University of Dhaka
Department of Applied Mathematics
MS in Applied Mathematics
Session: 2021- 2022

This department offers the program MS in Applied Mathematics which has duration of one academic year. In the program there is a provision for taking up thesis work, subject to the approval of the academic committee of the department.

Each student in Group A (non-thesis group) has to take seven courses (each of 4 credits), while each student in Group B (thesis group) has to take six courses, out of the courses offered by the academic committee of the department. Students of Group B are allowed to submit their dissertation within four months after the completion of their theory examination.

Group A (Non-Thesis Group)

Credit Requirements	**32 credits**
Theory Courses	28 credits
Viva Voce	4 credits

Group B (Thesis Group)

Credit Requirements	**34 credits**
Theory Courses	24 credits
Thesis	8 credits (6 credits for dissertation and 2 credits for presentation)
Viva Voce	2 credits

Evaluation: Incourse 30 marks (Attendance 5 + Incourse examination 25), Final Examination (Theory, 4 hours): 70 marks. **Eight** questions will be set, of which any **Five** are to be answered.

Course Titles

AMT 501	Theory of Relativity And Cosmology	4 credits
AMT 502	Geophysical Fluid Dynamics	4 credits
AMT 503	Mathematical Hydrology	4 credits
AMT 504	Applied Numerical Methods	4 credits
AMT 505	Magnetohydrodynamics	4 credits
AMT 506	Riemannian Geometry	4 credits
AMT 507	Stochastic Modeling in Finance	4 credits
AMT 508	Aerodynamics	4 credits
AMT 509	Computational Fluid Dynamics	4 credits
AMT 510	Dynamical Meteorology	4 credits
AMT 511	Applied Dynamical Systems	4 credits
AMT 512	Biofluid Dynamics	4 credits
AMT 513	Mechanics of Flight	4 credits
AMT 514	Environmental Fluid Mechanics	4 credits
AMT 515	Financial Time Series Analysis and Forecasting	4 Credits

Detailed Syllabi

AMT 501: Theory of Relativity and Cosmology **4 credits**

Introduction and Specific Objectives

It is an excellent introductory combined course on theory of relativity and cosmology. This is a module principally on Einstein's general theory of relativity, a relativistic theory of gravitation which explains gravitational effects as coming from the curvature of space-time. It provides a comprehensive introduction to material which is currently the subject of enthusiastic study from the theoretical and experimental standpoints. In addition, in order to understand the general theory fully, some familiarity with tensor calculus is required. This will involve some self-study material at the start of the module. The rest of the course will be devoted to a detailed investigation of the theory itself together with applications to classical black holes and cosmology.

The objective of this course is to introduce the concept of space-time, the theory of special relativity and some preliminary ideas from general relativity, cosmology and the mathematical model of the expanding universe. The aim of studying cosmology is to construct mathematical models of the universe.

Learning Outcomes

Having successfully completed the course students will be able to:

- understand the physical principles which guided Einstein theory of relativity
- solve Einstein's equations in a variety of simple situations
- investigate the geodesic structure of the most important solutions of the theory
- understand the key properties of black holes
- understand the new world view of 4 dimensional Lorentzian space-time that replaced the Newtonian view of space and universal time
- understand that gravitational phenomena are manifestations of the geometry of space-time
- understand how geometry is encoded in a metric tensor, understand how Newtonian gravitation can be recovered in a limit from General Relativity
- understand how a black hole is described by the Schwarzschild metric
- understand how the whole universe can be modeled approximately by the Friedman metric
- derive the basic results in cosmology
- manipulate tensors in a competent manner

Course Contents

1. Inertial frame, Galilean transformations, Michelson-Morley experiment, Absolute motion and historical survey.
2. Lorentz transformations, postulates of the special theory of relativity, Lorentz transformation equation, Consequences of Lorentz transformations, relativistic formulae for velocity and acceleration.
3. Minkowski’s space and its properties.
4. Relativistic mechanics: Mass and momentum, Newton’s laws of motion, equivalence of mass and energy, transformation formulae for momentum, energy, force and density.
5. Relativistic optics, relativistic electrodynamics and relativistic fluid mechanics.
6. Principle of covariance and principle of equivalence.
7. Relativistic field equations: Energy-momentum tensor, Principle of Mach and Einstein’s law of gravitation, Schwrzschild’s solution of Einstein’s equation, Newton’s law as first approximation.
8. The three crucial tests of the general theory of relativity.
9. Cosmology: Cosmology models: (a) Robertson-Walker model (b) Friedmann Model (c) Einstein’s model (d) de Sitter model.
10. Introduction to unified field theory, String cosmology.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Goyal J.K., Gupta K.P. Theory of Relativity.
2. Steven Weinberg, Gravitation and Cosmology Principles and applications of the General Theory of Relativity.
3. Rashid H., Islam N., Theory of Relativity.

AMT 502: Geophysical Fluid Dynamics **4 credits**

Introduction and Specific Objectives

The spinning of the Earth, and the variation of radiation with latitude, create a playground for a number of waves and instabilities, driving both the weather over our heads and the undulations of the oceans. This course introduces approximations to the Navier-Stokes equations of fluid flow appropriate to geophysical scale flows. Two key themes that will recur throughout the class are rotation and stratification.

Learning Outcomes

At the end of the course the students will be able to

- investigate the fluid dynamics of the different kinds of flow and deformation processes in the Earth and terrestrial planets using numerical models.
- understand the equations that govern the flow of the atmosphere and oceans.
- solve important, challenging and multidisciplinary set of problems like: Earth system modeling, predictive understanding of climate variability (emerging new science!), forecast of various natural phenomena, natural hazards, environmental protection, natural resources, etc.

Course Contents

1. Fluid dynamics fundamentals, the Eulerian and Lagrangian perspectives.
2. Introduction to stratification, The equation of state, entropy, stratification, sound, buoyancy frequency.
3. Inertia gravity waves, introduction to rotation, and working on the sphere.
4. Geophysical Fluid Dynamics: the key approximations, the Shallow Water Equations.
5. Energy Conservation &Wave Basics, Rossby Waves
6. Geostrophic Adjustment and Balance the Quasi-Geostrophic Equations
7. Barotropic Instabilities, Stirring and Jets, The two layer equations , Continuous stratification
8. Baroclinic Instability, Turbulence.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Geoffrey K. Vallis, 2006, Atmospheric and Oceanic Fluid Dynamics: Fundamentals and Large-Scale Circulation, Cambridge University Press.
2. Cushmin-Roisin, Benoit, 1994, Introduction to Geophysical Fluid Dynamics, Prentice Hall.
3. Gill, Adrian, 1982, Atmosphere-Ocean Dynamics, Academic Press.
4. Pedlosky, Joseph, 1987, Geophysical Fluid Dynamics (Second Edition), Springer-Verlag.

