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Solar Powered Airplane, A Student Design/Build/Fly Project

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Abstract

The project objective was to involve undergraduate engineering students in a multi-semester project with intense technical challenges and a well-defined objective: The creation of a solar powered airplane with the goal of indefinite flight. During the last decade, dozens of planes have been designed, built and flown by the students. This has given them the opportunity to practice engineering design skills, develop leadership, and writing skills, and gain confidence as engineers.

Background

Students in the Mechanical engineering department at Brigham Young University (BYU) have been designing a solar powered airplane for about a decade. This section of the paper will review the history of the project.

SunBeam I: During the 2000-2001 school year, an attempt was made to fly BYU's first solar powered airplane. The goal was to make the world's smallest solar plane. The plane was named SunBeam. The design of the plane was documented in an AIAA paper.[1] Figure 1 is a picture of the plane.

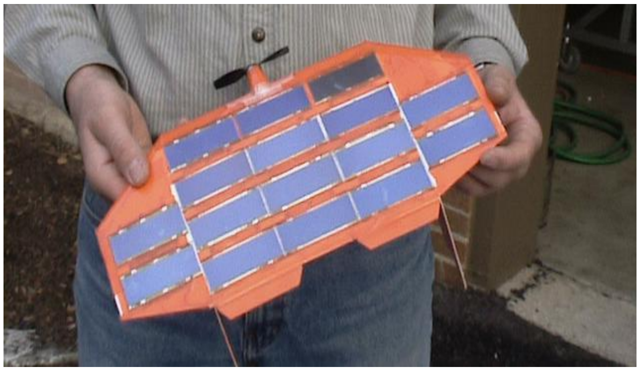

Figure 1: First BYU Solar Airplane, SunBeam I

The SunBeam plane had a wing span of 0.36 m (at the time, the smallest solar airplane flown had a wing span of 1 m). The plane flew using battery power. It used, on average, 3.3 W of power during the flights. The solar cells should have supplied 5.5 W of power. Because of our inexperience, we were not able to get the plane to fly on solar power. The plane was cannibalized for its parts and never flown after the summer of 2002.

SunBeam II-V: For four semesters, 3 to 5 students each semester asked to be mentored in an independent study course in aerodynamics. To give the class focus, the class goal was to design, build and fly a micro solar airplane. For the first third of the course, the students studied basic principles of airplane design. For the remainder of the course, the students applied the principles by designing, building and test flying candidate micro solar planes. Figure 2, below, shows one of the planes from that time frame.

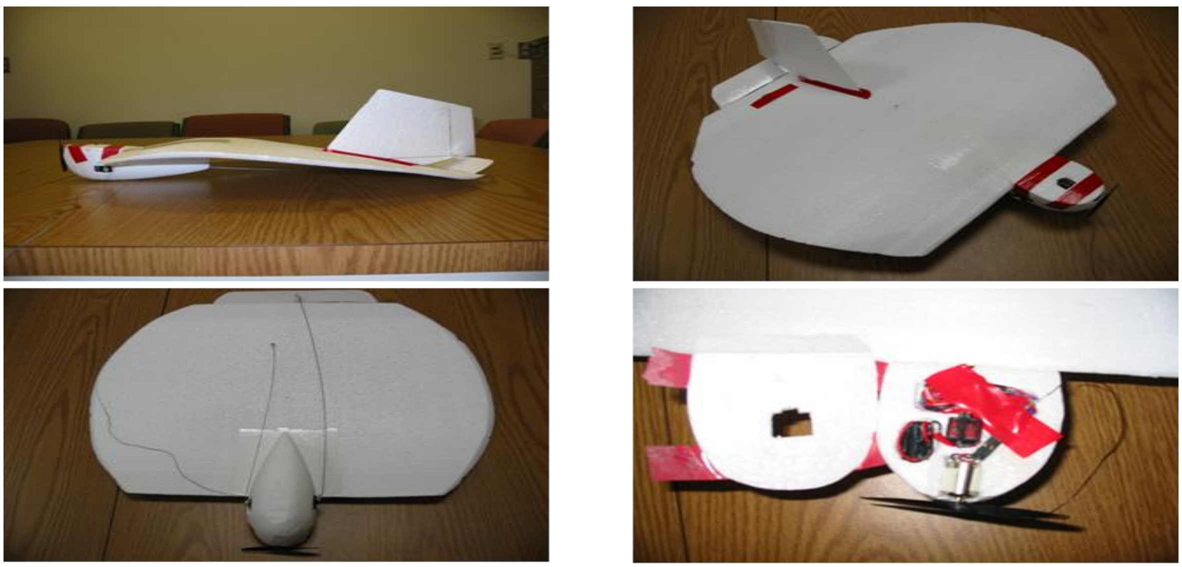

Figure 2: SunBeam II, Battery Prototype.

