



Sharif University of Technology
Department of Aerospace Engineering

Master Program in Flight Dynamics and Control

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Chapter 1: Department of Aerospace Engineering

The Department of Aerospace Engineering at Sharif University of Technology initiated its degree programs in 1987 as the Aerospace Engineering Group, part of the Mechanical Engineering Department. In 1999, the Aerospace Engineering Group separated from the Mechanical Engineering Department and continued its activities as an independent department.

In accordance with the general SUT philosophy, the faculties in Aerospace Engineering are a selected group from the world's most prestigious universities providing an atmosphere of expertise and collaboration that is unparalleled in other universities. Our faculty works closely with those in Mechanical Engineering, Applied Physics, and Electrical Engineering.

The graduate programs on M.Sc. and PhD level were established in 1993 and 1996, respectively. Since then, these programs have been continuously offered in four subjects of Flight Dynamics and Control, Aerodynamics, Propulsion and Structure. The master program in Space Engineering was also established in 2010.

Professors of the flight dynamics and control division perform their research activities in different fields including: design of flying vehicles, flight trajectory design and optimization, flight simulation, statistical analysis of flying vehicles, multi-disciplinary design optimization, design and analysis of flight tests, stability analysis and control of flying vehicles, aerospace robotics, design of intelligent guidance and control systems, instrumentation, aerospace system identification, analysis of multi-body dynamics, swarm intelligence, navigation systems, heuristic algorithms, etc.

This document introduces the master program in Flight Dynamics and Control for interested students and other parties.

Chapter 2: Overall Program

This chapter presents an overview on the master program in Flight Dynamics and Control. The general requirements of this program are as in table 1. Tables 2 and 3 present the list of main and elective technical courses, respectively.

Table 1 General Requirements of Flight Dynamics and Control division

Item	Units
Advanced Mathematics I	3
At least four courses from Table 2	12
At least three courses from Table 3	9
M.Sc. Thesis	6
M.Sc. seminar or another course from Table 3	2
Minimum required units for graduation	32

Table 2 Main Technical Courses

Course Title	Course Number
Advanced Automatic Control	45710
Advanced Aircraft Design /	45915/
Advanced Concepts in Design	45736
Advanced Flight Dynamics I	45705
Guidance and Navigation I	45715
Modeling of Aerospace Dynamic Systems	45747

Table 3 Elective Technical Courses

Course Title	Course Number
Adaptive Control	45760
Advanced Aircraft Performance	45738
Aerospace Technology Management	45540
Avionics	45419
Control Systems Design	45730
Digital Control	45755
Flight Simulation	45745
Flight Test Principles	45720
Fuzzy Control	45735
Guidance and Navigation II	45716
Helicopter Flight Dynamics	45740
Heuristic Optimization Algorithms	45770
Missile Configurative Design	45734
Missile Flight Dynamic	45725
Multi Variable Control	45750
Neural Networks	45775
Nonlinear Systems Analysis	45748
Optimal Control I	45765
Optimal Control II	45766
Spacecraft Dynamics and Control	45780
System Identification	45749
Max. one course from:	
• Other technical courses in the group,	
• Technical courses in other groups,	
• Any other course approved by the group.	

Chapter 3: Syllabus of the Courses

In this chapter, syllabus of each course is presented in detail.

Advanced Aircraft Performance, 45738

Prerequisite: Flight Dynamics I, 45156

Course Objectives:

Increase of the population and the rising demands for air transportation has opened new issues in air transportation and has changed the attitude on the performance of the aircrafts and the way of using them. As a result, this course focuses on better usage of the aircrafts and tries to provide a condition to design better aircrafts from the performance point of view. The main mentality in this course is keeping the air transportation economic in front of other kinds of transportation. Moreover, other topics such as optimality of flight path, sound pollution, formation flights and aerial traffic are also discussed as well as flight safety.

Syllabus:

1. Introduction and Basic Concepts
 - Performance Theory and Performance Problems
 - Nature of Passengers and Cargo Loads
 - Airport Issues
 - Airline Issues
 - Geographical Issues
 - Climate Issues
 - Aircraft Navigation
 - Systems Issues
 - Economic Issues
2. Mathematics and Performance Problems
 - Application of Calculus of Variations in Performance Problems
 - Lagrange Problems
 - Meyer Problems
 - Bolza Problems
 - State-Space Formulation
 - Application of the Control Theory
 - Singular Perturbations
3. Energy State Formulation

- Overview
 - Equation of motion and Performance Integrals
 - Quasi-Linear Maneuvers
 - Graphical Methods
 - Transition Flights
 - Supersonic Problems
4. Special Problems
- Optimal Trajectory in Wind-Fields
 - Discrete Dynamic Programming for Airline
- Sequential Decision Making
 - Reduced Order Model for Trajectory Optimizations
 - Issues in Formation Flights
 - Free Flight Concept
 - Continuous Descent Approach
 - Airspace Saturation

Course Outcome:

After completion of this course the student can understand:

1. Some basic issues in aircrafts performance,
2. The mathematical modeling of an aircraft performance problem,
3. How to solve an aircraft performance problem using the calculus of variation method.

References:

1. Visser, H.; *Airplane Performance Optimization*, Encyclopedia of Aerospace Engineering, 2010.
2. Writtenberg, H.; *Advanced Topics in Aircraft Performance Optimization*.
3. *Class notes of Delf University of Technology*.
4. *Class notes of University of Kansas*.

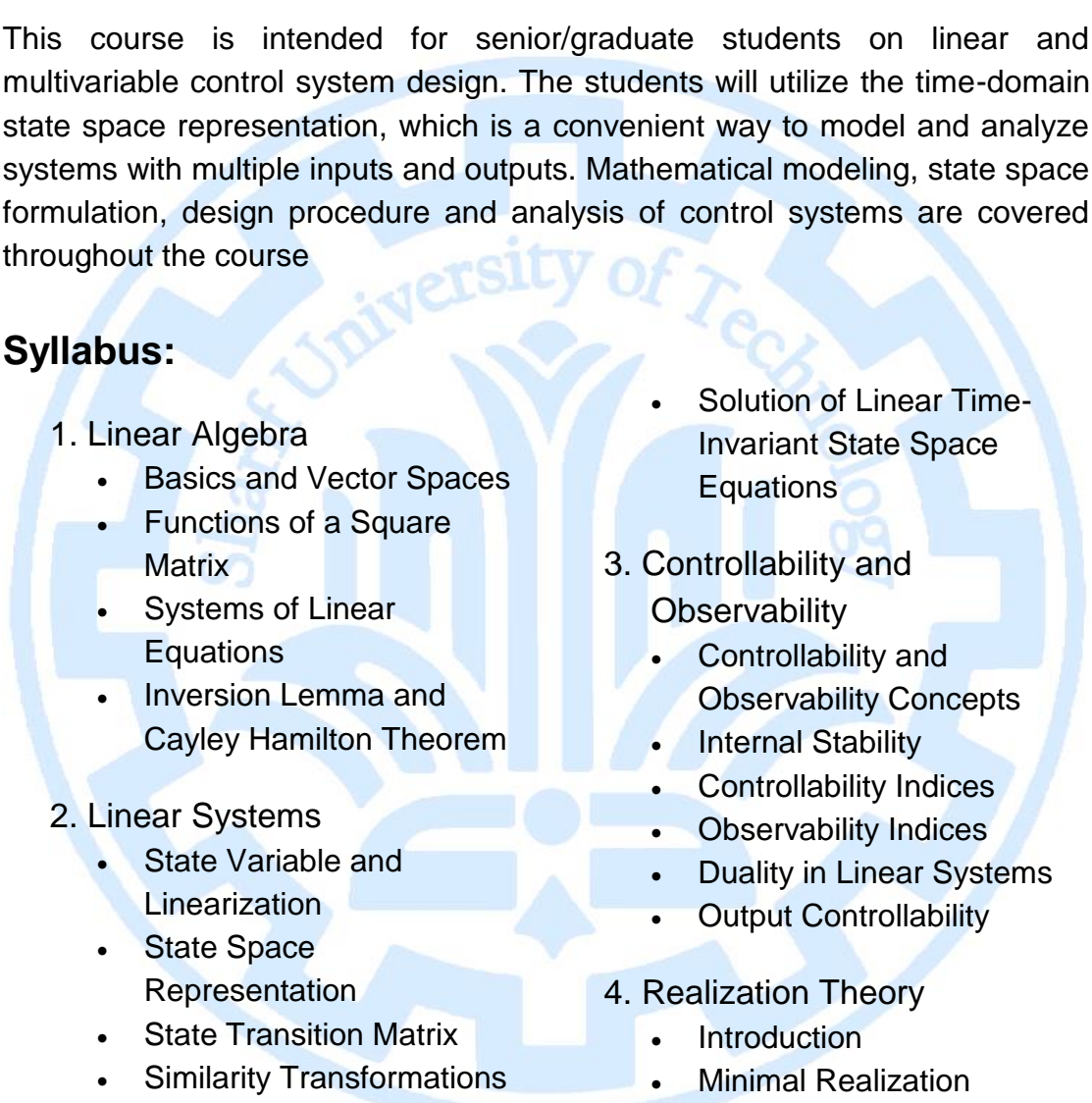
Advanced Automatic Control, 45710

Prerequisite: Automatic Control, 45135; Advanced Mathematics I, 45510

Course Objectives:

This course is intended for senior/graduate students on linear and multivariable control system design. The students will utilize the time-domain state space representation, which is a convenient way to model and analyze systems with multiple inputs and outputs. Mathematical modeling, state space formulation, design procedure and analysis of control systems are covered throughout the course

Syllabus:

- 
1. Linear Algebra
 - Basics and Vector Spaces
 - Functions of a Square Matrix
 - Systems of Linear Equations
 - Inversion Lemma and Cayley Hamilton Theorem
 2. Linear Systems
 - State Variable and Linearization
 - State Space Representation
 - State Transition Matrix
 - Similarity Transformations
 - Modal Matrix and Modal Decomposition
 - (Block) Diagonalization
 - Companion and Jordan Canonical Forms
 - Generalized Eigenvectors
 3. Controllability and Observability
 - Solution of Linear Time-Invariant State Space Equations
 - Controllability and Observability Concepts
 - Internal Stability
 - Controllability Indices
 - Observability Indices
 - Duality in Linear Systems
 - Output Controllability
 4. Realization Theory
 - Introduction
 - Minimal Realization
 - Controller/ Controllability Canonical Realization
 - Observer/ Observability Canonical Realization
 - Parallel and Series Systems
 - Realization of Multi-Input Multi-Output Systems

5. Stability

- Definitions
- Lyapunov Theory
- Generalized Energy Function
- Stability of LTI (Linear Time Invariant) Systems

7. State Estimators

- Observer Dynamics
- Full-Order Observer Design
- Reduced-Order Observer Design
- Feedback from Estimated States

6. State Feedback Techniques

- Output and State Feedback
- State Feedback Design (Bass and Gura, Ackermann's Formula, Controller Canonical)
- Regulator Design
- Tracker Design (Integral Control Technique, Precompensator or Feedforward Technique)

8. Optimal Control of Linear Systems

- Definitions
- Matrix Riccati Equation
- Optimal Control Formulation by Quadratic Integral Criterion (Lyapunov's 2nd Method)

Course Outcome:

At the conclusion of this course the student will be able to demonstrate an understanding of:

1. Linearization and State Space Formulation,
2. Controllability, Observability and Realization of Dynamic Systems,
3. Stability Analysis,
4. State Feedback Controller Design,
5. Observer Design,
6. (LQR) Linear Quadratic Regulator Design.

References:

1. Ogata, K.; *Modern Control Engineering*, Prentice Hall, 4th Edition, 2001.
2. KhakiSedigh, A.; *Modern Control Systems*, University of Tehran Press, 5th Edition, 2009.
3. Chen, Ch.; *Linear System Theory and Design*, Oxford University Press, 1999.

Advanced Concepts in Design, 45736

Prerequisite: Aircraft Design I and II, 45177 and 45118

Course Objectives:

For years, design was a kind of art that only some people had it. In this point of view, design is some sort of personal rather than educable issue. After some experience, design was portrayed in the context of decision in engineering. In this way, the experts need to understand the decision method of a designer. In spite of these things, they did not believe that someone should be brought up to be a designer. The new technologies, developed in recent years, push a serious need to train engineers for design as well as to train designers. Today, design has been demonstrated as *design science*. The objective of this course is to pass through these histories and educate design science so that students learn methods and the logic of design science and be aware of designer responsibilities.

Syllabus:

- | | |
|--|--|
| <p>1. Basic Concepts and Definitions</p> <ul style="list-style-type: none"> • Basic Definitions • History of Design • Basics of Decision Making • Technology Driven Design • Innovative Design • Passive Design Vs. Active Design • Mental Design | <ul style="list-style-type: none"> • Safety Management • Risk Management • Safety Program • Safety Investigation (Audit & Reporting) • Design for Safety Process |
| <p>2. Fundamentals of Design for Safety</p> <ul style="list-style-type: none"> • Understanding Safety and Dynamics of Safety • Accepted Level of Safety | <p>3. Accident and Accident Investigation</p> <ul style="list-style-type: none"> • Definition • Dynamics of Accidents • Accident Model • In-house Investigation • Independent Investigation • Accident Reporting • Punishment |

- 4. Design for Humankind
 - Basics of Human Design Drivers
 - Technology Life-Cycle
 - Economic Life-Cycle
 - Success and Failures
 - Reliability
 - Maintainability
 - Robustness
 - Fault Tree Analysis
- 5. Axiomatic Design
 - Four Basic Domains
 - Relationship between Domains
 - Principles of Axiomatic Design
- 6. System Approach to Design
 - Modeling Design Process
 - Challenges
 - Isolated Design Vs. System Design
 - Stakeholders Dynamics and Decision Making
 - System levels and Interfaces
 - Modes/ States/ Phases
- 7. Course Case Studies

Course Outcome:

After completion of this course the student can understand:

1. Basic concepts of decision making,
2. methods and the logic of design science and
3. The responsibilities of being a designer.

References:

1. Roskam, J.; *Airplane Design*, Part I-II, Dar- Corporation, USA, 1995.
2. Nicolai, L. M.; *Fundamentals of Aircraft Design*, METS Inc., 1984.
3. Suh, N.; *Axiomatic Design, Advances and Applications*, 1st Edition , Oxford University Press, 2001.
4. *Air Traffic Services Planning Manual*, International Civil Aviation Organization: DOC 9426.

Advanced Flight Dynamics I, 45705

Prerequisite: Flight Dynamics II, 45157

Course Objectives:

This course is offered to MSc students, studying in flight dynamics and control, and tries to extend the knowledge and skills they have previously obtained in Flight Dynamics II. Within the advanced topics, covered in this course, one can refer to the new materials on nonlinear dynamic analysis, analysis of coupling dynamics, pilot model, pilot rating, dynamic analysis of elastic flying vehicles, dynamic effects of atmospheric disturbances, design of control system and special topics on flight dynamics of unconventional flying vehicles.

