Insight into the benefits of ESA Education activities: an overview of the next European space- related workforce

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***Abstract*— Growing efforts are currently being addressed by ESA to support the next-generation of space professionals and researchers. ESA's Education Office is successfully creating a network of individuals sharing and promoting dedication to space technology on the basis of the values of trust and cooperation. In this framework, students and early-career researchers can rely on experienced tutors and professionals to improve their area of expertise effectively. This paper provides a detailed insight of the utterly positive return on the careers of who had first-hand experience of ESA's Academy activities, both through training courses and hands-on projects (as REXUS/BEXUS program). The authors have contributed in many different and unexpected ways to the advancement of their fields of study and/or work. Accordingly, the outcome of this paper is a vivid and varied patchwork of people from various professional backgrounds reflecting on their experience and thus depicting the actual situation of the young European generation in the space sector. What links the authors of this paper together is their participation in the five-day didactic training course "Concurrent Engineering Workshop" held in May 2018 at ESA ESEC facility. During the workshop, the students worked as a team to develop a mission architecture for a satellite impacting the Moon surface, surviving and deploying a scientific rover: LIAR mission (Lunar Impactor And Rover). The concurrent design study offered a realistic environment to work within, amidst different scientific backgrounds and expertise, thus leading to a challenging and rewarding learning opportunity. This paper will also discuss the Concurrent Engineering development cycle, by giving an overview of main carried out activities to present the most important lessons learned. During their involvement in ESA's educational programs, the participants had been given a precious perspective on the tools and strategies behind ESA's space missions. One year later, the participants are still in contact and committed to fruitful collaboration aimed, among other things, at creating a space start-up. The example highlights that educational support constantly proves to be the key to a successful and prolific future of space sector by encouraging and technically challenging passionate students.**

Keywords—Educational Activities; Early Career; ESA Academy; Network of Professionals

I. Introduction

The development of highly skilled individuals provides an invaluable asset to foster the growth and success of the European space sector. In this regard, ESA Academy learning courses provide a treasured opportunity to obtain an insight into how different disciplines depend heavily on each other during satellite development and how a space system works. Furthermore, the ESA Education Office is offering hands-on activities (as REXUS/BEXUS, Fly Your Satellite, etc.) aimed at improving the practical skills of students and preparing them to their prospective job in the space field.

In particular, the authors of this paper took part to the learning course ESA Academy "Concurrent Engineering Workshop May 2018" (or "CEW May 2018") hosted at the Training and Learning Centre of ESA-ESEC, Belgium. In this occasion, 20 students from different ESA member and associate states were invited to participate in an educational mission

https://doi.org/10.29311/2020.19

feasibility study. The attendees have been divided in small groups and assigned the design of different spacecraft subsystems. The course was orchestrated by ESA experienced professionals who introduced them to the Concurrent Engineering methodology [1], moderated their interactions and offered advices and solutions to emerging problems. The students were challenged to define a preliminary architecture for a prospective mission named Lunar Impactor and Rover (LIAR).

This paper will firstly provide an overview of the ESA Academy's Concurrent Engineering Workshop of May 2018, referring to the main challenges the students faced during the course. Then, it will present the most valuable lessons learned by the team both generally and individually on professional and personal levels. To conclude, some final thoughts and prospective collaboration opportunities are reported.

II. ESA ACADEMY CEW: LIAR MISSION

LIAR mission concept involved a satellite to reach and impact the Moon at high-speed, survive the landing and deploy a rover to search for water. Each team of students had specific objectives to reach at the end of the five-day workshop: the most challenging ones are briefly reported in Table 1.

TABLE 1. Challenging mission objectives

Team	Subsystem main objectives
Configuration	Define the location of the different subsystems and equipment on the spacecraft
Structures	Design a structure withstanding the impact on the Moon while being still able to deploy a rover
Propulsion	Determine the propulsive strategy, entailing burns and possible break at the Moon with a retro-stage
Mission	Define the orbit of the satellite, the ground station contact time and eclipse duration
AOCS	Select equipment based on pointing requirements and possible spin up/down methods for the solid stage
Power	Define the total power budget and determine how long the system/rover can survive a Lunar night
Comms	Design the communications subsystem and identify the OBDH hardware based on data rates and ground station contact
Thermal	Design the thermal control system for both spacecraft and rover and assist configuration
Optics	Define optic sensor for navigation and pictures of lunar surface to be fit on the rover

The participants were encouraged to propose their design ideas and left a huge amount of freedom in their solutions (even in the creation of the mission logo, see Fig. 1). The atmosphere of common ambition, joy in learning and willingness to cooperate was facilitated by a thoughtful acquaintance program organized by ESA. Indeed, the night before starting the lessons, the students were invited to play the Eco Design game to introduce them to the eco-design of a space mission. It was a treasured occasion not only to be aware of the environmental impact of a space mission, but also to get to know each other.

