Student Perspectives on the 2017 ESA Concurrent Engineering Challenge

Kelsey Doerksen* and Thomas Gerard Ewout van 't Klooster†

*University of Western Ontario, Department of Electrical and Computer Engineering, kdoerkse@uwo.ca

†Delft University of Technology, Faculty of Aerospace Engineering, t.g.e.vantklooster@student.tudelft.nl

***Abstract*—In September 2017, the first ESA Academy's Concurrent Engineering Challenge (CEC) was held, giving 88 Master's and PhD-level students from twelve ESA Member and Associate States a powerful platform to experience system engineering in an intense, fast paced, and real-world environment. Within four days, teams of physics and engineering students in Concurrent Design Facilities (CDF) located in Politecnico di Torino, Universidad Politécnica de Madrid, University of Strathclyde and ESA's European Space Security and Education Centre (ESEC) each developed a preliminary design for a satellite mission to map the Lunar south pole for water-ice as a precursor for the Moon village concept. Each team was divided into subsystem groups of two to three students each. As the subsystems design progressed, key parameters were regularly updated and shared within the team using ESA's Open Concurrent Design Tool (OCDT). The Challenge concluded with final presentations and critical discussion of the four satellite designs. Lessons learned during CEC were carried back by the students to their respective universities and projects and are discussed by the ESEC student team. The remaining co-authors are listed in the Acknowledgements section of the paper.**

Keywords*—*Concurrent Engineering, Open Concurrent Design Tool, Concurrent Design Facility

I. INTRODUCTION

The Concurrent Engineering Challenge is organised by the ESA Education Office and the ESA Systems and Concurrent Engineering Section to introduce university students to the concept and practice of concurrent engineering and support universities in ESA Member and Associate States in the development of their Concurrent Design Facilities. From the 11th-15th of September 2017, twenty-two Master's and PhD-level students in engineering or physics disciplines from across twelve ESA member states gathered at the ESA Academy's educational CDF in ESA's European Space Security and Education Centre in Belgium. They were joined remotely by three similar participating student teams in other educational CDFs located in Politecnico di Torino in Italy, Universidad Politécnica de Madrid in Spain, and University of Strathclyde in the United Kingdom. In each CDF, students were divided into subsystem groups of two to three students each, supported by two system engineers with concurrent engineering knowledge. These professionals were there to guide the students but not to drive their design. The four teams were given the same mission to work on largely independently: using a concurrent engineering process, design a preliminary satellite mission to map the Lunar South Pole for evidence of water and ice, with a view to future Lunar village colonisation, at a resolution of at least 100 [m^2/pixel]. To make this task achievable in the four days given, teams were to assume using commercial-off-the-shelf components (COTS) where possible, no specific launch date, piggybacking on the Ariane 5 launcher, imposing a total mass limit of 300 kg. At the end of every day, student teams presented that day's progress with one another, allowing a wide exchange of ideas. The Challenge concluded with final presentations and critical discussion of the four satellite designs.

II. BACKGROUND

A. Concurrent Engineering

Concurrent engineering is a system design practice that encourages immediate collaboration between groups working on interrelated subsystems, so that the whole system can be integrated seamlessly and quickly[1]. It requires all subsystem designers be together for several sessions using a tool such as the OCDT to share their relevant data with one another. By contrast, a typical system design process may begin with an objective, followed by an outline design; passed through various departments to fill in their specifics, until finally the system engineer must struggle to fit everything together, most likely requiring every subsystem to redesign their contributions several times before arriving at a functional end design. This process can be lengthy, whereas a concurrent engineering approach can reach the same stage in less time. Concurrent engineering is commonly utilised by ESA missions at their ESTEC facility, including the Mars Sample Return Carrier Mission, CLEP Assessment of a Europa Moon Penetrator, and SPADES Solid Propellant Autonomous Deorbit System assessment studies, to name a few[2]. The typical practice is to have eight sessions with all interested parties present, including representatives from the group commissioning the mission, spread out over the course of a month to allow the engineers involved to do any necessary additional research between sessions. A first iteration on the design often takes about three sessions, followed by a second iteration for improvements which takes around an additional two sessions. Further iterations are quicker, and will continue until the system engineers decide the changes between iterations are

[1] http://news.aucotec.com/5-benefits-concurrent-engineering/ — Visited on 12 September 2017

[2] http://m.esa.int/Our_Activities/Space_Engineering_Technology/CDF/Studies_Reviews — Visited on 12 September 2017

so incremental that another is unnecessary; usually no more than five iterations are required at the early stages [1].

