamics AME 309 and basic knowledge of linear algebra and linear ordinary and partial differential equations.

References: We will study contemporary papers but it is also useful to consult the following classic texts:

General fluid dynamics:
- Acheson, D.J. Elementary Fluid Dynamics
- Batchelor, G.K. Introduction to Fluid Dynamics
- Saffman, P.G. Vortex Dynamics
- Landau, L.D. & Lifshitz, E.M., Fluid Mechanics
- Kim & Karrila, Microhydronamics

Mathematical aspects of animal locomotion:
- Blake, R.W. Fish Locomotion
- Childress, S. Mechanics of Swimming and Flying
- Lighthill, M.J. Biofluiddynamics

Biophysical aspects of animal locomotion:
- Alexander, D. Nature's flyers: Birds, Insects, and the Biomechanics of Flying
- Alexander McNeil, R. Principles of Animal locomotion
- Dudley, R. The Biomechanics of Insect Flight
- Gray, J. Animal Locomotion
- Vogel, S. Life in Moving Fluids

Conference Proceedings:
- Pedley, T.J. (Ed.) Scale Effects in Animal Locomotion
- Wu, T. Y.-T. Brokaw, C.J., and Brennen, C. (Eds.) Swimming and Flying in Nature, Vols. 1 and 2

Homework assignments: There will be 4 to 5 homework sets. The purpose of the problem assignments is to help you understand the material and communicate your knowledge in writing. It is not necessary that you type your solution but write it in a neat and legible way.

Class project: Semester projects will require you to model, simulate, and analyze the locomotion of a biological organism or system (could be a problem discussed in a research paper or any problem that interests you) using the techniques we developed in class. The projects will be chosen as the semester progresses. A 1-2 pages (double spaced, 12pt Times New Roman, 1inch margins) description of your proposed investigation should be submitted no later than four weeks into the semester. Findings should be written up in a report and presented orally to the class at the end of the semester. Final reports are due one week before the end of the semester and should be no more than 10 pages (double spaced, 12pt Times New Roman, 1inch margins). The report should provide a legible and clearly written summary of your work. It should use the notation employed in class, feature animations and simulations where appropriate, and discuss briefly the significance of the results. Oral presentations will be for 15 minutes and scheduled during the final week of class.

Office hours: TBA

Grading: Grades will be based on the following categories:

Categories	Weight
Class attendance & Participation	20%
Homework assignments	20%
Final report	30%
Final presentaion	30%

AME 599 - Mechanics of locomotion in air, water and on land

Tentative schedule

	Topics/Daily Activities	Deliverable
Week 1	Introduction; concepts from classical continuum mechanics and tensor calculus; indicial notation	
Week 2	Conservation laws in integral and differential form, constitutive relations, energy balance	**Hw 1 due**
Week 3	Rigid-body motions; 3D Rotation tensors, Energy Balance, Momentum balance	
Week 4	Elastic continua; 1D elastic beams	**Hw 2 due**
Week 5	Elastic continua; 1D elastic beams and 2D elastic surfaces	
Week 6	Stokes flow: Stokes equations, boundary conditions, Lorentz reciprocal theorem, Green's function and integral representation of flows outside rigid and elastic bodies, multipole expansion	**Hw 3 due**
Week 7	Stokes flow: Far field expansion and Singularity solutions, Slender body theory, Faxen laws	
Week 8	Examples: swimming and pumping by cilia and flagella	**Hw4 due**
Week 9	Inviscid flow: Euler equations, boundary conditions, Helmholtz-Hode decomposition, Kelvin circulation theorem, Potential flow, Green's function and integral representation of potential flows outside rigid and elastic boundaries	

Week 10	Inviscid vortex sheet method	**Hw 5 due**
Week 11	Examples: swimming problems	
Week 12	Friction-driven locomotion. Examples of slithering snakes	
Week 13	Geometric mechanics methods in control, motion planning, and swimming gaits	
Week 14	Numerical algorithms	
Week 15	**Discussion of class projects**	
Final Exam period	**Final presentations**	**Final report due**

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, http://policy.usc.edu/scientific-misconduct.

Support Systems:

Student Counseling Services (SCS) – (213) 740-7711 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention. engemannshc.usc.edu/counseling

National Suicide Prevention Lifeline – 1 (800) 273-8255
Provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week. www.suicidepreventionlifeline.org

Relationship and Sexual Violence Prevention Services (RSVP) – (213) 740-4900 – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender-based harm. engemannshc.usc.edu/rsvp

Sexual Assault Resource Center
For more information about how to get help or help a survivor, rights, reporting options, and additional resources, visit the website: sarc.usc.edu

Office of Equity and Diversity (OED)/Title IX Compliance – (213) 740-5086
Works with faculty, staff, visitors, applicants, and students around issues of protected class. equity.usc.edu

Bias Assessment Response and Support
Incidents of bias, hate crimes and microaggressions need to be reported allowing for appropriate investigation and response. studentaffairs.usc.edu/bias-assessment-response-support

The Office of Disability Services and Programs
Provides certification for students with disabilities and helps arrange relevant accommodations. dsp.usc.edu

Student Support and Advocacy – (213) 821-4710
Assists students and families in resolving complex issues adversely affecting their success as a student EX: personal, financial, and academic. studentaffairs.usc.edu/ssa

Diversity at USC
Information on events, programs and training, the Diversity Task Force (including representatives for each school), chronology, participation, and various resources for students. diversity.usc.edu

USC Emergency Information
Provides safety and other updates, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible. emergency.usc.edu

USC Department of Public Safety – UPC: (213) 740-4321 – HSC: (323) 442-1000 – 24-hour emergency or to report a crime.
Provides overall safety to USC community. dps.usc.edu