Integrating Systems and Business Engineering in an International Context: The SpaceTech Postgraduate Program

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Abstract. Successful education of engineers needs continuous adaptation to track the changing needs of industry. The adaptation is not limited to technological advance or to the changing mentality of new students but also to end-to-end engineering approaches using Systems Engineering. However, industries today require more and more engineers with profound knowledge of business engineering to arrive at successful products – a fact which universities typically have not sufficiently taken into account yet.
The SpaceTech program of the Delft University of Technology is an international postgraduate program for experienced high potentials seeking expertise in space systems and business engineering. The program centres around a Central Case Project where a group of international participants exercise space systems engineering fundamentals together with marketing and business engineering tools to create a financially viable virtual business.
Based on more than 10 years of experience from the SpaceTech program, the learning objectives of Systems Engineering and business engineering and their interrelations are analyzed. Topics of past Central Case Projects are summarized and trends are extracted. The potentials of integrating Systems and Business Engineering are identified and their limitations in an educational environment are addressed.

Context

Early space activities were driven by a mixture of technological, scientific, military and political motivations and conducted solely by national entities. Over the decades, a broad and robust spectrum of commercial space applications has evolved that accounts for a substantial portion of today's space activities (Kreisel & Lee, 2008). While the space sector has applied systems engineering tools and processes from the very beginning, the commercial nature of many space missions has been and still is insufficiently covered in the engineering of missions.
Today, business and financing are still focused in specific sections of companies instead of a

penetration and close integration in respective engineering sections. This maintains an artificial separation of the two areas, leaving engineers looking at business and financing with a combination of suspicion and ignorance and – most importantly - a lack of knowledge. Instead, a close integration of business and systems engineering has the potential to lead to products which are closer tied to the needs of its customers, as engineers could take the market characteristics and user needs better into account. Moreover, the integration of business and financing engineering and space mission engineering enables the optimization of processes internal to the company. This may arise from a better understanding of the company internal needs and limitations, as well as through an improved insight into the customer's operational and business concept.

The engineers' lacking knowledge and know-how of business engineering and financing may partially be compensated in practise through being confronted with commercial aspects in their daily lives. Nevertheless, this may still leave open a broad and sound knowledge on business engineering and financials and, more important, cannot compensate the lack of a commercial mindset upfront when starting their career. Although curricula of Aerospace Engineering nowadays incorporates systems engineering and end-to-end-thinking, they either do not cover business aspects at all or limit those to off-site courses or ones which are not fundamentally incorporated in the study concept.

This deficiency of covering both systems engineering and business engineering was recognized by the SpaceTech post-graduate space education program, which had been established in 1995 at the Faculty of Aerospace Engineering of the Delft University of Technology. The present paper introduces the SpaceTech program in general and then focuses on the systems engineering and business engineering learning objectives and their inter-relations and application within the program. Finally, the potentials and limitations of their common application within an educational context are analyzed and summarized.

The SpaceTech Program

Most master degree programs are focused on students which have recently received their Bachelors degrees and which plan to pursue their advanced degree(s) before their employment. This is at least partially due to the fact that, once becoming employed full-time in industry, they cannot then spare the time for longer leave or absence from their jobs to get a masters degree. While many companies will support their employees either with time off or with financial help in getting an advanced degree, few are willing to lose an employee for the length of time normally needed to obtain an advanced degree as a full time student (Fletcher, 1997). Obtaining an advanced degree through normal part-time study, however, often takes a number of years.

Programme Structure

Recognizing these limitations led to the founding of the SpaceTech program in 1995. In view of the desire to reduce the length of "residence time" in order to obtain the Masters degree, the SpaceTech curriculum is taught in a total of only ten weeks of actual classroom instruction. These ten weeks are, however, divided into five two-week sessions, spread out over some ten months, with the sessions interspersed by periods of from six to eight weeks during which the participants can return to their normal jobs (de Bruijn et al. 2007). Thus, under most circumstances, the participants can continue to carry out the duties of their jobs to the satisfaction of their employers at the same time they are earning an accredited Masters of Space Systems Engineering degree, awarded by the Delft University of Technology.

Each two-week session is intense, with classes in the first three sessions taught for six days/week,

with a total of over 50 hours/week of actual classroom lectures and exercises. The contact hours associated with the classroom instruction and testing are shown in Table 1.The sessions are further divided up into the following five areas:

1. Space Mission Analysis and Design
2. System Engineering Principles and Tools
3. Space Applications (communications, earth observation, navigation)
4. Business Engineering
5. Interpersonal Skills including team building and team management.

