INTERNATIONAL DESIGN CONFERENCE - DESIGN 2006
Dubrovnik - Croatia, May 15 - 18, 2006.

DESIGN 2006

INNOVATIVE LIGHTWEIGHT AIRCRAFT DESIGN – A STUDENT COMPETITION

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Keywords: Student Education, Project Management, Life Cycle

1. Introduction

Education in engineering design is a challenging task. On the one hand the students have to get a broad theoretical basis and engineering expertise, on the other hand they have to learn how to apply their knowledge and how to face real technical problems [Pulko, 2004]. Since time in University is limited (in Germany a engineering degree at university level takes about 5 years to complete) often an emphasis is put on a sound theoretical education at the expense of practical experience.
This paper presents a student competition between four German universities, which provides a practical team-work project for engineering (design) students that nearly spans the whole life-cycle from brainstorming for product ideas to manufacturing and usage of the product. The development task is an aircraft or flight device totally made of steel. Aim of the project is to apply the theoretical knowledge at a practical task.

2. Motivation

The engineer has to take care of a lot of different and often conflicting factors. An example for this fact could be the trend to reduce weight and increase stability at the same time. In addition, while designing the designer has to consider the whole life-cycle. This instance is taught often in a theoretical way by lectures and exercises. If there are practical parts they often imply just a limited section of the whole product life-cycle. It is always difficult to combine a well-founded theoretical education in mechanical design with exercises that have a representing character towards the systematic and extensive problem solution actions by experienced engineers in practice.
The challenge for us involved in design education is to find a project with hands-on experience which at the same time motivates the students to exercise and to use what they have learned in theory. It is particularly difficult to find tasks and boundary conditions which can simulate a typical engineering situation including many different aspects. Furthermore the task should represent as much of the product life-cycle as possible. So an extensive task starts with the specification of requirements and requests of a product in a kind of requirement and performance specification, goes on with the product development process and its realisation in the manufacturing (including the interactions between design and manufacturing) and concludes in a competition with other manufacturers in the use period.
According to [Roddeck, 2000] the best way to learn something is to do it by yourself (see figure 1).
Furthermore, it is also a problem to find tasks that promote team-work and project management, which are also absolutely necessary in present design projects [Krug, 1997]. In fact, informal team-work is often required during the studies, but in most cases realistic team-work is not possible because in the deciding moments of the work period the groups get divided, e.g. when common preparation towards an examination is followed by separate "processing" of the examination. So it is important to have a task that gives the opportunity to work together for the entire project. Thus, a good exercise claims

from the students additionally the problem solution in a project team, where the boundary conditions of project management are met, i.e. they are forced to schedule their team, share the work and fulfil it in a time-oriented way driven by clearly outlined goals and deadlines.
A good way to combine these points is a practical project in a late phase of the study. Examples for such projects are listed in the next chapter.

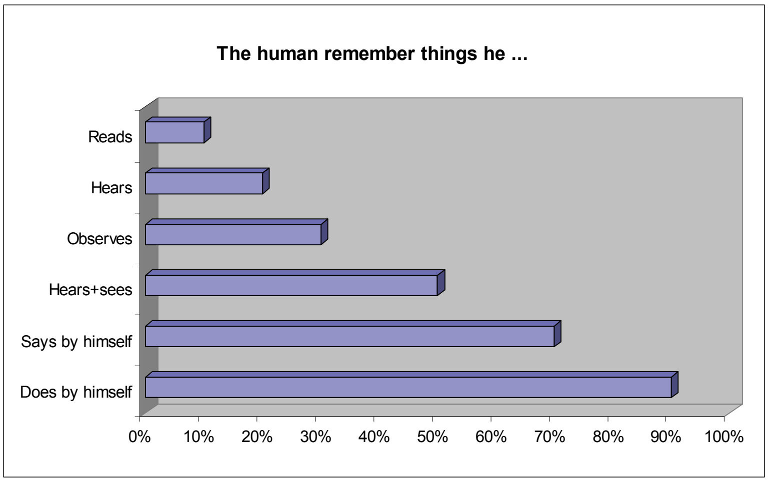

Figure 1. Dependence of capturing on form of intermediation [Roddeck, 2000]

