Challenge of teaching complex, end-to-end space system design and development process: Earth Observation Satellite System Design training course

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Abstract

The Earth Observation Satellite System Design training course was first offered in 2018 at ESA Academy's Training and Learning Facility at ESA's ESEC Galaxia site in Belgium, and again in 2021 in an online format under the Covid-19 pandemic situation. The course covers the end-to-end design and development process of satellite Earth observation systems.

Two major challenges were faced by the teaching experts, consisting of the active and retired ESA staff, as well as ESA Academy's instructional designers for its development:

(1) Condensing such a vast subject domain, associated with a complex, multi-disciplinary engineering undertaking, into a compact format (e.g. 4.5 days in 2018) without sacrificing the quality of the essential technical knowledge, engineering practices and logic as taught;

(2) Presenting the course materials in a comprehensive form to a group of 30 M.S. and Ph.D. students with their backgrounds generally not covering all of the technical disciplines associated with the course subject domain.

The 2021 online edition of the training course, which drew on lessons learnt from 2018, consisted of 18 lectures, plus 5 group project sessions where the students put their acquired knowledge into practice and learned to work in a project team environment.

This paper concentrates on the approach and logic adopted by the instructional team to address the above 2 challenges. Difficulties encountered in some of the areas, e.g. remote sensing instrumentation designs, are discussed.

Keywords

Earth observation, end-to-end system engineering, ESA Academy, instructional design, satellite system design

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Acronyms/Abbreviations

EO	*Earth observation*
EOSSD	*Earth Observation Satellite System Design*
ESA	*European Space Agency*
GPX	*Group Project session number X*
GS	*Ground segment*
MW	*Microwave*
NG	*Next Generation*

1. Introduction

ESA Academy's Training and Learning Programme offers a portfolio of 4-5 days training sessions dedicated to university students from ESA Member States, Canada, Latvia, Lithuania and Slovenia [1]. It aims to complement the typical academic education in space-related disciplines in universities, offering direct transfer of knowledge and practices from the Agency, space research institute and aerospace industry professionals. The "Earth Observation Satellite System Design (EOSSD)" training course was developed by a team of retired and active ESA staff, under a cooperation agreement between ESA and the Association of Retired ESA Staff. The course covers the end-to-end design and development process of satellite Earth observation (EO) systems. It encompasses the system requirements definition, general system architecture, the design engineering process, remote sensing instrumentation designs, satellite design, ground segment design, operations concept elaboration, system assembly/integration and verification, launch campaign, in-orbit validation and applications overview of Earth observation data. It was first offered in 2018 at ESA Academy's Training and Learning Facility in Transinne (Belgium) [2], and again in 2021 in an online format under the Covid-19 pandemic situation [3]. The 2021 edition of the training course, which had been improved using lessons learnt from the 2018 edition, consisted of 18 lectures augmented by 5 group project sessions where the students put their acquired knowledge into practice and learned to work in a project team environment.

The unique features of the EOSSD course are two-fold: (i) it covers an end-to-end design and development process of large, complex satellite systems such as e.g. the Sentinel satellite systems serving the European Union's Copernicus services [4]; (ii) the course materials are prepared and delivered by a team of experts consisting mostly of retired ESA staff, complemented by a number of active senior staff, all having extensive hands-on experience in managing space system developments together with industrial partners. They bring together a synthesis of the vast technical know-hows existing in Europe.

2. EOSSD Training Course Content Outline

Table 1 summarises all lectures and Group Project sessions from the 2021 online edition. Following a post-delivery review of the 2018 edition, two lectures have been added, namely - "Introduction to Remote Sensing Methods" and "Climate Monitoring using EO Data". The lectures cover step-by-step the end-to-end system design and development process, whereas the Group Project sessions allow the students to apply the design theories and procedures in order to come up with an outline design of a next generation (NG) Sentinel-3 observation system (a follow-up of the current Sentinel-3 Copernicus system) [5]. Considerable efforts have gone into ensuring that the training materials are complete in terms of design theories and dimensioning of a satellite system as schematically depicted in Fig. 1, and cover all associated constituent elements. Ample design examples of existing systems and those in developments are presented to illustrate the design theories. In addition, a selected set of relevant video animations are shown at appropriate moments in order to complement the information content of the lectures with real-world examples.

