INSTITUTE OF AERONAUTICAL ENGINEERING

Dundigal, Hyderabad - 500 043

AERONAUTICAL ENGINEERING

COURSE DESCRIPTION FORM

Course Title	COMPUTATIONAL AERODYNAMICS			
Course Code	A62114			
Regulation	R15 - JNTUH			
Course Structure	Lectures	Tutorials	Practicals	Credits
	3	1	-	4
Course Coordinator	Dr. G Malaikannan, Professor, Department of Aeronautical Engineering			
Team of Instructors	Mr. G Satya Dileep, Assistant Professor, Department of Aeronautical Engineering			

I. COURSE OVERVIEW:

The subject provides students with necessary skills and knowledge in basics and should be able to assess a problem for analysis using computational aerodynamics, formulate a problem, select a method and obtain a solution. Each unit provides systematic development of computational aerodynamics. The role of CA elaborate applications, including projects for students and professionals to use CFD in much more realistic situations

II. PREREQUISITE(S):

Level	Credits	Periods/ Week	Prerequisites
UG	4	4	Aerodynamics I
UG	4	4	Aerodynamics II

III MARKS DISTRIBUTION

Sessional Marks	University End Exam marks	Total Marks
Mid Semester Test There shall be two midterm examinations. Each midterm examination consists of subjective type and objective type tests. The subjective test is for 10 marks of 60 minutes duration. Subjective test of shall contains 2 parts; the student has to answer 2 questions, each carrying 5 marks. The objective type test is for 10 marks of 20 minutes duration. It consists of 10 Multiple choice and 10 objective type questions, the student has to answer all the questions and each carries half mark. First midterm examination shall be conducted for the first two and half units of syllabus and second midterm examination shall be conducted for the remaining portion	75	100

Sessional Marks	University End Exam marks	Total Marks
Assignment Five marks are earmarked for assignments. There shall be two assignments in every theory course. Marks shall be awarded considering the average of two assignments in each course.		

IV. EVALUATION SCHEME

S. No	Component	Duration	Marks
1.	I Mid Examination	80 minutes	20
2.	I Assignment	-	5
3.	II Mid Examination	80 minutes	20
4.	II Assignment	-	5
5.	External Examination	3 hours	75

V. COURSE OBJECTIVES:

I. Discuss the fundamental aspects of numerical discretization.

II. Understand the major theories, approaches and methodologies used in CFD.

III. Analyze to build up the skills in the actual implementation of CFD methods (e.g. boundary conditions, turbulence modeling etc.) in using commercial CFD codes

IV. Demonstrate the applications of CFD for classic fluid dynamics problems

V. Understand basic thoughts and philosophy associated with CFD.

VI. Demonstrate the basic concepts finite volume method.

VII. Understand the various grids used in practice, including some recommendations related to grid quality.

VI. COURSE OUTCOMES:

At the end of the course the students are able to:

1. Understand different applications of CFD in different branches of engineering and its importance.
2. Understand the necessary of conservation and non-conservation forms of governing equations
3. Explain different mathematical behavior of partial differential equations.
4. Understand the basic form and nature of governing equations of fluid dynamics.
5. Analyze the different mathematical models and computational methods for flow simulations.
6. Knowledge on basic space and time discretization methods.
7. Analyze on checking and assessing the accuracy of numerical results and choosing appropriate boundary conditions for model problems.
8. Analyze the accuracy and stability of finite difference methods for model equations.
9. Explain the Consistency analysis and von Neumann stability analysis of finite difference methods.
10. Understand the necessity finite difference modules for graphical representations.
11. Discuss the different types of grids with their characteristics.
12. Understand the basic concepts associated with finite volume method.
13. Apply the different types of techniques for numerical solution.
14. Analyze assessing the efficiency of numerical methods.

15. Analyze the applications of different types of grids in CFD techniques.
16. Apply different algorithms in numerical approach for CFD analysis.

VII. PROGRAM OUTCOMES:

Program Outcomes		Level	Proficiency assessed by
PO1	**Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	H	Lectures
PO2	**Problem Analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.	H	Assignments
PO3	**Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations	S	Assignments
PO4	**Conduct investigations of complex problems** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.	H	Laboratory experiments
PO5	**Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.	S	Assignments
PO6	**The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	N	----
PO7	**Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.	N	----
PO8	**Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	N	----
PO9	**Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.	N	----
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	N	----
PO11	**Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	N	----
PO12	**Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	N	----

N-None **S-Supportive** **H-Highly Related**

VIII. PROGRAM SPECIFIC OUTCOMES:

Program Specific Outcomes		Level	Proficiency Assessed by
PSO 1	**Professional skills:** Able to utilize the knowledge of aeronautical/aerospace engineering in innovative, dynamic and challenging environment for design and development of new products	H	Lectures and Assignments
PSO 2	**Problem solving skills:** Imparted through simulation language skills and general purpose CAE packages to solve practical, design and analysis problems of components to complete the challenge of airworthiness for flight vehicles	H	Projects
PSO 3	**Practical implementation and testing skills:** Providing different types of in house and training and industry practice to fabricate and test and develop the products with more innovative technologies	H	Guest Lectures
PSO 4	**Successful career and entrepreneurship:** To prepare the students with broad aerospace knowledge to design and develop systems and subsystems of aerospace and allied systems and become technocrats	S	Seminars and Projects