3. Examples of practical student projects

Many Universities integrate practical projects into their curricula. Only some of the most interesting ones will be listed below:

- There was a project with industrial robots at the technical college of Bochum with aim to guide a robot arm by a surface [Roddeck, 2000]. The students had to choose regulators and to program the controller.
- At the Technical University Berlin there was a project called "Global Product Development 2002: Projektarbeit mit Videokonferenzen im interkulturellen Team" which had the aim to establish a multicultural and video conference based product development team. Participating universities were TU Berlin, the University of Michigan, the Oxford University and the Seoul National University [Gautam et al, 2003]
- The Technical University of Darmstadt participates in a yearly international competition called "International Design Contest", which enables the students to build robots and to compete against other student teams [Jänsch et al, 2004]
- Every year the technical college of Stralsund and the TU Graz, besides others, give their students the opportunity to participate in the so-called formula SAE (founded 1981 by the Society of Automotive Engineers). Aim of the contest is to design and to build a prototype of a single-seater racing car and to compete against the products of other student groups of other European universities (the formula SAE was founded at the USA and is also established in Europe since 1998) [Roßmanek, 2005].
- An initiative of the 'automotive.saarland' network founded the 'projekt 24h' which is a long distance race like the 24h of LeMans. Students of the technical college of Saarbrucken and Kaiserslautern are participating [Beduhn, 2005].

The large number of projects underlines the importance of practical experience in the curricular design of design studies.

4. German student competition (“Stahl fliegt”) in lightweight aircraft model design

In order to complement technical knowledge with practical skills the German student competition “Stahl fliegt” (“steel can fly”) was created. This is sponsored on a yearly base by FOSTA (Forschungsvereinigung Stahlanwendung e.V., German research foundation for steel application) and was held for the first time in 2001. Since 2002 “Stahl fliegt” is a nationwide competition between several universities, Saarland University participates since 2003. The competition takes place yearly at the end of the summer term and is organised alternating by the participating universities. Meanwhile, four universities (RWTH Aachen, TU Darmstadt, University of Dortmund and Saarland University) compete in the race for the longest flight time. Every university is allowed to delegate up to three teams with a maximum of four team members each to the contest. A tutor (scientific assistant) must be named for each group.

At Saarland University the construction of the lightweight aircraft takes place in the advanced study period and is embedded in a project work that belongs to an applied laboratory course. Up to that term students get well educated in theoretical basics of mechanical engineering – especially mechanical design –, but there were less opportunities to transform their theoretical abilities into practical experience.