3. Instructional Design Model for Adult Learning

The training course programme content is dense and the learning is intensive. This required particular attention during the design phase in order to ensure an optimal flow of information and tailoring of the Group Project tasks at an appropriate level of complexity.

For the students to truly benefit from the training course, the adult learning theories and methodologies were followed. Emphasis was given to the application of instructional design methodologies [6] during the update of the lectures and Group Project tasks for the 2022 edition. The instructional system design model takes account of learning psychology to design, develop and implement effective training content. It is similar to "system engineering" applied to learning and is

Table 1. EOSSD course content – Lectures & Group Project sessions

Subject type	Lecture	Group Project – Element Design	Group Project – System Design
Introductory lectures	Course Introduction		
	Introduction to EO & EO Satellite Systems		
	Introduction to Remote Sensing Methods		
System requirements & space system fundamentals	From Observation Requirements to System Requirements		
	Orbit Selection and Launcher Alternatives		
		Group Project Session 1 - Orbit Selection	
Microwave remote sensing payloads	Electromagnetic Wave Theory & Antennas		
	Radar Remote Sensing		
	Microwave Radiometry		
		Group Project Session 2 - Microwave Instruments Design	
Optical remote sensing payloads	Basics of Space Optics		
	Passive Optical Payloads		
	Space Lidars		
		Group Project Session 3 - Optical Instrument Design	
Satellite design & development engineering	Risk Management & Technology Development		
	Satellite System Design & Payload Accommodation		
			Group Project Session 4 - Space Segment Design
Overall system design, testing & in-orbit delivery	Ground Segment & Operations Concept		
	On-Ground AIV		
	Launch Campaign		
	In-Orbit Verification		
			Group Project Session 5 - System Design
Applications of EO data	Development of Applications Based on EO Data		
	Climate Monitoring using EO Data		
			Group Project Session 5 - System Design (continued)
Group Project Presentations by Students			

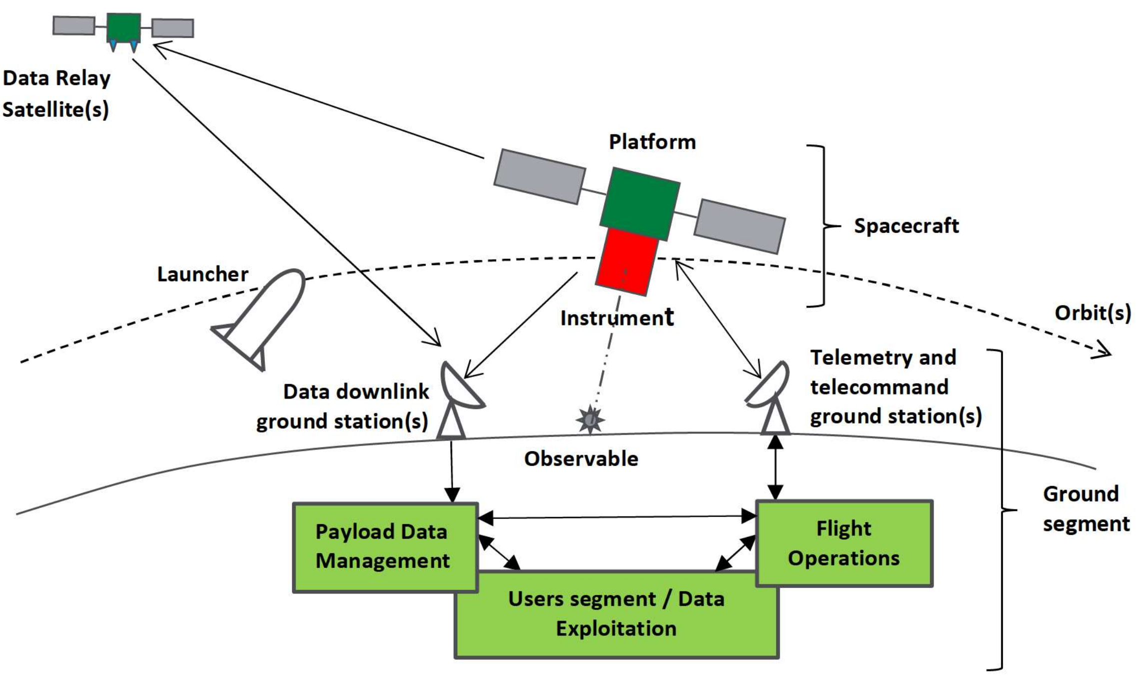

Fig. 1. Overall satellite observation system architecture model and constituting elements