Syllabus:

1. A Short Review on Basic Principles of Flight Dynamics
 - Static Stability
 - Linear Stability Analysis
 - Controllability of Steady State Flights
 - Dynamic Stability
 - Sensitivity Analysis of Dynamic Modes
 - Inertia and Dynamic Couplings
2. Nonlinear Stability Analysis of Flying Vehicles
 - Validation of Linear Equations of Motion
 - Nonlinear Simulation
3. Dynamic Analysis of an Elastic Flying Vehicle
 - Lyapunov Stability Analysis and Krasovski Method
 - Generation of Lyapunov Functions
 - Energy Method
 - Phase Space and Velocity Vector Method
 - Modeling of Elastic Behaviors: Static and Dynamic
 - Transfer Functions of an Elastic Flying Vehicle
 - Aerodynamic Coefficients of an Elastic Flying Vehicle
 - Equivalent Elastic Model

- Stability and Control Derivatives of an Elastic Flying Vehicle
4. Flying Vehicle Response within Atmospheric Disturbances
- Different Types of Atmospheric Disturbances
 - Deterministic Atmospheric Disturbances
 - Introduction to Stochastic Variables
 - Stochastic Atmospheric Disturbances
 - Response of a Flying Vehicle to Turbulence
5. Dynamic Analysis of a Manned Flying Vehicle
- Description Model of a Human Pilot
 - Pilot as a Controller
 - Flying and Handling Quality Concepts and Regulations
 - Pilot Model in the Control Loops
 - Pilot Induced Oscillations
6. Flight Control Systems
- Classification
 - Open-loop Analysis of Flying Vehicles
 - Stability Augmentation Loops
 - Autopilots
 - Control Allocation

Course Outcome:

At the conclusion of this course the student will be able to utilize the new topics for advanced dynamic analysis of more complicated flying vehicles than conventional aircrafts and in more details than they have previously obtained in flight dynamics II.

References:

1. Roskam, J.; *Airplane Flight Dynamics and Automatic Flight Control*, Part II, Darcorporation, 1998.
2. McLean, D.; *Automatic Flight Control System*, Prentice Hall, 1990.
3. Pamadi; *Performance, Stability, Dynamics, and Control of Airplanes*, 2nd Edition, AIAA Education, 2004.
4. Stengel, R.F.; *Flight Dynamics*, Princeton University Press, 2004.
5. Schmidt, D.K; *Modern Flight Dynamics*, 1st Edition, McGraw-Hill Education, 2012.

Advanced Mathematics I, 45510

Course Objectives:

This course starts with an introduction to the vector space, linear transformations and some applications of linear space. In the second section, the metric space and normed space are discussed, we introduced some norms, Banach space and fixed point theorem and some application of this theorem in engineering problems. Inner product space and orthogonality theorem and application of this theorem are presented in another section. Operator equations, Sturm-Liouville theorem and minimum functional theorem, variational formulations of boundary value problems are discussed in a fourth section. In the final section, we introduced approximated methods for boundary value problems such as the Ritz, Bubnov-Galerkin, Least Squares, Kantorovich and Terffetz methods.

Syllabus:

1. Vector Space and its Application

- General Comments and Notations
- Supremum and Infimum of Sets
- Functions
- The Field of Scalars
- Linear Vector Spaces and Subspaces
- Linear Dependence and Independence of Vectors
- Span, Basis and Dimension
- Linear Transformations
- Linear, Bilinear, and Quadratic Forms
- Kernel, Image and Nullity
- Some Applications of Linear Space

2. Normed Space and its Applications

- Function Space and Metric Space
- Holder and Minkowski Inequalities
- Normed Space and Definition of Different Norms
- Continuous and Bounded Linear Transformations
- Complete Normed Space: Banach Space
- Fixed Point Theorem
- Application of a Fixed Point Theorem for Solving of Linear Equations
- Application of a Fixed Point Theorem for Solving of

- Linear Differential Equations
 - Application of a Fixed Point Theorem for Solving of Integral Equations
 - Linear and Nonlinear Initial Value Problems
 - Application of Green's Function for Boundary Value Problems
 - Some Practical Problems
3. Inner Product Space and its Applications
- Inner Product Space and Cauchy-Schwarz Inequality
 - Orthogonal Vectors, Complements and Projection
 - Hilbert space
 - Orthonormal Bases and Generalized Fourier Series
 - Gram-Schmidt Theorem
 - Orthogonal Projection Theorem
 - Legendre, Laguerre, Hermite Polynomials
 - Best Approximation in Hilbert Space
 - Optimal Estimation of Random Signals
4. Variational Formulations of Boundary Value Problems
- Operator Equation
 - Representation of Linear Functionals
 - Self Ajoint Operators
 - Sturm-Liouville Theorem
 - The Minimum Functional Theorem
 - Concepts from Variational Calculus
 - Natural and Essential Boundary Conditions
 - Non-homogeneous Boundary Conditions
 - Problem with Equality Constraints and Lagrange Multipliers
 - The Penalty Function Method
 - Optimal Control Problems
5. Variational Methods of Approximation
- The Ritz Method
 - Convergence and Stability
 - The Weighted-Residual Method
 - The Bubnov-Galerkin Method
 - The Method of Least Squares
 - The Kantrovich Method
 - The Terffetz Method

Course Outcome:

At the conclusion of this course the student will be able to demonstrate an understanding of:

1. Linear space and its application in many engineering problems such as eigenvalue problem, linear differential equations, and so on,
2. Metric space, normed space, orthogonally theorem, and best approximation in Hilbert space and its application and
3. The minimum functional theorems and variational methods of approximation for solving of boundary value problems and its application.

References:

1. Reddy, J.N.; *Applied Functional Analysis and Variational Methods in Engineering*, McGraw-Hill Book Company, 1986.
2. Baker, A.C. and Porteous, H.L.; *Linear Algebra and Differential Equations*, Ellis Horwood Limited, 1990.
3. Masujima, M.; *Applied Mathematical Methods in theoretical Physics*, 2nd Edition, WILEY-VCH, 2009.
4. Chen, C.; *Linear System Theory and Design*, 3rd Edition, Oxford University Press, 1999.
5. Poznyak, A.S.; *Advanced Mathematical Tools for Automatic Control Engineers*, 1st Edition, Elsevier Ltd., 2008.
6. Strang, G. and Borre, K.; *Linear Algebra, Geodesy, and GPS*, Wellesley-Cambridge Press, 1997.

Control Systems Design, 45730

Course Objectives:

This course has been designed to familiarize graduated students with principles of designing systems and control elements of airplanes and missiles. At the first, history of control systems is presented. Afterward, airplanes and missiles control systems elements are introduced and control systems are investigated from different viewpoints including design topics and phases. Next chapter concentrates on aerodynamic considerations of control systems and thrust vectoring as well. Servomechanisms design and usage is studied subsequently. In the next chapter, sensors as an important parts of control systems are studied. Transformation functions of different channels are obtained utilizing linearization of equations of motion. Static and dynamic stability and different modes of motion is analyzed later. Consequently, different methods of control system design in time and frequency domains are presented. Flight computer design principles and its software considerations is discussed in advance. At the end of the course, complementary materials of control systems are studied.

Syllabus:

1. Introduction to Flight Control Systems Design
 - Main Components, Design Objectives and Design Cycle of Flight Control Systems
 - Open Loop and Closed Loop Control Systems
 - Feedback Effects on Control Systems
 - Different Feedback Control Systems
 - Continuous and Discontinuous Control Systems
 - Analog, Digital and Logical Control
 - Industrial Controllers
 - Summarization
2. Introduction to Flight Control Systems
 - History
 - Guidance, Navigation and Control
 - Flight Control Channels

- Flight Control Methods
 - Autopilot and SAS Comparison
3. Aerodynamic Considerations of Flight Control Systems
- Static and Dynamic Stability
 - Stability and Maneuverability
 - Stability Static Margin
 - Pressure Center Variation
 - Hinge Moment
 - Aeroelasticity Effects
4. Control Systems Performance
- Tail Control System
 - Wing Control System
 - Canard Control System
 - Aerodynamic Surfaces Configuration Effects
 - Aerodynamic Surfaces Sizing
 - Lateral Jet Control
 - Thrust Vector Control
 - Mass and C.G. Variation Effects
5. Flight Control Actuators
- Servomechanisms
 - Hydraulic Actuators
 - Pneumatic Actuators
 - Gas Actuators
- Electrical Actuators
6. Flight Control Sensors
- Accelerometers
 - Gyros
 - Angle of Attack Sensor
 - Other Sensors
 - Sensor Selection
7. A Review on Controller Design
- Controller Design Objectives
 - Design with Frequency Response
 - Design with Root Locus
 - Design with Pole Placement
 - Design with State Space
 - Design in Time Domain
8. Linearization of Equations of Motion and Obtaining Flying Vehicle Transfer Functions
- Coordinate Systems
 - Equations of Motion
 - Roll, Yaw and Pitch Channels Transfer Function
9. Aerodynamic Control Systems Design for Missiles
- STT, BTT and RA Missiles Introduction and Their Properties

- STT Missiles Lateral and Roll Channel Control System Design
 - BTT Missiles Lateral Control System Design
 - MIMO Control System Design
 - One Channel Flight Control System Design
10. Control System Design for Airplanes
- Airplane Longitudinal and Lateral Control
 - Attitude Control Systems
 - Flight Path Control Systems
 - Active Flight Control
11. Thrust Vector Control Systems Design
- Classifications and Applications
 - Mathematical Modeling
- Different Architectures of Thrust Vector Control
 - Controller Design
12. Flight Computer Design Principles
- Design Requirements
 - Design Input and Outputs
 - Key points in Flight Computer Software Selection
 - Flight Programming
13. Complementary Materials
- Sensitivity Analysis
 - Man's Effect in the Loop
 - Parameter Optimizations
 - Digital Controllers Design

Course Outcome:

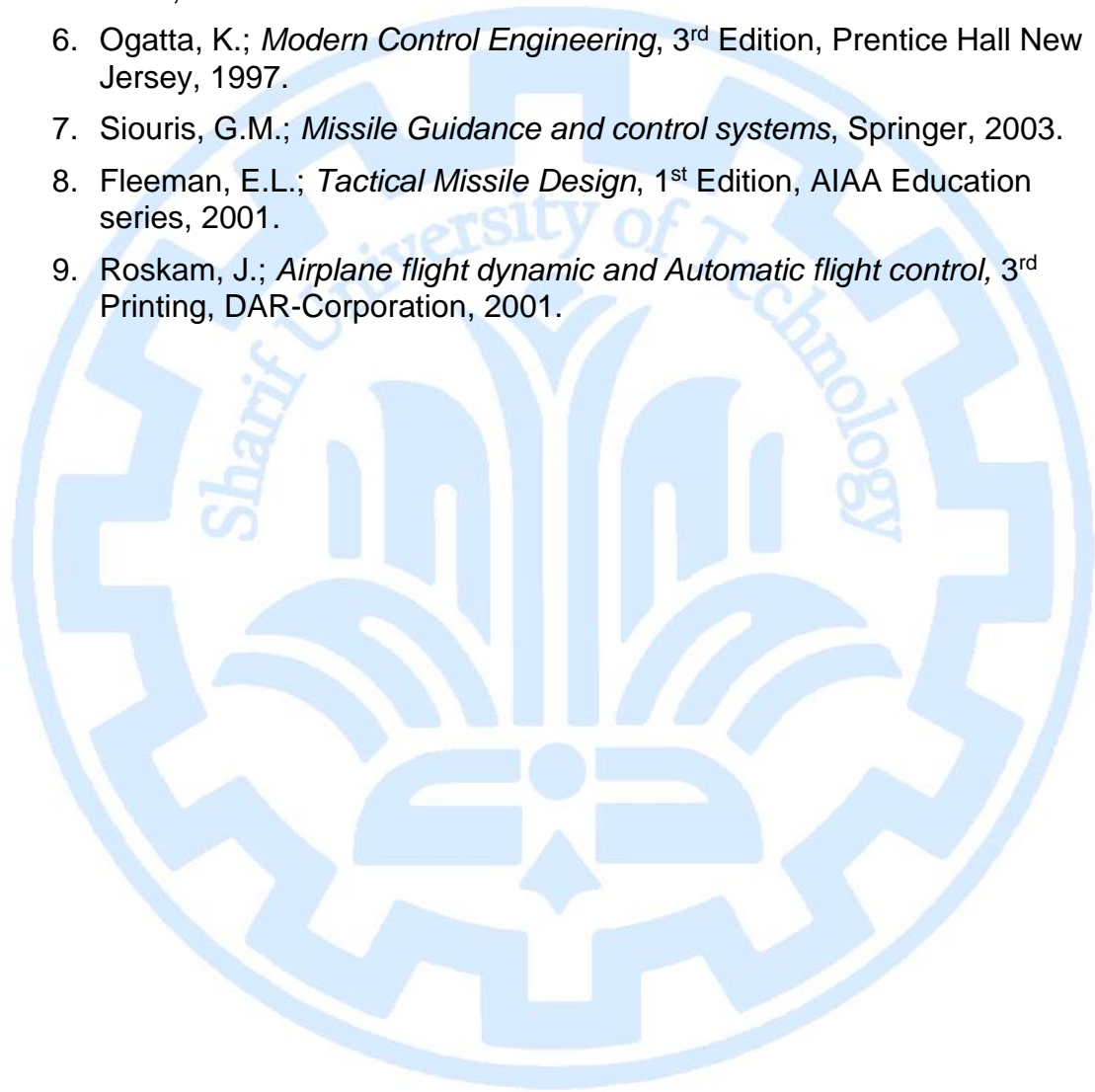
At the conclusion of this course the student will be able to demonstrate an understanding of:

1. Control systems elements of missiles and airplanes
2. Design Objectives and Methods of control system design
3. Design control systems for different channels of missile and airplanes

References:

1. Garnell, P.; *Guided Weapon Control Systems*, 2nd Edition, Pergamon Press, 1980.

2. McLean, D.; *Automatic Flight Control Systems*, Prentice Hall International (UK) Ltd, 1990.
3. Blakelock, J.H.; *Automatic Control of Aircraft and Missiles*, 2nd Edition, John Wiley & Sons, 1990.
4. Benjamin, C.K. and Golnaraghi, F.; *Automatic Control Systems*, 9th Edition, John Wiley & Sons, 2010.
5. Nise, N.S.; *Control Systems Engineering*, 4th Edition, John Wiley & Sons, 2004.
6. Ogatta, K.; *Modern Control Engineering*, 3rd Edition, Prentice Hall New Jersey, 1997.
7. Siouris, G.M.; *Missile Guidance and control systems*, Springer, 2003.
8. Fleeman, E.L.; *Tactical Missile Design*, 1st Edition, AIAA Education series, 2001.
9. Roskam, J.; *Airplane flight dynamic and Automatic flight control*, 3rd Printing, DAR-Corporation, 2001.

