DELFT AEROSPACE ENGINEERING INTEGRATED CURRICULUM

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ABSTRACT

The complex multidisciplinary problems and challenges in our society require deep problem solvers in science, management and engineering who are also capable of interacting with and understanding specialists from a wide range of disciplines and functional areas. Industry refers to these people as T-shaped professionals. The T-shaped professional model has been the reference for the bachelor and master curricula in Aerospace Engineering at Delft University of Technology. The bachelor provides the broad academic background in the domain of aerospace engineering. The life cycle of the engineering process and contextual storylines of famous persons in aviation, aeronautics or space form the cement and thread for the themes of the bachelor curriculum. The bachelor develops the academic intellectual skills and attitudes to analyse, apply, synthesize, and design, and prepares for the master. The master programme aims to develop the basic competences acquired in the bachelor to a higher level in terms of knowledge, critical reflection, making judgements and working independently. While “engineering and design” is the central theme of the bachelor, “research” is the theme of the master. This curricular framework gives the bachelor and master an own profile and identity. They use state-of-the-art content that is interwoven with thematic design projects and trainings for personal and system building skills, using international standard text books, up-to-date teaching methods, excellent facilities, with a focus on the aircraft and spacecraft throughout the programmes. Excellence programmes are available for the top 5 percent students in both bachelor and master. In these honours classes self-regulated students define their personal learning objectives and levels to be attained. Their key concept is that of open-ended learning and autonomy. In the bachelor the excellence programme substitutes design projects in the regular curriculum by one ambitious and compelling project with a high societal relevance and visibility. In the master it is a half-year add-on programme about taking the lead in the creation and operation of new products, systems or processes, and developing awareness and understanding of the importance and strategic impact of research and technological developments on society.

KEYWORDS

Integrated curriculum, T-shaped professional, aerospace, engineering education

INTRODUCTION

“To be the best Aerospace Engineering Faculty in the world that inspires students, staff and society with modern education and ambitious research of the highest quality for the future of aerospace”. That is the mission of the Faculty of Aerospace Engineering of TU Delft, so the goal is to attract, excite and educate students to become highly qualified engineers, and equip them with the knowledge, creative and communication skills that are needed in the globalising and changing society. Therefore the education is set in the context of the practice of engineering, design and research in aerospace engineering. It allows the faculty to showcase its areas of expertise and gives students the flexibility to choose experience that aligns with their interest.

THE CONTEXT

The Faculty of Aerospace Engineering of TU Delft has a reputation for excellence in education. With about 1650 bachelor and 650 master students the faculty is number one in the Western world of aerospace engineering education. The faculty works closely with industry and research institutes and covers almost all technical and societal issues related to aeronautical and space engineering, design and operation. Besides the disciplines that are directly related to aerospace vehicles, the faculty covers the use of spacecraft for planetary sciences and astronomical exploration, and wind energy as a spin-off from rotorcraft aerodynamics.

Aerospace engineering is associated with challenges, difficulty and complexity. As the bachelor curriculum relates to the aerospace domain from the first study year onwards, it is appealing ("rocket science") for young people, attracts freshmen students with high grades for their secondary education and is a favourite study for talented students with high ambition and strong motivation. The bachelor and master are fully taught in English so that 30% of the students are international and come from all over Europe, India and China. They bring the international spirit to the programmes and create a stimulating environment. This international character matches with the needs of aerospace industry for graduates with a global mindset and an awareness of cultural diversity.

THE PROFILE OF THE GRADUATES

The complex multidisciplinary problems and challenges in aerospace engineering require deep problem solvers in science, management and engineering who are also capable of interacting with and understanding specialists from other disciplines and functional areas. Industry refers to these people as T-shaped professionals (Figure 1). These professionals have enhanced skills in problem-solving, creativity, talent, intelligence, and the ability to perform complex work.

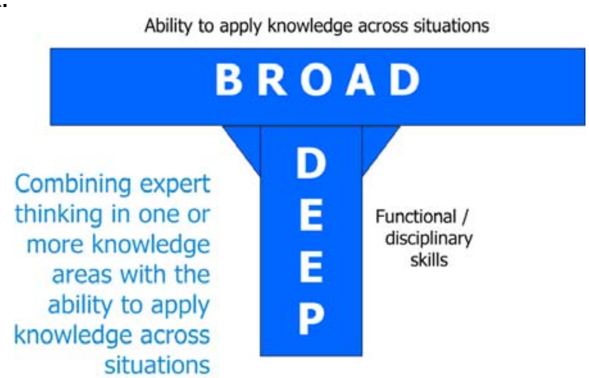

Figure 1 The T-shaped professional

Many industries and institutes look for young graduates who have the potency to develop into (top) management or specialist functions. Recruiters consider the successful completion of a master programme of high standards with a good reputation as the proof of excellence for potential top managers and specialists. The discipline of specialisation is less relevant than the fact that the candidate has demonstrated steep learning curves and proven his competence to master a deep working knowledge in a multidisciplinary field of high complexity. Aerospace engineering is such field. Mastering a deep working knowledge of fundamentals in a high tech environment has thus transformed into a selection criterion for top functions in the professional environment.

