From Soyuz-docking manoeuvres to microalgae cultivation: hands-on training for Master's students

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Abstract

A strong connection between research and teaching at a university is crucial to offer students a unique opportunity to put in practice the concepts taught in theoretical lectures. At the University of Stuttgart, several hands-on training courses have been offered for eight years within the module “Selected hands-on training for space”. Those are adapted to the current research at the Institute of Space Systems. During one semester, students participate in two of the offered courses and are evaluated through an exam or a report. Three ECTS for the space specialization in the aerospace engineering Master are granted after successful completion. The limited places offered are usually filled up in matter of hours and the students’ feedback has been very positive every year. The module includes up to five different courses, depending on the semester. The Life Support Systems seminar is focused on the cultivation of microalgae, linked to the institute’s ISS Experiment photobioreactor PBR@LSR. After learning the basic life support system concepts, the students build and conduct their own microalgae photobioreactor experiment. In the Missions Analysis practical seminar, based on the work of several PhD candidates, the participants learn and put in practice aspects of mission planning with the help of the Astos Solutions software as well as the SPICE toolkit. During the Rendezvous and Docking practical training, students learn about the operation and handling of a spacecraft. Besides theoretical lectures, guided sessions in the simulator allow to put into practice the handling of common complex procedures, audio-visual perception and motor skills. This seminar is linked to the research carried out in the SIMSKILL experiment. In the Earth Remote Sensing seminar, students learn how to handle payload data for Earth observation and their scientific evaluation. The Flying Laptop, a satellite fully built at the institute and launched in 2017, is used for this course. Finally, the research carried out in the field of electrolysers and fuel cells for space applications at the institute prompted the establishment of a training course. After deepening their knowledge on both electrolysers and fuel cells, the students prepare, carry out and evaluate various experiments. This paper presents the different training courses from our institute and their link to the current research.

Keywords

Earth-Observation, Fuel Cell, Hands-on training, Life Support System, Mission Analysis, Soyuz simulator

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Acronyms/Abbreviations

EL *Electrolyser*
FC *Fuel Cell*
IRS *Institute of Space Systems*
LSS *Life Support System*
PBR *Photiobioreactor*

1. Introduction

At the Institute of Space Systems (IRS – *Institut für Raumfahrsysteme*) at the University of Stuttgart (Germany) research in several space topics is being conducted, with topics ranging from small satellites to space stations. This research allows to get aerospace students closer to real projects, for example involving them in Bachelor's or Master's Thesis. Besides that, the institute offers yearly a Hands-on Training module. Students enrol for a three ECTS module and participate in two hands-on training seminars. Over the last years five different trainings have been offered looking at Life Support Systems (LSS), mission analysis, rendezvous and docking manoeuvres, Earth observation and Fuel Cells (FC) and Electrolysers (EL). Each training seminar is organized independently, all including some theoretical lectures and practical sessions. The evaluation process is also linked to each hand-on training seminar, with a theoretical and practical exam, a report and/or a presentation.

This paper presents the seminars offered at IRS, looking at the current research, the training goals and development.

2. Hands-on Training on Life Support Systems

2.1. Current research at IRS

The working group "Life Support Systems" at the IRS has been investigating the use of biological components as part of the LSS, to produce oxygen and food for future human space flight missions. Due to their high harvest index and high growth rates, microalgae are interesting for these types of applications. The experiment PBR@LSR on the International Space Station, with the goal of demonstrating long-term stability of the cultivation under space conditions, has been one focus of the working group [1]. Current projects include the use of such systems in the context of planetary habitats, including in situ resource utilization. Besides that, the gained knowledge in this field is being transferred to terrestrial applications

2.2. Training Goals

The goal of the seminar Life Support Systems [2] is to provide students a broad overview of the activities of the research group and *a* first contact with the conduction of biological experiments. The students should learn about the production methods of relevant experiment hardware, setup of experiments and the collection and evaluation of data.

2.3. Training development

After a lecture introducing the state of the art and research on biological LSS, the seminar consists of three parts. First, the students are involved in the production of the illumination unit, by SMD-soldering. This illumination unit allows defining a certain illumination spectrum and an intensity profile to reproduce illumination conditions [3]. This allows students to simulate the solar spectrum and intensity on Mars for their experiments. The second part of the seminar consists on the setup of the experiment, Figure 1, programming the illumination unit to match the given spectrum and intensity profile. In phase three, the students collect data for growth rate and nitrate absorption and made calculations with the acquired data for the dimensioning of a PBR as part of a LSS. This process allows the students to get a full overview of how a dimensioning study would be developed, from experiment hardware production to the conduction and evaluation.

