



Sharif University of Technology
Department of Aerospace Engineering

Master Program in Space Engineering

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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 select 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 levels 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 space engineering division perform their research activities in different fields including: space technologies development; space missions design and analysis; attitude and orbit dynamic, control, and determination; measurement systems in space; space navigation; satellite and spacecraft system design; etc.

This document introduces the master program in Space Engineering for interested students and other parties.

Chapter 2: Overall Program

This chapter presents an overview on the master program in Space Engineering. 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 Space Engineering 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
Spacecraft Dynamics and Control	45780
Satellite System Design	45782
Launch Vehicle System Design	45781
Modeling of Aerospace Dynamic Systems	45747
Advanced Orbital Mechanics	45784

Table 3 Elective Technical Courses

Course Title	Course Number
Adaptive Control	45760
Advanced Automatic Control	45710
Applications of Remote Sensing	45777
Attitude and Orbit Determination	45783
Control Systems Design	45730
Digital Control	45755
Flight Simulation	45745
Fuzzy Control	45735
Guidance & Navigation 1	45715
Guidance & Navigation 2	45716
Heuristic Optimization Algorithms	45770
Liquid Rocket Engine Design	45428
Missile Flight Dynamics	45725
Multivariable Control	45750
Neural Networks	45775
Nonlinear System Analysis	45748
Optimal Control 1	45765
Optimal Control 2	45766
Space Propulsion	45779
Space Structures Materials	45932
Space Systems Engineering	45785
System Identification	46749

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 details.

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

Precompensator or Feedforward Technique)

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,

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 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:

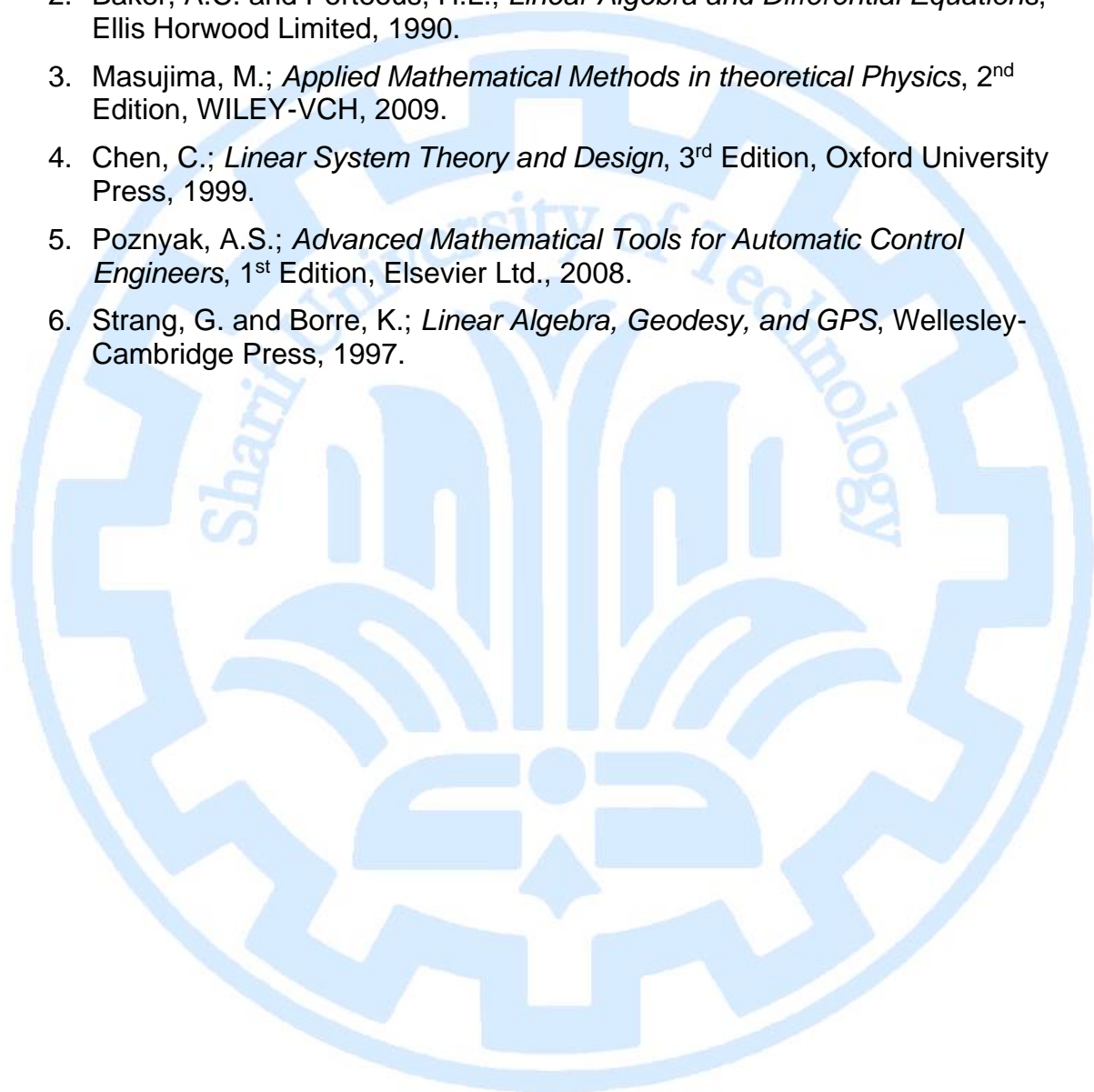
At the conclusion of this course the student will be able to demonstrate an understanding of:

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

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.



Advanced Orbital Mechanics, 45784

Prerequisite: Orbital Mechanics, 45407

Course Objectives:

The detailed definition of the different aspects of advanced topics in orbital dynamics has been provided in this course. After introducing the general concept of time and coordinate systems in space engineering applications, the three-dimensional interplanetary trajectories are presented. The advanced concepts of multiple planetary flybys and utilizing the atmosphere of planets for maneuvering in space are introduced.

The most commonly used orbital representation parameters are classical orbital elements. However, they are not efficient for many problems or are singular for some orbits, for instance circular orbits and equatorial orbits. Therefore, other orbital representation parameters such as Equinoctial Elements, Delaunay, Poincare, and Polar-nodal variables are presented. Then, the perturbed equations of motion in Cartesian coordinate system and the perturbation sources are introduced. Thereafter, the equation of variation in orbital elements and other orbital representation parameters are presented. The perturbation equations can also be used for orbit design. The orbit design is one of the most useful fields in space mission designs. After a review of special orbits, such as Molniya, Sun-synchronous, repeating ground track, and frozen orbits, the orbit design for earth coverage and ground station visibility is explained. Then, the constellation design approaches and some general constellation structures are introduced.

All of the previous subjects were based on the two-body and perturbed two-body problems. However, the three-body problem can better explain some orbital phenomenon and nowadays have been used for many applied space missions. After a review of the dynamics and equations of motion, the methods for finding periodic and quasi-periodic orbits and also transfer trajectories in restricted three-body problem are explained. Afterward, the more-body problems and also low thrust trajectory design in general are introduced. Different aspects of formation flying dynamics are also provided in this course. Starting with relative orbital dynamics and formation control problem, the tethered dynamics and control of formation flying spacecrafts are discussed.

