The Penn State Sailplane Course

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Abstract

Since 1989, the Department of Aerospace Engineering of The Pennsylvania State University has offered a special undergraduate project course that has a strong emphasis on "hands on" design and fabrication. Specifically, a group of approximately twenty-five students, freshmen through seniors, is involved in the design and construction of high-performance sailplanes. Students can and are expected to enroll in this course for every semester during their undergraduate study. The basic course structure consists primarily of three components. The first, lecture, provides the student with the necessary theoretical background of modern sailplanes and their design requirements. The second component is concerned with design groups of four to six students, in which the students design and analyze sailplanes, such as their performance, structure, stability and control, and so forth. The third component is the fabrication of parts that have been designed and analyzed theoretically, such as the current project of a full-size, 50-foot wingspan sailplane made out of modern composite materials. To a large part, the learning experience can be related to the integrated nature of the design course, as well as to the interaction of undergraduate students at all levels of their program.

Introduction

For the past twelve years, the Department of Aerospace Engineering of The Pennsylvania State University has offered in its undergraduate curriculum a rather unique flight vehicle design and fabrication course that attempts to provide aerospace-engineering students with a training that is comprehensive and applied.[1-3] The course has a strong "hands-on" component, with students designing and fabricating modern high-performance sailplanes. The students can and are expected to enroll in this course for every semester of their undergraduate experience. During that time, the students experience the cooperative, multi-disciplinary team environment that is required for solving the problems related to the design of an aerospace vehicle.

The course concept is based on similar student groups at German universities, the Akademischen Fliegergruppen (Academic Flying Groups) or, abbreviated, the Akafliegs. The members of these groups, some of which have been around since the early 1920s, concern themselves with the design, construction, testing, and flying of modern sailplanes. Although not part of the official curriculum at their respective school, the groups receive some logistical support from their institutions. In brief, their structure is similar to that of an American Greek-letter social fraternity, except that the focus of interest revolves around soaring. At eleven German colleges, such groups are strongly involved in sailplane related research, often with the support by the German Aerospace Research Center, DLR, which sees this as an effective and uncomplicated way of training future engineers.

Since their beginning, the Akafliegs have been a decisive factor in the development of sailplanes. For example, Fig. 1 shows the first, full composite sailplane, the Phönix that the Akaflieg Stuttgart brought to flight in 1957. Another example is, as shown in Fig. 2, the SB 10 by the Akaflieg Braunschweig, that flew first in 1972 and, until recently, was the largest flying glider with a wingspan of 95 feet. In this design, carbon-fiber composites were used for the first time in the primary structure of an aerospace vehicle.

Throughout the history of the Akafliegs, many engineers in the German aerospace industry and at the different research facilities have come from these groups. For example, Theodore von Kármán was a founding member of the Akaflieg Aachen, whereas Alexander Lippisch came from the Akaflieg Darmstadt. Well-known airfoil designers, F.X. Wortmann and R. Eppler, were active members of the Akaflieg Stuttgart, as K.H. Horstmann and A. Quast, the designers of the HQ-airfoils, come from the Akaflieg Braunschweig. All the engineers and designers employed by the leading, German sailplane manufacturers are former members of these groups.

Each group has about twenty active members, who are mainly, but not exclusively, engineering students. During their active member time, they get involved into many aspects concerning the construction of a modern flight vehicle. Although one of the main motivations of the members is to actually fly high-performance gliders, the learning experience is very comprehensive and complements well the official university curriculum. Despite this and, in part, due to the independence of the Akafliegs, the student members do not receive any course credit for their activities, although projects and theses are often related to the current design projects.

The Penn State Sailplane Project

Although the flight vehicle design and fabrication course at Penn State was modeled after the German Akaflieg, several changes were necessary in order to adopt the Akaflieg concept to the higher-education system in the United States. One of the most striking differences comes from the relatively low tuitions required by German universities, and from that, the reduced pressure on German students to pursue a college degree in the minimum time possible. In addition, the German higher-education system tends to be less structured than American universities that often employ numerous homework assignments and frequent testing. Hence, the idea was to make the new project course part of the aerospace engineering curriculum at Penn State, such that students can substitute some of their sailplane-course credits for required course work. In its twelve-year history, the course has evolved from its original concept as experience with the course has grown.

