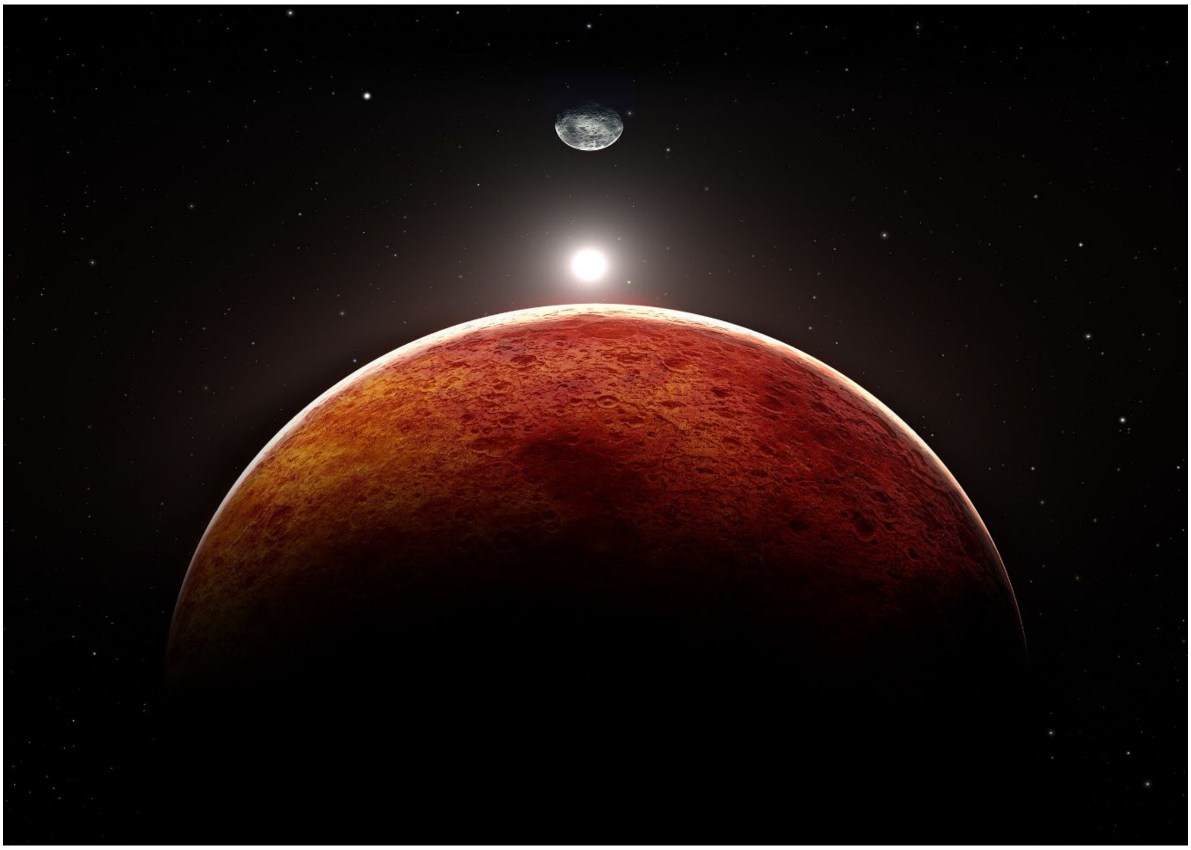
2nd level Specializing Master's Programme in

SpacE Exploration and Development Systems

a.a. 2024/25



The 2nd level Specializing Master's Programme in "SpacE Exploration and Development Systems" (SEEDS) started in 2005 following a proposal of Politecnico di Torino addressed to its European partners.

SEEDS is focused on the human and robotic exploration of space and on the related missions, systems, and technologies.

The purpose of the programme is to provide young graduates with the core applied physics and engineering skills required to develop space systems and missions from initial concept through design, assembly and verification, to launch and operations.

To reach these objectives SEEDS relies on the tight collaboration of three European Higher Education Institutions located in three different countries, namely Politecnico di Torino in Italy, Institut Supérieur de l'Aéronautique et l'Espace (ISAE, Toulouse) in France and University of Leicester in UK.

