AN ABSTRACT OF THE THESIS OF

Joshua R. Wilcox for the degree of Honors Baccalaureate of Science in Mechanical Engineering presented on June 4, 2013. Title: Development of a remotely piloted aircraft for the Design/Build/Fly competition as a capstone engineering design project

Abstract approved: ____

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The Design/Build/Fly competition (DBF) is an annual aerospace engineering competition hosted by the American Institute of Aeronautics and Astronautics (AIAA). Oregon State University's AIAA chapter competed for the first time at DBF in 2013 and finished in the top 25% which is a respectable finish for a first year team. By compiling observations from the 2013 competition and developing new strategies for future competitions, the team can be even more competitive in future years. This document is intended to become a "roadmap for success" for future Oregon State University DBF teams. The roadmap includes two aspects. The first is developing a class structure that will foster a competitive design. This will be coupled with a breakdown of the aspects necessary to produce the best possible plane and technical report at the design and build phases of the project. The capstone course and competition rules both try to challenge the students in similar ways. This document will propose an alignment of the requirements in the capstone course with the AIAA DBF rules to allow students to strive for the best in both instead of slitting their time between two sets of requirements. The documentation of the 2013 competition will help the future students gain a better understanding of the design and build process along with the actual competition setting.

Key Words: Capstone, Aerospace, Competition, AIAA,
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Honors Baccalaureate of Science in Mechanical Engineering project of Joshua R. Wilcox presented on June 4, 2013.

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Joshua R. Wilcox, Author

Development of a remotely piloted aircraft for the Design/Build/Fly competition as a capstone engineering design project

By

Joshua R. Wilcox

A PROJECT

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Table of Contents

Introduction:

The American Institute of Aeronautics and Astronautics (AIAA) holds an annual aerospace engineering contest known as Design/Build/Fly (DBF). This event, which is sponsored by AIAA, Cessna Aircraft, and Raytheon Missile Corporation, alternates each year between Tucson Arizona and Wichita Kansas. In 2013, Oregon State University competed in the DBF competition for the first time, placing 14th overall out of 90 teams in the competition. Although this was the best placement for a new team in the 2013 competition, [1] it is now up to future teams to perform even better in the competition. Lessons from the 2013 competition captured in this document can be used to provide recommendations for improvement in future years. By transferring the knowledge of previous years, the team can prevent repeating work already completed by former teams and focus on developing a further optimized design. Under the proper structure, a team of engineering students can design and build an airplane that is competitive at a national aerospace engineering competition in a way that fulfills the course requirements for a senior capstone class.

This document will outline the design and build process of the 2013 competition year, focusing on the successes and failures of the team. It will also suggest new ideas for team organization, deliverables, and project timelines that stem from the experiences of the 2013 competition. The competition objectives change annually, which prevents a full transfer of the design from year to year. Although the full plane design can't be reused, there are still many aspects of past designs that can be applied to the design of any given competition year. The design and build process are important but the structure of the team and the process for developing the design also deserve consideration to produce a competitive final product.

Report:

One critical aspect of the overall DBF score is the report submitted before the flight portion of the competition. This report highlights the importance of the documentation and presentation aspect of design in engineering. The report breaks down the design process used by the team including initial and final designs, manufacturing techniques, and the testing process. Teams must have a flyable airplane before submitting the report to adequately complete the sections of the report to the standards of the competition.

The 2013 capstone class required the students to develop a report following a detailed template for the capstone class. This fulfilled the writing intensive requirements of the course but did not create a document capable of acting as the DBF competition report. Unfortunately, this incompatibility forced the team to create two separate reports to fulfill the class requirements as well as the competition requirements. The DBF judges are the customer for the purposes of the DBF capstone project. It seems reasonable that the report being requested by the customer could also serve as the report for the capstone class. The length and technical content of the DBF report meets or exceeds the expectations of the capstone class [2] [3]. Using the DBF report for the capstone class will give an actual need and audience to the report that will better simulate the engineering documentation process in industry. The content of the DBF competition report is thorough enough that it would provide a sufficient amount of content to fulfill the writing intensive course requirements [3].