Course Structure

The course has about 20 to 25 undergraduates at all levels, freshmen through seniors, most of them majoring in aerospace engineering. The students are strongly encouraged to enroll in the course their freshmen year and remain in it through the duration of their undergraduate program. The course consists of three major components: lecture, design activities, and fabrication work.

Lecture

The main purpose of the lecture component is to provide the students with the theoretical background required for their design and fabrication activities. Hence, it is kept quite flexible in order to be able to address current needs and problems. A very valuable resource is Ref. 4, which deals with the design requirements of sailplanes from an engineering perspective.

The lecture emphasizes the basic theory of sailplanes and their design requirements. The challenge for the instructor is to present lectures such that they provide a positive learning experience for the fourth-year, aerospace engineering student, who might have been in this course for the past four years, as well as to the freshmen, who might have no background at all in aerospace engineering. Hence, after an introduction to basic sailplane related subjects, other topics are emphasized that are relevant to aircraft design, such as aerodynamics, stability and control, structural design, design and fabrication of composite structures, performance analysis of modern sailplanes, general design methods, and some sailplane history. For example, a brief description of existing sailplane designs makes the students appreciate the solution found by earlier designers facing similar problems.

Beyond these plain technical tasks, the lecture also covers other, less obvious, but important engineering skills. These instructions include basic and general aircraft-design principles, technical report writing, presentation methods, as well as professionalism and ethics. Besides the formal lecturing, the students skills and abilities in these subjects are constantly challenged through their design and fabrication activities.

Design Activities

About four to six students make up a design group. In these groups, the students design and analyze complete sailplanes or parts of them. The theoretical work includes performance analyses of modern high-performance gliders, their stability and control, as well as their structures. Other examples of that activity includes the design of testing procedures, such as the verification of the crash safety of sailplane cockpits, or the exploration of new fabrication methods for composite materials.

Ideally, the current theoretical work of a design group builds on the results of previous semesters. For example, through a donation, the course obtained an American Falcon, a composite sailplane that comes as a kit and requires assembly. This sailplane, whose open fuselage is shown in Fig. 3, has a faultily designed wing structure that failed in earlier structural load tests. The students analyzed the structure and, unaware of the actual structural test results, were able to predict the failure mode. In following investigations, the students identified the weak points and came up with suggestions for a fix. Other theoretical investigations, such as measures for improving the crash safety of the Falcon cockpit, have been undertaken.

Another ongoing design project is the Griffin, a 50-foot span, modern composite sailplane design, shown in Fig. 4. Over the years, the students moved from the conceptual and preliminary design to a detailed design of this glider, including its aerodynamics, structures, stability and control, control systems, as well as its fabrication methods. The design work is performed with regard to legal limits, giving the students a chance to gain experience with the FAA certification process.

Fabrication Work

A strong emphasis of the Penn State flight vehicle design and fabrication course is on "hands-on" experience in the laboratory, which the students are required to attend for several hours per week. Ideally, here the students put into reality what had previously been developed in the design groups. In the laboratory, students work in small teams usually consisting of at least one more experienced classmate acting as a leader. The students learn simple tasks, such as sanding, as well as more complex composite-material fabrication methods, such as the processing of pre-preg or hand lay-ups with vacuum bagging.

Examples of the results of this work include several radio-controlled sailplanes that have been designed and built by the students over the years. An example of a recent design is the Banshee III that is shown in Fig. 5. This all-composite design has a span of 9.5 feet. Even more impressive are the fuselage and horizontal tail molds of the full-size Griffin sailplane. This has been an ongoing project for the past seven years, which required the shaping of a positive fuselage plug from which the negative molds were taken. Figure 6 shows the fuselage-mold halves and the plug after they are being separated following the heat cure. In the fall of 2000, a test-cockpit section was built using these molds. The front-fuselage section is the result of several generations of sailplane-course students' theoretical and practical work.

Another project is the fabrication of the previously mentioned, kit-built sailplane, the American Falcon. This glider was donated to the course after the wing of another sailplane of this design had prematurely failed during a structural-load test. The donation has been very beneficial for the course, since it gives the students the chance of actually putting hands on a nearly finished sailplane. Major parts of the kit plane are prefabricated, but most of the control system and landing gear needs to be assembled, and the wing and fuselage halves must be joined. The students are currently redesigning the parts that failed during the above mentioned tests.

