INDIAN INSTITUTE OF TECHNOLOGY MADRAS
CHENNAI 600 036

International Interdisciplinary Master's Programs
Curriculum
Master of Technology in Computational Engineering
(2022-2024)

Curriculum (Master of Technology in Computational Engineering) (2022-2024)

Overview

The International Interdisciplinary Master's Programs (I2MP) are specially curated two-year programs that provide international students from any engineering background with a great opportunity to be part of the vibrant and world-class learning environment at IIT Madras. This document is aimed at providing a brief overview of the syllabus for the program.

IIT Madras is one of the only educational Institutions in India to offer this Interdisciplinary Master's Degree, providing students an unprecedented level of academic flexibility to learn and work in current areas that would define the future of global engineering and technology.

The International Interdisciplinary Master's degrees are available in nine interdisciplinary areas:

- Energy systems,
- Robotics,
- Quantum Science and Technology,
- **Computational Engineering**,
- Advanced Materials and Nanotechnology,
- Data Science,
- Cyber Physical Systems,
- Complex Systems and Dynamics, and
- Biomedical Engineering.

The International Interdisciplinary Master's Program provides a platform for international students with exceptional performance in their undergraduate programs to participate in these activities. In addition to courses in Data Science, and Biomedical Engineering, among others, the international students will take up courses in Indian culture as well. A dedicated research skills course will prepare them for their master's thesis work.

IIT Madras is constantly striving to expand the horizons of traditional engineering education and research and is home to the best and brightest. The institute has a rich culture of deep research, technology development and entrepreneurship, which have been developed over the decades without compromise on the teaching/learning of foundational science and engineering.

The Interdisciplinary Master's programs - offered to international students via the I2MP (International Interdisciplinary Master's Program), and to Indian students through the hugely popular Interdisciplinary Dual Degree (IDDD) - represent the culmination of decades of excellence at IIT Madras.

The first batch of foreign students joined the program in July 2022.

Program Structure:

The 2-year program is offered over 4 semesters. Students complete Core Courses, Electives (Free and Core) and a Research project.

The core courses are designed to give a complete overview of the entire domain, the students are free to choose electives that will enable them to chalk out a further path of their choice. A large set of carefully selected electives are provided which will the student to explore a particular aspect of the program according to their area of interest. I2MP Core/Core courses should be completed during four semesters with the approval of faculty advisors and the ID coordinator.

Students will learn the skills of carrying out research in the research skills course. It is designed to build a foundation for the thesis work that will be completed in the third and fourth semester.

The thesis will involve one year of work completed in third and fourth semester and will be supervised by faculty from IIT Madras.

***Note:** This document is meant to be a guide and is subject to final approval by departments. There may be periodic revisions to the syllabus. Students are requested to confirm their course choices and electives with their respective program coordinators before registering.

Topic	Page
Basket of I2MP Core Courses	4
Basket of HSS Elective Courses	5
Computational Engineering	6

Basket of I2MP Core Courses

Course No.	Course Name	Semester	Course No.	Course Name	Semester
CH5020	Statistical Design and Analysis of Experiments	Jul - Nov	CE5235	Introduction to Climate Dynamics and its Mysteries	Jul – Nov
CH5650	Molecular Data Science and Informatics	Jan - May	ED5015	Computational Methods in Design	Jan – May
CH5170	Process Optimization	Jan –May	ED5017	Digital Signal Processing for Engineering Design	Jan – May
CH5019	Mathematical Foundations of Data Science	Jan - May	ED5317	Strategies for Managing innovation	Jul – Nov
CH5023	Unconventional Oil and Gas Resources	Jan - May	ED5340	Data Science: Theory and practice	Jul – Nov
EE6432	Stochastic Control	Jul - Nov	ED6002	Optimization methods in Engineering Design	Jul – Nov
EE6180	Advanced Topics in Artificial Intelligence		ED5318	Biomimetic Design	Jan –May
EE6150	Stochastic Modeling and the Theory of Queues		PH5820	Classical Physics	Jul - Nov
EE5413	Linear Dynamical Systems	Jul - Nov	PH5825	Quantum Physics	Jan-May
EE5412	Mathematical Methods in System Engineering	Jul - Nov	EE5120	Applied Linear Algebra	Jul – Nov
EE5401	Measurements and Instrumentation	Jul - Nov	ED5012	Advanced Applications of Human Factors	Jan –May
EE5121	Convex Optimization	Jul - Nov	ME5201	Computational Methods in Engineering	Jul - Nov
EE6430	Fundamentals of Linear Optimization	Jan - May	ME5204	Finite Element Analysis	Jul - Nov

EE6415	Nonlinear Control Systems	Jan - May	ME5207	Design with Advanced Engineering Materials	Jul - Nov
EE6412	Optimal Control	Jan - May	ME6355	Topology optimization	Jan –May
EE6150	Stochastic Modeling and the Theory of Queues	Jan - May	ME6127	Energy & Environment	Jan – May
EE6112	Topics in Random Processes and Concentrations	Jan - May	ME5204	Finite Element Analysis	Jan – May
EE5180	Introduction to Machine Learning	Jul – Nov	MA5892	Numerical Methods in Scientific Computing	Jul - Nov
AM6016	Convective Transport Processes	Jul – Nov	AM5090	Flow Visualization and Imaging Techniques	Jan – May
MA5910	Data Structures in Scientific Computing	Jul - Nov	MA5470	Numerical Analysis	Summer
PH6012	Fundamentals of Semiconductor Physics and Devices	Jan - May			