The content of the lectures has been defined in a process involving major stakeholders of the program such as space agencies, large companies and small and medium enterprises. This content is continuously adjusted to the changing needs of the space sector. This, together with the profile of the lecturers, which come from academia, agencies, research institutions, and companies provides the program a setting extending significantly beyond a classical academic educational program. The program relates to the ISO/IEC 15288:2008 standard by factoring enterprise and agreement processes into the project and technical processes of the program.

In addition to the interactive classroom instruction, a major asset of the SpaceTech programme is the Central Case Project (CCP), aimed at the formation of a credible commercial space-related business. Participants exercise space systems engineering fundamentals together with marketing and business engineering tools to create a commercially viable virtual business. They then present this, in the form of an unsolicited proposal to potential investors, to a varied group of engineers, managers, and executives from the space community. During the Central Case Project, participants learn the important connections between mission and system design and the potential return to investors. They develop an instinct for the technical concepts and which of the parameters to adjust to make their newly conceived business more profitable.

Table 1: SpaceTech in-class modules and hours

Module	Hours
Space Engineering	138
Space Mission Analysis and Design	*44*
System Engineering	*36*
Business Engineering	*58*
Space Applications	108
Telecommunications	*38*
Earth Observation	*36*
Navigation	*34*
Central Case Project	190
Interpersonal skills	36
Practicals and Exams	56
Total in-class	528

In addition, between sessions, participants intensively work together on the joint Central Case Project, the final report which constitutes their joint thesis for the Masters Degree. Their time working on this is reported and each student is expected to spend at least 500 hours outside of class in completing his or her contribution to the CCP development, final report and presentation. The total course thus amounts to 1000 hours spread over some 40 weeks, or some 25 hours/week on average (de Bruijn et al. 2008). The detailed sequence of the program is shown in Figure 1.