The Rated Aircraft Cost (RAC) is a scoring factor that depends on the aircraft length, width, and weight [3]. This scoring factor favors aircraft that are lighter and smaller and is very important to the overall score. The competition report does not require a background research section like the capstone report, but the winning reports each year include an analysis of the RAC. [4] One change to future reports that could improve the team's competition score would be to change the background report content to an analysis of the points allocation. By using the background report to optimize the points allocation, the team would be able to start the physical design with a better understanding of the conceptual requirements. By underestimating the importance of a high internal payload capacity, the 2013 team missed out on the potential for added points in mission 2 without a large decrease in performance in other missions. Analyzing the points available in the first weeks of the term could have prevented this mistake. See Appendix A for a proposed term schedule. This schedule was written in reference to the 2013 competition but should require only minor changes for future competition years.

Team Layout:

The 2013 capstone DBF project was broken into 3 sub-teams. The responsibility of each sub-team can be seen in Table 1

Aerodynamics		Structures		Propulsion/Controls	
Design	Manufacturing	Design	Manufacturing	Design	Manufacturing
Airfoil Selection	Wing	Fuselage	Fuselage	Motor/ESC	Control Mounts
Flaps	Flaperons	Landing Gear	Landing Gear	Battery Packs	Motor Mount
Stabilizers	Empennage	Wing Location	Internal Payload	Servos	Battery Packs
Wing Size	Test Wing		External Pylons	Receiver	
Surface Joints			Wing/Body Join		
Flaperons			Payload Hatch		

Table 1: 2013 team responsibilities

This team structure was effective at creating a plane but certain aspects of the plane were neglected with the three team structure. The payload system was one of the neglected aspects of the plane. The final product payload system fulfilled the class requirements but was still below the level needed for competition. Although a low quality payload system is not desirable, it was considered a necessary design decision to focus the team efforts on higher priority projects such as an optimized fuselage. The capstone class should strive to produce a final product worthy of competing at an international aerospace competition. To bring the class product to this level, another sub-team should be added to the structure. See for a proposed team structure with 4 sub-teams.

Chief Engineer
Technical supervision
Team integration
Quality Control
Project Manager
Budget Control
Scheduling Meetings
Sponsor liaison

Aerodynamics			Structures			Propulsion/controls			Payload		
Optimize	Design	Mfg	Optimize	Design	Mfg	Optimize	Design	Mfg	Optimize	Design	Mfg
airfoil	Airfoil selection	Wing	Fuselage length	Fuselage	Fuselage	Motor choice	Motor/ESC	Control surfaces	Number of stores	Payload system	Interface
Wing size	Flaps		Gear type	Landing Gear	Landing gear	Voltage/weight	Battery packs	control mounts	Pylon location	Store location	Structure
wing location	Stabilizers						Receiver/servos	motor mount		Center of Gravity	Center of Gravity
	Wing Location						Surface Joints	battery packs			
	Wing size						Control Surfaces	Empennage			

Table 2: proposed team responsibilities

By adding a fourth sub-team and rearranging the responsibilities of each team, the new proposed team structure provides a more even distribution of workload. Optimization has also been added to the work breakdown as a new category. Optimizing aspects of the design are critical to achieving the highest performing aircraft and this will reduce the ambiguity of sub-team responsibilities for optimization. The new payload team will design and build the payload structure and interface while managing the airplane's center of gravity (CG). The propulsion and controls team will be responsible for manufacturing the control surfaces and the empennage which were previously under the aerodynamics team's duties during the 2013 year. The aerodynamics team will assume responsibility for designing the structure of the wing which was a duty of the structures team in the 2013 year.

