INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad - 500 043

AERONAUTICAL ENGINEERING

COURSE DESCRIPTION FORM

Course Title	**AEROSPACE PROPULSION – II**			
Course Code	**R15 – A62112**			
Course Structure	**Lectures**	**Tutorials**	**Practicals**	**Credits**
	4	1	-	4
Course Coordinator	C.Satya Sandeep - Assistant Professor			
Team of Instructors	Dr. M. Pandian - Professor , C.Satya Sandeep – Assistant professor			

I. COURSE OVERVIEW

This course presents aerospace propulsive devices as systems, with functional requirements and engineering and environmental limitations along with requirements and limitations that constrain design choices. Both air-breathing and rocket engines are covered, at a level which enables rational integration of the propulsive system into an overall vehicle design. Mission analysis, fundamental performance relations, and exemplary design solutions are presented.

II. PREREQUISITE(S)

Level	Credits	Periods	Prerequisite
UG	4	4	Engineering Physics
UG	4	4	Fluid Mechanics
UG	4	4	Engineering Thermodynamics

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 contain 4 questions; the student has to	75	100

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. **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	--	05
3	II Mid examination	80 minutes	20
4	II Assignment	--	05
5	External examination	3 hours	75

V. COURSE OBJECTIVES:

I. Discuss and revise the basic thermodynamics and propulsion concepts.

II. Understand the all types of engines for atmospheric travel and space travel.

III. Analyze parametric cyclic analysis of all Air breathing Engines

IV. Knowledge of all types of engines construction and its parts

V. Understand type of flow inside the engines.

VI. Knowledge of engines for the different payloads its mission profiles.

VII. Discuss the all types of engines working models with examples.

VI. COURSE OUTCOMES:

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

1. Apply knowledge and understand the essential facts, concepts and principles of thermodynamics.
2. Understand the basic knowledge in mathematics, physical science in propulsion.
3. Analyze and design a mathematical system or a Mechanical system or a process that meets desired specifications and requirements.
4. Understand all types of engines working principles and parts.

5. Analyze how the aerodynamics affects the aircraft engine design and its operation.
6. Understand the operating principles of gas turbines, rockets and combustion systems.
7. Demonstrate concepts introduced in fluid mechanics and thermodynamics to model engines for aircraft and spacecraft.
8. Implement concepts learned in chemistry, fluid mechanics and thermodynamics to model combustion systems.
9. Extend these techniques to analyze and evaluate new and novel engine designs.
10. Understand what engine performance measures are most relevant for different applications.

VII. HOW PROGRAM OUTCOMES ARE ASSESSED

Program outcomes		Level	Proficiency assessed by
PO1	**Engineering knowledge**: Knowledge in fundamentals of mathematics, science and engineering.	H	Lectures
PO2	**Problem analysis**: An ability to identify, formulate and solve problems in key areas of Aerodynamics, Structures, Propulsion, Flight Dynamics and Control, Design, Testing, Space and Missile Technologies and Aviation of Aeronautical Engineering discipline.	H	Assignments
PO3	**Design/development of solutions**: An ability to design and conduct experiments, analyze and interpret data related to various areas of Aeronautical Engineering.	S	Assignments,
PO4	**Conduct investigations of complex problems**: An ability in conducting investigations to solve problems using research based knowledge and methods to provide logical conclusions.	S	Assignments,
PO5	**Modern tool usage:** Skills to use modern engineering and IT tools, software and equipment to analyze the problems in Aeronautical Engineering.	H	Lectures, Tutorials
PO6	**The engineer and society**: Understanding of impact of engineering solutions on the society to assess health, safety, legal, and social issues in Aeronautical Engineering.		