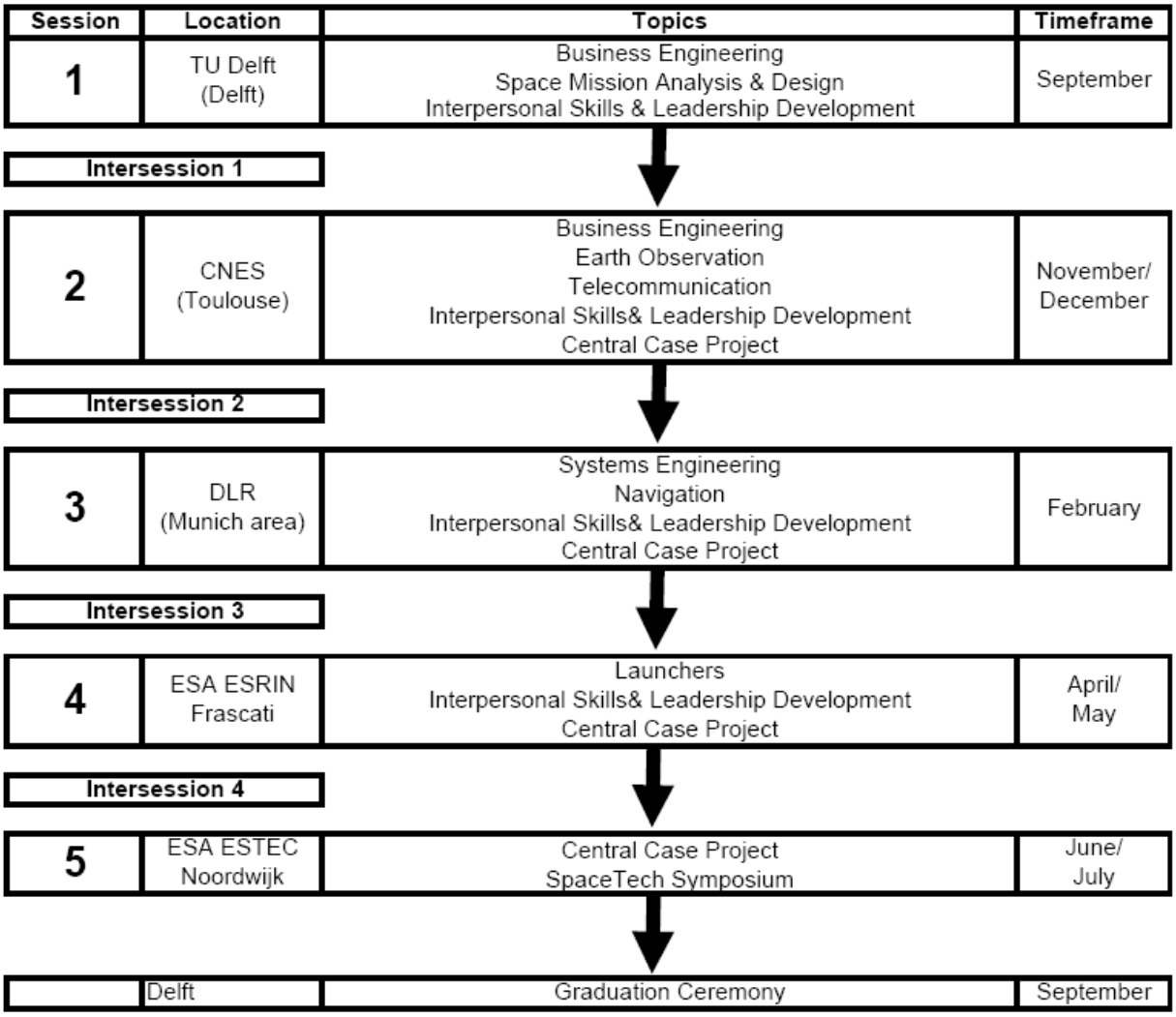

Figure 1: SpaceTech key program structure and typical locations

ORGANISATIONAL STRUCTURE

The organizational heart of SpaceTech is the Core Curriculum Committee (CCC) which directs SpaceTech's day-to-day program development and is composed of leading experts in the taught disciplines from academia, agencies and industry. The SpaceTech Program Director is chairman of the CCC and has the final responsibility for the program content. Besides the CCC, the Advisory Board (AB) helps to guide the program by advising on the specifics of the constantly changing needs of industry and agencies for space systems engineers and to improve the awareness of SpaceTech in industry and agencies worldwide. Next to this, SpaceTech also has an Alumni Association (AA) which is open to all SpaceTech graduates. The AA organizes informal events where alumni can stay in touch with each other and with the program and can further expand their international network. Finally, SpaceTech further has a program manager for academic accreditation, legal and international affairs, a marketing director to implement the marketing strategy and acquire participants, a financial administrator and program officers for daily operations and support.

Space Engineering

Systems Engineering

Systems engineering is a core module within the SpaceTech academic program. This module has been developed to facilitate the iterative evolution of the business need or opportunity identified by the participants into a coherent set of stakeholder expectations, a concept of operations for the envisioned system solution, a set of technical requirements, and the beginnings of a functional architecture for the envisioned system. The primary outputs expected from the participants to some level of detail, are reflected in Figure 2. The strategic alignment between the business opportunity identified by the participants, the concept of operations, and the system architecture being envisioned is emphasized in module discussions.