Industrial Engineers

The 2013 team was strong in design and manufacturing experience but lacked organization throughout the competition process. The addition of industrial engineers to this could alleviate the problems with communication and organization seen in the 2013 year. Along with overall team structure, industrial engineering experience could be used in the propulsions team for selection of components and the payload team for team data management. Creating a decision process for the propulsions team might further optimize the selection of a motor and battery for the competition. The propulsions team will monitor and adjust the center of gravity which involves the weight and location of each component of the plane. This process could be streamlined to provide more accurate results with less time if done correctly. To further help the team structure, a chief engineer and project manager will be added to the structure of the DBF team to provide added levels of organization and decision making. Their position in the team structure can be seen in Figure 1.

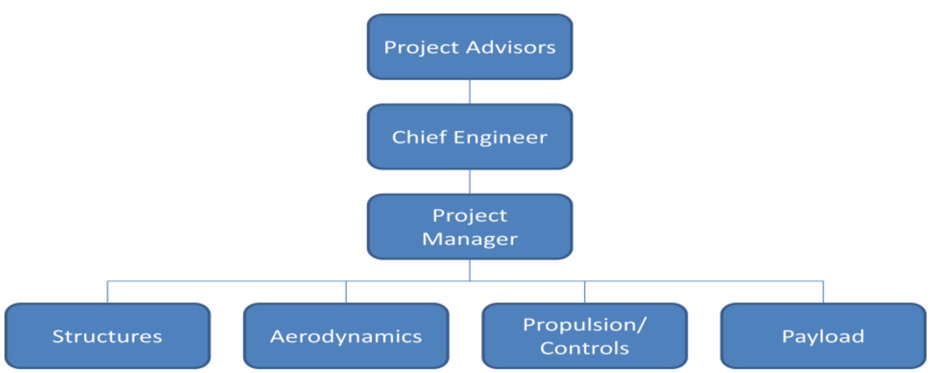

Figure 1: Team Structure

Chief Engineer

The chief engineer will provide technical supervision to the four teams and make high level systems decisions on the plane. The plane is a system that requires multiple interactions between each sub-system. The chief engineer will ensure that these interactions are identified and addressed throughout the process. It is important to note that the chief engineer must find the balance between making all the design decisions and letting the teams each build their own components without interaction. This balance will help satisfy the capstone requirements while also facilitating a successful completion.

Optimization of the design to the competition scoring, as well as the interface of the aircraft should be controlled by the chief engineer who has a full systems view of the project. During the early stages of design, many decisions are made that affect multiple sub-teams. Three examples of this interaction are:

- The wing design and fuselage design must be compatible.
- The payload design must be compatible with the wing, fuselage, or both depending on the competition year
- The propulsion system must be integrated into the main structure of the aircraft.

The responsibility for integration of these interactions into the design falls to the chief engineer who must closely manage these concerns and ensure the sub-teams are addressing them.

Project Manager

Issues regarding the full team including scheduling, management of project sponsors, and resource allocation will fall under the responsibilities of the project manager. This position would be ideally served by an industrial engineer. Resource allocation includes budget management as well as control of the donated resources such as carbon fiber or balsa wood. The project manager will organize regular full-team meetings and facilitate the interaction between the capstone team members and the underclassmen working on the project.

As the report is compiled, the project manager will delegate the details of the report in a way that supports the report as well as the build of the plane. The report is compiled at a critical time in the plane build schedule and proper allocation of team members will help smooth the process. The critical members of the build team with the most knowledge of the build need to continue working on the plane but their knowledge is important to the report as well. Managing their time spent on the report by identifying which aspects must be done by the key build members and organizing this will be a more efficient use of personnel.

Competition Schedule:

Oregon State University's long term schedule for the 2013 DBF competition was not ideal and could be improved in future years. This was not due to procrastination of the team as much of a lack of knowledge and resources coupled with mixed responsibilities. The project was not defined for the teams until week 3 of the term for the capstone students. This gave the students only 7 weeks to fully design the plane. This accelerated timeline, coupled with required report content that was not useful in the aircraft design, left the time available for design of the aircraft below necessary minimums. As a result, some aspects of the design suffered to allow others to be sufficiently engineered. The Structures team , for example, decided to focus their efforts on building a fuselage and overall configuration that was competition ready, which meant the payload interface and landing gear were not fully optimized. The addition of a fourth team should enhance the overall quality of the plane but reworking the expected schedule for the design and build of the aircraft will also allow for an earlier completion.