The graduate of the master programme is a Master of Science Aerospace Engineering. He is an academic professional who applies his knowledge and skills to solve practical problems. It is therefore of crucial importance that the authentic and relevant problems in the life of an engineer are also present as identifiable subjects in the bachelor and master curricula. Students have to learn how to analyse and solve such practical problems. This requires knowledge and the skills to listen and present, delegate, argument, negotiate and convince, criticize and accept critics. Since most engineers work in project teams, they have to be able to share their minds, and be flexible to accommodate their work to team insight and performance.

The educational programmes have to meet all these demands and offer students the opportunity to gain in-depth working knowledge in aerospace engineering sciences and qualifications in the interdisciplinary requirements, complemented with social and organisational skills so that all graduate engineers are capable of combining expert thinking with the ability to apply knowledge across situations.

REASONS FOR A RADICAL CHANGE

The bachelor and master degree programmes have been highly rated by students and exchange visitors since many years, and by the international accreditation committees who review the degree programmes every other six years. It is natural thing that external pressures and incremental changes lead to increasingly incoherent and overstuffed curricula. Curricula lose part of their profile and structure and, particularly in the master, tend to deteriorate into a series of specialist courses with little coherence. Also the learning and teaching environment change: today's students have different styles of learning, graduates need different competences in their jobs than ten to fifteen years ago. New pedagogical methods have been developed.

In 2006 faculty management realised that the above issues also evolved in the curricula of aerospace engineering and would not be mitigated by a gradual stepwise improvement. It was decided to go for a major overhaul and make a radical change in the bachelor as well as the master programme, making them more coherent, balanced, synergetic and compelling. September 2010 the bachelor and master innovation and development phases were completed and students were transitioned to the new programmes.

THE STAKEHOLDERS

To determine the profile, content and teaching methods of the upgraded bachelor curriculum the input was used from various stakeholders like society, industry and institutes, university, faculty, lecturers, pedagogical experts, and last but not least students, who are the customers, co-producers and product at the same time.

The current generation of students is enthusiastic, idealistic and inspiring, and familiar with powerful tools like computational, communication and search engines. They are strong in interacting, networking, communicating. They often miss the context of societal, business and political relevance to what is being taught, and hardly know what engineers do. At the university these students are immersed in a research environment in which engineering sciences and expert design are taught. This is an important concern because it is well known that engineering students learn differently than research oriented students. Engineering students want to see the practical use before the theory, learn from the concrete to the abstract by touching, taking apart and putting together. They discover first and learn on demand. Students in fundamental sciences like mathematics and physics primarily learn from the abstract to the concrete via the path of equations, theory, and analysis. For both types of students the road to understanding and motivation to learn the theory, comes through applications and connections to real-world problems.

Surveys under alumni and the professional field have shown that prospective employees have not only to learn to solve the problem right, but also to solve the right problem. The curriculum therefore should complement the teaching of knowledge and understanding in aerospace engineering sciences by transferrable skills in team work, communication, management and system-building engineering.

THE CURRICULAR FRAMEWORK

The T-shaped professional model, discussed above, is an important reference for the bachelor and master (Figure 2). The bachelor provides the broad academic background with consolidated knowledge of aerospace engineering, and the development of academic intellectual skills and attitudes to analyse, apply, synthesize and design, and a critical attitude, and communication skills, and an awareness of the scientific and societal context. The bachelor prepares for a wide range of national and international master programmes. It does not prepare for the job market because that market does not exist for BSc graduates. Industries and institutes either recruit academic Masters of Sciences or professional Bachelors of Engineering (undergraduate degree in professional higher education at a vocational university). The master provides the expert view in aerospace engineering and focuses on detailed knowledge of one or more subdisciplines together with academic intellectual skills and attitudes to model, analyse, solve, experiment and research: The master completes the education to the all-round aerospace engineer. This framework gives the bachelor and master an own profile, an own identity, and is fully in line with the Bologna Treaty's educational requirements and curriculum standards of the two-cycle bachelor master structure.

