

Engineering and Management of Space Systems

- an International Joint Master's Double-Degree Programme

Jasminka Matevska

*Faculty of Electrical Engineering and Computer Science
Bremen City University of Applied Sciences, Germany
jasminka.matevska@hs-bremen.de*

Marek Chodnicki¹

Faculty of Mechanical Engineering and Ship Technology

Zbigniew Łubniewski²

*Faculty of Electronics, Telecommunications and Informatics
Gdańsk University of Technology, Poland*

marchodn@pg.edu.pl¹

zbigniew.lubniewski@pg.edu.pl²

Abstract— Dynamic development of the European space sector results in a necessity for suitable Higher Education Institution graduates. Current study programs of Aerospace Technology are focused on the field of mechanical engineering. Although engineering methods for design, construction and assembly of mechanical systems are covered, interdisciplinarity and life cycle aspects are not considered in a sufficient degree. Due to the increasing digitalization, interconnection and distribution of technical systems, there is a high necessity to consider the systems with their interdisciplinarity during the entire life cycle from the initial idea through conception, design, production, integration, verification and validation to operation, maintenance and disposal in such a way that it best meets the expectations of the stakeholders and successfully accomplishes the planned mission. Current systems require different competencies depending on the characteristics of the application domain. The increasingly dynamic market requires an adaptation of traditional approaches and the introduction of agile methods in order to meet the requirements for greater flexibility and creativity. This, supplemented by management and social competencies, forms a future-oriented basis for mastering the ever-growing complexity of technical software-intensive systems. Our international interdisciplinary joint Master's double-degree program - Engineering and Management of Space Systems established as a cooperation of Bremen City University of Applied Sciences, Germany and Gdańsk University of Technology, Poland addresses all the above-mentioned systems engineering aspects and imparts competencies necessary to comprehend complex space missions as a "system of systems" during their entire life cycle. It is conducted in cooperation with the local space industry, in particular OHB, Airbus Defence and Space, and Ariane Group.

Keywords— *Systems Engineering, Interdisciplinarity, Industry Cooperation, Master's Study Program*

I. INTRODUCTION AND MOTIVATION

In the course of the continuously increasing digitalization, interconnection and distribution of technical systems and their growing complexity, a systems engineering approach has emerged. It takes a networked and interdisciplinary view of the scientific expertise of individual engineering disciplines. Systems engineering brings together all the disciplines involved in a structured process. This can include various technical, business, legal, logistical and also social or communicative aspects and should take into account the entire life cycle of the systems. The aim is to develop and adapt the respective system from the initial idea through conception, design, production, integration, verification and validation to operation, maintenance and disposal in such a way that it best meets the requirements of the respective stakeholders.

Business requirements are incorporated throughout the entire product life cycle in order to achieve an optimal balance of functions and interactions within the project budget, schedule, technical and other expectations and constraints. The increasing dynamics on the market require an adaptation of traditional procedures and the introduction of agile methods in order to meet the requirements for more flexibility and creativity.

In many branches of industry that usually recruit from the classical engineering sciences such as mechanical engineering, computer science and electrical engineering, there is an increasing need for specialists and managers who are trained to meet the requirements of systems engineering. This applies in particular to the aerospace industry, which is an interdisciplinary engineering science that combines various technical disciplines such as electronics, computer science, robotics, mechanical engineering and materials technology, and which is of particular importance in the state of Bremen as an

economic cluster "aerospace" with more than 140 companies and 20 scientific institutions in this field.

Existing well-designed aerospace degree programs focus primarily on the mechanical engineering aspects and disciplines and are quite successful in teaching the necessary skills to successfully develop a space system, particularly from a mechanical and physical perspective. However, a space system increasingly consists of monitoring and commanding electronic and software components that enable intelligent and autonomous functionality. A space mission also includes all ground systems that make the conception, design, simulation, verification, validation and operation of the flight systems and thus the mission with all its phases possible at all. Many of the ground systems are de facto complex software systems with very high requirements in terms of end-to-end consistency and transferability of huge amount of partly real-time data.

The "Engineering and Management of Space Systems (EMSS) M.Sc." program offers an interdisciplinary course of study for this promising industry including the monodisciplinary engineering sciences in the fields of computer science, electrical engineering and mechanical engineering and combines these with overarching interdisciplinary system skills. Based on the fundamental idea of systems engineering, students acquire technical know-how at the cutting edge of research and application skills for practical space-related projects on specific systems (e.g. satellite systems). In addition to technical skills, management and social skills are taught.