PO7	**Environment and sustainability**: The impact of professional engineering solutions in environmental context and to be able to respond effectively to the needs of sustainable development.		
PO8	**Ethics:** The knowledge of Professional and ethical responsibilities.		
PO9	**Individual and team work**: An ability to work effectively as an individual and as a team member/leader in multidisciplinary areas.	S	projects
PO10	**Communication**: An ability to critique writing samples (abstract, executive summary, project report), and oral presentations.		
PO11	**Project management and finance:** The need of self-education and ability to engage in life - long learning.		
PO12	**Life-long learning**: Knowledge of management principles and apply these to manage projects in multidisciplinary environments.	H	

VIII. HOW PROGRAM SPECIFIC OUTCOMES ARE ASSESSED

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 challenges of Airworthiness for flight vehicles.	S	Tutorials
PSO 3	**Practical Implementation and Testing Skills:** Providing different types of in house 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 sub systems of Aeronautical/Aerospace and allied systems to become technocrats.	S	Seminars and Projects

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

IX. SYLLABUS

UNIT – 1

Trans-Atmospheric and Space Flight Mission Propulsion Requirements- Propulsion Systems-Classification, Performance Characteristics: Hypersonic transport vehicles, military missiles, space launch vehicles, spacecraft- role, types, missions- profile, trajectories, operating conditions- gravity, atmosphere. Incremental flight velocity budget for climb out and acceleration, orbital injection- Breguet equation for cruise- mission propulsion requirements- thrust levels, burning time, economy.

High speed propulsion systems- types, construction, operating principles- sources of energy, generation of power, momentum, propellants- applications, performance parameters- specific thrust, specific impulse, internal efficiency, propulsive efficiency- typical values. Reaction control systems- applications.

UNIT – 2

Air Breathing Engines for Hypersonic Transport Planes and Military missiles – Supersonic Combustion – The Scram-Jet Engine: Performance of turbojets, ramjets at high speeds-limitations, Need for supersonic combustion- implications- criticality of efficient diffusion and acceleration, problems of combustion in high speed flow. The scramjet engine – construction, flow process- description, control volume analysis- spill over drag, plume drag. Component performance analysis- isolator, combustor- flow detachment and reattachment, thermal throat, scheduled, distributed fuel injection. Nozzle flow, losses- failure to recombination, viscous losses, plume losses. Scramjet performance, applications.

Combined cycle engines- turbo-ramjet, air turbo-rocket (ATR), ejector ramjet- Liquid-air collection engine (LACE) – need, principle, construction, operation, performance, applications to hypersonic transport plane and missile propulsion.

UNIT – 3

Chemical Rocket Engines: Rocket propulsion – history, principles, types, applications. The rocket equation. Vehicle velocity, jet exit velocity, mass ratio. Effect of atmosphere. Engine parameters, propellants.

Chemical rocket- the thrust chamber- processes- combustion, expansion- propellants. Thermo-chemical analysis of combustion, equilibrium energy balance, mass balance, combustion efficiency. Equilibrium composition, recombination. Nozzle expansion, performance, design parameters, analysis- non-equilibrium expansion- frozen equilibrium, shifting equilibrium. One

dimensional, two dimensional flows, presence of liquid drops and solid particles- two phase flow, losses, efficiency.
Performance measure of chemical rocket engines- thrust coefficient, specific impulse; engine parameters- thrust chamber pressure, temperature, characteristic velocity, exhaust velocity, effective velocity. Computing rocket engine performance- theoretical, delivered performance, performance at standard operating conditions, guaranteed minimum performance

