CROSSING BORDERS – 6 YEARS OF INTERNATIONAL AEROSPACE STUDENT DESIGN PROJECTS

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Abstract
The globalisation of the engineering workplace has elevated the importance of preparing engineering students for an international working environment. This paper reports on the development and results of an international aerospace design exercise, organised for students from Queen's University Belfast, Northern Ireland, and Delft University of Technology in the Netherlands. Six years of experience has demonstrated that if properly managed, taking into account learning styles and cultural dimensions, international design exercises such as these are extremely worthwhile and provide students with a number of additional competencies not readily encountered in most engineering degree courses, such as the abilities to work with teams of different cultures/learning styles, and to deal with the challenges of long distance communication.

Keywords: active learning, international design projects, cultural dimensions, group work

1. INTRODUCTION

The current aerospace market has seen a shift in the way aircraft design is approached. Design, development and manufacture have become largely international activities – for instance, Japan was a risk-sharing partner in the design and development of the Boeing 777, and the current development of the new Airbus A380 has involved partners from all over Europe. On a grander scale, the design and development of the International Space Station was elevated to a global level. The scale and risk associated with these projects has driven the need for distribution, and is shaping the aerospace companies of the future.

The multidisciplinary nature of these design activities poses a core challenge in the field of aerospace engineering in understanding the complex relationships which exist between the individual disciplines (such as aerodynamics, structures, propulsion, etc). The design of air- and spacecraft is a highly demanding due to the often conflicting requirements which exist, arising from factors such as safety, performance and environmental risk assessment, driven by regulations and customer demand which often have differing priorities. The designer is required to integrate the diverse disciplines, and develop a solution which will satisfy a multitude of constraints. With this in mind, design should be considered as a central discipline in any Aerospace Engineering educational programme.

Universities are tasked to prepare their students for a career in the society of the future. Students that start their education now will enter the labour market in the beginning of the 2010s and will stay active until at least the 2050s. Based on the observations given above, it is expected that more and more design projects will have an international nature. In response to this need, two aeronautical schools with a long standing working relationship - Delft University of Technology (TUD) and Queen's University Belfast (QUB) - conceived the idea to perform an international design exercise based on the existing Design-Synthesis Exercise (DSE) as run in Delft since 1999 [1]. Instead of developing a student exchange programme between the two universities, 3rd and 4th year students from both universities are selected to conduct a joint design synthesis exercise, with the support of staff on both sides.

This paper reports on the experience gained in the project over the years, the lessons learned and improvements made. It is hoped that this work will encourage more universities to develop co-operations, and highlight the advantages (and the pitfalls) of such an undertaking.

2. HISTORY OF THE INTERNATIONAL DESIGN EXERCISE

Based on an existing long-term relationship between TUD and QUB, a joint design synthesis exercise was developed in which six students who had advanced to the third year of their degree were selected from each university to participate. In order to facilitate the exercise, educational conflicts between the curricula of both institutes were resolved in order to produce what appeared to be a workable solution, and supporting infrastructure was put in place, including student access to videoconferencing, international phone privileges and their own electronic learning environment (Blackboard). To supplement this, the use of such technologies as internet chat, file exchange and Skype™ have been encouraged. The first international design synthesis exercise (IDSE) ran during the first half of 2002 [2].

2.1 Set-up of the exercise

A number of learning objectives were initially developed by the staff from the two universities, aimed at enhancing the student skills in a number of key areas:

- Design Skills
- Application of Knowledge
- Communication Skills (discussion, presentation, reporting)
- Team Working Skills
- Sustainable Development

Although the use of technologically-based solutions to facilitate communication is adequate, it has been found useful to ensure there are opportunities for 'face-to-face' contact between the students to promote team-building among the group. There are three such opportunities embedded in the exercise – an initial 'ice-breaking' session at the start of the exercise, a review at the final concept selection phase and at the design exercise symposium in Delft at the end of the exercise.

