INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

AERONAUTICAL ENGINEERING

COURSE DESCRIPTOR

Course Title	**COMPUTATIONAL AERODYNAMICS**				
Course Code	AAE013				
Programme	B.Tech				
Semester	VI	AE			
Course Type	Core				
Regulation	IARE - R16				
Course Structure	**Theory**			**Practical**	
	Lectures	**Tutorials**	**Credits**	**Laboratory**	**Credits**
	3	1	4	-	-
Chief Coordinator	Ms. D. Anitha, Assistant Professor				
Course Faculty	Mr G Satya Dileep, Assistant Professor Ms. D. Anitha, Assistant Professor				

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 elaborates applications, including projects for students and professionals to use CFD in much more realistic situations.

II. COURSE PRE-REQUISITES:

Level	Course Code	Semester	Prerequisites	Credits
UG	AAE003	III	Fluid Mechanics and Hydraulics	4
UG	AAE004	IV	Low Speed Aerodynamics	4
UG	AAE008	V	High Speed Aerodynamics	4

III. MARKS DISTRIBUTION:

Subject	SEE Examination	CIA Examination	Total Marks
Computational Aerodynamics	70 Marks	30 Marks	100

IV. DELIVERY / INSTRUCTIONAL METHODOLOGIES:

✘	Chalk & Talk	✔	Quiz	✔	Assignments	✘	MOOCs
✔	LCD / PPT	✔	Seminars	✘	Mini Project	✔	Videos
✘	Open Ended Experiments						

V. EVALUATION METHODOLOGY:

The course will be evaluated for a total of 100 marks, with 30 marks for Continuous Internal Assessment (CIA) and 70 marks for Semester End Examination (SEE). Out of 30 marks allotted for CIA during the semester, marks are awarded by taking average of two CIA examinations or the marks scored in the make-up examination.

Semester End Examination (SEE): The SEE is conducted for 70 marks of 3 hours duration. The syllabus for the theory courses is divided into FIVE modules and each module carries equal weightage in terms of marks distribution. The question paper pattern is as follows. Two full questions with "either" or "choice" will be drawn from each module. Each question carries 14 marks. There could be a maximum of two sub divisions in a question.

The emphasis on the questions is broadly based on the following criteria:

50 %	To test the objectiveness of the concept.
50 %	To test the analytical skill of the concept OR to test the application skill of the concept.

Continuous Internal Assessment (CIA):

CIA is conducted for a total of 30 marks (Table 1), with 25 marks for Continuous Internal Examination (CIE), 05 marks for Quiz/ Alternative Assessment Tool (AAT).

Table 1: Assessment pattern for CIA

Component	**Theory**		**Total Marks**
Type of Assessment	CIE Exam	Quiz / AAT	
CIA Marks	25	05	30

Continuous Internal Examination (CIE):

Two CIE exams shall be conducted at the end of the 8th and 16th week of the semester respectively. The CIE exam is conducted for 25 marks of 2 hours duration consisting of two parts. Part–A shall have five compulsory questions of one mark each. In part–B, four out of five questions have to be answered where, each question carries 5 marks. Marks are awarded by taking average of marks scored in two CIE exams.

Quiz / Alternative Assessment Tool (AAT):

Two Quiz exams shall be online examination consisting of 25 multiple choice questions and are be answered by choosing the correct answer from a given set of choices (commonly four). Marks shall be awarded considering the average of two quizzes for every course. The AAT may include seminars, assignments, term paper, open ended experiments, five minutes video.

VI. HOW PROGRAM OUTCOMES ARE ASSESSED:

Program Outcomes (POs)		Strength	Proficiency assessed by
PO 1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	Presentation on real-world problems
PO 2	**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	2	Seminar
PO 3	**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.	2	Seminars
PO 4	**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.	2	Videos on real time problems
PO 5	**Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and	1	Assignment

Program Outcomes (POs)		Strength	Proficiency assessed by
	modeling to complex engineering activities with an understanding of the limitations including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.		

3 = High; 2 = Medium; 1 = Low

VII. HOW PROGRAM SPECIFIC OUTCOMES ARE ASSESSED:

Program Specific Outcomes (PSOs)		Strength	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	1	Seminar
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.	2	Lectures and Assignment
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	-	-
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.	-	-

3 = High; 2 = Medium; 1 = Low

VIII. COURSE OBJECTIVES :

The course should enable the students to:	
I	Discuss the fundamental aspects of numerical discretization and the major theories, approaches and methodologies used in computational aerodynamics.
II	Analyze to build up the skills in the actual implementation of computational aerodynamics methods boundary conditions, turbulence modeling etc by using commercial CFD codes.
III	Demonstrate the applications of CFD for classic fluid dynamics problems and basic thoughts and philosophy associated with CFD.
IV	Understand the various grids used in practice, including some recommendations related to grid quality and choose appropriate data structure to solve problems in real world.