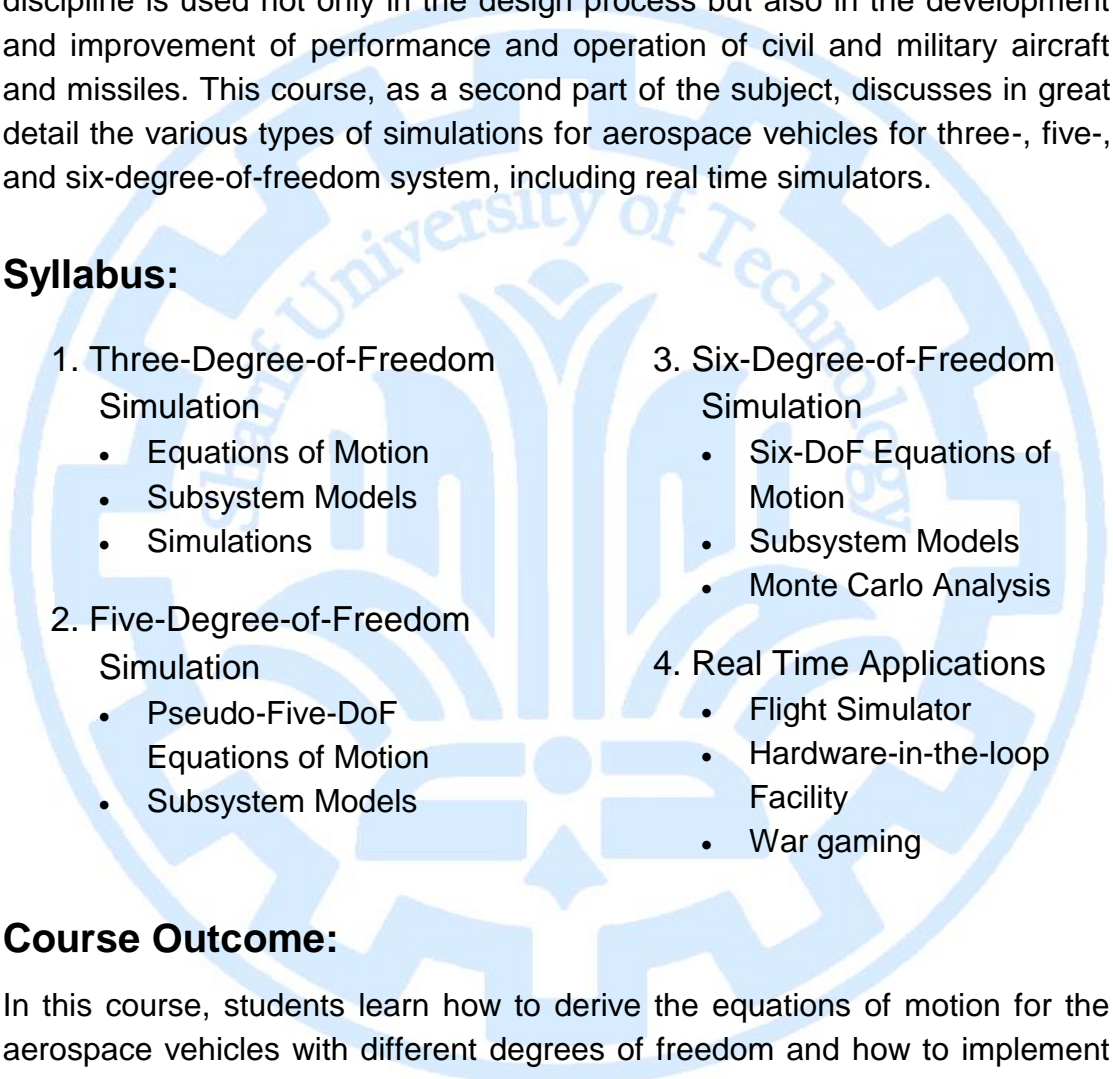


Flight Simulation, 45745

Course Objectives:

The subject of computer modeling and simulation of dynamics of aerospace vehicles has evolved into a major discipline in recent years. This new discipline is used not only in the design process but also in the development and improvement of performance and operation of civil and military aircraft and missiles. This course, as a second part of the subject, discusses in great detail the various types of simulations for aerospace vehicles for three-, five-, and six-degree-of-freedom system, including real time simulators.

Syllabus:

- 
1. Three-Degree-of-Freedom Simulation
 - Equations of Motion
 - Subsystem Models
 - Simulations
 2. Five-Degree-of-Freedom Simulation
 - Pseudo-Five-DoF Equations of Motion
 - Subsystem Models
 3. Six-Degree-of-Freedom Simulation
 - Six-DoF Equations of Motion
 - Subsystem Models
 - Monte Carlo Analysis
 4. Real Time Applications
 - Flight Simulator
 - Hardware-in-the-loop Facility
 - War gaming

Course Outcome:

In this course, students learn how to derive the equations of motion for the aerospace vehicles with different degrees of freedom and how to implement them on computer.

References:

1. Zipfel, P.H.; *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA, 2000.

Flight Test Principles, 45720

Prerequisite: Flight Dynamics I and II, 45156 and 45157; Airplane Design I and II, 45177 and 45118

Course Objectives:

This course deals with the Fundamentals of Flight Test Engineering in a comprehensive format. Academics and Flight Test Techniques for Performance, Stability, and Systems flight testing will be covered, along with Ground Testing, Flight Test Instrumentation, Data Acquisition and System Safety.

Syllabus:

1. Introduction, Test Team and Support
 - Why Flight Test?
 - Flight Test Phase
 - Certification Flight Test
 - Flight Test Operation
 - Flight Test Organization
2. Instrumentation and Data Processing
 - Airborne and Ground Systems
 - Instrumentation Management
 - Data Processing
3. Planning, Discipline and Safety Aspects
 - Test Plan
 - Risk Assessment Matrix
 - Crew Considerations
4. Pre-Flight Tests
 - Wind Tunnel Tests
5. Air data Measurement and Calibration
 - Propulsion Tests
 - Weight and Balance Tests
 - Ground Vibration Tests
 - Structural Loads Tests
 - Taxi Tests
 - Standard Atmosphere (T,p, ρ)
 - Pitot-static System (h,V)
 - Static Position Calibration
6. Climb, Descent and Turn Performance Test
 - The Energy Approximation
 - Performance Climb Procedures
 - Turn Performance Flight Test Techniques
 - Instrumentation

- | | |
|--|---|
| <p>7. Cruise Performance Tests</p> <ul style="list-style-type: none"> • Foundations • Endurance • Cruise Performance Test Methods • Instrumentation | <ul style="list-style-type: none"> • Static Lateral-Directional Stability Tests (Stability Derivatives, Control Effectiveness) • Instrumentation |
| <p>8. Takeoff and Landing Tests</p> <ul style="list-style-type: none"> • Performance Equations • Takeoff Flight Test Methods • Landing Flight Test Methods • Instrumentation | <p>10. Dynamic Stability Tests</p> <ul style="list-style-type: none"> • Equations of Motion • Longitudinal Dynamics • Lateral-Directional Dynamics • Dynamics Flight Test Method • Instrumentation |
| <p>9. Static Stability Tests</p> <ul style="list-style-type: none"> • Concepts of Static Stability • Longitudinal static Stability Test Methods | <p>11. System Identification</p> <ul style="list-style-type: none"> • Introduction and History • General Regression • Frequency Response Methods |

Course Outcome:

At the conclusion of this course the student will be able to demonstrate an understanding of:

1. The fundamentals required for performing the duties of a Flight Test Engineer
2. Flight-test methods through preparation of flight-test reports
3. Flight-test data analysis

References:

1. Ward, D.; *Introduction to Flight Test Engineering*, 3rd Edition, Kendall/Hunt, 2006.
2. Stoliker, F.N.; *Introduction to Flight Test Engineering*, AGARD, 1995.
3. Jeppesen and Smith, H.C.; *Introduction to Flight Test Engineering*, Library of Congress Cataloging-in-publication Number 92-33592, 1981.
4. Smith, H.C.; *Introduction to Aircraft Flight Test Engineering*, Jeppesen Sanderson, 1984.

Fuzzy Control, 45735

Course Objectives:

This graduate course concerns fuzzy logic for automatic control. The course objectives are to teach the basics of fuzzy logic, to show how to use fuzzy logic, and to teach how to design a fuzzy controller. Some advanced topics on fuzzy controllers are also covered.

Syllabus:

- 
1. Introduction, Definitions and Concepts
 - Intelligent Control
 - Fuzzy Logic
 - Fuzzy Control
 - Fuzzy Mathematics
 - Applications
 - Rule Base
 - Fuzzy Sets
 - Fuzzy System
 - Classic Versus Fuzzy Control System Design
 - An Example of Fuzzy Control
 2. Fuzzy Mathematics
 - Fuzzy Sets and Membership Functions
 - Mathematical Operations on Fuzzy Sets
 - Fuzzy Relations
 - Linguistic Variables
 - Fuzzy Rules
 - Approximate Reasoning
 3. Fuzzy Systems
 - Fuzzy Rule Base
 4. Design of Fuzzy Systems Using Input-Output Data
 - Fuzzy Inference Engine
 - Fuzzifier
 - Defuzzifier
 - Mathematical Representations of Fuzzy Systems
 - The Approximation Properties of Fuzzy Systems
 - Look-up Table Scheme
 - Gradient Descent Training
 - Batch Algorithm
 - Clustering
 5. Design of Fuzzy Controllers
 - Trial and Error Approach
 - Control surface of a fuzzy controller
 - Stable Fuzzy Controllers
 - Optimal Fuzzy Controllers
 - Robust Fuzzy Controllers
 - Fuzzy System as Sliding Mode Control
 - Fuzzy Sliding Mode Control

- Fuzzy Supervisory Control
- Fuzzy Gain Scheduling
- TSK Fuzzy Systems

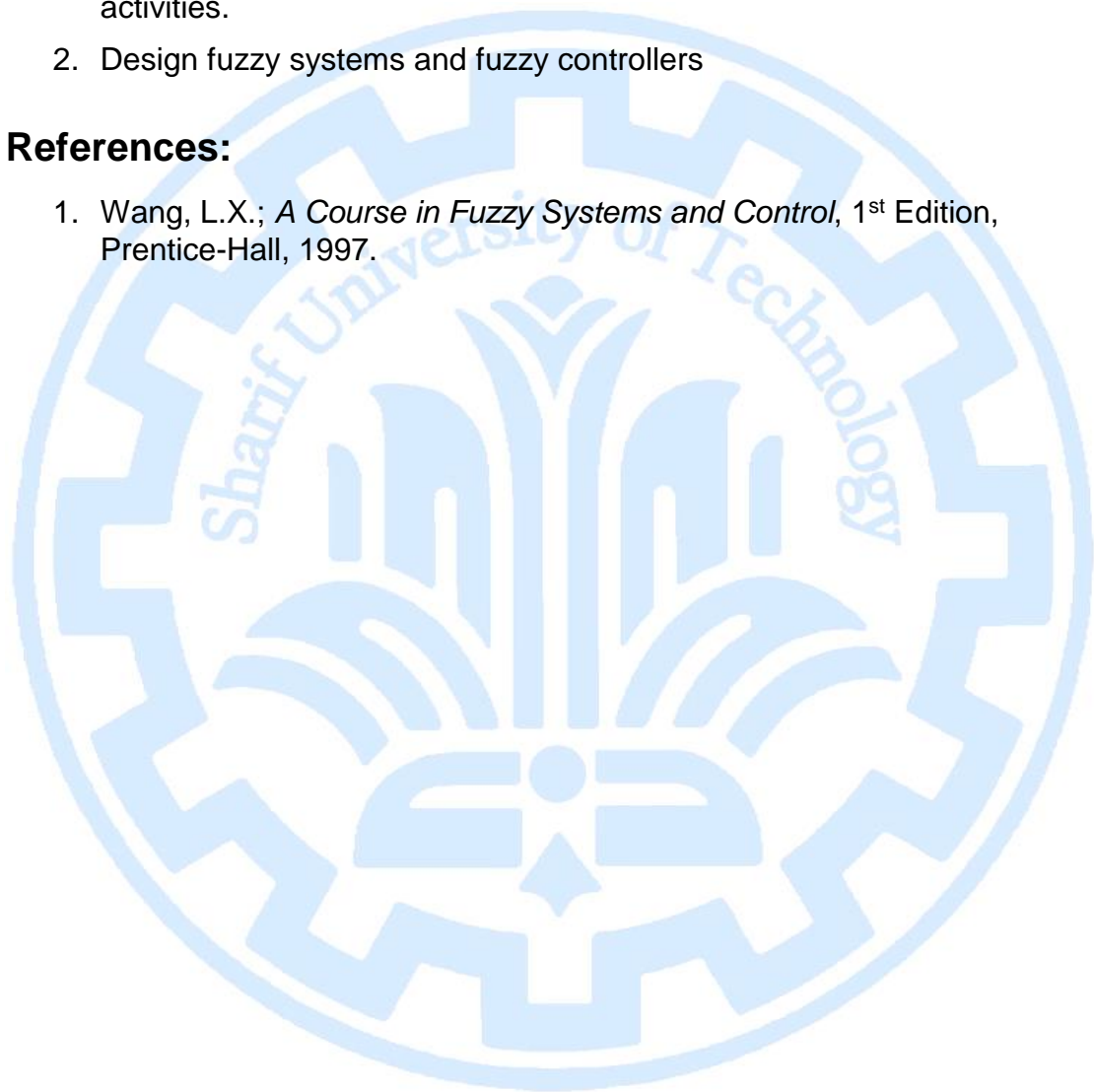
Course Outcome:

Upon completion of this course the students will be able to:

1. Utilize the state of the art topics of fuzzy control in their research activities.
2. Design fuzzy systems and fuzzy controllers

References:

1. Wang, L.X.; *A Course in Fuzzy Systems and Control*, 1st Edition, Prentice-Hall, 1997.



Guidance and Navigation I, 45715

Prerequisite: Flight Dynamics II, 45157; Automatic Control, 45135

Course Objectives:

The objective of this course is to introduce the students the essential knowledge and skills they need to analyze and design various guidance and navigation systems. The course is broken into two parts that deal with both subjects of guidance and navigation. In the first part, the common tactical and strategic guidance algorithms, utilized in aerospace vehicles, are introduced. The second part covers the principles of radio and inertial navigation systems.