In order to compliment the exercise, there are courses on Systems Engineering, Project Management and Oral Presentations integrated into the module design, and the formal assessments required for each are incorporated into the exercise - for example, all the reviews are also graded for oral presentation skill level, and the project plan is graded for the integrated application of system engineering and project management tools in their design process.

2.2 The Designs

Over the past six years, there has been a number of challenging design problems undertaken within the International Design Synthesis Exercise. While a full description of each of the exercises has been published in the Delft Aerospace Design Projects booklet series [3], a brief outline of these is given below to demonstrate the successes associated with this exercise.

2.2.1 LARES **(2002)** ***– An ultra-long range reconnaissance aircraft***

The 2002 assignment was to design an ultra-long range reconnaissance aircraft with the ability to fly around the world with one refuelling, capable of performing long range or long duration earth observation missions. The final design developed by the students was a twin boomed aircraft constructed from composite materials incorporating a turbo-fan engine.

2.2.2 SUPERGROVER **(2003)** ***– 50-seat lifting-wing fuselage aircraft***

In 2003 the students were tasked with the development of a 50-passenger lifting-wing aircraft, capable of performing both passenger and cargo transport missions. In this is type of aircraft the cabin is wider and thus offers more flexibility for interior lay-out. The final design is capable of carrying 50 passengers/luggage or 6000 kg of cargo. The fuselage was designed in order to only generate lift during take-off and landing so as to shorten the required runway length. Students also made a model of the aircraft with a view to wind tunnel testing.

2.2.3 HORIZON **(2004)** ***– a solar powered aircraft for flight around the world***

This assignment was inspired by a request from Bertrand Picard, the famous balloonist. He is intending to fly around the world non-stop in a solar powered aircraft as part of a record attempt. The students showed in their design the current technical limits of renewable energy and challenges faced during the record attempt. The report was presented to Bertrand Picard’s project team.

2.2.4 HERA **(2005)** ***– Humanitarian Emergency Relief Aircraft***

In this exercise, students were asked to design a civilian cargo aircraft for humanitarian aid missions who were clearly distinguishable from the military aircraft, with an increased attention to ‘fit-for-purpose’. The design resulted in a 4-engined turboprop aircraft capable of landing and take-off from any terrain under almost any conditions which was cheap to operate and to purchase.

2.2.5 Hyperworks Hyperion (2006) - Interception Unmanned Aerial Vehicle.

For 2006, the object was to develop an unmanned aerial vehicle (UAV) meant primarily for interception of civil aircraft, with an emphasis on reduction of cost compared to current solutions. To look at the usefulness of the design, operational concepts for EU coverage were taken into account. The final design includes, among many other things, multiple cameras with allow the user to look almost everywhere around the aircraft. Though the estimated production costs, at 1.3 million euros was slightly higher than expected, the altitude, speed, range and endurance were all better than required, allowing for better operational capabilities and coverage.

2.2.6 Neutral carbon emissions trainer aircraft

The current design project for the TU Delft and QUB combined assignment is to design a four-seat aircraft which will provide general aviation users with an acceptable and affordable environmentally friendly alternative. This alternative aircraft must be suited for flight training, PPL and instrument rating, normal private use and have neutral carbon emissions and a restricted noise level. The design should be primarily driven by environmental considerations.

Whilst work is currently still ongoing, the design chosen from multiple concepts, uses electric propulsion with lithium power cells and is expected to meet all the requirements.

3. DIFFERENCES IN LEARNING STYLES AND CULTURES IN GROUP WORK

3.1 Student Learning Profiles

The make-up of the team (effectively two sub-teams of QUB and TUD) presents a number of challenges in accounting for student learning profiles, and the potential differences in the manner in which the students have been trained to 'learn'. In order to assess the variety of learning styles, and to assist in the delivery of material to best suit the needs of the diverse group of students, a learning style profile was developed for each of the students. This was supplemented with a 'behavioural' profile, and together they can be used to give an overview of the group dynamics, assisting in highlighting any potential difficulties which may arise due to conflicting needs within the group.