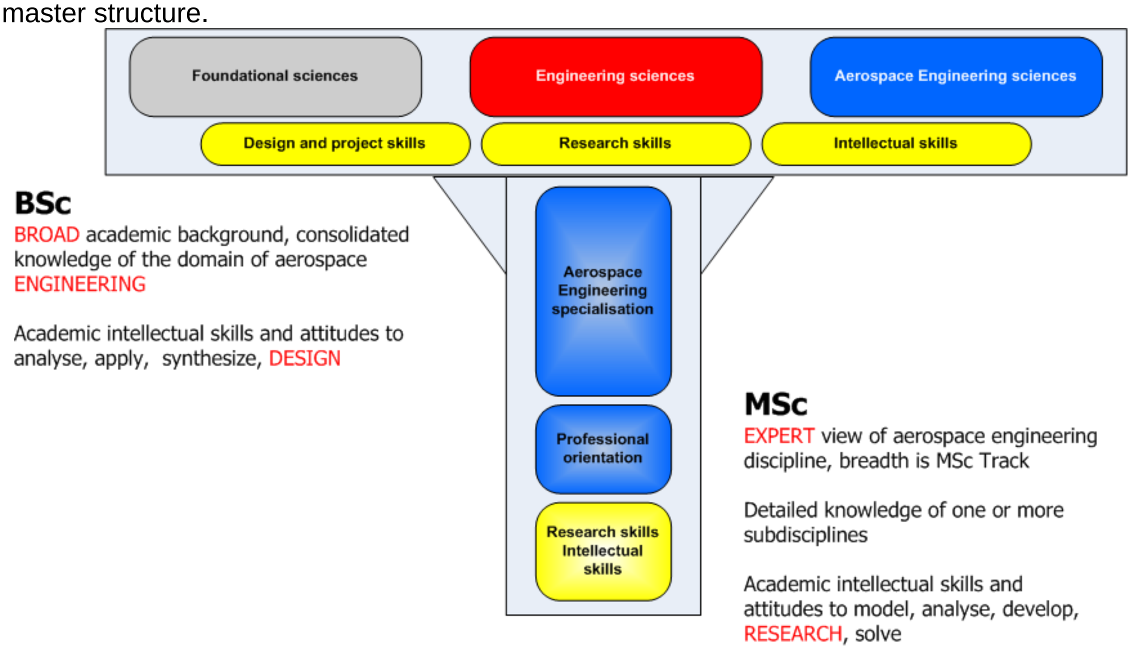

Figure 2 The T-shaped professional as reference for the bachelor and master programmes

For the bachelor and master programmes the eight touchstones are:

1. Knowledge, skills, practices and values found in engineering, design and research work in the field of aerospace engineering are reflected
2. Technical fundamentals, set in the context of engineering, designing, building and operating aircraft and spacecraft, are leading (core knowledge in engineering work, key problem solving strategies)
3. Disciplinary courses are interwoven with learning activities that develop personal, professional and system building skills
4. Students are exposed to experiences that are representative for their future profession of aerospace engineer or scientist (professional roles in projects, authentic real-life cases, design-build-test and research learning experiences)
5. Individual assessments assure that each student attains the required levels in knowledge, skills and attitude
6. Differentiation in the programmes is available in both programmes and provides opportunities for broadening or specialisation
7. Talented students are challenged by dedicated honours programmes in which autonomy and self-directed learning are the key attributes
8. The aircraft and spacecraft are the central objects of study

PROFILE OF THE BACHELOR

The bachelor programme is implemented as follows:

- “Object-oriented learning”: shaped around the engineering, design and operations of aircraft and spacecraft
- Is has a thematic structure that represents the life cycle of an engineering process
- It has a learning-by-doing (-together) approach and makes use of state-of-the-art learning materials like E-books and active learning methods to apply theory and consolidate knowledge.
- Its constituents are mostly multidisciplinary courses in which the teaching staff from different chairs collaborate to achieve a broad and consolidated knowledge of engineering sciences applied to aerospace engineering
- It trains the students explicitly in the development of academic skills; in the first year focusing on study planning; in later years on autonomy and self-directed study
- It achieves a social integration of the students in the faculty.

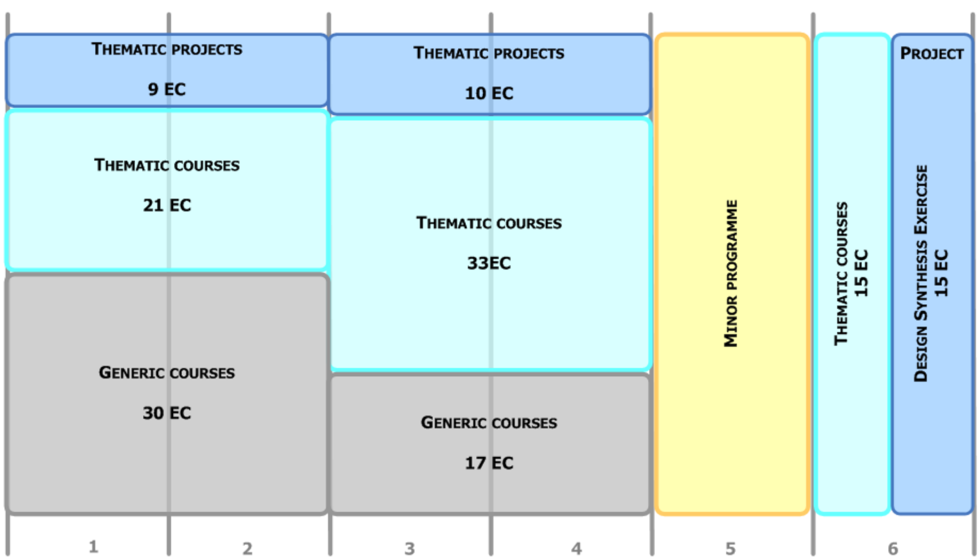

Figure 3 Schematic of the curricular structure. Each semester most thematic courses are “linked” to the thematic project to provide an integrated student experience

The first year bachelor courses are representative for the content and teaching formats for the rest of the bachelor. At the end of the first semester the freshmen students are able to draw their conclusion about their personal interest and compatibility with the educational programme.