Syllabus:

1. Time and Coordinate Systems

- Solar, Sidereal and Universal Time
- Julian Date
- ECI, True and Mean of Date Inertial reference frame
- ECEF, WGS84 Coordinate System
- Transformation Between Coordinate Systems
- Universal formulations

2. Three-Dimensional Interplanetary Trajectory

- Launch Window
- Multiple Planetary Flybys
- Aero-Gravity Assist
- Optimal Trajectory and Optimal Transport

3. Orbital representations (Elements)

- Classical Orbital Elements
- Equinoctial Elements
- Delaunay Variable
- Poincare variables
- Polar-nodal variables

4. Orbital Perturbation

- Special
 - Cowell's Method

- Encke's Method
- Gravity Potential of Central Body
- Third Body Effect
- Atmospheric Drag
- Solar Radiation Pressure
- Small Forces
- Numerical Techniques
- General
 - Variation of Parameters
 - Lagrange Planetary Equations
 - Gaussian Formulation
 - Hamilton's Formulation
- Propagator
 - Kosai's Method
 - Brouwer's Method
 - Operational Techniques (SGP, SGP4, SDP4, ...)
 - Semi-Analytical Solutions

5. Orbit Design

- Single
 - Special orbits
 - Coverage, Ground station visibility
 - Orbit maintenance aspects
- Constellation

6. Three body problem

- Equations of Motion
 - Circular 3BP

- Elliptic 3PB
- Phase Space Structure
- Periodic and Quasi Periodic and Associated Un/Stable Manifolds
- Transfer Trajectory (TPBVP)
- Station Keeping
- Coupled 3BP
- Flyby
- 7. Formation flying
 - Two-body problem
 - Relative Motion (Cartesian Coordinate, Orbital Elements)
 - Linearized Relative Orbit Motion
- Relative Orbit Control Methods
- Tethered Satellites
- Three-body problem
 - Natural Formation
 - Non-Natural Formation
 - Formation Keeping
 - Continuous, Discrete, Optimal
- 8. More-Body Problems
 - 4BP
 - 5BP
- 9. Low Thrust Trajectory
 - Formulations (2BP/3BP)
 - Optimization

Course Outcome:

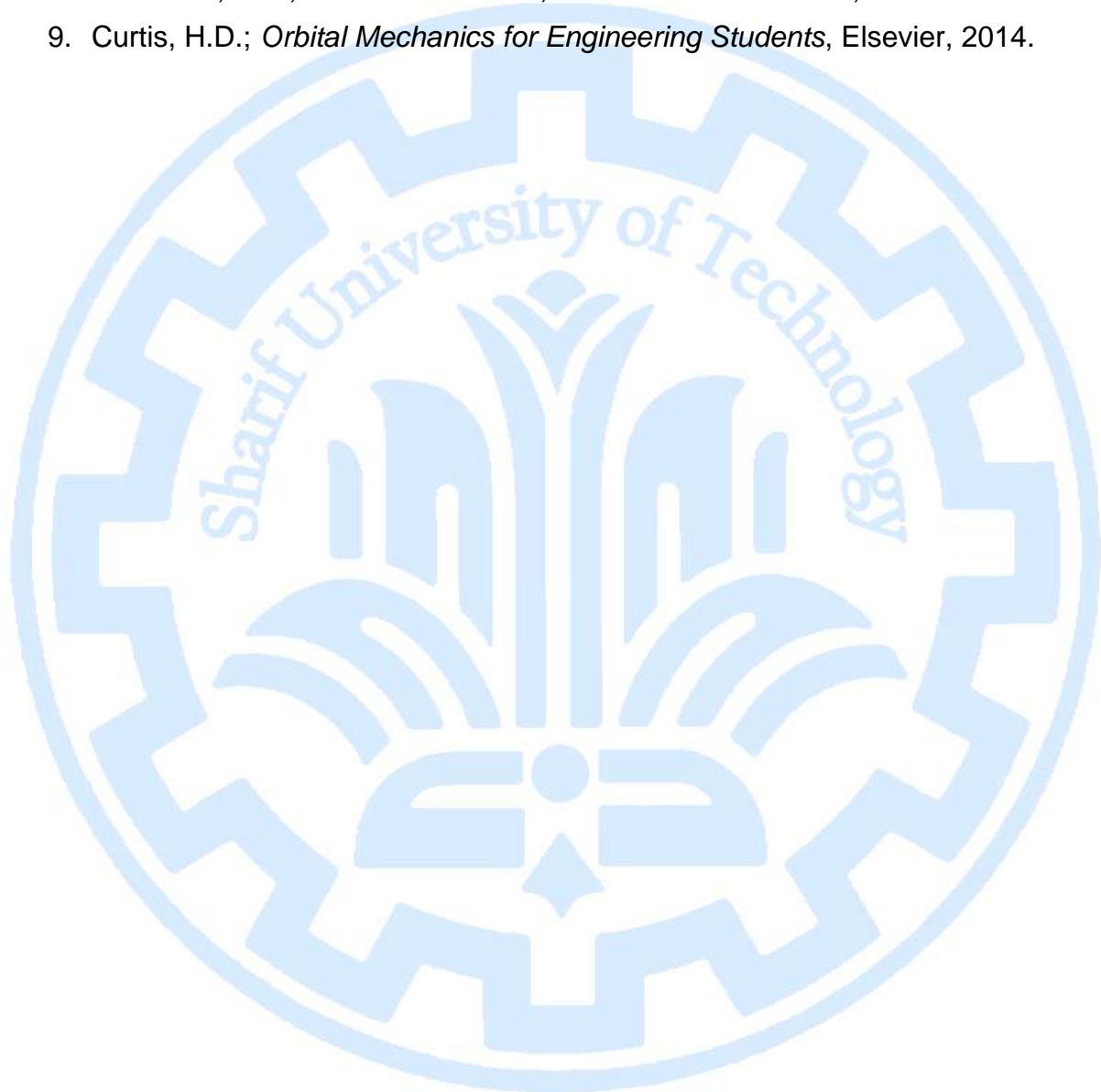
This course can develop the students' understanding of the following areas in orbital dynamics:

1. Three-dimensional interplanetary trajectories
2. Orbital perturbations and propagation methods
3. Restricted three-body problem
4. Orbit and constellation design
5. Satellite formation and relative motion of two spacecraft in proximity
6. Space trajectories optimization

References:

1. Vallado, D.A.; *Fundamentals of Astrodynamics and Applications*, Space Technology Library, 2013.
2. Battin, R.H.; *An Introduction to the Mathematics and Methods of Astronautics*, AIAA Education Series, 1987.
3. Wertz, J.R.; *Mission geometry orbit and constellation design and management*, Space Technology Library, 2001.

4. Szebehely, V.G; *Theory of Orbits: The Restricted Problem of Three Bodies*, Academic Press, 1967.
5. Capderou, M.; *Satellites, Orbits and Missions*, Springer-Verlag, 2005.
6. Xu, G., *Orbits*, Springer-Verlag, 2013.
7. Alfriend, K.T., et. Al.; *Spacecraft Formation Flying Dynamics, Control and Navigation*, Elsevier Astrodynamics Series, 2010.
8. Chobotov, V.A.; *Orbital Mechanics*, AIAA Education Series, 1996.
9. Curtis, H.D.; *Orbital Mechanics for Engineering Students*, Elsevier, 2014.



Application of Remote Sensing, 45777

Course Objectives:

This course intends to give students an overview of remote sensing concepts, the ways in which remote sensing systems are used to acquire data, how these data may be analyzed digitally and how the information is used in studies of the natural and human environments. At the end of the course, students should have a good knowledge of the different types of remote sensing imagery that are available and the digital processing and analysis procedures that are used for different applications. Students should also be capable of undertaking basic computer-assisted image analysis, use of aerial image for construction of Map, Interpretation of satellite images and other topics.