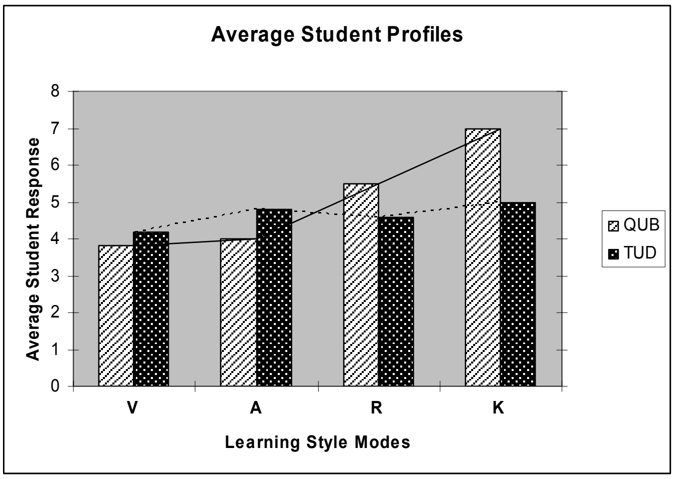

Figure 1: Average Student Profile for VARK questionnaire

To this end, a VARK questionnaire, developed at Lincoln University [4] was given to all students and staff. The VARK test is focussed on eliciting information pertaining to the preference for 'taking in' and 'putting out' information in a learning context. While some parts of the learning process are difficult to influence, preferred learning modes allow flexibility for students to modify their behaviours associated with their learning, if not their preference. The questionnaire was designed not to necessarily improve learning styles, but to inform and highlight the issues surrounding learning preferences to students and educators. It is based on Stirling's [5] three modal categories of visual, aural and kinaesthetic, but was further developed in light of research which indicated that the categories were insufficient to describe all student preferences. The categorisations were updated to include visual (V), aural (A), read/write (R) and kinaesthetic (K), although an additional category of multimodal (MM) also exists. The questionnaire consists of 13 multiple choice questions which allow for an expression of three or four modal preferences, offered as alternative actions in response to each of the questions. Each question places the 'reader' in a situation and asks for a perception of their preferred action.

The responses to the questionnaire by the students undertaking the project in the 2006-2007 sessions indicated that there are distinctive differences in the learning profiles displayed by the students from the two universities (Figure 1). While the students from QUB displayed a preference for a kinaesthetic learning style (requiring 'multi-sensory' experiences, in which learning is facilitated through application), there was no such obvious preference displayed by the students from TU Delft, where a tendency towards a 'multi-modal' preference (i.e. requiring an even range of styles of learning) was indicated. This was also reflected in the responses obtained from the academics and researchers who are associated with the project.

3.2 Cultural Dimensions to Team Working

Next to differences in learning styles, working in intercultural groups adds a new dimension to cooperation in student teams. To make students aware of this, they were introduced to Hofstede's theory [6], [7] on culture as mental software. He defines 4 cultural dimensions which can be used to explain the difference in working methods of people in general. These four dimensions are listed in Table 1 together with their results for the Netherlands and Ireland.

Cultural Dimension	**Ireland**	**The Netherlands**	**World Average**
Power Distance (PD)	28	38	55
Individualism vs. Collectivism (IC)	70	80	43
Uncertainty Avoidance (UA)	35	53	64
Masculinity vs. Femininity (MF)	68	14	50

Table 1: Hofstede's Cultural Dimensions

The low PD in both countries accounts for the ability to work in group design projects where more informal exchanges with staff members occur. Also, there are no class differences within the group of students to overcome, which makes working together easier. The high IC score is both a blessing and a curse. While it means the students will bond more easily as a team, it also indicates that individual pride and respect are highly held values – 'degrading' a person is not well received, accepted, or appreciated, and care has to be taken in putting across views or opinions.

However, there are also differences in the two outlooks. The countries score differently on UA - Ireland has a relatively low-ranking score, while the Netherlands is more mid-range. This would be indicative of a potential for the Delft students to tend towards 'rulebook' thinking, and possibly encounter problems with out-of-the-box design problems. The most distinct difference between the Ireland and the Netherlands is the score on MF. The Netherlands scores very low on this, indicating a low level of differentiation and discrimination between genders. This leads to a straight forwardness from the Dutch students, which can potentially be misunderstood.