“Making connections” has become an important facet in the bachelor. Each semester has been shaped around a theme and contains thematic courses with an associated thematic project, and generic courses (Figure 3). The central idea of this structure is the relation of the courses with the projects. Within a semester, thematic courses also relate to each other through a contextual storyline. For each semester a storyline relates the biography of a famous person in aviation, aeronautics or space (Anthony Fokker, Burt Rutan, Paul MacCready, Edwin Hubble) to the knowledge and skills that are educated in the semester. This structure provides the students with a compelling and integrated experience that encourages making connections between disciplines and consolidating knowledge. The thematic courses provide the theoretical foundation for the project; the project provides motivation and application for the theory. So besides the courses with their disciplinary lines of advancement, project work in teams and lab work in small groups are an important line of advancement that stretches over the full bachelor. The projects are the spaces in the curriculum where the young students develop into critical and tenable professional engineers.

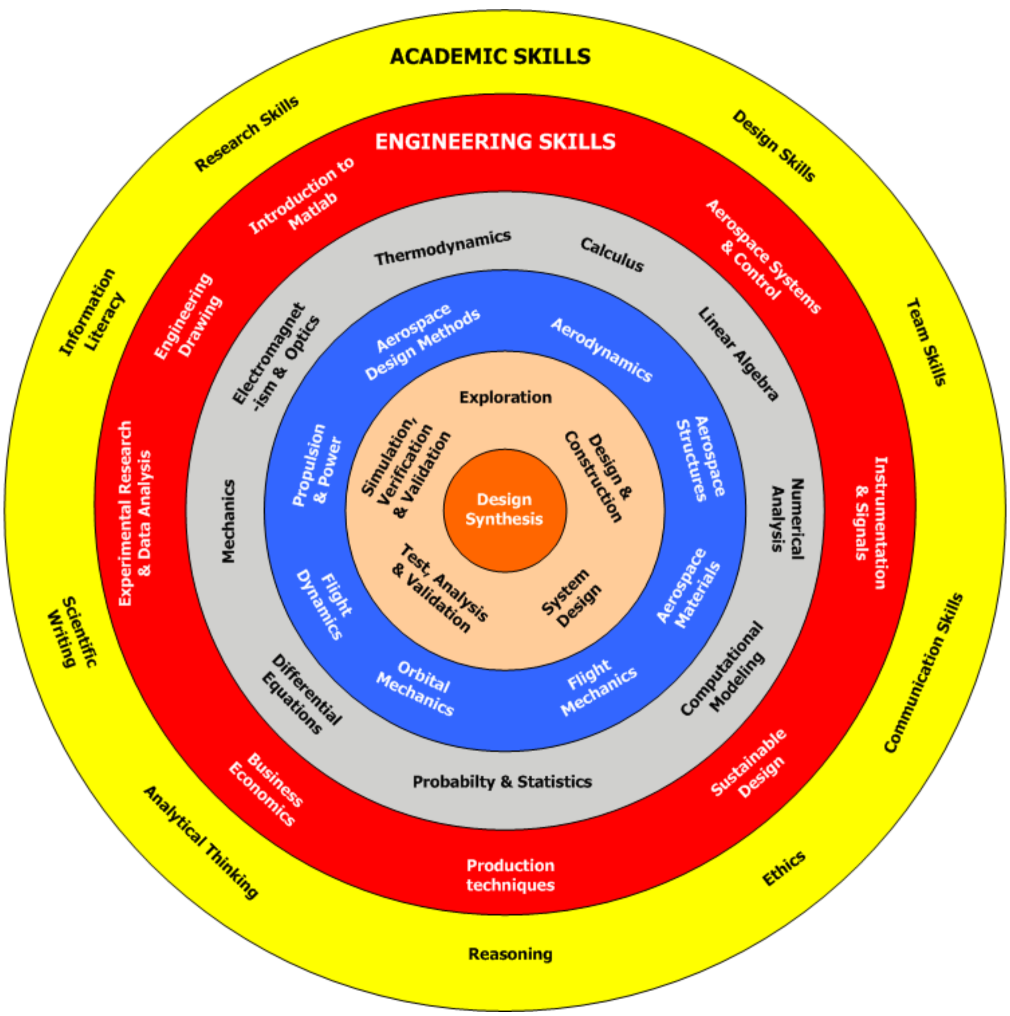

Figure 4 The onion-shell model of the bachelor Aerospace Engineering

The thematic structure assures that the experience students achieve from one semester to the next forms a coherent whole: the thematic projects and courses from one semester are connected through lines of advancement in both knowledge and skills. In the first semester, students are introduced to the many aspects of aerospace engineering in an exploratory fashion through an introductory course with project that provide the student with the “big picture”, the framework for the practice of engineering, the context for his study in the coming semesters. In the following semesters students mature along the disciplinary lines of advancement and encounter multiple experiences in open-ended design projects, lab work and trainings. This combination provides the opportunity to develop depth and sophistication over time. This arrangement helps students transition from a more concrete perspective on engineering sciences to one that integrates both the concrete and abstract concepts. Thus the students develop, practice and build up the knowledge and skills they need to succeed in the final project of the bachelor, the Design Synthesis Exercise, as the stepping stone to the master programme.