AMT 503: Mathematical Hydrology **4 credits**

Introduction and Specific Objectives

Hydrology treats the flow of water on and below the surface of the Earth. It involves mainly water quality and treats river flood forecasting and ground water flow to wells. It also treats soil deposition, stream erosion and sediment transport. Bangladesh is a riverine country. We have many international and national rivers. Mathematical Hydrology deals with the occurrence, movement, and storage of water in the earth system. So hydrology is a very important subject for our country. The objectives of this course are to give a clear concept to students about use of Hydrology in science and water engineering fields. This course will help the student to identify surface flow, river flow, flood forecasting, measure soil erosion, channel erosion by using different kind of conceptual, mathematical and hydrodynamic.

Learning Outcomes

- Identify different kind of flow
- Apply a unit hydrograph to derive a runoff hydrograph
- Identify grain size of soil, soil properties and soil water.
- Measure soil erosion, sediment transport, sediment load
- Understand groundwater system.
- Measure flood, flood forecast and warning
- Analysis of frequency, find out returned period of flood
- Apply of conceptual, mathematical and hydrodynamic model in real life problem.

Course Contents

1. **Introduction and Hydrologic processes:** Continuity equation, discrete time continuity, momentum equation, open channel flow, porous medium flow, water balance.
2. **Instantaneous Unit Hydrograph (IUH)** and its applications.
3. **Soil properties and classification:** soil moisture, soil porosity, grain size analysis, soil texture, percolation, bypass flow, lateral flow, field capacity, wilting point, hydraulic conductivity.
4. **Sedimentation:** process of erosion, surface erosion, channel erosion, sediment transport, sediment yield, measuring surface and channel erosion.
5. **Groundwater:** groundwater system, shallow aquifer, deep aquifer, base flow.
6. **Flood routing:** Basic equations, reservoir flood routing, river flood routing, lumped flow routing and distributed flow routing.
7. **Frequency Analysis:** Rational method, empirical formulae, return period, extreme value distributions, frequency analysis using frequency factors.
8. **Flood forecasting** and warning.
9. **Linear Channels** and its mathematical applications.
10. **Conceptual and Mathematical Methods:** (i) Nash model (ii) Time area method, Clerk's model (iii) Dooge's model (iv) Chow and Kulandaiswany model (v) Muskingum model
11. **Hydrodynamic Models:** (i) Saint-Venant Equations from Navier-Stokes equations (ii) Kinematic Wave (KW) models (iii) Diffusion Wave Models (iv) Steady dynamic wave models (v) Dynamic Wave models (vi) Gravity wave models (vii) Tank Model (viii) Soil Water Assessment Tool (SWAT) Model.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Applied Hydrodogy, Ven-Te-Chaw et.al.
2. A text book of Hydrology, P. Jayarami Reddy.
3. Hydrologic System Vol I & II, V.P. Singh.
4. Engineering Hydrology, V. Subramanga.
5. Hydrology, H.M. Raghunath.

AMT 504: Applied Numerical Methods **4 credits**

Introduction and Specific Objectives

It is an excellent introductory combined course of Finite Element Method (FEM) and Finite Difference Method (FDM). The approaches of this course are motivated by two primary considerations: audience and pedagogy. Regarding audience, the purpose is to make the method understandable and usable to people in all fields of engineering and physical sciences. Regarding pedagogy, the purpose is to make the technical derivations and explanations as lucid and as simple as possible, without being simplistic. FEM is a general and powerful numerical method, applicable to a broad variety of mathematical problems that arise in almost all areas of science and engineering. FDM is introduced in this course to solve partial differential equations approximately. To apply the FDM, all derivatives in a differential equation are replaced by approximating difference quotients. Both FEM and FDM procedure reduce the ordinary and partial differential equation problems to the system of algebraic equations.

Learning Outcomes

The students can learn the solving techniques: FEM and FDM for 1D to 2-3D problems arising in applied mathematics, engineering and other physical sciences, which have no even exact solutions. The students will be able to develop: mathematical intuition and problem-solving capabilities, understanding of which tool is appropriate to tackle which problem, ability to find information through tools like the world-wide web to solve problems, ability to use computers to illustrate the arguments and competency in mathematical presentation.

Course Contents

1. Introduction to FEM: Discretization, Construction of basis functions, Numerical integration; coordinate transformation, local and global derivatives, mesh generation, h-p convergence, finite element approximation of line and double integrals.
2. Method of Weighted Residuals: Subdomain, Collocation, Galerkin, and Least-Squares methods, Matrix Formulation; Modified Galerkin techniques, Element/stiffness matrix. Solutions of 1-D linear and nonlinear BVP.
3. Galerkin methods for 1-D heat and Wave equations, 2D Poisson's and Laplace's equations.
4. Finite element solution of BVP: Outline of FE procedures for 1-D and 2-D problems (Poisson's and Laplace's equations), Matrix Formulation, Element concept, Triangular, Rectangular and Quadrilateral elements (linear and quadratic elements).
5. Variational Formulation of BVP: Functional and Variational Calculus, Construction of Functionals, Rayleigh Ritz Method and Finite elements.
6. Elliptic PDEs: Difference equations for Poisson's and Laplace's Equations BVP, matrix formulation, Convergence by iterative methods, and error analysis.
7. Parabolic problems: Derivation of difference formulas for IBVP, Matrix formulation, Heat Equation, Forward, Backward and Crank-Nicolson Methods, Difference methods in 2-space dimensions, ADI method, Stability and error analysis.
8. Hyperbolic problems: Difference methods for a scalar IVP and IBVP, Lax-Wendroff and Courant-Friedrichs-Lewy explicit methods, Wendroff implicit method, Wave Equation in time dependent and two space dimension, Convergence and stability analysis.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. P.E. Lewis and J.P Ward, The finite element method; Principles and Application, Addison-Wesley, 1991.
2. O.C. Zienkiewicz and K. Morgan, Finite Elements and approximations, John Wiley and Sons.
3. C.F. Gerald and P.O. Wheatley, Applied Numerical Analysis, Addison-Wesley, 1998.
4. M.A. Celia and W.G. Gray, Numerical Methods for Differential Equations, Prentice-Hall Int. Inc.
5. G.D. Smith, Numerical solution of Partial differential equations, Clarendon press, Oxford, 1978.