HSS Elective Courses Basket

Course Number	Course Number	Semester
HS6080	An Intro. to Classical Sanskrit Literature	
HS6026	Indian Aesthetic Thought	
HS5711	Ethics	Jul - Nov
HS5650	Drama	Jul - Nov
HS5712	Advanced Topics in Economic Development	Jul - Nov
HS5813	Post-Colonial & New Writings	Jul - Nov
HS6520	Culture and Development	Jan – May
HS6160	The Literature of Environmental Justice	Jul – Nov
HS5060	Technology & Sustainable Development	Jan – May

*All courses will be taken with the prior approval of faculty advisors and the ID coordinato

Computational Engineering

The development of Engineering Analysis and design tools for Complex Engineering problems is facilitated through the International Masters programme in Computational Engineering. Computing tools for the development of Engineering software tools are pervasive. They involve CPU-intensive calculations in most disciplines such as Aerospace, Civil, Chemical, Electrical, Mechanical, Materials, Naval Engineering, etc. The graduates from this program will reinforce their Simulation and Mathematical modelling expertise in their core Engineering discipline. This is facilitated through a focused bundle of courses that hone their skill set on tools and techniques from Computer Science, Applied Mathematics, and their own discipline in a structured and systematic way. The graduates are expected to compete and reinforce the development of Engineering software development.

S. No.	Course Number	Course Name	L	T	E	P	O	C
Semester 1								
1	GN5004	Research Skills	0	0	0	3	0	3
2		I2MP Core 1*						9 to 12
3	Core - 1	CORE-1 basket	3	0	0	0	6	9
4	Core - 2	CORE-2 basket	3	0	0	0	6	9
5	Elective 1	Elective 1: Preferably chosen from a chosen elective stream	3	0	0	0	6	9
6	AM5801	Computational Laboratory	0	0	0	3	2	5
		Total Credits						44 to 47
Semester 2								
1	HS5050	Indian Culture	0	0	0	3	0	3
2		I2MP Core 2*						9 to 12
3	HS Elective		3	0	0	0	6	9
4	Core – 3	CORE - 3 basket	3	0	0	0	6	9
5	Core – 4	CORE - 4 basket	3	0	0	0	6	9
6	AM5035*	High-Performance Computing Lab	0	0	0	3	2	5
7	Elective 2	Elective 2: Preferably chosen from a chosen elective stream	3	0	0	0	6	9
		Total Credits						53 to 56

Summer								
1	ID5390	Summer Project / Summer Industrial Internship/(Project I)	0	0	0	0	15	15
		Total Credits						15
Semester 3								
1	Elective - 3	Elective 3: Preferably chosen from the same Elective Stream	3	0	0	0	6	9
2	ID5391	Project II	0	0	0	0	30	30
		Total Credits						39
Semester 4								
1	ID5392	Project III	0	0	0	0	40	40
		Total Credits						40

I2MP Core and HS Electives are given on pages 4-5.

Baskets of Core Courses

		Basket of courses for CORE – 1: Numerical Methods						
1	AM5600	Computational Methods in Mechanics	3	0	0	0	6	9
2	ME6000	Computational Methods in Engineering	3	0	0	0	6	9
3	ME6150	Numerical Methods in Thermal Engineering	3	0	0	6	6	10
4	MA5470	Numerical Analysis	3	0	0	0	6	9
5	PH5730	Methods of Computational Physics	3	0	0	0	6	9
6	CH6060	Numerical Techniques for Engineers	3	0	0	0	6	9
7	MM5024	Numerical Methods for Metallurgists	3	0	0	0	6	9
8	OE5450	Numerical Techniques in Ocean Hydrodynamics	3	0	1	0	6	12
9	MA5890	Numerical Linear Algebra	3	0	0	0	6	9
10	MA5892	Numerical Methods in Scientific computing	3	0	0	0	6	9

		Basket of courses for **CORE - 2:** Computational Implementation						
1	MA5910	Data Structures in Scientific Computing	3	0	0	0	6	12
2	ID6105	Computational Tools: Algorithms, Data Structures and Programs	3	0	0	0	6	9
3	EE4371	Introduction to Data Structures and Algorithms	3	0	0	0	6	9

		Basket of courses for **CORE - 3:** Discretization Methods						
1	CE5610	Finite Element Analysis	3	0	0	0	6	9
2	AM5630	Foundations of Computational Fluid Dynamics	3	0	0	0	6	9
3	CH6110	Finite Element Methods in Engineering	3	0	0	0	6	9
4	ME6800	Finite Element Analysis	3	0	0	0	6	9
5	OE5500	FEM applied to Ocean Engineering	3	0	0	0	6	9
6	CH6020	Computational Fluid Dynamics Techniques	3	0	0	0	6	9
7	AM5450	Fundamentals of Finite Element Analysis	3	0	0	0	6	9
8	ME5204	Finite Element Analysis	3	0	0	0	6	9
9	OE5450	Numerical Techniques in Ocean Hydrodynamics	3	0	0	0	6	9

		Basket of courses for **CORE - 4:** HPC/ Parallel Computing						
1	AM5080	High-Performance Computing for Engineering Applications	3	0	0	0	6	9
2	ID5130	Parallel Scientific Computing	3	0	0	1	6	10