A CURRICULAR STRUCTURE WITH A STORY

At its core any curriculum is fundamentally about something. The Faculty of Aerospace Engineering emphasises its “object-oriented” curriculum, which is fundamentally about how one engineers aircraft and spacecraft. The curriculum tells this story. The organisation retains the “object orientation” by focusing on the kinds of roles and activities that aerospace engineers fulfil during the different phases of an aerospace engineering project (Figure 5). Initially, any engineering project requires exploration of the problem space: What is the context of this project? What do the requirements really mean? What solutions already exist? This is then followed by conceptual design and detailed design: What kind of structure should we build? What are the subsystems involved, and how do they interface with each other? How should we document it? Real engineering problems require extensive analysis, modelling, and testing, verification and validation in the end: What experiment should we run? How can we model the system? How do we evaluate and prove the proposed solution?

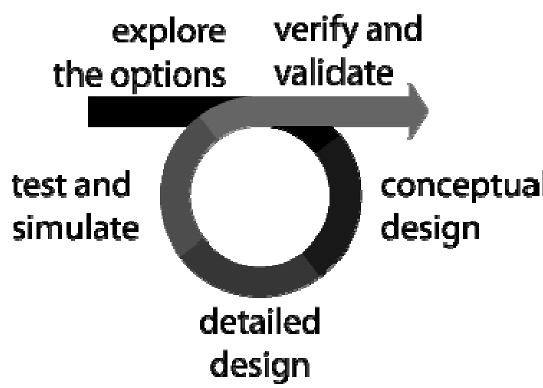

Figure 5 The phases of an engineering design process form the themes of the five semesters

This series of phases provides the themes for the curriculum each semester (Figure 6). The first semester focuses on exploration of the aerospace domain. It includes a project in which the first design-build-test experience is a concrete experience the student can reflect upon. It is complemented and followed by an exposure to theory and abstractions in the thematic courses. In this project the students investigate the concept of a flying wing, do their first aerodynamics back-of-an-envelope analysis, design the aerodynamic profile, shape it, manufacture it, test it in a wind tunnel, analyse the results and iterate the design, fly the wing in a competition. Also the spaceflight perspective is addressed by analysing how the wing should look like to fly in another planetary atmosphere. The second semester focuses on conceptual design. Since engineering students learn best from the concrete to the abstract, this project is shaped around the design, construction and testing of light-weight structures. It makes use of the faculty's model collection of aircraft and spacecraft systems and the materials and structures lab test facilities. The third semester project about system design addresses the higher and more abstract level of the designing major aircraft or spacecraft systems, considering the different disciplines of aerodynamics, flight mechanics, structures, materials, spaceflight and aerospace design methods. It takes the interfaces to the overall system into account using various simulation models in a Matlab environment. Drawings are made in CATIA, a commercial Computer Aided Design software suit frequently used in aerospace industries. The fourth semester's theme focuses on abstracter analysis, modelling and simulation, and use of authentic noisy measurement data. Last but not least the first half of the last semester the framework focuses on verification and validation, using advanced simulation models of structural behaviour and flight dynamics and in-flight measurement data. The project integrates multiple topics from the semester. Students report the outcome of this research oriented work in a scientific paper. Finally, all five themes are synthesized in the Design Synthesis Exercise. This capstone project provides the opportunity to apply all theory and build the students' confidence in engineering.

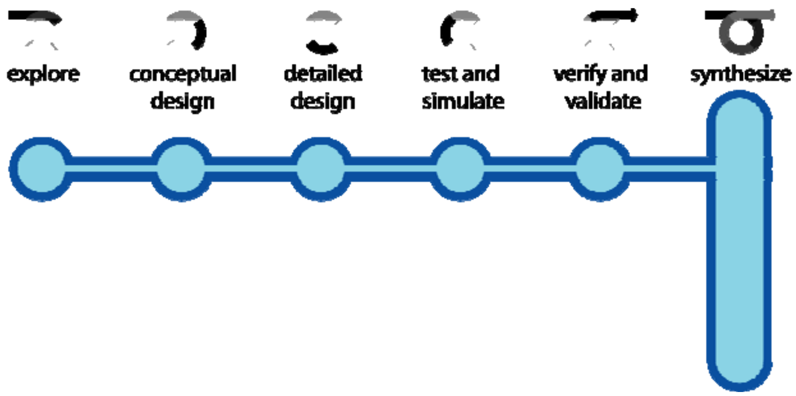

Figure 6 The themes for the semesters

The themes provide the "boundary conditions". They define the types of activities and roles students undertake during the semester, neither their specific context nor content. Within these boundary conditions, the expertise and passion of the staff have resulted in compelling projects. They provide a concrete, authentic context for student's work – students not just learn the theory; they use the theory in cooperation with young researchers, so that they develop an appreciation for what the theory means in practice.