After several attempts to build solar planes in this way, it was concluded that it was too difficult for an inexperienced student to design, build and fly a novel airplane in one semester. The students rated the class as a positive learning experience, but more planes were crashed than flown. None of the battery powered prototypes were judged worthy of adding solar cells to for a solar powered flight. Each new semester another attempt began with novice students. They could progress to about the same level as the students from the previous semester. Little progress was made towards flying a solar powered plane.

SunBeam VI: Instead of trying to make a micro solar plane, the goal shifted to making any size solar powered airplane. During the summers of 2004 and 2005, Alan Cocconi flew his solar airplane, SoLong. It is shown in Figure 3.

Figure 3: Alan Cocconi with his solar plane, SoLong[2]

In June of 2005 he achieved an impressive flight that exceeded 48 hours in duration. He was able to fly the plane and charge its batteries during the day and then fly on battery power at night. During the 2006-7 school year, an attempt was made to build a ¼ scale plane similar to SoLong. Figure 4 illustrates one of the planes build with three different wings that were tested.

Figure 4: SunBeam VI. ¼ scale plane, similar to SoLong

This plane was designed, built and flown by the faculty advisor. SunBeam VI was a successful airplane. Engineering principles were used to predict the power required to fly the plane. This power was compared to the power that could be captured by solar cells and the power required to fly the plane using batteries. From an educational perspective, a new idea germinated.

The idea was to involve students in the project at a low level of effort over several semesters. This way, overlap would occur between the students so that experienced students could help train and transfer knowledge to novice students. The hope was that progress towards the goal of solar flight could be made. Also to help knowledge transfer, students would archive findings so each semester they were not re-inventing the past experiences learned. More will be said about this process later in the paper. For now, we will return to the evolution of the BYU solar airplanes.

SunBeam VII: SunBeam VI was a success. It flew well. Much flight data was obtained; however, it crashed and was damaged beyond repair before it was flown on solar power. Also, the wing was too small for the solar cells available in the lab. The next step was to scale up and attempt to replicate SoLong. The philosophy was that airplane design is an evolutionary process. Revolutionary designs, at least those from novice students, are seldom successful. Alan Cocconi had written an informative summary of many of SoLong's components, dimensions, and design features. Figure 5 below shows the BYU replica of SoLong, named SunBeam VIIB.

Figure 5: SunBeam VIIB, built during the winter of 2009-2010

Two versions of SunBeam VII were made over a two year time period. The first plane, made during the 1st year, took a long time to build and crashed beyond repair 20 seconds into its 1st flight. The cause of the crash was due to a small asymmetry in the wing, or due to insufficient yaw control. The problem with yaw control was due to an error in calculating the V-tail angle. During the flight, after launch, the plane began a slow roll to the right. The pilot was not able to correct the roll before the plane crashed.

The second plane, SunBeam VIIB, (shown above) took a second year to build. It had a higher quality wing (better craftsmanship) and the V-tail angle problem was resolved. During taxi tests on a rural road, the plane kept veering off the road. After several attempts the wing skin started to delaminate from the wing ribs. Upon studying the problem more, it was found that while hurrying to finish the plane near the end of the semester, the students had failed to properly clean and prepare the fiberglass wing skin before epoxying it to the ribs. The school year ended without a successful flight. This was discouraging. A method for achieving more flight tests was needed.