4. DIFFERENCES IN SYSTEMS ENGINEERING AND DESIGN APPROACH

Systems Engineering (SE) is about effective communication between disciplines at the right times to facilitate some engineering process [7]. This aspect of teamwork at a reduced scale is a key feature of the IDSE Systems Engineering component. The complexity of the teamwork element is increased for the students due to the international nature of the exercise, but that thereby increases the learning outcome by better simulating some of the challenges experienced in industry. It has been evident since the beginning of the IDSE that the SE component has provided a facilitating role in getting the two teams to interact on a more open while yet technical level. Obviously, the core aim of the SE process is to deliver a fully integrated product relative to its value over the life cycle; however communication and the passing of data, information and knowledge is the activity which realises this.

4.1 Differences in SE Teaching at TUD and QUB and its Consequences on Students

The main cultural differences that were evident through the SE component tended to be the higher confidence levels in the TUD members, and the subtle differences in the approach to the relation of SE to design. The TUD team tends to be the more forward in wanting to drive the project forward as quickly as possible to the technical phases while the QUB team tends to take the more pragmatic role, while also embracing a top-down approach in putting the SE components in place as a framework for more effective design. The latter is particularly evident in the earliest stages, beginning when the two teams have the kick-off week collocated at TUD. Subsequently, the teams can be seen to build their technical, organisational and personal relations and this leads to a mutual and comparative learning process that is readily evident as one of the key outcomes from the IDSE.

In addition to any cultural differences that influence the teams, it is significant that QUB teaches design from the outset of the undergraduate course, design forming the spine of the course, with SE as an integrated facilitating component, gradually moving from concept to preliminary to detailed design as the course unfolds. On the other hand TUD tends to teach design as the ultimate culmination of the course material, like in the US approach, with SE as a formalised process with associated tools, taught as a discipline in its own right. Although there is a basic need to have analytical skills in order to verify the design intent, there is now a heightened recognition of the need for the teaching of design theory and practise in conjunction with SE in a facilitating role. The SE component, including process, methods and tools, helps to manage the technical process in progressing to a well balanced design, which has been developed with the help of analytical decision making tools rather than being driven by any one discipline that is allowed to have too much influence [8]. The practical recognition of this has led to the establishment of a more collaborative and innovative approach to the effective integration of SE into the design synthesis process by staff who now deliver the same SE material together as part of the IDSE to provide this collaborative framework. This is then supported by the appropriate analysis methods and tools when and where they are required in the design process. Additionally, individuals get to know counterparts well in a facilitating technical environment while the two teams are exposed to either’s cultures in an international multi-team environment in a way that leads to enhanced learning and a more realistic simulation of industrial practise and challenges.

In the teaching associated specifically with the IDSE, TUD had a more formalised approach to SE implementation, while QUB tended to have a more flexible approach. Again, it has been evident that a more balanced joint approach has evolved where delivery of theory is matched by applied workshop and collaborative support, the latter facilitated by weekly video-conferencing. These types of teaching practises have cross-fertilised and translated to other relevant modules in the courses. In particular, it has been evident that the Requirements and Functional Analysis, Project Management, and Design Trade-Off phases are particularly good at ensuring both organisational and technical integration. In the assessment procedure, the SE components are decomposed into a number of required stages with associated implementation requirements that are governed by a check list. The assessment of the relevant reporting by the students is rated according to the inclusion, content and quality of the SE elements and their presentation, consistency, quality and ultimate integration.