UNIT – 4

Liquid Propellant Rocket Engines, Solid Propellant Rocket Motors: Liquid propellant rocket engines- structure- principal components, basic parameters- propellant combination, chamber pressure, nozzle are ratio, feed system, thrust level, Propellants – properties- considerations for selection- storage, feed, control, injection, ignition. Combustion chamber and nozzle, shape, size materials, cooling – thrust vector control, combustion instabilities. Engine control, optimization, system integration. Liquid propellant rocket performance data.
Solid propellant rocket motors- basic configuration, essential differences from liquid propellant rocket engines, propellant composition, combustion chambers, ignition surface recession rate, gas generation rate, effect of propellant temperature, combustion pressure, charge design- thrust profile, burning stability, erosive burning. Combustion chamber integrity- thermal protection. Combustion instabilities- types, corrective measure. Solid propellant motor components and motor design. Applications, performance analysis. Examples of solid propellant boosters. Hybrid propellant rockets, selection of rocket propulsion systems.
Advanced thermal rockets- fundamental physical limitation of thermal rockets, improving efficiency of thermal rockets in the atmosphere, pulse detonation engine, rotary rocket engine, variable exhaust velocity, Particulars of propulsion systems of selected space vehicles and military missiles.

UNIT – 5

Electric Thrusters- Mission Applications of Space Flight: Limitations of chemical rocket engines. Electric propulsion systems- structure, types, generation of thrust. System parameters- interrelations. Electro thermal thrusters- resisto jet, arc jet, solar/laser/microwave thermal propulsion- operating principles, components, system parameters, performance, applications.
Electrostatic thrusters- ionization potential, ionization schemes. Beam current, power, acceleration, voltage, power efficiency, thrust-to-power ratio, specific impulse. Screen, accelerator grids, potential, charge distribution, saturated current density, electric field intensity, exhaust neutralization, propellant choice. Estimation of performance, electrical efficiency, power to thrust ratio, thrust per unit area, applications.
Electromagnetic thrusters- magneto plasma dynamic (MPD), pulsed plasma (PPT), Hall Effect and variable I_{sp} thrusters- principle, construction, operation, performance, applications. Electric space power supplies and power conditioning- batteries, fuel cells, solar cell arrays, solar generators, nuclear power generators. Current technology of electric propulsion engines, applications- overview. The problem of gravity loss. Criteria for selection of engine. Particulars of select current electric propulsion systems.

TEXT BOOKS

1. Sutton, G.P. and Biblarz, O., Rocket Propulsion Elements, 7th edn. Wiley, 2001, ISBN: 0-471- 32642-9.
2. Hill, P.G. and Peterson, C.R., Mechanics and Thermodynamics of Propulsion, 2nd edn. Addison Wesley, 1992.
3. Kerrebrock, J.L., Aircraft Engines and Gas Turbines, 2nd edn. , MIT Press, 1992, ISBN: 0-262- 11162-4.
4. Turner, M.J.L., Rocket and Spacecraft Propulsion, 2nd edn. Springer, 2005, ISBN: 3 540- 22190.
5. Tajmar, M., Advanced Space Propulsion Systems, Springer, 2003, ISBN: 3-211-83862-7.

REFERENCES

1. Jensen, G.E. and Netzer, D.W., ed. Tactical Missile Propulsion, AIAA, 1996, ISBN 56347-118-3.
2. NASA JPL Advanced Propulsion Concepts Notebook Online, http://sec353.jpl.nasa.gov/apc/.
3. Encyclopedia Astronautics, http://www.astronautix.com/.

X. COURSE PLAN:

The course plan is meant as a guideline. There may probably be changes.

Lecture No.	Course Learning Outcomes	Topics to be covered	Reference
1	Hypersonic transport vehicles, military missiles, space launch vehicles,	Hypersonic transport vehicles, military missiles, space launch vehicles,	T1:4.1
2	spacecraft- role, types, missions-profile, trajectories, operating conditions-	spacecraft- role, types, missions-profile, trajectories, operating conditions-	T1:4.1
3	Gravity, atmosphere. Incremental flight velocity budget for climb out and acceleration,	Gravity, atmosphere. Incremental flight velocity budget for climb out and acceleration,	T1:4.5
4	Orbital injection- Breguet equation for cruise– mission propulsion requirements- thrust levels, burning time, economy.	Orbital injection- Breguet equation for cruise– mission propulsion requirements- thrust levels, burning time, economy.	T1:4.5
5	High speed propulsion systems- types, construction, operating	High speed propulsion systems- types, construction, operating principles-	T1:4.1

