ENGINEERING PROGRAMME

2024-2025

Year 2 / Year 3

Specialisation option

Propulsion and Transport

OD PROPULSION

PROGRAMME SUPERVISOR
Georges SALAMEH

ENGINEERING - OD PROPULSION

Autumn Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 73	12	Core course	COMBUP MOTCI THERMPRO TURBO	Combustion and polluting emissions in propulsion Internal combustion engines Thermodynamics for propulsion Turbomachines for propulsion
UE 74	13	Core course	DYGAZP ENERGP P1PROPULS PRAUT PROAE	Gas dynamics Energy management in automotive applications Project 1 Automotive propulsion - electric and hybrid Propulsion systems in aeronautics

Spring Semester

Course unit	ECTS Credits	Track	Course code	Title
UE 83	14	Core course	LASPA P2PROPULS PROMA TFERO TPPRO	Space launchers Project 2 Marine propulsion Railway engineering Practical work in Propulsion

ENGINEERING - OD PROPULSION

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Combustion and polluting emissions in propulsion [COMBUP]

LEAD PROFESSOR(S): Xavier TAUZIA

Requirements

basic knowledge of thermodynamics

Objectives

The main objectives are:

- To provide fundamental knowledge on combustion and the formation of pollutant emissions. At the end of the course the students will be able to:
▪ Write combustion reactions in the case of stoichiometric or lean mixture
▪ Calculate the heating value from formation enthalpies
▪ Calculate the adiabatic temperature after combustion
▪ Evaluate auto ignition
▪ Calculate laminar flame velocity
▪ Use the mixing variable Z to describe diffusion flames

- To introduce combustion in thermal machines (in particular internal combustion engines and gas turbines): fuel choice and fuel induction system, combustion settings, ...

- To present the main strategies of emission abatement, including after treatment.

Course contents

The fundamental aspects of combustion are presented in the first part of the course. The main points presented in these lectures are:
▪ A brief introduction to combustion phenomena and the main applications
▪ Initial and final state: thermodynamics, equilibrium
▪ Chemical kinetics
▪ Reactive flow governing equations
▪ Auto-ignition
▪ Gaseous premixed flames
▪ Laminar diffusion flames
▪ Turbulent flames

The second part of the course deals with combustion and polluant formation and abatment in reciprocating piston egines (spark ignited and compression ignited) , gas turbines and burners (premixed an diffusive combustion). Fuel choice (with the help of e well to wheel analysis) is discussed and fuel induction system are described. Parameters and settings influencing combustion are presented (air/fuel ratio, dilution with residual gases, phasing, staging ...) with abnormal combustion (knock, instabilities, extinction) which occurrence limit the range of acceptable settings. Strategies to reduction pollutant production during combustion are studied (optimal settings, burnt gas recirculation, water injection, ...). Finally, the main after treatment devices dealing with gaseous and solid emission are presented (Three way catalyst, oxidation catalyst, Nox trap, SCR, particulate filters, scrubbers)

This second part includes numerous exercices, solved in class.

Course material

▪ Poinsot & Veynante, Theoretical and Numerical Combustion
▪ http://elearning.cerfacs.fr/combustion/index.php

Assessment

Collective assessment: EVC 1 (coefficient 0.25)

Individual assessment: EVI 1 (coefficient 0.75)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	20 hrs	10 hrs	0 hrs	0 hrs	2 hrs

Internal combustion engines [MOTCI]

LEAD PROFESSOR(S): Xavier TAUZIA

Requirements

basic knowledge of applied thermodynamics

Objectives

The objectives of this course are to provide:
1. the core elements on reciprocating internal combustion engines with a particular focus on thermodynamics
2. a more detailed description of the main processes which take place in the engine, including technological aspects and strategies; interactions and trade-offs are highlighted.
3. an industrial point of view concerning mainly the calibration of automotive engines

Course contents

In the first part of the course the following points are presented: a historical perspective, general principles, some technological aspects, the different types of engine, characteristic dimensions, performance, and efficiency; intake and exhaust systems, supercharging and turbocharging, emission reduction, cooling, lubrication and friction.