LEARNING AND TEACHING METHODS

Active learning is based on a simple proposition: people retain more information if they are actively involved in using information (Figure 7). Studies show that passive approaches (e.g. listening to a lecture, watching a demonstration) yield retention on the order of 20-50%, while active approaches (discussing an idea, solving a problem, writing a simulation) yield retention of 70-90%. In brief, active learning is any approach that engages students in using the material they are learning. Both staff and students have to get used to the active attitude that is expected. For courses with an instruction format like lecturing, instruction or application session the in-class time is constrained to 30%. This leaves sufficient time for self-study. For deep learning a consolidation of knowledge is required, which takes significantly more time than just the acquisition of new knowledge.

Active learning is broader than project work. It encompasses a broad spectrum of teaching methods, ranging from 1) "interactive engagement lecturing techniques" which are practiced in a large lecture, via 2) "studio classroom sessions" where students get short instructions

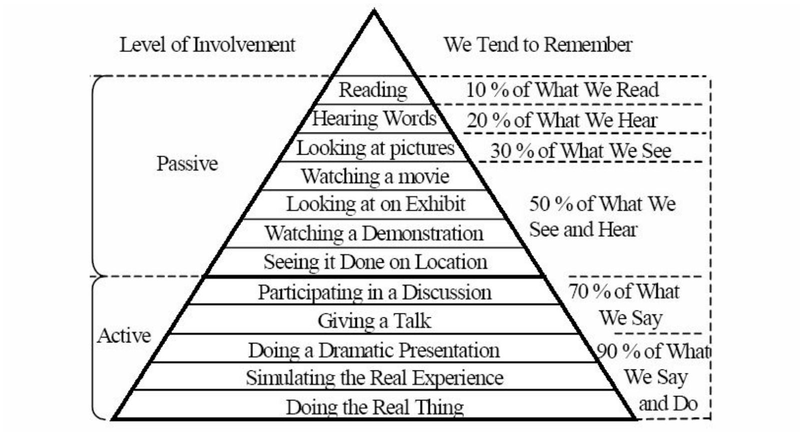

Figure 7 The pyramid of learning

and individually or in small groups do computer-based work in real time, to 3) online homework systems in which students have access to self-paced tutorials that provide individualised coaching with hints and feedback specific to individual misconceptions.

The choice for teaching, learning and assessment method has been aligned with the learning objectives, pedagogical approach and available resources (Figure 8). Most courses in mechanics, physics and engineering make use of state-of-the art commercially available study books with accompanying software applications, thus minimising development or maintenance cost.

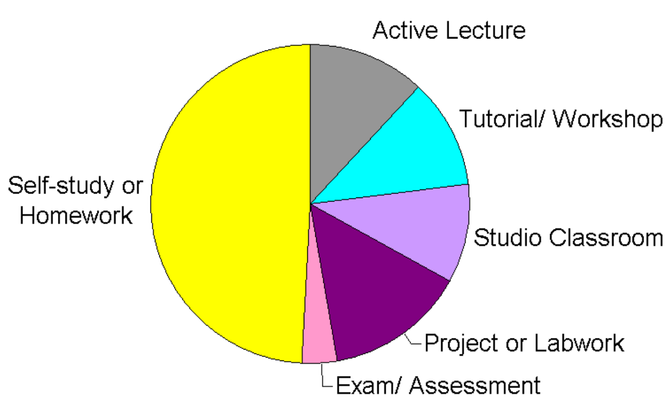

Figure 8 Distribution of teaching and learning methods in the first year

A STRONG BACHELOR GRADUATE

The thematic projects contain trainings on intellectual and communication skills, and have explicit relationships between courses, so that students have the opportunity to consolidate, synthesize and apply their knowledge every semester, rather than simply during their last ten weeks of the bachelor (Figure 4). The thematic structure enforces the students throughout the curriculum to practice the various components of an engineering project. So when students enters the Design Synthesis Exercise project, he will be repeating a cycle that he has already experienced, and he will be refining skills of project management, teamwork, reporting an presentation he already learnt and practiced earlier. Thus the bachelor graduate has learnt to appreciate the engineering process, to contribute to the development of new engineering products and systems, while working in an engineering environment.

PROFILE OF THE MASTER

The master completes the educating to an all-round aerospace engineer. The programme aims to develop the basic competences acquired in the bachelor to a higher level in terms of knowledge, critical reflection, making judgements and working independently. Specialisation is necessary to achieve the higher attainment levels, and therefore students narrow down into a field of expertise in aerospace engineering. While “engineering and design” is the central theme of the bachelor, “research” is the theme of the master.