Syllabus:

1. Introduction to Remote Sensing

- The Basic Concepts of Remote Sensing
- Airborne and Space Borne Sensors
- Passive and Active Remote Sensing
- Applications of Remote Sensing
- A Brief History of Remote Sensing
- Energy Interactions in the Atmosphere
- Energy Interactions with Earth Surface and Features
- Spectral Reflection Curves

2. Basic Principles of Electromagnetic Radiation

- Electromagnetic Waves Spectrum
- Energy Sources and Electromagnetic Radiation

3. Remote Sensing Platforms

- Classification of Remote Sensing from the Perspective of Distance
- Principles of Satellite Motion
- Type of Orbits
- Ground Track
- Resolution Types
- Remote Sensing Satellites

4. Remote Sensing Sensors

- Classification of Remote Sensors

- Spatial, Spectral, Radiometric, and Temporal Resolutions
 - Quality of Image in Optical Systems
 - Photographic and Television Cameras
 - Hyper-Spectral Imager
 - Microwave Sensors Antenna
 - Satellite-born Microwave Radiometers
 - Altimeters
 - Side-Looking Airborne Radar (SLAR)
 - Synthetic Aperture Radar
5. Photogrammetry in Visible band
- An Introduction to Photogrammetry
 - Geometric Transformations
 - Photogrammetric Measurements
 - The Geometry of Image
 - Error Corrections
- Analytical Spatial Positioning
 - Stereoscopy
 - Multiple Photo Orientation
 - Camera Calibration
6. Satellite Image Interpretation
- Multispectral Scanners
 - Thermal Scanners
 - Features of the Remote Sensing Satellites
 - Geometric Corrections
 - Ground Control Points and Co-Registration
 - Atmospheric Corrections
 - Concepts of Color
 - Contrast Stretching
 - Filtering and Edge Enhancement
 - Image Classification
 - Image Transformations
 - Image Processing Software
 - Contrast Stretching
 - Histogram
 - Thresholding

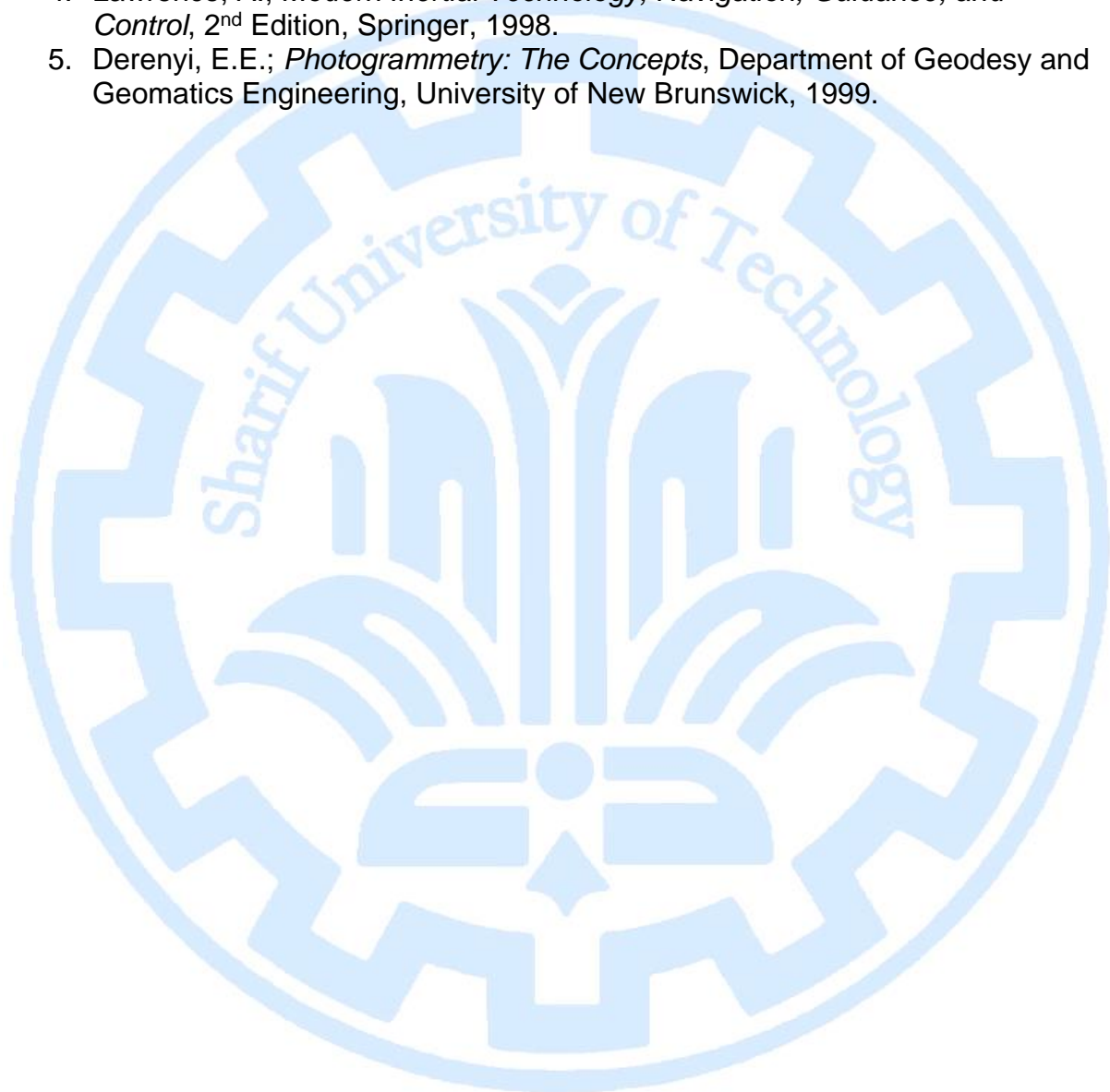
Course Outcome:

Students who successfully complete the course will demonstrate the following outcomes:

1. Become conversant in the terminology of remote sensing
2. Fundamental understanding of different remote sensors
3. Become familiar with aerial and satellite image interpretation
4. Become familiar with photogrammetry and its applications

References:

1. Joseph, G.; *Fundamentals of Remote sensing*, Second Edition, University Press, 2005.
2. Lillesand, T.M., Kiffer, R.W., and Chipman, J.; *Remote Sensing and Image Interpretation*, 5th Edition, John Wiley and Sons, 2003.
3. Richards, J.A. and Xiuping, J.; *Remote Sensing Digital Image Analysis*, 3rd Edition, Springer, 1999.
4. Lawrence, A.; *Modern Inertial Technology, Navigation, Guidance, and Control*, 2nd Edition, Springer, 1998.
5. Derenyi, E.E.; *Photogrammetry: The Concepts*, Department of Geodesy and Geomatics Engineering, University of New Brunswick, 1999.



Attitude and Orbit Determination, 45783

Prerequisite: Dynamics, 45113; Orbital Mechanics, 45407

Course Objectives:

This course provides an overview of various attitude and orbital determination methods and algorithms for spacecrafts. The course starts with a short review of attitude parameterization methods, attitude kinematics, attitude dynamics, and orbital dynamics. It continues with the introduction of some sensors used in attitude determination such as rate gyros, earth sensor, horizon sensor, sun sensor, magnetometers, star trackers etc. Also, additional sensors used for orbit determination such as GPS, Radars and Ground tracker will be discussed.

Subsequently, deterministic attitude determination methods such as TRIAD, QUEST, Markley's SVD and Mortari's ESOQ and ESOQ2 will be discussed. Also, some classical approaches for deterministic orbit determination, like the Gauss and Laplace methods will be presented. Probability and Stochastic Processes will be shortly reviewed in order to create a foundation for state estimation. Kalman filtering theory will be reviewed, as well as the extension of this theory to nonlinear dynamic systems – the Extended Kalman Filter (EKF). This theoretical foundation will be used to develop an Extended Kalman Filter for attitude and orbit determination.

Chapter four provides more details about star sensors, camera modeling, star catalogue, centroiding algorithm and star identification methods. In continue, attitude estimation by integration of attitude sensors and rate gyros for continues attitude determination will be presented. In next chapter, methods of orbit estimation by using of ground stations for spacecraft tracking will be discussed. Finally, more advanced topics for augmented attitude and orbit estimation method by using of magnetometers, starlight and GPS will be discussed.