IX. COURSE OUTCOMES (COs):

COs	Course Outcome	CLOs	Course Learning Outcome
CO 1	Understand the applications of CFD in various engineering fields and to generate governing equations in conservative and non-conservative form.	CLO 1	Understand the necessity of CFD tool as both research and design areas in modern computational world.
		CLO 2	Explain the applications of computational fluid dynamics tool in various engineering branches other than aerospace engineering.
		CLO 3	Recognize the selection of type of flow from the finite control volume and infinitesimal small fluid element depending upon the requirements.
		CLO 4	Develop the governing equations required for computational aerodynamics in both conservation and non-conservation forms.
CO 2	Understand the mathematical behaviour of partial differential equations and classify into hyperbolic, parabolic and elliptical natures.	CLO 5	Explain the need of classification of quasi linear partial differential equations by Cramer's rule and Eigen Value Method.
		CLO 6	Understand the concepts of range of influence and domain of dependence for a flow field.
		CLO 7	Explain the general behavior of the partial differential equations which falls in hyperbolic, parabolic and elliptic equations.
		CLO 8	Demonstrate the CFD aspects of the hyperbolic, parabolic and elliptic equations in aerodynamic problems and physical problems.
CO 3	Acquire the concepts of finite difference method through discretization and grid generation techniques.	CLO 9	Discuss the concepts of finite differences approximation for first order, second order and mixed order derivatives.
		CLO 10	Distinguish between explicit and implicit approaches that are needed for solving different finite differential equations.
		CLO 11	Explain the Consistency analysis and von Neumann stability analysis of finite difference methods and physical significance of CFL condition.
		CLO 12	Discuss the different types of grids available for different flow fields available in computational fluid dynamics.
		CLO 13	Understand the need for generating grids for solving the finite differential equations in analyzing a flow field.
		CLO 14	Explain the technique of pressure correction method with the need of staggered grid and its philosophy.
CO 4	Identify different CFD techniques available for different partial differential equations.	CLO 15	Discuss the aspects of numerical dissipation and numerical dispersion and explain the applications of each in CFD techniques.
		CLO 16	Explain the technique of pressure correction method with the need of staggered grid and its philosophy.
		CLO 17	Explain the numerical procedures for analysis like SIMPLE, SIMPLER SIMPLEC and PISO algorithms and differentiate with regular CFD techniques.
CO 5	Explore the concepts of finite volume methods, and its difference from finite difference method.	CLO 18	Discuss the concepts of finite volume method and explain the difference from finite difference method for solving different flow field.
		CLO 19	Demonstrate the need of finite volume discretization and its general formulation of a numerical scheme in finite volume method.
		CLO 20	Understand the principle of two dimensional finite volume methods in solving flow fields with finite control volume.

X. COURSE LEARNING OUTCOMES (CLOs):

CLO Code	CLO's	At the end of the course, the student will have the ability to:	PO's Mapped	Strength of Mapping
AAE013.01	CLO 1	Understand the necessity of CFD tool as both research and design areas in modern computational world	PO 1,PO 2	3
AAE013.02	CLO 2	Explain the applications of computational fluid dynamics tool in various engineering branches other than aerospace engineering.	PO 1	3
AAE013.03	CLO 3	Recognize the selection of type of flow from the finite control volume and infinitesimal small fluid element depending upon the requirements.	PO 2	3
AAE013.04	CLO 4	Develop the governing equations required for computational aerodynamics in both conservation and non-conservation forms.	PO 2,PO 3	3
AAE013.05	CLO 5	Explain the need of classification of quasi linear partial differential equations by Cramer's rule and Eigen Value Method.	PO 2	2
AAE013.06	CLO 6	Understand the concepts of range of influence and domain of dependence for a flow field.	PO 1	2
AAE013.07	CLO 7	Explain the general behaviour of the partial differential equations which falls in hyperbolic, parabolic and elliptic equations.	PO 2,PO 3	2
AAE013.08	CLO 8	Demonstrate the CFD aspects of the hyperbolic, parabolic and elliptic equations in aerodynamic problems and physical problems.	PO 3	2
AAE013.09	CLO 9	Discuss the concepts of finite differences approximation for first order, second order and mixed order derivatives.	PO 2,PO 3	3
AAE013.10	CLO 10	Distinguish between explicit and implicit approaches that are needed for solving different finite differential equations.	PO 2,PO 3	3
AAE013.11	CLO 11	Explain the Consistency analysis and von Neumann stability analysis of finite difference methods and physical significance of CFL condition.	PO 2,PO 3	3
AAE013.12	CLO 12	Discuss the different types of grids available for different flow fields available in computational fluid dynamics.	PO 3	2
AAE013.13	CLO 13	Understand the need for generating grids for solving the finite differential equations in analyzing a flow field.	PO 3	2
AAE013.14	CLO 14	Describe the various CFD techniques available for solving the finite differential equations for a flow field.	PO 4	2
AAE013.15	CLO 15	Discuss the aspects of numerical dissipation and numerical dispersion and explain the applications of each in CFD techniques.	PO 4,PO 5	2
AAE013.16	CLO 16	Explain the technique of pressure correction method with the need of staggered grid and its philosophy.	PO 2,PO 4	2
AAE013.17	CLO 17	Explain the numerical procedures for analysis like SIMPLE, SIMPLER SIMPLEC and PISO algorithms and differentiate with regular CFD techniques.	PO 4,PO 5	3
AAE013.18	CLO 18	Discuss the concepts of finite volume method and explain the difference from finite difference method for solving different flow field.	PO 3,PO 4	2