B. Lunar South-pole Mission

The CEC's mission was based on ESA's announced intention to build a permanently manned lunar base by 2030, with robots sent up to begin construction in the next decade[3]. This would serve a primarily research purpose, similar to the Halley Research Station in Antarctica, but the lunar village could one day be used as a stepping stone for many space industries and colonising Mars. It is important to know how the human body adapts to low gravity in the long term for these future endeavours to be successful. The dark side of the Moon is an ideal place for ultra-sensitive radio-telescopes, as it is completely insulated from the noise coming from Earth. It would be vitally important that those stationed there will be able to supply their own food, water, and air continually, so efforts are being made to identify vital resources such as water-ice on the Moon in readiness for early colonisation.

III. Subsystem Designs

The following section will be detailing each subsystem a part of ESEC's team AMOONDSEN. All subsystems utilised the OCDT tool provided by ESA, and the following sub-sections will provide more in-depth information on what was learned.

A. Attitude and Orbit Control Systems

Attitude and Orbit Control Systems (AOCS) is required to select sensors and actuators to facilitate the monitoring and control the attitude of the satellite in low-Earth orbit from the launcher release, during transfer, lunar orbit, emergency situations, through disposal phase. The team's first step was to prepare worst-case scenarios and calculate the thrust required to position the satellite accordingly. Three iterations of actuator structures were implemented in cooperation with Structures, Power, and Propulsion. Four COTS reaction wheels in tetrahedral orientation combined with twelve 1N hydrazine thrusters were chosen for the final design iteration. The system ensures 100% momentum reserve and is fully redundant. For AOCS sensors, six sun sensors, two star trackers, and two inertial momentum units were chosen, with the driving criteria for this decision being price, mass, and accuracy, with accuracy requirements provided by the Instrumentation subsystem.

B. Communications and Data Handling

The role of the Communications and Data Handling subsystem was to enable the satellite to send and receive information to and from the ground station on Earth, as well as store instrumentation data onboard. During the daily updates between teams, it quickly became apparent that the initial requirements set during the early stages of the project greatly affected the overall complexity of the subsystem. The updates provided an opportunity to collaborate with the other university's and learn the reasons behind their design decisions. This collaborative effort allowed the ESEC's team to re-evaluate decisions made, and discover issues with their own design and other teams', thereby increasing the overall quality of the subsystem. For example, AMOONDSEN choose to utilise a patch antenna array for its satellite downlink. In contrast, other teams used higher frequency band transmitters, which greatly reduce difficulties that arise in the use of arrays, in spite of the minimal amount of COTS antennas and transmitters available for those frequencies. A key lesson learned by the team throughout this process was that trade-offs between complexity, COTS availability, and the ability to fulfil data budget requirements must be made for mission success. Additionally, it was crucial to have constant open communication between the subsystem and the Instrumentation and Mission Analysis teams, as Instrumentation required specific data rates to meet their mission objectives while Mission Analysis provided the windows of opportunity for satellite-to-Earth communication.

C. Propulsion

The propulsion team was responsible for finding a suitable propulsion system to transfer the satellite from its parking orbit to the moon, and to keep and correct its altitude and attitude in lunar orbit. Following trade-off studies, chemical propulsion was chosen. With regards to complexity and mass, a main engine consisting of six hydrazine thrusters of 20 N and an I_{sp} of 225 s was selected. Based on the delta-V for the mission, it was possible to compute the propellant mass for the system, which was found to be 158 kg of hydrazine. At first, a blow-down feeding system was initially chosen for the propellant, but due to structural considerations, a regulated tank pressure feed system was the chosen solution. Concluding the design is the choice of nitrogen as feeding pressurant, with a mass of 2.8 kg at an operating pressure of 276 bar.

D. Configurations

The responsibility of the Configurations team was to gather the subsystem designs of the other teams and combine them into a single SolidWorks model for analysis of the entire spacecraft. The inputs that drove the satellite configuration design were derived from the payload envelope, centre of mass, and moment of inertia requirements from the Ariane 5 launcher. Configurations worked closely with the Structures team early in the design process to help develop a consistent structure design that would accommodate all subsystems and the spacecraft design requirements. As the design phase progressed, the focus shifted to collaborating with the Instrumentation, Propulsion, and AOCS teams to determine optimal component placement. Ultimately, an octagonal satellite structure was chosen. Positioned at one end of the satellite is the mounting ring and thrusters. The other end, which is Nadir-facing during science operations, has the instrumentation apertures. The outer side panels of the octagon have seven solar panels mounted to them, with the remaining

[3]http://www.esa.int/About_Us/Ministerial_Council_2016/Moon_Village — Visited on 12 September 2017

panel reserved for the patch antenna array. Inside the satellite is mounted the propellant tank, onboard computer, transceivers, electronic power system, and AOCS components.