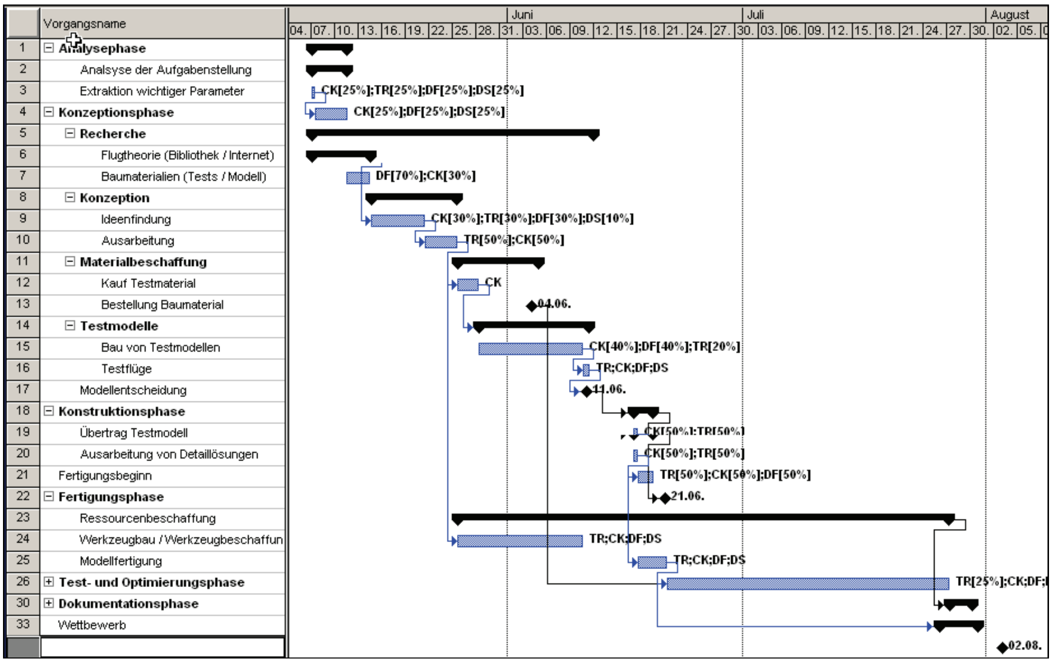

Figure 2. Typical project plan used for the “Stahl fliegt” competition

The lightweight materials normally used in aircraft construction are aluminium, titanium and fibre-reinforced plastics. But the regulations of the “Stahl fliegt”-competition only allow steel for part construction and adhesives only for joining them. So the students have to tease out the technical limits of the allowed materials to design a steel-lightweight aircraft that is able to fly.

In the following, the regulations with their restrictions to the aircraft design are listed:

- As building materials only steel or metallic materials are allowed which have an iron weight proportion of at least 70%. The use of adhesives is only accepted for joining purposes.
- The assembled aircraft model has to fit into a cube with 1m edge length.
- The maximum weight is restricted to 1000g.
- The use of a remote control is prohibited.

- Propulsions are allowed, if they meet the other conditions; so they must also be built of steel and have to work without additional propulsion media, such as fuels or propellants.
- The students have to document their working process from the first ideas right down to the manufacture and assembly of the aircraft.
- The students have to present their aircraft before take-off and have to explain their solution.

Additionally, they are two more significant restrictions

- The construction time is limited by the readout of the remit and the competition day (approximately three months).
- The FOSTA sponsors provide each team with a budget of 250 €, which they can use to buy the materials and tools needed. If they need more resources, they have to acquire additional sponsors.

As already mentioned, the intention of the "Stahl fliegt"-competition is the construction of lightweight aircraft, that really fly. The assessment is divided in two parts: the results of the flying competition documented by the flight time – not the distance – and the overall result of the project work represented by the documentation and the grade of innovation of the whole design and construction.

In the flight contest, each group gets five flying attempts of which the best three count; the result is the arithmetical average of these three attempts. Each university gets two times twenty minutes of time to perform the five flying attempts.

The documentation and grade of innovation is assessed by a jury made up of the professors involved. The winning teams are invited for an official award ceremony the following spring.

By attending the project work 'Innovative Lightweight Aircraft Design' ("Stahl fliegt") and the following flight competition, the students can acquire further technical skills, e.g. in flight theory and manufacturing. Furthermore, the project work helps the students to make experiences in project management. That means that the students will be pressed for time and by that they will have to schedule their available project time, create a project plan, share duties and responsibilities and so on (see figure 2). Students also have to cope with a restricted budget, throwbacks and technical problems. If they need more resources they will have to organise these themselves, e.g. make extended know-how accessible (e.g. specialised workshops) and perhaps even have to negotiate with potential sponsors to increase their budget. Therefore, they learn important things about team-work, project organisation and control and have the opportunity to improve their soft skills. That means that they will probably be confronted with conflicts, the dynamics of groups, successes and disappointments.

Beyond that, the competition gives the students a platform to compare their own ideas and their proficiency level with those of fellow students from other universities.

The project is valuable as an education exercise, because it gives a precise task (build a flying object which stays a maximum of time in the air) and some restrictions (budget, materials, dimensions, time, etc.) to the students. The students have to follow all steps through the product life-cycle by themselves. Due to the restrictions the students will have to abandon known trails and find new, perhaps innovative, solutions.