		Suggested Elective streams						
	Stream 1	**Computational Fluid Dynamics**						
1	AM5630	Foundations of Computational Fluid Dynamics	3	0	0	0	6	9
2	AM5570	Introduction to Turbulence	3	0	0	0	6	9
3	AM6513	Advanced Computational Fluid Dynamics	3	0	0	0	6	9
4	AM5640	Turbulence Modeling	3	0	0	0	6	9
5	ME6650	Computational Fluid Dynamics of Turbomachinery	3	0	0	0	6	9
6	ME6151	Computational Heat and Fluid Flow	3	0	0	0	6	9
7	CH6020	Computational Fluid Dynamics Techniques	3	0	0	0	6	9
8	AM6512	Application of Molecular Dynamics	3	0	0	0	6	9
9	ME6280	Design and Optimization of Energy systems	3	0	0	0	6	9
10	OE6020	Meshfree methods applied to hydrodynamics	3	0	3	0	6	12
11	PE6031	Reservoir Simulation	3	0	0	0	6	9
12	AM5530	Advanced Fluid Mechanics	3	0	0	0	6	9
13	CH5140	Process Analysis and Simulation	3	0	0	0	6	9
14	CH5541	Advanced Momentum Transport	3	0	0	0	6	9

15	ME5110	Inverse Methods in Heat Transfer	3	0	0	0	6	9
16	AS5420	Introduction to CFD	3	0	0	0	6	9
17	AS6041	Advanced CFD - Eddy Resolving Methods	3	0	0	0	6	9

	Stream 2	**Computational Solid Mechanics**						
1	AM5450	Fundamentals of Finite Element Analysis	3	0	0	0	6	9
2	AM6512	Application of Molecular Dynamics	3	0	0	0	6	9
3	AM6291	Computational Structural Dynamics	3	0	0	0	6	9
4	ME7680	Optimization Methods for Mechanical Design	3	0	0	0	6	9
5	ME6280	Design and Optimization of Energy systems	3	0	0	0	6	9
6	E7730	Advanced Finite Element Analysis	3	0	0	0	6	9
7	AM5390	Advanced Structural Mechanics	3	0	0	0	6	9
	Stream 3	**Computational Materials Engineering**						
1	ME7244	Foundations of Computational Materials Modeling	3	0	0	0	6	9
2	MM6010	Computational Materials Thermodynamics	3	0	0	0	6	9
3	ME7160	Computational Methods in Design & Mfg.	3	0	0	0	6	9
4	AM6512	Application of Molecular Dynamics	3	0	0	0	6	9
5	MM5011	Modeling of Transport Phenomena in multi-phase systems	3	0	0	0	6	9
6	MM5003	Atomistic Modeling of Materials	2	1	0	0	6	9
7	ED5053	Mechanics of Materials with Microstructure	3	0	0	0	6	9

	Stream 4	Computational Biology						
1	BT6090	Intro. to Bioinformatics & Computational Biology	3	0	0	0	6	9
2	BT6270	Computational Neuroscience	3	0	0	0	6	9
3	BT5420	Computer Simulations of Biomolecular Systems	3	0	0	0	6	9
4	BT5240	Computational Systems Biology	3	0	0	0	6	9
5	ME5560	Heat and Mass Transfer in Biological Systems	3	0	0	0	6	9
6	AM6110	Bio-Fluid Mechanics	3	0	0	0	6	9
7	AM5510	Biomedical Signals and Systems	3	0	0	0	6	9
8	AM5515	Digital Healthcare Technology and Applications	3	0	0	0	6	9

	Stream 1/2/3/4	Other Relevant Computational Courses (This list is based on the list of all acceptable courses, based on COT)						
1	CS6350	Computer Vision	3	0	0	0	6	9
2	CS6360	Computer Graphics	3	0	0	0	6	9
3	EE6130	Advanced Topics in Signal Processing	3	0	0	0	6	9
4	CS5691	Machine learning	3	0	0	0	6	9
5	CS6023	GPU programming	3	0	0	0	6	9
6	AM5011	Virtual Reality Engineering	3	0	0	0	6	9
7	ED6005	Deep Learning for Medical Image Analysis	4	0	0	0	6	12

Detail Syllabus of courses

Advanced Fluid Mechanics - AM5530	
Description	Introduce fundamentals of Viscous Flows, Boundary Layers, Turbulence and Stability to students
Course Content	Introduction basic equations of motion of fluid flow, Equation of continuity, Navier Stokes equations, Euler's equations, Bernoulli's equation, Idean fluid flow, Flow past circular cylinder with and without circulation, airfoil, viscous fluid flow, exact solutions of Navier Stokes equations, Prandtl's boundary layer equations, Blasius solution, Approximate methods Transition and turbulent flows, Flow through pipes and flow past a flat plate, Turbulent boundary layer, One and two-dimensional compressible flows, Compressible viscous flows, Compressible boundary layers
Text Books	G. K. Batchelor, "An Introduction to Fluid Mechanics"
Reference Books	• Frank M. White, "Viscous Fluid Flow" • G. K. Batchelor, "An Introduction to Fluid Mechanics" • John C. Tannehill, Dale Anderson & R.H. Pletcher, "Computational Fluid Mechanics and Heat Transfer" • John D. Anderson Jr., "Modern Compressible Flow" • H. Schlichting & K. Gersten, "Boundary Layer Theory"
Prerequisite	