During the first day of the workshop, ESA's experts illustrated the mechanisms behind the Concurrent Engineering method and made the students exercise with the Open Concurrent Design Tool (OCDT), which is used by ESA in professional CDF studies. On the second day, the students started to perform some initial analyses and outlined a first mission scenario, whilst the demanding requirements arose several design issues.

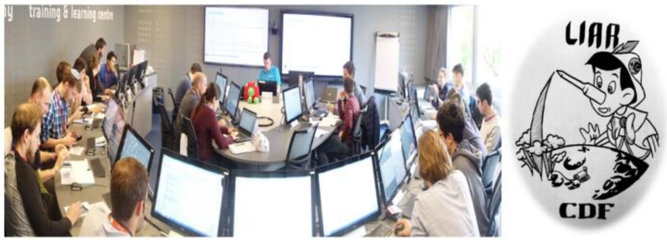

Fig. 1 - Left: ESA Academy's Concurrent Engineering Workshop in May 2018. Right: Mission logo designed by students

However, after two days of cooperation, sharing and plans modifications, a second iteration was successfully concluded and a coherent "low-cost" mission defined. Results were presented to ESA's professionals: the satellite was shaped as a nail, to keep the rover safe in the head of the structure during the impact on the Moon's South Pole. The rover would then be deployed to explore the lunar surface while being connected to the satellite with a cable to transmit data to the Earth.

III. BENEFITS OF PARTICIPATING IN THE WORKSHOP

Participating in the CEW May 2018 has offered valuable teachings and a precious insight on a realistic mission design environment. The most meaningful lessons learned are reported in this section:

- Creativity naturally stems from diversity (i.e. a team of people with very different backgrounds), and becomes innovation when it is goal-oriented;
- Flexibility, fast adaptive reasoning and a sharp sense of compromise are necessary skills in concurrent engineering, especially when contradictory requirements arise during the sessions;
- Cross-communication ability and trust are the first steps to successfully establish bonds among representatives of different disciplines, thus significantly increasing the efficiency of the design cycle;
- Bearing in mind that everyone depends on the data from others can help in better focusing on generating reliable and reasonable data in very short time periods;
- A proper balance between leadership and listening capabilities is required to make the design proceed;
- One team member should be charged on periodically checking the shared documents status to have a realistic appraisal on how things are getting done, while keeping up-to-date the information on his/her subsystem;
- The concurrent approach and acquired mindset can be applied in our every-day life activities;

Furthermore, it should be noticed the acquired skills and network of contacts last even after the workshop, being possibly the starting point of prospective collaborations and projects.

https://doi.org/10.29311/2020.19

IV. Concurrent engineering approach in different areas

In this section, the application of the Concurrent Engineering methodology to different scientific areas is discussed based on each author's point of view.

A. Management of Several Research Activities

While pursuing her studies, Federica from Sapienza University of Rome carried out multiple team-oriented extracurricular activities to gain practical knowledge into the methodology behind the structural design of space systems. In this regard, ESA's Academy program played a fundamental role in her professional development. She garnered considerable hands-on experience by taking care of the end-to-end mechanical design, analyses and testing of STRATONAV experiment for the SNSB/DLR/ESA BEXUS program. The project was successfully launched in October 2016 from the SSC Space Center in Kiruna (Sweden). She also cured the PDR level structural simulations for LEDSAT CubeSat of ESA's "Fly Your Satellite!" project. Interested in space systems design cycle, she was involved in a Concurrent Engineering study at the Concurrent Design Facility (CDF) of the Italian Space Agency in Rome as thermal control designer. However, it was only thanks to ESA Academy that she had the opportunity to apply such methodology to her main field of study, thus leading to improve her productivity during her PhD program to design an advanced integrated control system for vibration damping in large space antennas [2].