All three partners share common features including: strong links with space industry, heritage in space research and exploration and the inclusion of high-level expertise in the delivery of teaching, based on both the academia and the industry.

Organization of the courses

The 2nd level Specializing Master is a full time programme of one academic year duration for a total of 80 ECTS.

An internship period will follow. During the internship period, participants will elaborate a project work. The Project Work is without any doubts one of SEEDS main qualifying features. It lasts more than six months and is divided into three phases (see table n. 1), each one performed in a different SEEDS site.

The final event of the SEEDS Master will be held at ASI or ESA/Estec, where the final presentation of the main outcomes of the Project Work will be given by the team of students. The Project Work deals with the design of a wide human space exploration mission. A different mission is identified every year in cooperation with the three SEEDS sites and in agreement with the National Space Agencies and main supporting industries.

The teaching programme includes 5 months classroom activities with academic and corporate teaching staff and it is structured as follows (see table n. 2):

- 7 courses
- Internship

SUBJECT	ECTS	Hours
Fundamentals of space sciences and techniques	6	60
Space Management and utilization	6	60
Space exploration systems I	6	60
Space exploration systems II	6	60
Human space systems I	7	70
Human space systems II	6	60
Space telecommunications, GNC and avionics	8	80
Internship	35	875
	80	1325

INTERNSHIP PHASE 1 PROJECT WORK I (Toulouse) CEF (Concurrent Engineering Facility) sessions at the French Space Agency
INTERNSHIP PHASE 2 PROJECT WORK II (Torino) CEF (Concurrent Engineering Facility) sessions at the Italian Space Agency
INTERNSHIP PHASE 3 PROJECT WORK III (Leicester)
Final event of SEEDS Master Presentation of PROJECT WORK activities at ASI or ESA/ESTEC

Fundamentals of space sciences and techniques

Ing-Ind/03 - Ing-Ind/05 - 6 CFU (60 hours)

Prof. Sabrina Corpino

TOPIC:
Orbits and Astrodynamics
SUBTOPICS:
Introduction to astrodynamics
Two body problem
Conservation of mechanical energy and angular momentum
The trajectory equation
Elliptical and circular orbits. Parabolic and hyperbolic orbits
Main reference frames
Orbital elements
Orbit perturbation and orbit generators
Ground track. Specialized orbits.
Transfer trajectories. Mars trajectory. STK exercise
Entry, descent, landing and ascent.
TOPIC:
Mission Analysis
SUBTOPICS:
Objectives and mission requirements (high level/decomposition)
Mission Constraints, mission phases and mission scenarios

Mission modes of operations
Functional architecture and system scenarios, command and control, FDIR, procedures
Mission Execution and product support
Test and exercise on mission modes of operations vs functions

TOPIC:
Space and Planetary Environment
SUBTOPICS:
Space environment and effects introduction and overview
Radiation definitions and environments (SPE, GCR, trapped)
Radiation interactions and analysis methods
Radiation effects (physical, biological) and countermeasures
Meteoroids and debris environment, effects and shielding analysis and design
Plasma environment and effects and charging countermeasures
Vacuum and atmosphere environment (incl. Atox), effects (incl outgassing / contamination), countermeasures, synergistic effects
Planetary environment, effects, countermeasures on bodies of concern (e.g. Moon, Mars, NEO)
Planetary protection rules and implementation approach

Space Management and utilization

Ing-Ind/05 - 6 CFU (60 hours)

Prof. *Paolo Maggiore*

TOPIC:
Space management and utilization
SUBTOPICS:
Ergonomics aspects and flight crew interface design requirements of manned space habitats
Quality Concept in Space, Product Assurance and relevant disciplines Root cause analysis concept, Human error prevention, Reliability and Safety Engineering Activity in Space , Normative reference
PMP requirements
PA Requirements

Space exploration systems I

Ing-Ind/14 - Ing-Ind/07 - 6 CFU (60 hours)

Prof. Lorenzo Casalino

TOPIC

Space Robotics

SUBTOPICS:

Introduction
The environment where space robots must operate
Robots for space operations
Planetary exploration missions
Manipulatory systems
Mobility on planetary surfaces
Mobility in planetary atmosphere
Wheeled vehicles
Legged vehicles:
Power systems for robots
Vision systems and vision based control
Future possibilities
Practical applications

TOPIC: Space Propulsion

SUBTOPICS:

Fundamentals
Solid Propellant Motors
Liquid Rocket Engines
Hybrid Rocket Motors
Cold gas systems
Introduction to electric propulsion
Electrothermal thrusters
Electrostatic thrusters
Hall Thrusters
Unsteady electromagnetic thrusters
Advanced propulsion concepts

Space exploration systems II

Ing-Ind/05 - 6 CFU (60 hours)

Prof. *Nicole Viola*

TOPIC:

Systems Engineering I

SUBTOPIC:

Systems Engineering and Systems Design
Requirements definition and Functional Analysis
Requirements definition and Concept of Operations
Trade-Off Analysis
Model Based System Engineering

TOPIC:

Systems Engineering II

SUBTOPIC:

Mission Definition
System Concept Definition
Exploration System Architecture
Functional Analysis and Functional Architecture
Concurrent Design Processes
Physical Architecture and Layout
System Budgets
Integrated Design Environment
Specifications and Verification

Human space systems I

Ing-Ind/06 7 CFU (70 hours)

Prof. *Domenic D'Ambrosio*

TOPIC:

Planetary Aerothermodynamics

SUBTOPICS:

Definition of the atmospheric re-entry problem
A basic introduction to Fluid Dynamics, with emphasis on compressible flows
Aerothermodynamics phenomena occurring during re-entry: an overview
Approaches to the re-entry problem

Mathematical and physical models for high-temperature, reacting compressible flows
Numerical simulation in aerothermodynamics
Thermal protection systems
Ground and flight experiments in aerothermodynamics
Exercises

TOPIC:

Computational aero-thermodynamics, TPS preliminary sizing

SUBTOPICS:

Missions Critical Issues and Overview
Planetary Atmospheres, Basic Thermodynamics and Regimes
Flow Physics for re-entry vehicle mission scenarios
Re-entry and Vehicle Design Considerations
Hypersonic and Rarefied Flow aerodynamics
Engineering and CFD methodologies
Aero-heating prediction methodology
Entry trajectory simplified approach
Heat shields configuration and heat transfer

TOPIC:

Thermal Control

SUBTOPICS:

Thermal Environments in Space Exploration
Fundamentals of Thermal Control and Thermal Functions
Thermal Control Architecture and Design
Active Thermal Control Systems Architecture and Components
Thermal Modelling architecture and analysis methods (Requirements and Verification)
Entry Thermal Protection System (TPS)

Human space systems II

Ing-Ind/04 - Ing-Ind/05 - 6 CFU (60 hours)

Prof. Alfonso Pagani

This module delves into the intricacies of Human Space Systems, offering a comprehensive examination of some key elements that enable human presence and operations in the space environment. Covering topics such as space structures and materials, environmental control and life support (ECLS), electrical systems, and electromagnetic compatibility (EMC), students will gain a deep understanding of the engineering, design, and operational aspects critical to space exploration. With a focus on both theoretical principles and practical applications, this course equips students with the knowledge and skills needed for careers in spacecraft design, space station management, and aerospace research. Emphasis is placed on developing solutions that ensure the safety, sustainability, and functionality of human missions in the challenging realm of outer space.

Upon completion of this course, students will possess a solid foundation in the design and operation of Human Space Systems. They will be equipped to:

1. Analyze and design space structures and materials for various mission scenarios.
2. Understand and address environmental control and life support challenges, ensuring crew well-being and mission success.
3. Competently work with electrical systems, ensuring power reliability and efficiency in space projects.
4. Apply electromagnetic compatibility principles to minimize interference and ensure the integrity of space systems.
5. Contribute effectively to space exploration endeavors, emphasizing safety, sustainability, and innovation in the human spaceflight domain.

<u>SUBMODULE " SPACE STRUCTURES AND MATERIALS" (32 hours)</u>

Part 1. General aspect of Design of Space Structures.