Computational Laboratory - AM5801	
Description	Computational method discusses how functions, derivatives, integrals and differential equations are numerically handled. Furthermore, develop an understanding on the speed of convergence and error approximation. Finally, provide a foundation for numerical methods for engineering problems.
Course Content	Error Analysis, Interpolation, Linear Algebra, Solution of Linear Algebraic Equations, Solution of Non-linear Equations, Numerical Integration and Differentiation, Solution of ODEs and PDEs.
Text Books	Numerical methods using MATLAB, by J.H. Mathew, K.D. Fink, Prentice Hall, 2004.
Reference Books	• Applied Numerical analysis using MATLAB, 2nd edition by L.V. Fausett, Pearson, 2007. • • Applied Numerical Methods W/MATLAB: for Engineers & Scientists, S.V. Chapra, McGraw-Hill Higher Education, 2004.
Prerequisite	

Computational Methods in Mechanics - AM5600	
Description	Review of Linear Algebra, Solution of nonlinear algebraic equations, Equations of Applied Mechanics and solution procedures, Transform techniques, Variational Principles of Mechanics, Weighted residual methods, Finite Element, Finite Difference and Finite Volume methods. Time integration techniques
Course Content	Review of Linear Algebra, Solution of nonlinear algebraic equations, Equations of Applied Mechanics and solution procedures, Transform techniques, Variational Principles of Mechanics, Weighted residual methods, Finite Element, Finite Difference and Finite Volume methods. Time integration techniques.
Text Books	**1.** Alan Tayler – Mathematical Models in Applied Mechanics, Oxford Press. 1986. **2.** Press et al. Numerical Recipes in C/C++, Cambridge University Press, 2002. **3.** Boresi and Chong – Approximate methods in Engineering Mechanics. Elsevier. 1991
Reference Books	**1.** Alan Tayler – Mathematical Models in Applied Mechanics, Oxford Press. 1986. **2.** Press et al. Numerical Recipes in C/C++, Cambridge University Press, 2002. **3.** Boresi and Chong – Approximate methods in Engineering Mechanics. Elsevier. 1991
Prerequisite	

Computational Tools: Algorithms, Data Structures and Programs - ID6105	
Description	This is intended to be an intermediate course in the development of necessary tools for scientific problem-solving. The focus will be on learning data structures and algorithms through the code development process. The course would emphasize the self-learning aspect (need-based learning, on-demand learning) with reference to new programming paradigms and emerging coding practices from the Engineering industry.
Course Content	Fundamentals of programming, with emphasis on engineering problem solving; Broad spectrum of tools needed for Code development; Compilers, linkers, debuggers; Code (software) development process; Code optimization techniques, memory hierarchy, Performance measuring tools for programs; Utility of Data Structures such as Arrays and pointers, Linked lists, Queues, stacks and trees; Sorting and searching methods and their algorithmic efficiency; Implementation specific examples drawn from grid generators, mesh based and mesh-free methods used in engineering, other relevant engineering applications Introduction to Symbolic Computing; Using Maple and Mathematica for scientific problem solving; Demonstrating the utility and implementation of these tools in solving PDE's.
Text Books	**1.** S R. Lerman, Problem solving and computation for scientists and engineers, PHI (1993). **2.** A.V. Aho et al., Data Structures and Algorithms, Pearson (2002). **3.** I.P.Stavroulakis and S.A. Tersian, Partial Differential Equations: An Introduction with Mathematica and Maple, World-Scientific (1999). **4.** R.E. Bryant and D.R.O'Hallaron, Computer Systems: A Programmers perspective, Pearson (2016). **5.** F.T. Willmore, et al., Introduction to Scientific and Technical Computing, CRC Press (2017).

Reference Books	**1.** J.A. Storer, An Introduction to Data Structures and Algorithms, Springer (2001). **2.** R Lohner, Applied CFD Techniques, Wiley (2008). **3.** I.K.Shingareva and C.Lizárraga-Celaya, Maple and Mathematica, 2nd Ed., Springer (2009). **4.** F.E. Harris, Mathematics for Physical Science and Engineering: Symbolic Computing, Elsevier (2014).
Prerequisite	Introduction to Computing or equivalent

Research Skills - GN5004	
Description	This course is meant to build research skills in post-graduate students. For students entering postgraduate programs from a course-heavy undergraduate program, the basic tools for a healthy relationship with research need to be explicitly brought to bear. The course will involve the practice of research paper review and critical analysis, literature search, and communication & interpersonal skills for researchers. ● Understand the roles and responsibilities of researchers ● Identify attitudes and habits required for success in research ● Recognise ethical & safety issues ● Perform detailed literature search harnessing modern tools ● Practice reading and critical analysis of peer-reviewed research articles ● Communicate & analyse sample research findings in various format (posters, PPTs, reports)
Course Content	● Introduction to research ● Literature search ● Critical analysis of research articles ● Technical writing ● Lab safety ● Ethics, Workplace diversity
Text Books	● The Elements of Style by William Strunk Jr. and E. B. White, 2003 ● The Joy of Research by C. Balaji, 2015 ● The Grammar of Science - Karl Pearson ● Truth and Beauty - Aesthetics and Motivations in Science - S. Chandrasekhar ● Advice to a Young Scientist - P. B. Medawar ● Science and Hypothesis - H. Poincare
Reference Books	Will be shared as required
Prerequisite	