Besides these three larger projects, students often pursue smaller ones, such as experimenting with new fabrication methods of composite parts. About once every year, the course conducts a design competition, in which the students and their engineering skills are challenged by a multi-objective design problem. This, for example, can be the design and construction of a simple balsa-wood glider with a limited wing geometry that has to maximize its endurance while satisfying certain structural or material limitations.

Documentation

The students are required to document their design and fabrication activities in a notebook. The notebook is a mental aid for the students with which they document their thought processes and decisions for later references. Course members keep one another informed about the current design and fabrication activities through presentations. Any long-term efforts are documented by the students in written reports, especially when it concerns the documentation necessary for FAA certification. In general, the students develop an appreciation of the documentation when working with the records of their predecessors.

Course Grading and Credits

The performance of a student is based on a combination of his or her documentation, which includes notebook and written reports, group presentations, an evaluation by his or her peers, as well as a faculty and teaching assistant evaluation. In particular, the peer evaluation has proven to be very effective, since the students spend a lot of their time working in teams whose members depend strongly on each other.

Within the major, students in the sailplane course receive credit for two required laboratory courses, two required semesters of design, as well as one technical elective. Some students opt to fulfill their optional senior-thesis requirements with the sailplane course. The course credit system for the sailplane course is set up in a progressive manner, which means that the longer a student stays in the course, the more credits will he or she will receive. According to this scheme, a student, who enrolls in the sailplane course for the full four years, will earn a total of 20 credits. For this effort, the student can substitute up to 11 of these credits for departmental graduation requirements. The total number of credits earned after each year is listed in Table 1. If a student begins taking the course at a later stage of his or her undergraduate study, the number of possible earned credits are, of course, less. Nevertheless, the ratio of required coursework credits allowed to those earned remains at approximately 2 to 3.

				Years Completed
Starting Year	1	2	3	4
Freshman	0	2 Design 2 Lab	4 Design 2 Lab 3 Tech. E.	4 Design 4 Lab 3 Tech. E. (3 Thesis)
Sophomore	2 Design	4 Design 2 Lab	4 Design 2 Lab 3 Tech. E. (3 Thesis)	X
Junior	4 Design	4 Design 4 Lab (3 Thesis)	X	X
Senior	4 Design (3 Thesis)	X	X	X

The Learning Process

The sailplane course has proven to be quite successful and is popular among students. Many students and graduates consider it their most favorite undergraduate course. Graduates report that the experiences learned have a high relevance in current professional lives. The course is often cited by students as providing significant motivation to chose and stay in the aerospace engineering major. Furthermore, the percentage of sailplane students that go on to graduate school at either Penn State or other universities is significantly above average. It is also somewhat surprising that over half of the sailplane-course students have a spacecraft, rather than an aircraft, concentration in their studies.

A major part of the success of the sailplane course is due to the "learning-as-needed" approach. This means, in particular, the learning process takes place while the students try to solve specific problems that they encounter during design or fabrication work. The project itself only provides the necessary framework of problems that need to be solved. This approach to learning requires considerable initiative by the students, who must be highly self-motivated in order to tackle the problems. The roll of the instructor then becomes one of being another source of information, who occasionally provides needed guidance during the search for answers. This freedom in learning greatly encourages the kind of creativity that is highly desired for engineers.

A more tangible reason for the success of this course is the integrated problem approach. From early on, the students learn that an aerospace vehicle as a complex entity, and its design requires the interaction of many disciplines. An obvious example is the interdependence between the aerodynamics and the structure of a wing. The integrated problem approach demonstrates to the student the importance of the different fields during the design process. It also helps the student to appreciate the relevance of certain subject he or she learns during the undergraduate course work. The ideal student, who enrolls in this course beginning freshmen year, is exposed to this integrated problem view, often much earlier than through the conventional curriculum. This increases the interest in other curriculum courses, especially after having seen the usefulness of a particular subject in solving a specific problem. Additionally, over the four years the student attends the course, certain basic concepts in aerospace engineering are reinforced simply through repetition, for example such concepts as boundary-layer theory, laminar, turbulent, and separated flow. The physical reality of some of the problems encountered in the laboratory helps to support this learning experience.

Secondary learning effects not only result from the extensive teamwork, but also because the environment is like that of a one-room schoolhouse. Very often, a younger student learns from an upper classmen. As a result, the less experienced student learns the particular subjects in terms that are relevant and easily understood. Furthermore, the student doing the explaining has his or her knowledge reinforced.