E. Mechanisms

Mechanisms refers to the mechanical parts on the spacecraft that can move relative to others. Initially, the team focused its work on the mechanisms surrounding the solar panels. The requirements of the mission led to the initial hypothesis to use deployable, rotating solar panels with sun tracking capability. Progress on the project gradually reduced the power needed from the panels, and so a simplified architecture using fixed panels was chosen, negating the use of orientation mechanisms. During the early iterations of the project, deployable and pointing systems for communication antennas was also investigated, however an immovable array was chosen for the final design. In accordance with the final mass of the satellite and launcher selected, a deployment system was chosen. Although the depth of complexity of final design was not large, the team was able to experience and take-away the importance of communication with other teams, adapting work according to other teams' needs, and gaining knowledge about space systems requirements and standards.

F. Instrumentation

The instrumentation team was responsible for designing the scientific payload of the satellite. The primary science objective was to image the Lunar South Pole with a minimum resolution 100 [m^2/pixel]. The difficulty lay in confining such an imaging system to the space, power, and communication constraints of the satellite. As such, the team worked closely with the groups responsible for these subsystems. The model of concurrent engineering proved invaluable to the initial design stages as the requirements and specifications of the instruments often changed as the design progressed. It was found that ESA's team of students differed in approach from the others, in that the design of the imaging system was done in accordance with optical principles rather than finding specs of a COTS component, likely due to all three team members being physicists by training. The approach allowed greater flexibility when dealing with orbital height requirements, though proving to be challenging to implement. Ultimately, the design was successful and mission requirements satisfied. The CEC provided the Instrumentation team important experience in practical, real-world engineering. Lessons learned during CEC enabled a different thought process to be used for design and enabled students to better apply knowledge gained in the teams' physics training to engineering projects.

G. Power

The Power team was responsible for ensuring the satellite could generate and store sufficient energy throughout the mission. This included sizing the solar panels and batteries, and collating the power budget. The concurrent engineering process enabled the team to start from abstract notions of typical panel and battery performance and gradually arrive at a more precise design as other groups solidified their requirements. The power budget collates how much power each component would require during each mission phase, and was used to conclude that deployable solar panels would not be required for satellite mission success. Opting for body-mounted over deployable panels traded mass and complexity for the expense of redundant panels. From the CEC, the team learned how to design in a nonlinear way and how to use trade-offs to make important decisions, applicable to any engineering project.

H. Structures

The Structures team was responsible for designing the structure of the satellite to comply with requirements of the mission, including: fitting within the predefined dimensions, compatibility with the adapter ring surface, having a first natural frequency higher than 60 Hz, providing an interface between payload and fuel tanks, and complying with the mechanical load design safety factors. The proposed structural design was composed by an octagonal load bearing column made of CFRP with an aluminium core and trusses to link the load bearing column to the ring adapter and tank holders. The material choices were made by comparing specific mechanical properties to minimise the mass required to withstand the loads. The structural design was carried out by analysing the maximum stresses and displacements obtained in the different components for the most critical loading case, which is the maximum acceleration reached during the launch of the satellite. A simplified Fem analysis was performed in ANSYS for validation purposes. Buckling was considered during design in those components subjected to compression loads. At the end of the last iteration of the design, the structure fulfilled the structural requirements and weighed at around 20% of the dry mass of the satellite, 18.35 kg, which matched the typical value provided in Space Mission Analysis and Design [2].

I. Thermal

The task of the Thermal team was to make sure that the satellite could cope with the wide range of temperatures to be experienced throughout the mission. The first step for the team was to obtain the minimum and maximum allowable temperatures for each subsystem. The next step was to evaluate the worst case thermal scenarios. The hot case involved the situation where the satellite is receiving solar and Earth radiation, Earth Albedo, Moon Albedo, and dissipated power from the electronic equipment onboard. The cold case involves the satellite being in both Earth and Moon eclipse. Starting with a 1 m^2 satellite configuration assumption, the hot and cold case temperatures of 35 ^oC and 5 ^oC were found respectively. The thermal design was iterated as the concurrent engineering process continued and new information surfaced. This involved taking the dissipated power of all subsystems into account, the satellite configuration, the required surface areas for balancing equations, and monitoring the operating temperature of all components. The resulting design consisted of the satellite covered in a Kapton foil-type multi-layer insulation without a radiator. COTS heaters were chosen to ensure that components remained within required temperature range. The final satellite thermal range was found to be -7 ^{o}C to 23 ^{o}C respectively.