In the second part of the course, system engineering, V cycle, powertrain objectives, control strategies, test facilities and calibration methods are described.

Some exercises on thermodynamic cycle calculation, performance and efficiency evaluation are solved during tutorial sessions.

Alternative fuel fro decarnonation, fuel systems and combustion are covered in the Combustion and Pollutant Emissions course (COMBUP). Fundamentals aspects of gas dynamics and turbomachinery are covered in Gas Dynamics and Turbomachinery courses (TUMAC and DYGAZ).

Course material

J.B Heywood, Internal Combustion Engines Fundamentals, Mac Graw Hill, 2011
W.W. Pulkrabek, Engineering Fundamentals of the Internal Combustion Engine, Prentice Hall, 2003

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	24 hrs	6 hrs	0 hrs	0 hrs	2 hrs

Thermodynamics for propulsion [THERMPRO]

LEAD PROFESSOR(S): Pascal CHESSE

Requirements

Objectives

The objective of this course is to provide a good knowledge of energetics that can be useful to any engineer working in the field of propulsion.

Course contents

The first part of this course is an introduction to thermal radiation.
The basics of heat transfer are presented in the second part with an application to real systems. Conduction and convection are introduced in this context. Then, a thermal analysis of a heat exchanger is undertaken to introduce the notion of logarithmic average value of temperature and the NUT number. This part of the course concludes with a case study on an exchanger.
In the last part of the course the notion of exergy is introduced. Exergy leads to a better representation of the energy transfer in any system taking into account irreversibility. A detailed assessment of the energy performance of each sub-assembly of a global process is therefore carried out. This concept will be applied to several concrete cases (compressor, turbine, exchanger).
Lectures will be followed by a series of application exercises related to propulsion.

Course material

Michel FEIDT - Energétique : Concepts et Applications, Dunod Ed. (2006)
Lucien BOREL and Daniel FAVRAT - Thermodynamique et Energétique : de l'énergie à l'exergie, Presses polytechniques et universitaires romandes (2005)
Richard E. SONNTAG, Claus BORGNAKKE and Gordon J. VAN WYLEN - Fundamentals of thermodynamics, Ed. Wyley &Sons (1998)
Renaud GICQUEL - Systèmes énergétiques (3 volumes), Presses des Mines Paris Tech (2009)

Assessment

Collective assessment: EVC 1 (coefficient 0.25)

Individual assessment: EVI 1 (coefficient 0.75)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	22 hrs	0 hrs	0 hrs	2 hrs

ENGINEERING - OD PROPULSION

Year 2 / Year 3 - Autumn Semester - Course Unit 73 / 93

Turbomachines for propulsion [TURBO]

LEAD PROFESSOR(S): Pascal CHESSE

Requirements

Objectives

The objective of this course is to explain the operation of incompressible fluid turbomachinery (pump, hydraulic turbine) and compressible fluid (turbine, compressor) turbomachinery and their applications in the field of propulsion.

Course contents

The course begins with a presentation of the general working principles of a turbomachine and a classification of turbomachines. The Euler theorem is then introduced followed by the layout and functioning of a centrifugal pump: wheel, diffuser, volute. The course then deals with machine yield, cavitation and Rateau coefficients. The second part of the course deals with compressible fluid, including centrifugal compressor and similitude conditions.
The lectures are followed by a series of exercises related to the field of propulsion, and then a lecture on turbochargers.

Course material

M. SEDILLE, Turbomachines hydrauliques et thermiques, Tomes 1,2,3, Masson Paris
M. PLUVIOSE, Turbomachines, Vuibert Ed.

Assessment

Collective assessment: EVC 1 (coefficient 0.25)

Individual assessment: EVI 1 (coefficient 0.75)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	8 hrs	22 hrs	0 hrs	0 hrs	2 hrs

Gas dynamics [DYGAZP]

LEAD PROFESSOR(S): David CHALET

Requirements

Objectives

The objective of this course is to study the physical phenomena related to gas flows in a system, whether for propulsion (compressible flows) or for air conditioning (incompressible flows).