Syllabus:

1. Introduction, Definitions and Concepts
 - Guidance, Navigation and Control
 - Elements of a Guidance System
 - Guidance Phases
 - Guidance Trajectories
 - Guidance Sensors
2. Classification of Guidance and Navigation Systems
 - Basic Navigation Systems
 - Combined Navigation Systems
 - Classification of Guidance Systems
3. Three-point Guidance Laws
 - Line-of-Sight Guidance Laws in BR systems
4. Two-point Guidance Laws
 - Command to Line-of-Sight Guidance
 - CLOS Guidance with Lead Angle
 - Combined Lead and LOS Guidance Laws
 - Three-dimensional Implementation of CLOS Guidance
 - Pursuit Guidance
 - Proportional Navigation Guidance
 - 3D Implementation
 - Analytical Solution of TPN
 - Simulation of PN
 - Performance of TPN
 - Comparison of Beam Rider and PN
 - Proportional Navigation Command Guidance
 - Proportional Navigation Inertial Guidance

- Implementation of Proportional Navigation Guidance
 - Linearization of PN
 - Analysis of the Homing Loop Using Adjoint Theory
 - TPN versus APN
 - Optimal Two-point Guidance
 - Pulsed Guidance
5. Ballistic Guidance Laws
- Ballistic Trajectories
 - Required Velocity
 - Gravity Turn
 - Lambert Problem
 - Velocity to be Gained
 - Cross Product Steering
 - Lambert Guidance
 - General Energy Management (GEM) Steering
 - Explicit Versus Implicit Guidance
 - Q and Q* Guidance
 - Preset Guidance
6. UAVs Guidance Laws
- UAV Guidance Problems
 - Application of Tactical Guidance Laws in UAVs
 - Trajectory Tracking
 - Terrain Following/Terrain Avoidance
 - Cooperative Missions
7. Principles of Inertial Navigation
- Components
 - Two-dimensional Navigation
 - Coordinate Systems
 - 3D Strapdown Navigation System
 - Strapdown System Mechanizations
 - Attitude Representation
 - Navigation Equations in Component Form
 - Effects of Elliptic Earth
8. Inertial Sensors
- Gyroscope principles
 - Single-axis Rate Gyroscope
 - Accelerometers
 - Force balanced sensors
9. Tests and Calibration of Inertial Navigation Systems
- Test Equipments
 - Calibration of Accelerometers
 - Calibration of Rate Gyros
 - Hardware-in-the-loop Simulation
10. Initial Alignment
- Coarse Alignment
 - Fine Alignment

Course Outcome:

Upon completion of this course, the students will be able to analyze and design guidance and navigation systems for aerospace vehicles.

References:

1. Zarchan, P.; *Tactical and Strategic Missile Guidance*, 4th Edition, AIAA Education Series, Vol. 199, 2002.
2. Siouris, G.M.; *Missile Guidance and Control Systems*, Springer-Verlag, 2004.
3. Titterton, D.H. and Weston, J.L.; *Strapdown Inertial Navigation Technology*, 2nd Edition, AIAA, 2004.
4. Rogers, R.M.; *Applied Mathematics in Integrated Navigation Systems*, 2nd Edition, AIAA Education Series, 2003.

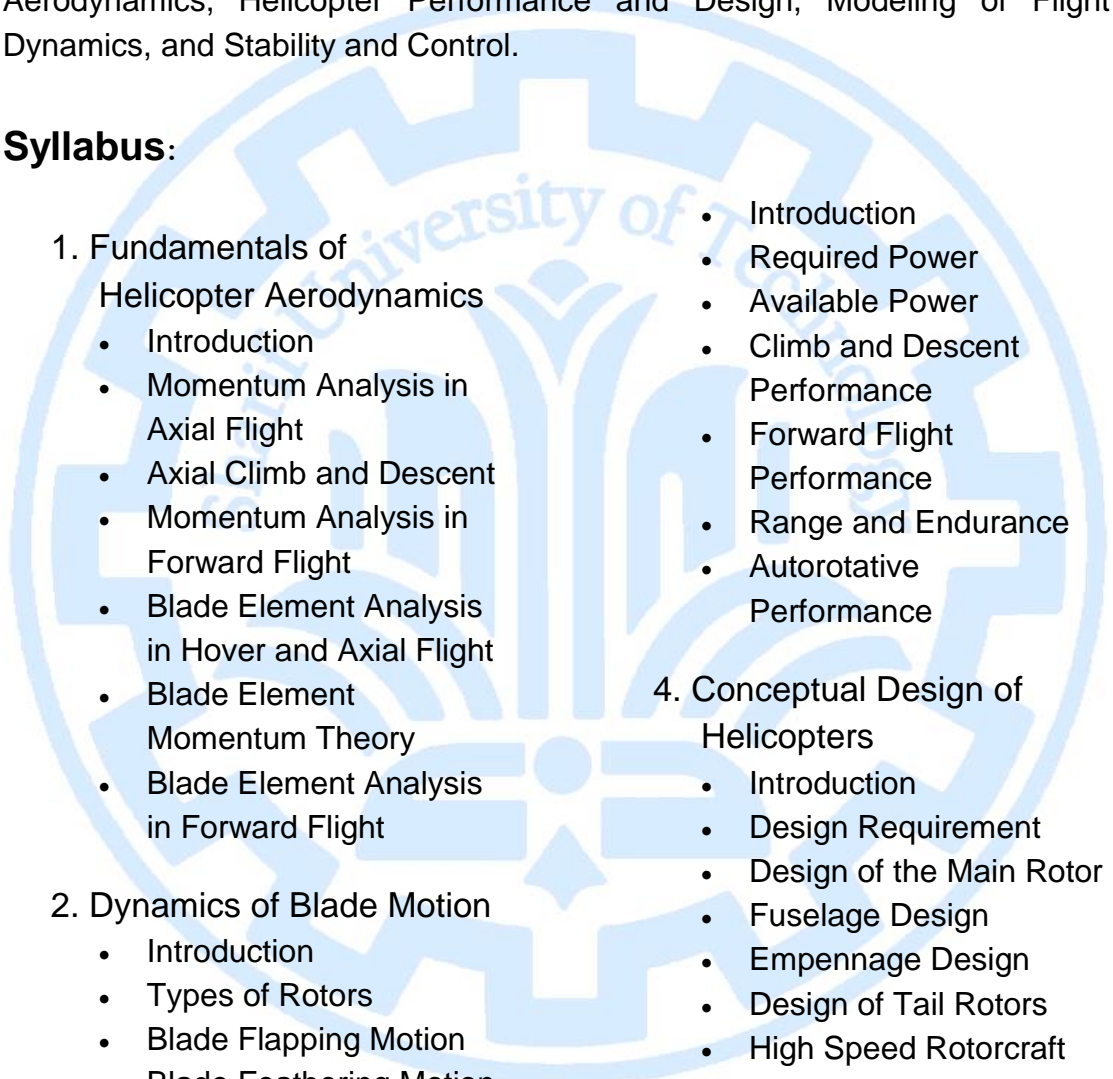


Helicopter Flight Dynamics, 45740

Course Objectives:

Helicopter is a vertical take-off and landing flying vehicle with complicated and coupled dynamics. This course discusses some basic concepts in Rotor Aerodynamics, Helicopter Performance and Design, Modeling of Flight Dynamics, and Stability and Control.

Syllabus:

- 
1. Fundamentals of Helicopter Aerodynamics
 - Introduction
 - Momentum Analysis in Axial Flight
 - Axial Climb and Descent
 - Momentum Analysis in Forward Flight
 - Blade Element Analysis in Hover and Axial Flight
 - Blade Element Momentum Theory
 - Blade Element Analysis in Forward Flight
 2. Dynamics of Blade Motion
 - Introduction
 - Types of Rotors
 - Blade Flapping Motion
 - Blade Feathering Motion
 - Blade Lagging Motion
 - Swashplate Mechanism
 - Coupling Flap-lag and Flap-Pitch Motion
 3. Basic Helicopter Performance
 - Introduction
 - Required Power
 - Available Power
 - Climb and Descent Performance
 - Forward Flight Performance
 - Range and Endurance
 - Autorotative Performance
 4. Conceptual Design of Helicopters
 - Introduction
 - Design Requirement
 - Design of the Main Rotor
 - Fuselage Design
 - Empennage Design
 - Design of Tail Rotors
 - High Speed Rotorcraft
 5. Modeling Helicopter Flight Dynamics
 - Introduction
 - Helicopter Nonlinear Equations of Motion
 - Equations of Equilibrium, Trim conditions

- Helicopter Linearized Equations of Motion
- Stability Derivatives
- Lateral and Directional Modes in Hover and Forward Flight
- Control Response in Hover and Forward Flight
- Response to Vertical Gusts

Course Outcome:

In this course, students will be familiarized with the fundamentals of helicopter flight dynamics and learn how to use theoretical methods in order to calculate the flight characteristics of a helicopter and how to simulate and analyze its dynamic behavior.

References:

1. Padfield, G.; *Helicopter Flight Dynamics*, 2nd Edition, AIAA, 2007.
2. Bramwell; *Helicopter Dynamics*, Butterworth-Heinemann Ltd, 1976.
3. Prouty, R.; *Helicopter Performance, Stability and Control*, 2nd Edition, Krieger Pub Co., 2002.
4. Leishman, J.; *Principles of Helicopter Aerodynamics*, 2nd Edition, Cambridge University Press, 2006.
5. Newman, S.; *The Fundamentals of Helicopter Flight*, 1st Edition, Butterworth-Heinemann, 1994.

Heuristic Optimization Algorithms, 45770

Course Objectives:

In this course, the modern heuristic optimization algorithms such as Evolutionary Algorithms, Ant Colony Optimization, Simulated Annealing, Tabu Search and Particle Swarm Optimization is introduced with a concentration on the application of these algorithms in aerospace problems. The course begins with a classification of the optimization problems and the definition of the primary concepts such as discrete and continuous search domains, multi-objective optimization, dynamic optimization, global optimization, stochastic optimization and swarm intelligence. Then some heuristic methods is introduced in detail including the basic and original algorithms, characteristics, adaptation to constrained and multi-objective problems, parallelization and successful aerospace applications. The course ends with some miscellaneous and complementary materials such as parameter tuning techniques, rotated search domains, hybrid metaheuristics, etc.

Syllabus:

1. Introduction, Definitions and Concepts
 - Optimization
 - Operations/Operational Research (OR)
 - Optimization and Engineering
 - Definition of an Optimization Problem
 - Feasibility Problem
 - Classification of the Optimization Problems
 - Classification of the Optimization Techniques
 - Heuristic Algorithms vs. Metaheuristics
 - Nature-Inspired Optimization
 - Population-Based Optimization
 - Swarm Intelligence
 - Parallel Algorithms
 - An Overview of Mathematical Optimization
2. An Overview of Heuristic Optimization Algorithms
 - Random Search
 - Simplex Algorithm
 - Neighborhood Search
 - Hill Climbing Methods
 - Greedy Algorithms
 - Simulated Annealing
 - Tabu Search
 - Evolutionary Algorithms
 - Ant Colony Optimization

- Particle Swarm Optimization
 - Other Heuristics
3. Simulated Annealing
- Real Annealing and Simulated Annealing
 - Metropolis Algorithm
 - Simulated Annealing Algorithm
 - Convergence of Simulated Annealing
 - Continuous Simulated Annealing
 - One-loop Simulated Annealing
 - Temperature Scheduling
 - Parallelization of Simulated Annealing Algorithms
 - Multi-objective Simulated Annealing
 - Constrained Simulated Annealing
 - Applications
4. Tabu Search
- Basic Tabu Search
 - Short-term Memory
 - Long-term Memory
 - Continuous Tabu Search
 - Diversification and Intensification
 - Parallelization
 - Constrained Tabu Search
 - Multi-objective Tabu Search
 - Applications
5. Evolutionary Algorithms
- Definitions
 - Drivers of Evolution
- Genetic Algorithms
 - Steady State GAs
 - Memetic Algorithms
 - Estimation of Distribution Algorithms
 - Differential Evolution
 - Parallelization
 - Evolutionary Multi-objective Optimization
 - Constrained Evolutionary Optimization
 - Adaptive Evolutionary Algorithms
 - Applications
6. Ant Colony Optimization
- Definitions
 - Collective Behavior of Social Insects
 - Basic ACO Algorithms
 - Pheromones and Memory
 - Ant Algorithms for TSP
 - Adaptation to Continuous Problems
 - Parallelization of ACO algorithms
 - Multi-objective ACO
 - Adaptation to Constrained Problems
 - Applications
7. Particle Swarm Optimization
- Basic Idea
 - Canonical PSO Algorithm
 - Neighborhood Topologies
 - Continuous and Constrained PSO
 - Multi-objective PSO
 - Parallelization of PSO Algorithms

- Applications
 - Tuning the Parameters of the Optimization Algorithms
 - Correlation Handling
8. Miscellaneous and Complementary Topics
- Normalization
 - Test Functions

Course Outcome:

At the conclusion of this course the student will be able:

1. Utilize state of the art heuristic optimization algorithms in their research activities.
2. Design and propose new and hybrid optimization algorithms.
3. Customize heuristic optimization algorithms for special applications

References:

1. Michalewicz, Z. and Fogel, D.B.; *How to Solve it: Modern Heuristics*, Springer, 1999.
2. Dreco, J., et. Al.; *Metaheuristics for Hard Optimization*, Springer, 2005.
3. Glover, F and Laguna, M; *Tabu Search*, Springer, 1997.
4. Sivanandam, S.N. and Deepa, S.N.; *Introduction to Genetic Algorithms*, Springer, 2008.
5. Haupt, R.L. and Haupt, S.E.; *Practical Genetic Algorithms*, 2nd Edition, Wiley Interscience, 2004.
6. Abraham, A., Jain, L. and Goldberg, R. (Eds); *Evolutionary Multi-objective Optimization*, Springer, 2005.
7. Dorigo, M. and Stutzle, T.; *Ant Colony Optimization*, 1st Edition, A Bradford Book, 2004.
8. Clerc, M.; *Particle Swarm Optimization*, Wiley-ISTE, 2006.
9. Rao, S.S.; *Engineering Optimization: Theory and Practice*, 3rd Edition, John Wiley & Sons, 1996.

Missile Flight Dynamics, 45725

Course Objectives:

This course is defined to familiarize aerospace graduated students with missile vibrational behavior analysis and also development of equations of motion. This course fundamentally considers dynamic behavior of rockets and missiles with analytical view. Sources of errors affecting on the dispersion of missiles are considered and the required criterion for comparing their dynamics are presented. Flight simulations with different degrees of freedom are developed and then linear and angular motions based on similar dynamic systems are developed. Equations of motion using both Lagrange's and Newton's approach are developed in various coordinate systems. Dynamic stability regions are analytically determined and evaluated.

