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INTRODUCING CONCURRENT ENGINEERING TO SPACE AND SATELLITE TECHNOLOGY UNDERGRADUATE COURSE

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ABSTRACT

In recent decade concurrent engineering has become a de facto leading methodology of work in space, aeronautics and sometimes even automotive industry. It has been used in designing ESA space missions for 20 years now, with rst Concurrent Design Facility (CDF) built in ESTEC in 1998. Still, it has not become a universal standard in engineering, and universities are specically reluctant to adopt it into their curricula. As a result, virtually no students are accustomed to the method at the time of their graduation.

As a countermeasure, ESA Academy has decided to offer multiple hands-on courses in their Teaching and Learning Centre in Redu. The main aim is to broaden the gap between university courses and professional space industry requirements. Such courses include: Concurrent Engineering Workshops, CubeSat Concurrent Engineering and most recently Concurrent Engineering Challenge 2017 which the author of this paper is alumnus. Multiple students have beneted greatly from this courses and have been spreading the knowledge either running courses as tutors or implementing the principles in student organisations.

Only a handful of European academia can afford building designated CDFs. However, as this paper shows, implementation of elements of concurrent engineering is possible with limited resources. This papier focuses on concurrent engineering implementation at Gdansk University of Technology. Their recently opened Master's course of Space and Satellite Technologies, backed up by Polish Space Agency is a response for demand for high qualied personnel from Poland's rapid growing space sector. Both tutor and student perspective on concurrent engineering implementation will be presented.

I. INTRODUCTION

Concurrent engineering is a novel design methodology. It stems from aerospace engineering in 1990s, but has been widely accepted in engineering companises including, but not limited to Motorola, Apple, and most importantedly, European Space Agency[1]. This is due to the fact that modern projects, especially in space sector, typicaly are *systems*. What that means is very rarely, specialists from only a single field are required (as it used to be in manufacturing in mid-XX century). Instead, any product nowadays is a synergy of mechanics, electronics, control systems, IT. Each specialist, especially those with great experience in their respective fields, are accustomed to a certain work style and tools. These include manufacturing drawings for mechanical engineers, circuit diagrams and BOMs (bills of material) for electrical engineers, etc. Sometimes, such techniques are very obscure and unfamiliar to those outisde a professional group. This leads to problems with sharing data, solutions and decisions while working in a greater group. The effect can be accelerated if the proffesionals come from various cultural backgrounds, as it is often the case with mutinational crew of international entities, such as European Space Agency.

Concurrent Engineering proposes an additional layer of tools, procedures and documentation to focus on sharing useful informations between the group. The most important task is the hand of a *system engineer*, who is responsible for a holistic view over whole enterprise. Usually, these are experts from a single field with additional training in various other fields. Such a person is not expected to be an omnibus – expert in all disciplines. They are, however, expected to understand and discuss with others the best solution.

Due to its novel character and need for field expertise, not many Universities in Europe provide *stricte* system engineering education. Those that do, mostly British, include: TU Delft, Cranfield University, Strathclyde University, University of Glasgow, University College London and University of Southampton[2].

II. SPACE SECTOR IN POLAND[3]

Geopolitical changes after 1989 enabled Poland to collaborate with countries outside the former Eastern Bloc. In 1994, Poland signed a cooperation agreement with the European Space Agency, which was later extended in 2002. This agreement allowed Poland to participate in the ESA's scientific programmes, resulting in the presence of Polish instruments on the majority of the Agency's research missions. Meanwhile, the first private Polish companies offering satelite-based applications and services were created.

In 2007, the signing of the Plan for European Cooperating States (PECS) enabled significant extension of Poland's cooperation with ESA. Under the PECS Agreement 48 projects were financed for a total amount of 11.5 million euros. These activities were implemented by Polish companies, scientific and research entities and higher education institutions in cooperation with ESA. Concurrently, availability of products and services based on satellite technologies offered by Polish companies increased significantly.