In general, the project can be divided in seven main phases (shown in figure 2):

- Analysis of the task and the restrictions in the original specifications.
- Generating ideas, e.g. by using the brainstorming-method or by assessing and adapting from known patterns.
- Structuring of the ideas and the principle solutions found in the period before, e.g. by using the morphological matrix, evaluation methods, etc..
- Conceptual design by selecting a combination of principle solutions, manufacturing of test aircrafts, performing test flights and, based on their results, finally layout and detail design.
- Manufacture of the final chosen solution.
- Flight tests with the real aircraft and final optimisations.
- Use period (the flight competition itself).

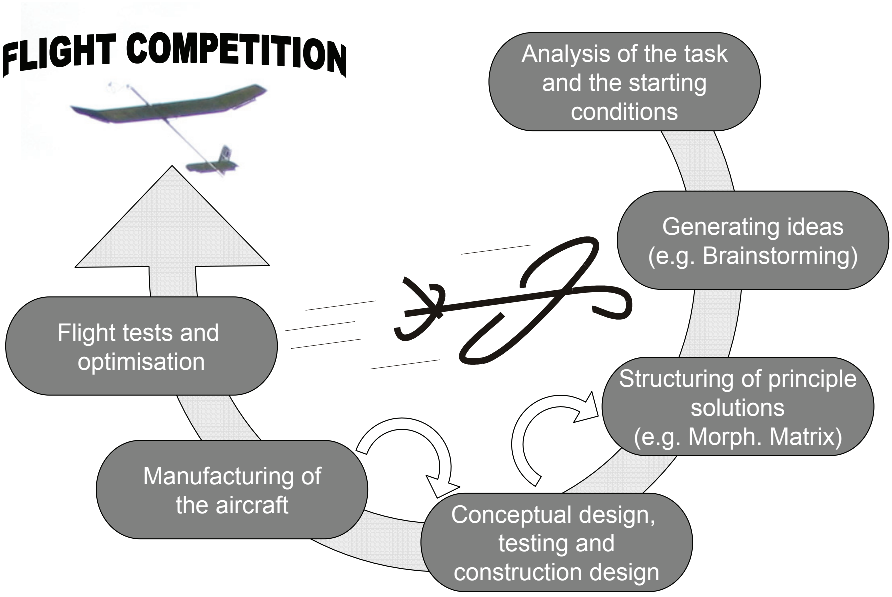

Figure 3. "Stahl fliegt" – life-cycle

The first six periods can be processed by the students as a kind of semester work at the university. The use period is to be simulated in a flying competition with other universities. The phases are interlinked and do not follow just linear life-cycle patterns. For reasons of clearness, not all possible interactions are shown in figure 3. Following all the steps through the entire life-cycle the students are to learn that often a design solution fulfils not the requirements of manufacturing.

5. Competition 2005

The competition 2005 was hosted by the RWTH Aachen. Altogether seven teams from the RWTH Aachen, the TU Darmstadt, the University of Dortmund and Saarland University participated.
The project started with a kick-off meeting for all the students and the tutors in April 2005.
The following images were taken at different phases of the project, starting with the generation of ideas (figure 4), first conceptual tests (figure 5) up to the building of the final model (figure 6). The competition took place at a slope in Belgium close to Aachen in July 2005. The RWTH Aachen team won the competition with an average flying time of 7,72 seconds. (They had a "record" flight of 54,5 seconds duration, but this was unofficial because it took place during the warm-up period). The RWTH Aachen team used a flying wing model (see figure 7). The team of TU Darmstadt scored second with an average flying time of 5,65 seconds. They used an innovative very light-weight flying object inspired by paper planes (see figure 8). The team from Saarland University was awarded the third place (the average flying time was 4,63 seconds). Their model is also shown in figure 8, too. In this case the average flying time corresponds with the final ranking.
The flying times are highly influenced by wind conditions. In previous competitions the winning team sometimes had flying times over 20 seconds.