Course contents

In the first part of the course, gas dynamic equations are presented in steady state conditions.
Differents cases are studied:
- Quasi-monodimensional flows of a non-viscous compressible fluid-isentropic solution
- Laws of discontinuity associated with the conservative form of equations
- Quasi-monodimensional flows with shock: calculation techniques

Numerical aspects are also covered.

The second part of the course will identify vehicle needs in term of cooling or heating for the cabin (automotive, railways application, plane, etc.). An energy balance will be established and the different solutions will be studied.

Course material

Assessment

Collective assessment: EVC 1 (coefficient 0.1)
EVC 2 (coefficient 0.1)

Individual assessment: EVI 1 (coefficient 0.4)
EVI 2 (coefficient 0.4)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	22 hrs	8 hrs	0 hrs	0 hrs	2 hrs

Energy management in automotive applications [ENERGP]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

Thermodynamics
heat transfer
énergetics

Objectives

The objective of this course is to identify the needs and energy flows that exist in the field of automotive propulsion in order to optimize the complete running of the vehicle.

A part of this course will look at hydrogen in propulsion:

Hydrogen fuel cells are becoming technologically mature enough to be integrated into propulsion chains for transport applications. This module aims to give students a first insight into these hydrogen technologies and to provide them with the knowledge to be able to pre-design a propulsion chain integrating hydrogen and a fuel cell based power source for mobility applications.

Course contents

The first part of the course covers engine thermal management. The subject will be introduced with a detailed explanation of the thermal balance of an engine, which will make it possible to define the issues and the relevant parameters. The main existing or planned technologies will be presented and explored, with a particular focus on their impact on engine performance and pollutant emissions (low-performance technologies will also be discussed).

The second part focuses on energy storage in batteries.

In the third part of the course, we discuss hydrogen in propulsion:
- 1. operating principle of a fuel cell
- 2. fuel cells for mobility
- 3. hydrogen as an energy carrier
- 4. hydrogen as a solution for massive energy storage.
- 5. project/case study: dimensioning of a hydrogen propulsion chain in various land mobility applications (private vehicle, commercial vehicle, heavy goods transport).

Course material

PEM Fuel Cell : Theory and Practice, F. Barbir, ed. Elsevier
Fuel Cell Systems explained, J. Larminie and A. Dicks, John Wiley & Sons Ltd.

Assessment

Collective assessment: EVC 1 (coefficient 0.35)

Individual assessment: EVI 1 (coefficient 0.65)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	22 hrs	8 hrs	0 hrs	0 hrs	2 hrs

Project 1 [P1PROPULS]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

thermodynamics
fluid mechanics
energetics
combustion
internal combustion engine
turbomachines
heat transfer
gas dynamics

Objectives

Part1: Introduction to the use of multi-physical and multi-level simulation tools (0D / 1D and 3D) in relation to propulsion (GT-Power).
Part 2: Introduction to the use of the simulation tool Simcenter Amesim, in relation to propulsion.
Part3: Introduction to the use of a CFD simulation tool: StarCCM+

Course contents

Part 1:
As part of this course, the GT-Suite simulation tools developed by Gamma Technologies will be used. These tools are among the most widely used in the propulsion sector (aeronautics, land and sea) and provide the basis for the use of tools developed by other companies.
This parts begins with a presentation of all the GT-Suite tools as well as the main physical principles, models and solvers used.
In a second step, a single-cylinder gasoline model will be created from scratch in the form of a tutorial in order to understand how engine models are built. This will be followed by a phase of optimizing engine performance for the students through the use of a variable valve lift strategy.
Finally, multi-cylinder engine models will be used and various means of optimization will be used to increase engine performance and reduce consumption.

