Dr. HM Lacker Fall 2006

BME 382
Engineering Physiology II

The Department of Biomedical Engineering

CLASS HOURS
Monday 2:30-3:55 pm (Cullimore: Lecture Hall III)
Thursday 2:30-3:55 pm (Cullimore: Lecture Hall III)

OFFICE HOURS (Fenster 615)
Monday 4-5:30 pm
Thurs. 1-2:30 pm or by appointment
Email: hmlacker@aol.com

Recitation Sessions: (go over homework and review class material)

TEXT
Modeling and Simulation in Medicine and the Life Sciences, 2nd Edition, Hoppensteadt & Peskin
ISBN:0-387-95072-9 (required)

Human Physiology, From Cells to Systems, 4th Edition, Sherwood,
ISBN: 0-534-56826-2 (reference)

COURSE DESCRIPTION
Prerequisites: Math 111, Math 112, CIS 101, Phys 111, Phys 121, Chem 125, Chem 126, BME 106

This is the second of a pair of 1 semester courses (BME 381,382) that introduce students to the modeling of organ function and organ systems of the human body. The subjects covered are similar to those taught in introductory systemic physiology courses in medical school, biology or biomedical engineering departments (BME 106). The approach, however, is that of an engineer integrating and applying quantitative concepts acquired in basic undergraduate physics, chemistry, mathematics, and computer science courses to the modeling of dynamical systems of the human body with feedback control. Emphasis will be placed on feedback control, mathematical modeling, and numerical simulation.

BME 381 and BME 382 are similar courses and differ primarily in the physiological systems for which the students learn to develop models.

COURSE OBJECTIVES
The course objectives are to enable biomedical engineering students to apply some of the basic tools that they have learned in electrical and mechanical engineering analysis, mathematics, computer science, general physics and chemistry courses so that they can develop models that quantitatively predict the functioning of physiological systems in the human body. Such models provide quantitative insight into the normal feedback mechanisms that control physiological variables of the human body. This quantitative approach applies engineering systems analysis to systemic physiology and employs the ideas of feedback control, mathematical modeling and numerical simulation. This engineering approach to physiological function is designed to give the student the potential to better understand human disease and to use this understanding for the construction of new technologies for diagnosis and treatment.

TOPICS COVERED
Topics covered in this course include: engineering aspects of design of the pulmonary and systemic circulations, Sagawa model of the heart as a time varying pump, models of the uncontrolled circulation, baroreceptor feedback loop, autoregulation, fetal circulation, circulation changes at birth, dynamics of the arterial pulse, structure and function of the kidney, control of body fluid volume and electrolytes, filtration mechanisms, renal countercurrent mechanism

without juxtaglomerular feedback, distal nephron and hormonal control of salt and water reabsorption, nephron function with juxtaglomerular feedback included; optimal design of nephron loop lengths to maximize renal concentrating ability; muscle cross bridge dynamics and models of calcium for the control of contraction.

LEARNING OUTCOMES

By the end of the course you should be able to do the following:

- **Modeling:** Apply knowledge of math, engineering and science to understand the principles of modeling physiological and biophysical systems.

- **Computer Simulation:** Learn to utilize Matlab software to program numerical solutions to physiological and biophysical processes.

- **Physiological Applications:** Apply knowledge of math, engineering and science to identify formulate, and solve problems in physiology and biophysics and learn theoretical tools and methodology that are needed to design effective, efficient and safe equipment that interact with and assist physiological systems.

COURSE OUTLINE*

Date	**Topic**	**Material**	**Recitation Class Work (Weekly Meeting)**	**Assignment**
9/7	Plan of the Circulation (systemic and pulmonary circulations in series with symmetrical and asymmetrical features),Volume, Flow Pressure; Resistance and Compliance Vessels	Chapters 1.1, 1.2		Read Chapters 1.1,1.2 Exercise Problem: 1.1
9/11	The Heart as a Pair of Pumps (output sensitivity to diastolic filling (venous pressure); Cardiac Pressure - Volume Cycle; Dynamic Ventricular compliance (Sagawa) model	Chapter 1.3, 1.4	Review Answers to Exercise Problem 1.1 and class material	Read Chapter 1.3,1.4