The master programme has the following salient features:

- The student develops a thorough and detailed knowledge of one identifiable field of expertise in aerospace engineering
- The student has sufficient flexibility and autonomy in composing and planning his individual study programme (self-directed learning)
- The student acquires professional skills in a three-month internship
- Transparent quality assurance procedure for thesis project

At the start of his master, each student chooses a particular field of aerospace engineering (Figure 9). In this field he composes his individual study programme of obligatory and elective courses, a Master Orientation Project or Literature Study, an internship and the concluding thesis project. The obligatory courses develop the expert view of the student. The elective courses offer the flexibility to meet specific interest in a specialisation in subfields of expertise or add multi-disciplinary elements, repair deficiencies or add personal interest. The elective courses are selected by the student in consultation with the professor.

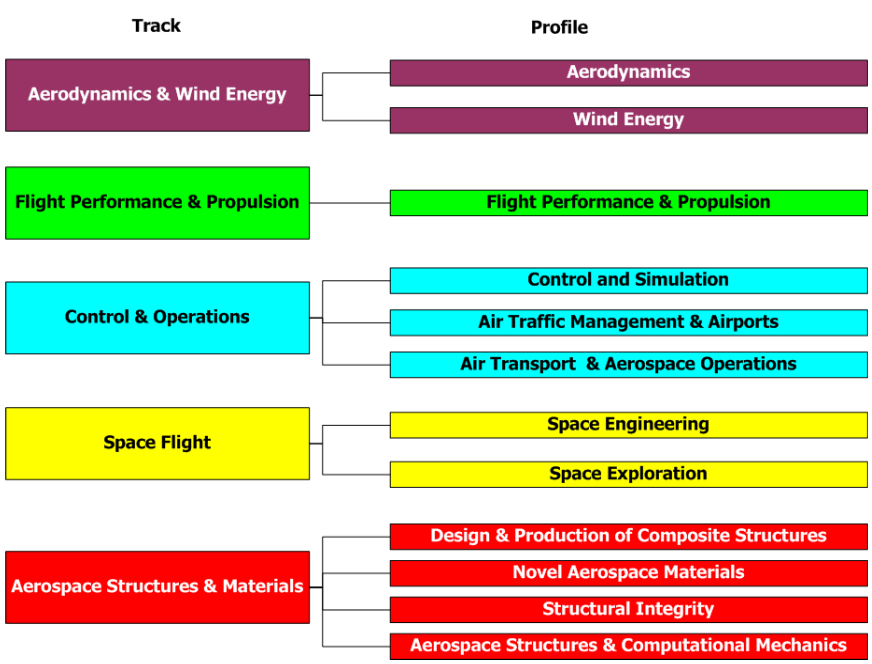

Figure 9 The available specialisations and subspecialisations in the master

Each individual programme (Figure 10) contains a Master Orientation Project or a Literature Study. The Master Orientation Project is primarily for students who do not want to develop into a researcher but an engineer. Its objectives are familiarising in a field of expertise and getting a sneak preview of what it means to perform independent research or expert design type of work on a day to day basis. The project prepares the student for the choice of the subject of his thesis. The Literature Study is a preparatory research in direct relation to the second-year thesis subject, with the aim to achieve maximum depth in the thesis later on. Both the Master Orientation Project and Literature Study address and practice the theory about doing research that is taught in the obligatory course Research Methodologies. This course focuses on the key questions what research is and how to systematically perform scientifically correct research, which research methods exist and what can be the differences and similarities in research projects. The student learns how to establish a research plan. This is the first step to be taken at the start of the thesis project, a step many students have found difficult to take in the past.

The internship is a key element in the master is highly appreciated by students, alumni and the professional field. It allows the student to experience the professional environment, develop organisation sensitivity, and make an active contribution to aerospace related industries or research institutes. It exposes students to a real work environment for a period of 12 weeks on a full-time basis. About 80% of the students take an internship abroad, adding to the international character of the programme.

It is a “learn and explore” kind of internship, enabling students to acquire professional skills different from those taught in the programme. Beside the company assignment, the internship has a dedicated assignment about the engineering profession and a personal reflection on performance in the internship. The assignment about the engineering profession is a search in the company about how well the company meets professional standards in respect of topics like sustainable development, project or risk management, value management, health and safety management. Another dedicated assignment about the personal reflection on performance is about the student himself, where questions are addressed such as: What did I learn about myself in the professional working environment? Did I discover unsuspected talents? Which points for personal improvements remain?