Other learning effects were not anticipated with the initial course concept, but also appear to be quite beneficial in the student's development. Over the four years that students are enrolled in the course, they get to know each other rather well. As a result, their cooperation goes beyond the time spent in course and a bonding develops between the different undergraduate levels. This helps newer students orient themselves in the, sometimes confusing, world of a large college. For example, students advise one another on course and teacher selections, especially based on their upper-classmates experiences.

In addition, the students tend to be rather frank with one another, sometimes providing very personal and honest criticism, which is, nevertheless, very constructive. In this context, the members of the course seem to have a relationship that is more like that of "family" rather than of classmates, which results in the integration of students of very diverse types of personalities.

This honest and open interaction is clearly, in part, due to the non-competitive nature of the course.

Conclusion

The sailplane course that is offered by the Department of Aerospace Engineering at Penn State is well liked by its students and is quite successful in teaching them the integrated approach that is needed in the design of aerospace vehicles. As a result, students receive a well rounded understanding of aerospace engineering that is appreciated well beyond the university. The course has been quite successful in training good engineers and, hence, has achieved its primary objective.

The course has matured and can now look back over a decade of history. This and the ever growing number of alumni from the course that are willing to help with their expertise, show the effort at Penn State to be a very good implementation of the Akaflieg concept to the higher-education system in the United States. In fact, due to ongoing changes in the German higher-educational system that will impose new financial and time constraints on long-time students, the German academic flying groups are considering the Penn State approach as a possible model for their future.

It is clear that the course concept can be adjusted and applied to other majors in engineering and science. The successful implementation, however, depends very strongly on the instructor, who has to be well informed about the subject in order to be able to provide the necessary guidance and oversight.

Acknowledgement

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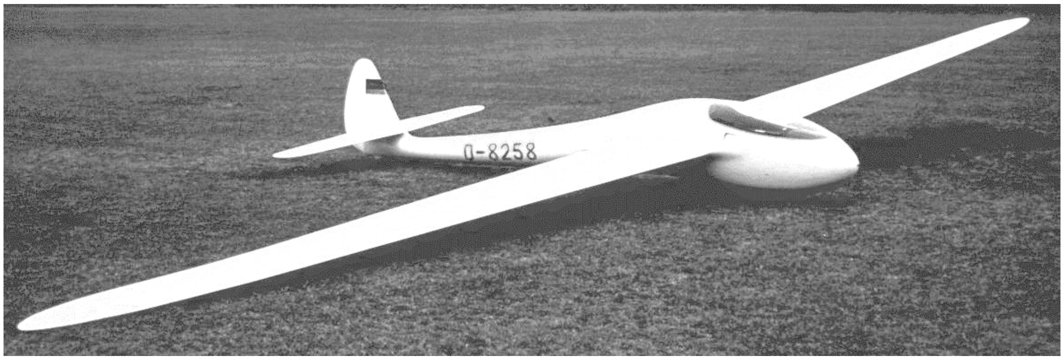

Figure 1: The first, full composite sailplane, the FS 24 Phönix, completed by the students of Akaflieg Stuttgart in 1957.