Application of Molecular Dynamics - AM6512	
Description	The primary objective of this course is to introduce the concept, theory and applications of Molecular Dynamics to the students of different departments such as Applied Mechanics, Chemistry, Biotechnology, Materials Science etc. Another objective is to help students in developing fundamental skill of building models, running simulations and analyzing Molecular Dynamics (MD) data which will be extremely helpful in their future research.
Course Content	Introduction; Concept of Length Scale & Time Scale; Hierarchy in materials (e.g. bone, nanocomposites, clay); Different material characterization techniques (e.g SEM, TEM, AFM, Nanoindentation, etc); Limitations of experimental techniques and necessity of

	molecular modelling for further details; Introduction to different modeling (simulation) techniques (e.g. MD, CG, DEM, FEM etc); Concept of multiscale modeling. Theory of Molecular Dynamics (MD); MD and its general applications; mathematical formulation of MD; Energy terms and Concept of force field; Different potentials (bonded and non-bonded) and their suitability to material types; PBC; Ewalds summation techniques; Force field parameter derivations; Steps in running MD. Application of MD; Lipid protein interaction; Surface modifications – organic and inorganic; Functionalization of polymers; Interactions in Polymer clay nanocomposites; Protein-ligand interactions; Clay water interactions; Ion channels; Artificial bone. Analysis of MD Data; Auto correlation functions; Radial Distribution Functions; Thermodynamic properties; Binding Energy & Total Free energy; Mechanical properties; Interface adhesion
Text Books	**1.** Molecular Dynamics Simulation: Elementary Methods, J. M. Haile, Wiley Professional, 1997. **2.** Molecular Modelling: Principles and Applications (2nd Edition): A. R. Leach, Prentice Hall, 2001
Reference Books	**1.** Understanding Molecular Simulation, Second Edition: From Algorithms to Applications. Frenkel & Smit, Academic Press, 2001
Prerequisite	NULL

High Performance Computing for Engineering Applications - AM5080

Description	To give the student a basic introduction to the skills needed to utilize high performance computing resources for engineering applications.
Course Content	Introduction to concepts and practice of high-performance computing: HPC programming languages, libraries and tools. Introduction to Modern processors: performance metrics and benchmarks, memory hierarchies, multicore and multithreaded processors, vector processors, switch and networking technologies. Basic Optimization technique for serial code. Data access Optimization: Bandwidth-based performance modeling, Case study: Dense Matrix transpose, The Jacobi Algorithm. Basics of Parallel computers: shared memory, distributed memory and hybrid systems, Networks. Fundamentals of Parallelization: Data and functional parallelism, parallel scalability, basic ideas in parallel algorithms for numerical linear algebra. Introduction to OpenMP. Open MP-parallel Jacobi algorithm. Introduction to MPI. Basic ideas in MPI programming: communication parameters, serialization, synchronization, reducing communication overhead. Brief introduction to GPU programming, CUDA. HPC practical sessions on Open MP, MPI and CUDA.
Text Books	**1.** Georg Hager and Gerhard Wellein, Introduction to High-Performance Computing for Scientists and Engineers, Chapman&Hall/CRC, Special Indian Edition, 2011. **2.** K.Dowd and C.Severance, High Performance Computing, O'Reilly, 1998.
Reference Books	**1.** S.Goedecker and A.Hoisie. Performance Optimization of Numerically Intensive Codes, SIAM, 2001. **2.** Suely Oliveira, David E. Stewart, Writing Scientific Software: A Guide to Good Style. Cambridge University Press, 2006.
Prerequisite	NULL

High Performance Computing Lab - AM5035	
Description	To give the student a basic introduction to the skills needed to utilize high-performance computing resources for engineering applications. This course represents the lab component of the AM5080 High-Performance Computing for Engineering Applications course. The objective is to implement some of the techniques learned in the theory course.
Course Content	The laboratory component will require the student to write computer programs using a careful choice of algorithms and other tools, from scratch, based on the concepts learnt in the theory course. Develop simple programs to demonstrate Point to Point Communication, Collective Communication, Performance Monitoring: Benchmarking, Code Parallelizability, Code Profiling, Inter-Processor Communication, Synchronization: Blocking Communication, Non-Blocking Communication, Matrix Operations: System of Equations, Matrix Multiplication, Dense Matrix Calculations, Sparse Matrix Vector Multiplication and Beowulf Clustering.
Text Books	1. Georg Hager and Gerhard Wellein, Introduction to High Performance Computing for Scientists and Engineers, Chapman&Hall/CRC, Special Indian Edition, 2011. **2**. K.Dowd and C.Severance, High Performance Computing, O'Reilly, 1998.
Reference Books	**1**. S.Goedecker and A.Hoisie. Performance Optimization of Numerically Intensive Codes, SIAM, 2001. **2**. Suely Oliveira, David E. Stewart, Writing Scientific Software: A Guide to Good Style. Cambridge University Press, 2006.
Prerequisite	UG-level course on computer programming and Numerical techniques

Indian Culture - HS5050	
Description	This course is an introduction to Indian culture, history, philosophy, religion, economy, society, art, architecture, fine arts, literature, science and technology. The course would be a survey of ancient, medieval, modern and contemporary India. The orientation of the course is to provide a practical understanding of India's "unity in diversity" while utilizing textual resources to provide a theoretical framework. Documentaries, films, field visits to museums, archaeological sites, historical places and music and dance concerts would form an integral part of the course work to show the linkages with the past and to analyze how relevant the past is to an understanding of contemporary India. **Outcomes**: Students would gain a nuanced understanding of the complex cultural history of the Indian subcontinent which possesses mind boggling diversity of religions, regions, languages, ethnicity and socio-economic groups. This course would also highlight the challenges of negotiating diversity in contemporary India. It would highlight how Indian democracy serves as the crucible of contestation and dialogue between variegated viewpoints.