Syllabus:

1. Introduction to Flight Dynamics
 - Terms and definitions
 - Coordinate Systems
 - Types of Simulations (One, Two ..., Six Degree of Freedom)
 - Difference Between Applications of Simulation and Flight Dynamics
 - Introduction to Equations of Motion Using Lagrange and Euler Approaches
 - Two Degree of Freedom Flight Considering Drag and Gravity Forces
 - Horizontal Flight Considering Thrust Force Without Drag (Variable Mass)
 - Vertical Flight Considering Thrust Force Without Drag (Variable Mass)
 - Horizontal Flight Considering Thrust and Drag Forces (Variable Mass)
2. Equations of Linear Motion
 - Horizontal Flight Considering Drag
 - Vertical Flight Considering Drag and Gravity Forces
 - Two Degree of Freedom Flight in Vacuum
3. Rigid Body Angular Motion (Pendulum Motion)
 - Simple Pendulum Motion
 - Complex Pendulum Motion
 - Spherical Pendulum Motion

- 4. Simple Angular Motion
 - Constrained Pitching Motion Considering Static Aerodynamic Forces and Dynamic Stability Analysis
 - Constrained Pitching Motion Considering Static and Dynamic Aerodynamic Forces and Dynamic Stability Analysis
 - Constrained Pitching Motion Considering Constant Control Surface Deflections or Geometrical Asymmetries
 - Stability Derivatives Determination Using Pitching Motion Analysis
 - 5. Pitching and Heaving Motion
 - Pitching and Heaving Equations of Motion Considering Gravity Force
 - Dynamic Stability Analysis
 - 6. Pitching, Heaving, Yawing and Swerving Motion
 - Pitching, Heaving, Yawing and Swerving Equations of Motion
 - Dynamic Stability Analysis
 - 7. Rolling Motion
 - Rolling Motion of Missiles Flying With Constant Speed
 - 8. General Rigid Body Motion and Stability
 - Wobbling Coordinate Systems
 - Complete Motion With Static Fluid Forces
 - Complete Angular Motion With Static Fluid Forces
 - Complete Angular Motion With Static And Dynamic Fluid Forces
 - Free Flight Motion With Static And Dynamic Fluid Forces
 - 9. Missile Dynamics Transfer Functions
 - Pitch Channel Transfer Function
 - Yaw Channel Transfer Function
 - Roll Channel Transfer Function
 - 10. Flexible Body Equations of Motion
 - 11. Flight Performance Analysis
- Rolling Motion Velocity Half-Life
 - Retardation Motion with Rolling
 - Rolling Stability Derivatives Determination Using Rolling Motion Data

Course Outcome:

The out comings of this course are development in:

1. Analyzing the vibrational motion of missiles
2. Analyzing the dynamic behavior of rockets and missiles
3. Modeling the angular motion of different types of missiles
4. Deriving the equations of motion in various coordinate systems
5. Determining the stability regions of dynamic motion
6. Analyzing the sources of dispersion
7. Analyzing the performance of flight of Missiles

References:

1. Schmidt, D.K.; *Modern Flight Dynamics*, 1st Edition, McGraw-Hill Education, 2011.
2. Zipfel, P.H.; *Modeling and Simulation of Aerospace Vehicle Dynamics*, AIAA , 2001.
3. Etkin, B. and Reid, L.D.; *Dynamics of Flight: Stability and Control*, 3rd Edition, CRC press, 1995.
4. Nicolaidis, J.D.; *On Missile Flight Dynamics*, Catholic University of America, 1963.

Modeling of Aerospace Dynamic Systems, 45747

Course Objectives:

The subject of computer modeling and simulation of dynamics of aerospace vehicles has evolved into a major discipline in recent years. This new discipline is used not only in the design process but also in the development and improvement of performance and operation of civil and military aircraft and missiles. This course, as a first part of the subject, discusses the theoretical concepts that provide mathematical foundation for the simulation of aerospace systems. This includes frames of reference and coordinate systems, kinematics of translation and rotation, translational and attitude dynamics, as well as perturbation techniques used for modeling.

Syllabus:

1. Introduction to the subject
 - Virtual Engineering
 - Modeling of Flight Dynamics
 - Simulation of Aerospace Vehicles
2. Mathematical Concepts in Modeling
 - Classical Mechanics
 - Tensor Elements
 - Modeling of Geometry
3. Frames and Coordinate Systems
 - Frames
 - Coordinate Systems
4. Kinematics of Translation and Rotation
 - Rotation Tensor
- Kinematics of Changing Time
- Attitude Determination
5. Translational Dynamics
 - Linear Momentum
 - Newtonian Dynamics
 - Transformations
 - Simulation Implementation
6. Attitude Dynamics
 - Inertia Tensor
 - Angular Momentum
 - Euler's Law
 - Gyrodynamics
7. Perturbation Equations
 - Perturbation Techniques
 - Linear and Angular Momentum Equations

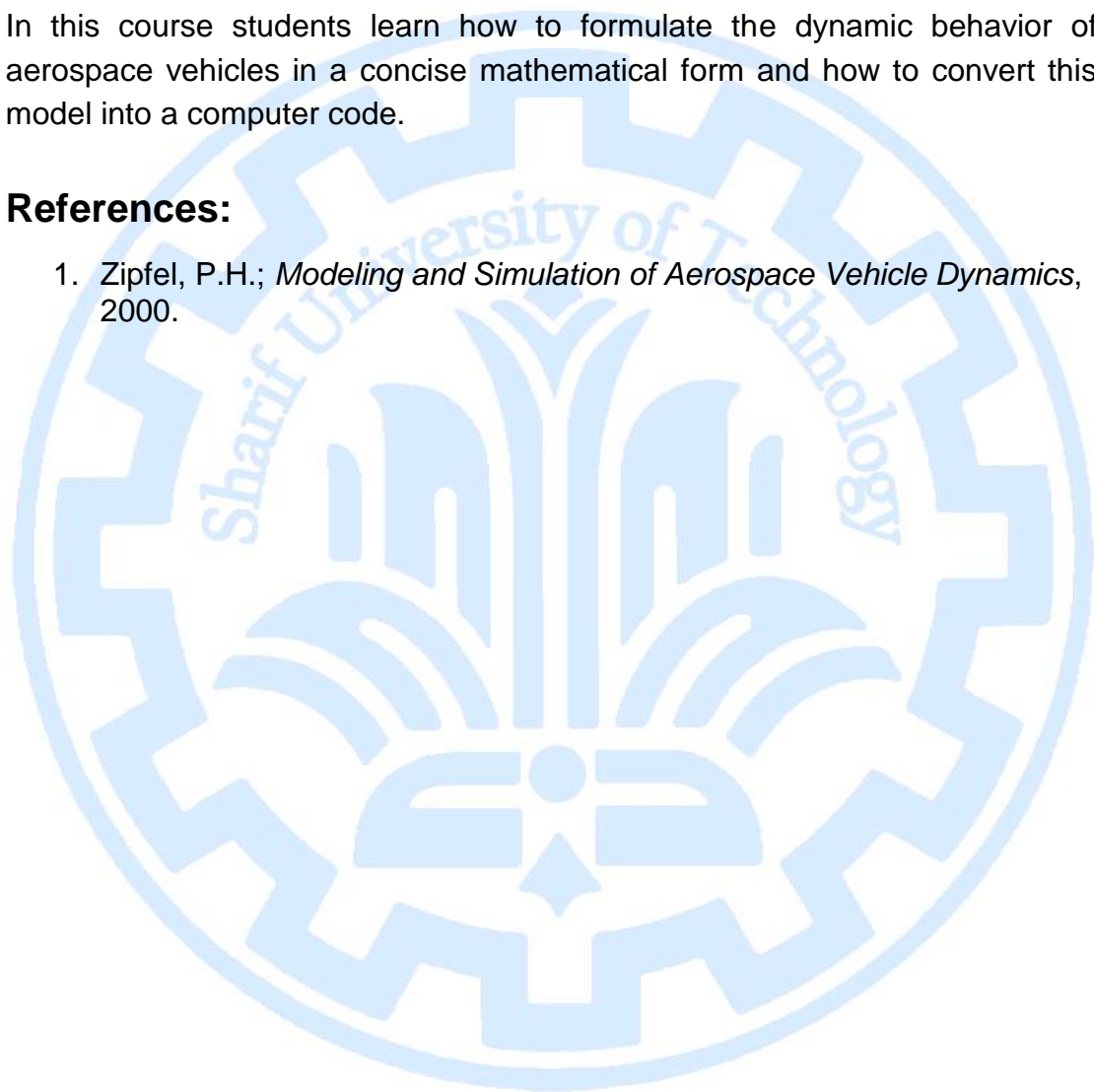
- Aerodynamic Forces and Moments
- Perturbation Equations of Steady Flight
- Equations of Unsteady Flight

Course Outcome:

In this course students learn how to formulate the dynamic behavior of aerospace vehicles in a concise mathematical form and how to convert this model into a computer code.

References:

1. Zipfel, P.H.; *Modeling and Simulation of Aerospace Vehicle Dynamics*, 2000.



Multivariable Control, 45750

Course Objectives:

This course is designed to familiarize graduated student with multivariable control. At the first, the nature of multivariable systems will be discussed. All Representation of multivariable systems will be studied later. In advance, Extension of SISO frequency domain concepts such as gain, bandwidth, etc. to multivariable systems will be taught. Generalization of frequency domain stability analysis to multivariable systems is another subject of this course. At the end of course, design techniques for multivariable systems based on the frequency domain will be considered.

Syllabus:

1. Aims of Control
 - Input-output response
 - Stability
 - Noise Suppression
 - Small Parameter Variations
 - Large Parameter Variations
 - Interactions
2. The Sensitivity Function
 - Open Loop Control
 - Closed Loop Control
 - Model Uncertainty
 - Disturbance Rejection
3. Structure for Control
 - One-degree of Freedom Control
 - Two-degree of Freedom Controllers
 - Design of Single loop Two Degree of Freedom Control Systems.
4. Introduction to Multivariable Systems
 - Loop Interaction
 - The Need for Multivariable Control
5. Measures of Multivariable Gain
 - Vector Norms and Induced Norms
 - The Singular Value Decomposition
 - System Norms
6. Linear System Models: Representations and Standard Forms
 - The State-space Description
 - State –space Standard Forms and Realization
 - Transfer Function Matrix Standard Forms

- Matrix Function Description
 - Reosenbrock's System Matrix
 - Transformation of system Matrices
 - Summary of Transformations
7. Controllability and Observability
- Controllability
 - Observability
 - Decoupling Zeros
 - Realizations and Reconstruction
8. Poles and Zeros of MIMO Systems
- Poles of a System
 - Zeros of a System
 - Cancelations, Stabilizability, and Detectability
9. Multivariable Model Handling Techniques
- Interconnections and Operations
10. Model Error Reduction
- System Gramians
 - Order Reduction Methods
11. Multivariable Interaction
- Measures of Interaction for Constant Matrices
 - Extension of Interaction Measures to Dynamical Systems
12. Stability of MIMO Systems
- Internal Stability
 - The Generalized Nyquist Stability Criterion
 - The Gain Space
 - Performance and Robustness Limits
13. Simply Structured Design
- The Nyquist Array Design Method
 - Structure of Multivariable Systems
 - Achieving Diagonal Dominance
14. Case Studies
- A Chemical Reactor
 - A Reheat Furnace
 - An Islanded Distributed Generation Unit
 - The Automotive Gas-turbine
 - The Rolls Royce Spey Gas-turbine Engine
 - Level Control Systems
 - Gasifier Challenge Problem

Course Outcome:

After studying this course, the student would be able to demonstrate an understanding of:

1. Nature of multivariable system interactions

2. Representation of multivariable systems and the associated canonical forms with each representation
3. Extension of SISO frequency domain concepts such as gain, bandwidth, etc to multivariable systems
4. Generalization of frequency domain stability analysis to multivariable systems.
5. An understanding of design versus synthesis techniques and a review of design techniques for multivariable systems based on the frequency domain.

References:

1. Rosenbrock, H.H.; *State Space and Multivariable Theory*, 1st Edition, Nelson, 1970.
2. Rosenbrock, H.H.; *Computer Aided Control System Design*, Academic Press, 1974.
3. Rosenbrock, H.H. and Storey, C.; *Mathematics of Dynamical Systems*, Nelson, 1970.
4. Patel, R.V. and Munro, N.; *Multivariable System Theory and Design*, Pergamon Press, 1982.
5. Kailath, T.; *Linear Systems*, Prentice Hall, 1983.
6. Stephanopoulos, G.; *Chemical Process Control*, 1st Edition, Prentice Hall, 1984.
7. Yeung, L.F and Bryant, G.F; "New Dominance Concepts for multivariable control systems design", *International Journal of Control*, Vol. 55, No. 4, p.p. 969-988, 1992.
8. Maciejowski, L.M.; *Multivariable Feedback Design*, Addison-Wesley, 1989.
9. Skogestad, S. and Postlethwaite, I.; *Multivariable Feedback Control: Analysis and Design*, John Wiley & Sons, 1996.

Neural Networks, 45775

Prerequisite: Advanced Mathematics I, 45510

Course Objectives:

This course gives an introduction to basic neural network architectures and learning rules. Emphasis is placed on the mathematical analysis of these networks, on methods of training them and their application to practical engineering problems in such areas as pattern recognition, signal processing and control systems. The course is organized for the senior or graduate level students and they will be able to implement and simulate network models using MATLAB.

Syllabus:

1. Neuron Model and Network Architectures
 - Notation
 - Neuron Models
 - Network Architectures
2. Vector Spaces and Linear Transformations
 - Linear Vector Spaces
 - Linear Independence
 - Spanning a Space
 - Inner Product
 - Norm
 - Orthogonality
 - Vector Expansions
 - Linear Transformations
 - Matrix Representations
 - Change of Basis
 - Eigenvalues and Eigenvectors
3. Fundamental Structures for Pattern Recognition and Clustering
4. Perceptron Learning Rule
 - Learning Rules
 - Perceptron Architecture
 - Perceptron Learning Rule
 - Proof of Convergence
5. Hebbian Learning
 - Linear Associator
 - The Hebb Rule
 - Pseudoinverse Rule
 - Variations of Hebbian Learning
6. Performance Optimization
 - Necessary Conditions for Optimality
 - Quadratic Functions
 - Steepest Descent

- Newton's Method
 - Conjugate Gradient
7. Widrow-Hoff Learning
- ADALINE Networks
 - Mean Square Error
 - LMS Algorithm
 - Analysis of Convergence
 - Adaptive Filtering
8. Hopfield Network
- Hopfield Model
 - Lyapunov Function
 - Effect of Gain
 - Hopfield Design
9. Backpropagation
- Multilayer Perceptron
- The Backpropagation Algorithm
 - Drawbacks of Backpropagation
 - Heuristic Modifications of Backpropagations
 - Numerical Optimization Techniques
10. Competitive Networks
- Hamming Network
 - Competitive Layer
 - Learning Vector Quantization
 - Grossberg Network

Course Outcome:

At the conclusion of this course the student will be able to demonstrate an understanding of:

1. Neural network architectures, learning rules, and training techniques
2. Design of neural networks
3. Neural network application to practical engineering problems

References:

1. Haykin, S.; *Neural Networks: A Comprehensive Foundation*, 2nd Edition, Prentice Hall, 1999-2012.
2. Hagan, M.; *Neural Network Design*, PWS Publishing Company, 1996.
3. Fausett, L.; *Fundamentals of Neural Networks Architectures, Algorithms And Applications*, 1st Edition, Pearson, 1993.