	principles- sources of energy,	sources of energy,	
6	generation of power, momentum, propellants,- applications, performance parameters-	generation of power, momentum, propellants,- applications, performance parameters-	T1:2.5
7	specific thrust, specific impulse, internal efficiency,	specific thrust, specific impulse, internal efficiency,	T1:2.5
8	Propulsive efficiency- typical values. Reaction control systems- applications.	Propulsive efficiency- typical values. Reaction control systems- applications.	T1:2.5
9	Performance of turbojets, ramjets at high speeds- limitations. Need for supersonic combustion- implications Criticality of efficient diffusion and acceleration, problems of combustion in high speed flow.	Performance of turbojets, ramjets at high speeds- limitations. Need for supersonic combustion- implications Criticality of efficient diffusion and acceleration, problems of combustion in high speed flow.	T1:2.5
10	The scramjet engine- construction, flow process- description, control volume analysis- spill-over drag,	The scramjet engine- construction, flow process- description, control volume analysis- spill-over drag,	T1:4.3
11	Plume drag. Component performance analysis- isolator, combustor- flow detachment and reattachment, thermal throat, scheduled, distributed fuel injection. Nozzle flow, losses- failure to recombination,	Plume drag. Component performance analysis- isolator, combustor- flow detachment and reattachment, thermal throat, scheduled, distributed fuel injection. Nozzle flow, losses- failure to recombination,	T1:4.4
12	Viscous losses, plume losses. Scramjet performance, applications.	Viscous losses, plume losses. Scramjet performance, applications.	T1:4.5
13	Combined cycle engines- turbo-ramjet, air turbo-rocket (ATR), ejector ramjet	Combined cycle engines- turbo-ramjet, air turbo-rocket (ATR), ejector ramjet	T1:4.6
14	Liquid-air collection engine (LACE)- need, principle, construction, operation,	Liquid-air collection engine (LACE)- need, principle, construction, operation,	T1:4.6
15	Applications to hypersonic transport plane and missile propulsion.	Applications to hypersonic transport plane and missile propulsion.	T1:4.1
16	Rocket propulsion- history,	Rocket propulsion- history, principles,	T1:1.3

	principles, types, applications. The rocket equation.	types, applications. The rocket equation.	
17	Vehicle velocity, jet exit velocity, mass ratio. Effect of atmosphere. Engine parameters, propellants	Vehicle velocity, jet exit velocity, mass ratio. Effect of atmosphere. Engine parameters, propellants	T1:2.1
18	Chemical rockets- the thrust chamber- processes- combustion, expansion- propellants	Chemical rockets- the thrust chamber- processes- combustion, expansion- propellants	T1:2.4
19	Thermo-chemical analysis of combustion, equilibrium energy balance, mass balance, combustion efficiency. Equilibrium composition, recombination.	Thermo-chemical analysis of combustion, equilibrium energy balance, mass balance, combustion efficiency. Equilibrium composition, recombination.	T1:2.4
20	Nozzle expansion, performance, design parameters, analysis- non-equilibrium expansion- frozen equilibrium, shifting equilibrium.	Nozzle expansion, performance, design parameters, analysis- non-equilibrium expansion- frozen equilibrium, shifting equilibrium.	
21	One dimensional, two dimensional flows, presence of liquid drops and solid particles- two phase flow, losses, efficiency.	One dimensional, two dimensional flows, presence of liquid drops and solid particles- two phase flow, losses, efficiency.	T1:3.2
22	Performance measures of chemical rocket engines- thrust coefficient, specific impulse; engine parameters	Performance measures of chemical rocket engines- thrust coefficient, specific impulse; engine parameters	T1:3.3
23	thrust chamber pressure, temperature, characteristic velocity, exhaust velocity, effective velocity	thrust chamber pressure, temperature, characteristic velocity, exhaust velocity, effective velocity	T1:3.1
24	Computing rocket engine performance- theoretical, delivered performance, performance at standard operating conditions, guaranteed minimum performance.	Computing rocket engine performance- theoretical, delivered performance, performance at standard operating conditions, guaranteed minimum performance.	T1:3.4
26	Liquid propellant rocket engines- structure- principal components, basic parameters	Liquid propellant rocket engines- structure- principal components, basic parameters	T1:6.1