The concurrent engineering method changed the way she approached to both her PhD project and related activities. In the first case, the methodology came to use when designing an integrated system for attitude and vibration control as different scientific areas were to be coordinated: structure, control, power, mission analysis. Furthermore, as she is currently involved in several research programs, she has to constantly share and coordinate data exchanges and actions among different groups of people. Her management skills were utterly improved when she drew inspiration from the OCDT software structure. She resorted to Google Drive to organize the activities, create shared folders for each project according to subsystems, documents (i.e. reports, minutes of meeting, etc.) and actions/tasks to do. She found out referring to a shared Google file updated in real time by each team member has drastically reduced the time related to exchange information via other platforms. Furthermore, she uses it also to easily share files from CAD models and FEM analyses tools and directly edit them in the Drive folder. Thanks to ESA Academy, she practically learnt how to improve time management, solutions exchange and document compiling.

B. Sperimental Problems Prediction

In his career as Ph. D. student in Mechanical Engineering, Francesco from Sapienza found Concurrent Engineering approach extremely useful when he had to design a new experimental setup consisting of two plates connected by two nonlinear springs. He needed the method to study the effect of the nonlinear connections on the response of the coupled structure, evaluating its nonlinear normal modes. Concurrent engineering has been fundamental, since its use allowed him to already foresee and prevent some issues that would have arisen during the experimental phase. The crucial step of the design, where the Concurrent Engineering method has been effective, was the shaping of the springs. The nonlinear spring is the key element since it is responsible for the nonlinear vibrations to be measured on the final assembly. During its design, different shapes have been proposed to increase the effect of the geometric nonlinearity, thus obtaining high varying stiffness even for low deformations. However, fatigue effects and manufacturing process have been considered simultaneously, to choose the proper material and thickness that could be feasible with a reduction of costs. The final design has led to an M-shaped spring, 0.5 mm thick and made up of harmonic steel, satisfying all the previous requirements.

The workshop experience has been significant to learn how to deal with someone's other ideas and evaluate whether they are applicable to the current situation or would be ineffective to the observation of the studied phenomena.

C. Organizational Perspective in Artifical Intelligence

In parallel to this project, Javier from University of Cincinnati continued his training in Fuzzy Artificial Intelligence (AI) applied to aerospace systems. The tools provided by ESA have enabled him to work effectively in large teams, where the organizational system is vital for the success of the project. In particular, he applied these insights in the development of an algorithm that ratifies the coherence between the data obtained from all the sensors of a given system during his Master thesis. He fully created a Coherence Package (developed in MATLAB) and tested in a real scenario of the sensors + actuators + human factor system of the Boeing 737 MAX, where case studies and action-to-take decision-making were performed by the algorithm.

The lesson learned that affected the most his work was the organizational perspective when coding the algorithms. It is crucial to have a clear mindset to fully understand the scope of the function and not get lost in intermediate steps. The participation in ESA Workshop helped him in the management of his task, separating the workload in packages and thus to be able to assess them better. Moreover, according to Javier, being up to date with all the individuals of a time was a major challenge during the workshop. A minor change implied a great consequence in the rest of the group. That is why it is crucial also when coding an AI software to have a common up-to-date reference where keeping on working.

D. Development of an Instrument for Lunar Soil Volatiles Characterization

Before participating in the ESA Academy CEW May 2018, Mattia was employed at OHB System (Weßling) for his master thesis. He was the responsible for the overall LUVMI-VS (Lunar Volatile Mobile Instrumentation – Volatile Scout) instrument [3] and designer of the Volatile Sampler subsystem developed under the Horizon 2020 program. Due to this, the instrument had to be designed in a flexible way to be compatible with different lunar landers (Alina 2, Peregrine Lander, Israeli Lunar Lander) and rovers (LUVMI, LUVMI-X). To achieve this, several concurrent design activities were carried out internally and externally together with the different partners.

https://doi.org/10.29311/2020.19

The experience he matured at the workshop was crucial in this sense: he understood the strong interaction between the different subsystems and how to discuss choices with all the disciplines while keeping an open mentality approach. The most important concurrent engineering session was carried out after the ESA Workshop. This session took place in the ESA-ESTEC facility. Thanks to the workshop, he was already confident with the system in use and he could fully dedicate to the implementation of the data in the database. As a result, the instrument successfully entered to be part of the studied mission. He is now employed fulltime at OHB as a mechanical development engineer with focus on opto-mechanics and he is constantly referring to ESA Academy's teachings in his everyday working life.

