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Experiences using Flying Models in Competitions and Coursework

Robert P. Hansen , Lyle N. Long[/], Todd A. Dellert
United States Military Academy/ [/]Pennsylvania State University

Abstract

The use of flying model airplanes in the undergraduate aerospace engineering curricula of the United States Military Academy and the Pennsylvania State University are described. Free-flight model gliders serve as projects in two courses that are part of the Aerospace Systems curriculum at the United States Military Academy. These course projects are described, and the educational benefits to the students are assessed. The experiences of the United States Military Academy and the Pennsylvania State University gained through involvement in student radio-controlled aircraft design competitions are also described. The United States Military Academy has fielded undergraduate teams in both the Society of Automotive Engineers (SAE) Aero Design competition and American Institute of Aeronautics and Astronautics (AIAA) Design, Build, and Fly competition in recent years. Undergraduate students from the Pennsylvania State University have participated in the Micro Air Vehicle (MAV) competition. The student design experience in each of these efforts is found to be very rewarding, however, differences do exist. The total cost for each of these competition projects varies by thousands of dollars. The cost per student, however, is found to be relatively similar with a maximum difference of less than $200. This paper describes and contrasts the costs, required effort, and benefits of these different student competitions.

Introduction

Many of the modern concepts of flight were developed with the use of flying models. Sir George Cayley is credited with building and flying the first model glider in 1804[1]. Samuel Langley achieved successful unmanned, powered flight in 1896 using his famous Aerodrome models[2]. While the economics of using smaller-sized aircraft to test new principles or designs is obvious, the great pioneers of aeronautical engineering also used models to develop their basic understanding of the science of flight. The focus of this paper is to discuss how two schools use flying models in the education of future generations of aeronautical engineers.

The design, building, and flying of model airplanes have been a component of some engineering curricula for many years. For example, the Aerospace Engineering Department at the Pennsylvania State University (PSU) has offered a Flight Vehicle Design course for many years[3]. In this course (taught by Prof. M. Maughmer) the students design and build radio-controlled gliders and full-size sailplanes. The students work in teams and learn from each other. The course includes students at all levels (freshman to graduate students), and has been extremely successful. This course is modeled after the well-known Akaflieg[4] program in Germany. The Mechanical Engineering program at the United States Military Academy (USMA) has two courses that require students to build simple, free-flight, hand-launched gliders as part of the course work. Each of these projects is tailored to the level of aerospace science the student has been exposed to. This paper will describe the implementation of flying models in two courses taught at USMA.

National student design competitions have added an additional experience for students to learn through the use of operating models. The Mechanical Engineering program at the United States Military Academy and the Department of Aerospace Engineering at the Pennsylvania State University both enter student competitions that involve the design, construction, and flight of radio-controlled aircraft. The United States Military Academy has fielded teams in both the Society of Automotive Engineers (SAE) Aero Design competition[5] and American Institute of Aeronautics and Astronautics (AIAA) Design, Build, and Fly competition[6] in recent years. The Pennsylvania State University has participated in the Micro Air Vehicle (MAV) competition[7]. The competition projects at USMA serve as the capstone project for the undergraduate's program. The PSU students involved in the MAV project receive Technical Elective credits.

The AIAA and SAE competitions require large model aircraft (over six feet of wing span) while the MAV competition places emphasis on building and flying a very small airplane. Both of these design competitions hold many educational benefits for the participating students, however, the difference in the size of the projects do lead to differences in cost and student experiences. The purpose of this paper is also to contrast the effort, costs, and benefits associated with these two different types of projects.