The capstone class is divided into two terms. Fall term is focused on the design of the project while winter term is focused building and testing. When students leave for winter break, it is expected that the design be complete and ready to build when classes resume in January. In winter term, the students have 5 weeks to fully assemble their initial prototype and another 5 weeks to test it and refine the design. While this schedule is nearly parallel with the required competition schedule, there are slight modifications that need to be made for complete integration of the two processes.

Future teams will be able to start by researching the methods used for plane design by past Oregon State University DBF teams. This research will be worth the short time it takes to read through the past report from their respective team. Much of the initial time spent by the 2013 team was used to develop an understanding of the standard practices for remote control (R/C) vehicles and how the DBF plane would be different. This was necessary for the first year but now that there is background knowledge of the competition in the club, and reports documenting much of the process, the initial research phase can be reduced. The ability to transition from background understanding to new designs in week 3 instead of week 4 will allow an extra week for refining the design.

Final Competition Preparation:

Successful teams from Oregon State University in other technical competitions, as well as other teams in the DBF competition have passed on the following advice about the week of final competition:

There are two objectives during competition:

- The first is competing at the highest level possible with the product you have produced.
- The second is to prepare for future years through the involvement of younger members and the collection and storage of any data that might be useful.

One objective is short term while one objective is long term, but both have a positive impact on the program as a whole. The first point is easier to focus on because it shows quicker rewards but the second point should not be neglected. Unknowns during the initial design phases of the project caused significant delays in the 2013 competition year for the Oregon State University DBF team. Since 2013 was their first competition year, the team did not have any prior knowledge of the competition or the design methods that should be considered. To help relieve this stress in future years, the team took notes during the competition of designs and ideas they liked and didn't. These notes were shared with members who expected to return the next year as seeds for future growth. It is key that these objectives are clearly passed to the entire team before they arrive at competition so all members are aware of them.

Proper packing is also an essential aspect of the competition weekend. The team must be able to transition from the lab space where the plane was built to the pit and flight line at the airstrip. Any tools or materials that might be needed during competition must be with the team ready to be used instead of sitting back in the lab at the university. The 2013 team developed a packing list that was added to during competition as they found missing items on the list. This revised list can be found in Appendix B

Airplane Design:

This section will outline the basic procedures used to design the airplane for the 2013 DBF competition. It will be broken into the three sub-teams seen in Table 1. Since the mission requirements change annually, the descriptions for the design for each sub-team will be generalized for application to future competitions. Many design decisions however, were heavily influenced by the Mission requirements in which case the final design, along with reasoning for the decision will be included. The missions for the 2013 competition are listed in Table 3.

Mission:	Description:
1: Short Takeoff	Aircraft must takeoff within a 30' x 30' square and fly as many laps as possible in 4 minutes. Score is based on the number of laps completed.
2: Stealth Mission	Aircraft must takeoff within a 30' x 30' square and fly three laps holding as many internal stores as possible. The score is based off of the number of internal stores successfully flown.
3: Strike Mission	Aircraft must takeoff within a 30' x 30' square and flythree laps with a random payload configuration. The score is based on the time to fly three laps with the given configuration.

Table 3: 2013 Missions

All of the tree sub-teams was given the following project description. This description helped define the team priorities in making design decisions. The project description supplied by the project advisors was as follows:

> Student teams will design, fabricate, and demonstrate the flight capabilities of an unmanned, electric powered, radio controlled aircraft that can best meet a specified mission profile in accordance with the design requirements issued by the American Institute for Aeronautics and Astronautics (AIAA), Applied Aerodynamics, Aircraft

> Design, Design Engineering and Flight Test Technical Committees and the AIAA Foundation. The goal is a balanced design possessing good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance. Complete requirements published in the 2012-13 competition rules will be delivered to the selected teams. Teams may share critical aircraft components for the actual assembling and flight testing. [5]