The process of developing Spacecraft Structures: design objectives; design phases; mission analysis and requirements; overview of manned structures. Space Mission Environment: ground environment; space environment; protecting the manned structures from meteoroids and orbital debris.

Design loads cycles. Reliability and confidence: safety factors; design and stress analysis requirements for reliability. Verification approach: analyses; strength; thermal. Tests: test or verifying mechanical requirements; dynamic mathematical model and modal survey. Fracture control requirements for space flight structures and pressure vessels: structure life analysis; proof test; design criteria for controlling stress corrosion cracking, cycling loading spectral.

Part 2. Basics of elasticity and Analysis of Aerospace Structures.

Theory of Elasticity. Equilibrium. Stresses, Strains, Displacements. Stress-strain; Strain-Displacements.

Common types of structural components and their structural efficiency: forms of construction (truss, plates, shell, skin-stringer, corrugated shell, integral skin-stringer, honeycomb, waffle, multilayered, filament wound, etc.); comparison of key features.

Part 3. Other Topics.

Materials: main parameters affecting the behaviour of aerospace materials (thermal, moisture and radiation environments; mechanical loads, static and dynamic behaviour, etc.); common structural materials (alloy of aluminium, titanium, magnesium, nickel-based steel, composites); materials and material configurations selections (physical and mechanical properties; advantages, disadvantages and typical applications).

Testing: static and dynamic test plans for materials, components and modules.

Analysis and simulation: failure criteria; tools for structural modelling and stress analysis; typical problems; multiobjective and multidisciplinary optimization. Fundamentals of structural dynamics: basic concepts from the theory of vibration; dynamic loads classification and their levels; modelling for response analysis (SDOF and MDOF models; continuum models; FEM); modal analysis and transient analysis. Inflatable structures for manned and unmanned modules: materials; method of fabrication; inflatable and expandable and rigidation techniques; load conditions and constraints; computational simulation and evidence of nonlinear phenomena; case studies and examples of inflatable modules.

<u>SUBMODULE "ENVIRONMENTAL CONTROL & LIFE SUPPORT" (32 hours)</u>

ECLS overview and general definitions

a. Functional breakdown:
   - "Provide Resources"
   - "Manage Wastes"
   - "Maintain Environment"
   - "Maintain Crew Health"
   - "Respond to Environmental Contingencies"
   - "Support Special Operations"
b. Open vs closed loop, centralized vs decentralized concepts
c. Link with type of mission (LEO, Moon, Mars) with increasing complexity

Function 1: "Provide Resources"

a. Gases (Oxygen, Diluent gas, Gases for specific usage, Vacuum & venting)
b. Potable & technical water
c. Food (fresh, dry) Addressing for each case:
   - Needs – quantity & quality
   - Storage and Generation Systems
   - Regenerative Systems
   - Monitoring & control
   - Analysis (approaches, tools)

Function 2: "Manage wastes"

d. Gases (Carbon dioxide, Trace gases)
e. Waste water (Gray water, Urine, Black water)
f. Solid waste (metabolic, trash) Addressing for each case:

- Quantity & quality
- Storage Systems
- Regenerative Systems
- Monitoring & control
- Analysis (approaches, tools)

Function 3: "Maintain Environment"

g. Pressure & Composition (Total pressure and atmosphere composition, pressure changes: positive and negative, Atmosphere Control & Supply (ACS)
h. Thermal-hygrometric Comfort (Air temperature and humidity, Ventilation, Temperature & Humidity Control (THC)
i. Contamination (airborne trace gas and odor, particulate & bio-contamination; fluid and surface particulate and molecular contamination; Atmosphere Revitalization & Sampling (ARS)
j. Ionizing radiation control (effects on humans, radio-protection) Addressing for each case:
   - Requirements and typical levels
   - Analysis (approaches, tools)

Function 4: "Respond to Environmental Contingencies"

k. Atmosphere pressure & composition contingencies
l. Fire, smoke, smouldering
m. Radiation
n. Fire Detection & Suppression (FDS)
o. Analysis (approaches, tools)

Function 5: "Support Special Operations"

p. Support Extra Vehicular Activity (EVA - prebreathing, decompression, low pressure operations)
q. Support Intra Vehicular Activity
r. Airlocks

