THE INTEGRATED CURRICULUM

Attracting, exciting and educating students to become highly qualified aerospace engineers

“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 our faculty, and so our 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. Our education is set in the context of the practice of engineering, design and research in aerospace engineering. It allows us to showcase areas of faculty’s expertise and gives students the flexibility to choose experiences that align with their interests. These facets have always been an important asset in our curriculum and in the recent innovation of the curricular framework in particular.

TEXT: Aldert Kamp, Director of Education Aerospace Engineering

REASONS FOR A RADICAL CHANGE
Our bachelor and master degree programmes have been highly rated by students and exchange visitors for many years, and also by the international accreditation committees who review the degree programmes every six years. But over the last ten years, external pressures and incremental changes had led to an increasingly incoherent and overstuffed bachelor curriculum in which rote learning was widely used. The master curriculum had lost most of its profile and structure and had deteriorated into a large number of specialist courses with overlap and little coherence. Also the learning and teaching environment changed: students have different styles of learning, graduates need different competences in their jobs than ten to fifteen years ago, and new pedagogical methods have been developed that are complemented by e-learning. In 2006 faculty management agreed that we would not be able to resolve the above issues by a gradual step-wise improvement of the programmes, so it was decided to make a radical change in the bachelor and master curriculum to make them more coherent, balanced, synergetic and compelling.
THE STAKEHOLDERS
The input from various stakeholders is used to determine the profile, content and teaching methods of the curriculum: society, industry and institutes, university, faculty, lecturers, pedagogical experts, and last but not least students, who are our customer as well as our product.

The current generation of students is enthusiastic, idealistic, inspiring and familiar with powerful tools like computational, communication and search engines. They are strong in interacting, networking, and communicating. But they often miss the context of societal, business and political relevance to what is being taught, and they don’t know what engineers do. At the university these students are immersed in a research environment in which engineering sciences and 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 and learn from the concrete to the abstract by touching, taking apart and putting together (Figure 2). They discover first and learn on demand. Students in science, like mathematicians and physicists primarily learn from the abstract to the concrete via the path of mathematics, equations, theory, and analysis. For both types of students the road to understanding and the motivation to learn theory comes through applications and connections to real-world problems.

Surveys under alumni and our 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 complements the teaching of knowledge and understanding in aerospace engineering by transferrable skills in team work, communication, management and system-building engineering (Figure 4). The complex multidisciplinary problems in our field require deep problem solvers in the home discipline of aerospace engineering who are also capable of interacting with and understanding specialists from other disciplines. Our programmes therefore offer students the opportunity to gain in-depth knowledge in aerospace engineering sciences, as well as qualifications in the interdisciplinary requirements, so that our graduates are capable of combining aerospace expert thinking with the ability to apply knowledge across situations. Industry refers to these people as T-shaped professionals.

THE CURRICULAR FRAMEWORK
This T-shaped professional model forms a reference for the bachelor and master curricula (Figure 5). The bachelor provides the broad academic background with consolidated knowledge in the domain of aerospace engineering, and academic intellectual skills and attitudes to analyse, apply, synthesize, and design, and prepares for the master. The master provides an expert view in the aerospace engineering discipline, and focuses on detailed knowledge of one or more sub disciplines together with academic intellectual skills and attitudes to model, analyse, solve, experiment and research: The master completes the education to an all-round aerospace engineer. With the new framework we have given both the bachelor and master programme their own profile and identity.

PROFILE OF THE BACHELOR
“Making connections” has become an important facet in the bachelor. Each se-
mester has been shaped around a theme and contains thematic courses with an associated thematic project, and generic courses. The central idea of this structure is the clear relation of the courses with the projects. Within a semester, thematic courses relate to each other and to the thematic project through a contextual storyline, derived from the expertise and the experience of the faculty. This structure provides the students with a compelling and integrated experience that encourages making connections between disciplines and consolidating knowledge: the thematic courses provide a theoretical foundation for the project; the project provides motivation and application for the theory. The thematic structure assures that the experience students have from one semester to the next, forms a coherent whole. The links between thematic projects and courses from one semester to the next provide clearly defined lines of advancement for both disciplinary knowledge and skills. In the first semester, students are introduced to the many aspects of aerospace engineering in an exploratory fashion in an introductory course and project that provide the student with the “big picture”, the framework for the practice of engineering, and the context for their work in coming semesters. In subsequent semesters, along each line of disciplinary development, there are multiple experiences, providing the opportunity to develop depth and sophistication over time. This organisation of the disciplinary lines helps students transition from a more concrete perspective on aerospace engineering to one that integrates both concrete and abstract concepts. This structure allows students to practice, develop and consolidate the knowledge and skills they need to succeed in the final project of the bachelor, the Design Synthesis Exercise, and 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 fulfill during the different phases of an aerospace engineering project. 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 (Figure 6): what kind of structure should we build? What are the systems involved, and how do they interface with each other? How should we document it? Real engineering problems require extensive analysis, modelling, and testing, as well as and verification and validation: What experiment should we run? How can we model the system? How do we evaluate and prove the proposed solution?