Experiences from Coursework Building Projects

During the second term of the junior year and the first term of the senior year, students in the Aerospace Systems track at the USMA are required to take ME387, Introduction to Applied

Aerodynamics and ME481, Aircraft Performance, Stability and Control, respectively. A highlight of the courses is the glider design project. Students are supplied with the materials to construct a small balsa/foam glider. Through these two course projects the students are able to analyze some of the basic design elements of the airplane, i.e. total weight, wing planform area, wing loading and shape, and center of gravity placement. The initial project in ME387 is a smaller (three foot wing span) project with all of the glider components, minus the wing, provided. This is based on the fact that the students only have the knowledge base of an introductory aerodynamics course. During the follow-on ME481 project, the students are responsible for all aspects of glider construction. The "fly-offs" for both of these courses are conducted in an indoor facility.

In ME387, students are provided with the fuselage, horizontal and vertical tail and lead weights. The selection and construction of the wing is the student's responsibility. For this project, the span is limited to three feet. This is due to the fact that the fuselage, vertical and horizontal surfaces are sized based on a planform area that is calculated with a span of three feet and a chord that is valid for a range of values from approximately 6-12 inches, based on taper utilized. An abbreviated design process is utilized for the wing selection. Most students choose to construct a foam wing, using a department supplied hot-wire foam cutter, covered with an iron-on plastic film. The use of the hot wire foam cutter allows the construction of cambered and tapered wings in much less time than would be required by built-up methods. Wing loadings range from approximately 5 to 8 oz/ft^2. The grade for the project is based on a written design report and four flight elements: the achieved lift to drag ratio (L/D), the amount of departure from the straight line glide path, quality of construction, and originality and application of aerodynamic principles (use of dihedral, taper, camber, etc.). The L/D ratio is determined from the equations for steady-state, unpowered flight by dividing the total distance flown by the launch height (an 18 foot launch platform is used). Normal L/D ratios achieved range from approximately 4 to 11. Examples of ME387 gliders are shown in Figure 1.

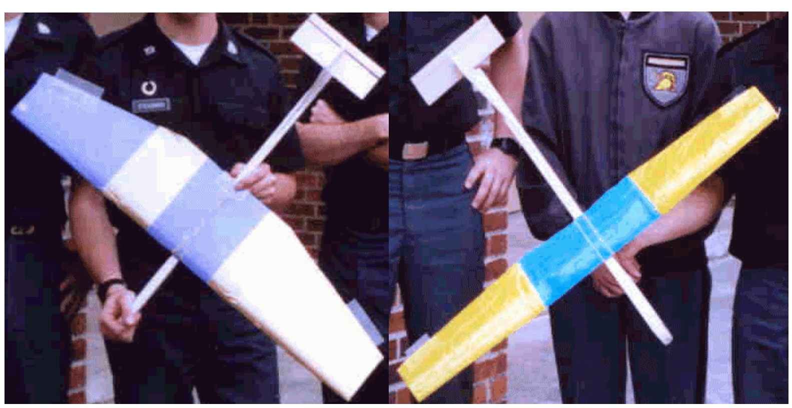

Figure 1. Free-Flight Gliders used by USMA ME387 Students

In ME481, students are responsible for construction of the entire glider. There is no limit on the span of the wing. An abbreviated design process is again utilized for the fuselage, wing and tail surface sizing and selection. Most students choose to build a foam wing and tail surfaces covered with an iron-on film. Fuselage construction materials range from balsa and plastic tubing to aluminum. Wing loadings range from approximately 12-15 oz/ft^2. The grading criteria remains very similar to ME387, except that in ME481, the students must demonstrate a 360-degree turn and a vertical loop. This is accomplished by the use of manually adjustable ailerons and/or tabs on the wings and tail surfaces. Figure 2 shows representative gliders constructed in ME481. In both projects, time-of-flight is also recorded allowing the calculation of the total airspeed, rate of descent, and lift and drag coefficients for a particular trim configuration.

