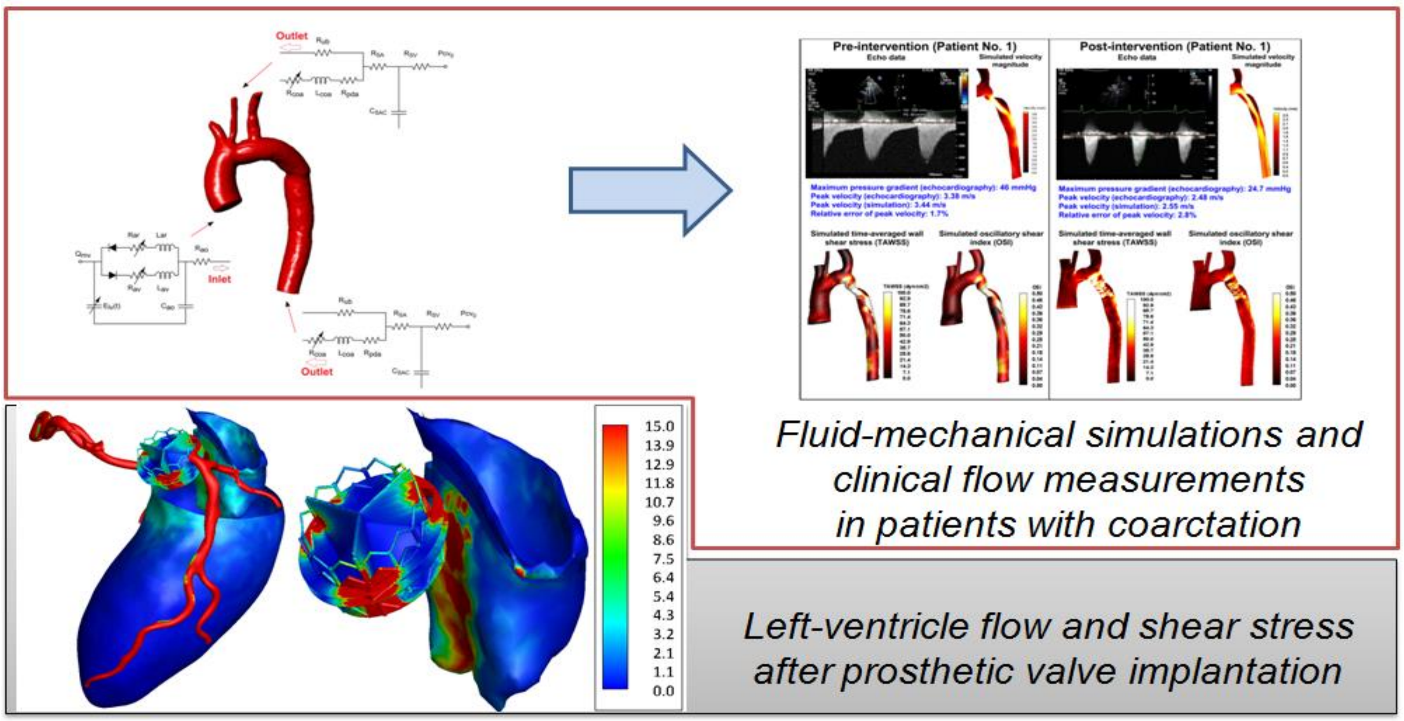
Department of Mechanical Engineering
School of Computational Science and Engineering
School of Biomedical Engineering
McMaster University

MECH ENG 762
Computational Modeling of Circulatory System
Term 2 (January – April 2020)



https://www.eng.mcmaster.ca/mech/people/faculty/zahra-k-motamed

Instructor:	Dr. Zahra Motamed
Office:	*ABB-C* 307
Email:	motamedz@mcmaster.ca
Office hours:	TBD
Lectures:	Mondays, 10 AM to 13 PM at JHE 219
Tutorials:	none
Laboratories:	none
Course website:	via *Avenue to Learn* (avenue.mcmaster.ca)

Course Description & Objectives:

The circulatory system consists of the heart and a network of vessels that transport the blood. The heart consists of two pulsatile pumps in series and circulates blood through the vasculature. The vasculature consists of arteries, arterioles, capillaries, venules and veins. The circulatory system also includes local circulation subsystems such as cerebral, pulmonary and renal circulations. Mechanics of the circulatory system may be studied from two biomechanical perspectives: solid mechanics of the blood vessels and fluid mechanics of the blood flow. The main objectives of the course are to learn basics of modeling of circulatory mechanics and getting familiar with the current challenges involved in the modeling process. Computational modeling of circulatory system presents formidable mathematical and computational challenges: modeling must incorporate motions of blood and vessel walls, complex biomechanics of the heart, a large network of the blood vessels with complicated geometries, persistent pulse-driven changes in flow and pressure, complicated exchanges happening in local circulatory subsystems and in some cases behavior of blood cells. After a brief review of circulatory physiology and fluid mechanics, the course will progress from modeling blood flow in small-scale steady/pulsatile to model large-scale or complex pulsatile flow. This course will cover various methods for modeling mechanics of the circulatory system and its subsystems. We will discuss the application of these concepts in the development of circulatory medical devices (e.g., stents, grafts, heart valves, trans-catheter valves and ventricular assist devices).

Significance:

The main purpose of modeling circulatory mechanics is to study circulatory diseases. *In vivo* measurements are difficult, and even impossible in some cases. Non-invasive measurements are useful but do not always allow studying realistic conditions. Computational modeling of the circulatory system can fill this gap by playing major roles in uncovering causes of pathologies, in enabling prediction of effectiveness of interventions, in allowing systematic testing of possible clinical solutions, and in enabling personalization of interventions. Additionally, development and innovation of extra-corporal systems strongly rely on knowledge of the circulatory mechanics. Therefore, modeling is crucial for design and development of medical devices, and for evaluating of the hemodynamic effects of medical devices after implantation in the patient body.

Course Topics:

Major topics to be covered include:

- Anatomy and physiology of cardiovascular system
- Flow, pressure and wave reflection in the circulatory system
- Medical image modalities and acquisition
- Medical image processing
- 3-D geometry reconstruction
- Fundamentals of hemodynamics
- Boundary conditions
- Computational fluid dynamics methods
- Soft tissue mechanics and computational fluid structure interaction
- Multi-scale simulations
- Lumped parameter mathematical models

Audience:

This course has been designed for graduate students in science and engineering interested in learning about circulatory mechanic and its biomedical applications. The course will be of particular interest of students in the following departments and schools:

Mechanical Engineering, Chemical Engineering, Computing and Software, Electrical and Computer Engineering, Engineering Physics, School of Biomedical Engineering and School of Computational Science & Engineering. Students from the Faculty of Health Sciences are also welcome to register for the course.

Email Policy:

All emails directed to the instructor should include a subject prefix of "ME [course number]-[subject]".

Course Materials:

Lecture Notes:

The lectures notes will be made available on *Avenue*. The lectures notes do not always repeat materials from supplementary references.

Textbooks:

There is no specific textbook for this course. The instructor will provide reading material including course notes, articles, videos and schematics. Following are some useful references for the course:

- Yamaguchi T (2000) Clinical Application of Computational Mechanics to the Cardiovascular System, Springer.
- Zamir M (2016) Hemo-Dynamics, Springer.
- Humphrey JD (2001) Cardiovascular Solid Mechanics: Cells, Tissues, and Organs, Springer.
- Guccione JM, Kassab GS, Ratcliffe MB (2010) Computational Cardiovascular Mechanics: Modeling and Applications in Heart Failure, Springer.
- Chandran KB, Rittgers SE, Yoganathan AP (2012) Biofluid Mechanics: The Human Circulation, Second Edition, CRC Press, Taylor & Francis Group.
- Nichols W, O'Rourke M, Vlachopoulos C (2011) McDonald's Blood Flow in Arteries, Sixth Edition, CRC Press, Taylor & Francis Group.
- Waite L, Fine JM (2017) Applied Biofluid Mechanics, Second Edition, McGraw Hill.
- Waite L (2006) Biofluid Mechanics in Circulatory Systems, McGraw-Hill.
- Kleinstreuer C (2006) Biofluid Dynamics: Principles and Applications, CRC Press, Taylor & Francis Group.