SunBeam VIII (SunBeam Fling): After two years working on SunBeam VII and the accompanying discouraging experiences, a new approach was needed. The new goal was to be able to fly more by using a modified commercially available plane. The Great Planes Fling Sail plane was selected as a starting point. They are inexpensive and similar to solar powered planes. A Fling was purchased and modified for electric powered flight. Battery powered flight test began after a few days of work. Hard landings that damaged components were solved by repairing the damage, or buying new components. Instead of spending a year building a complex plane followed by minimum amounts of flight testing, a rapid turnaround was achieved. The flight testing soon validated predictions of power required for flight. The test pilot quickly became more skilled at flying using less and less power. It was found that the plane could fly on as low as 15 W of power. A new wing, designed to be covered with solar cells was built and tested (without solar cells). Then, a second wing covered with solar cells was built. The solar cells increased the drag on the plane compared to the non-solar wing. The plane was underpowered in solar powered flight. The plane did achieve a 1:42 hour flight under a combination of solar power and slope lift. The plane and two wings are shown below in Figure 6.

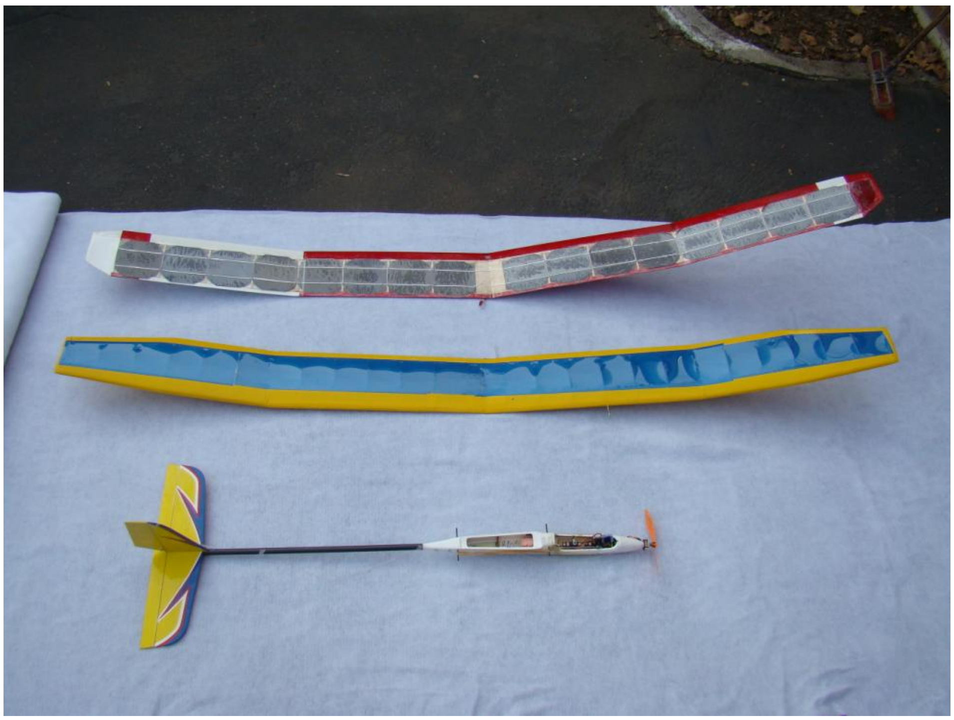

Figure 6: SunBeam Fling with two new wings, one solar.

SunBeam IX (SunBeam Magellan): With the success of SunBeam Fling, we iterated the process starting with the commercially available plane, ICARE Magellan-E XL. This plane was selected because of its larger wing and V-tail (less drag). After testing the original airplane, a solar cell covered wing was built and tested (first without solar cells, and later with solar cells). While the plane was being tested, other students in the group tested motor-prop combinations in the wind tunnel. Still other students built and tested solar panels and learned the advantages of using a Maximum Power Point Tracker (MPPT) to get maximum performance from the solar cells. In the spring of 2011, the Magellan based airplane flew for 42 minutes on a combination of solar power and slope lift. Figure 7 was taken during that flight.

Figure 7: SunBeam Magellan (SunBeam IX) during solar powered flight.

The pilot rated the flying qualities of the plane as poor. This was because we had increased the wing span to have space for enough solar cells to meet the input voltage requirements of the MPPT. The tail size was also increased, but apparently not enough.

SunBeam X: At the beginning of the fall semester, 2011, the team set out to improve on the performance of the SunBeam Magellan airplane. A new fuselage was designed to be used with the SunBeam Magellan solar wing. The fuselage was longer to increase its volume to hold four times the batteries of the previous plane. This also moved the tail farther from the wing, allowing for a decrease in the tail size and improved stability. There was also a switch from the V-tail design to a conventional rudder-elevator configuration. Figure 8 is a picture of SunBeam X during solar flight test. Figure 9 presents SunBeam X's specification.