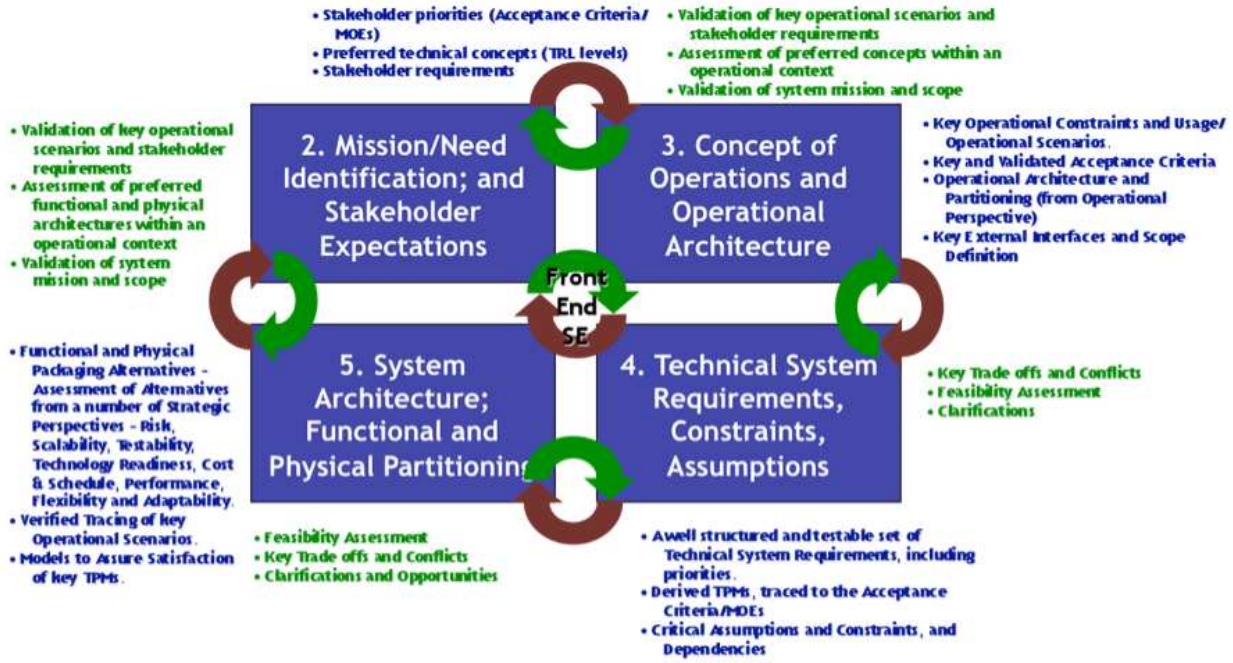

Figure 2. Primary results from the front end of Systems Engineering (Larson et al., 2008).

The systems engineering module is divided into about 50% lectures and 50% group work and exercises to apply the concepts and principles discussed in the lectures. The outline of the module is reflected in Table 2. This module is based on a core systems engineering course (Fundamentals of Systems Engineering) at Stevens Institute of Technology (USA).

Table 2. Outline of the systems engineering core module (Verma 2008).

Topic	Module	
Name	#	Name
Introduction	1	Business Drivers for Systems and Software Engineering
	2	Overview of Systems and Software Engineering
Need statement	3	Understanding and Synthesizing a System Need or Mission
Stakeholder Identification and	4	Identifying Stakeholders and their expectations; Eliciting

Mission Requirements		stakeholder requirements
System Concept Definition	5	Understanding the Intent and Composition of a Concept of Operations
	6	Understanding system scope & boundary; context diagram; key drivers; constraints
	7	Developing System Scenarios using Use Cases and Activity Diagrams
System Requirements and Architecture	8	Generating, Evaluating, and Selecting Implementation Concepts and Sub-Concepts
	9	Synthesizing and Organizing Technical System Requirements
	10	Synthesizing and Analyzing Functional and Non-Functional Requirements
	11	Managing System Requirements
	12	Risk Management
	13	Developing the Functional System Architecture
	14	Preparing for the System Requirements Review

The systems engineering module is covered in approximately 40 hours over 4 days. The response to this module and its applicability to the Central Case Project has been very positive from a participant perspective. The module is closely aligned with the Business Engineering module in that business related constraints (schedule, budget and cost, market segmentation, competition and risk, legacy constraints) and opportunities are translated into drivers when addressing the opportunity from a systems engineering perspective.

Business Engineering

The business engineering part of SpaceTech is geared around commercial space business and its major issues and offers hands-on training by leading practitioners, combining interactive lectures and actual sector information with focused exercises.
The objective is to enable participants to deal with crucial business issues, to identify drivers of new business ventures and to manage the interferences with systems engineering in a fast track approach (cf. Figure 3). It is noted that business engineering flows similar principles as system engineering does, involving different disciplines, however. The following overview is based on the SpaceTech 11 curriculum (2008-2009):

- **General Introduction:** Space Business, Space Commercialization, Space Marketing, Status Quo, Trends & Outlook, Exercises
- **New Business Creation & Finance:** Definitions & Terminology, Financials (Profit & Loss Account, Cash Flow Statement, Balance Sheet), Performance & Benchmarks, Tool-Building, Financing Basics & Valuation

- **Fundamentals of Business Engineering**: Business Plans, Risks, Business Models, Contractual Relationships & Know-How, Corporate Finance & Venture Capital, Integrated Business Planning, Presentation Issues, Integration Exercises
- **Market Analysis:** Introduction, Market Entry Considerations, Scenario Planning & Value Chain Analysis, Market Segmentation Modelling, Public vs. Private Goods, Exercises
- **Space Risks & Insurance:** Risk Management (Basic Principles, Process, Space Risk Management Plan Methodology, Case Study), Basic Insurance Principles & Space Specifics, Stakeholders & Players, Making it Work in Practice, Market Data, Case Study
- **Legal & Regulatory Issues:** International Legal Framework, Commercial and Private Parties in the Space Arena, Trading and Contracting, Specifics of Selected Space Sectors, Issues Related to the CCP
- **Central Case Project (CCP) Support:** Topic Introduction and Selected Scenarios, Business Aspects, Hands-on Coaching throughout the entire Master Program, Background Information on actual developments in the sector and selected topics.