AMT 505: Magneto-Hydrodynamics **4 credits**

Introduction and Specific Objectives

Magnetic fields are of vital importance in astrophysics and geophysics, playing crucial roles in the dynamics of galaxies, stars (including star formation) and planets (including the Earth). Magneto-hydrodynamics (MHD) is concerned with understanding the nature of fluid flows in the presence of magnetic fields. It therefore combines electromagnetic theory with fluid dynamics. This course gives a basic introduction to MHD, detailing how magnetic fields can have significant effects on the nature of fluid flows (including the important topic of plasma confinement in fusion devices) and how fluid flows can self-consistently lead to the generation of magnetic fields via dynamo action (which is believed to be important for the maintenance of the magnetic field of both the Earth and Sun).

Learning Outcomes

Students should be familiar with the basic properties of electrically-conducting fluids. In particular they should be acquainted with the induction equation and the importance of stretching and diffusion, the role of the Lorentz force and its relevance to plasma confinement, dynamo theory and the dynamics of magnetic waves.

Course Contents

1. **Introduction of MHD and its applications:** Overview of MHD, Brief reminder of the laws of electrodynamics. (Maxwell's equations) and discuss importance for various term. Derivation of MHD equations from Maxwell's equations (mass continuity, Navier-Stokes, energy), MHD vortices equation, MHD approximation, Magnetic field visualization (stream lines and magnetic field lines), Flux functions, Volume flux, Magnetic flux, Scaling parameters in MHD, The Lorentz force, Magnetic pressure and tension force, Maxwell stresses.
2. **MHD Equilibriums:** Magneto-hydrostatic (Equilibria), Force-free fields, The plasma beta, pressure balance and plasma confinement, Pinch fields (theta pinch, z-pinch, linear pinch, cylindrical pinch or screw pinch).
3. **The induction Equation:** The magnetic induction equation (stationary and moving), Non-dimensionalisation and magnetic Reynolds number, Behavior of the magnetic field at the diffusive and perfectly conducting limit, problems and solutions involving induction equation. Clebsch representation, Thebondi gold theorem, Alfven's Frozen flux theorem, consequence of Alfven's theorem, Ferraro's law of isorotation, Cauchy solution, introduction and diffusion.
4. **Steady-State Flows:** Uni-directional flows, MHD Couette and poiseuille flow, MHD flow past a continuously moving plate, Unsteady MHD flow through two parallel porous plates, Similarity of magnetic boundary larger equations, The Hartmann layer, Hartmann flow between two planes (transverse magnetic field), Rayleigh-Benard convection.
5. **MHD waves:** Brief introduction to waves, Linearized MHD equation (mass continuity, motion equation, induction, gas law, solenoidal constraint), Alfven waves and characteristic, importance of wave motion in solar interior and atmosphere, magneto acoustic waves,(sound waves, acoustic waves, magnetic waves), Related problems and solutions.
6. **MHD Turbulence:** The emergence of turbulent flows and its properties, Equations of motion of turbulent flows, Eddy viscosity concept, Theoretical assumption for the calculation of turbulentflows, Turbulent boundary layer flows in channel and flow along a flat plate, Introduction, mean value fluctuations, Reynolds equations and stresses, Prandtl Mixing length theory, Prandtl Momentum transfer theory, Taylor's vorticity transport theory, Von-karmann similarity hypothesis, Homogeneous and Isotropic turbulence.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. P.A. Davidson, An introduction to Magnetohydrodynamics, Cambridge press, 2001.
2. V.C.A. Ferraro and C. Plumpton, An Introduction to Magneto-fluid mechanics, Oxford press,
3. J.P.Goedbloed and Stefaan Poedts, Principles of Magnetohydrodynamics, Cambridge press, 2004.
4. Chandrssekhar, Hydromagnetic and hydrodynamic stability, 1981.

AMT 506: Riemannian Geometry **4 credits**

Introduction and Specific Objectives
This course is an introduction to the beautiful theory of Riemannian Geometry, a subject with no lack of interesting examples. The core of this course will be an introduction to Riemannian geometry - the study of Riemannian metrics on abstract manifolds. This is a classical subject, but is required knowledge for research in diverse areas of modern mathematics. We will try to present the material in order to prepare for the study of some of the other geometric structures one can put on manifolds. They are indeed the key to a good understanding of it and will therefore play a major role throughout the course.

Learning Outcomes
On completion of this course, students will be able to understand
- the basic topology and differentiation in$\mathbb{R}^n$
- the inverse and implicit function theorems
- to work with sub-manifolds in their various forms
- to calculate with the geometry of curves and surfaces
- the integration on surfaces and calculate such integrals
- the Gauss-Bonnet theorem and its application.

Course Contents
1. **Introduction:** Fundamental notions, Background and scopes of Riemannian geometry, Riemannain manifolds, Riemannian submanifolds, Pseudo-Riemannian manifolds.
2. **Curvature of Riemannian manifolds:** Einstein space, Constant Riemannian curvature, Riemannian curvature, Recurrent space, Ricci-recurrent space, Geodesic curvature, scalar curvature, sectional curvature, Ricci curvature, Ricci decomposition, Weyl curvature, conformal curvature tensors.
3. **Smooth Manifolds:** Functions on smooth manifolds, Pull-back of function, Tangent vector and tangent space, push-forward of tangent vectors, smooth vector fields, Lie brackets (commutator), Lie algebra, Examples of matrix groups.
4. **Metrics and Connections:** Metrics and connections, Riemannian metrics. Affine connection, torsion and curvature tensors, Parallel transport, Geodesics, Levi-Civita connection, Coordinate representation of the curvature tensors.
5. **Exterior Algebra and Differential Forms:** Differential form, Exterior derivatives, exterior algebra (Grassman algebra), Grassman manifolds, the exterior derivative in calculus, wedge product, Poincare's Lemma. Fundamental theorem of Riemannian geometry.
6. **Symplectic Geometry:** Symplectic topology, Symplectic space, symplectic manifolds, Symplectic structure, Symplectomorphism, Darboux theorem on symplectic manifold and related theorems on symplectic manifolds.
7. **Contact Geometry:** Contact structure, Contact space, contact manifolds, Darboux theorem on contact manifold, complex manifolds, complex projective space, theorem on complex contact manifolds.