J. Trajectory Analysis

The Trajectory Analysis team was responsible for defining the overall scope of the mission. This involved determination and optimisation of launch opportunities, transfer windows, staging locations, transfer trajectory and operational orbit as well as disposal strategy at the end of the mission. Decisions were based on the mission statement and the derived mission requirements. The main outputs of Mission Analysis for the other subsystems include the delta-v budget, illumination and eclipse times, communication windows to Earth or relay stations as well as relative motion to target bodies for scientific operations. In this study, Mission Analysis performed a trade-off on the transfer capabilities from Earth to Moon, looking at direct, bi-elliptic, and low energy transfer options, of which the weak stability boundary transfer was chosen due to low delta-v requirements. Additionally, an orbit with the capabilities for observation and mapping of the Lunar South Pole had to be developed. After conducting studies of high elliptic, EML halo and LLO orbits, a quasi-frozen LLO was chosen due to the long-term orbit stability, resulting in low station keeping costs. Moreover, the Instrumentation team confirmed that the speed above ground and observation periods in the chosen orbit were within the feasible range for the mission's optical components.

IV. Completed Design

Team AMOONDSEN's satellite design presented on the final day of CEC 2017 consisted of a 286.40 kg wet mass satellite, equipped with a CCD camera, IR spectrometer, meteorite scanner, particle detector, and radiation detector as its payload. The satellite is powered by seven fixed GaAs solar panels which generates a total 240 Watts of power in the Sun. Two quadrifilar helix antennas, a four-patch antenna array, and two transponders make-up the Communications system's equipment. The satellite is an octagonal structure, with the final Configuration model shown in Figure 1 [3].

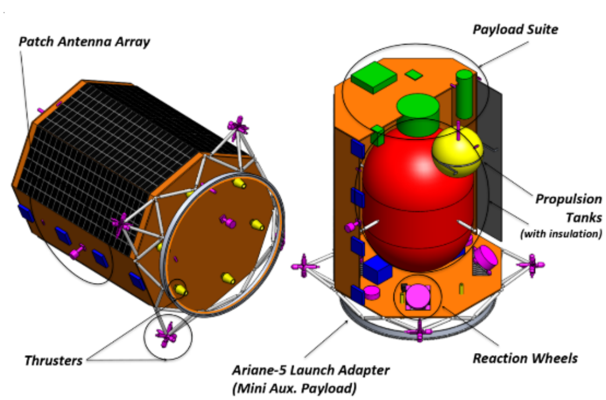

Fig. 1: AMOONDSEN Final Iteration

V. Learning Outcomes

A key take-away from the challenge regarding concurrent engineering is its increased communication capabilities. The CDF combined with the use of the OCDT enabled all subsystems to communicate on-demand with one another and update designs that would affect other subsystems in real-time. This made it easier, and possible, to complete a preliminary design of a satellite in such a short period of time. Utilising concurrent engineering to increase communication abilities between the team is a directly transferable lesson that members can take with them throughout their current education and future projects. For example, the University of Western Ontario, of which CEC alumnus Kelsey Doerksen is a Masters student, is looking to begin a final-year project for undergraduate students to design a CubeSat in eight months' time, to be run and assisted by Ms. Doerksen. Utilising the OCDT and employing concurrent engineering techniques such as hosting design meetings in a classroom-style CDF on campus, will produce better communication between members of a large team with various engineering backgrounds and ideas.

In addition, the experience of working with individuals from a wide-variety of educational and cultural backgrounds provided a unique opportunity for every member to learn something from one another. Projects within the space industry are inherently a collaborative effort, whether that be between varying disciplines such as scientists and engineers, or between nations. Opportunities to better hone and develop ones' teamwork and interpersonal skills is valuable and CEC was no exception to this. Very few of the members entering the challenge knew one another prior, and by the end of the week strong bonds had been developed through successful teamwork practices, facilitating new networks between peers.

ECTS credits were also provided to ESEC team members whose universities could accept them. Rohan Chotalal and Adam Dabrowski both received two ECTS credits, and Darian van Paridon received one ECTS credit towards their degrees.

In summary, CEC has shown that a concurrent engineering design process proves to be beneficial for many space system design projects. This process can be applied in a strictly academic format in the form of a course, and involves the possibility of implementing a concurrent engineering facility for project work at the university level. Discussions and shared experiences from attendees, detailed in the Post Challenge section of this paper, assures that not only the participating students from the 2017 CEC will benefit from the experience gained, but that future students will as well.