27	propellant combination, chamber pressure, nozzle area ratio, feed system	propellant combination, chamber pressure, nozzle area ratio, feed system	T1:6.1
28-29	Thrust level. Propellants – properties- considerations for selection- storage, feed, control, injection, ignition	Thrust level. Propellants – properties- considerations for selection- storage, feed, control, injection, ignition	T1:6.2
30	Combustion chamber and nozzle, shape, size, materials, cooling- thrust vector control,	Combustion chamber and nozzle, shape, size, materials, cooling- thrust vector control,	T1:6.3
31	Combustion instabilities. Engine control, optimization, system integration.	Combustion instabilities. Engine control, optimization, system integration.	T1:6.3
32	Liquid propellant rocket performance data	Liquid propellant rocket performance data	T1:6.4
33	Basic configuration, essential differences from liquid propellant rocket engines, propellant composition, combustion chambers, ignition, surface recession rate, gas generation rate	Basic configuration, essential differences from liquid propellant rocket engines, propellant composition, combustion chambers, ignition, surface recession rate, gas generation rate	T1:6.4
34	Effect of propellant temperature, combustion pressure, charge design- thrust profile, burning stability, erosive burning. Combustion chamber integrity- thermal protection	Effect of propellant temperature, combustion pressure, charge design- thrust profile, burning stability, erosive burning. Combustion chamber integrity- thermal protection	T1:8.3
35	Combustion instabilities- types, corrective measures. Solid propellant motor components and motor design. Applications, performance analysis.	Combustion instabilities- types, corrective measures. Solid propellant motor components and motor design. Applications, performance analysis.	T1:8.3
36	Examples of solid propellant boosters. Hybrid propellant rockets, selection of rocket propulsion systems	Examples of solid propellant boosters. Hybrid propellant rockets, selection of rocket propulsion systems	T1:8.4
37-38	Advanced thermal rockets- fundamental physical limitations to thermal rockets, improving efficiency of thermal rockets in the atmosphere	Advanced thermal rockets- fundamental physical limitations to thermal rockets, improving efficiency of thermal rockets in the atmosphere	T1:8.5

39	Pulse detonation engine, rotary rocket engine, variable exhaust velocity, optimizing the ascent, descent. SSTO (single stage to orbit)- concept, practical approaches	Pulse detonation engine, rotary rocket engine, variable exhaust velocity, optimizing the ascent, descent. SSTO (single stage to orbit)- concept, practical approaches	T1:18.1
40	Particulars of propulsion systems of sleeted space vehicles and military missiles	Particulars of propulsion systems of selected space vehicles and military missiles	T1:18.3
41	Limitations of chemical rocket engines. Electric propulsion systems- structure, types, generation of thrust. System parameters- interrelations	Limitations of chemical rocket engines. Electric propulsion systems- structure, types, generation of thrust. System parameters- interrelations	T1:19.1
42	Electro thermal thrusters- resist jet, arc jet, solar/ laser/ microwave thermal propulsion- operating principles, components, system parameters, performance, applications	Electro thermal thrusters- resisto jet, arc jet, solar/ laser/ microwave thermal propulsion- operating principles, components, system parameters, performance, applications	T1:19.1
43	Electrostatic thrusters- ionization potential, ionization schemes. Beam current, power, acceleration, voltage, power efficiency, thrust-to-power ratio, specific impulse. Screen, accelerator grids, potential, charge distribution, saturated current density, electric field intensity, exhaust neutralization, propellant choice	Electrostatic thrusters- ionization potential, ionization schemes. Beam current, power, acceleration, voltage, power efficiency, thrust-to-power ratio, specific impulse. Screen, accelerator grids, potential, charge distribution, saturated current density, electric field intensity, exhaust neutralization, propellant choice	T1:19.2
44	Estimation of performance, electrical efficiency, power to thrust ratio, thrust per unit area, applications	Estimation of performance, electrical efficiency, power to thrust ratio, thrust per unit area, applications	T2:6.5
45	Electromagnetic thrusters- magneto plasma dynamic (MPD), pulsed plasma (PPT), Hall effect and variable I_{SP} thrusters- principle, construction, operation, performance, applications	Electromagnetic thrusters- magneto plasma dynamic (MPD), pulsed plasma (PPT), Hall effect and variable I_{SP} thrusters- principle, construction, operation, performance, applications	T2:6.6
46	Electric space power supplies and power conditioning- batteries, fuel cells, solar cell arrays, solar	Electric space power supplies and power conditioning- batteries, fuel cells, solar cell arrays, solar generators, nuclear	T2:6.7