N-None **S-Supportive** **H-Highly Related**

IX. SYLLABUS:

UNIT – I

BASIC ASPECTS OF COMPUTATIONAL AERODYNAMICS

Why Computational Fluid Dynamics? What is CFD? CFD as a research tool, as a design tool. Applications in various branches of engineering. Models of fluid flow- Finite Control Volume, Infinitesimal Fluid Element. Substantial derivative- physical meaning of Divergence of velocity. Derivation of continuity, momentum and energy equations- physical boundary conditions- significance of conservation and non-conservation forms and their implication on CFD applications- strong and weak conservation forms- shock capturing and shock fitting approaches.

UNIT– II

MATHEMATICAL BEHAVIOR OF PARTIAL DIFFERENTIAL EQUATIONS AND THEIR IMPACT ON COMPUTATIONAL AERODYNAMICS

Classification of quasi-linear partial differential equations by Cramer's rule and eigen value method. General behavior of different classes of partial differential equations and their importance in understanding physical and CFD aspects of aerodynamic problems at different Mach numbers involving hyperbolic, parabolic and elliptic equations- domain of dependence and range of influence for hyperbolic equations. Well-posed problems

UNIT– III

BASIC ASPECTS OF DISCRETIZATION

Introduction to finite differences- finite difference approximation for first order, second order and mixed derivatives. Pros and cons of higher order difference schemes. Difference equations- explicit and implicit approaches- truncation and round-off errors, consistency, stability, accuracy, convergence, efficiency of numerical solutions-Von Neumann stability analysis. Physical significance of CFL stability condition. Need for grid generation. Structured grids-Cartesian grids, stretched (compressed) grids, body fitted structured grids, H-mesh, C-mesh, O-mesh, I-mesh, Multi-block grids, C-H mesh, H-O-H mesh, overset grids, adaptive grids. Unstructured grids- triangular/ tetrahedral cells, hybrid grids, quadrilateral/ hexahedra cells.

UNIT– IV

FINITE VOLUME METHODS

Basis of finite volume method- conditions on the finite volume selections- cell-centered and cell-vertex approaches. Definition of finite volume discretization-general formulation of a numerical scheme- two-dimensional finite volume method with example

UNIT– V

CFD TECHNIQUES

Lax-Wendroff technique, MacCormack's technique-Crank Nicholson technique-Relaxation technique- aspects of numerical dissipation and dispersion. Alternating-Direction-Implicit (ADI) Technique. Pressure correction technique- application to incompressible viscous flow- need for staggered grid. Philosophy of pressure correction method- pressure correction formula. Numerical procedures- SIMPLE, SIMPLER, SIMPLEC and PISO algorithms. Boundary conditions for the pressure correction method

TEXT BOOKS:

T1. Anderson, J.D., Jr., "Computational Fluid Dynamics- The Basics with Applications", McGraw-Hill Inc, 2012.
T2. Anderson, D.A., Tannehill, J.C., Pletcher, R.H., "Computational Fluid Mechanics and Heat Transfer", 1st edition, 1997.

REFERENCES:

R1. Hirsch, C., "Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics", Vol. I, Butter worth-Heinemann, 2nd edition, 2007.
R2. Versteeg, H.K. and Malalasekera, W., An Introduction to Computational Fluid Dynamics-The Finite Volume Method
R3. Tu, J., Yeoh, G.H., Liu, C., Computational Fluid Dynamics-A Practical Approach, Butterworth-Heinemann, 2008

X. COURSE PLAN:

At the end of the course, the students are able to achieve the following course learning outcomes.

Lecture No.	Course Learning Outcomes	**Topics to be covered**	**Reference**
1-2	Define fluid dynamics	Computational Fluid Dynamics introduction	T1 - 1.1
3-4	Examine the CFD as a research tool and a design tool	CFD is a Research tool, as a design tool and Applications in various branches of engineering Models of fluid flow, Finite Control Volume, Infinitesimal Fluid Element	T1 - 1.2,1.3, 2.2
5-6	Relate substantial derivative and divergence of velocity	Substantial derivative	T1 - 2.3
7-8	Evaluate divergence of velocity	physical meaning of Divergence of velocity	T1 – 2.4
9-10	Describe the basic equations	Continuity, Momentum & Energy Equations	T1 – 2.5, 2.6, 2.7
11-12	Apply various boundary conditions	Physical Boundary Conditions	T1 – 2.9
13-14	Explain importance of conservative forms of CFD	significance of conservation and non-conservation forms and their implication on CFD applications	T1 – 2.10
15-16	Discuss various methods of conservative forms	Strong and weak conservation forms	T1 – 2.10
17-18	Explain various methods of shock approaches	Shock capturing and shock fitting approaches.	T1 – 2.10
19-20	Explain the different type of equations by using different methods discuss quasi linear PDE	Classification of quasi-linear partial differential equations by Cramer's rule and Eigen value method	T1 – 3.2
21-22	Define different types of PDE	General behavior of different classes of partial differential equations	T1 – 3.4
23-24	Describe aero dynamical problems	Partial different equations importance in understanding physical and CFD aspects of aerodynamic problems.	T1 – 3.4