Evaluation
Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References:

1. C. S. Isham, Modern Differential Geometry, World Scientific, 1999.
2. V. I. Arnold, Mathematical Methods of Classical Mechanics, Springer-Verlag, 1978.
3. W. H. Chen, S. S. Chern and K. S. Lam, Lectures on Differential Geometry, World Scientific.
4. R. W. R. Darling, Differential Forms and Connections, Cambridge University Press, 1994.
5. Mikio Nakahara., Geometry, Topology and Physics, IoP, 2003.
6. T. Frankel, The Geometry of Physics: An Introduction, Cambridge University Press, 1997.
7. Sigmundur Gudmundsson, An Introduction to Riemannian Geometry (internet edition).

AMT 507: Stochastic Modeling in Finance **4 credits**

Introduction and Specific Objectives

Derivative securities (such as options) depend on the values of primary securities (such as stock or bond prices). During the last thirty years trading in derivative securities have undergone a tremendous development and nowadays derivative securities are traded on markets all over the world in large numbers. The purpose of the course is to exhibit basic features of advanced financial derivatives, starting with basic model specifications, introducing the concept of arbitrage, and ending with a risk-neutral valuation formula and its analysis. The unit aims to provide a concise mathematical formulation of the main characteristics of financial instruments, with an emphasis on quantitative aspects of stock price, options, and other financial derivatives.

Learning Outcomes

On successful completion the students will have acquired active knowledge and understanding of some basic concepts and results in financial mathematics including:

- hedging strategies and managing market risk using derivatives;
- discrete and continuous time security markets;
- arbitrage, risk-neutral valuation, the fundamental theorem of asset pricing;
- European options, exotic options, American options;
- interest rate models and interest rate derivatives;

Course Contents

1. **Discrete time security markets:** Single period models, Multiperiod Models, The Cox-Ross-Rubinstein model; Self-financing portfolios; Contingent claims; Arbitrage; Martingale measures; Risk-neutral valuation.
2. **Stochastic calculus I:** Martingales, Brownian motion, Stochastic Integration.
3. **Continuous time security markets:** The Black-Scholes model; Option pricing, The Greeks, Volatility, criticism.
4. **Stochastic calculus II:** Girsanov's theorem, The Brownian martingale representation theorem.
5. **Risk-neutral pricing:** The Model, Risk-neutral measure, Price under the risk-neutral measure, hedging, Fundamental theorem of asset pricing, Dividend paying shares.
6. **Forward and Futures contracts:** Forward contracts, Future contracts.
7. **Exotic options:** Knock-out Barrier Options, Generatsation of the Itˆo-formula, Lookback options, Asian options Chooser options, Digital option, Forward-Start option, Basket-option.
9. **American options:** Introduction, Perpetual American put option, Finite expiration American put option, American call option.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Bjork, T., Arbitrage Theory in Continuous Time, Oxford University Press 1998.
2. Etheridge, Alison, A course in financial calculus, Cambridge University Press, 2002.
3. Hull, J. C., Options, Futures, and Other Derivatives Prentice-Hall 2006.
4. S. E. Shreve. Stochastic calculus for finance. I: The binomial asset pricing model. New York: Springer, 2004.

AMT 508: Aerodynamics **4 credits**

Introduction and Specific Objectives

The objective of this course is to develop an understanding of low-speed aerodynamics and an introduction to compressible flows. The course covers concepts in incompressible airfoil theory, including symmetric and cambered airfoils using the analytical approach. The course also covers incompressible lifting theory, including down wash, Kutta condition, application of fundamentals to the design of a wing to meet given performance criteria. The course also covers topics in compressible flow and shock wave including expansion waves, linear theory and linearized supersonic flow. Finally, the course covers several methods/models, Euler codes, CFD tools, credibility of CFD simulations, ground-based test programs, flight-test programs, integration of experimental and computational tools and the aerodynamics design philosophy. The objective of this course is to introduce students to the fundamentals, physical mechanisms, solution techniques, importance of incompressible and compressible flows and the design and operation of flow systems induced by flight vehicles or flying objects or submerged objects in the atmosphere.

Learning Outcomes

After successful completion of this course, the students will be able to understand the basic aerodynamic terminologies, various aspects of the link between the body shape and its aerodynamic characteristics, characteristics and dynamics of incompressible flow and the lifting theorem. They will be able to understand the characteristics of Incompressible flow over airfoils and finite wings and have a deeper understanding of compressible flow and shock wave. They will also be able to solve the shock wave problems mathematically. Besides The learners will be able to linearize and then solve the Aerodynamic flow equations. Finally, they will learn the challenges and techniques of developing any solution methods (CFD, empirical, and experimental) for solving aerodynamic problems in real word.

Course Contents

1. **Fundamentals of Aerodynamics:** Importance of Aerodynamics; The standard Atmosphere; Airfoils and wings; Angle of Attack; Aerodynamic Forces and Coefficients; Buoyancy Force; Mach Number; Pitot Tube; Laws of Thermodynamics; Equation of State; Continuity Equation; Momentum Equation; Energy Equation.
2. **Dynamics of An Incompressible; Inviscid Flow Field:** Measurement of Airspeed; Pressure Coefficient; Governing Equation for Irrotational, Uniform Flow with Source, Sink, Vortex and Doublet; Lifting and Nonlifting Flow over a Circular Cylinder; The Kutta-Joukowski Theorem of Lift. The Flow over a Circular Cylinder-The Real Case.
3. **Incompressible Flow Over Airfoils and Finite Wings:** Airfoil Nomenclature and Geometry Parameters; The Kutta Condition; Classical Thin Airfoil Theory and Its Application for Symmetric Airfoil; The Delta Wing; Estimation of Delta wing performance in subsonic condition.
4. **Compressible Flow and Shock Wave:** Compressibility; Isentropic Relations; Speed of Sound; Special form of energy equation; Calculation of Normal Shock-Wave Properties; Oblique Shock Waves; Oblique Shock-Wave Properties; Derivation of Prandtl-Meyer Function for Expansion Waves; Calculation of airspeed for subsonic compressible flow and supersonic flow.
5. **Linear Theory and Linearized Supersonic Flow:** The Velocity Potential Equation; The Linearized Velocity Potential Equation; Prandtl-Glauert rule; Critical Mach Number; Derivation of the Linearized Supersonic Pressure Coefficient Formula and its application to Supersonic Airfoils.
6. **Tools for Defining the Aerodynamic Environment:** CFD Tools; Semiempirical Methods; Surface Panel Methods for Inviscid Flows; Euler Codes for Inviscid Flow Fields; Two-Layer Flow Models; Unified Computational Techniques; Establishing the Credibility of CFD Simulations; Ground-Based Test Programs; Flight-Test Programs; Integration of Experimental and Computational Tools; The Aerodynamics Design Philosophy.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Fundamentals of Aerodynamics, 2nd Edition, John D. Anderson, JR.