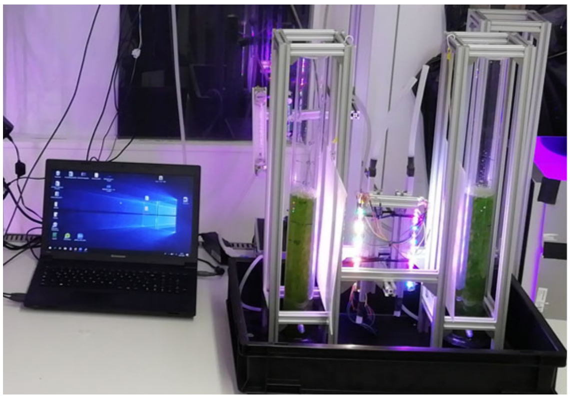

Figure 1: Test stand for the LSS seminar experiments

3. Hands-on Training on Mission Analysis

3.1. Current research at IRS

Multiple research groups at the IRS use the software ASTOS and SPICE. While some utilize SPICE data to explore the dust regime in the Saturnian system, others implement the university satellite within the SPICE framework to establish optical laser downlinks [4]. ASTOS simulations are for example used to prevent star tracker blinding. Using ASTOS, it is also possible to perform automated analysis for future spacecraft constellations in Earth vicinity and around Lagrange points, e.g. for potential sunshades around Sun-Earth Lagrange Point 1 [5].

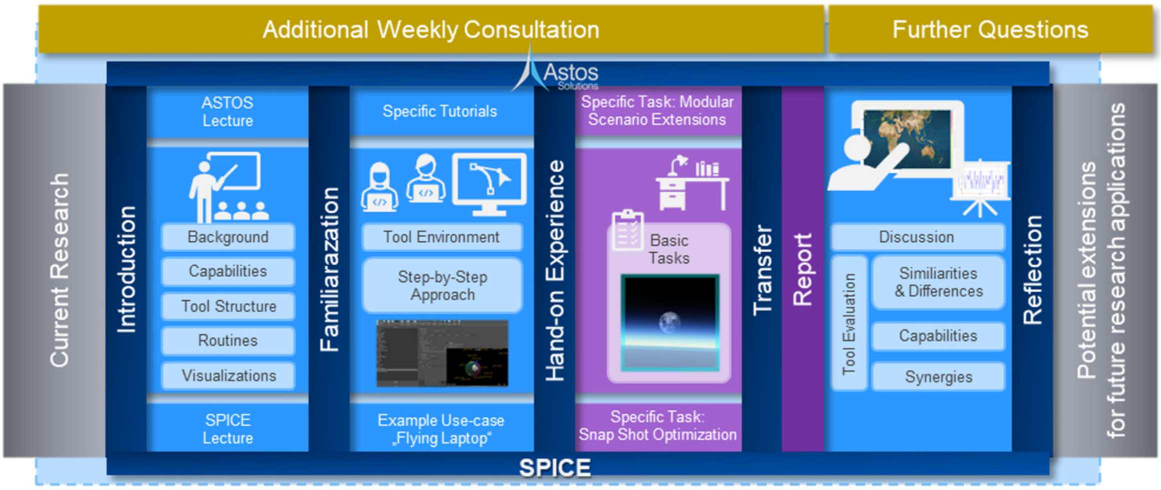

Figure 2. Overview of the Mission Analysis seminar

3.2. Training Goals

The goal of this seminar is to provide hands-on experience with those tools, with respect to typical mission statements. Students should be able to describe the basic functionalities of both programs and their logical frameworks. In addition, they should be able to explain the similarities and differences and justify their preferred tool for potential scenarios. Furthermore, based on their own experience they should be able to judge the user friendliness.

3.3. Training development

The seminar, Figure 2, starts with lectures describing both tools, including some background knowledge and their capabilities. Once the students are familiarized with the tools the hands-on training begins with tutorials. Within these, the students perform a step-by-step approach within the project environment to solve first SPICE / ASTOS tasks. This gained knowledge is then used to carry out the semester task. This is divided into four subtasks: three basic and a more complex one, leaving space for creativity. The phase-specific objective is the efficient interaction with the software tools. For trouble-shooting and further questions, the students can request support via mail or join the weekly consultation. The task processing including a final report of the results achieved is performed in pairs to simulate the future cooperative work environment within project teams and reviews. After report submission, a final meeting to discuss their impressions regarding the similarities, differences, opportunities, capabilities and further aspects of the tools is carried out. This meeting should support the students to reflect and evaluate the lessons learned during the seminar. While the selection of the specific tasks is based on current research at IRS the final team reports are used as baseline for innovative ideas and potential extensions for future research.