9/14	Mathematical Model of the Uncontrolled Circulation --Steady State Solution of Mean Pressures, Volumes and Flow	Chapter 1.5.		Read Chapter 1.5 Exercise Problem: 1.2,1.3
9/18	Dynamics of the Uncontrolled Circulation: Numerical Solution of the Initial Value Problem (Euler's Method)	Class Notes	Review HW problems 1.2, 1.3	Study Class Notes Exercise Problems: 1.4,1.5
9/21	Analytic Solution of the Initial Value Problem for the Uncontrolled Circulation. Compare solution to Numercial Solution of 9/18	Class Notes		Create Computer Program to Solve for Transients to Hand out Initial Value Problems for Uncontrolled Circulation (1 wk. assignment)
9/25	Generalization of the Numerical Method for other First Order Dynamical Systems,, multiple (stable and unstable) steady states	Class Notes	Review Numerical Solutions to Assigned Initial Value Problems and Check for consistency with analytic and steady state solution.	(continue with above)
9/28	The Need for External Circulatory Control Mechanisms,Neural Control: The Baroreceptor Loop	Chapter 1.7,1.8		Read 1.7 and 1.8 Exercise Problems: 1.7-1.9
10/2	Contolled Circulation: Model Formulation, Solution and Analysis	Chapter 1.8	Review Solutions to Exercise Problems: 1.7-1.9	Exercise Problems: 1.6, 1.10, 1.11
10/5	Autoregulation	Chapter 1.9		Read 1.9 Exercise Problems:1.12, 1.13
10/9	Model of Fetal Circulation: Formulation and Solution and Analysis of Steady State	Chapter 1.10	Review Solutions to Exercise Problems: 1.12, 1.13	Read 1.10 Exercise Problems:1.14-1.15
10/12	Changes in the Circulation that Occur at Birth--Solution and Analysis of Fetal Circulation Model with changes in Pulmonary and Systemic Resistance Parameters			Exercise Problem:1.16

10/16	Simple Model of the Arterial Pulse: Periodic Solution, Calculation of Mean Arterial Pressure	Start Chapter 1.11	Review Solution to Exercise Problems:1.14-1.16	Read Chapter 1.11 Exercise Problems 1.17,1.18
10/19	Model formulation, solution and analysis of Arterial Blood Pressure for given non-uniform interbeat intervals and non-uniform stroke volumes	Finish Chapter 1.11		Exercise Problems 1.19,1.21
10/23	Arterial Blood Pressure for regular arrhythmia: Periodic Solution (after multiple beats)	Class Notes	Review Solution to Exercise Problems:1.19-1.21	Exercise Problems 1.22-1.23
10/26	Introduction to the Kidney, Anatomy, Evolution, Problem of Salt and Water Balance	Chapter 4.1 and Class Notes		Exercise Problems 1.24, 1.25 Read 4.1
10/30	Dynamics of Sodium and Water Transport along Renal Tubules	Chapter 4.2	Review Solution to Exercise Problems:1.22-1.25	Study for Midterm Exam
11/2	Midterm Exam			Read 4.2
11/6	. The Loop of Henle Model Formulation of the Countercurrent Mechanism	Chapter 4.3	Review Solution to Midterm Exam Problems	Read 4.3 Exercise Problem 4.1
11/9	Countercurrent Model Solution and Analysis	Start Chapter 4.4		Start reading 4.4 Exercise Problem 4.2
11/13	The Juxtaglomerular (JGA) Apparatus and the Renin-Angiotensin System	Finish Chapter 4.4	Review Solutions to Exercise Problems 4.1, 4.2	Finish reading 4.4 Exercise Problem 4.3
11/16	The Distal Tubule and Collecting Duct: Concentrating and Diluting Modes	Chapter 4.5		Read 4.5 Exercise Problem 4.4
11/20	Remarks on the Significance of the JGA Apparatus, Introduction to the multi-nephron Kidney with different Henle Loop Lengths	Chapter 4.6, 4.7	Review Solutions to Exercise Problems 4.3, 4.4	Read 4.6 & class notes Exercise Problems 4.5, 4.6

11/21(Classes follow a Thurs. Schedule;No class on 11/22	Solution of the 2 Nephron Kidney	Class Notes	Review Solutions to Exercise Problems 4.5, 4.6	Read class notes
11/27	Optimal Distribution of Loop Lengths to achieve maximum concentrating ability	Class Notes		Study class notes Problem Exercise 4.7
11/30	Introduction to Muscle Mechanics: The Force Velocity Curve	Chapter 5.1	Review answer to Exercise Problem 4.7 and Optimal Loop Lengths in a 2 Loop Nephron or distribution of Nephrons	
12/4	Crossbridge Dynamics Model Formulation	Chapter 5.2		Start reading Chapter 5.2 Exercise Problem 5.1
12/7	Crossbridge Dynamics Model Solution	Chapter 5.2	Review answer to Exercise Problem 5.1	Finish reading Chapter 5.2 Exercise Problems 5.2 , 5.3
12/11	Crossbridge Dynamics Model Analysis			Exercise Problems 5.4 , 5.5
12/13	Crossbridge Dynamics: Muscle Superisometric Yield Force :Experiment and Model Predictions	Chapter 5.2	Review answers to exercise Problems 5.2 -5.5	Review for Final Exam
TBA	Final Exam		Review for Final Exam	

***The Course Outline may be modified at the discretion of the instructor or in the event of extenuating circumstances. Students will be notified in class of any changes to the Course outline and schedule of studio sessions.**

GRADING
4 Quizzes (Unannounced): 40%
Midterm Exam: 30%
Final Exam: 30%

Attendance is mandatory. Failure to attend class regularly will result in a failing grade.
No makeup examinations will be administered. If a valid, documented excuse for a missed exam is provided, the weight of the Final Exam will increase to compensate for the missed grade.