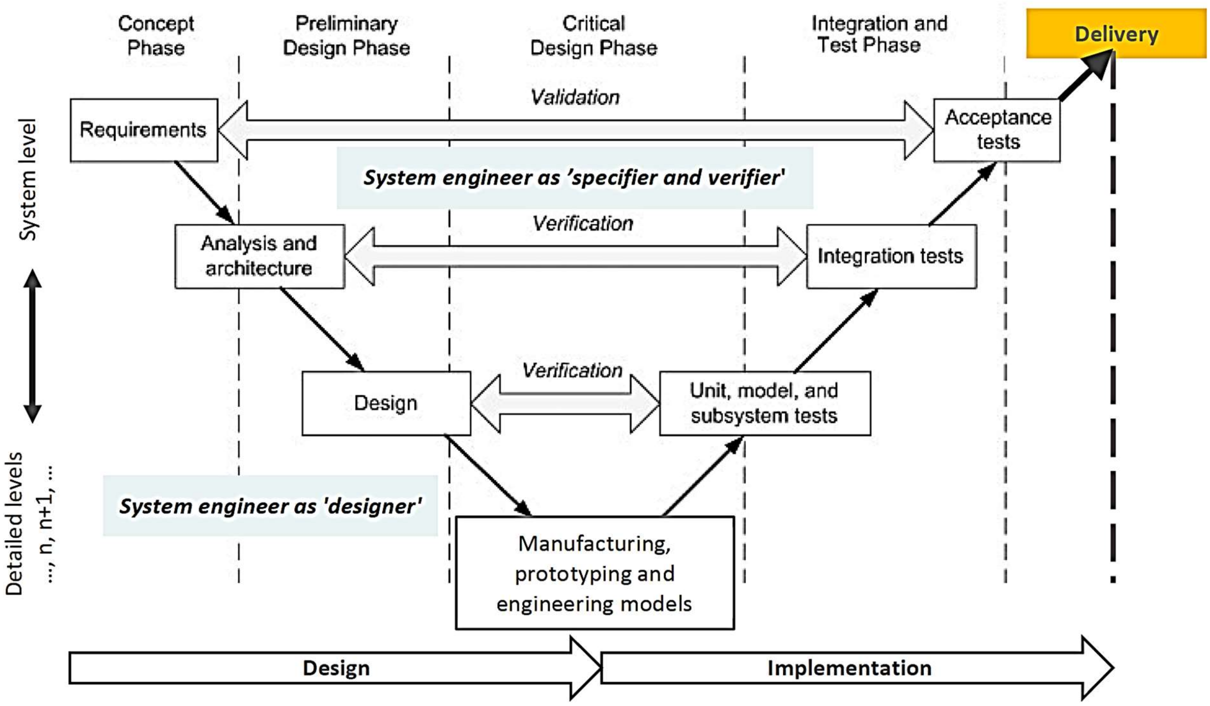

Fig. 2. The 'V' process of design and implementation

objective-oriented. Furthermore, the course elaboration guidelines established by ESA Academy for e-learning content development and delivery were followed.

4. Course Concept for Enhancing Training and Learning Experience

The EOSSD being a practice-oriented course, the payload and system design theories and procedures must be structured into the form of a complete development engineering process. The most common model for such development projects is the "V-process of design and implementation" as depicted in Fig. 2. The horizontal axis represents the elapsed time from the beginning of the project, also reflecting the maturity of the design. The vertical axis represents the level of detail of the system definition and design.