ECLSS, Advanced Life Support (ALS) & Closed Ecological Life Support Systems (CELSS) implementation

- Architecture of complete systems (including redundancy approach)
- Analysis aspects (system level, Equivalent System Mass)
- Design aspects (system level)
- Budgets (mass, volume, power, data, …)
- Verification
- Research activities

In-Situ Resource Utilization (ISRU)

- Definitions
- Technologies (Water & Oxygen production)
- Architectures and budgets
- Research activities

Planetary Protection

- Legislation, Policy & Requirements (forward & backward contamination)

- Implications for spacecraft (bioshield, organics inventory)
- Implications for ground facilities (sterilization, quarantine)

<u>**SUBMODULE: ELECTRICAL SYSTEMS & EMC (26 hours)**</u>

<u>**Electrical Systems Section**</u>

- Overview of Electrical Requirements for Space Projects
  - Power Quality Requirements
  - Power Users Requirements
- Electrical Systems Architectures
  - Definitions
  - Functional blocks
  - Functional Architectures
  - Performances trade-off
  - Application fields
- Electrical Systems Units
  - Solar Panels
  - Batteries
  - Power Control & Distribution Units
    - DC/DC conversions
    - Battery Charge Modules
    - Protection Circuits
  - Harness
- Electrical Systems Analyses methods
  - Voltage Drop Analyses
  - Power System Sizing
    - Solar Panels Sizing
    - Batteries Sizing
  - Power System Stability (DC/DC converters cascade)
- Challenges & Innovative Areas

<u>**EMC Section**</u>

- Overview of EMC requirements for Space Projects.
  - Conducted Emission
  - Conducted Susceptibility
  - Radiated Emission
    - Electric Field Measurement
    - DC Magnetic field Emission
    - Low Frequency Electric and Magnetic Field Measurements
  - Radiated Susceptibility
  - Susceptibility to electrostatic discharges
- EMC approach for System level activities
  - EMC Programme
  - Early EMC activities
  - EMC Control Plan
- Design Techniques for EMC

    - Unit Level Design
        - Shielding
        - Electrical I/F’s and Filtering
        - PCBs layout
        - Design Rules for Magnetic Field Reduction
    - System Level Design
        - Grounding techniques
        - Bonding techniques
        - Power Supply Distribution
        - Harness
        - Protection against ESD
        - Design Rules for Magnetic Field Reduction
        - Design methods for RFC

- Test Methods and Instrumentation for EMC.
    - Conducted Tests
        - Conducted Emission Measurements
        - Conducted Susceptibility Measurements
    - Radiated Tests
        - Radiated Emission Measurements
        - Radiated Susceptibility Measurements
        - DC and low frequency magnetic field measurements
    - Instrumentation and Facilities
- Analysis methods and computational models for EMC.
    - Typical EMC analyses and Model
        - E- field Radiated Emission/Susceptibility Analyses
        - Shielding effectiveness Analyses
        - RFC Analyses
        - DC Magnetic Analyses
    - Overview of commercial EMC Computational solvers

Space telecommunications, GNC and avionics

Ing-Ind/03 - Ing-Ind/05

- 8 CFU (80 hours)

Prof. Mauro Mancini

TOPIC:

Attitude Determination, Guidance and Control

SUBTOPICS:

Attitude kinematics, determination and representation

Attitude Dynamics and control

Attitude Hardware
Engineering applications
TOPIC:
Space Telecommunications
SUBTOPIC:
Introduction
Fundamentals of noise in communications systems
Fundamentals on antenna and propagation
Fundamentals on digital transmission systems
Fundamentals on source coding
Link budget for radio communication systems
Spacecraft ranging and Doppler measurements
Space telecom systems
TOPIC:
Space Avionics
SUBTOPICS:
Mission scenario and profile
Spacecraft avionic subsystems
The avionics validation and verification flow
EPS
Introduction
Electrical systems and EMC - Unit and System level.
Power Conditioning & Regulation
System Analyses
EMC approach for System level activities.
Design Techniques for EMC - Unit and System level
Exercises