Although manifold business and finance-related training courses and educational programs, from short courses to MBAs to entire studies, are available worldwide, only few of them deal with the early-stage development of businesses, respectively creating them from scratch, and certainly none is dedicated to end-to-end commercial space projects.

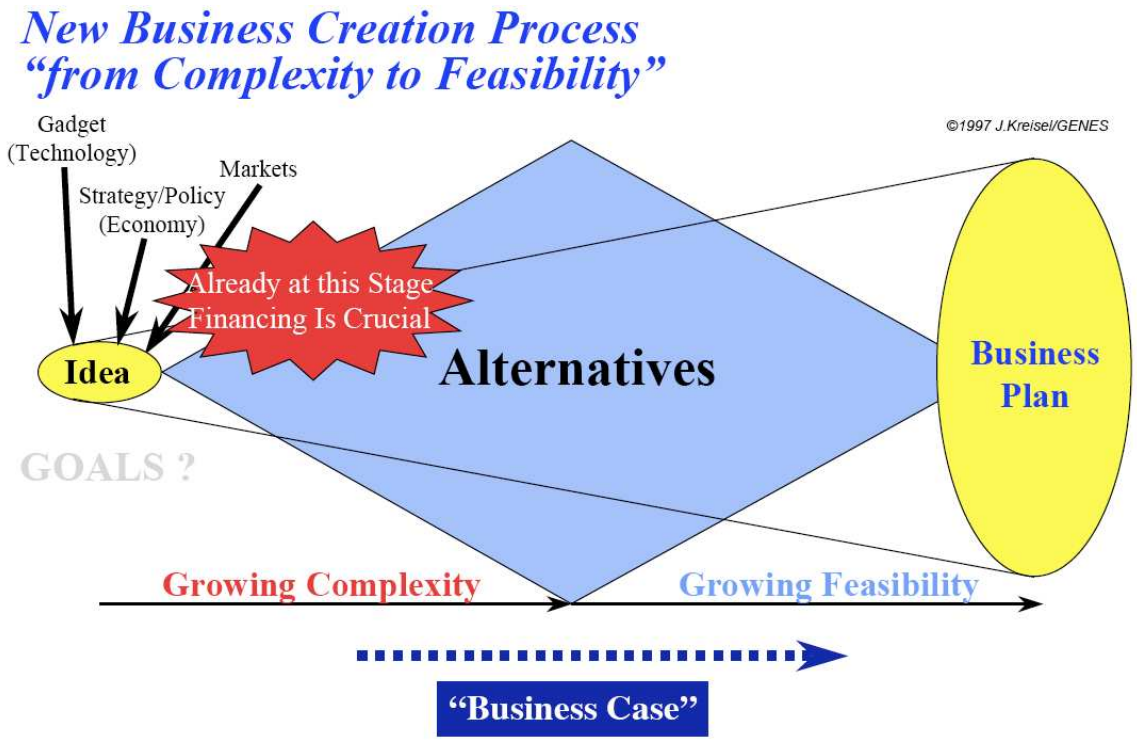

Figure 3. New Business Creation & Finance Process (Kreisel, 2000)

Observations made at SpaceTech over more than a decade confirm that space project managers mostly lack the very basics of business and are often not aware of what drives their institutions, the markets they are in or new businesses envisaged by their entities. Here, SpaceTech provides the necessary skill set to bridge the gap between non-technical objectives and technical and systems approaches supported by international environment and based on independency.
With regards to commercial satellite constellations for instance, business engineering is interlinked with system engineering at various levels by several hard and soft interfaces. SpaceTech enables participants to identify major drivers and develop a sense for their overall impact. In this context, financial considerations are of major importance, as they integrate other – mostly hardly factual information – and allow qualitative and quantitative assessments of an overall endeavor, including the technical system as one major input and feeding back in to the system engineering approach and technical design process (cf. Figure 4).