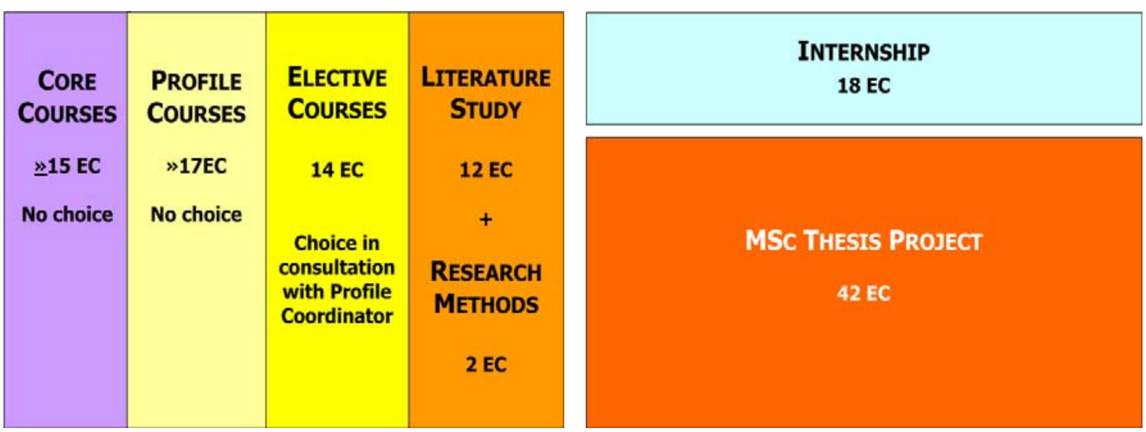

Figure 10 Standard outline of the Master Aerospace Engineering

The master is concluded by the thesis project, an in-depth research or expert design project in the field of expertise the student has chosen. A student chooses to take an in-depth mono-disciplinary thesis project or link his thesis to a multidisciplinary project that runs with contributions and support from other research groups. The thesis project then has its main point in one specialisation but crosses over with another one.

DIFFERENTIATION AND EXCELLENCE

Today's job market is calling for engineers with wide-ranging knowledge who are willing to look beyond the boundaries of their own degree discipline. The major/minor system in the first semester of the third year of the bachelor enables the student to add another dimension to his study in the form of a minor. The minor programme is a cohesive package of third-year courses on academic level about a subject of personal choice, which may be a technical, managerial, economical specialisation, or general topics of contemporary liberal arts.

An important facet of making the curriculum compelling has been to accommodate differentiated levels of ambition and interest of the individual students. Some elements of the curriculum should therefore offer a level of adaptability to the preferences of interest and ambition level of the students through "outcome-based" education, i.e. by offering curriculum elements that challenge ambition or content levels students can choose from. These elements are not per a curriculum of subjects students have to know, but rather based upon the student who decides what is important for him to learn. For the 5% highly talented and most ambitious bachelor students the AExcellence programme provides these students with the opportunity to link learning to personal interests and goals. The programme is for self-regulated students who define their personal learning objectives and levels to be attained, who attempt to monitor, regulate and control their learning process, motivation and behaviour. The AExcellence programme is embedded in the regular bachelor and concentrates on one ambitious and compelling theme each year with a high societal relevance and visibility, and consequential strong interest from students, faculty and audience. Potential subjects are a totally new and environmentally-friendly aircraft concept, the development of personal air transport (such as flying taxis and cars), an intensification of the search for alien life, a start on colonizing space or diverting dangerous asteroids. The AExcellence programme is an interesting nursery garden of talents for prospective master and potential PhD students.

In the master TU Delft offers a supplementary Honours Track programme for its ambitious master students with an excellent track record. The programme offers the opportunity to attain a higher level of personal development by broadening or strengthening the skills young scientists or professionals need in aerospace engineering. The half-year study programme comprises two obligatory courses on ethics and creativity in engineering. The remaining 70% is an individual programme that is defined by the student on the basis of personal learning objectives that should be related to taking the lead in the creation and operation of new products, systems or processes, and developing awareness and understanding of the importance and strategic impact of research and technological developments on society.

NEXT STEP

Much of the thinking that has driven today's bachelor and master programmes will probably remain valid for the next decade. Also in future aerospace engineering will reach across disciplinary boundaries. Therefore the curricula do not and should not restrict themselves to disciplinary silos. The pace of technological change accelerates, expertise knowledge is volatile. A curriculum that emphasises the fundamentals is therefore more valuable. The graduates must be prepared to predict, create, and manage the technologies of the future, not simply respond to the technologies of today. They must not only have a superb command of engineering fundamentals, but also a broad perspective regarding the role of engineering in society, the creativity to envision new solutions to the world's problems in the domain of aerospace engineering and beyond.

CONCLUSION

This paper has presented the framework of the Delft Aerospace Engineering integrated bachelor and master curricula where acquiring disciplinary knowledge, its application in lab work and authentic projects is interwoven with the development of academic skills like communication, design and research.

The bachelor and master have an own profile and identity. Engineering and design are the central themes for the bachelor, research and specialisation for the master. The bachelor curriculum has a well-structured knowledge base in a motivational context of aerospace engineering themes and hands-on projects and experiments, where learning-by-doing-(together) creates good interaction with others and an atmosphere of collaboration.

Although the faculty was unfamiliar with the CDIO approach when writing the blueprint for the innovation of the curricular framework, the development process and the bachelor curriculum are very much in line with the CDIO approach and meet many of the CDIO Standards.

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Biographical information

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