Course Content	**1.** Ancient India - An overview of Indus Valley Civilization **2.** Political economy and society in Ancient India **3.** The origins of Art, culture, philosophy and religion in various regions of Ancient India **4.** An introduction to early Hinduism, Buddhism and Jainism 4. Early Medieval India - The history of three powerful kingdoms - Harshavardhana, Pulakesin-II and Mahendravarma and Narasimhavarma Pallava **5.** Medieval Art and Architecture - Ajanta, Ellora, Mamallapuram, Kailasanatha, Brihadeeswara, Gangaikonda Cholapuram, Srirangam, Madurai, Chidambaram and Darasuram **6.** Indo-Saracenic art and architecture - Taj Mahal, Agra and Delhi Red Forts, Jaipur Hawa Mahal, Bada Imambara Lucknow - Chikan **7.** Sufi Islam, Medieval devotional movements and the origins of Sikhism as a new faith **8.** Indian Medicine - Charaka, Susruta and Vagbhatta **9.** Science and Technology tradition in India - Bhaskara, Aryabhatta and Brahmagupta **10.** Mughal Empire - state and economy **11.** India under the British rule - East India Company, 1857 First War of Independence and India under the British Crown **12.** India's Freedom Movement, Round Table Conferences and Partition - Tilak, Gandhi, Nehru, Patel, Ambedkar, Jinnah, Azad and Prasad **13.** India's Constituent Assembly Debates **14.** Post-independence India - 1947 to 2021
Text Books	**1**. Basham, A.L., (ed) A Cultural History of India, Oxford: Oxford University Press, 1975. **2**. Guha, Ramachandra, India After Gandhi: The History of World's Largest Democracy, New Delhi: Picador India, 2017. **3**. Austin, Granville, Working in a Democratic Constitution: A History of the Indian Experience, Oxford: Oxford University Press, 2003.
Reference Books	**1**. Pulakkat, Hari, Space, Life, Matter: The Coming of Age of Indian Science, Gurugram: Hatchette India, 2021. **2**. Coomaraswamy, Ananda, The Dance of Shiva, New Delhi: Rupa Publications, 2013. **3**. Guha, Ramachandra, Gandhi Before India, New Delhi: Penguin India, 2013. **4**. Basham, A.L., The Wonder That Was India, New Delhi: Picador India, 2004. **5**. Austin, Granville, The Indian Constitution: Cornerstone of A Nation, Oxford: Oxford University Press, 1999. **6**. Nehru, Jawaharlal, The Discovery of India, New Delhi: Penguin India, 2008. **7**. Narayan, R.K., Malgudi Days, Mysore: Indian Thought Publications, 1943. **8**. Eck, Diana L., India: A Sacred Geography, New York: Three Rivers Press, 2012. **9**. Lahiri, Nayanjot, Time Pieces: A Whistle-Stop Tour of Ancient India, Gurugram: Hachette India, 2018. **10**. Singh, Upinder, A History of Ancient and Early Medieval India: From Stone Age to the 12th Century, New Delhi: Pearson Education India, 2009.
Prerequisite	