2. Foundations of Aerodynamics: Bases of Aerodynamic Design, Arnold M. Kuethe, Chuen Yen Chow.
3. Aerodynamics for Engineers, 5th Edition, John J. Bertin, Ressell M. Cummings.
4. Introduction to Flight, John D. Anderson, JR.

AMT 509: Computational Fluid Dynamics **4 credits**

Introduction and Specific Objectives

The Computational Fluid Dynamics (CFD) is an inherently interdisciplinary branch of science which has an extremely broad spectrum of applications. CFD become an essential tool in analysis and design of thermal and fluid flow systems in wide range of industries. Fluid dynamics uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Few prominent areas of applications of CFD include meteorology, transport systems (aerospace, automobile, high-speed trains), energy systems, environment, electronics, bio-medical (design of life-support and drug delivery systems), etc. There has been considerable growth in the development and application of CFD in all aspects of fluid dynamics. CFD has become a standard modeling tool widely utilized within industry. The correct use of CFD as a design analysis or diagnostic tool requires a thorough understanding of underlying physics, mathematical modeling and numerical techniques. This course aims to provide precisely these insights of CFD. Finite difference and finite volume methods will be discussed as different means of discretization of the fluid dynamics equations. A necessary theoretical background concerning accuracy, convergence, consistency, and stability of the numerical schemes will be provided.

Learning Outcomes

The goal of the course is to provide a description of fundamental and general techniques which are commonly used in solving numerically equations governing fluid flows. The numerical methods will be implemented on computers and applied to solutions of simple model problems which illustrate a variety of physical phenomena encountered in fluid mechanics: one-dimensional diffusion, multidimensional diffusion, and linear and nonlinear convection-dominated problems. On successful completion of the course, students will be able to: Use Finite difference and finite volume method to model flow problems and to select the proper governing equations for the physics involved in the model and understand the results. Understand both flow physics and mathematical properties of governing Navier-Stokes equations and define proper boundary conditions for solution.

Course Contents

1. Classification of Partial Differential Equations, Boundary and Initial Conditions, Derivation of Finite Difference equations: simple method, general method, higher order derivatives, multidimensional finite difference formulas, higher order accuracy schemes.
2. Analysis and Application of Numerical Schemes: Consistency; Stability; Convergence; Fourier or von Neumann stability analysis;
3. Application of FDM to model equations: wave, Heat, Laplace and Burgers equations,
4. Grid generation: Introduction, Coordinate Transformation, differential equation methods, algebraic methods, transfinite interpolation methods, unstructured grid generation, mesh adaption
5. Finite Volume Method: Basic Technique, Model Equations in Integral Form, Finite Volume Discretization of Equations, Finite volume method for One-Dimensional and two-Dimensional problem.
6. Finite volume method for convection-diffusion problems: steady one dimensional convection-diffusion, discretisation schemes, central differencing scheme, upwind differencing scheme, hybrid differencing scheme, higher order differencing scheme (QUICK, TVD)
7. Navier-Stokes equations: Stream function - vorticity formulation; Primitive variable formulation; Pressure correction techniques like SIMPLE, MAC, Fractional Step;
8. Application of pressure correction methods in Lid-driven cavity flow. Numerical heat transfer: Brief discussion of numerical methods for conduction and convection.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. T. J. Chung `Computational Fluid Dynamics 2e', Cambridge University Press, 2010
2. H.K. Versteeg and W. Malalasekera, `An introduction to computational fluid dynamics: The finite volume method 3e', Pearson Education, 2007.
3. Anderson, D.A., Tannehill, J.C. and Pletcher, R.H. Computational Fluid Mechanics and Heat Transfer. Taylor & Francis, 1997.
4. Charles Hirsch, `Numerical Computation of Internal and External Flows', Vol.1 (1988) and Vol.2 (1990), John Wiley & Sons.
5. J. H. Fergiger, M. Peric, `Computational Methods for Fluid Dynamics 3e', Springer, 2002.

AMT 510: Dynamical Meteorology 4 credits

Introduction and Specific Objectives

The objective of the program for the graduate is to become familiar with key atmospheric variables and structures, the types of weather data available, the manner by which these data are collected, and some of the ways (e.g. WRF-ARW and other numerical models) that these data are displayed, analyzed, and used in the forecasting system. Students can demonstrate the ability to produce forecasts of basic weather variables including high and low pressure, temperatures and precipitation that are related to tropical cyclones, tornadoes and thunderstorm and extreme temperature.

The aims of this course are also :

- to produce graduates who possess quantitative, scientific reasoning skills that can be applied to atmospheric problems.
- to produce graduates who have a general knowledge of a range of atmospheric phenomena and applications, and have expertise in one or more program sub-disciplines or related interdisciplinary areas.
- to produce graduates who are equipped to contribute to solving problems in the atmospheric sciences and related disciplines, through service in business or as educators, researchers, and leaders in academia, government, the private sector, and civil society.

Learning Outcomes

The graduate can demonstrate

- the ability to analyze and interpret conventional maps of surface and upper-air data as well as soundings on a thermodynamic diagram
- fundamental knowledge of the basics by which atmospheric observations are taken, both in-situ and remotely
- the knowledge of synoptic-scale weather systems
- skills for interpreting and applying atmospheric observations
- the knowledge of the atmosphere and its evolution.
- the knowledge of the fundamental forces that drive atmospheric motions both in the horizontal and vertical
- the knowledge of the basics underlying weather forecasting and numerical weather prediction.