4.2 Value of SE in the International Design Synthesis Exercise

Through the years of the exercise, all of the staff involved have developed a better understanding of the role of SE in design education and recognise that the collaborative engagement in the IDSE has validated the value of a SE approach, while exposing the students and staff to some of the more practical implementation challenges faced in industry. Consequently, the students end up having a much deeper understanding of the true nature of SE, the teaching of which is only effectively delivered through experiential methods. SE forms a methodology for the rationalisation of the design process. Therefore, the SE component facilitates both the individual understanding of the design process and the team implementation. However, it is important to note that SE is being delivered as a facilitating approach that ultimately allows the collaborative team to direct more of their effort towards design innovation, given that the basic requirements have already been satisfied in an effective and formalised manner through SE. Ultimately, design synthesis is being achieved more effectively through SE education, providing the students with a model that they can take into their industrial careers, where the challenges are greatly magnified due to the complexity and magnitude of prevailing global aerospace design practise.

5. LESSONS LEARNED

After two years a formal evaluation of the exercise was made [9]. The most important observation was that while the results did not differ from the other national design exercises, the students did spend considerably more time on communication, hence why it took the team more effort than the equivalent one-nation teams to reach the same level. Even though the English language is being used throughout the Delft curriculum, some language problems did arise, largely in part to colloquialisms and context which can cause problems in understanding.

Apart from the communication issues, it was found that the exercise ran like a normal design exercise, with the students encountering the problems that would be expected in any design exercise - finding the necessary data, getting hold of the appropriate software, team organisation, timely delivery of reports, and coping with last minute changes in the design.
A second evaluation after three years reaffirmed the initial findings, and found that although the general cooperation and end result were great, it had not yet reached its full potential. The following problems were identified:

- Difference in number of ECTS and hours required
- Learning objectives on systems engineering, oral presenting and reporting were not quite aligned

- Lack of a common team spirit between students on both sides
- Communication problems due to cultural and learning style differences
- Difference in semester systems used in Delft and Belfast causing scheduling issues

These issues were resolved by aligning the learning objectives, scheduling and the number of ECTS. Each side now had exactly the same deliverables and were required to spend the same number of hours on the exercise.

The lack of team spirit was resolved by having the students stay together in one building during the first start-up week allowing for bonding, including an instructor-led teambuilding session at the start of the exercise. In this team building session [10] Hofstede's cultural dimensions are tackled in a workshop highlighting the issues which could occur. Also students use VARK questionnaires and Belbin [11] tests to find out about their learning styles and natural team roles which they then further explore in team challenges. The teambuilding also addresses the challenges of long-distance communications. In addition to this, the students were encouraged to socialise and cultural visits/events were added to the exchange experience to foster mutual understanding of each other's culture.

6. CONCLUSIONS & RECOMMENDATIONS

International design exercises are an excellent opportunity for students to gain valuable insight into working in an international environment.

Despite the extra communication hurdles the students have had to overcome, the results from the exercise have been of a consistently high standard. There is no distinction between the nature of the local and international projects, with the IDSE tackling problems which are both highly challenging and topical within the aerospace industry. The added bonus of an international design project is that it teaches students additional competencies such as working with different cultures, different learning styles and the ability to communicate effectively over long distances.

Important points to take into account however are:

- Initial teambuilding and creating an understanding of cultural and learning style dimensions are essential to overcome the ever recurring communication problems.
- The schedule and number of hours to be spent must be aligned to avoid delays and misalignment in the progress of the team.
- Using SE as an integrated tool in an international design project highlights its use and importance as a tool in design cooperation for students in their future career.
- The learning objectives and student deliverables of the exercise must be aligned and defined according to the SMART principle (Specific, Measurable, Achievable, Realistic and Time-Constraint), so that no communication problems can exist between students and staff no matter from which side.

Finally the authors would like to point out that an IDSE is not just a fantastic learning experience for students, it is also an incredible learning experience for staff and a good way of exchanging educational views and methods between staff on an international level.

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Curriculum Vitae (CV)

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Joris Melkert is assistant professor at the Faculty of Aerospace Engineering of TU Delft. He lectures in aircraft design, aircraft systems and sustainable development. Next to that he is responsible for the DSE. In the period 2001-2004 he held the position of Head of the Bureau of Strategic Development of the Faculty of Aerospace Engineering. In this position he was, amongst others, responsible for the international activities of the Faculty.

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