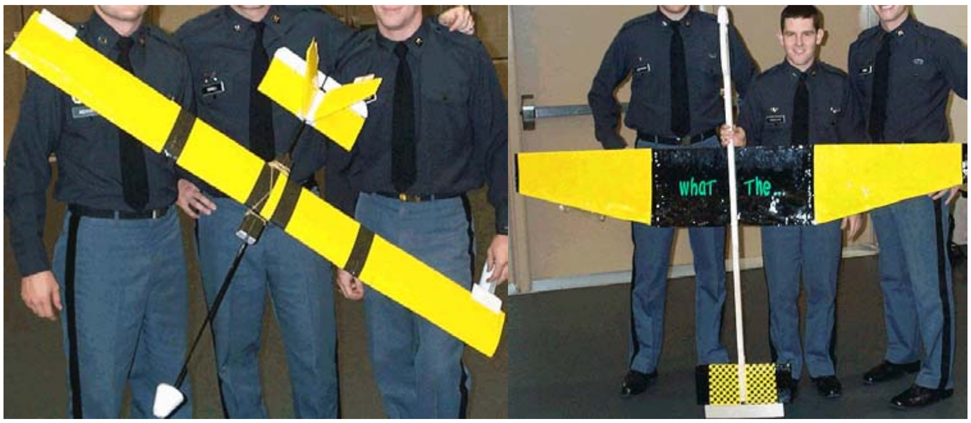

Figure 2. Free-Flight Gliders used by USMA ME481 Students

These course projects hold the great advantage of providing a direct hands-on experience for the students that allow them to relate the theory of flight to something they build and fly. Because the USMA capstone projects described below require built-up construction (all student attempts to build foam wings for these larger airplanes have failed), these course projects do not particularly prepare the students well for the building skills they will need for the AIAA and SAE competitions. Also, in the process of trimming the free-flight airplanes built in ME387 and ME481, the gliders often land awkwardly or strike obstacles causing damage and necessitating field repairs that make a good trim even more difficult. Without extended trials and a very accurate means of incrementally changing the deflection of the manual trim tabs, it is also difficult to ascertain the maximum L/D for any glider. Thus, a glider of lesser design may perform better in terms of the measured L/D simply because it found its correct trim positions when other groups could not.

Experiences from Student Design Competitions

Penn State University participated in the Micro Air Vehicle competition in 2001[7], and will also be participating in 2002[8]. To date, this event has been held five times. The objectives of this competition are quite simple:

- Fly and photograph a 1.5 meter size symbol on the ground located 600 meters from the launch site and hidden from view by a square enclosing fence 3.5 meters wide and 1.5 meter high.
- Provide a legible image of the symbol to the competition judges at the launch site.

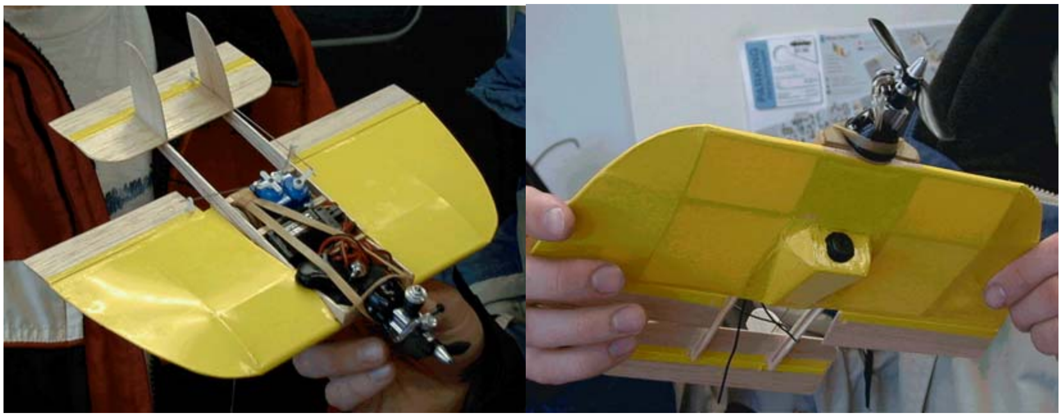

Figure 3. Penn State's 2001 MAV Entry

The smallest vehicle (largest dimension, excluding antenna) that completes this mission wins. The winning vehicles in recent years had wing spans of approximately 6 or 7 inches. One of the Penn State vehicles is shown in Figure 3. Embedded in the lower surface is a wireless video camera. The aircraft shown in the figure has an 0.010 cubic inch displacement glow engine, but some of the 2002 entries will be electric powered.