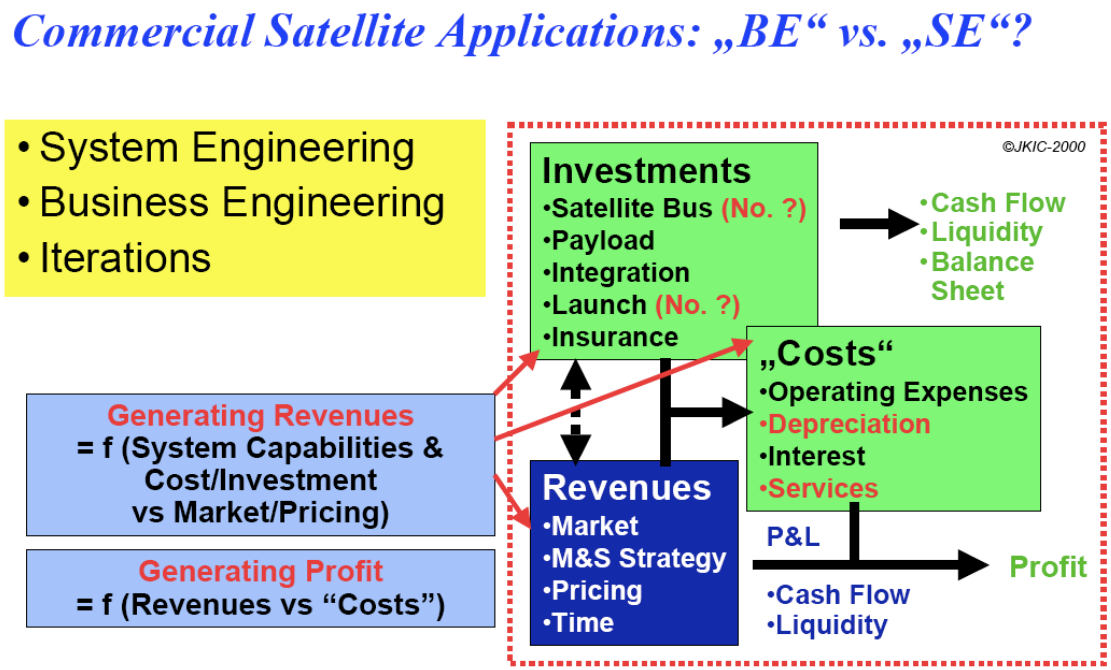

Figure 4. System and business engineering key interdependencies (Kreisel, 2000)

What is sketched in simple terms above, is in reality a rather complex system of systems, which requires a sophisticated reduction of parameters in order to be controlled and managed. It is still widely misunderstood, at least underestimated, to what extend business engineering, once incorporated, can increase efficiency and flexibility as well as adjustments already early in the process and thereby generate benefits to public as well as commercial factors in the international space arena.

Integrating Systems and Business Engineering

Although Systems Engineering and Business Engineering are treated in different modules of the SpaceTech program, both modules refer to each other throughout the individual lectures. Especially the Systems Engineering module integrates the business aspect from the very beginning. A closely coupled integration of both areas is only realized in the Central Case project, however, when participants need to apply both approaches intertwined to arrive at a successful proposal. The quality of the integration of Systems Engineering and Business Engineering which

is achieved by the participants is continuously monitored and, if necessary, enforced by professional coaches.

While systems engineering represents a structured approach to successfully design and implement a complex system, the system can be turned into a viable business concept only if business engineering methods are applied concurrently. The relation of systems engineering and business engineering through subsequent phases has been detailed in (Gill & Fox, 2005) for a combined communication-navigation service for the maritime market (Gill et al., 2005). Although a rigid correlation of both approaches is neither generic nor adequate, mutual benefits were found in applying both approaches in parallel as shown in Table 3.

Table. 3 Mapping of Systems Engineering (SE) phases to Business Engineering (BE) (Gill & Fox, 2005)

SE Phase	BE Aspects
Need Statement	• Market identification • Environment analysis
Stakeholder Identification and Mission Requirements	• Market analysis (incl. competition) • Customer interviews • SWOT analysis • Pricing strategy • Revenue estimates • Risk identification
System Concept Definition	• Draft cost estimates • Draft business schedule • Regulations and legal aspects • Accessibility of services • Risk analysis
System Requirements and Architecture	• Business-related interfaces • Refined cost models • Procurement strategy • Business development strategy • Staffing plan • Cost models • Partnership and Financing • Risk mitigation

Integrated Space Engineering

Case Studies

The SpaceTech program looks back to 10 fully worked out proposals for space systems supporting a sustainable business case. With a typical number of 12 participants per year, the invested effort of the participants equals to 6000 hours (3.6 FTE), not counting the hours of the space system, business, and personal skills coaches, respectively. The worked out documentation typically comprises several thousand of pages, which are summarized in an executive summary. Each executive summary is publicly available (SpaceTech, 2008).