Technology & Sustainable Development - HS5060	
Description	The course starts with an introduction to technology, society and sustainable development from the perspectives of the history of industrialization and technology, and science and technology studies (STS). We will take a critical look at discourses of development and sustainability and their relationship with technology. In the second part of the course, we will discuss specific aspects of technology and sustainable development on the basis of case studies such as energy production and consumption, global warming, agriculture, traffic and transport, urbanization, water and wastewater management, industrial production and human consumption, pollution and waste, and limits of natural resources. **Learning Outcomes:** The students will learn about the relationship between science, technology and society, and how technology affects sustainable development. The students will learn how to argue in class, how to develop their own semester project, to give an oral presentation and to give comments to the presentations of other students, and how to write a term paper.
Course Content	Introduction to Science and Technology Studies • The Social Construction of Scientific and Technical Realities • The Evolution of Large Technological Systems • Do Artefacts have Politics? • The Normative Structure of Science • The Industrial Revolution • India's Technological Imaginary • The Club of Rome and the Limits to Growth • The Brundtland Report • Deconstructing Development Discourse • What is Sustainable Technology? Perceptions, Paradoxes and Possibilities • The United Nations' sustainable development goals of the 2030 Agenda
Text Books	Sergio Sismondo, An Introduction to Science and Technology Studies. Chichester, West Sussex: Wiley, 2010. Andrea Cornwall and Deborah Eade, Deconstructing Development Discourse: Buzzwords and Fuzzwords, Oxford: Oxfam, 2010 – Chapter 1, 2, and 14. Karel Mulder et al, what is Sustainable Technology? Perceptions, Paradoxes and Possibilities, Sheffield: Greenleaf Publishing, 2011 – Chapter 1, 13, and 14.
Reference Books	Langdon Winner, "Do Artifacts have Politics?", in Winner, L., The whale and the reactor: a search for limits in an age of high technology, Chicago: University of Chicago Press, 1986: 19-39. Bernward Joerges, "Do Politics have Artefacts?" Social Studies of Science 29:3 (1999): 411-.31. Melvin Kranzberg, "Technology and History: Kranzberg's Laws," Bulletin of Science Technology & Society 15:5 (1995): 5-13. Anil K. Gupta and Sreeja S. Nair, "Urban floods in Bangalore and Chennai: risk management challenges and lessons for sustainable urban ecology" Current Science 100:11 (2011): 1638-1645. Wiebe E. Bijker, Thomas P. Hughes and Trevor Pinch, The Social Construction to Technological Systems Cambridge, Mass.: MIT Press, 1987 / 2012. Robert K. Merton (1942/1973) "The Normative Structure of Science." In Robert K. Merton, The Sociology of Science: Theoretical and Empirical Investigations. Chicago: University of Chicago Press, 1973: 267–278. Eric Hobsbawm, "The Industrial Revolution," chapter 2 in E Hobsbawm, The Age of Revolution 1789 – 1848, New York: Vintage Books, 1962/1996: 27-52. Prasannan Parthasarathi, "Trade and Industry in the Indian Subcontinent, 1750–1913," in Jeff Horn, Leonard N. Rosenband, and Merritt Roe Smith (eds.), Reconceptualizing the Industrial Revolution, Cambridge, Mass.: MIT-Press, 2010: 271–290 David Arnold, Everyday Technology: Machines and the Making of Modern India, Chicago
Prerequisite	

Turbulence Modeling - AM5640	
Description	Most fluid flows in industry and in nature are turbulent. For example, atmospheric and oceanic flows are turbulent, combustion in an aircraft or IC engine is turbulent, and even human breathing is turbulent. Laboratory experiments of turbulent flows are difficult, expensive and many times impossible! For example, how to measure airflow in a human lung or measure tomorrow's weather?! Modeling turbulence, therefore, is a pragmatic approach to solve industrial flow problems and understand physics of the fluid flow. This course aims at building fundamentals/theory of various turbulence modeling techniques (from statistical to eddy-resolving methods), their advantages and challenges while implementing them in a computer program or CFD application software.
Course Content	Introduction to turbulence theory, statistical analysis (random process, ensemble mean, variance, single- and multi-point statistics, spatial and temporal correlation), Cartesian tensors, governing equations of fluid motion, Reynolds averaged Navier-Stokes (RANS) equations, turbulence closure problem, Equation for fluctuating fluid motion, Reynolds stress transport equation, statistical stationarity and statistical homogeneity. Turbulence kinetic energy equation; turbulence characteristics: diffusive, dissipative and redistribution; mean kinetic energy equation and turbulence production, Turbulent boundary layer: outer layer and inner layer, inertial and viscous sub-layers, inner scaling, RANS modeling: Boussinesq approximation, eddy-viscosity, zero-equation modeling, two-equation modeling, standard k-ε model, model constantsRNG k-ε model, one-equation modeling, k-ω models, wall-functions, Low-Reynolds number (LRN) models, ε boundary conditions, Initial conditions, Realizability constraints, Reynolds stress models (RSM): pressure strain-rate modeling (slow and rapid parts), wall-correction, algebraic stress models, Direct numerical simulation (DNS), Kolmogorov hypothesis, large eddy simulation (LES): resolved and sub-grid scales, filtered Navier-Stokes equations, Filter types, sub-grid scale (SGS) modeling: Smagorinsky model, one-equation kSGS model, Dynamic Smagorinsky model, Scale similarity models, grid convergence in LES, hybrid RANS-LES approach, detached eddy simulation (DES).
Text Books	**1.** Turbulent Flows – Stephen B. Pope **2.** An Introduction to CFD: The Finite Volume Method – Versteeg & Malalasekera **3.** Modelling Turbulence in Engineering and the Environment: Second-Moment Routes to Closure – Kemal Hanjalic & Brian Launder **4.** Turbulence Modeling for CFD – David C. Wilcox
Reference Books	**1.** Turbulent Flows – Stephen B. Pope **2.** An Introduction to CFD: The Finite Volume Method – Versteeg & Malalasekera **3.** Modelling Turbulence in Engineering and the Environment: Second-Moment Routes to Closure – Kemal Hanjalic & Brian Launder **4.** Turbulence Modeling for CFD – David C. Wilcox
Prerequisite	PG-level fluid mechanics and basic CFD knowledgee