Optimal Control I, 45765

Prerequisites: Automatic Control, 45135; Differential Equations, 22016

Course Objectives:

This course is designed to introduce the theoretical and algorithmic fundamentals of deterministic optimal control (OC) that is implementable for solution and analysis of continuous/discrete dynamic systems. In this framework, optimal policy generally refers to optimal control input signals, optimal guidance strategies and/or optimal trajectories that minimize a generalized performance index under various constraints.

As OC methodologies can be utilized in many fields such as science and engineering, the course starts with a general definition and formulation of the OC problem and introduction of common performance functions. The method of dynamic programming based on the Bellman's principle of optimality is one of the conventional solution schemes used for OC, and as such its concept is initially discussed for discrete systems and subsequently generalized to cover all other systems. Calculus of variation (CV) is another solution approach for OC problems that is also attended to as a major topic in this course. Upon conceptual introduction of functional, extremal, variation and the fundamental principle of CV, a two point boundary value problem (TPBVP) evolves for the derivation of extremals. Application of CV for two widespread problems of quadratic regulator and tracking results in the so called Riccati equation for linear systems that is easily implementable. The concluding materials cover modeling state and control constraints using the Pontryagin's minimum principle. Other direct optimization approaches such as nonlinear programming (NLP) will also be introduced.

Syllabus:

1. Introduction
 - Optimal Control Problem Introduction and Formulation
 - System Classification and Control Laws
2. Performance Measures
 - Conventional Performance Measures
 - Selection and Weighting Functions
3. Dynamic Programming (DP)

- OC Policy Definition and Bellman's Optimality Principle
 - Recurrence Relation for DP
 - DP for Linear/ Nonlinear, Discrete/ Continuous Systems
 - Hamilton-Jacobi-Bellman Equation
4. Calculus of Variation (CV)
- Basic Concepts and Related Mathematics
 - Definition of Functional and Variations
 - Fundamental Principle of CV and the Euler's Equation (TPBVP)
 - Functionals of Several Functions
 - Generalized Boundary Conditions
 - Constrained and Cornered Extremals
5. Application of CV to OC Problems
- Necessary Equations for OC Problems
- Hamiltonian and the Generalizing Boundary Equations
 - Linear Quadratic Regulator (LQR) and Tracking (LQT) Problems
 - Pontryagin's Minimum Principle for Control Constrained Problems
 - Explicit Modeling of State Inequality Constraints
 - Singular Intervals
 - Minimum Time OC and the Switching Functions
6. Numerical Methods for OC
- Review of the Basic TPBVP
 - Steepest Descent and Variation of Extremals
 - Quasilinearization and Gradient Projection
 - Sequential Quadratic Programming
 - Shooting method and Multiple SM
 - Levenberg-Marquardt Method

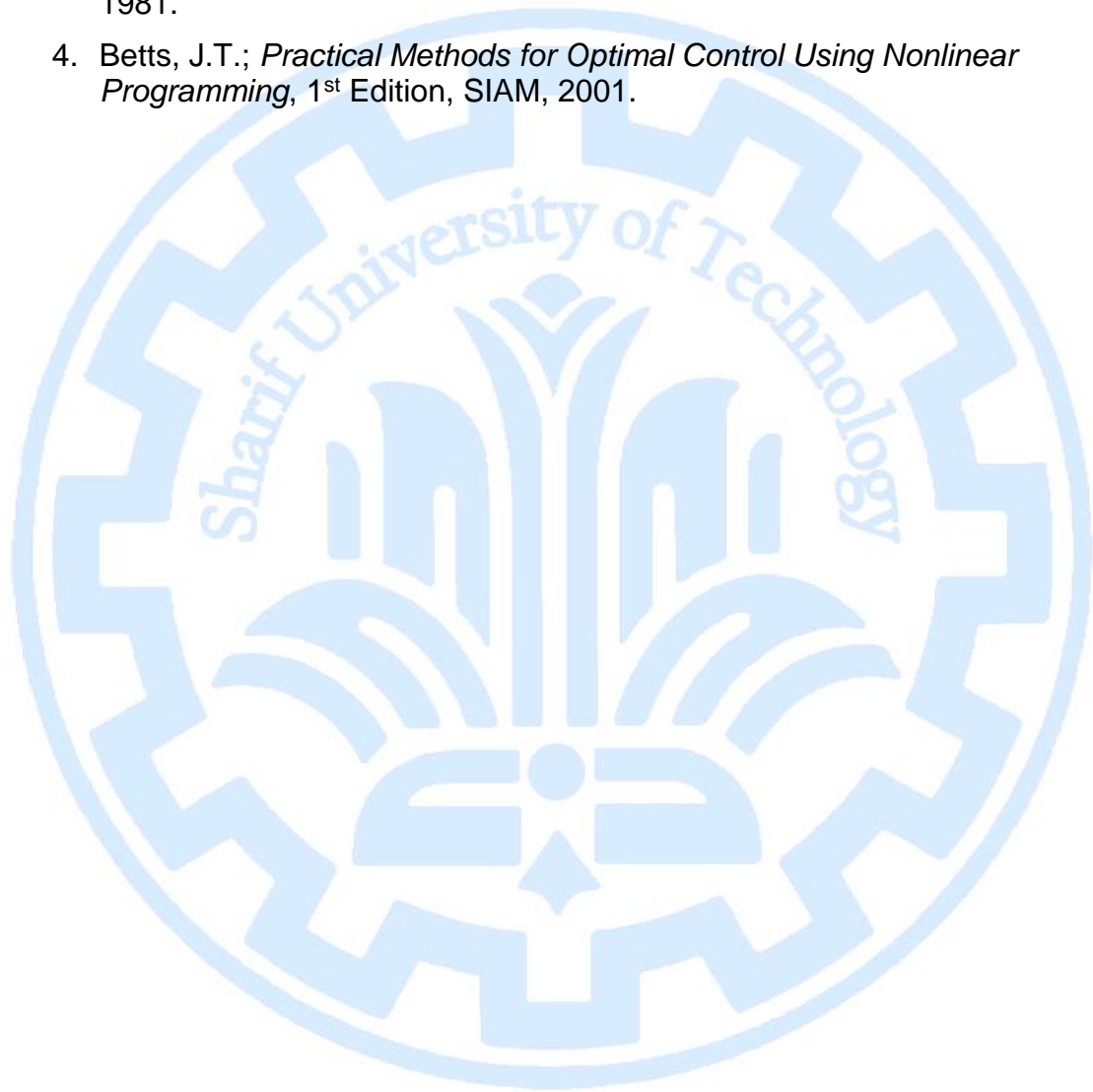
Course Outcome:

Upon successful completion of this course the student have gained the following understanding and capabilities:

4. Modeling and formulation of OC problems for all dynamic systems
5. CV and its utility in constrained optimization of cost functions
6. Optimal controller design using the DP and CV approaches
7. Ability to solve LQR and LQT as typical widespread OC problems
8. A basic familiarity with various gradient based numerical optimization schemes

References:

1. Kirk, D.E.; *Optimal Control Theory, An Introduction*, Dover publications, 2004.
2. Rao, S.S.; *Engineering Optimization; Theory and Practice*, 4th Edition, John Wiley & Sons, 2009.
3. Bryson, A. and Ho, Y.C.; *Applied Optimal Control*, Hemisphere Pub., 1981.
4. Betts, J.T.; *Practical Methods for Optimal Control Using Nonlinear Programming*, 1st Edition, SIAM, 2001.



Optimal Control II, 45766

Prerequisite: Optimal control I, 45765

Course Objectives:

This course combines the role of two basic level courses in probability theory and random processes to pave the way for a basic introductory course in stochastic systems (SS) and optimal estimation. In this sense, some basic fundamentals of probability theory, random variables and processes are initially reviewed. Upon introduction of Gaussian processes and the Markov properties, priory statistical analysis (SA) of stochastic systems with no measurements is addressed. Differentiation of white and colored process noise is highlighted and the concept of shaping filter for conversion is reviewed.

Subsequently, with addition of the measurement units, the least square error (LSE) parameter estimation method that leads to conceptual development of discrete time linear Kalman filter (KF) for noise removal (out of measured data) is introduced. The LSE KF is next extended to nonlinear measurement models and also augmented with system equations to establish what is called the secondary SA or optimal estimation for stochastic systems with measurements. Filter implementations for nonlinear and/or hybrid system and measurement models are generalized. In this respect the linearized and (LKF) and extended Kalman filters (EKF) are covered.

Additionally, several related topics such as filter divergence, stationary processes and the concept of noise and/or parameter modeling for stochastic estimation will be discussed. The problem of optimal smoothing and prediction as well as optimal control in presence of uncertainty (LQG) concludes the major topics intended for coverage in this course.

Syllabus:

1. Review of Statistical Concepts
 - Discrete and Continuous Random Variables
 - Discrete and Continuous Random Vectors
 - Multivariate Probability Functions and Conditional Distributions
2. Introduction to Random Process

- Correlation and Power Spectral Density Functions
 - Stationary Process, White Noise and Simulation
 - Random Sequences and Markov Properties
 - Gauss-Markov Random Processes
3. Stochastic Systems and Covariance Analysis
- Mean and Covariance Propagation
 - Colored Noise and Shaping Filters
 - Discrete and Continuous Systems
 - Error Analysis of Linear Systems
 - Error Models for Measuring Systems
 - Monte-Carlo Simulation
4. Optimal Filtering and Prediction
- State Estimation Concept and Criteria
 - Cramer-Rao Inequality
- Least Square Estimation (Ordinary, Weighted, Recursive)
 - Filtering and the Measurement Effect
 - Kalman Filters for Linear Systems (Discrete/Continuous)
 - Linearized (LKF) and Extended Kalman Filters (EKF) for Non-Linear Systems
 - Filter Divergence
5. Optimal Prediction and Smoothing
- Smoothing for Single and Multistage Processes
 - Various Forms of Smoothing
6. Optimal Control in Presence of Uncertainty
- Linear Quadratic Gaussian Regulators
 - Average Behavior of Controlled Systems
7. Special topics
- Nonlinear Filtering
 - Adaptive Estimation

Course Outcome:

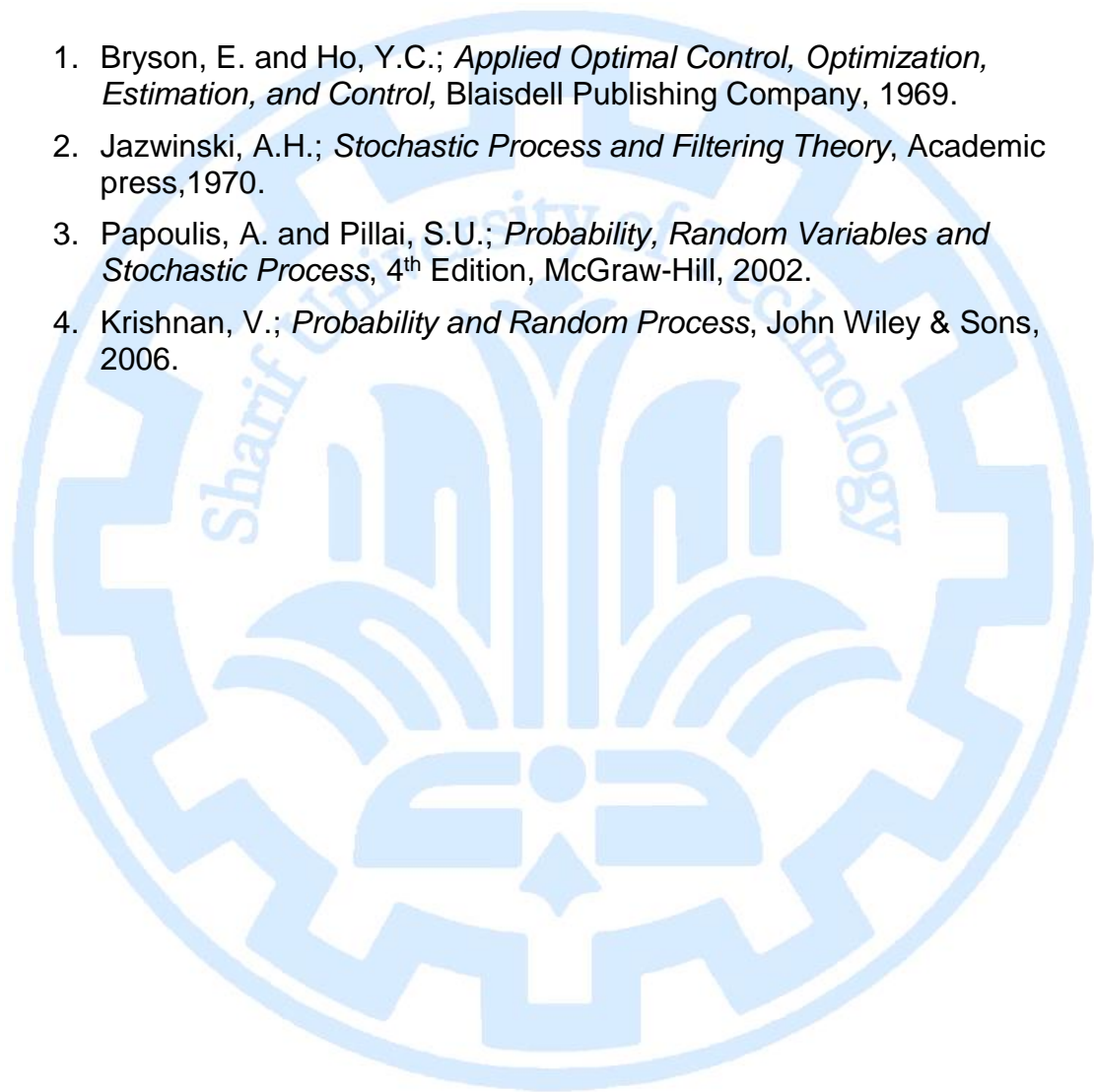
Upon conclusion of this course the students have gained the following understanding and/or capabilities:

1. Familiarity with random process and their statistical properties.
2. Stochastic systems and covariance analysis.
3. Least square weighted estimation.

4. State estimation via batch or recursive Kalman filters for linear/nonlinear systems.
5. Parameter estimation and system identification.
6. Filter divergence and remedies.
7. Optimal control of uncertain systems with measurement models.

References:

1. Bryson, E. and Ho, Y.C.; *Applied Optimal Control, Optimization, Estimation, and Control*, Blaisdell Publishing Company, 1969.
2. Jazwinski, A.H.; *Stochastic Process and Filtering Theory*, Academic press, 1970.
3. Papoulis, A. and Pillai, S.U.; *Probability, Random Variables and Stochastic Process*, 4th Edition, McGraw-Hill, 2002.
4. Krishnan, V.; *Probability and Random Process*, John Wiley & Sons, 2006.