Course Contents

1. **The atmosphere**: Concept of Metrology, The atmosphere (water vapor, Dust, Ozone), Different layers of atmosphere, Aerosols, The wind, Formation of clouds with different types, Precipitation, Lightning and Thunder, Thunderstorm formation and safely.
2. **Atmospheric Forces:** Pressure gradient force, viscous force, gravitational force, centripetal acceleration and centrifugal force, gravity revisited, the Coriolis force and the curvature effect, constant angular momentum oscillations, Hydrostatic equation, pressure as a vertical coordinate and generalized vertical coordinate, Kinematics, scale analysis

3. **Conservation Laws**: Total differentiation, Vectorial form of momentum equation in rotating coordinates, Component equations in spherical coordinates, Geostrophic approximation and geostrophic wind, Approximate Prognostic equations, Rossby number, Hydrostatic approximation, potential temperature, Adiabatic laps rate, static stability, Equivalent potential temperature, The Pesudoadiabtic Laps rate and conditional stability.
4. **Elementary applications of the basic equations**: Natural coordinates, geostrophic flow, inertial flow, Cyclostrophic flow, he gradient wind approximation, Trajectories and streamlines, Barotropic and Baroclinic atmospheres, Vertical motion (Kinematic and adiabatic method), surface pressure tendency.
5. **Atmospheric oscillations:** Pure internal gravity waves, Pure inertial oscillations, Rossby and Inertial gravity waves, Free Barotropic and Forces Topographic Rossby waves.
6. **Quasi-geostrophic Analysis:** Derivation of the Quasi-geostrophic equations, Potential vorticity derivation of the Quasi-geostrophic equations, Potential vorticity thinking.
7. **The Planetary boundary layer:** Atmospheric turbulence (Reynold's averaging), Turbulent kinematic energy, Well mixed boundary layer, The flux gradient theory, The mixing length hypothesis, The Ekman layer and Modified Ekman layer, The surface layer
8. **Tropicial Dynamics:** The intertropical converges zone, Equatorial wave disturbances, Africal wave disturbances, Tropical Monsoons, The Walker curculaton, El Nino and the southern oscillations, Equatorial Intraseasonal Osciallation, Development of rotation in Supercell Thunderstroms, The Right-Moving Strom, Dynamics of Mature Hurricanes and Hurricane development, Scale analysis of large scale tropical motions, Equatorial Rossby and Rossby gravity modes, Equatorial Kelvin waves.

Evaluation
Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. James R . Holton, An Introduction to Dynamic Meteorology.
2. D.H. Maclntosh, A.S Thom, V.T. Saunders, Essentials of Meteorology.
3. Haltiner and Martin, Dynamical and Physical Meteorology.
4. L Hess, Introduction to Theoretical Meteorology Holt Rian hart and Winston, Inc., New York.
5. H. Gordon Nostrand, Elements of Dynamic Meteorology D Van-Co, Inc., New York.

AMT 511: Applied Dynamical Systems 4 credits

Introduction and Specific Objectives
Dynamical systems theory is the mathematical theory of time-varying systems and it is used in the modelling of a wide range of physical, biological, engineering, economic and other phenomena. This course presents a broad introduction to the area, with emphasis on those aspects important in the modelling and simulation of systems. General dynamical systems are described, along with the most basic sorts of behaviour that they can show. The dynamical systems most commonly encountered in applications are formed from sets of differential equations. The most regular kinds of behaviour-equilibrium and periodic---are the most easy to analyze theoretically; linearization about such trajectories are discussed, for periodic behaviour this is done using the Poincare' Map. Much more complex behaviours, including chaos, may be found; these are described by means of their attractors. In applications it is often important to know how the observed behaviour changes with changes in the system parameters; such changes can often be sudden, but frequently conform to one of a relatively small number of scenarios: the study of these forms the subject of bifurcation theory. The simplest bifurcations are discussed. Many physical systems can become unstable in the sense that small disturbances superimposed on their basic state can amplify and significantly alter their initial state. In this course we introduce the basic theoretical and physical methodology required to understand and predict instability in a variety of situations with focus on hydrodynamic instabilities.

Learning outcomes

At the end of the course, the students will be able to understand the general concept of a dynamical system, and the significance of dynamical systems for modelling real world phenomena. The students will be able to analyze simple dynamical systems to find and classify regular behavior. They will be able to identify limit cycles and their characteristics. They will be introduced to some simple bifurcation scenarios in 1D and 2D, and will learn how to analyze. They will also get some basic idea of maps and their bifurcation. The students will know some of the more complex behaviors (including chaotic), and understand some of the features of the attractors characterizing such behavior. The students will get a basic idea of stability theory and will be able to derive linearized stability equations for a given basic state and perform a normal-mode analysis leading to an eigenvalue problem.

Course Contents

1. **Basic Features of Dynamical Systems**: Basic concepts of dynamical systems: states, state spaces, dynamics. Discrete and continuous time systems with motivating examples. Trajectories, fixed points, periodic orbits, attractors and basins.
2. **Linear Systems and Phase Plane**: Systems of first order differential equations, classification of linear systems, classification of fixed points (saddle, node, focus, centre). Phase portraits, existence, uniqueness and topological consequences (Hartman-Grobman Theorem), fixed points and linearization
3. **Limit Cycles**: Van der Pol oscillator, ruling out closed orbits, Liapunov functions, Poincaré-Bendixson Theorem, Liénard Systems, relaxation oscillations
4. **Bifurcation Theory**: Classification of bifurcation: saddle-node, transcritical, pitchfork, Hopf bifurcation, Bifurcation in 1D and 2D with examples, global bifurcation of cycles.
5. **Maps**: Poincaré maps, linearization and characteristic multipliers of periodic orbits, and stability; bifurcations of one-dimensional maps.
6. **Chaos**: Lorenz equations, simple properties of Lorenz equations, chaos on a strange attractor, Lorenz map, exploring parameter space; One dimensional map, fixed points and cobwebs, logistic map, Liapunov exponent, period doubling; Strange attractors, Hénon map, Rössler system
7. **Stability Theory:** Nonlinear dynamics. Linear instability versus nonlinear instability. Dispersion relation, marginal stability curve. Role of weakly nonlinear theory, e.g. normal form for pitchfork bifurcation. Global stability.
8. **Linear Stability Analysis:** A case study of Rayleigh-Bénard convection: Introduction to physical system, Boussinesq equations, dimensional analysis, Basic state, linear theory, normal modes, marginal stability curve: Analytical approach for idealized boundary conditions.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. S. H. Strogatz, Nonlinear Dynamics and Chaos with Applications to Physics, Biology, Chemistry and Engineering (Westview Press, 2000).
2. P. G. Drazin, Nonlinear Systems (Cambridge University Press, Cambridge, 1992)
3. Stephen Wiggins, Introduction to Applied Nonlinear Dynamical Systems and Chaos, Springer-Verlag, New York, NY, USA, second edition, 2003.
4. P. G. Drazin, Introduction to hydrodynamic stability. Cambridge University Press (2002)
5. Kathleen T. Alligood, Tim D. Sauer and James A. Yorke, Chaos: An Introduction to Dynamical Systems, Springer-Verlag, New York, NY, USA, 1996.