The SpaceTech proposals, developed in the Central Case Projects over the past 10 years, are listed and categorized in Table 4. Categorization follows the major application areas of space, i.e. earth observation, communications, and navigation. Two years focused on others areas, such as science, technology demonstration and education (#4) and servicing (#5). It is recognized, that the majority of CCP proposals (7 out of 10) has a focus on communication applications. This relates closely to the present commercial space sector with 85% of the commercial turnover worldwide being generated in the telecommunications area (as of 2003). It is noted that more than half of the proposals combined several application sectors to maximize the return from an extended value chain. Recent trends related to the commercialization of earth observation are reflected by the proposal of 2008 suggesting an operational system for the monitoring of land and ocean colour (Martinez et al., 2008). It is interesting to note that none of the groups were able to define a viable business case solely within the navigation sector, while a combination of communication and navigation applications has been proposed three times.

Table 4. Proposals from the SpaceTech program over 10 years. Categorization is done in Earth Observation (EO), Telecommunications (COMM), navigation (NAV) and others. The latter refers to science, technology demonstration and education (#4) and Servicing (#5). Bold capital characters indicate major contributions.

CCP #	Title	EO	COMM	NAV	Others
1	BusinessSpace Automated Services (BAS) for Automated Meter Reading (AMR)	x	**X**		
2	MediaGlobe - Innovative multimedia information broadcasting services		**X**		
3	WINS – Worldwide Intermodal Navigation Service		**X**	**X**	
4	OceanMotion – Weather forecast and optimal routing in the maritime sector	x	**X**		
5	EasySpace – Science, Technology Demonstration and Education using a Satellite Kit				**X**
6	On-Orbit Servicing (OOS) – Lifetime Extension for Geostationary Satellites		x		**X**
7	ICON – Communication Navigation Systems for Worldwide Vessel Tracking		**X**	**X**	
8	S@tMax – Mobile Internet Protocol (IP) connectivity for Telematics		**X**		
9	Clepsydra – Television and Radio Broadcasting, Certified time services via Satellite to handheld devices		**X**		
10	LOGOS – an operational system for land and ocean colour applications	**X**	x		

Central Case Projects can also be sponsored. In such cases, a broad topic is defined by the sponsor together with a statement of work. Major benefits for the program and its participants are a close link to present-days challenges in the commercial space sector, the availability of additional information, and an improved network. The sponsor's benefit is, among others, an independent analysis and synthesis of a system and business proposal according to the statement of work. The defined topic shall leave the participants sufficient room for out-of-the-box thinking. The relevance of the proposals originating from the SpaceTech program is reflected by the fact that CCP topics #6 and #7 were partially sponsored. A full sponsoring has been achieved for CCP's #8, #9, and #10 by two national space agencies in Europe and a medium-size space enterprise in Germany, respectively. The CCP topic #11 is supported by a major U.S. company.

Potential

It has been found that new participants entering the SpaceTech program typically do not have significant knowledge in Business Engineering. Thus, the program is structured such that the first taught module is Business Engineering. This ensures that the participants start with a module where they share an almost common low-level of knowledge and that the seed of a business-oriented mindset is laid as early as possible. In this way, SpaceTech allows the participants to experience and combine non-technical objectives, such as financial considerations, and technical and systems approaches in an international environment. As a result, Central Case Projects lead to highly realistic and valuable results which render SpaceTech a unique program on post-graduate space education world-wide. This conclusion is confirmed through the strong attention and support which CCP results receive from space industries and space agencies likewise.

SpaceTech apparently generates a new breed of senior space leaders that not only experience major career steps within 2-3 years after graduating from the program, but also drives entirely new developments within the sending organizations. SpaceTech provides unique extension of the engineering skill-set and creates business acumen in the sector. One important asset, besides the program content and experiences, is the potential to support the migration of space organizations into active players and beneficiaries of the economic upside beyond the traditional space business and value chain. In addition, the combination of space systems and business engineering, only offered by SpaceTech, fosters new trade-offs and nurses innovative approaches at system and technical as well as on business level. The combination of such learning experience and cultural evolution is an asset in itself and appreciated by sending institutions and participants alike, although not measurable in the near-term. Finally, the Central Case Project can become the tool for assessing new endeavours in space by international and independent teams supported by leading practitioners and help taking space missions to a new level.