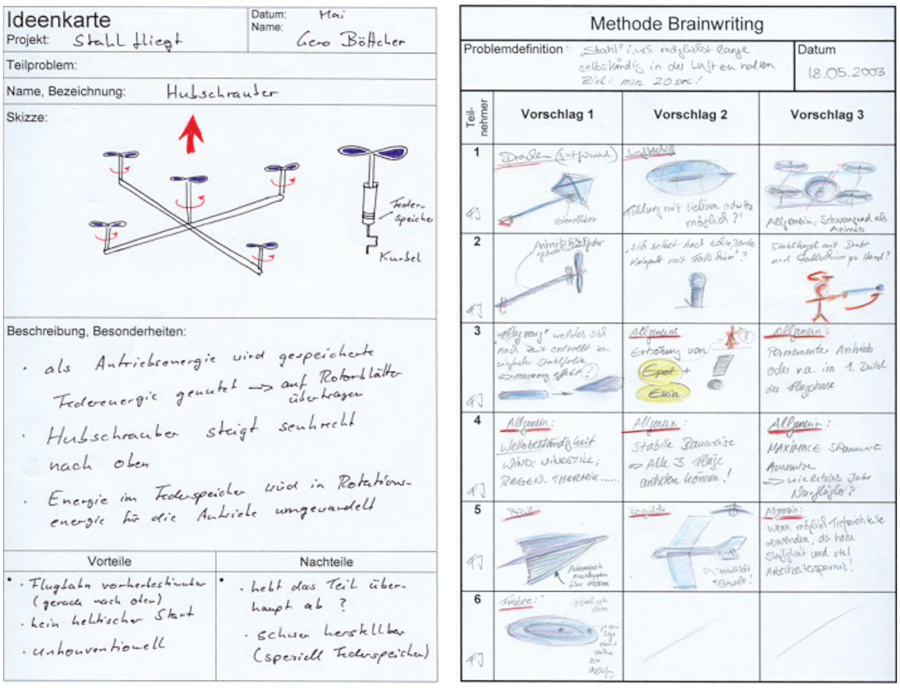

Figure 4. Generation of Ideas (Team TU Darmstadt 2003)

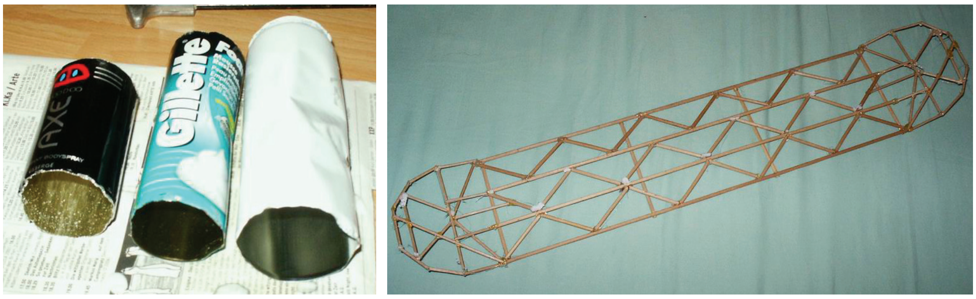

Figure 5. First conceptual tests

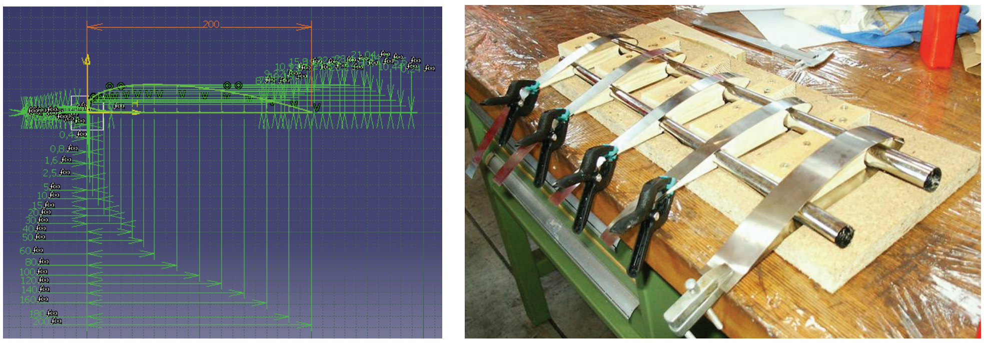

Figure 6. Airfoil modelling with CAD and building of the wing structure

Figure 7. Flying wing model from the RWTH Aachen (1st place)