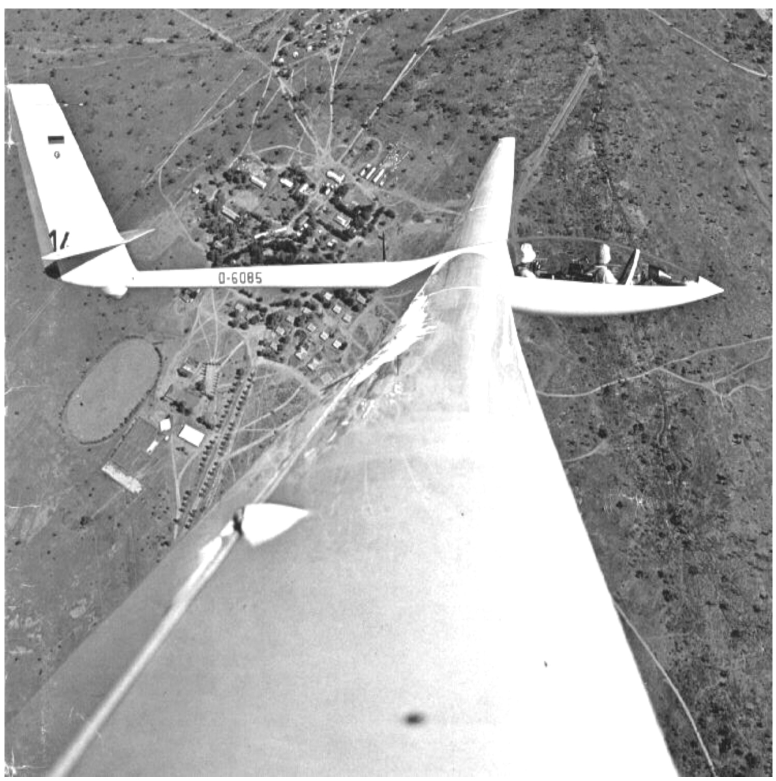

Figure 2: The SB 10 that was designed and built by the students of the Akaflieg Braunschweig, flew first in 1972 and, until recently, was the largest flying glider with a wingspan of 95 feet.

Figure 3: The American Falcon fuselage shells are being separated. The student is holding the left shell. The inside of the right fuselage shell is facing up and the steal frame of the landing-gear inside of it is visible.

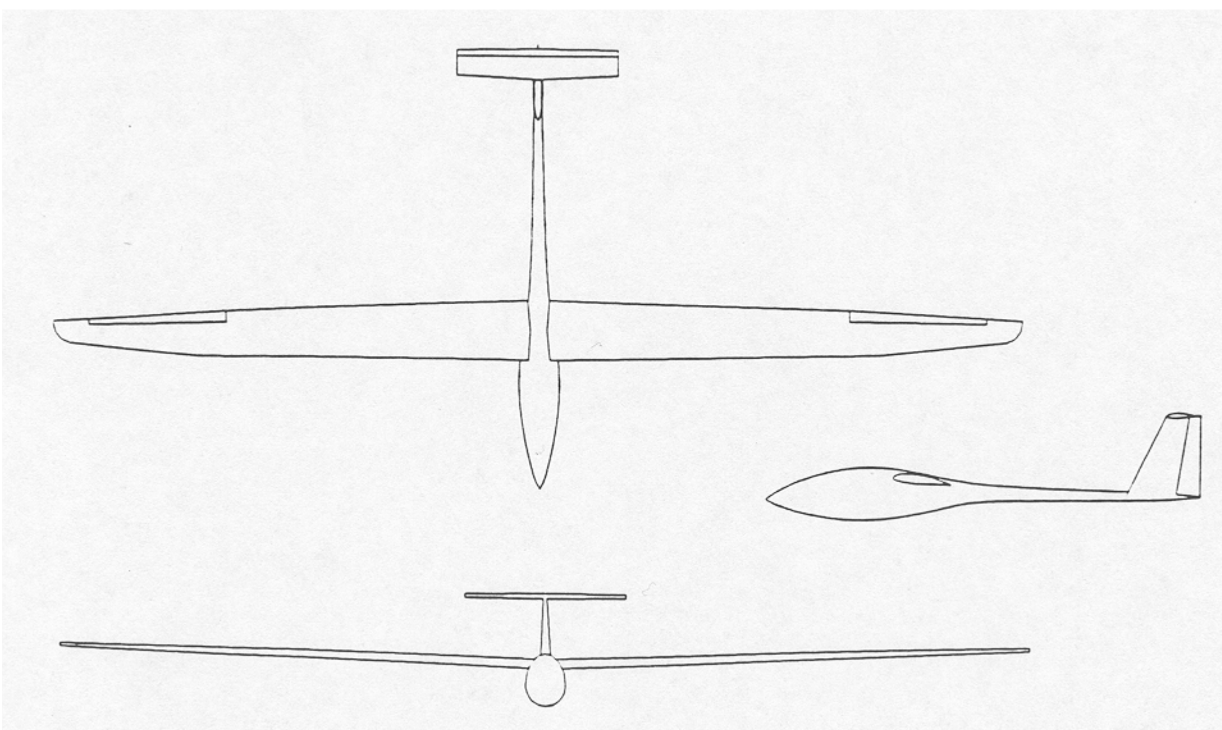

Figure 4: Three view of the Griffin, a 50-foot span, modern composite sailplane.

Figure 5: The students of the Penn State Sailplane Course with one of their RC-model designs, the Banshee III.

Figure 6: The negative mold halves for the Griffin fuselage have been separated for the first time after the 48-hour heat cure. The fuselage plug is still in the right mold half.

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