Convective Transport Processes - AM6016	
Description	The primary focus of this course is to introduce fluid dynamics and the convective transport of passive scalar quantity for Newtonian, incompressible fluids. The prediction of passive scalar transport on coupled processes and its application in practical situations will be emphasized.
Course Content	Review of basic Fluid dynamics: Navier-Stokes, energy and species transport equations, Vorticity and temperature fields, Boundary layer equations, Fully developed laminar flow in ducts and pipe flow with developing velocity and temperature fields, Internal turbulent flows, Internal mixed convective flows, Fluid flow over isothermal plates, inclined surfaces, plumes, wakes, flow in stratified media, external turbulent flows, the effect of buoyant forces on turbulent flows, Heat transfer equipment, Mass Transfer, Laminar concentration boundary layer, Mass transfer to plates, Spheres and Cylinders, Mass Transfer involving flow through pipes, Mass transfer equipment, Combined convection of passive scalar, Conjugate problems, Analysis of stress distribution due to a passive scalar.
Text Books	• Fundamentals of Momentum, Heat and Mass Transfer, Welty, Wicks, Wilson and Rorrer, 5th Edition, John Wiley, 2010 • An introduction to Convective heat transfer Analysis, Patrick Oosthuizen and David Naylor, Mc Graw Hill, 1999 • Noda N, Hertnarski R, B, and Tanigawa Y, Thermal Stresses, CRC Press, 2002.
Reference Books	• Laminar flow and convective transport processes, L.Gary Leal, Butterworth-Heinmann, 1992. • Transport Phenomena, Byron Bird, Warren E Stewart, Edwin N Lightfoot, Jonh Wiley, 2010. • Advanced Mechanics of Solids, Srinath L.S., Tata McGraw Hill, 1993.
Prerequisite	

Foundation of CFD – AM5630	
Description	Governing Equations of Fluid Mechanics, Navier Stokes Equations, Nonlinearity, Physical Meaning, Forms suitable for CFD, Discretization, Grids, Finite Difference, Finite Volume and Finite Element Methods as applied to Navier Stokes Equations, Diffusion and convection problems, velocity pressure coupling, Numerical solution techniques, Steady and Unsteady Problems, Complex Geometries, Reynolds Mean Momentum equation, Overview of Turbulence Models, High Accuracy Methods, DNS, LES.
Course Content	Governing Equations of Fluid Mechanics, Navier Stokes Equations, Nonlinearity, Physical Meaning, Forms suitable for CFD, Discretization, Grids, Finite Difference, Finite Volume and Finite Element Methods as applied to Navier Stokes Equations, Diffusion and convection problems, velocity pressure coupling, Numerical solution techniques, Steady and Unsteady Problems, Complex Geometries, Reynolds Mean Momentum equation, Overview of Turbulence Models, High Accuracy Methods, DNS, LES.

Text Books	**1.** An Introduction to CFD: The Finite Volume Method – Versteeg & Malalasekera **2.** Computational Methods for Fluid Dynamics – Joel H. Ferziger, Milovan Peric, Robert L. Street **3.** Numerical Heat Transfer and Fluid Flow – Suhas V. Patankar
Reference Books	**1.** An Introduction to CFD: The Finite Volume Method – Versteeg & Malalasekera **2.** Computational Methods for Fluid Dynamics – Joel H. Ferziger, Milovan Peric, Robert L. Street **3.** Numerical Heat Transfer and Fluid Flow – Suhas V. Patankar
Prerequisite	PG-level fluid mechanics

Flow Visualization & Imaging Techniques - AM5090

Description	Familiarize with theoretical and practical aspects of flow visualization and scientific imaging. Learn the image processing techniques to treat experimental images. Apply the principles to experimental images using open-source programs, analyze and interpret the data.
Course Content	Review of fluid flows: Differential analysis of fluid flows, Streamlines, Pathlines, Streaklines, Timelines Basics of scientific photography: Focal length, Exposure triangle, Lighting, Stroboscopic imaging, High-speed photography, Basic image correction and editing Smoke, dye and tracer visualizations Interferometric and Schlieren techniques Particle Image Velocimetry (PIV), Particle Tracking Velocimetry (PTV) and Laser-Induced Fluorescence (LIF), Microscopic flow visualization Post-processing, data assimilation and representation of flow field data with case studies.
Text Books	•Flow Visualization: Techniques and examples, edited by A J Smits, Imperial College Press (2nd Revised edition, 2012). •Flow Visualization by W. Merzkirch, Academic Press, (2nd edition, 1987).
Reference Books	•Handbook of experimental fluid mechanics, edited by Cameron Tropea, Springer-Verlag (1st edition, 2007) •Particle Image Velocimetry: A Practical Guide, Springer-Verlag (2nd edition, 2007)
Prerequisite	

Project I - ID5390, Project II - ID5391 & Project III - ID5392	
Description	Computational Engineering
Topic	Detached eddy simulation of crossflow airblast atomization of a liquid jet
Abstract	A number of industrial systems need the bulk liquid mass to be broken up into tiny droplets. Therefore, knowing how liquids break apart is essential. The objective of this study is to carry out a numerical simulation of a two-phase flow. The liquid jet injected from an orifice is atomized by a high-speed gas stream in a crossflow configuration 3.1. I used Ansys Fluent 2023R1 to model the multi-phase flow numerically. The delayed detached eddy simulation (DDES) is used to compute the gas-liquid flow. The Volume of Fluid (VOF) method is implemented to capture the gas-liquid interface. In this work, I looked into breakup lengths and jet penetration in the crossflow airblast atomizer. The simulation results is validated with an in-house experimental study by Patil and Sahu (2021). The current research investigates the influence of non-uniformity in the air velocity (due to wall boundary layer development) on the jet breakup process. This will compliment the experimental data since measurement of air velocity within the atomizer is very challenging.