Part 2:
Simcenter Amesim is simulation software for modeling and analyzing multi-domain 1D systems. The software offers a 1D simulation suite to model and analyze multi-domain intelligent systems and predict their multi-disciplinary performance.
To create a simulation model of a system, a set of libraries can be used, containing predefined components for different physical domains.
The user can compose a model of a physics-based system. The sub-models of a system must be linked together. Each sub-model has ports, which can have multiple inputs and outputs.
Powertrain electrification in the automotive sector, reusable launch systems in the space sector, or the use of alternative fuels (LNG) for ships are examples of technology implementations that can be modelled with Simcenter Amesim.
First of all, the basics of 0D/1D simulation will be presented. Secondly, tutorials and quick examples will be provided to get the hang of the software. A hybrid motorisation model will be created based on certain constraints and characteristics. Finally, the course will end with a case study to be analysed by the simulation tool.

Part 3: CFD calculation software, StarCCM + developed by Siemens is used. This part of the course starts with a presentation of the software: interfaces, tools, geometries, physical models, meshing, running a calculation, post-processing, analysis.

There will then be three practical exercises:
Practical class 1: calculation of the flow around a car in a wind tunnel

Practical class 2: calculation of the flow in a ducted fan
Practical class 3: calculation of the flow through a 2D axisymmetric nozzle

Course material

Part 1:
1. Anderson, J., Modern Compressible Flow, 1st edition, McGraw-Hill, New York, 1982.
2. Kolade, Babajide, Boghosian, Michael E., Reddy, P.S., and Gallagher, Shawn, Development of a General Purpose Thermal-Hydraulic Software and its Application to Fuel Injection Systems, SAE, 2003-01-0702, 2003
3. Colebrook, C. F., "Turbulent flow in pipes, with particular reference to the transition region between smooth and rough pipe laws," Jour. Ist. Civil Engrs., London, Feb. 1939.
4. Nikuradse, J., "Strömungsgesetze in rauhen Rohren." VDI-Forschungsheft 361. Beilage zu "Forschung auf dem Gebiete des Ingenieurwesens" Ausgabe B Band 4, July/August 1933.
5. Serghides, T.K., "Estimate friction factor accurately." Chemical Engineering, 91, 63-64, 1984.
6. Wagner, W., Strömung und Druckverlust. Vogel Fachbuch Kamprath-Reihe, 2001.
7. White, F.M., Fluid Mechanics 2nd Edition. McGraw Hill, 1986.
8. Idelchik, I.E., Handbook of Hydraulic Resistance, JAICO, 2003.
9. Fox, R. and McDonald, A., Introduction to Fluid Mechanics, Fourth Edition, John Wiley and Sons, Inc.: New York, N.Y., 1992.
10. Miller, D.S., Internal Flow Systems, Second Edition, BHR Group Limited, 1990.
11. Cruz, D.A., Coelho, P. M., & Alves, M. A., "A Simplified Method for Calculating Heat Transfer Coefficients and Friction Factors in Laminar Pipe Flow of Non-Newtonian Fluids", Journal of Heat Transfer, 134, 2012.
12. Trinh, Tuoc, "The wall shear rate in non-Newtonian turbulent pipe flow", 2010.
13. Aymanns, R., Scharf, J., Uhlmann, T., and Lückmann, D.; "A Revision of Quasi Steady Modelling of Turbocharger Turbines in the Simulation of Pulse Charged Engines," Dresden Supercharging Conference, 2011
14. Aymanns, R., Scharf, J., Uhlmann, T., Pischinger, S.; "Turbocharger Efficiencies in Pulsating Exhaust Gas Flow", Motortechnische Zeitschrift, Aug. 2012.

Part 2:
https://www.plm.automation.siemens.com

Chasse A, Pognant-Gros P, Sciarretta A (2009), Online implementation of an optimal supervisory control for a parallel hybrid powertrain, SAE Int. J. Engines, vol. 2, no. 1, p. 1630-1638, paper 2009-01-1868

L. Guzzella, A. Sciarretta: "Vehicle Propulsion Systems. Introduction to Modeling and Optimization", 3rd edition, Springer-Verlag, Berlin Heidelberg, ISBN 978-642-35913-2, 2013

Sciarretta A, Dabadie JC, Font G (2015), Automatic Model-Based Generation of Optimal Energy Management Strategies for Hybrid Powertrains, Proc. of the SIA Powertrain Conf., Versailles, France, 27-28 May 2015.