CLO Code	CLO's	At the end of the course, the student will have the ability to:	PO's Mapped	Strength of Mapping
AAE013.19	CLO 19	Demonstrate the need of finite volume discretization and its general formulation of a numerical scheme in finite volume method.	PO 3	3
AAE013.20	CLO 20	Understand the principle of two dimensional finite volume methods in solving flow fields with finite control volume.	PO 4	3

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

Course Outcomes (COs)	Program Outcomes (POs)			Program Specific Outcomes (PSOs)
	PO 1	PO 2	PO 5	PSO 2
CO 1	3	2	1	2
CO 2	3	2	1	2
CO 3	3	2	1	
CO 4	3	2	1	
CO 5	3	2	1	2

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

CLOs	Program Outcomes (POs)												Program Specific Outcomes (PSOs)			
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
CLO 1	3	3														
CLO 2	3															
CLO 3		3											1			
CLO 4		3	2													
CLO 5		2														
CLO 6	2															
CLO 7		3	2										1			
CLO 8			2										1			
CLO 9		3	3										2			
CLO 10		3	3										2			
CLO 11		3	3										2			
CLO 12			2										1			

CLOs	Program Outcomes (POs)												Program Specific Outcomes (PSOs)			
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2	PSO3	PSO4
CLO 13			2										1			
CLO 14				2										1		
CLO 15				3	1									2		
CLO 16		2		2										1		
CLO 17				3	2									2		
CLO 18			3	1										1		
CLO 19			3										2			
CLO 20			3											1		

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XIII. ASSESSMENT METHODOLOGIES – DIRECT

CIE Exams	PO 1, PO 2, PO 3, PO 4, PO 5	SEE Exams	PO 1, PO 2, PO 3, PO 4, PO 5	Assignments	PO1, PO2	Seminars	PO1, PO2, PO3
Laboratory Practices	PO 4, PO 5	Student Viva	-	Mini Project	PO4, PO5	Certification	PO 5
Term Paper	-						

XIV. ASSESSMENT METHODOLOGIES - INDIRECT

✔	Early Semester Feedback	✔	End Semester OBE Feedback
✘	Assessment of Mini Projects by Experts		

XV. SYLLABUS

Unit-I	INTRODUCTION
Need of computational fluid dynamics, philosophy of 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 difference: finite difference approximation for first order, second order and mixed derivatives, 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 artesian 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, hexahedral cells.	
Unit-IV	**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.	
Unit-V	**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 methods with example.	
Text Books:	
1. J. D. Anderson, Jr., "Computational Fluid Dynamics- The Basics with Applications", McGrawHill Inc, 2012. 2. D A Anderson, J C Tannehill, R H Pletcher, "Computational Fluid Mechanics and Heat Transfer", 1st edition, 1997.	
Reference Books:	
1. Hirsch, C., "Numerical Computation of Internal and External Flows: The Fundamentals of Computational Fluid Dynamics", Vol. I, Butter worth-Heinemann, 2nd edition, 2007. 2. Hoffmann, K. A. and Chiang, S. T., "Computational Fluid Dynamics for Engineers", Engineering Education Systems, 4th edition, 2000. 3. Patankar, S.V., "Numerical Heat Transfer and Fluid Flow", Hemisphere Pub. Corporation, 1st edition, 1980. 4. H K Varsteeg, W Malalasekera, " An Introduction to Computational Fluid Dynamics – The Finite Volume MEthod", Longman Scientific and Technical, 1st edition, 1995.	

XVI. COURSE PLAN:

The course plan is meant as a guideline. Probably there may be changes.