4. Hands-on Training on Rendezvous and Docking

4.1. Current research at IRS

During more than a decade a 1:1 scale version of the Soyuz Spacecraft's descent module has been used for the instruction of students at the IRS, Figure 3. Additionally, a mobile version of the simulator and a Virtual Reality concept are being used for both teaching and research. The technical development of such simulator has been supported by the continuous participation of students in both Bachelor's and Master's theses.

Within the framework of the Soyuz Simulator project, a series of research experiments have been run during the last years by developing portable versions of the bigger simulator. SIMSKILL in Antarctica [6], and SIMSKILL-RU [7] and SIMSKILL-VR [8] in the facilities of the IMBP in Moscow, Russia. The goal of this research is to understand how human performance is affected by surrounding stressors such as isolation, confinement and hypoxia (lower oxygen concentration). With the experience gained in such international projects, the seminar at the institute benefits from the developed technologies and training procedures.

4.2. Training Goals

The Soyuz Rendezvous and Docking seminar aims to provide students with both theoretical insight on the Soyuz spacecraft, and more generally on human spaceflight. The seminar starts with four different lectures, some of them taught by a Soyuz Astronaut. The main goal is then to learn how such a spacecraft is flown by getting familiarized with the vehicle's systems and flight behaviour.

Figure 3. Student at the Soyuz Simulator at IRS

4.3. Training development

Students get acquainted with the internal systems of the Soyuz-TMA spacecraft, the mission phases to the ISS and back, the safety procedures to follow, among others. During the practical training, a series of approach and docking scenarios to the ISS are proposed. During the later weeks of the seminar, rendezvous and phasing are taught as well, a mission phase that requires also knowledge on orbital mechanics, being provided in parallel with a theoretical session.

At the end of the seminar, a final check flight and a theoretical test are performed, in order to check the knowledge and piloting performance acquired during the semester.

5. Hands-on Training on Earth Observation

5.1. Current research at IRS

The small satellite Flying Laptop, launched in July 2017, was developed and built by PhD, graduate and undergraduate students at IRS with assistance by industry and research institutions. The project goals include technology demonstration, earth observation and improving the education of students at the University of Stuttgart in the fields of satellite development, integration, test, and operations. The satellite houses a multispectral camera system, a panoramic camera and an AIS Receiver as payload sensors.

To use the payload data of the Flying Laptop, it has to be assembled, processed, stored and provided [9]. The processing includes the calibration and georeferencing of the image data as well as the decoding of the AIS messages. Using georeferencing, the data can be used to determine the satellites attitude to improve its pointing [10].

5.2. Training Goals

Earth observation, using satellites, is a vital part for environmental monitoring, infrastructure and agriculture. Therefore, the main goal of this seminar is that students learn about the capabilities of satellite data, including spatial and spectral information. In addition, students need to look into the boundary conditions of Earth observation, including satellites orbit, its pointing capabilities and downlink capacities. During the training, the students have to define their own observation application. This preferably includes data from the Flying Laptop satellite, but can also use different satellite systems and sensors. The data has to be retrieved and analysed with either self-defined algorithms or common tools like image processing and GIS software.

The grade for the seminar is given by evaluating the results of the students in a 10 to 20 pages report.

5.3. Training development

The Training includes three lectures. The first lecture gives an overview of the Flying Laptop Mission and its payloads. It also introduces boundary conditions, and camera systems. Previous seminar results as well as possible future applications are discussed. The second lecture has its focus on the satellite operations and image processing, looking particularly at sun synchronous orbit, different pointing modes and the automated processing pipeline of the Flying Laptop, among others. The third lecture includes an exercise on how to fetch data from the Flying Laptop satellite and how data is represented in Python. The concept of images being arrays and how to modify them with python code is shown. The metadata of satellite images is observed and evaluated.

The students are then assigned into teams of two and granted access to the Flying Laptop data. As a first step, the application feasible within one semester is defined in consultation with the supervisor. During the semester, the students are free to schedule meetings with the supervisor to discuss the progress, possible issues and obstacles.

Since each student team is defining their own application, the results are diverse. They range from image processing for the Flying Laptop data, to vegetation observation with the Flying Laptop images, to measurements with Sentinel 2 and Sentinel 5P, and ship tracking with the AIS receiver of Flying Laptop. **Fehler! Verweisquelle konnte nicht gefunden werden.** shows an example of the results obtained by a group of students in 2018. The multispectral camera system of the Flying Laptop, with its green, red and near infrared channels, was used to create NDVI (Normalized Differential Vegetation Index) images. The scale is chosen to show the round, artificially irrigated fields in the desert of Abu Dhabi.