Part3:
StarCCM+ basic training by Siemens

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	1	0 hrs	0 hrs	0 hrs	32 hrs	0 hrs

Automotive propulsion - electric and hybrid [PRAUT]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

gas dynamics
fluid mechanics
energetics

Objectives

The objective of this course is to study the different elements of an automotive propulsion system and to be able to simulate this kind of system.

Course contents

First, an overview will focus on the effects of airflow around and within the vehicle, caused by its relative motion with respect to the surrounding air. This part of the course focuses on the basic concepts of aerodynamics applied to the automobile with the aim of shedding light on phenomena affecting the overall performance of the vehicle, and in particular its drag, which directly impacts fuel consumption.

The second part of the course will cover the electrification of vehicles (hybrid and electric vehicles): presentation of the different principles, architectures, associated functionalities, etc. This part concludes with an application.

In the last part of the course, the goal is to become familiar with the concept of the electric hybrid vehicle which is the subject of many preconceived ideas in the media. The part of the course is largely lecture-based but students will also have the opportunity to understand these complex systems as well as the challenges of optimization during the 8 hours of hybrid practical work.
Lectures will begin with a historical review from the creation of Ferdinand Porsche's first hybrid vehicle to their mass production following the appearance of the first Prius, with a link between their democratization and the rising public awareness of the importance of climate issues and the development of anti-pollution standards.
The course will cover the fundamental principles of hybridization: operation of the ICE with better efficiency (concept of CSP engine according to its operating point), energy recovery during braking, stop/start, plug-in, etc. The different hybrid architectures will also be detailed with a critical analysis of their respective advantages and disadvantages.
The various storage elements will be discussed (batteries, supercapacitors, flywheels, pneumatic energy) while trying to avoid repetition with regard to courses on full electric vehicles.
A chapter will be devoted to the problem of optimizing these vehicles, comparing their best consumption performance, compared to pure thermal vehicles, with their disadvantages in terms of weight, complexity or pollution (batteries, but also different use of ICE giving different pollution)

In the last part of this course, simulation software (Simecenter Amesim) is used to apply the concepts covered.

The simulation tool will be used to analyze and compare the performance (fuel consumption, pollutant emissions, energy flow, etc.) of a hybrid vehicle over different driving cycles (urban, mixed, highway). Solutions on the control strategy and/or on the architecture of the system will be implemented to reduce polluting emissions.

Course material

https://www.plm.automation.siemens.com

Assessment

Collective assessment: EVC 1 (coefficient 0.3)

Individual assessment: EVI 1 (coefficient 0.3)
EVI 2 (coefficient 0.4)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	20 hrs	0 hrs	10 hrs	0 hrs	2 hrs

ENGINEERING - OD PROPULSION

Year 2 / Year 3 - Autumn Semester - Course Unit 74 / 94

Propulsion systems in aeronautics [PROAE]

LEAD PROFESSOR(S): Vincent BERTHOMÉ

Requirements

Objectives

The objective of this course is to study in detail the thermodynamics of turbojet engines used in aeronautical propulsion.

Course contents

The course begins with the historical background of aeronautical propulsion and the associated stakes.

Following this, a presentation of aeronautical propulsion systems (turboshaft and turbojet engines) will be provided. The cycle of a single-flow turbojet engine will be studied as well as its operation without adaptation. Finally, a study of the turbofan engine will be presented.

The final part of the course deals with helicopter engines (general and thermal thermodynamics, role and operating principle, rotary wings).

Course material

Assessment

Individual assessment: EVI 1 (coefficient 0.5)
EVI 2 (coefficient 0.5)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	30 hrs	0 hrs	0 hrs	0 hrs	2 hrs

Space launchers [LASPA]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

Thermodynamics
Gas dynamics
turbomachines
Combustion
energetics

Objectives

The objective of this course is to provide specialised training on space propulsion systems (with the intervention of engineers from Arianegroup).
The objective of the turbopump training module is to introduce a non-specialist to the requirements, main concepts, risks and technologies related to one of the key sub-systems for liquid propulsion systems.