Syllabus:

1. Introduction
 - Introduction to Space Navigation and Its History
 - Attitude Representation, Euler Angles, Quaternion's, Rotation Vector
 - Attitude Dynamics, Numerical Integration
 - Classical Orbital Parameters, Orbit Mechanics, Analytical Solutions
 - Introduction to Solar System
 - Standard Coordinate Systems and Time

- Navigation System Requirements for Different Applications
2. Spacecraft Sensors
- Rate Gyros and Accelerometers
 - Earth Sensor and Horizon Sensor
 - Sun Sensor
 - Star Sensor
 - Magnetometers and Flux Gates
 - Ground Sites and Onboard Radio Systems
 - GPS
3. Introduction to Estimation
- Linear and Nonlinear Least Squares, Recursive Least Squares
 - Batch Output Error Method
 - Attitude Estimation from Vector Observation (TRIAD, QUEST, SVD, ESOQ)
 - Orbit Estimation (Gauss and Laplace Methods, Nonlinear Least Squares)
 - Review of Random Variables and Kalman Filter
4. Attitude Estimation
- Star Modeling and Star Catalogue
 - Camera Modeling and Star Image Centroiding
 - Star Identification Method (Angle, Triangle)
 - Lost in Space Mode and Search Less Methods
 - Attitude Estimation Using Star Sensor
- Attitude Estimation Using Magnetometers and Earth Sensors and Sun Sensors
 - Continues Attitude Estimation by Using Rate Gyros and Other Sensors
5. Orbit Estimation
- GPS Observations
 - Position and Velocity Estimation by Using GPS Observations
 - Spacecraft Tracking by Using of Range, Range Rate and LOS Observations
 - Spacecraft Tracking by Bearing Only Measurements and Observability Analyses
 - Spacecraft Tracking by Range Measurements and Observability Analyses
 - Onboard Orbit Estimation
 - Position Estimation Using Near Earth Planets
 - Continues Position and Velocity Estimation Using Kalman Filter
6. Joint Attitude and Position Estimation
- Attitude and Position Observability Analysis from Vector Measurements
 - Attitude and Position Estimation from Magnetometers Measurements
 - GPS Ambiguity Resolution

- Attitude and Position Estimation by Using Three GPS Observations
- Starlight Method for Interplanetary Missions
- Relative Spacecraft Attitude and Position Estimation

Course Outcome:

In this course, students will be familiarized with various attitude and orbit representation parameters, and will be able to realize the advantages and disadvantages of these parameters. In addition, the students will be accustomed to different sensors and roll of each sensor in attitude and orbit determination. The students who successfully pass the course will be able to implement and test different algorithms for attitude and orbit estimation and can develop their studies and abilities in this field.

References:

1. Crassidis, J.L. and Junkins, J.L.; *Optimal Estimation of Dynamic Systems*, CHAPMAN & HALL/CRC, 2005.
2. Wertz, J.R.; *Spacecraft Attitude Determination and Control*, Kluwer Academic Publishers, 1995.
3. Guochang, X.; *Orbits*, Springer, 2008.
4. Tapley, B.D., Schutz, B.E. and Born, G.H.; *Statistical Orbit Determination*, Elsevier Academic Press, 2004.
5. Picasane, V.L.; *Fundamentals of Space Systems*, Oxford University Press, 2005.
6. Curtis, H.D.; *Orbital Mechanics for Engineering Students*, Elsevier Butterworth Heinemann, 2005.

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 of 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
- Wargaming

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.

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
 - Fuzzy Inference Engine
4. Design of Fuzzy Systems Using Input-Output Data
 - Fuzzifier
 - Defuzzifier
 - Mathematical Representations of Fuzzy Systems
 - The Approximation Properties of Fuzzy Systems
5. Design of Fuzzy Controllers
 - Look-up Table Scheme
 - Gradient Descent Training
 - Batch Algorithm
 - Clustering
6. 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

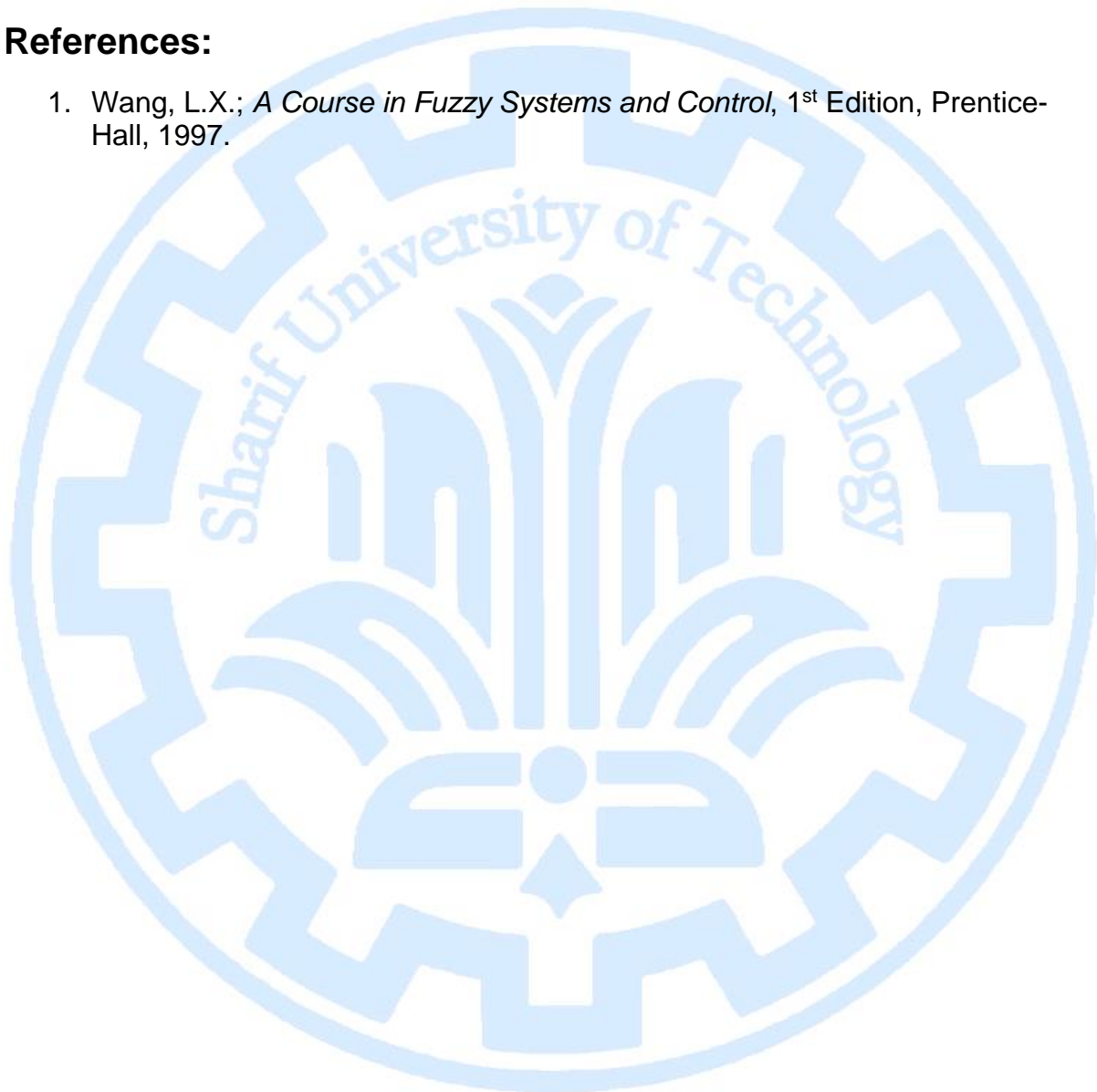
Course Outcome:

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
 - Command to Line-of-Sight Guidance
 - CLOS Guidance with Lead Angle
4. Two-point Guidance Laws
 - 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
- Combined Lead and LOS Guidance Laws
- Implementation of 3D CLOS

- 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
 - 8. Inertial Sensors
 - Gyroscope principles
 - Single-axis Rate Gyroscope
 - Accelerometers
 - Force balanced sensors
 - 9. Tests and Calibration of Inertial Navigation Systems
 - Test Equipment
 - Calibration of Accelerometers
 - Calibration of Rate Gyros
 - Hardware-in-the-loop Simulation
 - 10. Initial Alignment
 - Coarse Alignment
 - Fine Alignment
- Two-dimensional Navigation
 - Coordinate Systems
 - 3D Strapdown Navigation System
 - Strapdown System Mechanizations
 - Attitude Representation
 - Navigation Equations in Component Form
 - Effects of Elliptic Earth

Course Outcome:

Upon completion of this course, the students will be able to analyze and architect 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.