These phases provide the themes for the curriculum each semester (Figure 7). The first semester focuses on exploration of the aerospace domain, with a project in which the first design-build-test experience is a concrete experience the student can reflect upon. This is complemented and followed by an exposure to theory and abstractions in the thematic courses. The second and third semesters focus on conceptual and detailed design respectively. Since engineering students learn best from the concrete to the abstract, the conceptual design is shaped around the design and construction of structures, whereas the system design around the higher and more abstract levels of the design of systems. The fourth semester’s theme focuses on the more abstract analysis, modelling and simulation; and in the first half of the last semester the framework focuses on verification and validation. Finally, all five themes are synthesised in the Design Synthesis Exercise. This capstone project provides the opportunity to apply all theory and build the students’ confidence in engineering. The themes provide the “boundary conditions”. They define the types of activities and roles students undertake during the semester, but not the specific context or content. Within these boundary conditions, the expertise and passion of the staff have resulted into a compelling project for each semester. For example, the theme for the fourth semester is “Test, Analysis and Simulation.” The defined student role in this theme is an “analyst”, and the kinds of activities students undertake include developing and applying mathematical models and correlating model predictions with measurement data. The project includes the development of models and experiments and integrates multiple topics from the semester. Most importantly, it provides a concrete, authentic context for student’s work – students do not just learn the theory; they also use the theory, 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 the information. 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 short, active learning is an 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. Project work such as in the Design Synthesis Exercise (DSE) requires substantial investments indeed, from the tutors as well as the students. Active learning is broader
BSc
BROAD academic background, consolidated knowledge of the domain of aerospace ENGINEERING

Academic intellectual skills and attitudes to analyse, apply, synthesise, DESIGN

MSc
EXPERT view of aerospace engineering discipline, breadth is MSc Track

Detailed knowledge of one or more subdisciplines

Academic intellectual skills and attitudes to model, analyse, develop, RESEARCH, solve

Figure 5. The T-shaped professional model as a reference for the bachelor and master curricula

than project work. It encompasses a broad spectrum of teaching methods, ranging from "interactive engagement lecturing techniques", which are practiced in a large lecture via "studio classroom", where students get short instructions and individually or in small groups do computer-based work in real time, to 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 Fellowship", the new learning centre adjacent to the faculty (Figure 8), provides the inviting work spaces that attract students and allow them to work together in a stimulating environment, which in it's turn builds the social and learning community of aerospace students. The choice for the specific teaching, learning and assessment methods has been made in line with the learning objectives and required active participation by the students, and the available teaching capacity. For many courses in mechanics, physics and engineering we make use of state-of-the-art commercially available software applications that minimize development or maintenance cost.

A STRONG BACHELOR GRADUATE
The thematic projects contain training on intellectual and communication skills, and have explicit relationships between courses, so that students have the opportunity to consolidate, synthesise and apply their knowledge every semester, rather than simply during their last ten weeks of the bachelor. Furthermore, the thematic structure enforces the students throughout the curriculum to practice the various components of an engineering project. So when students enter the DSE, they will be repeating a cycle that they have already experienced, and they will be refining skills of project management, teamwork, and communication they have 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 education to an all-round aerospace engineer. It 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. To achieve the attainment levels, specialisation is necessary and

Figure 6. Design, build and test experience in the second first-year project

Figure 7. The engineering design cycle forms the series of themes throughout the bachelor curriculum
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.

A student chooses a particular field of aerospace engineering. In this field he defines his individual study programme of core, profile and elective courses, a Master Orientation Project or Literature Study, the internship and the thesis project. The core and profile courses develop a broad respectively expert view in a certain field of aerospace engineering. The elective courses offer the flexibility to meet specific interest in a specialisation in a (sub) field 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. Students may also fill part of the elective space by courses abroad as part of an exchange programme.

Each individual study programme 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 into an engineer. Its objectives are familiarising in a field of expertise and getting a sneak preview of what it means to perform independent research type of work on a daily 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 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 course Research Methodologies. This course focuses on the key questions regarding what research is and how to systematically perform scientifically correct research, which research methods exist and what the differences and similarities in research projects can be. The student learns how to establish a research plan. This is also the first step to be taken at the start of the thesis project in the second year, a step many students have found difficult to take in the past.

The internship is a key element in the programme that is highly appreciated by students, alumni and the professional field. It allows the student to experience the professional environment 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. 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 one of the following areas: sustainable development, project and risk management, value management, health and safety management, or knowledge management. The assignment about the personal reflection on performance is about the student, 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 improvement remain? About 80% of the students take an internship abroad, adding to the international character of the programme.

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 (Figure 9). A student can choose to take an in-depth multidisciplinary thesis project or link his thesis to a multidisciplinary project that runs with contributions and support from other sections. The thesis project then has its main point in one specialisation but crosses over with another one.

NEXT STEP

The bachelor is an integrated curriculum in which mutually supporting disciplinary courses are interwoven with thematic projects and trainings for personal and system building skills. The bachelor and master curricula use state-of-the art active and experiential learning techniques and projects. In the next years the curricula have to settle in, consolidate and prove their strengths, and staff and students have to celebrate its success. Two elements still have to be developed to complement the bachelor curriculum: a minor programme with two or three interdisciplinary minors with the flavour of aerospace engineering, and an excellence programme for our top 5% bachelor students. With these items in place the faculty is well prepared to attract, excite and educate future generations of students to become highly qualified all-round aerospace engineers. ➤