MAV vehicles can be built fairly easily using balsa, cynoacrylate (CA) glue, and an iron-on covering such as Monokote. Some of the teams also use composite materials. This competition, like several of the other competitions, is very valuable because it gets the students thinking about the aircraft as a system. They quickly realize how important all the various aspects are: weight, aerodynamics, propulsion, stability, control, electronics, and structures. Having each student consider all these aspects is valuable. Penn State is considering a new three-credit course based upon MAV vehicles such as these, which could include a local MAV contest. The winning team could then be sent to the national contest.

Most of these MAV vehicles require the components shown in Table 1. Approximate weights and cost for each of these are also shown. The total weight is therefore roughly 5.1 ounces. If the wing has 0.15 sq. ft. of area, the wing loading would be 33 oz./ft^2. This is a very high wing loading, and consequently the vehicles must fly very fast, which means only experienced R/C

Table 1. Weight and cost of Electric Powered MAV vehicles

Component	Weight (oz.)	Approx. Cost ($)
Two micro servos	0.4	$ 50
Electric motor & prop	0.4	$ 27
Speed Controller	0.1	$ 25
Receiver	0.2	$ 26
Battery	2.0	$ 17
Camera	1.0	$ 300
Structure	1.0	$ 5
TOTAL	**5.1**	**$ 450**

pilots can fly these vehicles. A very interesting aspect of this competition is the need for the onboard video camera. This is not only needed to return the image of the target, but it is essential to flying the vehicles. These vehicles are so small that at 600 meters, they can hardly be seen, let alone flown by eye. The 'pilot' flies the airplane through either a television monitor or video glasses. It is actually easier to fly these aircraft through the monitor than by watching them, since it gives you the illusion of being in the airplane. Many of the complicated topics covered in traditional aerospace coursework "come to life" in these hands-on projects. The availability of several R/C Flight Simulators[9] helps enormously in learning to fly radio controlled airplanes. These MAV vehicles, however, are not suitable as trainers. Also, the 600 meter distance requirement stresses the radio systems; many of the micro receivers and video transmitters will not work reliably beyond about 300 meters.

In the MAV competition, the students have the opportunity to build and experiment with a large number of vehicles. Competitions involving larger models force the students to choose a design early on, since the construction process requires several months. In addition, since the Reynolds numbers are so low, the airfoil shape is not as critical as in larger vehicles. The students learn early on to compute the flight speed from the simple aerodynamic formula $V = \sqrt{W / \frac{1}{2}\rho C_L S}$, where W is weight, ρ is density, C_L is lift coefficient, and S is wing area. In fact, many of the concepts required for aircraft design[10] can be incorporated into these small, radio-controlled aircraft projects.

Another advantage of this competition is the relatively low cost of the designs. Each vehicle can be built for roughly $150 (excluding the onboard camera), and many of the parts can be used several times in different vehicles. However, most of the components are small and fragile, so a good supply of spare parts is needed. In addition to the vehicle costs, there is also the cost of the base unit. This is primarily the wireless video receiver, antenna (e.g. Yagi), battery chargers, radio transmitter, and television monitor. These will cost roughly $1000. Some traditional R/C model building tools are also required, such as knives, saws, glue/epoxy, heat guns, voltmeters, control horns, linkages, tachometers, and a balance. The other major expenses are travel costs to the contest sites. When vans or buses are possible, the costs are greatly reduced, but if each student has to fly to the competition, the travel costs might be several hundred dollars per student. The MAV vehicle itself, however, is significantly cheaper to build than many of the other student competitions.