VI. Post Challenge

Following the CEC, a participant, Maxime Valencon, was driven by what he had learnt throughout the week and proposed presentations and hands-on activities on concurrent engineering methodology and software at Cranfield University. The development of a partnership between the major Concurrent Design Facility of CNES and Cranfield University was also favoured following the Challenge, initiated by

Maxime Valencon, proposing lectures and conferences with professionals on-campus, as part of the MSc in Astronautics and Space Engineering. This outreach resulted with professors, teachers, and students becoming interested in the CEC and various concurrent engineering hands-on projects proposed by ESA Education Office. From this gained interest and partnership, it was proposed to use concurrent engineering tools such as the OCDT in a design project, a key component of the MSc at Cranfield, to provide a good background in concurrent engineering for students' future careers in Space Engineering. Adam Dabrowski, a PhD student and alumnus of CEC 2017, has been running concurrent engineering seminar exercises as a part of the Space and Satellite Technologies course at Gdask University of Technology. Four of the students whom attended the seminar participated in ESA Academy's CubeSat Concurrent Engineering Workshop 2018. Moreover, the methodology was picked up by a student research group in their CubeSat project, in which the students described the approach as very helpful and empowered their work.

In addition, Kelsey Doerksen curated a presentation about the challenge for undergraduate students at Carleton University in Ottawa, Canada, that were a part of a 4th-year satellite design project. Following this, two students, Lucas Brewster and Bryan Southwell, expressed great interest and applied to be a part of ESA Academy's CubeSat Concurrent Engineering Workshop 2018 and participated in January 2018. Similarly, William Ferguson delivered a presentation on his experience of the CEC to some of his fellow PhD students in the Centre for Doctoral Training in Metamaterials at the University of Exeter, prompting several of them to apply to future ESA Academy training sessions.

Furthermore, at the faculty of Aerospace Engineering at Delft University of Technology, an initiative has been made to establish a concurrent design facility. This is useful for the final year bachelor thesis project, as design decisions, trade-offs, and preliminary designs can be made with greater efficiency.

VII. Conclusion

The Concurrent Engineering Challenge taught the ESA student team a creative, holistic approach to designing the components of a space mission, while maintaining awareness of all members' work. In four days, starting from largely theoretical understandings of the different spacecraft subsystems, the team designed a preliminary satellite mission to locate water-ice on the Lunar South Pole. Following CEC, students returned to their respective universities with newfound skills, applicable to many areas, and could offer valuable experience to others; promoting students, professors, and members of their community to engage in future ESA Academy training sessions. The Concurrent Engineering Challenge facilitated a deep and practical understanding of the key benefits and applications of concurrent engineering, enabling the participants to apply their knowledge to a unique problem, whilst encouraging a rich exchange of ideas across various disciplines. Through doing so, students enhanced their skills in teamwork and open communication in a novel and engaging way, which are applicable to their future career and educational projects.

Acknowledgements

The following members of AMOONDSEN are acknowledged for their participation in the formation of this paper: Adam Dabrowski, William Ferguson, Jack-Antoine Charles (also supported by Professor Bestaoui Yasmina), Jakub Porebski, Kasia Ciechowska, Mario Gonzalez, Marius Schwinning, Maxime Valencon, Sean Pepper, Verena Kunberger, Yuchen Shang (also supported by the EPSRC CDT in Intelligent Sensing and Measurement, grant: EP/L016753/1), Rohan Chotalal and Renato Amorim. In addition, the university students that participated to the ESA Academy's Concurrent Engineering Challenge 2017 from ESEC wish thanks to all those at ESA involved in running the challenge, in particular: Robin Biesbroek, Johan Vennekens, Natacha Callens, Ariane Dédeban, Delphine Gorlé, and Benoit Demelenne. The students would also like to thank the ESA Education Office for the opportunity and sponsorship to participate in this event. The inputs of the participants from the other educational CDFs in Politecnico di Torino, Universidad Politécnica de Madrid, and the University of Strathclyde are also acknowledged.

References

[1] R. Biesbroek, Private conversation, ESA CDF, Redu, Belgium, March 2018.

[2] J. R. Wertz and W. J. Larson, *Space Mission Analysis and Design*. Microcosm, 3rd ed., 1999.

[3] ESA Academy Team, *ESA Concurrent Engineering Challenge Final Presentation*. European space Security and Education Centre, 2017.