E. Concurrent Engineering for Wastewater Treatment

Apart from making a PhD in wastewater treatment in microgravity conditions [4], Anna from Wroclaw University of Science and Technology is working on projects from various environmental engineering sectors. These projects require coordination of many areas, i.e. Heating, Ventilation and Air Conditioning (HVAC), sanitary installations, electrics. After the CEW May 2018, she familiarized other employees of the company she is working with (a polish company mostly designing ventilation and environmental systems) with these techniques. None of them had previously used it and unanimously stated that it could be a very useful work tool. Indeed, in the design of environmental systems each system might heavily influence the others and a Concurrent Engineering approach can significantly help to create statements (e.g. with the required total power for a building and to redistribute it among different subsystems).

As she is not a typical PhD student in space engineering, she was very afraid that her knowledge would be insufficient and would clash with widespread criticism. However, teachers and other participants never criticized, but they conducted an open, friendly discussion. Such an environment has allowed her to gain knowledge in new fields in a stress-free way. The workshop showed her that the most important features in a space field are not only knowledge, but also people, interdisciplinarity and open-mind.

F. Fundamental Training for the Systems Engineering

Now that he is working as a Systems Engineer, Ferran from DAS Photonics is getting the chance to apply everything he lived during the CEW May 2018 every single day. Not only the technical aspects, but also and foremost, all the knowledge and experience learned regarding teamwork and interpersonal processes. Having the possibility of working under such a multicultural environment, mainly focused in the information exchange, was one of the most enriching experiences he has ever had and, certainly, the lesson that most affected his career. Discovering the best approach of sharing data efficiently while communicating effectively changed completely his way of working.

G. Lessons learned in University and ESA Academy Projects

After the CEW May 2018, Lars from Delft University of Technology has used the acquired knowledge in the Stratos III [5] and SPEAR projects of Delft Aerospace Engineering, where it proved to be a very effective way of keeping track of requirements and design changes, but also to better see the impact that different subsystems have on each other. This latter is also his biggest lesson from the CEW May 2018: in a complex system, every subsystem influences the other subsystems, and one cannot design one, without considering the other subsystems.

During the workshop, he learned of the existence of other ESA Academy projects such as REXUS/BEXUS. Later he proposed a new project within the Parachute Research Group (PRG) Of Delft Aerospace Rocket Engineering (DARE). This new project had the goal to flight test the Stratos III and IV drogue parachute at supersonic conditions. This new project became the Supersonic Parachute Experiment Aboard REXUS or SPEAR in short. During his time within the SPEAR project, he could apply the knowledge acquired during the CEW May 2018, and he learned to interact with a launch provider. During the REXUS/BEXUS project, the team and he learned how to properly approach to design reviews and learned got more insight into how the space industry works.

H. Wider View for a System Engineer

Andreas from the University of Stuttgart has compared different system engineering methods (Subversion, Git, IBM Collaborative Lifecycle Management, Aras Innovator) during his Bachelor thesis and now he has just presented a final thesis concerning autonomous systems control. As he had concerned himself with other approaches to system engineering, testing the ESA system first hand was a very useful process. This helped him understand the challenges for a concurrent engineering platform better and provided him with ideas on how to tackle problems like data availability and integration and contradicting requirements. For instance, in order to know how accurate a control system needs to be, he generally needs data from trajectory planning and sensor team. He got insight into how this data transfer is handled via the excel system in ESA developments. The professional from ESA orchestrating the workshop moderated contradictory requirements from different groups and showed how to conciliate different point of views and ideas to achieve a common solution. The most intriguing lesson learned was to achieve the understanding of problems that did not arise in his particular field of expertise in order to modify his own system such that the common solution was satisfactory for all involved disciplines. Keeping the bigger picture in mind and always thinking about how other contributors might be affected by everyone changes during a development was definitely a skill he is grateful to have acquired participating in this workshop.