Spacecraft Dynamics and Control, 45780

Prerequisite: Orbital Mechanics, 45407

Course Objectives:

The attitude kinematics and rigid-body dynamics of satellites in free Newtonian space and in an orbit around Earth are introduced. The different attitude representations and their differential equation as well as the Euler's dynamic equation are derived. The motion of rigid-body without external torque and in presence of external torque is discussed. Furthermore, the passive and active attitude stabilization and control of satellite in the orbit using gravity gradient, magnetic actuation, momentum exchange devices and reaction thrusters are taught. Moreover, the basic attitude determination concepts and formulas are introduced.

Syllabus:

1. Introduction and Overview
 - Introduction to Orbital Mechanics and Attitude Dynamics
 - Two-Body Problem
 - Coordinate Systems
 - Orbital Maneuvers
 - Orbital Perturbations
2. Attitude Kinematics
 - Description of Attitude Kinematics Using Reference Frames
 - Rotation Matrices
 - Euler Angles
 - Euler's Eigenaxis Rotation
 - Euler Parameters/Quaternions
 - Gibbs Parameters
 - Kinematic Differential Equations
3. Rigid Body Rotational Dynamics
 - Equations of Motion for Rigid Satellites
 - Angular Momentum
 - Euler's Equations
 - Moments of Inertia and Principal Axes
4. Torque-Free Motion
 - Torque-Free Motion of an Axisymmetric Rigid Body
 - General Torque-Free Motion
 - Stability of Torque-Free Motion About Principal Axes
5. Body-Fixed Torque Motion

- Spinning Axisymmetric Body with Constant Body-Fixed Torque
 - Asymmetric Rigid Body with Constant Body-Fixed Torques
 - Linear Stability of Equilibrium Points
 - Nonlinear Analysis of Constant Torque About the Major or Minor Axis
 - Nonlinear Analysis of Constant Torque About the Intermediate Axis
6. Rigid Body in a Circular Orbit
- Equations of Motion
 - Linear Stability Analysis
 - Dual-Spin Satellite
 - Passive Damping of a Dual-Spinner
7. Attitude Control and Stabilization
- Gravity Gradient Stabilization
 - Time Behavior of Pure GG stabilization
 - GG Stabilization with Passive Dampers
 - GG Stabilization with Active Magnetic Damping
- Attitude Control in Space (Slew Maneuvers)
 - Quaternion Feedback Control
 - Control using Reaction/Momentum Wheel
 - Control using Control Moment Gyro (CMG)
 - Control using Thruster and Pulse Modulation
 - Control using Magnetic Actuation
8. Attitude Determination
- Introduction of Attitude Sensors
 - Describing the Measurements Required to Determine the Attitude of a Spacecraft
 - Basic Attitude Determination Algorithms (Triad, q-Method, QUEST)
9. Advanced Topics
- Design of ADCS (Attitude Determination and Control Subsystem)
 - Tethered Satellites
 - Effects of Flexibility

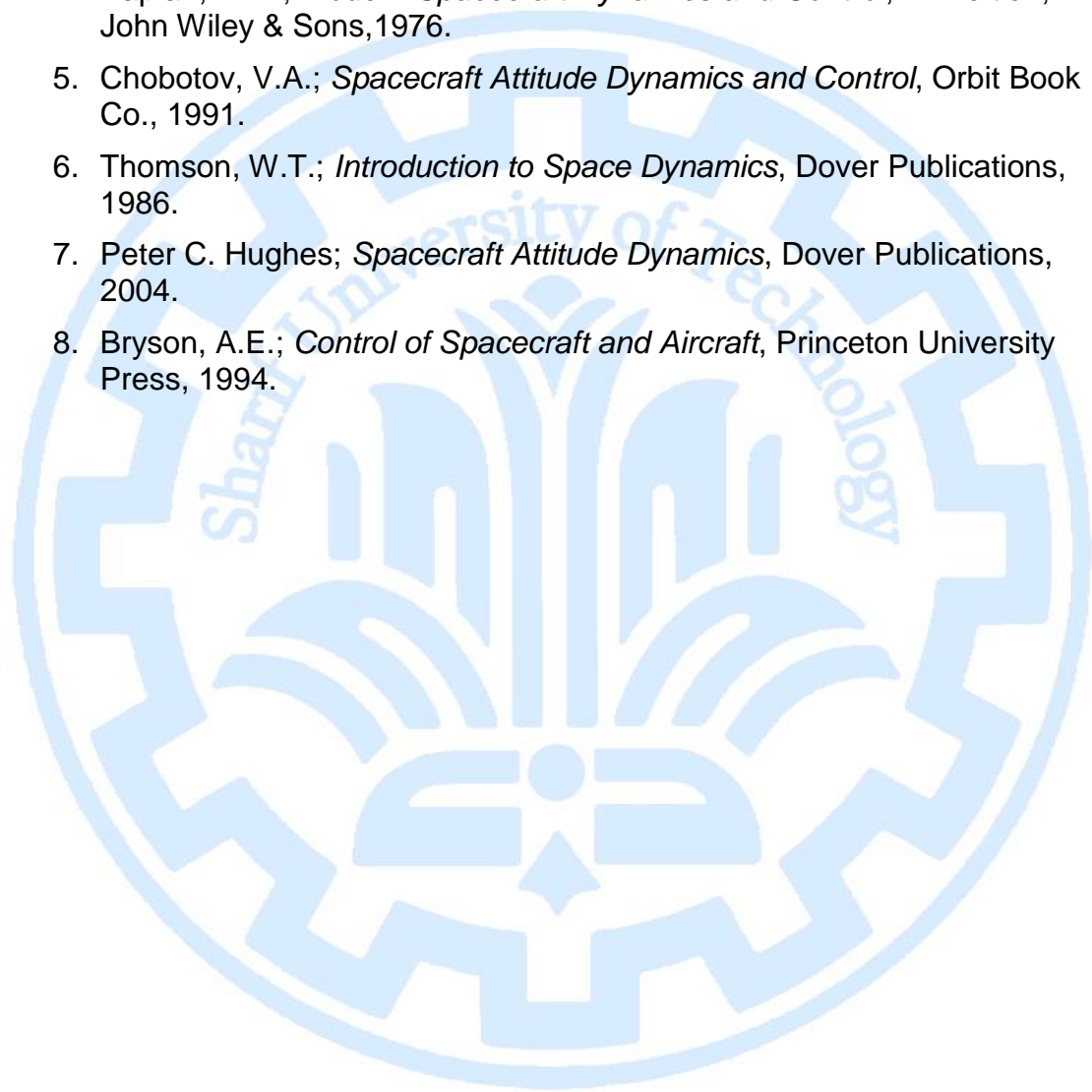
Course Outcome:

After studying this course, the student would be able to demonstrate an understanding of:

1. Different attitude representations
2. Attitude dynamics in orbit
3. Different attitude control using satellite actuators

References:

1. Wie, B.; *Space Vehicle Dynamics and Control*, AIAA, 1998.
2. Marcel, J.S.; *Spacecraft Dynamics and Control: a Practical Engineering Approach*, Cambridge University Press, 1997.
3. Wertz, J.R.; *Spacecraft Attitude Determination and Control*, 1st Edition, Springer, 1978.
4. Kaplan, M.H.; *Modern Spacecraft Dynamics and Control*, 1st Edition, John Wiley & Sons, 1976.
5. Chobotov, V.A.; *Spacecraft Attitude Dynamics and Control*, Orbit Book Co., 1991.
6. Thomson, W.T.; *Introduction to Space Dynamics*, Dover Publications, 1986.
7. Peter C. Hughes; *Spacecraft Attitude Dynamics*, Dover Publications, 2004.
8. Bryson, A.E.; *Control of Spacecraft and Aircraft*, Princeton University Press, 1994.



System Identification, 45749

Prerequisite: Flight Dynamics I and II, 45156 and 45157; Airplane Design I and II, 45177 and 45118

Course Objectives:

This course is offered to graduates, flight test engineers, simulation engineers, control system designers, aircraft designers, flying qualities engineers and anyone who like to identify trustworthiness of mathematical models based on measured data from an experiment, or understand how it is done. Topics covered include: introduction to the identification process, time-domain approach for identification of time-invariant systems, frequency domain method and Kalman filter.

Syllabus:

1. Introduction to System Identification
 - Introduction and Brief History
 - Nonparametric vs. Parametric Methods
 - Model Parameterization and Prediction
 - Frequency Response and Time Response Methods
 - Basic Steps in the Identification Process
2. Collection of Time History Data, Data Consistency and Reduction
 - Overview of Data Requirements for System Identification
 - Conditions on the Data Set and Commonly Used Input Signals
 - Optimal Input and Recommended Pilot Inputs for Frequency-Response Identification
 - Instrumentation Requirements and Flight Testing Considerations
 - Piloted Frequency Sweeps
 - System Identification Testing of Off-line Simulation Models
 - Modeling Measurement Errors in Flight Test Data Consistency and Identifiability (Kinematic Consistency Methods, Translational Consistency, Detection of Faulty Data)
 - The Correlation Approach

3. Nonparametric Frequency

Domain Identification

- Transient Response Analysis
- Fourier Analysis
- Spectral Analysis
- Estimating the Disturbance Spectrum
- Frequency-Response Analysis and Identification (Fourier Transform and Spectral Functions, Coherence Function)
- SISO Frequency-Response Analysis and Identification
- MISO/MIMO Identification

4. Transfer Function Modeling

- Motivations for Transfer Function Modeling
- Selection of Input-Output Variable Pair
- Pendulum example
- Handling Qualities Applications
- Flight Dynamics Identification (Fixed and Rotary Wing)

5. State-Space Model Identification

- State-Space Model Structure
- Identification Cost Function and Solution Algorithm
- Accuracy Analysis
- Cramer-Rao Inequality and Bounds
- Physical Model Structure
- Accurate Determination of Stability and Control Derivatives from Nonlinear Simulation Using System Identification
- Identification of a 3-DOF Longitudinal Model of a Fixed-Wing UAV

6. Complementary Topics

- Recursive Estimation Methods
- Choice of Identification Criterion
- Verification of Identification Methods
- Minimizing Prediction Error
- Linear Regression and Least Square Estimation
- A Statistical Framework for Parameter Estimation and Maximum Likelihood Method
- Kalman Filter Interpretation

Course Outcome:

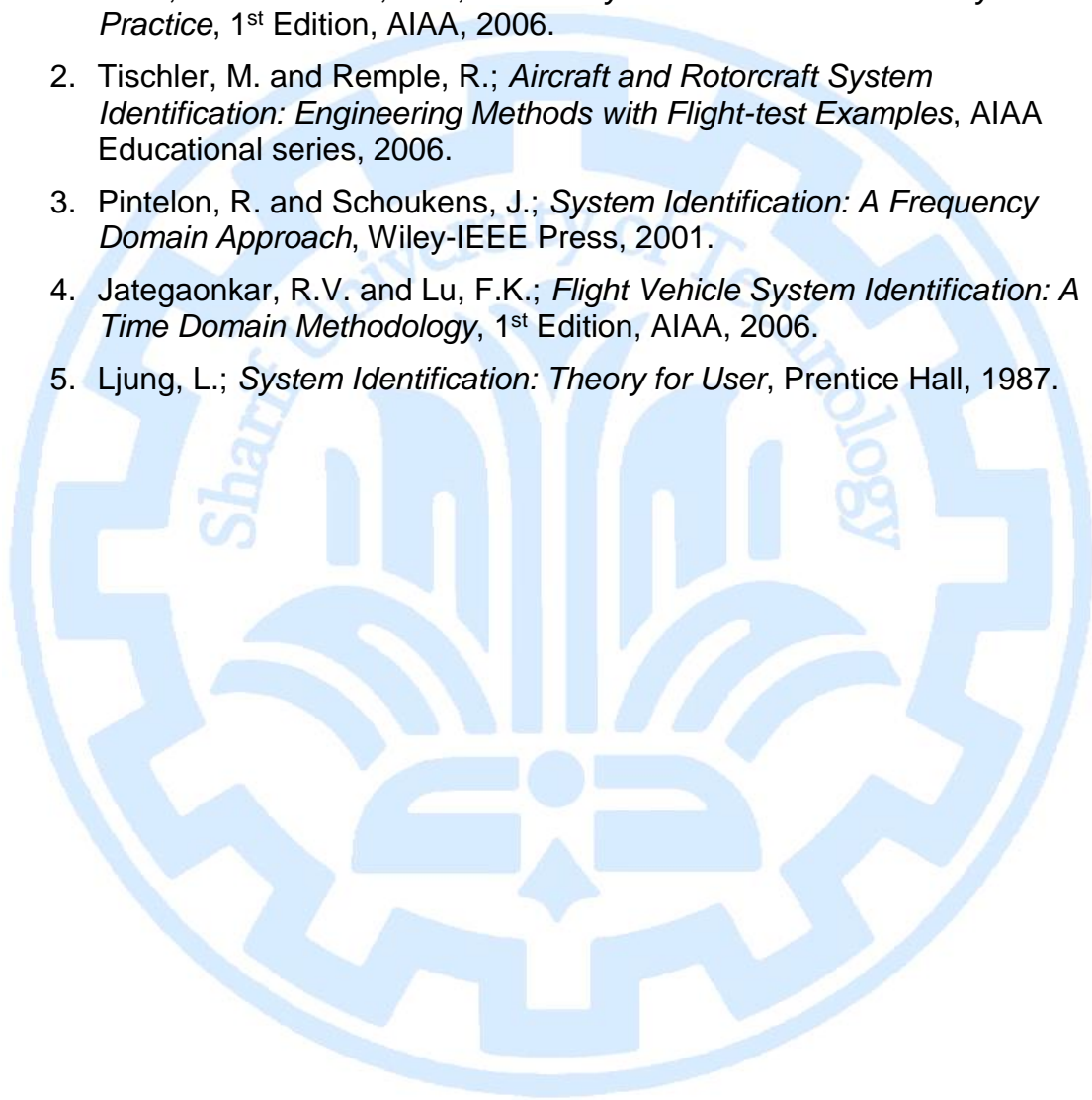
At the conclusion of this course the student will be able to demonstrate an understanding of:

1. Experiment design, instrumentation, data analysis, modeling, and validation

2. Building mathematical models for aircraft dynamics based on measured flight data
3. Identifiability and robustness
4. The use of the software on real flight data (and to interpret results)

References:

1. Klein, V. and Morelli, E.A.; *Aircraft System Identification: Theory and Practice*, 1st Edition, AIAA, 2006.
2. Tischler, M. and Remple, R.; *Aircraft and Rotorcraft System Identification: Engineering Methods with Flight-test Examples*, AIAA Educational series, 2006.
3. Pintelon, R. and Schoukens, J.; *System Identification: A Frequency Domain Approach*, Wiley-IEEE Press, 2001.
4. Jategaonkar, R.V. and Lu, F.K.; *Flight Vehicle System Identification: A Time Domain Methodology*, 1st Edition, AIAA, 2006.
5. Ljung, L.; *System Identification: Theory for User*, Prentice Hall, 1987.