Figure 8 SunBeam X during solar powered flight.

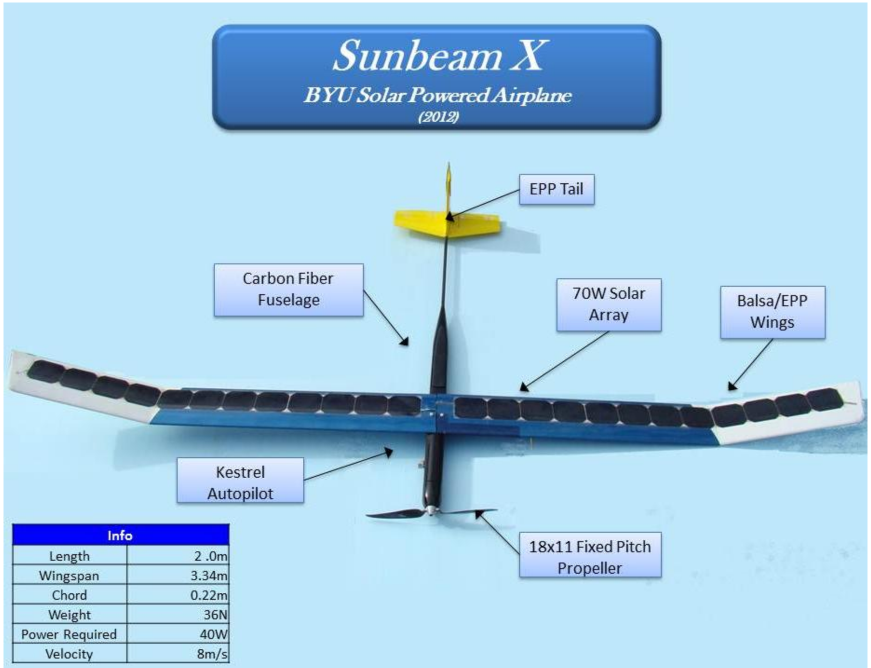

Figure 9: SunBeam X specifications.

Three identical planes were built. During April and May of 2012 the planes were flown. The planes had good flying qualities. One plane crashed when it encountered strong turbulence flying near the ground or due to a radio glitch. It was repaired. A second plane crashed when a joint in the wing spar broke. Much of this plane was destroyed in the crash. The third plane flew well and achieved 2 hours, 15 minutes of flight on May 17, 2012. The flight was powered by solar cells and slope lift. The flight ended when the gear box between the motor and the propeller failed. The flight was a success.

Meeting the Academic Objective

Now that a brief history of the airplanes studied has been presented, the educational approach and objective of the project will be reviewed. The latest version (last four years) of the mentored education project allowed about 100 undergraduate students to contribute to the solution of a significant engineering problem. It allowed for increased interaction and knowledge transfer between underclass and upperclass students. The students had the opportunity to develop leadership and writing skills resulting in several technical papers written and presented at student conferences. The product was a cutting-edge environmentally friendly solar powered airplane that flew for 2 hour and 15 minutes on solar power. The remainder of this paper will describe the educational activity in more detail.

Mentored Learning Environment

During the 2007/8 to 2010/11 school years, students were recruited to work on the BYU Solar Airplane Project. Over 100 Students registered for a special-topics course (MeEn 595R).

During the 1st semester, the students were taught basic aircraft design fundamentals. The students each built a radio controlled sailplane and conducted studies focused on the sailplane's aerodynamics, structure, control, and propulsion. This first semester established a common level of background knowledge among the students. Figure 10 shows a group of novice students flying their 1st planes along with some upperclass students and their solar plane prototype. From the looks on their faces, they are enjoying the experience.

Figure 10: Students testing their 1st planes and the SunBeam Magellan prototype, Spring 2011

During the 2nd semester of the course, the students worked as a group to design and build a solar powered airplane. The students divided into specialty teams focused on aerodynamics, structures, control, or power systems. This allowed the students to focus in an area that was interesting to them and to organize the work by dividing it into smaller tasks. The students documented their progress by writing reports. The reports were used in future semesters to help the project advance.