	generators, nuclear power generators.	power generators.	
47	Current technology of electric propulsion engines, applications-overview. The problem of gravity loss. Criteria for selection of engine. Particulars of select current electric propulsion systems	Current technology of electric propulsion engines, applications-overview. The problem of gravity loss. Criteria for selection of engine. Particulars of select current electric propulsion systems	T2:6.7
48	Power, thrust, energy. Nuclear fission- basics, sustainable chain reaction, calculating criticality	Power, thrust, energy. Nuclear fission-basics, sustainable chain reaction, calculating criticality	T2:6.8
49-50	Reactor dimensions, neutron leakage, control, reflection, prompt and delayed neutrons, thermal stability	Reactor dimensions, neutron leakage, control, reflection, prompt and delayed neutrons, thermal stability	T2:7.1
51	Nuclear propulsion- history, principles, fuel elements, exhaust velocity, operating temperature	Nuclear propulsion- history, principles, fuel elements, exhaust velocity, operating temperature	T2:7.2
52	The nuclear thermal rocket engine-radiation and management, propellant flow and cooling, control, start-up and shut-down, nozzle, thrust generation	The nuclear thermal rocket engine-radiation and management, propellant flow and cooling, control, start-up and shut-down, nozzle, thrust generation	T2:7.3
53	Potential applications of nuclear engines- operational issues, interplanetary transfer maneuvers, faster interplanetary journey	Potential applications of nuclear engines- operational issues, interplanetary transfer maneuvers, faster interplanetary journey	T2:7.3
54	Development status of nuclear engines, alternative reactor types, safety issues, nuclear propelled missions	Development status of nuclear engines, alternative reactor types, safety issues, nuclear propelled missions	T2:7.4
55	Advanced nuclear propulsion systems- Fission fragment propulsion	Advanced nuclear propulsion systems-Fission fragment propulsion	T2:7.1
56-57	Radioisotope nuclear rocket fusion propulsion	Radioisotope nuclear rocket fusion propulsion	T2:7.2

XI. MAPPING COURSE OBJECTIVES LEADING TO THE ACHIEVEMENT OF THE 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	H	S	H	S	H						S	H			H	
II	H		S										H		S	
III	H	H	H	S								S		H		
IV		H	S	H	S								S			H
V	S	H		S	S									H		
VI		H	S	S						S			H			
VII	H	H	S									S				H

N = None **S = Supportive** **H = Highly related**

XII. MAPPING COURSE OUTCOMES LEADING TO THE ACHIEVEMENT OF THE 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	S	S	S							S		H		H		
2	S	H	H										S			
3		H	S	S								S			H	
4	S	S	S									S				
5		H	H											H		
6	S	H	H										H		S	
7	H		S		S											H
8	S	H		S	S					S		S				
9	H	S		S								S		H		
10	S	H	S	S	S											

N = None **S = Supportive** **H = Highly related**

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