Course contents

The course starts with a general overview of space propulsion, the associated issues and the typical course of a mission.
Our attention will turn to liquid propellant systems and the details of the rocket stage that contribute to its propulsion (pressurization reservoirs, turbopumps, propellant chambers). In order to understand the challenges of this type of propulsion system, the interface and stage optimisation problems will be analysed. A practical application will be conducted on the dimensioning of a launcher (Ariane5).

Part 1: Overview of launchers and engines

1- Launchers

- Review of spatial mechanics
What is it like to be in orbit?
o circular and elliptical orbits.
o low, medium, GTO, geostationary orbits, para and hyperbolic orbits

- The different types of propellants
o Solid propellants
o "Storable" liquid propellants
o Cryogenic liquid ergols

- Advantages and disadvantages of the different types of propellants
o Isp
o constructive index of floors

- One-stage DeltaV > multi-stage launchers

2- Overview of rocket engines

- Theory of the nozzle
o Sonic blocking at the neck
o Relaxation, ejection speed and Isp
o Under-relaxed, adapted and over-relaxed nozzle dimension of the diverging part according to the type of stage (booster, "main" stage, upper stage)

o Jet separation

- The 5 main engine cycles
o Motors without pump
 >Motor / Solid stage (= powder stage)
 > Motor / Pressurized stage
o Motors with pump
 > Derived flux motors:
 ▪ the Gas Generator cycle (example: the Vulcain / Vulcain 2 / Vulcain2.1 engine of Ariane 5/6)
 > Integrated flux motor:
 ▪ The Staged Combustion cycle (example: the SSME engine of the American space shuttle)
 ▪ The Expader cycle (example: the Vinci engine of Ariane 6)

Advantages and disadvantages of each of these 5 engine cycles.

Part 2: Propulsion systems - stage aspects

- Rocket staging and examples
  - Staging concept
  - Main functions of a propulsive stage
  - Ariane 5
  - Saturn V
  - Ariane 6
  - Industrial cycle linked to stage manufacturing
  - Pressurized stage
    >Example: EPS stage (Ariane 5 ES)
    >Basic equations
  - Stage with turbopumps
    >Basic equations
    >NPSP and constraints on tank pressure

- Mechanical structures and stage layout
  - Thrust cone
    > Functions
    > Example: EPS thrust cone (Ariane 5)
  - Tanks
  - Thrust Vector Control (TVC)
    > TVC mechanisms
    > Constraints

- Launcher and stage management until launch
  - Definition
  - Ariane 5 management at Kourou
  - Propellant loading
  - Engine chill-down
  - Example of count-down sequence (Ariane 5)

- Optimized stage design
  - Key parameters and fundamental equations
  - Specific impulse optimization
  - Common facts about optimized lower or upper stages

- Propellants
  - Advantages and drawbacks of a propellant / a propellant combination
  - Common oxidizers and fuels

- Feed, pressurization and command systems
  - Feed system
    >Main functions

> POGO effect and POGO suppressor device
- o Pressurization system
  - > Introduction
  - > Tank pressure control
  - > Example: EPC pressurization system (Ariane 5)
- o Command system
  - > Functions
  - > Example: ESC-A command system (Ariane 5)

- ▪ Other subsystems
- o Stage separation systems
- o Attitude control and propellant settling systems
- o Specific systems
  - > Dedicated to upper stage in-orbit restart
  - > Dedicated to first stage retrieval / reuse

Part 3: Turbopumps
The skills acquired during the course will allow the participants to:
- Identify the main requirements for the turbopump subsystem and explain the 3 main functions
- Identify the main integration constraints on the propulsion system
- Recognise the different turbopump layouts
- Identify the 4 secondary functions allowing for smooth operation of a turbopump and associate them with the functional assemblies from a 2D section of the machine.
- Determine the size of the turbopump and its speed of rotation; choose the number of pump and turbine stages
- Recognize the different technologies used for the different functional assemblies
- Be aware of the complexity of the phenomena (cavitation, aeroelasticity, ...) involved in a machine with an extreme power to mass ratio, and the need for a rigorous development plan dealing with all the failure modes.

The presentation is illustrated by numerous examples based on turbopumps developed during the Ariane programmes and on competitors' equipment.