AMT 512: Biofluid Dynamics **4 credits**

Introduction and Specific Objectives
Due to its inherent complexity and increasing industrial applications, Biofluid dynamics has evolved as an important research and teaching area and shows how to apply the principles towards solutions of transfer problems in the human body and medical devices. The objective of this course is to equip students with the fluid dynamics tools in order to design and perform research in physiological and biofluid mechanics. Review and understand emerging biomimetic approaches, emphasizing the quantitative understanding and fundamental engineering concepts.

Learning Outcomes
Understand the governing physics of fluid mechanics as applied to the biological problems Be familiar with the current state of the art computational modeling tools learn to conduct biofluids research on an interesting problem and apply engineering fundamentals to contribute its solution learn the fundamentals of interdisciplinary (biology/engineer) work(collaboration/research). A biomechanical engineering perspective will be followed throughout the course; more applications from general Bio-Fluid Mechanics topics but Cardiovascular Fluid Dynamics will be also reviewed.

Course Contents
1. **Elements of Continuum Mechanics:** Biological Transport Processes, Basic Momentum, Heat, and Mass Transfer Concepts, Conservation Laws, Two-Phase Flows, Biomechanics Review.
2. **Biofluid Dynamics Concepts:** Transport Phenomena, The Cardiovascular System, Problems
3. **Analysis of Arterial Diseases:** Vessel Occlusions, Aneurysms, Examples of Computerized Disease Management, Problems
4. **Biofluid Mechanics of Organ Systems:** The Lungs, the Kidneys, the Liver Problems.
5. **Case Studies in Biofluid Dynamics:** Prerequisites for Modeling and Simulating, Nanodrug Delivery in Microchannels, Particle Deposition and Targeting in Human Lung Airways, Fluid-Structure Interactions in Stented Aneurysms

Evaluation
Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. C. Kleinstreuer, Biofluid Dynamics: Principles and Applications, CRC Press, Taylor&Francis Group, 2006.
2. J. N. Mazumdar, Biofluid Mechanics, World Scientific, 2004.
3. Y.C. Fung, Biodynamics: Circulation, Springer-Verlag NY, 1997.
4. L. Waite, Applied Biofluid Mechanics, McGraw Hill, 2007.
5. J. Mark and C. Ross Ethier, Problems for Biomedical fluid mechanics and transport phenomena, CUP, 2014.

AMT 513: Mechanics of Flight **4 credits**

Introduction and Specific Objectives
The flight and maneuvers of an aeroplane provide glorious examples of the principles of mechanics. However this course is about flying and is an attempt to explain the flight of an aeroplane in a simple and interesting way. The governing equations for aircraft flight stability and control are presented, and used to analyze the flight performance of aircraft in different situations. Analysis of a range of fundamental aerodynamic problems relevant to aircraft is covered using analytical and numerical techniques.

Learning Outcomes
Relate concepts of aerodynamics and associated fluid mechanics to aircraft design and operation. Apply basic aerodynamic principles to analyze the aerodynamic characteristics of idealized representations of

aircraft components and systems. Derive and apply the aircraft flight mechanics equations to analyze the flight performance of aircraft in different situations. Identify limitations of the aerodynamics and flight mechanics principles and equations as applied to aircraft.

Course Contents

6. **Overview of Aerodynamics:** Introduction and Notation, Fluid Statics and the Atmosphere, The Boundary Layer Concept, Inviscid Aerodynamics, Review of Elementary Potential Flows, Incompressible Flow over Airfoils, Trailing-Edge Flaps and Section Flap Effectiveness, Incompressible Flow over Finite Wings, Flow over Multiple Lifting Surfaces, Wing Stall and Maximum Lift Coefficient, Wing Aerodynamic Center and Pitching Moment, Inviscid Compressible Aerodynamics, Compressible Subsonic Flow, Supersonic Flow, Problems.
7. **Overview of Propulsion:** Introduction, The Propeller, Propeller Blade Theory, Propeller Momentum Theory, Off-Axis Forces and Moments Developed by a Propeller, Turbojet Engines: The Thrust Equation, Turbojet Engines: Cycle Analysis, The Turbojet Engine with Afterburner, Turbofan Engines, Problems.
8. **Aircraft Performance:** Introduction, Thrust Required, Power Required, Rate of Climb and Power Available, Fuel Consumption and Endurance, Fuel Consumption and Range, Power Failure and Gliding Flight, Airspeed, Wing Loading, and Stall, The Steady Coordinated Turn, Takeoff and Landing Performance, Accelerating Climb and Balanced Field Length, Problems.
9. **Aircraft Controls and Maneuverability:** Longitudinal Control and Maneuverability, Effects of Structural Flexibility, Control Force and Trim Tabs, Stick-Free Neutral and Maneuver Points, Ground Effect, Elevator Sizing, and CG Limits, Stall Recovery, Lateral Control and Maneuverability, Aileron Reversal, Other Control Surface Configurations, Airplane Spin Problems.
6. **Aircraft Equations of Motion:** Introduction, Newton’s Second Law for Rigid-Body Dynamics, Position and Orientation: The Euler Angle Formulation, Rigid-Body 6-DOF Equations of Motion, Linearized Equations of Motion, Nondimensional Linearized Equations of Motion, Transformation of Stability Axes, Problems.
7. **Linearized Longitudinal Dynamics:** Fundamentals of Dynamics: Eigen problems, Longitudinal Motion: The Linearized Coupled Equations, Short-Period Approximation, Long-Period Approximation, Pure Pitching Motion,
8. **Aircraft Handling Qualities and Control Response:** Introduction, Pilot Opinion, Dynamic Handling Quality Prediction, Response to Control Inputs, Nonlinear Effects and Longitudinal-Lateral Coupling, Problems.
9. **Aircraft Flight Simulation:** Introduction, Euler Angle Formulations, Direction-Cosine Formulation, Euler Axis Formulation, The Euler-Rodrigues Quaternion Formulation, Aircraft Position in Geographic Coordinates, Problems.