25-26	Explain hyperbolic and parabolic equations	At different Mach numbers involving hyperbolic, parabolic and elliptic equations	T1 – 3.4
27-28	Discuss problems	dependence and range of influence for hyperbolic equations, Well-posed problems	T1 – 3.4
29-30	Describe discretization and the grid discuss different type of derivatives	Introduction to Finite Differences finite difference approximation for first order, second order and mixed derivatives	T1 – 4.2
31-32	Explain advantages and disadvantages of schemes	Pros and cons of higher order difference schemes	T1 – 4.2
33-34	Discuss different type of approaches to solve the equations	Difference equations- explicit and implicit approaches	T1 - 42
35-36	Explain Von-Nuemen stability analysis and errors	truncation and round-off errors, consistency, stability, accuracy, convergence	T1 – 4.5
37-38	Explain the CFL condition	Von Neumann stability analysis Physical significance of CFL stability condition	T1 – 4.5
39-40	Explain different types of grids	Need for grid generation Structured grids	R1 – 6.1
41-42	Define the need of grids and their uses	Cartesian grids stretched (compressed) grids body fitted structured grids	R1 – 6.1.1, 6.1.2, 6.1.3
43-44	Discuss the different type of meshes and the multi block grids	H-mesh, C-mesh, O-mesh, I-mesh & Multi-block grids, C-H mesh, H-O-H mesh, overset grids,	R1 – 6.1.4
45-46	Examine the structured and unstructured grids and cells	Adaptive grids, Unstructured grids Triangular/ tetrahedral cells, hybrid grids Quadrilateral/ hexahedra cells	R1 – 6.2
47-48	Explain finite volume methods	Basis of finite volume method conditions on the finite volume selections	R1 – 5.2
49-50	Define cell entered and cell vertex approaches	Cell-centered and cell-vertex approaches	R1 – 5.2.1
51-52	Explain finite volume discretization	Definition of finite volume discretization General formulation of a numerical scheme	R1 - 5.2.2, 5.2.3
53-54	Discuss FVM	2-dimensional finite volume method with example	R1 – 5.3
55-56	Explain the numerical solution of flow problems Discuss the finite difference method for solving fluid flows	Lax-Wendroff technique ,Mac Cormack's technique-Crank Nicholson technique	T1 – 6.2, 6.3
57-58	Explain the diffusion behavior of the numerical solution, the application of the of many fluid problems	Relaxation technique, aspects of numerical dissipation and dispersion, Alternating Direction Implicit Technique	T1 – 6.5, 6.6, 6.7
59-60	Explain the techniques that used application in the numerical solution of incompressible Navier-storke equations	Pressure correction technique- application to incompressible viscous flow	T1 – 6.8
61-62	Describe the staggered grid and the method	Need for staggered grid. Philosophy of pressure correction method	T1 – 6.8.2
63-64	Discuss the numerical procedures	Pressure correction formula Numerical procedures	T1 – 6.8.3
65-66	Explain the algorithms to solve the equations	SIMPLE, SIMPLER, SIMPLEC and PISO algorithms	R2 – 6.4, 6.6, 6.7, 6.8
67-68	Apply the boundary conditions for pressure correction	Boundary conditions for the pressure correction method	T1 – 6.8.6

XI. MAPPING COURSE OBJECTIVES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES

Course Objectives	Program Outcomes												Program Specific Outcomes			
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
I	S	H	S	S	S								H		H	S
II	S			H	S								H	H		S
III		S	H		H								H		H	
IV	H	H	S	H	S									H	H	S
V	S		H	H	S											
VI	H	S	S	S	H								H	H	H	S
VII		H		H	S								S	H		

S-Supportive **H-Highly Related**

XII. MAPPING COURSE OUTCOMES LEADING TO THE ACHIEVEMENT OF PROGRAM OUTCOMES:

Course Outcomes	Program Outcomes												Program Specific Outcomes			
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
1		H	H	S	H									H	S	S
2	H				H								H	H		S
3	S	H	H	H	H									H	S	S
4	S		S	H										S		S
5	H		H	H	H								H	H	H	
6		S	H	H									H			
7		H		H	S								H	H	S	S
8	H			S									S		S	S
9	H	H											H	H	H	
10	H	H		S										H	S	S
11	S	S	H		H									H		
12	H			H									H			S
13		H	H											H	H	
14			S	S	H								H	H		
15		H														S
16			S		S								H	H	H	

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Prepared by: Prepared By: Dr. G Malaikhannan, Professor, Dept of AE, Mr. G Satya Dileep, Assistant Professor, Dept of AE

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