II. STUDY PROGRAM STRUCTURE

The "Engineering and Management of Space Systems" study program is set up as an interdisciplinary course designed as a strategic cooperation between Bremen University of Applied Sciences (HSB), Germany and the Technical University of Gdańsk (Gdańsk Tech), Poland [1]. On HSB side the study programme is assigned to the Faculty of Electrical Engineering and Computer Science and conducted in cooperation with the Mechanical Engineering Department of the Faculty of Nature and Technology. On Gdańsk Tech side this study program is assigned to the Faculty of Electronics, Telecommunications and Informatics and conducted in cooperation with the Faculty of Mechanical Engineering and Ship Technology. The teaching language is English.

The international orientation of the course in cooperation with the two partner cities Bremen and Gdańsk strengthens the intercultural and linguistic skills of the students. These skills are an important prerequisite for successful positioning on the job market in times of globalization, converging markets and internationally active companies with transnational development teams.

The course is structured as a "joint double degree" program, in which one semester is completed in Gdansk and one in Bremen. The credits earned are credited to the curricula of the respective courses at both universities. The third semester comprises the Master's thesis and the Master's seminar and can be completed either in Bremen or Gdansk. The overall study program comprises at least 90 ECTS.

During the preparation phase, three pilot runs were run. The program was successfully accredited in December 2023 by the German Accreditation Council. The accreditation is valid until 30th Sep. 2031. The first official run has started in the current summer semester 2024.

The degree (as a double degree with one degree from each of the two participating universities) enables students to take up a qualified career as well as a doctorate. In addition to subject-related technical competences and management skills, the course concept also integrates the acquisition of skills in the areas of communication, cooperation and academic self-image. Thus, this degree program also lays the foundation for the ability to learn throughout life and strengthens graduates for the perception of social roles and effectiveness as professionals as well as responsible citizens.

III. CURRICULUM

The EMSS curriculum includes mandatory, special elective and elective modules. Each module comprises a workload of 180 hours, which corresponds to 6 ECTS credits. The Master's thesis including the Master's seminar comprises 30 ECTS.

The following modules are mandatory:

- Engineering Foundations of Satellite Systems
- Space System Management
- Space Systems Engineering
- Project Management (incl. Teamwork and Communication)
- Interdisciplinary Project 1 & 2 (Satellite Mission)

Due to the interdisciplinary orientation, it is possible to specialize in the following disciplines:

- Computer Science
- Electronics Engineering
- Space Technologies

According to the specialization, the following special elective modules are assigned as shown in TABLE I.

TABLE I. SPECIAL ELECTIVE MODULES

<i>Specialization</i>	<i>Special Elective Modules</i>
Computer Science	Software Engineering and Management Methods for Developing Complex Software Systems
Electronics Engineering	Electrical Control Systems Measurement and Instrumentation
Space Technologies	Mechanical Engineering and Aviation Design and Modelling of Space Propulsion Systems

Additionally, various elective modules included. A selection is listed as follows:

1. Model-based Systems Engineering
2. Non-Chemical Space Propulsion Systems

3. Orbital Mechanics
4. Objective Programming and Spatial Data Processing
5. On-board Software Engineering
6. Antenna Technique and GNSS Applications Programming
7. Satellite Communications
8. Optical Communications
9. Ground Segment Engineering
10. Current Topics of Systems Engineering

An exemplary selection for the Computer Science specialization could be as depicted in TABLE II. :

TABLE II. COMPUTER SCIENCE SPECIALIZATION

Mandatory Modules	Engineering Foundations of Satellite Systems Space System Management Space Systems Engineering Project Management Interdisciplinary Project 1 & 2
Special Elective Modules	Software Engineering and Management Methods for Developing Complex Software Systems
Elective Modules	On-board Software Engineering Satellite Communications

In order for the profile to be completed in sufficient depth, the technical tasks within the interdisciplinary projects and the Master's thesis should have a Computer Science or Software Engineering focus.

IV. CERTIFICATION

The content and objectives of the course take into account the international standards of systems engineering, based on the certification programs of the International Council on Systems Engineering (INCOSE) and the German chapter of the Gesellschaft für Systems Engineering (GfSE), core curriculum for SE-ZERT®, level D [4] as shown in TABLE III.

TABLE III. MAPPING OF CURRICULA

SE-ZERT® C/D	EMSS
Systems Engineering Foundations Interfaces across Projects Cross-cutting Functions within Development Projects	Space System Management Space Systems Engineering
Cross-Project Interfaces Interfaces among Systems Engineering and Project Management Conflict Manangement and Social Skills	Project Management Space System Management Interdisciplinary Project, Part 1 & 2
Requierements Management Validation & Verification Realisation Processes Operational and Disposal Aspects	Interdisciplinary Project, Part 1 & 2 Engineering Foundations of Satellite Systems Special Mandatory Modules Elective Modules

The proof of academic equivalency and certification have been already discussed with the INCOSE and GfSE colleagues and will be followed as next steps upon successful completion of the first official run.