During the 3rd semester, the students were asked to take a leadership roll in the airplane construction and flight test. They were team leaders for one of the specialty teams.

New students were continually recruited to work on the project. Eventually, the group consisted of novice students, workers in specialty teams, and team leaders. This turned out to be an excellent opportunity for mentored learning between the more experienced student team leaders, the team members, and the novices who joined the program.

Achieved Outcomes

One outcome was the coordinated teaching/learning/research with undergraduate students working as a team to solve a significant engineering challenge. The overlap between new and old students facilitated knowledge transfer from semester to semester, resulting in students coming up to speed quicker in the research area and allowing for new learning to occur. The overlap provided a training ground for students to learn leadership skills. During the project timeline, the airplanes evolved and their performance improvement showed technical advancement.

One course requirement was that the students write reports documenting the work of the semester. Several students documented their contributions to the project and presented their papers at three AIAA Student Conferences held during the springs of 2010, 2011, and 2012. The documented work helped transfer knowledge with-in the group of BYU students working on the project and improved the students' ability to communicate technical ideas. Students also used the subject material for several technical writing class projects.

Another anticipated outcome was the demonstration of indefinite flight. To date, this has not been achieved; however, solar powered planes were flown and achieved an endurance of 2 hour and 15 minutes during the spring of 2012. Earlier in the paper (Fig. 8) is a picture of the airplane we call SunBeam X in solar powered flight.

The current learning environment, with the overlap between novice and more experienced students, has made it possible to advance technology. In the early years, it took a group of 15-20 students working two semesters to build one plane. In the latest semester, a group of 10 students were able to build three identical planes and keep them repaired after they were damaged during hard landings. In the early years, very little time was ever spent doing flight tests. In the latest semester, many flight tests were conducted which led to the discovery of ways to fine tune and improve the airplane. These improvements could be due to an improved educational process, or due to the adjustment of goals for the size and type of airplane to build, or probably a combination of both.

Preparing Students for the Future

BYU is a recognized leader in the area of control of small unmanned aircraft. Some students from the solar airplane group transfer to the small unmanned aircraft lab where they continue to study and conduct research. Also, many of the students who participated in this activity learned skills that prepared them to work in the aerospace industry after graduation and to pursue graduate studies in this or related areas.

Over the 3 semesters that students are involved in the project, they were observed to mature and gain confidence. Few had previously designed or build anything in their lives. At first they were hesitant to make decisions or build. By the end of 3 semesters, they could recognize tasks that needed to be done and would initiate action to complete the task. As a faculty advisor, it was rewarding to observe the transition.

Student Comments

Students were asked how they felt about participating in the Solar Airplane project. All of the comments received were positive. Some of their comments were:

> "I enjoyed being able to work side-by-side with a faculty member on a significant project. This was more enjoyable than being taught by a faculty member."
> "I was reminded that engineering is fun and hands on."
> "It provided a break in my week from more typical education activities."

"In real life, you have to learn to deal with failure, to learn from your mistakes, to press forward until success is achieved."
"It was rewarding taking an idea from a concept to flight test of a functioning airplane."

Funding

The project was funded by a Mentored Education Grant (MEG) provided by the BYU Office of Research and Creative Activities. $9,000 was awarded to be used during the 2010 and 2011 calendar years. Most of the funding was used to buy hardware to build the prototype airplanes. This included photovoltaic cells, batteries, airplane electronics and structural materials. The funding was also used to rent BYU vehicles so the students could safely travel to the airplane test site to test the airplanes. The progress made and mentored learning achieved could not have been possible without the MEG funding.

Conclusions

The solar airplane design, build and fly project turned out to be an outstanding opportunity for mentored learning. It allowed undergraduate students to contribute to the solution of a significant engineering problem. It increased interaction and knowledge transfer between underclass students, upper-class students, and faculty. It also helped students develop leadership and writing skills. The results were much more than the environmentally friendly solar powered airplane the students created. The increased confidence and maturity of the students was significant.

Bibliography

1. Roberts, C, M. Vaughan, and W. J. Bowman, "Development of a Solar Powered Micro Air Vehicle," 40^{th} Aerospace Sciences Meeting and Exhibit, Reno, Nevada, paper number AIAA 2002-0703, 14-17 January 2002.

2. www.solar-flight.com/solong/index.html