Appendix A- List of all AE Courses

In this appendix, all courses, taught by the department of aerospace engineering, are listed.

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45000	PHD QUALIFYING EXAM		Ph.D.	0
45001	RESEARCH PROPOSAL		Ph.D.	0
45030	AER ROBOT WORKSHOP 1	Prerequisite: 45132	B.Sc.	1
45040	COMPOSITE MAT LAB		B.Sc.	1
45041	STRUCTURE LAB	Prerequisite: 45133	B.Sc.	1
45050	AERODYNAMICS LAB 1	Prerequisite: 45115 or 28487	B.Sc.	1
45070	ENGINE WORKSHOP 1	Prerequisite: 45134	B.Sc.	1
45071	ENGINE WORKSHOP 2	Prerequisite: 45117	B.Sc.	1
45080	INSTRUMENTATION WRKSHP	Prerequisite: 45135	B.Sc.	1
45081	AIRFRAME WORKSHOP	Prerequisite: 45136	B.Sc.	1
45082	INSTRUMENT LAB 2	Prerequisite: 45416	B.Sc.	1
45085	CONTROL SYSTEM LABORATORY	Prerequisite: 45135	B.Sc.	1
45090	MODEL A/C WORKSHOP 1		B.Sc.	1
45091	MODEL A/C WORKSHOP 2		B.Sc.	1
45112	STATICS	Prerequisite: 24011 and 22015	B.Sc.	3
45113	DYNAMICS	Prerequisite: 45112	B.Sc.	4
45114	NUMERICAL METHODS	Prerequisite: 40151 and 22034	B.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45115	AERODYNAMICS 1	Prerequisite: 45124 or 28461 and 45132 or 28414	B.Sc.	3
45116	AERODYNAMICS 2	Prerequisite: 45115 or 28487	B.Sc.	3
45117	PROPULSION PRIN	Prerequisite: 45134 Corequisite: 45116	B.Sc.	3
45118	AIRCRAFT DESIGN 2	Prerequisite: 45177 or 28479	B.Sc.	3
45119	NUMERICAL METHODS	Prerequisite: 22015 and 40151 or 40153	B.Sc.	2
45124	FLUID MECHANICS 1	Corequisite: 22034	B.Sc.	3
45125	THERMODYNAMICS 2	Prerequisite: 45134 or 28161	B.Sc.	3
45126	HEAT TRANSFER 1	Prerequisite: 22035 Corequisite: 45134 or 28161	B.Sc.	3
45132	INTRO TO AEROSPACE	Prerequisite: 31123	B.Sc.	2
45133	STRENGTH OF MATERIALS	Prerequisite: 45112 or 28261	B.Sc.	3
45134	THERMODYNAMICS 1	Prerequisite: 24011 Corequisite: 45124	B.Sc.	3
45135	AUTOMATIC CONTROL	Prerequisite: 45144 or 28568	B.Sc.	3
45136	A/C STRUCTURAL ANALYSIS	Prerequisite: 45133	B.Sc.	3
45137	A/C STRUCTURAL DSGN	Prerequisite: 45136 or 28955	B.Sc.	3
45144	VIBRATIONS	Prerequisite: 45113 or 22034 and 28567	B.Sc.	3
45145	CAD 1	Prerequisite: 40151 or 40153	B.Sc.	3
45153	AERO TECH LANGUAGE	Prerequisite: 31101 or 31124	B.Sc.	2
45154	MATERIALS SCIENCE	Prerequisite: 45133 or 28262	B.Sc.	3
45156	FLIGHT DYNAMICS 1	Prerequisite: 45115 or 45113 and 28487 or 28567	B.Sc.	3
45157	FLIGHT DYNAMICS 2	Prerequisite: 45156 or 45135 and 28481 or 28416	B.Sc.	3
45177	AIRCRAFT DESIGN 1	Prerequisite: 45116 or 28476 or 45157 or 28446	B.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45400	INDUSTRIAL TRAINING		B.Sc.	0
45401	COMPOSITE MATERIALS	Prerequisite: 45133 or 28262	B.Sc.	3
45402	HELICOPTER AERODYN	Prerequisite: 45115	B.Sc.	3
45403	EXPERIMENTAL AERODYN	Prerequisite: 45115	B.Sc.	3
45404	PROPELLER THEORY	Prerequisite: 45116 or 28476	B.Sc.	3
45405	VISCOUS FLOW	Prerequisite: 45115 or 28487	B.Sc.	3
45406	INTRO TO CFD	Prerequisite: 45119 or 45116	B.Sc.	3
45407	ORBITAL MECHANICS	Prerequisite: 45113 or 22034 and 28567	B.Sc.	3
45408	INTERNAL COMB ENGINE	Prerequisite: 45134 or 28161	B.Sc.	3
45409	FUEL & COMBUSTION	Prerequisite: 45134 or 28161	B.Sc.	3
45410	ROCKET PRINCIPLES	Prerequisite: 45117 or 28482	B.Sc.	3
45411	TURBOMACHINERIES	Prerequisite: 45125 or 28162 and 45116 or 28476	B.Sc.	3
45412	INDUSTRIAL MANAGEMENT		B.Sc.	3
45413	SATELLITE SYSTEMS	Prerequisite: 45135 or 28416	B.Sc.	3
45414	AUTO SYS IN SPACE	Prerequisite: 45135 or 28416	B.Sc.	3
45415	MATERIALS & CONSTR METDS	Prerequisite: 45133 or 28262	B.Sc.	3
45416	PRECISION INSTRUMENT 1		B.Sc.	3
45417	MICROPROCESSOR 1	Prerequisite: 25091	B.Sc.	3
45418	INTRO FINITE ELEMENT METD		B.Sc.	3
45419	AVIONICS		Both	3
45420	AEROSPACE TECH TRANSFER		Both	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45421	STRENGTH OF MATERIALS 2	Prerequisite: 45133	B.Sc.	3
45422	PILOT TRAINING		B.Sc.	2
45424	VISCOUS FLOW	Prerequisite: 45124	B.Sc.	3
45425	INTRO MISSILE DESIGN		Both	3
45426	MANUFACTURING METHODS		Both	3
45427	MACHINE DESIGN 1	Prerequisite: 45133 or 28262	Both	3
45428	LIQ ROCKET ENGINE DSGN		B.Sc.	3
45429	SPACE ENG PRIN	Prerequisite: 45132	B.Sc.	3
45430	ORG & ENG ETHICS		B.Sc.	2
45431	AERO GAS TURB ENG DESIGN	Prerequisite: 45124 and 45134 or 28161 and 28461	B.Sc.	3
45432	ENGINEERING ECONOMICS		B.Sc.	3
45500	BSC PROJECT		B.Sc.	3
45510	ADV MATH 1		M.Sc.	3
45511	ADV MATH 2		M.Sc.	3
45515	ADV NUMERICAL METHODS		M.Sc.	3
45520	CONTINUM MECHANICS		M.Sc.	3
45525	PERTURBATIONS THEORY		M.Sc.	3
45530	ENERGY METHODS		M.Sc.	3
45531	CONTINUOUS SYS VIBRATION		M.Sc.	3
45532	NONLINEAR VIBRATION		M.Sc.	3
45535	SELF STUDY		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45536	RESEARCH METHODS		M.Sc.	3
45540	AEROSPACE TECH MNGMT		M.Sc.	3
45541	STRATEGIC MNGMT IN AEROSP		M.Sc.	3
45545	ADV DYNAMICS		M.Sc.	3
45550	NON-THESIS RES PROJ		M.Sc.	3
45560	MSC THESIS		M.Sc.	6
45600	MSC SEMINAR		M.Sc.	2
45605	ADV THERMODYNAMICS		M.Sc.	3
45610	ADV FUEL & COMB		M.Sc.	3
45615	GAS DYNAMICS 1		M.Sc.	3
45616	GAS DYNAMICS 2		M.Sc.	3
45620	ADV TURBOMACHINERY		M.Sc.	3
45622	NUM METH IN TURBOMACH		M.Sc.	3
45625	MISSILE AEROTHERMODYN		M.Sc.	3
45630	COMBUSTION INSTABILITY		M.Sc.	3
45635	ACOUSTICS		M.Sc.	3
45637	THERMOACOUSTICS		M.Sc.	3
45640	ADV HEAT TRANSFER		M.Sc.	3
45641	RADIATION HEAT TRANSFER		M.Sc.	3
45643	CONVECTION HEAT TRANSFER		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45645	ADV PROPULSION PRIN		M.Sc.	3
45699	SP TOPICS IN PROPULTION		M.Sc.	3
45700	MSC PROJECT		M.Sc.	6
45705	ADV FLIGHT DYNAMICS 1		M.Sc.	3
45706	ADV FLIGHT DYNAMICS 2		M.Sc.	3
45710	ADV AUTOMATIC CONTROL		M.Sc.	3
45715	NAVIGATION & GUIDANCE 1		M.Sc.	3
45716	NAVIGATION & GUIDANCE 2		M.Sc.	3
45720	FLGHT TEST PRINCIPLES		M.Sc.	3
45725	MISSILE FLIGHT DYNAMICS		M.Sc.	3
45730	CONTROL SYS DESIGN		M.Sc.	3
45733	ADV AIRCRAFT DESIGN		Ph.D.	3
45734	MISSILE CONFIG DESIGN		Ph.D.	3
45735	FUZZY CONTROL		M.Sc.	3
45736	ADV CONCEPTS A/C DSGN	Prerequisite: 45118 and 45177	M.Sc.	3
45738	ADV. AIRCRAFT PERFORMANCE	Prerequisite: 45156	M.Sc.	3
45740	HELICOPTER FLIGHT DYN		M.Sc.	3
45743	AERO GAS TURB ENG CONTROL	Prerequisite: 45117 and 45135	M.Sc.	3
45745	FLIGHT SIMULATION		M.Sc.	3
45746	DYNAMICAL SYSTEMS		Ph.D.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45747	MODELING AEROSPACE DYN SYS		M.Sc.	3
45748	NONLINEAR SYS ANALYSIS		M.Sc.	3
45749	SYSTEM IDENTIFICATION		M.Sc.	3
45750	MULTIVARIABLE CONTROL		M.Sc.	3
45755	DIGITAL CONTROL		M.Sc.	3
45760	ADAPTIVE CONTROL		M.Sc.	3
45765	OPTIMAL CONTROL 1		M.Sc.	3
45766	OPTIMAL CONTROL 2		M.Sc.	3
45770	HEURISTIC OPTIM ALGORITMS		M.Sc.	3
45775	NEURAL NETWORKS		M.Sc.	3
45777	APPL OF REMOTE SENSING		M.Sc.	3
45779	SPACE PROPULSIONS	Prerequisite: 45417	Both	3
45780	SPACECRAFT DYN & CONTR	Prerequisite: 45407	M.Sc.	3
45781	LAUNCH VEHICLE SYS DESIGN		M.Sc.	3
45782	SATELLITE SYSTEM DESIGN		M.Sc.	3
45783	ATT & ORBIT DETERMINATION		M.Sc.	3
45784	ADV ORBITAL MECHANICS	Prerequisite: 45407	M.Sc.	3
45785	SPACE SYSTEMS ENGINEERING		M.Sc.	3
45799	SP TOPICS IN FLIGHT DYN		M.Sc.	3
45805	ADV VISCOUS FLOW 1		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45806	ADV VISCOUS FLOW 2		M.Sc.	3
45809	FLUID FLOW CONTROL	Prerequisite: 45805	M.Sc.	3
45810	TURBULENCE		M.Sc.	3
45811	SHEAR LAYER TURBULENCE		M.Sc.	3
45813	TURBULENCE SIMULATION		M.Sc.	3
45815	SUBSONIC AERODYNAMICS		M.Sc.	3
45816	SUPERSONIC AERODYNAMICS		M.Sc.	3
45817	HYPERSONIC AERODYNAMICS		M.Sc.	3
45818	ADV AERODYNAMICS		M.Sc.	3
45820	UNSTEADY AERODYNAMICS		M.Sc.	3
45825	GRID GENERATION METHODS		M.Sc.	3
45830	CFD 1		M.Sc.	3
45831	CFD 2		M.Sc.	3
45832	FINITE ELEMETS METD IN FLUID		Ph.D.	3
45834	ADV HELICOPTER AERODYN		Ph.D.	3
45835	KINETIC THEORY OF GAS		M.Sc.	3
45836	AERODY OF WIND TURBINES	Prerequisite: 45115	M.Sc.	3
45837	INTAKE AERODYNAMICS	Prerequisite: 45116 and 45117	M.Sc.	3
45840	MICRO_NANO FLOWS		M.Sc.	3
45899	SP TOPICS IN AERODYN		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45900	PHD THESIS		Ph.D.	24
45905	ADV STRUCTURAL ANALYSIS		M.Sc.	3
45910	AEROELASTICITY		M.Sc.	3
45915	ADV AIRCRAFT DESIGN		M.Sc.	3
45920	FINITE ELEM METHOD 1		M.Sc.	3
45921	FINITE ELEM 2		M.Sc.	3
45923	BOUNDARY ELEMENT METHOD		M.Sc.	3
45925	ADV STRUCTURAL DESIGN		M.Sc.	3
45930	ADV COMPOSITE MATERIALS		M.Sc.	3
45932	SPACE STRUCT MATERIALS		M.Sc.	3
45935	FRACT FATIG CREEP		M.Sc.	3
45937	MECH BEHAVIOR OF MAT		M.Sc.	3
45938	NANO MECHANICS		M.Sc.	3
45940	METALLORGY IN MANUF		M.Sc.	3
45945	ADV MACHINE DESIGN		M.Sc.	3
45946	ADV COMPUTATIONAL DYN		Ph.D.	3
45947	SHELL & PLATE THEORY		Ph.D.	3
45950	ADV OPTIMIZATION		M.Sc.	3
45951	MULTIPHASE FLOWS		M.Sc.	3
45955	STRUCTURAL DYNAMICS		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
45957	MODAL ANALYSIS		M.Sc.	3
45960	ADV MAT & MANUF PROC		M.Sc.	3
45965	VISCOELASTICITY		M.Sc.	3
45970	JIG & FIXTURE DESIGN		M.Sc.	3
45973	EXP STRESS ANALYSIS		M.Sc.	3
45975	FRACTURE MECHANICS		M.Sc.	3
45980	PHD THESIS		Ph.D.	24
45999	SP TOPICS IN AEROS STRUCT		M.Sc.	3
45AP0	ADVISOR PROFESSOR		B.Sc.	3
45AP2	ADVISOR PROFESSOR		B.Sc.	2
45TA0	TEACHING ASSISTANT		Ph.D.	3