Challenges

However, the tight integration of Systems Engineering and Business Engineering, as it is implemented within the SpaceTech program, also faces challenges and constraints. Although the integration of both areas is primarily achieved in the CCP, a fully consistent and inter-related curriculum in both lecture modules has not yet been achieved. Areas to be considered in this context are nomenclature, detailed processes, and consistent case studies.

The Central Case Project is executed in an academic environment. This introduces constraints which would not necessarily exist in an actual business creation. The available total period to

conduct the CCP is ten months which comprises additional compulsory activities such as preparation of exams, writing of individual reports, or following lectures.

A further limitation of the CCP setting is that participants are required to self-organize the process of the CCP. Thus, hierarchical structures have to be developed first and implemented later-on, such as the definition of individual participants being responsible to coordinate inter-sessions of the program. In contrast to an actual business creation, the lack of authority or pre-defined roles among the participants may cause conflicts, delays and distortions of actual processes faced in reality.

Due to the very fact that the CCP combines Systems Engineering and Business Engineering so closely, CPP topics are essentially limited to certain areas. As observed above, telecommunications is a frequently selected area for a CCP. In contrast, deep space exploration or human space flight would be less attractive for a CCP, as they imply either a heavily constrained, or even not existing, business case.

Although extensive literature researches, market analyses, interviews with key stakeholders are conducted by the participants, the results of a CCP will only be defended in a public final presentation at the end of the curriculum. Thus, the validity of the worked-out proposal in terms of its feasibility under systems, technical and business aspects cannot, in general, be proven.

Beyond the intrinsic challenges within the SpaceTech program itself, it has been found that confusion exists in the market due to a lack of clear distinction between the various programs on post-graduate space education. The offered programs differ substantially in scope and characteristics, coverage and focus, quality and organization. However, up until now, there was no coordination between the programs. To clarify the distinction between these programs and to implement coordination between them, a Virtual Space Academy has recently been initiated which will allow coordination of post-graduate space education and realize cross-fertilization between the programs to enhance and stimulate space education (Gill et al., 2008).

Summary and Conclusions

The SpaceTech program of the Delft University of Technology is an international postgraduate program for experienced high potentials seeking expertise in space systems and business engineering. Together with the fields of space mission analysis and design and space applications, SpaceTech provides a worldwide unique end-to-end space engineering approach.

A major asset of the SpaceTech programme is the Central Case Project which aims at the formation of a credible commercial space-related business. The Central Case Project actually integrates systems engineering and business engineering into a concurrent activity of a team of closely interacting international participants. An uptake in sponsoring of Central Case Projects by agencies and companies likewise supports the high relevance of Central Case Projects in the present-days space arena.

It has been found that SpaceTech provides a unique extension of the systems engineering skill-set and creates business acumen in the space sector. Of particular relevance in that respect is the potential of SpaceTech to support the migration of space organizations into active players and beneficiaries of the economic upside beyond the traditional space business and value chain. In addition, the combination of space and business engineering, only offered by SpaceTech, fosters new trade-offs and nurses innovative approaches at system and technical as well as on business level.

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BIOGRAPHY

Eberhard Gill holds a diploma in physics and a PhD in theoretical astrophysics of the Eberhard-Karls-University Tübingen, Germany. He holds a Master of Space Systems Engineering of the Delft University of Technology. He has been working at the German Aerospace Center (DLR) in the field of precise satellite orbit determination, autonomous navigation and spacecraft formation flying. He has been Co-Investigator on several international missions. Since 2007, he holds the Chair of Space Systems Engineering of the Delft University of Technology. In 2008, he has been appointed program director of the SpaceTech post-graduate program.

Joerg Kreisel holds a degree in aerospace engineering from RWTH Aachen and is alumnus of the International Space University. . Mr. Kreisel specializes in technology commercialization since 1987. After a career in space business he became venture capitalist. He has been involved in numerous international activities in both space and early-stage equity finance. Mr. Kreisel is CEO of JKIC independent space business and finance advisors, responsible for SpaceTech business engineering. JKIC supports space institutions, industry, SMEs and selected investors worldwide using its proprietary global network of leading expertise. Focus is space ventures, business partnerships, equity finance, global links and strategy development

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