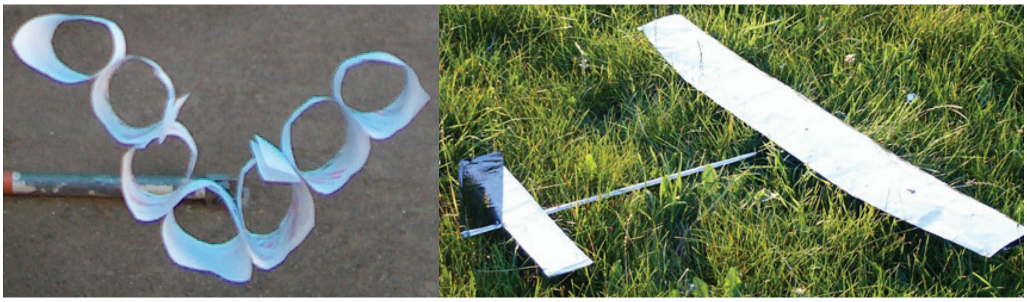

Figure 8. Concept model of TU Darmstadt (2nd place) and Flying model of Saarland University (3rd place)

6. Lessons learnt

The two main aspects the students learn through the "Stahl fliegt"-project are on the one hand the experience made in project work, i.e. developing a project plan, deriving tasks out of it and pursuing them in a target- and cost-oriented way. This includes responsibility assignment with independent work in the framework of fixed deadlines. On the other hand they get the practical experience of manufacturing their design solution by themselves. So they experience, that the design process is more than just calculating, technical drawing and creating CAD-models. It is also testing and sometimes a negative feedback from the manufacturing side. Additionally, they have to work within quite rigid technical boundaries so that it is essential to find new innovative trails to improve the flight properties of their aircraft. This includes the search for – or in some cases even the design of – cheap and adequate tools to ensure the manufacturing of their ideas. Furthermore the students learn the analysis of a task and to concentrate on essentials which lead to a (hopefully) successful project end. In this special case these are the selection of the needed parameters of the common flight physics, such as a minimum induced resistance, a high snatch, a small angle of glide and general parameters like a slow flight velocity, a steady flight characteristic – but also good crash behaviour.

7. Future plans

Next year there will be a further “Stahl fliegt” competition. The four universities named above will participate again. Although in general the students groups change every year, there is a steady improvement in development of an innovative aircraft. The students build upon the work of their predecessors and also have benefit from the documentations made by former groups. A lot of ‘dead end’ ideas and weak spots have been collected and documented over the years. So last, but not least, the students experience the role and value of knowledge and its systematic documentation in practical design projects.

8. Conclusion

Design education at universities is mostly done theoretical. The German competition “Stahl fliegt” (“steel can fly”) gives students the opportunity to apply their theoretical knowledge in a practical project. During the semester project they have to organise their team, create, structure and evaluate concepts and principle solutions, calculate, simulate, build, and document the flying model, finally participate in the final competition. They have to learn to deal with strict restrictions and have to use a material (steel) they probably would normally not use for building a model plane otherwise. The final competition provides direct feedback how the own model plane compares to the teams of the other universities and offers the opportunity to meet other students. From the educators’ point of view the project is an ideal enrichment and complement for the curriculum of students who major in mechanical engineering or design. The best of all is: The project is great fun for all the participants!

Acknowledgements

The authors would like to thank the FOSTA (Forschungsvereinigung Stahlanwendung e.V.) for the sponsoring of the ‘Stahl fliegt’ competition.

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