Lecture No	Topics to be covered	Course Learning Outcomes (CLOs)	Reference
1	Computational Fluid Dynamics introduction	CLO 1	T1 : 1.1
2-3	CFD is a Research tool, as a design tool and Applications in various branches of engineering	CLO 2	T1 : 1.2,1.3,1.4
4-5	Models of fluid flow, Finite Control Volume Infinitesimal Fluid Element Substantial derivative	CLO 3	T1 : 2.2, 2.3
6	Physical meaning of Divergence of velocity	CLO 3	T1 : 2.4
7-8	Continuity, Momentum Equations	CLO 4	T1 : 2.5, 2.6
9-10	Energy Equations	CLO 4	T1 : 2.7
11-12	Physical Boundary Conditions	CLO 4	T1 : 2.9
13-14	Significance of conservation and non-conservation forms and their implication on CFD applications	CLO 4	T1 : 2.10
15	Strong and weak conservation forms	CLO 4	T1 : 2.10
16	Shock capturing and shock fitting approaches.	CLO 4	T1 : 2.10

Lecture No	Topics to be covered	Course Learning Outcomes (CLOs)	Reference
17-18	Classification of quasi-linear partial differential equations by Cramer’s rule and Eigen value method	CLO 5	T1 : 3.2,3.3
19	General behaviour of different classes of partial differential equations	CLO 7	T1 : 3.4
20	Partial different equations importance in understanding physical and CFD aspects of aerodynamic problems.	CLO 8	T1 : 3.4
21	Different Mach numbers involving hyperbolic, parabolic and elliptic equations	CLO 7	T1 : 3.4
22	Dependence and range of influence for hyperbolic equations, Well-posed problems	CLO 6	T1 : 3.4
23-24	Introduction to Finite Differences finite difference approximation for first order, second order and mixed derivatives	CLO 9	T1 : 4.1, 4.2, 4.3
25	Pros and cons of higher order difference schemes	CLO 9	T1 : 4.3
26-27	Difference equations- explicit and implicit approaches	CLO 10	T1 : 4.4
28	Truncation and round-off errors, consistency, stability, accuracy, convergence	CLO 11	T1 : 4.5
29-30	Von Neumann stability analysis Physical significance of CFL stability condition	CLO 11	T1 : 4.5
31	Need for grid generation Structured grids	CLO 12	R1 : 6.1
32-33	Cartesian grids stretched (compressed) grids body fitted structured grids	CLO 12	R1 : 6.1.1, 6.1.3
34-36	H-mesh, C-mesh, O-mesh, I-mesh & Multi-block grids, C-H mesh, H-O-H mesh, overset grids,	CLO 12	R1 : 6.1.3, 6.1.4
37-38	Adaptive grids, Unstructured grids Triangular/ tetrahedral cells, hybrid grids Quadrilateral/ hexahedra cells	CLO 13	R1 : 6.2
39-40	Lax-Wendroff technique, Mac Cormack’s technique Crank Nicholson technique	CLO 14	T1 : 6.2, 6.3, 4.4
41-42	Relaxation technique, aspects of numerical dissipation and dispersion, Alternating Direction Implicit Technique	CLO 15	T1 : 6.5, 6.6, 6.7
43	Pressure correction technique- application to incompressible viscous flow	CLO 16	T1 : 6.8
44-45	Need for staggered grid. Philosophy of pressure correction method	CLO 16	T1 : 6.8.2, 6.8.3
46-47	Pressure correction formula and Numerical procedures	CLO 16	T1 : 6.8.4
48-50	SIMPLE, SIMPLER, SIMPLEC and PISO algorithms	CLO 17	R4 : 6.4, 6.6, 6.7, 6.8
51	Boundary conditions for the pressure correction method	CLO 16	T1 : 6.8.6
52	Basis of finite volume method conditions on the finite volume selections	CLO 18	R1 : 5.1
53	Cell-centered and cell-vertex approaches	CLO 18	R1 : 5.2
54-55	Definition of finite volume discretization General formulation of a numerical scheme	CLO 19	R1 : 5.2.2, 5.2.3
56-57	2-dimensional finite volume method with example	CLO 20	R1 : 5.3.1

XVII. GAPS IN THE SYLLABUS-TO MEET INDUSTRY / PROFESSION REQUIREMENTS:

S no	Description	Proposed actions	Relevance with POs	Relevance with PSOs
1	Transformation of space coordinates into computational coordinates	Assignments / Seminars/ NPTEL/ Guest Lectures	PO 1, PO 2, PO 5	PSO 2
2	Numerical calculations for solving PDEs	Seminars / Laboratory Practices / Video Lectures	PO 1, PO 2, PO 3, PO 4	PSO 2, PSO 3
3	Transformation of space coordinates into computational coordinates	Assignments / Seminars/ NPTEL/ Guest Lectures	PO 1, PO 2, PO 5	PSO 2

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HOD, AE