UNIVERSITÀ DI PISA

ROCKET PROPULSION

LUCA D'AGOSTINO

Anno accademico	2021/22
CdS	AEROSPACE ENGINEERING
Codice	665II
CFU	12

Moduli	Settore/i	Tipo	Ore	Docente/i
ROCKET PROPULSION	ING-IND/07	LEZIONI	120	LUCA D'AGOSTINO

Learning outcomes

Knowledge
Covering the main aspects of rocket propulsion systems and address the main problems of their conception, analysis, design, integration and use.

Assessment criteria of knowledge
Student examination, consisting in the illustration, discussion and application of the topics dealt with in the lectures.
The examination is intended to verify the degree of understanding of the course topics and the ability to use it to develop original solutions.

Skills
At the end of the course the student must be able to:

- Formulate, discuss and solve technical and engineering problems concerning the conceptual definition, operation, architecture, performance evaluation, sizing and design of chemical propellant rocket engines for space applications applying the knowledge and methods illustrated in the course.
- Devise and solve original models for the analysis and study of engineering problems related to the course program, using in an original and creative way the approaches illustrated in the lessons.

Assessment criteria of skills
Student examination consisting in the solution (either written or on the blackboard) of one or more problems concerning the course program. The use of the material distributed by the instructor during the course is permitted, unless otherwise indicated at the assignement of the problem.

Behaviors
The student must demonstrate that he/she is able to work collaboratively and to behave loyally and respectfully towards his/her teacher, the university staff, his/her colleagues and in general the University as a whole.

Assessment criteria of behaviors
Direct interaction with the student during lessons, recitations and exams.

Prerequisites

All the topics of:

- the courses of three-year degree in aerospace engineering and in particular those of the courses of Applied Thermodynamics, Physics II, Electronics, Fluid Dynamics and Aircraft Engines;
- the courses of Fluids Dynamics of Propulsion Systems I and II of the first and second year of the master's degree in aerospace engineering.

All the topics of the three-year degree courses in aerospace engineering and in particular those of the courses of Applied Thermodynamics, Physics II and Electronics of the second year, Fluid Dynamics and Motors for Aircraft of the third year.
More generally, the fundamentals of:
Thermal-Fluid Sciences:

- applied thermodynamics, heat transfer (conduction, convection, radiation)
- fluid mechanics, aerodynamics, gas dynamics

Physics and Mechanics:

- mechanics, acoustics, thermodynamics, electromagnetism, optics
- analytical mechanics (kinematics, statics, dynamics)
- structure mechanics and dynamics

Applied Mathematics:

- calculus, series, ODE's, PDE's, geometry, vector and tensor analysis
- complex calculus, ODE's, special functions, EVP's and BVP's
- numerical analysis, multiple nonlinear equations, integration, ODE's, PDE's
- computer programming, BASIC, FORTRAN, C, MathLab, MathCad, etc.

Manufacturing Technologies
Aircraft Propulsion:

- cycles, engines, turbomachines, operation parameters, requirements, applications

Teaching methods

- Lectures are carried out with the help of transparencies.
- The teaching material used in class is made available to students via the elearning site.
- The elearning site is used for student communications and exam management.
- The weekly reception is accessible to students without reservation.
- The exercises of the course are similar to those proposed at the exam. They are accompanied by the solution to allow for verification, and consist of the independent development of application problems on the topics covered by the lectures.