Evaluation

Incourse Assessment and Attendance 30 Marks, Final examination (Theory: 4 hours) 70 Marks. Eight questions of equal value will be set, of which any five are to be answered.

References

1. Philips, Mechanics of Flight, wiley, 2004.
2. Philpott & Barnard , Mechanics of Flight, Pearson, 2006.

AMT 514: Environmental Fluid Mechanics **4 credits**

Objectives: The course is designed to understand and explore recent advancements of Fluid Mechanics in the urban environment. More than half of the world population live in cities and the built environment dominates day-to-day life of city dwellers. Thus it is important to understand how airflow can be estimated and by far be controlled for a better urban environment.

Outcome: Upon completion, the students will be able to

- Identify urban topology.

- Understand boundary layer turbulence.
- Explore the canonical flows to build models for urban airflow.
- Understand flow control/Estimation strategies.

Syllabus:

1. **Urban environment:** Atmospheric boundary layer, Meso and micro scale topology, Flows in street canopies, Blue-Green planning.
2. **Boundary Layer turbulence:** Shear boundary layers, Equations of motion, Viscous sublayer, Law of the wall, Inertial sublayer and logarithmic layer, Friction velocity and friction Reynolds number.
3. **Flows in urban street canopies:** Modelling in urban street canopies**,** Plane Couette flow, Mean velocity, Flow patterns and structures, Self-sustaining process, Streaks and rolls, Streak spacing and roll size, Total stress and shear stress, Reynolds stresses.
4. **Energy budget:** Kinetic energy, Turbulent kinetic energy, Turbulence intensity, Energy production and dissipation, Total energy Budget.
5. **Kolmogorov scales:** Eddies, Energy spectrum, Energy dissipation through eddies, Importance of small eddies.
6. **Natural and forced ventilation:** Natural ventilation for built environment, Heating, Rayleigh-Bénard convection, Mean flow structures, Flow patterns, Temperature stratification, Mixing.
7. **Computational models:** Direct numerical simulation (DNS), Large eddy simulation (LES) and RANS.
8. **Flow control and estimation:** Controllability, Observability, Proper Orthogonal Decomposition (POD), Gappy POD method, Flow reconstructions from surface measurements, Reduced ordered modelling (ROM).

Referencess:

1. Urban Climates, T. R. Oke, G. Miles, A. Christen and J. A. Voogt (2017).
2. Air Pollution Control Engineering, L. K. Wang, N. C. Pereira, Y. Hung (2004).
3. Turbulence, Coherent Structures, Dynamical Systems and Symmetry, P. Holmes, J. Lumley, G. Berkooz and C. Rowley, Cambridge University Press (2012).
4. Turbulent Flows, S. B. Pope, First edition (2000).

AMT 515 : Financial Time Series Analysis and Forecasting (4 Credits)

1. **Introduction and Fundamental Concepts and Trends:** Examples of Time Series, A Model-Building Strategy, Time Series Plots in History; Time Series and Stochastic Processes, Means, Variances, and Covariances, Stationarity; Deterministic Versus Stochastic Trends, Estimation of a Constant Mean, Regression Methods, Reliability and Efficiency of Regression Estimates, Interpreting Regression Output, Residual Analysis.

2. **Models for Stationary and Non-Stationary Time Series:** General Linear Processes, Moving Average Processes, Autoregressive Processes, The Mixed Autoregressive Moving Average Model, Invertibility, Stationarity Through Differencing, ARIMA Models, Constant Terms in ARIMA Models, Other Transformations.

3. **Model Specification, Parameter Estimation and Model Diagnostics:** Properties of the Sample Autocorrelation Function, The Partial and Extended Autocorrelation Functions, Specification of Some Simulated Time Series, Nonstationarity, Other Specification Methods, Specification of Some Actual Time Series; The Method of Moments, Least Squares Estimation, Maximum Likelihood and Unconditional Least Squares, Properties of the Estimates, Illustrations of Parameter Estimation, Bootstrapping ARIMA Models; Residual Analysis, Overfitting and Parameter Redundancy.

4. **Forecasting:** Minimum Mean Square Error Forecasting, Deterministic Trends, ARIMA Forecasting, Prediction Limits, Forecasting Illustrations, Updating ARIMA Forecasts, Forecast Weights and Exponentially Weighted Moving Averages, Forecasting Transformed Series, Summary of Forecasting with Certain ARIMA Models

5. **Seasonal Models:** Seasonal ARIMA Models, Multiplicative Seasonal ARMA Models, Nonstationary Seasonal ARIMA Models, Model Specification, Fitting, and Checking, Forecasting Seasonal Models.

6. **Time Series Regression Models:** Intervention Analysis, Outliers, Spurious Correlation, Prewhitening and Stochastic Regression.

7. **Time Series Models of Heteroscedasticity:** Some Common Features of Financial Time Series, The ARCH(1) Model, GARCH Models, Maximum Likelihood Estimation, Model Diagnostics, Conditions for the Nonnegativity of the Conditional Variances, Some Extensions of the GARCH Model.

8. **Markov Chain Monte Carlo Method:** Introduction, Bayesian Interface, Markov Chain Monte Carlo (MCMC), Metropolis-Hastings Algorithm, Gibbs Sampling, Case Study: The Impact of Jumps on Dow Jones.

Evaluation: Incourse 30 marks (Attendance 5 + Incourse examination 25), Final Examination (Theory, 4 hours): 70 marks. **Eight** questions will be set, of which any **Five** are to be answered.

References:

1. Jonathan D Cryer and Kung Silk Chan, Time Series Analysis With Applications in R, Second Edition, Springer, 20082. Bjork, T., Arbitrage Theory in Continuous Time, Oxford University Press 1998.
2. Robert H Shumway & David S Stoffer, Time Series Analysis and Its Applications with R examples, Third
   Edition, Springer,2011
3. Ruey S Tsay, Analysis of Financial Time Series, Wiley, 2002