I. Exchange of Methodologies is Fundamental

Chaggai from Delft University of Technology participated in the CEW May 2018 based on his experience: he noticed that the best ideas during a design process often appear suddenly and require a quick change of direction in the design. After being selected as a participant, he was confirmed in his belief that by applying the concurrent engineering method to a rapidly changing environment, new concept designs and emerging ideas could be easily adjusted to a newborn project to obtain a

https://doi.org/10.29311/2020.19

final mission architecture. Learning how to implement concurrent engineering into a project was far from the most important lesson learned at the concurrent engineering workshop. Moreover, the ESA Academy CEW May 2018 creates a very pleasant and stimulating environment in which new insights are obtained. He particularly reminds of a discussion he had with the participants on how they would approach a problem. The way they approached the problem was vastly different to his personal methodology of naturally taking inspiration from the surrounding environment. A much more rigidly structured approach was pitched to him, leading to vastly different creative ideas to the same problem. Lastly, during the workshop Chaggai noticed that he really enjoys working on complex problems in a high-paced development role. Based on this he decided to start his career as a mechanical engineer in the R&D department of ASM.

J. Inspiration for PhD Program and Future Career

Christopher is a PhD student at University of Surrey and he believes that attending and completing the ESA Academy CEW May 2018 was a truly rewarding and inspiring learning experience. It allowed him to develop a much deeper respect for the challenges involved in the design of space missions and new spacecraft concepts and gave him a new perspective on the exceptional things that can be achieved when people, of differing expertise and priorities, work together as a coordinated team.

His experience at the training course can be credited for a multitude of positive changes in his academic studies, career aspirations and personal life. His desire to pursue a career as a spacecraft structures engineer was solidified by his experience as part of the spacecraft structures and mechanisms subsystem team during the workshop. Through discussion with the diverse group of postgraduate student participants he was inspired to study a PhD in aerospace structures and is now studying a PhD at the University of Surrey in the design and optimization of smart multi-stable composite structures for aerospace applications, with a keen desire to pursue a career in aerospace structures research. It has also opened his mind to the idea of pursuing such a career elsewhere in the world, not just exclusively in his home country.

Since completing the course, he has applied the concepts of concurrent engineering to a number of academic and extra-curricular activities, most notably during the design of the University of Surrey rocket for the UKSEDS National Rocketry Championship. The respect for multidisciplinary design developed through an understanding of concurrent engineering has also been invaluable to his PhD as the project involves a number of disciplines such as aerospace, materials, electrical and electronics, and control engineering.

K. Team Activities Management for Satellite Simulators

Laurentiu from Terma GmbH is currently working as a software engineer, developing satellite simulators that are used mainly to train satellite operators. He also participates in a research project at University Politehnica of Bucharest, in the field of space launch vehicles named “Advanced Control Techniques for Future Launchers”. He can mention the usefulness of the concurrent engineering concepts while working within the university research project, where he is part of the guidance team, tasked with developing the guidance subsystem for a future launch vehicle. This subsystem was developed in parallel with the control subsystem, and as a result, the concepts of concurrency came to play. The collaboration between the two team became paramount, especially during the development of the requirements and also of the validation methods. Within the satellite simulator project, a large team has to achieve a great level of synchronization, thus the concurrent engineering aspects arise at a great time. While developing the models, the team members must collaborate in order to efficiently set the functional requirements, and subsequently write the code for the models.

V. CONCLUSIONS

To conclude, being able to apply a new understanding of the concurrent engineering approach and prior knowledge of space engineering to design the mission architecture of a realistic and challenging space mission was a unique educative experience. Finally, the training course was an incredible opportunity to network with likeminded people across Europe aspiring to become the next generation of space engineers and scientists. In this regard, the authors of this paper are also starting to cooperate to found a start-up. They have been so profoundly inspired during the workshop they have decided to improve the design of the rover of LIAR mission in the frame of the ROVERSPACE start-up, starting from applying their layout concept of air-less tires. Their highest ambition is to deliver new ideas into the market, but also to create partnerships that will, most likely, last way beyond this project and will be of benefit for all of them throughout their careers.

ACKNOWLEDGMENT

The authors wish to thank ESA Education Office for giving them the opportunity of participating both in training courses and hands-on projects and for providing them invaluable guidance, advices and teaching throughout the course of these activities. Furthermore, they would like to thank ESA Education Office for the sponsorship provided to the main author, thus giving her the opportunity of presenting this paper on behalf of the others.

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