Syllabus

Introduction . Instructor, lecture notes, homeworks and their solutions, student reception, exams. Approaches to profession and education, educational objectives, study tips, teachers and students, on your work. The international R&D context. Useful background material, reference texts. Documenting and presenting your work. Some useful insight on aerospace programs (from Augustine's Law).
Rocket Propulsion Fundamentals. Rocket propulsion systems and technologies; mass, momentum and energy balances; free rocket performance; performance parameters; single and multistage rockets; optimization of multistage rockets; electrical rocket optimization.
Space Shuttle Mission . Space Shuttle System; navigation and flight; guidance, navigation and control; ascent to orbit, orbital operations and maneuvers; re-entry; landing; on-orbit functions and requirements.
Space Shuttle Propulsion . SSME Propulsion system: Space Shuttle Main Engine (SSME), external tank, solid rocket boosters, main propulsion subsystem, orbital maneuver subsystem, reaction control system; SSME combustion devices, powerhead, igniters, preburners, injectors, combustion chamber and nozzle; SSME heat transfer.
Space Shuttle Turbomachinery . SSME turbopumps, operation, parameters and design, cavitation and suction performance; SSME turbines, operation, parameters and design; vehicle/engine requirements; low/high pressure oxidizer/fuel turbopumps; selection, design, architecture, development; axial balance; bearings and seals, critical speeds, rotodynamics; development problems and solutions.
Mission Analysis. Atmosphere, orbital mechanics, elliptical orbits, disturbances, maneuvers, impulsive and low thrust transfers, launch, ascent into orbit, re-entry in the atmosphere.
Chemical Rocket Performance . Characteristic performance parameters; nozzles: optimal expansion, configuration of the flow, bell nozzles, operational limitations, optimization, non-conventional nozzles; cold gas rockets.
Solid Propellant Rockets . Architecture, generalities and classifications; solid propellants, combustion, instabilities, ignition transients, two-phase flow effects, heat transfer, thermal protections.
Liquid Propellant Rockets . Architecture, general and classifications; liquid propellants, mono-, bi-and tri-propellant, combustion, performance, effects of non-equilibrium, injection, sizing of the combustion chamber, instability (injection and thrust coupling mechanisms), propellant management and cycles, tanks and propellant sloshing, regenerative cooling.
Turbomachines . General information, types and architectures, Euler equation, efficiencies,. Stresses and materials, velocity triangles, characteristic parameters, similarity; turbopumps, inducers, compressors, turbines and hydraulic turbines. Axial machines: flow velocity, bladings, fluid forces on profile cascades, losses; compressors: flow instabilities; turbines: degree of reaction, chocked distributors, stagnation temperatures. Radial machines: radial cascades, slip velocity.
1D Unsteady Duct Flows . Compressible flows: general equations, total or stagnation properties. Unsteady duct flows: sonic speed in compliant ducts, continuity and momentum equations, incompressible flows in rigid ducts. Steady duct flows losses in pipes, sudden expansions, conical diffusers, entrances and contractions, pipeline components. Small-amplitude flow oscillations: dynamic transfer matrix formulation for incompressible/compressible fluids in rigid ducts, pressure accumulators, throttleing valves, straight ducts with/without mean flow and losses.
Hybrid Rockets . Generalities, speed of regression and its axial distribution, the oxidizer/fuel ratio, length of grain, combustion history, chamber pressure, thrust, grain temperature effects, thermal radiation and the speed of reaction.
Two-Phase Flows and Cavitation. General, conservation and constitutive equations, phase changes, boiling and cavitation, nucleation, bubble dynamics, cavitation forms and similarity parameters, patterns of liquid/gas, liquid/gas/vapor and liquid/vapor flows, thermal effects, simulation of cavitating flows.
Cavitating Turbopumps . Characteristic and similarity parameters, pumping and suction performance, thermal cavitation. Instabilities induced by cavitation: classification and characteristics, rotating cavitation, self-induced oscillations, rotordynamic forces, flow fluctuations of the feed system, propulsively coupled oscillations (POGO).

Heat Radiation . Electromagnetic radiation; radiant energy transfer, thermal radiation, Kirchhoff's 1stand 2nd laws of radiation, blackbody radiation. Radiative properties of materials: emittances, absorptances, reflectances, transmittances. Radiation networks: radiosity and view factors; enclosures with gray, black and nongray surfaces. Radiation in weakly absorbing media, monochromatic absorptances, emittances and transmittances of gases; total absorptance, emittance and transmittance of multicomponent gases. Equivalent and geometric beam lengths between two radiating surfaces, omnidirectional gas emission to a single and multiple surfaces; enclosures with participating medium and gray surfaces, closed chamber with optically thin medium; radiation of flames.

Bibliography

References

Instructor hand-outs.

The bibliographic references recommended for the further study of the main topics covered in the course are:

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Kuo K. K. and Summerfield M., editors, 1984, “Fundamentals of Solid-Propellant Combustion”, AIAA, Vol. 90.
Yang V. Brill T.B., Wu-Zhen Ren editors, 2000, “Solid Propellant Chemistry, Combustion and Motor Interior Ballistics”, AIAA, Progress in Aeronautics and Astronautics, Vol. 185.
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Murthy S.N.B. and Murray E.T., ed., 1996, “Developments in High-Speed Vehicle Propulsion Systems”, Progress in Astronautics and Aeronautics, Vol. 165, AIAA, ISBN 1-56347-176-0.
Callen H.B., 1985, “Thermodynamics and an Introduction to Thermostatitstics”, John Wiley & Sons, ISBN 0-47186-256-8.
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Currie I. G., 1993, “Fundamental Mechanics of Fluids”, McGraw-Hill.
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Bayvel L., Orzechowshi, 1993, “Liquid Atomization”, Taylor & Francis, ISBN 0-89116-959-8.
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Oran E.S, Boris J.P., editors, 1996, “Tactical Missile Propulsion”, Progress in Astronautics and Aeronautics, Vol. 170, AIAA, ISBN 1-56347-118-3.

Non-attending students info

It is advisable to integrate the study with the performance of the proposed exercises, available on e-learn.
The contents of the course are partly re-elaborated each year. It is advisable to keep up-to-date on the latest versions of the documents supporting the lessons through e-learn and consulting the instructor.

Assessment methods

Student examination consisting of:

- Illustration and discussion of the topics covered in the course.
- The solution (written or on the blackboard) of one or more problems related to the course program.

The use of the material distributed by the teacher during the course is allowed, unless otherwise specified when assigning the problem.
The exam aims to verify the degree of understanding of the course topics and the ability to use it to develop original solutions.

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