Each sub-team used this project description along with their team specific responsibilities to develop a list of customer requirements and engineering requirements with the project advisors. Both the customer and engineering requirements were worded in such a way that the team was primarily for their portion of the total plane but they also had to ensure that each aspect was integrated to create a fully functional system. The team then developed testing procedures to validate the engineering requirements. By passing the testing procedures associated with a given engineering requirement, the team was able to receive the points associated with the given engineering requirement. Design links are developed as a way to connect the design to each specific engineering requirement. Figure 2 shows the progression from customer requirements to design links.

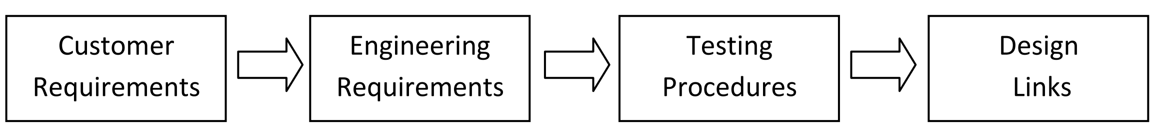

Figure 2: Design Process

Structures:

The structures team was responsible for the fuselage, landing gear, internal and external payload configurations, and the wing mount surface. Sufficient strength in each component as well as the entire system to support necessary loads was the largest driver of design decisions for these components. Minimizing weight was the next largest priority. Increasing the plane's empty weight (defined for the competition as flight capable without payload) required adding more lift which slows the plane and causes a reduction in the score. Ease of manufacturing, as well as aerodynamics were also key factors in the design of the structural components. While the structures team did not design any of their components to add lift to the plane, there was an interest in minimizing the drag. Minimizing the drag of the non-lifting bodies increases the overall speed of the airplane and thus the competition score.

Fuselage:

Three designs were considered by the capstone structures sub-team. The designs can be seen in Table 4. A carbon monocoque fuselage with balsa bulkheads and a carbon fiber tail boom was chosen because of its favorable weight, mechanical properties, and manufacturability. All lines that define the exterior surfaces are tangent to each other at any given point on the fuselage which helps keep the air flowing smoother over the plane.

The fuselage was shaped to allow internal stores to be loaded and secured in accordance to the competition rules. These requirements included a removable payload bay door located on the bottom of the fuselage. This removable door also allowed easy access to the propulsions and controls equipment to make changes or replace batteries.

Fuselage Structure Design		Design #1	Design #2	Design #3
Figure of Merit	**Weight**	**CF shell w/ front and rear balsa bulkheads**	**Mono-body CF shell**	**CF shell with balsa ribs**
Weight	0.35	1	1	0

Mechanical Properties	0.25	1	-1	0
Ease of access to controls	0.15	0	1	1
Manufacturability	0.25	1	1	-1
Total	**1.0**	**0.85**	**0.5**	**-0.1**

Table 4: Decision matrix for fuselage [6]

Carbon fiber was chosen as the primary structure because it was calculated to be lighter than a comparable sized plane made with balsa and Mylar. This was verified by the club team who built a plane using balsa and Mylar for the fuselage. Once both fuselages were built, they were weighed empty. The carbon fiber fuselage was lighter by approximately 15%. Two forms of prepreg carbon fiber were used to make the airplane fuselage. The skin is a carbon fiber weave pattern laid in both [0/90] and [±45] directions. Unidirectional strips of carbon, which can be seen in Figure 3**Error! Reference source not found.**, were also added in stacks of 3 plies to reinforce areas of high stress. The stacked unidirectional strips add strength and rigidity to the fuselage with little extra weight. One ply was found to be sufficient for the skin of the main