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

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.

Launch Vehicle System Design, 45781

Course Objectives:

This course is generally designed to learn general system design process of launch vehicle (LV). In the beginning, some introduction and definitions are presented and system design of LV is discussed afterward. Engine design is noticed for both liquid and solid propellants. Subsequently, structural and aerodynamic design is presented as well as guidance, navigation and control systems. The final course topics focus on some complementary topics such as separation, ground station, etc.

Syllabus:

1. Introduction

- Terms and Definitions
- Aeronautics Historical Review
- Orbits
- Orbital Mechanics
- Orbital Elements
- Coordinate Systems

2. LV System Design

- Introduction to LVs
- Classification of LVs
- LVs Staging, Number of Stages
- Mass and Thrust Budgeting
- Introduction to Conventional LV's Subsystems
- LV Subsystems Relation
- LV Performance Indexes
- Design Phases
- System Design Process

3. LV Flight Trajectory

- Equations of Motion
- Flight Trajectory
- Types of Losses
- LV Path Planning
- Satellite Injection to Orbit

4. LV Propulsion System

- General Design
- Liquid Propellant Engine Elements
- Liquid Propellant Engine Design Procedure
- Liquid Propellants
- Feeding System Design
- Tanks and Pressure Vessels
- Turbo-pump Design
- Combustion Chamber Design
- Combustion Instability

- Solid Propellant Engine Elements
 - Solid Propellant Engine Design Procedure
 - Solid Propellants
 - Grain Design
 - Ignition System Design
 - Nozzle Design
 - Burning Rate and Temperature Relation
 - Erosive Burning
5. Control Mechanism Design
- Jet Vane Thrust Vector Control
 - Variable Nozzle
 - Gimballed Nozzle
6. Structural Design
- Structural Elements
 - Structural Loads
 - Types of Structures
 - Structural Design Procedure
 - Structural Materials
 - Composite Structures
 - Engine Structure Design
 - Component's Structure Design (Stabilizers, Control Fins, etc)
 - Adaptor Design
 - Aero-elasticity Considerations
7. Aerodynamic Design
- Aerodynamic Design Procedure
 - Aerodynamic Design Criterion
 - Configuration Design
 - Control Fin and Stabilizer Design
8. Guidance, Navigation and Control
- LV Guidance Methods
 - Guidance Laws
 - Trajectory Shaping
 - Navigation Systems and Methods
 - Sensors
 - INS Types
 - Autopilot Design Procedure
 - Actuators and Servomechanisms
 - Controller Design in Different flight Phases
9. Separation Mechanisms and Retrorockets
10. Miscellaneous Topics
- Flight Computer
 - Ground Station
 - Launch Station

Course Outcome:

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

1. Overall view on LV subsystems and system design procedures
2. Design process of engine as an important section of LV
3. LV Structure and aerodynamic design
4. LV Guidance, Navigation and Control design

References:

1. Cornelisse, J.W.; *Rocket Propulsion and Spaceflight Dynamics*, Pitman Publishing, 1979.
2. Curtis, H.D.; *Orbital Mechanics for Engineering Students*, Elsevier Aerospace Engineering Series, 2010.
3. Sutton, G.P.; *Rocket Propulsion Elements*, 3rd Edition, John Wiley & Sons, 1963.
4. Huang, D.H. and Huzel, D.K.; *Design of Liquid Propellant Rocket Engines*, United States: NASA, Nasa-sp-125, 2nd Edition, 1971.
5. Blakelock, J.H.; *Automatic Control of Aircraft and Missiles*, 2nd Edition, John Wiley & Sons, 1991.
6. Linshu, H.E.; *Ballistic missiles and Launch Vehicles Design*, China Press, 2002.
7. Karimi Mazrae Shahi, H. and Hashemi Doulabi, S.M.; *Missile Design (Ballistic and Launch Vehicle)*, Jahad Daneshgahi Publication, Tehran Center, 2006.
8. Eskandari Jam, J. and Rahimi Damirchi, F, *Introduction to: Launch Vehicle Design Principles*, Malek-Ashtar University Publication, 2006.

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
 - Perturbation 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.



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
 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
- 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)

- 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
 - Rolling Motion Velocity Half-Life
- Retardation Motion with Rolling
 - Rolling Stability Derivatives Determination Using Rolling Motion Data
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

Course Outcome:

The outcomings 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.



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
 - Cancellations, 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. Maciejoski, 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 Ricatti 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
3. Dynamic Programming (DP)
 - Selection and Weighting Functions
 - 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:

1. Modeling and formulation of OC problems for all dynamic systems
2. CV and its utility in constrained optimization of cost functions
3. Optimal controller design using the DP and CV approaches
4. Ability to solve LQR and LQT as typical widespread OC problems
5. 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

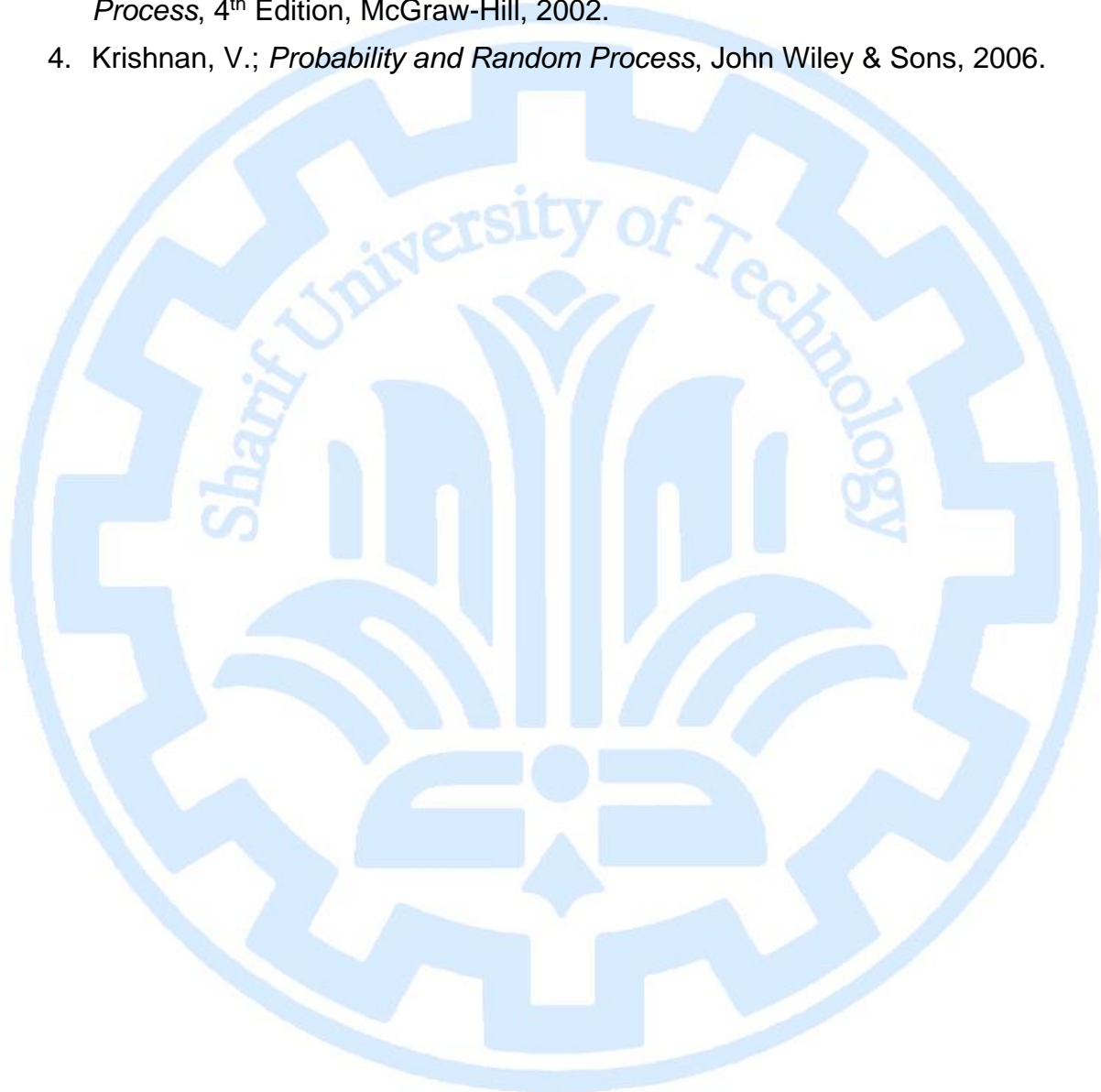
Course Outcome:

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.



Satellite System Design, 45782

Prerequisite: Orbital Mechanics, 45407

Course Objectives:

This course has been designed to give an introduction to the design of the space missions and satellites. The course starts with introduction of satellite systems and missions and the space mission analysis and design process. After the review of the orbit design as a major task in mission design, the course continues with general satellite system design. After the configuration is fixed, the subsystem design processes is presented. This includes the Attitude Determination and Control, Orbit Determination and Control, Thermal Control, Electric Power, Propulsion, Structures and Mechanisms, Communication, and Command and Data Handling Subsystems. Then, the selection of launch system as a part of space mission design is presented. Finally, by introducing some of the major items in manufacturing and test and their effect in design process, the students would learn the fundamentals of the space mission and satellite system design.

Syllabus:

1. Introduction and Overview
 - Introduction to Satellite System and Subsystems
 - Satellite Categories
 - Satellite System Engineering
 - Space Mission Phases
 - Identifying Alternative Mission Concepts and Architectures
 - Identifying System Drivers and Critical Requirements
 - Characterizing the Mission Architecture
 - Mission Evaluation
 - Requirements Definition
2. Space Mission Analysis and Design
 - Space Mission Life Cycle
 - Mission Objectives
 - Preliminary Estimate of Mission Needs, Requirements, and Constraints
 - Mission Characterization
3. Orbit and Constellation Design
 - Orbit Selection and Design Process
 - Orbital Perturbations
 - Orbit Lifetime
 - Earth Coverage
 - Earth Eclipse

- Orbital Maneuvers and ΔV Budget
 - Orbit Selection
 - Constellation Design Considerations
 - Space Environment and Survivability
4. Spacecraft Design and Sizing
- Requirements, Constraints, Design Process
 - Spacecraft Configuration
 - Design Budgets (Mass/Power/...)
 - Spacecraft Bus Sizing and Initial Estimations
 - Integrating the Spacecraft Design
 - Spacecraft Lifetime and Reliability
5. Attitude Determination and Control Subsystem
- Introduction to Attitude Control Approaches, Actuators, and Sensors
 - Control Modes and Requirements
 - Disturbance Moments and the Required Control Moment
 - Select and Size ADCS Components
 - Control Algorithms
6. Orbit Determination and Control
- Introduction to Guidance, Navigation, and Control Subsystem
 - Orbit Determination and Control Requirements
 - Orbit Maintenance
 - Autonomous Orbit Determination and Control Subsystem Sizing
7. Thermal Control Subsystem
- Thermal Requirements
 - Introduction to Thermal Equilibrium and Temperature
 - Spacecraft Thermal Environment
 - Thermal Control Components
 - Thermal Control System Design Process
 - Thermal Control Challenges
 - Mass and Power Estimates
8. Electric Power Subsystem
- Power Subsystem Functions
 - Preliminary Power Subsystem Design Process
 - Power Sources
 - Energy Storage
 - Power Distribution
 - Power Regulation and Control
9. Space Propulsion Subsystem
- Propulsion Subsystem Selection and Sizing
 - Basics of Rocket Propulsion

- Types of Rocket Propulsions
 - Component Selection and Sizing
10. Structures and Mechanisms Subsystem
- Design Process for Structures and Mechanisms
 - Structural Design Philosophy and Criteria
 - Structural Requirements
 - Design Options
 - Material Selection
 - Preliminary Sizing of Structural Members
 - Structural Mechanics and Analysis
 - Mechanisms and Deployables
11. Communication Subsystem (Telemetry, Tracking, and Command)
- TT&C Subsystem Tasks
 - TT&C Subsystem Requirements
 - Design Process for the TT&C Subsystem
 - Selection Criteria for the TT&C Subsystem
12. Command and Data Handling (Computer) Subsystem
- C&DH Components
 - C&DH Requirements
 - C&DH System Sizing Process
13. Launch System
- Steps in Selecting a Launch System
 - Launch Vehicle Considerations
 - Launch System Selection Process
 - Typical Launch Systems and Launch Sites
 - Launch Vehicle Ascent Environments and Payload Fairing Constraints
14. Spacecraft Manufacturing and Test
- Engineering Data
 - Manufacturing, Procurement, and Scheduling
 - Manufacture of High-Reliability Hardware
 - Influencing the Design
 - Challenges for Manufacturing, Material, Test, and Launch Processing
 - Design for Reliability
 - Inspection and Quality Assurance
 - Qualification Program and Test Flow

Course Outcome:

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

1. Space mission analysis and design process
2. Orbit design
3. Satellite system design
4. Satellite subsystems design
5. Launch system selection
6. Fundamental of manufacturing and test of satellite systems

References:

1. Larson, W.J. and Wertz, J.R.; *Space Mission Analysis and Design*, 3rd Edition, Microcosm Inc., 1999.
2. Fortescue, P., Stark, J. and Swinerd, G.; *Spacecraft Systems Engineering*, 3rd Edition, John Wiley & Sons Ltd., 2003.
3. Brown, C.D.; *Elements of Spacecraft Design*, AIAA Education Series, 2002.
4. Griffin, M.D. and French J.R.; *Space Vehicle Design*, 2nd Edition, AIAA Education Series, 2004.
5. Wertz, J.R.; *Spacecraft Attitude Determination and Control*, Microcosm Inc., 1978.

Space Propulsion, 45779

Prerequisite: Propulsion Principles, 45117

Course Objectives:

This course has been designed to:

1. Introduce the physical background and engineering of electric propulsion technologies.
2. Introduce the fundamentals, design, and performance characteristics of electric propulsion technologies.
3. Perform preliminary design of different electric thrusters driven by space propulsion requirements.