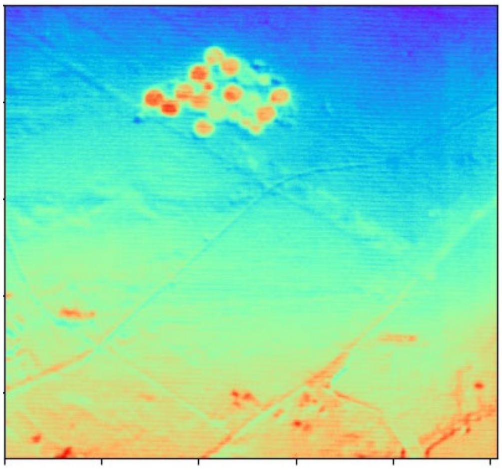

Figure 4: NDVI of fields in the desert of Abu Dhabi

The training has four main tasks: Earth observation (what satellite data can be used for and what the results imply), data processing (how to alter data and apply their own algorithms for their applications), work on a self-defined topic autonomously and self-determined in a team (promoting motivation and creativity) and the written report at the end of the training.

6. Hands-on Training on Fuel Cells and Electrolysis

6.1. Current research at IRS

At the IRS research of Fuel Cells and Electrolysis, looking both at the LSS and energy system has been conducted. The main focus has been on the integration and synergies for human space flight missions [11].

6.2. Training Goals

The hands-on training shall provide a detailed insight into space flight related electrochemical technologies. This kind of practical experience enables deeper understanding of the subject. Students shall learn underlaying principles and the operating principle of fuel cells (FCs) and electrolysers (ELs). Further goals are to demonstrate practical challenges and characterize FCs and ELs by experiment. Furthermore, students shall identify synergistic potentials between those technologies and LSS. In order to consolidate the different lessons learned, students shall individually work on exercises, which focus on the design and dimensioning of FC and EL in the scope of a LSS.

6.3. Training development

An introducing lecture teaches the electrochemical fundamentals and provide an overview on different types and categories depending on electrolyte and utilisation. Moreover, the operating principles are explained and students learn theoretically how to characterize FCs and ELs, and how to determine efficiencies and losses

The following hands-on training, Figure 5, is divided into 4 different workstations, two students team up and pass through each station. Students self-sufficiently set up the circuit and implement measurement technology. Two experiments are designed for the characterisation of a single cell proton exchange membrane electrolyser (PEM-EL). The first one covers determination of a polarisation curve, second one includes determination of energetic and faraday efficiencies. Thereby each group analyses a different operating point. Accordingly, two experiments are designed for the characterisation of a single cell PEMFC, which also include determination of polarisation curve, energetic and faraday efficiency.

Finally, the students write a report including experimental setup, results and analysis. The report also includes two design exercises.

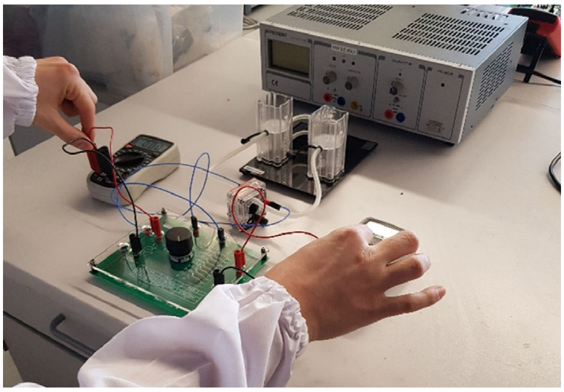

Figure 5. Students carrying out an experiment to determine polarization curve, energetic and faraday efficiency

7. Conclusions

At the Institute of Space Systems – University of Stuttgart research in several space fields has been carried out of decades. As a university institute, it is our goal to prepare the future aerospace engineers. Besides the theoretical courses, a hands-on training module has been offered for several years. This includes seminars in Life Support Systems, Mission Analysis, Rendezvous and Docking manoeuvres, Earth Observation and Electrolysis and Fuel Cells. This allows students to learn by doing and, at the same time, get closer to the research currently taking place at our institute.

The students are evaluated through practical exercises, reports or presentations. Team work is in most cases also a key element. With that, soft-skills play also an important role in this module.

The feedback from the students has been very positive over the years, encouraging us to continue offering this module every year. The number of offered places is limited and, unfortunately, some students are left out every year.

From the lecturers' point of view, this module offers us the opportunity to get a different point of view in our research, from the fresh view of highly motivated students, which in many cases, then decide to carry out their Master Thesis or further research with us.

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