The EOSSD course starts at the upper-left corner with the definition of the requirements, followed by high-level trade-offs and analysis of the system such as the orbit selection and considerations of launcher alternatives. The lectures on the remote sensing payload designs (microwave and optical) constitute one of the core building blocks/elements for an observation system, ultimately driving its complexity and development risks. Payload designs are typically specialist subjects, touching a number of fundamental subjects such as the electromagnetic and optical theories, signal detection and noise. An ample variety of remote sensing instrumentation types commonly deployed for Earth observations, both active and passive, are covered (see the list of payload lectures in Table 1). Due to the vastness of the subject domains, it was necessary to restrict the lectures to the most fundamental aspects of each of the instrument types. State-of-the-art instrumentation design examples from the existing and planned ESA missions are used in order to illustrate how the design theories had been turned into reality. The Sentinel-3 Copernicus system design example is extensively used throughout the course for this purpose. As a preparation for participating in the course, the students are recommended to read the Sentinel-3 mission description document prior to its start [7].

The Group Project, carried out by the students, serves as yet another means to enhance the training and learning experience. Each step of the Group Project closely follows the relevant set of lectures, allowing the students to learn by doing (see Table 1 for the execution flow and order of the Group Project sessions with respect to the lectures). The conduct of the Group Project naturally follows the "V process of design and implementation", emphasizing again the systematic approach to a complex engineering development.

Table 2. Group Project team composition, respective responsibilities and tasks

Project team role	Responsibilities and Tasks
System lead engineer	System requirements compliances; system concept and architecture; project team task distribution and coordination; orbit selection; launcher selection; overall data flow
Altimetry/microwave (MW) payload engineer	Altimetry/MW payload design; observation performance; payload interface specification (accommodation)
Optical payload engineer	Optical payload design; observation performance; payload interface specification (accommodation)
Altimetry satellite engineer	Altimetry satellite design (microwave payload accommodation; communication subsystem; power subsystem; fuel budget); launcher accommodation; space segment interface specification
Optical satellite engineer	Optical satellite design (optical payload accommodation; communication subsystem; power subsystem; fuel budget); launcher accommodation; space segment interface specification
Ground segment/operations engineer	Ground segment design; data downlink performance; ground segment data flow; operations concepts elaboration

5. Group Project as a Teamwork Exercise and for Enhancing Interactions with Space System Experts

One of the important goals of the Group Project is to initiate the students into the necessary teamwork in a project environment, beside applying the acquired knowledge for designing a system. Thus, they are grouped into project teams, each team consisting of 6 members and each member with his/her specific assigned role within the Group Project as listed in Table 2. As the Sentinal-3 next generation system will consist of a series of satellite-pairs – namely the Altimetry and Optical satellites – there are 2 satellite engineers in each group designing one satellite each. The students are instructed to coordinate their work with other team members by means of extensive discussions and consensus building. And they are even encouraged to exchange information with the members of the other project teams. Those collective reflection and questioning process, plus exchanges and consultations with the space system experts, facilitate active learning and proactive design work.

The input to the Group Project is the set of system and observation requirements shown at the top of the Group Project flow chart in Fig. 3. The Sentinel-3 Next Generation (NG) system shall be an evolution of Sentinel-3, with the main difference that the altimetry and optical observation functions be separated onto 2 satellites, not necessarily flying in the same orbit. This brings positive benefits as