V. DEVELOPMENT OF COMPETENCES IN COOPERATION

Students who already have a Bachelor's degree first learn the technical basics of the application domain (Mechanics, Mechatronics and Avionics in Space Systems and Satellite Technologies) at the Gdansk University of Technology. This technical knowledge is then expanded with competencies in space systems engineering, project management, communication, teamwork and social skills at the Bremen City University of Applied Sciences. Students can apply these knowledge in two consecutive semesters (Interdisciplinary Project 1 & 2). A realistic satellite mission is planned as an overall project and developed up to a "Preliminary Design Review" level in teamwork. A scientific approach is taught in particular within the modules Space Systems Engineering, Interdisciplinary Project 1 & 2 and in the Master's seminar and is assessed by corresponding achievements (scientific project report or Master's thesis).

Numerous colleagues from the local aerospace industry in Bremen (e.g. OHB, Airbus Defence and Space, Ariane Group, ZARM) are actively contributing to this transfer of skills. They are involved through company visits, guest presentations, active support in teaching and project work. Long-term cooperation is planned.

Each winter semester various experienced colleagues from different disciplines and space companies in Bremen are presenting different technical disciplines and aspects of the space domain. During the winter semester 23/24 the following guest presentations took place:

- Straightforward Research - 6 Minutes of Microgravity with TEXUS
- Engineers' Calculation Models – from Analytical Models to Digital Twins
- Ground Segment for Space Applications - Overview of operational Ground Segment engineering in DLR and ESA environment
- Launcher Electrical System: A Generalized Functional Description of the Ariane Launcher's Avionics
- Software related Space Systems Engineering
- ESA OPS-SAT Presentation
- Spacecraft On-Board Software Engineering
- Programme Management Office - Key-Player in Space Exploration Projects
- Bremen, the City of Space, Space Coordinator Bremen State

Furthermore, the second part of the Interdisciplinary Project at HSB was conducted in cooperation with OHB. The Head of the Department of Satellite Systems Engineering was the main lecturer.

VI. SUMMARY

The international double degree Master's degree program in Engineering and Management of Space Systems provides a future-proof basis for mastering the constantly growing complexity of software-intensive technical systems in the space industry and space missions in their entirety as a "system of systems", thus offering potential graduates excellent career perspectives.

During the preparation phase and the three pilot runs the program has also met with an extremely positive response from the international specialist community: At the "ESA Space Educational Activities Symposium" in Barcelona, Spain, at the end of April 2022, the course project [2] was presented and acknowledged with great interest by the specialist community, including the director of the ESA Space Academy, also with regard to possible collaborations. Furthermore, the Systems Engineering community acknowledged the concept at the "Tag des Systems Engineering" in November 2022 in Paderborn, Germany [3].

With the interdisciplinary international double degree Master's program EMSS, Bremen University of Applied Sciences and Gdansk University of Technology offer an innovative and future-oriented study program that has a unique selling point throughout Germany and Poland conducted in a strong cooperation with the local space companies. Thus, we can make an important contribution to securing skilled staff in the aerospace industry, especially in the Bremen region.

The concepts of this degree program are easily transferable to other (systems) engineering programs. In particular, the consideration of both the interdisciplinary aspects and the entire life cycle of the systems, supplemented by the teaching of social and management skills, form a good basis for meeting the current requirements in systems engineering and mastering the ever-growing complexity of distributed interconnected interdisciplinary systems.

ACKNOWLEDGMENT

The realization of this program was only possible thanks to the support of many academic and non-academic staff members of both universities, as well colleagues from the space industry, namely:

HSB: Andreas Teufel, Anne Brümmer-Kock, Yana Yerofeyeva, Thomas Trittin, Antonio Garcia, Uwe Apel, Sören Peik, Lars Braubach, Friedrich Fleischmann, Ludger Kempen, Christian Dierken, Thorsten Teschke, Indulis Kalnins

Gdańsk Tech: Justyna Szostak, Edmund Wittbrodt, Aleksandra Wiśniewska, Paulina Strakowska, Marcin Jasiukowicz

Airbus (incl. Airbus Defence & Space): Maik Purrmann, Temenushka Manthey, Christina Jetzschmann, Ingo Möller, Andreas Schütte, Anna Chrobry

Ariane Group: Celen Nil

OHB: Raphaël Lescouzères, Erik Dehnhardt

ZARM: Marcel Bernauer

The City of Bremen Space Coordinator: Siegfried Monser

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