In November 2012, Poland became the 20th member state of the European Space Agency, contributing about 30 million euro annually. This paved the way for Polish economic operators to faster develop space and satellite technologies by providing them with the possibility of full participation in the most of the Agency's programmes. The dedicated support mechanism for the Polish industry has been created by ESA (Polish Industry Incentive Scheme – PLIIS), which will be available until the end of 2019. By mid-2016 209 project proposals were submitted in PLIIS open competitions, of which 85 were approved for implementation with a budget of nearly 16 million euro. At the same time the Polish space governance structure matured: in 2015 the Polish Space Agency was established and in 2016 a long-term strategy for development of the space sector was defined.

The first four years of the Poland's membership in ESA was a period of intensive development of the Polish space sector. A number of existing companies and R&D institutions became interested in the space area and new spacefocused business ventures were established.

The number of organizations interested in ESA contracts increased from less than 50 in 2012 to over 300 in 2016. Polish companies began seeking technological niches compatible with their competences and targeting subcontractor positions for the European satellite systems integrators. The relative competitiveness of the Polish entities is demonstrated not only by conducting projects under the PLIIS mechanism, but also successfully competing for contracts in ESA optional programmes. During the four years they were able to utilise 100% of the available funds in 8 out of 10 optional programmes in which Poland participated.

III. SPACE AND SATELLITE TECHNOLOGIES IN POLAND

As described in previouse section, Polish space sector is rapidly growing. This results in an increasing demand for highly qualified employees. One of most interesting initiatives was established in Gdańsk. Since summer semester of the academic year 2016/2017, two faculties of Gdansk University of Technology GUT (Faculty of Mechanical Engineering and Faculty of Electronics, Telecommunications and Informatics) together with the Gdynia Maritime University (Faculty of Electronics) and the Polish Naval Academy in Gdynia (Faculty of Command and Naval Operations) have opened intercollegiate master-degree studies called: Space and Satellite Technologies (TKiS). Each of these faculties offer for their candidates and conduct special education in case of certain speciality. This initiative is supported by Polish Space Agency and received additional funding from the National Centre for Research and Development. Under the project entitled: Adaptation of the second-degree studies Space and Satellite Technologies, to the needs of the labor market, people involved in the space industry were included in the didactics[4]. With support of external industry specialists, the course attracted numerous students, mostly from the local area, but also from whole of the country. Still, a need for novel techniques was present among students, and more importantly, academic staff of Gdańsk University of Poland. This coincided with ESA efforts to broaden the gap between academia and proffesionals careers for space engineers.

IV ESA ACADEMY PROGRAMME AND 2017 CONCURRENT ENGINEERING CHALLENGE

The ESA Academy programme established in 2016 is the overarching framework of activities provided by the ESA Education Office for university students from ESA Member and Associate States. The purpose of this programme is to complement and enrich the students' traditional University education through a suite of activities, enabling direct transfer of knowledge from agency, academic and industry professionals, hands-on and training experience as well as access to world class facilities. The ESA Academy aims to improve students' skills and boost their motivation, enabling them to pursue further opportunities within 'Space' and/or within other Science, Technology, Engineering or Mathematics (STEM) subjects and to bridge the gap between studies and professional life[5].

One of most requested and anticipated courses within ESA Academy was Concurrent Engineering Challenge. Instead of a typical semi-academic lecture/seminar style, the idea was to run 4 simultaneous courses: at ESA Education in Redu, Strathclyde University in London, Politechnico di Torino and Technical University of Madrid. Each location had a proper Concurrent Design Facility with computers, concurrent engineer tools set up and system engineer support.

The Challenge facilitated a deep and practical understanding of the key benefits and applications of concurrent engineering. The Challenge enabled the students 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 team-work and open communication in a novel and engaging way.

Lessons learned during the Challenge were carried back by the students to their respective universities and projects. New lectures and practical tutorial possibilities were created as returning students offered their experience to aid lecturers in need of resources in teaching this new concept; for example in Cranfield University or Gdańsk University of Technology where presentations and workshops were delivered[6].