Part 4: Propulsion Systems Training: Combustion Organs
- Missions and constraints for combustion units
- Design of an injection head
- Design of a chamber body and a GG / Pre-burner
- Design of a divergent
- Design of an igniter

Course material

Part 3: turbopumps
Ph. Hill, C. Peterson, Mechanics and Thermodynamics of Propulsion - Second Edition, 1992, DDISON-WESLEY Publishing Company
DK Huzel, DH Huang , Modern Engineering for Design of Liquid-Propellant Rocket Engines, 1992, Progress in Astronautics and Aeronautics, Volume 147.
G.P. Sutton, Turbopumps, a Historical Perspective, 2006, 42nd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, 9-12 July 2006, Sacramento, California

Assessment

Collective assessment:	EVC 1 (coefficient 0.25)
Individual assessment:	EVI 1 (coefficient 0.25)
	EVI 2 (coefficient 0.25)
	EVI 3 (coefficient 0.25)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	30 hrs	0 hrs	0 hrs	0 hrs	2 hrs

Project 2 [P2PROPULS]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

thermodynamics
fluid mechanics
energetics
combustion
internal combustion engine
turbomachines
heat transfer
gas dynamics

Objectives

The objective of this project is to give students the possibility to solve a real problem with different student groups.

Course contents

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	2	0 hrs	0 hrs	0 hrs	48 hrs	0 hrs

Marine propulsion [PROMA]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

internatl combustion engines
fluid mechanics
thermodynamics
combustion
energetics

Objectives

This course aims to introduce the specificity of naval propulsion devices.
The objective is to present major marine propulsion devices (propellers, shaft lines, diesel engines) as well as their design; starting with the power requirements of ships.

Course contents

The first part of the course provides a complete overview of the different modes of naval propulsion (sail, internal combustion engine, nuclear) and their application depending on the ship type. There will be a focus on marine diesel engines and their application in the naval field.

The second part of the course presents the power transmission on a ship and different types of propulsion devices (wheels, propellers, hydrojets etc). Different propulsion architectures are presented, from conventional to hybrid. A particular focus is made on diesel engines and their specificities for marine applications: components, supercharging, injection, fuels. The environmental constraints on emissions are also presented, with solutions to meet them: including internal engine systems, exhaust post-treatment systems, gas/dual fuel engines, and alternatives fuels.

Company visit: MAN - Energy Solutions company - Saint Nazaire site
- The site specializes in the assembly of diesel engines from 500 to 26,500 kW for power stations and marine propulsion (civil and military).
- Programme for the visit:
    - Presentation of the site
    - Workshop visit

Intervention on submarine propulsion (Naval Group): definition, history, technologies, on-board energy, performance.

Course material

Ship Resistance and Propulsion: Practical Estimation of Propulsive Power (Google Digital book)
Anthony F. Molland, Stephen R. Turnock, Dominic A. Hudson
Cambridge University Press, 8 August 2011

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	30 hrs	0 hrs	0 hrs	0 hrs	2 hrs

Railway engineering [TFERO]

LEAD PROFESSOR(S): Georges SALAMEH

Requirements

energetics

Objectives

The objective of this course is to study the materials used for rail transport, but also the constraints associated with this type of transport.

Part 1:
The railway system; infrastructure constraints; rolling stock (architecture, performance, the main trains produced by Alstom); the role of signalling; standards and regulations: a considerable impact on design; design sequence: from specifications to train; challenges for the future: interoperability, cybersecurity, Co2 free and Ecodrive

Part 2:
The objective is to provide the definition of a modern railway traction system and explain why, contrary to what one might imagine, it is a very complex system that has to comply with very strict environmental, normative and contractual requirements specific to railways and closely linked to its history and development.

Part 3:
Present the design principles and technologies developed for train braking, from tramcars to very high speed trains. Highlight the main technical and economical issues.

Course contents

After a general overview of the rail transport in the world, a presentation of the different rolling stock and traction modes (internal combustion engine, electric, etc) will be given. The advantages and disadvantages will be studied and applications will be carried out, in particular at the level of the dynamic modelling of the vehicle. Propulsion and braking will also be covered.