Syllabus:

1. Introduction

- Electric Propulsion Background
- Electric Thruster Types
- Ion Thruster Geometry
- Hall Thruster Geometry
- Beam/Plume Characteristics

2. Thruster Principles

- The Rocket Equation
- Force Transfer in Ion and Hall Thrusters
- Thrust
- Specific Impulse
- Thruster Efficiency
- Power Dissipation
- Neutral Densities and Ingestion in Electric Thrusters

3. Basic Plasma Physics

- Introduction
- Maxwell's Equations
- Single Particle Motions
- Particle Energies and Velocities
- Plasma as a Fluid
- Diffusion in Partially Ionized Gases
- Sheaths at the Boundaries of Plasmas

4. Ion Thruster Plasma Generators

- Introduction
- Idealized Ion Thruster Plasma Generator
- DC Discharge Ion Thruster
- Kaufman Ion Thrusters
- Ion Thrusters
- Microwave Ion Thrusters

- 2-D Computer Models of the Ion Thruster Discharge Chamber
 - Hall Thruster Performance Models
 - Channel Physics and Numerical Modeling
 - Hall Thruster Life
5. Hall Thrusters
- Introduction
 - Thruster Operating Principles and Scaling

Course Outcome:

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

1. space propulsion requirements and maneuvers
2. plasma physics with emphasis in technologies as ion engines and Hall thrusters

References:

1. Goebel, D.M. and Katz, Ira; *Fundamentals of Electric Propulsion: Ion and Hall Thrusters*, JPL Space science and Technology Series, NASA, 2008.
2. Turner, M.J.; *Rocket and Spacecraft Propulsion: Principles, Practice and New Developments*, Springer, 2009.
3. Wertz, J.R. and Larson, W.J.; *Space Mission Analysis and Design*, Springer Publishing Co., 1999.
4. Jahn, R.G.; *Physics of Electric Propulsion*, Dover Publications, 2006.

Space Structures Materials, 45932

Course Objectives:

By increasing number of space flights a new research area has been opened for the researchers. Lack of gravity in the space, make space a favorite place for researchers in different areas to do their own researches. Environmental change and meteorology as well as earth can be effectively and economically studied from space. Nowadays, increasing in applications of satellites made them part of our life in a way that living without them seems impossible. On the other hand, increasing space flights and their large costs, forces us to employ new technologies in order to keep space flights economical, reasonable and durable.

Since satellite environment is highly different from airplane environment, it dictates applying different science in design, produce and analysis of structures. Satellite structure should withstand against launch loads (acceleration, Acoustic and thermal loads) and resist all random loads, which could occur during required performance maneuvers in earth orbit. In addition, satellite structure should be designed such a way that it has a suitable frame to locate for different subsystems (like thermal control subsystems, optician components, electronic components mechanism, etc.). Appropriate satellite structure design, would develop a clean environment in assembly process of all subsystems. Since satellite weight is an important parameter related to space flight's cost, decreasing weight based on safety factors is an important part in structure design of satellites.

Syllabus:

1. Introduction

- Satellite
- Platform
- Payload
- Satellite-launcher Synchronizer

2. Satellite Subsystems

- Introduction
- Location of Subsystems and Their Objective

3. Space Mission Life Cycle

- Introduction to Design phases: Preliminary Design to Utilization

4. Structure and Mechanism Design Flow

- Structure and Mechanism Design Flowchart

- Satellite Mission (Statement, Requirements and Mission Analysis)
 - Systemic Specifications
 - Subsystem Specifications
 - Preliminary Design Structure Architecture
 - Preliminary Design Loads
 - Structure and Satellite Preliminary FEM Model
 - Structure Elements and Brackets Safety Margin Derivation
 - Subsystems' interfaces Control
 - Tools, Devices and Materials Technical and Performance Specification
 - Tools, Devices and Materials Purchasing Specification
 - Preliminary Design Review Report
 - Updating Systemic Specifications
 - Updating Structure Architecture
 - Structure and Satellite Detailed Geometrical Model
 - Structure and Satellite Precise Preliminary FEM Model
 - Ultimate Loads of Critical Design
 - Segments Safety Margin Derivation
 - Critical Design Review Report
 - Systemic Specifications Finalization
 - Developing Manufacturing Plans and Integration
 - Developing Test Procedures
5. Structure Subsystem and Launcher Relation
- Structure Subsystem and Launcher Relation Document
 - Launch Container
 - Structure and Launcher Synchronizer Plan
 - Applied Loads from Launcher on Satellites
6. Structure and Satellite Configuration
- Sizing
 - Mass Specifications
 - Mass Estimation
 - Mass Growth
 - Mass Margin
7. Mass Specifying
- Maximum Satellite Launch Weight
 - Synchronizer Mass
 - Fuel and Pressurized Liquid Mass
 - Total Permitted Wet Mass
 - Subsystems Mass Budgeting
8. Moments of Inertia
- Coordinate System

- Satellite Subsystem Locating
9. Satellite Design and Analysis
- Satellite Geometrical Modeling
 - Applied Loads on Satellite
 - Modal Analysis
 - Quasi-static Acceleration Limit
 - Structure Static Analysis
 - Joint Analysis
 - Random Load Sources Identification
 - Random Vibration Analysis
 - Safety Factor
 - Structure's Safety Margin
10. Manufacturing Plans
- Parts and Plans Coding
 - Manufacturing Plans' Tolerances
 - Components Quality Control
11. Structure Material Selection
- Aluminum Alloys
 - Polymers
 - Sandwich Planes
 - Standard Joints
12. Satellite Mechanisms
- Solar Arrays, Antenna, Reflector and Boom Mechanism
 - Mechanisms Dynamic Analysis
13. Environmental Tests
- Mass Properties Test
 - Vibration Tests (Resonance Search Test; Sinusoidal, Random and Acoustic Vibration Test)
14. Selected Topics in Satellite Structure Design (Thermal Topics in Satellite, etc.)

Course Outcome:

Aerospace students in structure division, learn the basics and requirements of design and analysis of aerial structures in relevant courses. This course covers most of the topics about design and analysis of aerial structures. However, the main objective of this course is to teach requirements as well as design and analysis methods of satellites to graduate students.

References:

1. Wijker, J.; *Spacecraft Structures*, Springer, 2008.
2. Wijker, J.; *Random Vibrations in Spacecraft Structures Design, Theory and Applications*, Springer, 2009.
3. Fortescue, W., Stark, J. and Swinerd, G.; *Spacecraft systems engineering*, 3rd Edition, John Willy and Sons Ltd, 2003.

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
8. Attitude Determination
- Control using Reaction/Momentum Wheel
 - Control using Control Moment Gyro (CMG)
 - Control using Thruster and Pulse Modulation
 - Control using Magnetic Actuation
 - 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:

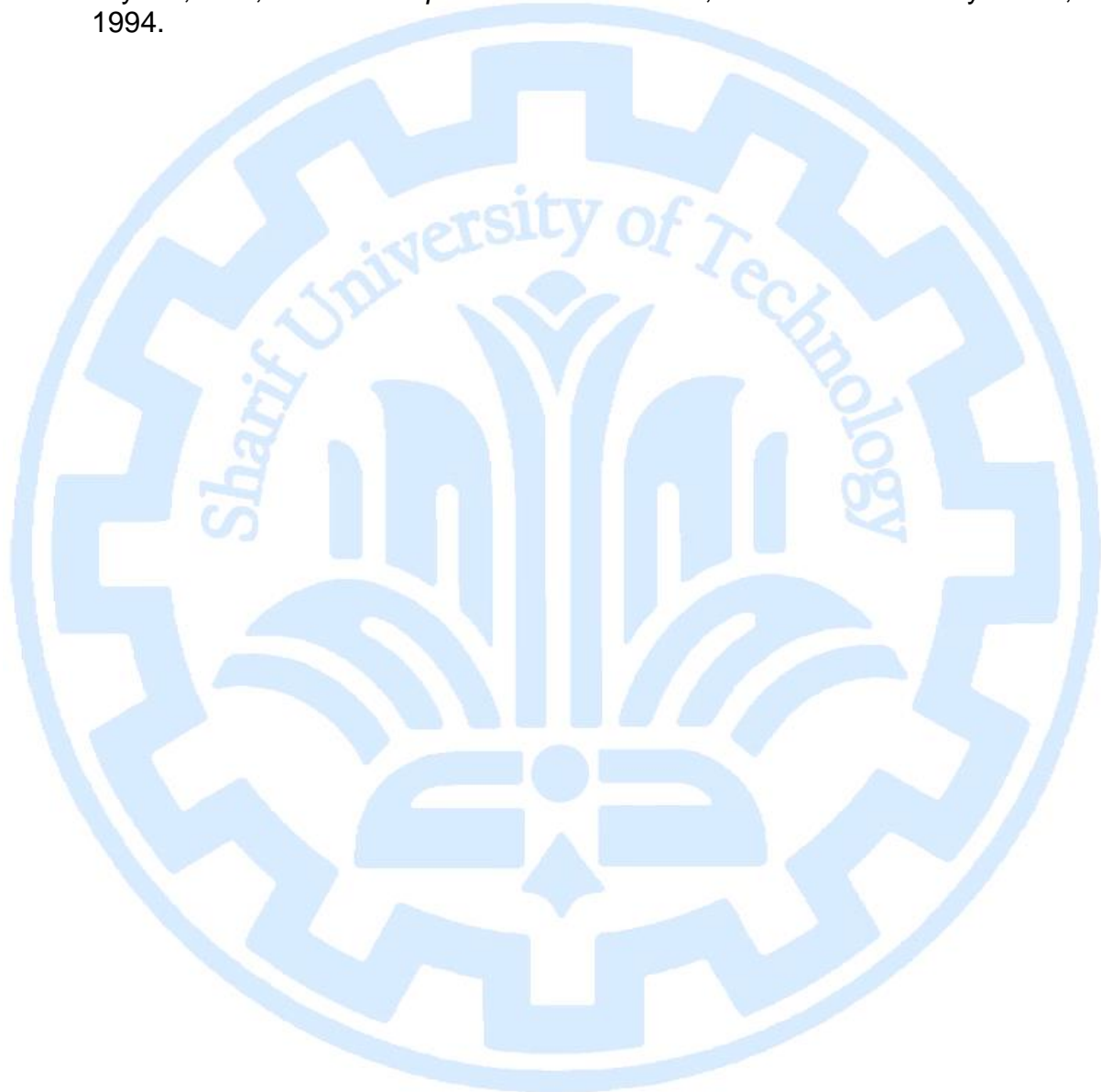
After studying this course, the student would be able to demonstrate an understanding of:

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.



Space Systems Engineering, 45785

Course Objectives:

This course is designed to familiarize students with engineering processes for designing the whole space systems. In this regards, it is necessary to introduce space environment including planets, orbits, electromagnetic fields, heat transfer and so on. Investigation about various space missions is an important section of this course. The course describes the basic mission objectives and examines the principles and practical methods for mission design and operations in depth. Considering the cooperation of many separate elements in constructing space missions, the harmonic operation of them is discussed in detail. The translation of needs from the users, designing system's architecture, defining the strategy and oversee the integration of elements to form the final result are presented in this course. Design, development and verification of the space systems as engineering processes are discussed in important parts of the course. Risk management and failure mode analysis of space systems are also introduced in detail. Quality assurance, test and evaluation and standards of space systems including reliability considerations, factory, field and flight tests, EcSS and Military standards construct other parts of this course.

This course is designed to provide:

1. A detailed introduction to space systems engineering
2. The ability for designing space missions and systems
3. The ability for verifying and validating the space missions and system designs
4. The conceptual framework for developing unmanned and crewed space missions
5. Analyzing the orbits and trajectories required to perform unmanned and crewed space missions
6. A disciplined approach for identifying opportunities to influence the design of a system from a reliability perspective
7. Insight to the risk management and decision making process

Syllabus:

1. Introduction to Space and Space Systems Engineering
 - Introduction to Space Environment
 - Introduction to Newton's and Kepler's Laws
 - Brief Introduction to Orbits and Orbital Mechanics
 - Perturbed Orbits
 - Brief Introduction to Two, Three and Many Body Problems
 2. Space Missions
 - Navigation
 - Reconnaissance
 - Remote Sensing
 - Communications
 - Search and Rescue
 - Space Exploration
 - Meteorology
 - Astronomy
 - Crewed Space Missions
 3. Space Systems
 - Launch Vehicles
 - Satellites
 - Manned Vehicles
 - Space Stations
 4. System Engineering in Space Systems
 - Space Mission Need Analysis
 - Space Mission Requirements
 - Space Mission Feasibility Study
 - Conceptual Space Mission Design, Operations Concept Development
 - Technology Development Projects
 - System Design and Development
 - Manufacturing and Integration
 - Project Management
 - Risk Management and Other Program Issues
 - Failure Modes and Effects Analysis (FMEA)
 - Failure Modes, Effects and Criticality Analysis (FMECA)
 - Fault Tree Analysis (FTA)
 - Fault Tolerant Design
5. Quality Assurance of Space Systems
 - Place and Importance of Reliability Engineering
 - Mathematical Fundamentals of Reliability
 - Reliability of Parts and Components
 - Reliability of Systems
 - Reliability of Maintainable Systems
 - Physical Models of Reliability
 - Reliability Experiments
 - Reliability Assessment
 - Reliability Simulation
 - Reliability Implementation
 6. Experiment Designing, Test and Evaluation of Space Systems
 - Design Phase Experiments

- Development Phase Experiments
 - Manufacturing Phase Experiments
 - Production Phase Experiments
 - Factory Acceptance Tests
 - Field Acceptance Tests
 - Flight Acceptance Tests
 - Environmental Tests
7. Space Operations
- Introduction to Space Launch Sites
8. Space Standards
- Launch Site Operations
 - Launching, Ascending, Entry, Descending and Landing
 - Space Maneuvers
 - European Cooperation for Space Standardization (Ecss Standards)
 - National Aeronautics and Space Administration (NASA Standards)
 - Military Standards

Course Outcome:

The out comings of this course are development in:

1. Enhanced understanding of the big picture for space missions and systems
2. Working technical knowledge of how all the elements of a space mission work and the key trades that lead to a successful mission
3. Enhanced introduction to system architecture and design
4. Practical experience with using data and systems engineering processes in the space technology series to develop conceptual designs for space missions and systems
5. Mission and systems design verification and validation
6. Establishing an framework for future space learning

References:

1. Wiley, J.L. and Wertz, J.; *Space Mission Analysis and Design*, 3rd Edition, Torrance, CA: Microcosm Press, 1999.
2. Wiley, J.L. and Kirkpatrick, D.H.; *Applied Space Systems Engineering*, 1st Edition, Learning Solutions, 2008.
3. Wiley, J.L. and Pranke, L.; *Human Space Flight: Mission Analysis and Design*, 1st Edition, McGraw-Hill Companies, 1999.
4. Eckart, P.; *The Lunar Base Handbook: An Introduction to Lunar Base Design, Development, and Operations*. Columbus, OH: McGraw-Hill Companies, 2006.
5. NASA System Engineering Handbook, December 2007.

6. Blanchard, B.; *System engineering and analysis*, 5th edition, Prentice Hall International Series in Industrial & Systems Engineering, 2010.
7. *System Engineering Fundamentals*, Defense Acquisition University, 2005.
8. Nikookar, M; *Applied Statistics and Probability*, Amir Kabir University Publication, 2004.
9. Bender, R.; *Launching and Operating Satellites*, Legal Issues, 1998.
10. 2005 IEEE Aerospace Conference Digest, Big Sky, Montana, 2005.



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

- 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

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

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, being 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
45115	AERODYNAMICS 1	Prerequisite: 45124 or 28461 and 45132 or 28414	B.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
45400	INDUSTRIAL TRAINING		B.Sc.	0
45401	COMPOSITE MATERIALS	Prerequisite: 45133 or 28262	B.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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 MANAGMENT		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
45421	STRENGTH OF MATERIALS 2	Prerequisite: 45133	B.Sc.	3
45422	PILOT TRAINING		B.Sc.	2
45424	VISCOUS FLOW	Prerequisite: 45124	B.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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	CONTINUUM 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
45536	RESEARCH METHODS		M.Sc.	3
45540	AEROSPACE TECH MNGMT		M.Sc.	3
45541	STRATEGIC MNGMT IN AEROSP		M.Sc.	3

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
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

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
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

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
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

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
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

Course Number	Course Name	Prerequisite & Corequisite	Level	Unit
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
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