V MECHATRONICS IN SPACE APPLICATIONS

A hands-on concurrent engineering course (called *Mechatronics in space applications*) was delivered to students of Space and Sattelite technologies at Gdańsk University of Technology. 31 students of various backgrounds were divided into 4 academic majors: mechatronics, electronics, marine systems and safety systems.

An issue that is prevalent with second cycle courses implemented according to Bologna declaration[7] is that students arrive from various first study courses. While this is an excellent opportunity for students to broaden their horizons in different fields, sometimes even in different countries, it raises various challenges for lecturers. These students frequently have very different levels of expertise in mathematics, engineering etc. It is usually very difficult to run a lecture to match understanding of all groups.

However, in case of concurrent engineering classes, varied students' backgrounds proved to be beneficial. Students were asked to chose a single team from 9 typical concurrent design facility teams (see Table 1). Members of the teams turned out to have graduate study course experience matching their concurrent engineering teams. That way they can excell in their design task easier, without need for additional knowledge update. This allowed them to focus on the task of communication and sharing knowledge and data with other teams. Such experience allowed them (for most of them, first time in their life) to cooperate with specialists of different fields and embraced need for clear explanations and concurrent engineering tools.

Concurrent engineering teams	No. of students	Graduate study course
Instruments	2	Physics (x2)
Mechanisms	4	Mechanical Engineering (x2), Mechatronics (x2)
Structure	3	Mechanical-medical engineering (x2), Materials engineering
Thermal	2	Mechatronics, Physics
Propulsion	5	Power Engineering (x2),
Power	4	Power Engineering (x2), Electrical Engineering
ADCS	4	Geodesy and cartography (x2), Mechatronics (x2)
Communication	5	Informatics (x3), Control Engineering and Robotics (x2)
Data handling	2	Informatics (x2)

Table 1: Students' concurrent engineering teams matching perfectly with their chosen graduate study courses.

The course included lecture introduction to system engineering, concurrent design, etc. followed by hands-on project of designing an polar orbit satellite. Most of examples and data were taken from J. Wertz's "*Space Mission Engineering. The New SMAD*"[8], similarly as in ESA Academy courses.

According to post-course polls, all (100%) students *enjoyed the experience* and *would recommend it* to all students of different studies.

Fig. 1: Students during *Mechatronics in space applications* course consulting "*Space Mission Engineering: The New SMAD*".

VI OTHER SYSTEM ENGINEERING INITIATIVES AT GUT

Gdańsk University of Technology has consistently pursued a number of initiatives that affect development of the University as SMART University. The activities are so planned and conducted in such a way so as to implement the strategic objectives of the University and so that the obtained indicators are higher from year to year.

These include the CDIO™ INITIATIVE, an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating (CDIO) real-world systems and products. Throughout the world, CDIO Initiative collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment.

The CDIO Initiative was developed with input from academics, industry, engineers, and students and was specifically designed as a template that can be adapted and adopted by any university engineering school. Because CDIO is an open architecture model, it's available to all university engineering programs to adapt to their specific needs and it is being adopted by a growing number of engineering educational institutions around the world. CDIO is currently in use in university aerospace, applied physics, electrical engineering, and mechanical engineering departments[9]. GUT has been accepted 3 years ago as a member of CDIO Initiative[10].

Other initiatives similar in approach to system engineering education is mechatronics education[11]. The typical universit alumn is a *specialist* with a high knowledge of a single field or a *generalist* with very basic knowledge in many subjects. The industry desires an *omnibus* with broad knowledge in various fields. A *mechatronic* comprises both specialist and generalist abilities with most important – training in communitation and cooperation with specialists from all disciplines (*Linz model of a mechatronic*).

Finally, multiple space technology projects have been started. These include HEDGEHOG REXUS Project[12], SIMLE StarDust[13] or SpaceCube.

This shows that concurrent engineering adoption to Gdańsk University of Technology Space and Satellite Technology Course was a natural step towards educating better engineering personnel for Polish space sector.

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