The current PSU students have received independent study credits for working on these projects (two credits each of two semesters). This works well when there are a small number of students, but our ultimate goal is to make these hands-on activities a regular part of the curriculum. The PSU Aerospace engineering students are required to take courses in areas such as stability and control, aerodynamics, structures, propulsion, experimental techniques, and design. It would be fairly straight-forward to incorporate these MAV vehicles into each of the above courses.

The United States Military Academy has fielded teams in both the Society of Automotive Engineers (SAE) and American Institute of Aeronautics and Astronautics (AIAA) Design, Build, and Fly competitions in recent years. Student teams in the AIAA competition design, fabricate, and demonstrate the flight capabilities of an unmanned, electric powered, radio-controlled aircraft which can best meet a specified mission profile. The goal is a balanced design possessing good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance. In addition, a written report is evaluated prior to the flight competition and is utilized in calculating the team's overall final score. The design requirements and performance objective are updated for each new contest year, but generally involve some type of maximum payload judging criteria. The changes provide new design requirements and opportunities, while allowing for application of technology developed by the teams from prior years. Figure 4 shows the airplanes constructed for last year's USMA AIAA competition entries.

Figure 4. Airplanes Built by USMA Teams for the AIAA Competition

The SAE competition requires the use of a gasoline engine instead of electric motors. Teams design and build a radio-controlled aircraft that is optimized for weight carrying under specified design restrictions (maximum planform area, etc.). An additional challenge is to accurately predict the amount of weight the aircraft is capable of carrying. In contrast to the MAV competition, these projects involve very large (8 to 10 foot wing span) airplanes of considerable weight (15-50 lbs). The USMA teams usually consist of 9 to 12 students. The USMA students participating in these design competitions work on the project for an entire academic year and obtain three credit hours each semester.

The major advantage of these large projects is the exposure the students get to the entire design process. Without a doubt, both the AIAA and SAE competitions allow students to exercise the mechanical engineering design process from beginning to end, to include cost estimation and actual product generation. Students attack the process in a very serious manner, knowing they will be responsible for producing a system that must meet a specific need, i.e. compete in an actual flying competition. The synthesis of classroom knowledge and personal creativity to build and test a physical model is by far, one of the most fulfilling academic experiences for the students. Unlike the MAV project, where the small size of the aircraft allows for rapid construction and some experimentation and iteration, the AIAA and SAE projects rarely allow for a redesign because of the time needed to build. This should be viewed as a disadvantage of the bigger projects. The end product of the AIAA and SAE projects relies heavily on the quality of the design process conducted by the students. In this sense, the large-scale nature of these projects is an advantage because it forces very detailed planning in the early stages of design. Ultimately, the students are responsible for all decisions they make in the design process. Mentorship is provided, but experiencing success and failure are understood to be critical elements to the student learning process.

The interaction with technical specialists (metal working, welding, wood working, electrical motors and engines) is also a valuable experience. The majority of the USMA students involved in the SAE or AIAA competitions do not possess the technical building skills required of such a large project. They must, therefore, seek the help of technical shop specialists and convey to them verbally and through engineering drawings, their intent/desires. This highlights an important aspect of the design process when working in a multi-disciplinary atmosphere -- communication. The smaller PSU teams working on the MAV vehicle generally require much less assistance from outside of their group. As part of the design analysis and communication of the design, the USMA students utilize nearly every computer tool that they have been introduced to during their academic career. These tools include MATLAB, Mathcad, COSMOS, Excel, Compufoil, and Pro/Desktop.

The logistics of space is also an issue with these larger projects. Unlike the MAV aircraft, which are so small they can be constructed on a student's desk, the SAE and AIAA projects require a large, dedicated building table and a room. The AIAA and SAE airplanes also require very large fields away from people and cars for test flying. The logistics of transporting the SAE or AIAA airplanes to the competition sites is an additional complicating factor. Table 2 summarizes the attributes of the MAV and SAE/AIAA competitions.