<u>Honor Code Violations/Disruptive Behavior:</u> NJIT has a zero-tolerance policy regarding cheating of any kind and student behavior that is disruptive to a learning environment. Any incidents will be immediately reported to the Dean of Students. In the cases the Honor Code violations are detected, the punishments range from a minimum of failure in the course plus disciplinary probation up to expulsion from NJIT with notations on students' permanent record. Avoid situations where honorable behavior could be misinterpreted. No eating or drinking is allowed in class. Cellular phones must be turned off during the class hours.

CONTRIBUTION OF COURSE TO MEETING THE PROFESSIONAL COMPONENT
This course meets the professional component by introducing students to the general study and function of each of the major organs and systems of the human body. Students are taught to approach hypothetical situations by employing engineering concepts and ideas of feedback control, signal processing, mathematical modeling, and numerical simulation. In this way a hierarchy of models will be constructed. This course prepares students for careers which can include heath-related professions as well as various professional within biomedical engineering.

RELATIONSHIP OF COURSE TO PROGRAM OUTCOMES
Successful understanding and application of quantitative physiology requires an integration of multiple disciplines including chemistry, physics, electrical engineering, mechanical engineering, mathematics and computer science. Students will engage in studio lab projects that will involve programming skills to build models and simulate solutions to physiological and pathological conditions such as exercise or hemorrhage. The ability to identify, formulate, and solve problems related to physiological processes is practiced throughout the course through the use of in-class examples, homework problems, and exams. The ability to communicate effectively and to write well is exercised on exams through the use of short-answer and essay type questions in which students must clearly explain and justify their answers not only through calculations.

BME 381: Learning Outcome Summary

Outcome # 1. Apply knowledge of math, engineering and science to understand the principles of modeling physiological and biophysical systems		
Strategies & Actions	**Program Outcomes**	**Assessment Methods**
Hierarchical Models of Physiological and Biophysical Systems are formalized into self-consistent and complete mathematical systems; available data is used to identify normal and/or pathological model parameters; steady-state and dynamical closed form and/or numerical solutions are constructed; solution analysis related to model limiting behavior, model self-consistency, physical and physiological plausibility are explored.	A,E,K,L,M	Homework, Recitation Sessions, Quizzes, Examinations
Outcome # 2. Learn to utilize Matlab software to program numerical solutions to physiological and biophysical processes		
Strategies & Actions	**Program Outcomes**	**Assessment Methods**
Numerical Solutions to non-linear systems of differential equations are obtained using simple (Euler) explicit finite difference equations. Root finding algorithms (Bisection, Newton or Newton like methods) are employed to solve algebraic implicit systems when explicit solutions to variables can not be obtained in	A,E,K,L,M	Homework, Recitation Sessions, Quizzes, Examinations

closed form. Numerical solutions are compared to limiting analytic solutions to test for logical coding errors and self-consistency.		
Outcome # 3. Physiological Applications: Apply knowledge of math, engineering and science to identify formulate, and solve problems in physiology and biophysics and learn theoretical tools and methodology that are needed to design effective, efficient and safe equipment that interact with and assist physiological systems.		
Strategies & Actions	**Program Outcomes**	**Assessment Methods**
(see also Strategies & Actions for Outcome #1) Model Solutions are analyzed to strengthen intuition and insight into physiological system behavior and possible implications for effective, efficient and safe equipment design.	A, E,K,L,M,O	Homework, Recitation Sessions, Quizzes, Examinations

Person(s) who prepared this description and date of preparation: Dr. H. Michael Lacker, January 2007

ABET Outcomes expected of graduates of BME BS program by the time that they graduate:

(A) an ability to apply knowledge of mathematics, science, and engineering
(B) an ability to design and conduct experiments, as well as to analyze and interpret data
(C) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
(D) an ability to function on multi-disciplinary teams
(E) an ability to identify, formulate, and solve engineering problems
(F) an understanding of professional and ethical responsibility
(G) an ability to communicate effectively
(H) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(I) a recognition of the need for, and an ability to engage in life-long learning
(J) a knowledge of contemporary issues
(K) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
(L) an understanding of biology and physiology
(M) the capability to apply advanced mathematics (including differential equations and statistics), science, and engineering to solve problems at the interface of engineering and biology
(N) an ability to make measurements on and interpret data from living systems
(O) an ability to address problems associated with the interaction between living and non-living materials and systems