Evaluation:

The final grade will be calculated by combining presentations, term project paper and the final exam as follows. The percentage marks will be converted to a final letter grade using the standard conversion scale shown in the McMaster Graduate Calendar.

First presentation & Abstract (**February 7th**):	**20%** (15 minutes presentation of project definition and two-page abstract defining the project)
Second presentation (**March 6th**):	**20%** (20 minutes presentation of project update)
Final project presentation	**10%** (30 minutes presentation of project)
Term project paper	**50%** (Deadline for submission: **April 20th**)

Term Project: All students will be required to work individually on a research project. The final deliverable will be a written research report. Each student will select a topic (not related to their thesis research) and will prepare a report. The research report **should be written as a scientific journal article**. **This article can be either an original modeling research paper or a comprehensive review paper about modeling of circulatory system**. Some potential topics (but not limited to) are listed below:

- Device modeling: ventricular assist devices, trans-catheter heart valves, stents, grafts, etc.
- Circulatory surgical planning modeling
- Cell-level modeling: red blood cells, platelets, white blood cells, endothelial cells, etc.
- Modeling of vascular and mini-vascular pathologies
- Modeling of ventricular pathologies
- Modeling of valvular pathologies

Presentation: Each student will give three presentations.

Attendance: ***Class attendance is highly recommended***.

Class Website: All registered students will have access to the class website via *Avenue* (avenue.mcmaster.ca). Class announcements, course information and course documents are contained on this website. This website will be continuously updated with related information throughout the semester.

Learning Outcomes:

Upon successful completion of the course, it is expected that the students will be able to:

- Understand the physiology and anatomy of the circulatory system
- Understand medical imaging
- Know specific circulatory diseases and how they are related to mechanics
- Understand fluid and solid mechanics models currently used for circulatory research problems
- Understand the effect of mechanical forces on various circulatory cells
- Understand biomechanical issues in select circulatory medical devices
- Be familiar with the state-of-the-art computational modeling methods
- Have the understanding and the capability to develop simple models of circulatory function under varying preload, afterload, and contractility
- Have the understanding and the capability to develop simple models of blood flow in devices and circulatory system
- Have the understanding and the capability to develop simple models of stress and strain in blood vessels and heart tissue
- Develop critical thinking regarding the current research challenges in circulatory mechanics

- Have the understanding and the capability to carry out a circulatory-mechanics research project

Policy Reminders: Students are reminded of the following Policies, which could be relevant to activities in this course.

Adverse Discrimination: The Faculty of Engineering is concerned with ensuring an environment that is free of all adverse discrimination. If there is a problem that cannot be resolved by discussion among the persons concerned, individuals are reminded that they should contact the Department Chair, the Sexual Harassment Officer or the Human Rights Consultant, as soon as possible.

Academic Integrity (Ethics and Dishonesty) Academic dishonesty consists of misrepresentation by deception or by other fraudulent means and can result in serious consequences, e.g. the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: "Grade of F assigned for academic dishonesty"), and/or suspension or expulsion from the university.

It is your responsibility to understand what constitutes academic dishonesty. For information on the various kinds of academic dishonesty please refer to the Academic Integrity Policy, specifically Appendix 3, located at: http://www.mcmaster.ca/senate/academic/ac_integrity.htm

The following illustrates only three forms of academic dishonesty:

1. Plagiarism, e.g. the submission of work that is not one's own or for which other credit has been obtained.
2. Improper collaboration in group work
3. Copying or using unauthorized aids in tests and examinations.

The instructor and university reserve the right to modify elements of the course during the term. The university may change the dates and deadlines for any or all courses in extreme circumstances. If either type of modification becomes necessary, reasonable notice and communication with the students will be given with explanation and the opportunity to comment on changes. It is the responsibility of the student to check their McMaster email and course websites weekly during the term and to note any changes.