North Dakota State University
Department of Mechanical Engineering

ME 721: Advanced Dynamics, Fall 2023

INSTRUCTORS: Dr. Majura F. Selekwa
101B Dolve Hall
majura.selekwa@ndsu.edu
701-231-5667

Class meeting time: T-Th 12:30pm-1:45pm
Office hours: M-W 01:00pm-02:00pm

BULLETIN DESCRIPTION: Newtonian dynamics; dynamics of particles; dynamics of rigid bodies; variational principles; d'Alembert's principle; Hamilton's principle; Lagrange's equation of motion; multi-body dynamics

COURSE DESCRIPTION: This course deals with advanced concepts in Newtonian dynamics of particles and systems of particles. The course will address methods of developing mathematical models that describe the dynamics of systems of rigid bodies, the formulation of equations of motion, and solution techniques for solving those equations.

CREDITS: This is a 3-credit course with a weekly load of two 1-hour lectures and one 2-hour laboratory session. This course is for ME graduate students only; it can potentially be cross-listed with Civil Engineering department.

PREREQUISTES: Graduate Standing.

TEXTBOOK: Donald T. Greenwood: *Advanced Dynamics*, Cambridge, 2002 or 2003. Access to Haim Baruh: "*Analytical Dynamics*" McGraw Hill, 1999 will be useful.

OBJECTIVES AND OUTCOMES: Students will learn to (1) develop mathematical models for the dynamics of systems of rigid bodies, (2) formulate and solve equations of motion for complicated mechanical systems, and (3) apply the knowledge gained to analyze and design real engineering systems. At the end of this course, students should be able to:

- Formulate and analyze motions of mechanical systems using Newton's equation.
- Formulate and analyze motions of mechanical system using energy methods, such as Hamilton's principles and Lagrange's method.
- Use the fundamental engineering science of dynamics to solve practical engineering problems.
- Use appropriate computer software for modeling and analyzing the dynamics of mechanical systems.
- Work in groups and gain multidisciplinary skills.

- Research and develop better tools for analysis and design of mechanical systems, and effectively communicate their research results.

GRADING: There will be five homework assignments handed out after every major topic, two quizzes done after every two major topics, one term research project and a final exam completed in the finals week. The final grade will be based on the following apportionment:

- Homework Assignments 40%
- Term Research Project 30%
- Final Exam 30%

Final course grade scale:

A 90%-100% B 80%-89% C 70%-79% D 60%-69% F <60%

RESEARCH PROJECT: Students will be required to analyze the dynamics of a real engineering system with an adequate level of complexity. Specific tasks will include setting up the mathematical model of the system, finding the equations of motion, and simulating the dynamic responses using numerical methods in MATLAB. A final project report is required; it must be in the form of a scholarly article using ASME standards.

SPECIAL SERVICES: Any students with disabilities or other special needs who need special accommodations in this course are invited to share these concerns or requests with the instructor as soon as possible.

ACADEMIC HONESTY STATEMENT: Academic dishonesty and cheating of any kind (including plagiarism) result in an automatic course failure and possible referral to appropriate university disciplinary entities. All work in this course must be completed in a manner consistent with NDSU University Senate Policy, Section 335: Code of Academic Responsibility and Conduct (http://www.ndsu.nodak.edu/policy/335.htm).

ATTENDANCE POLICY: Although attendance will not be recorded and will never count towards the final grade of the course, students are strongly encouraged to attend all class sessions in order to be able to cope with the pace of the course. According to NDSU Policy 333, attendance in all classes is expected.

Tentative Course Schedule

Week	Topics

1	• Introduction
	    • Course Syllabus and Policies
	    • Review on Basic Newtonian of Dynamics.
	    • Particle Motion in Space

2-3	• Dynamics of Systems of Particles
	    • Equation of Motion, Momentum and Energy methods for Systems of Particles
	    • Foundations of Analytical Dynamics:
	        • *Generalized Coordinates, Positions and Velocities*
	        • *Constraints : Holonomic and Non Holonomic*
	    • Variational Methods for Systems of Particles
	        • *Virtual variations: Virtual displacements and Virtual Work*
	        • *Generalized Work and Energy*
	        • *Generalized Momentum and Impulse Response*
	HW 1 in Week 3
	Project Topics Distributed

4-6	• Lagrangian and Hamiltonian Analytical Mechanics
	    • d'Alembert's Principle and Lagrange's Equations.
	    • Hamilton's Equations
	    • Integrals and Constants of Motion
	        • *Jacobi's Energy Integral for Conservative Systems*
	        • *Momentum Integral for Systems with Ignorable Coordinates*
	        • *Routh's Method for Ignoration of Coordinates*
	        • *Integrals for Systems with Separable Coordinates*
	    • Systems with velocity dependent Non-Conservative Forces
	        • *Dissipative and Gyroscopic Forces*
	    • Configuration and Phase Spaces
	    • Constrained Impulsive Systems
	HW2 in Week 5

7-9	• Rigid Body Kinematics
	    • Rigid Body Motion: Rotations, Euler angles and rotation matrices
	    • Euler-Rodriguez Rotation Formula and Principal axes
	    • Angular Velocities about Principal axes
	    • Euler Parameters and Quaternions
	HW3 in Week 8

10-12	• Rigid Body Dynamics
	    • Dyadic Operations: Inertia Tensor and Ellipsoid of Inertia
	    • Newton-Euler Equations of Motion
	        • *Rigid Body Kinetic Energy*
	        • *Rigid Body Momentum*
	        • *Newton-Euler Equations*
	        • *Modified Euler Equations*
	    • Analytical Formulations for rigid bodies
	        • *Generalized coordinates and Velocities*
	        • *Generalized Force, Work and Kinetic Energy*
	        • *Euler-Lagrange Equations*
	        • *Impulse momentum Constrained impulsive response*
	HW 4 in Week 11

13	• Differential Equations of Motion
	    • Quasi-coordinates and Quasi Velocities for particles and Rigid bodies
	        • *Kane's and Gibb-Appell Equations*
	    • Systems with non-holonomic Constraints
	        • *Maggi's Equations and Boltzmann-Hamel Equations*.
	• Paper Review: Udwadia, Maggi, Hamel,
	
	HW5 in Week 14.

14-16	• Introduction to Multibody Dynamics (MBD) -Open Chain and Closed chain interconnected multi-body system MBS -Newton-Euler Equations for Interconnected Multibody Systems -Lagrange's Equations applied to Multibody systems • Turn in the project report
17	**FINAL EXAM**