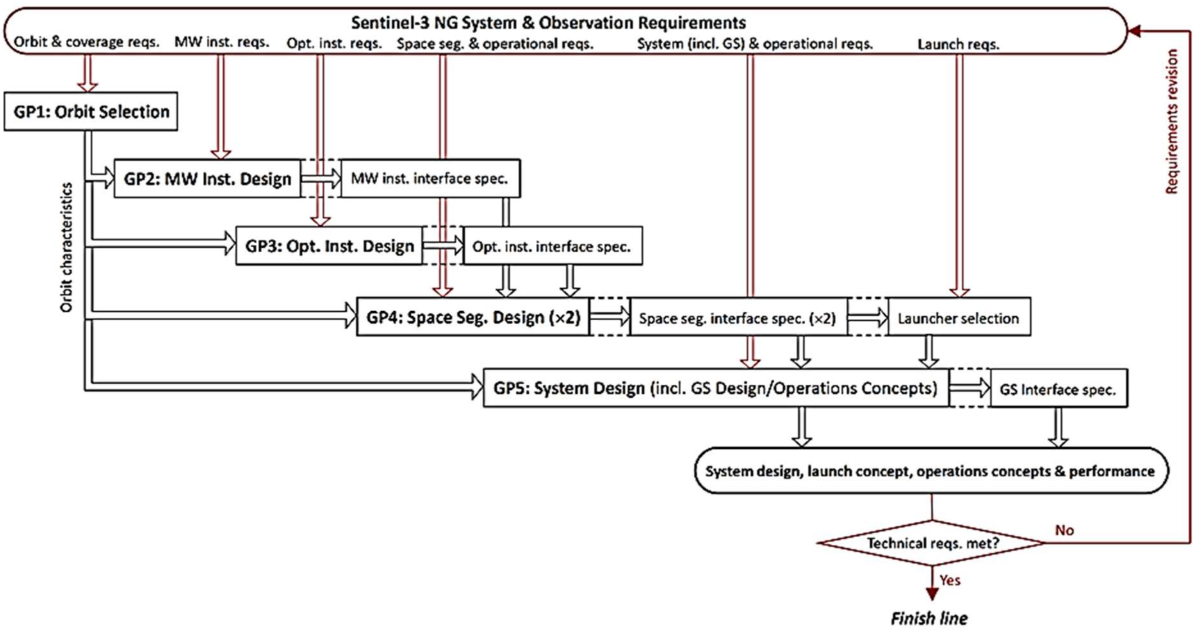

Fig. 3. Group Project flow chart

follows: (1) a simpler payload accommodation on both satellites as the available space around the respective platforms would be less crowded as compared to that of Sentinel-3; (2) a growth potential for the payload instrumentation in order to improve its observation data quality. Those benefits provide more freedom to the students for optimizing the performance versus power, mass and data-rate budgets of the individual satellites. Fig. 4 shows an example of students' design outcome as presented to the space system experts.

6. Conclusion

The EOSSD training course was delivered twice by ESA Academy, first in 2018 at its Training and Learning Facility and again in an online format in 2021. A total of 60 students from ESA's Member and Associated-States so far have taken the challenge with successful completion. The success of the course was measured based on the quality of their Group Project outcomes as well as from students' feedbacks on a detailed set of questionnaires concerning the course contents and deliveries. The next edition of the course is planned to be offered in 2023.

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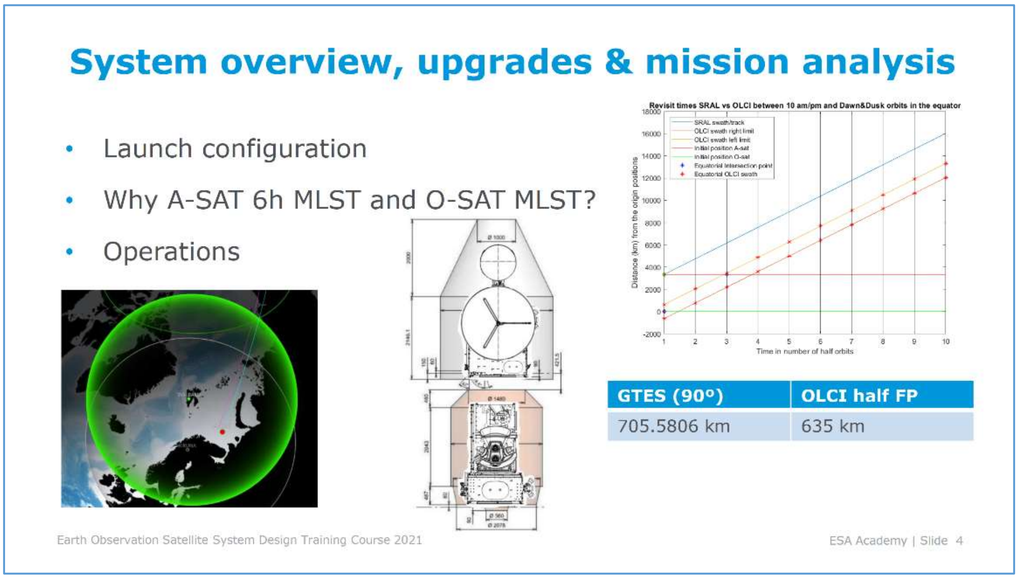

Fig. 4. An example of Group Project design outcome as presented by a student team