A disadvantage of these projects is the cost. The cost of building an airplane ranges from approximately $750 for the SAE competition to $2000 for the AIAA competition. The large increase for AIAA is mainly due to the cost of the electric motors and batteries required. With the cost of travel (SAE: Orlando, Florida; AIAA: Patuxent River, Maryland or Wichita, Kansas), lodging, per diem and shipping of the airplane to the competition site, the total cost is between $7000-$8000 per team, per year. Table 3 summarize the costs of the MAV and SAE/AIAA competitions.

Table 2. Summary Comparison of MAV and AIAA/SAE Design Project Attributes

	Design Effort	Building Effort	Support Logistics	Safety Risks	Opportunities for Redesign	Quality of Student Experience
MAV	Mod	Low	Low	Low	High	High
AIAA and SAE	High	High	High	Mod	Low	High

Table 3. Summary Comparison of MAV and AIAA/SAE Design Project Costs

	Project Cost/Team[1]	Project Cost/Student[2]	Travel and Lodging (per person)[3]	Total Cost/Team[4]	Total Cost/Student
MAV	$450	$225	$600	$1650	$875
SAE	$750	$83	$600	$6150	$683
AIAA	$2000	$222	$600	$7400	$822

Notes:
1. One-time cost items not included: radio control transmitter (all) and wireless video receiver, monitor, and antenna (MAV only).
2. MAV assumes 2 students per team; AIAA and SAE assume 9 students per team.
3. Estimates. Competition location varies each year for MAV; Orlando, FL for SAE; Patuxent River, MD or Wichita, KS for AIAA.
4. Assumes all team members travel to competition site.

Conclusion

The introduction of flying airplane models into an undergraduate aerospace engineering curriculum has many potential benefits. First and foremost, it is the most realistic hands-on experience, short of a full-sized aircraft, that a student can be exposed to. As gauged from current activities involving flying models at Penn State and the United States Military Academy, student enthusiasm is greatly increased using models that the students can build and fly. Allowing students to build their own airplane also gives them significant insights into structure and performance issues and allows them to consider the total aircraft system to an extent that is hard to reproduce in the classroom. Use of a foam cutter in ME387 and ME481 allow students to build tapered and cambered wings with ease relative to built-up methods. The course projects using foam wings do not prepare the students particularly well for the more complex construction required in the capstone design projects for the AIAA and SAE competitions. Both the MAV competition and the SAE and AIAA competitions have provided PSU and USMA students with worthwhile design experiences, although with different levels of cost and varying levels of exposure to the design process, building effort, and redesign opportunities.

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Biographies

LIEUTENANT COLONEL ROBERT P. HANSEN, PhD, PE, is an Assistant Professor in the Mechanical Engineering Program of the Department of Civil and Mechanical Engineering at the United States Military Academy. He currently teaches courses in design and numerical methods and does research in computational fluid dynamics. He is a member of ASEE, ASME, and AIAA.

LYLE N. LONG is a Professor in the Department of Aerospace Engineering at the Pennsylvania State University. He is also a Professor of Acoustics and an Affiliated Professor of Computer Science and Engineering. He is the Director of the Institute for High Performance Computing Applications and is the Co-Director of Rotorcraft Center of Excellence at Penn State. His research covers areas such as computational fluid dynamics, aeroacoustics, rarified gas dynamics, programming and parallel processing. He is an Associate Fellow of AIAA and a member of ASEE.

MAJOR TODD A. DELLERT, MS, is an Instructor in the Mechanical Engineering Program of the Department of Civil and Mechanical Engineering at the United States Military Academy. He currently teaches courses in applied aerodynamics and helicopter aerodynamics. He is a member of ASEE and the student section advisor of the USMA ASME Chapter.