Part 1:
The rail system:
- A constrained system
- An economically viable and efficient system
- A safe system
- An environmentally friendly system
- An evolving system

Infrastructure constraints:
- Size and its diversity,
- Wheel-rail contact,
- Parameters that limit speed.

Rolling stock
- Architectures
o Classic horizontal mechanical architecture, Jacob concept of modularity
o Vertical mechanical architecture, floor height, number of levels, number and width of doors
o Electrical architecture - distributed or concentrated motorization
o Interior architecture
o Passive safety

- The main mechanical components:
o Body,
o Bogie,
o Interior fittings.
- Performance:
o Travel time: acceleration speed
o Acoustics: interior noise - exterior noise
o Aerodynamics: drag, cross winds, blast effect, climatic comfort
o Electromagnetic compatibility: capacity to "pollute", sensitivity to "pollution"
o Stability: derailment criteria
o Eco-design: harmful effects
o Comfort
- The main trains produced by Alstom.

The role of signalling.

Standards and regulations: a considerable impact on design.

Design sequence: from specifications to train.

Challenges for the future:
- Interoperability
- Cybersecurity
- Co2 free and Ecodrive

Part 2:
The origin of the railway system and few key railway figures

Definition of the railway system: the railway traction system constitutes a coherent whole with very close interaction with the collection system, the power supply and the rails
o power supply and substation
o current collection system (overhead line, 3rd rail, Aesthetic Power Supply)
o current feedback
o rail adhesion and rail/wheel contact

Railway dynamics
o Resistance to motion
o Calculation of wheel effort to fulfil performance requirements

Components of the traction equipment
o Power conversion principle or how to transfer the power collected on the line voltage to apply the required effort on the wheel while respecting the constraints regarding power supply, standards and the environment.
(Inverter) / (chopper) / (4quadrant rectifier)
oThe building block of power conversion: the semiconductor
o Power modules - cooling and protection
o Traction motors
o Mechanical force transmission

Onboard auxiliary converter

More and more respectful of the environment: Hybrid traction and energy storage

A world in constant evolution: what are the trends ?

Part 3:
1. Issues and problems with railway braking
2. Braking performance
3. Braking control
4. Produce brake force and dissipate braking energy

5. Wheel-rail adhesion and wheel slide protection

Part 4:
Alstom company visit - La Rochelle site
- The site is Alstom's global design and manufacturing center for very high speed trains (TGV) and trams.
- Visit programme:
    - Presentation of the site
    - Workshop visit
    - Discussions with engineers

Course material

Part 2:
The figures for the world rail are taken from the UIC (International Union of Railways) website.

Part 3:
▪ Rolling stock in the Railway System – Part 1 to 3 - PMC Media House GmbH (2020)
▪ The Railway Pneumatic Brake – Magazine of the Association Française des Amis des Chemins de Fer – Nbr 407 (1991) - 410 (1991) - 412 (1992) - 415 (1992) - 422 (1993) - 428 (1994) - 430 (1995) - 440 (1996) - 441 (1996)

Assessment

Individual assessment: EVI 1 (coefficient 1.0)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	30 hrs	0 hrs	0 hrs	0 hrs	2 hrs

ENGINEERING - OD PROPULSION

Year 2 / Year 3 - Spring Semester - Course Unit 103 / 83

Practical work in Propulsion [TPPRO]

LEAD PROFESSOR(S): Vincent BERTHOMÉ

Requirements

Objectives

Application of various courses in the Propulsion specialisation.

Course contents

- turbine / fuel cell
- heat exchanger
- nozzles
- gearboxes / hybrid car
- combustion / fan
- engine disassembly and reassembly
- spark-ignition engine
- diesel engine

Course material

Assessment

Collective assessment: EVC 1 (coefficient 1)

LANGUAGE OF INSTRUCTION	ECTS CREDITS	LECTURES	TUTORIALS	LAB	PROJECT	EXAM
French	3	0 hrs	0 hrs	32 hrs	0 hrs	0 hrs