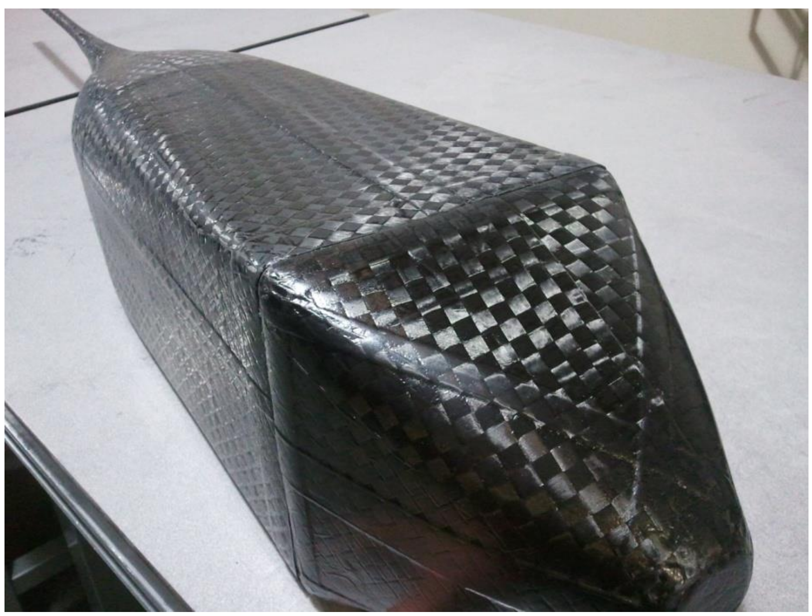

Figure 3: Fuselage

fuselage if it was supported with the unidirectional strips. If a second ply was added to the entire fuselage, the additional weight would offset any gains in total weight over a balsa and Mylar construction.

When calculating the forces felt by the fuselage, it is also critical to remember the potential for buckling and side loads on the skin by hands when carrying the plane or foreign objects during storage. While these forces might be difficult to quantify, even a small amount of added support from the skin bucking greatly helped the durability of the plane. During testing it was determined that the balsa bulkheads could be replaced with carbon fiber sandwich panel ribs in the same locations to increase accessibility and rigidity of the nose cone and tail cone areas of the plane.

Composite materials require careful consideration to the manufacturability of the components during the design stage. To ease the difficulty of manufacturing the fuselage, the nose cone and main fuselage were designed as two separate components. Both the main fuselage and the nose cone were created with a male mold which requires that the part be drafted towards an open end of the part to allow removal of the mold. This had to be an integral part of the design from the early stages of development and is an example of the difficulties with working with composite materials. The manufacturing section of this document will provide more details about manufacturing a carbon fiber fuselage.

Landing Gear:

Tail dragger and tricycle landing gear are both popular designs on remote control aircraft as well as full size planes. Table 5 lists the advantages and disadvantages of both styles but each design will be different and might be better suited for one landing gear configuration more than the other. Both styles were used on the initial prototypes but the competition plane was a tail dragger due to the preference of the pilot flying the plane for competition.

Tricycle Gear	Tail Dragger
Low angle of attack on initial takeoff roll	High angle of attack at initial takeoff roll
Brings CG towards nose	Brings CG towards tail
Higher weight	Lower weight
Shorter wheelbase	Longer wheelbase

Table 5: Landing gear options

The carbon fiber landing gear on the 2013 airplane was modeled off the shape of a purchased aluminum landing gear used on the balsa prototype plane. The first design iteration carbon fiber landing gear was a sandwich composite with a 1/16th inch balsa core with 3 plies of carbon on either side.

This landing gear weighed 60% of the aluminum gear but it failed during a test flight due to separation of the core and buckling of the carbon fiber in compression. It was determined that the sandwich composite was too stiff to properly absorb the loads incurred during landing. By designing a new landing gear of carbon fiber without the sandwich core, the team was able to gain the needed flexibility while adding strength. The solid carbon fiber gear was 75% of the aluminum gear, which was not as light as the sandwich

Figure 4: Landing Gear

version, but it was much stronger and more flexible. This second version made without a core was used on the competition plane. All three versions of main landing gear can be found in Figure 4

Internal Payload

The capstone team and the club team each designed an internal storage system for their respective prototypes that was subjected to static testing for loading purposes and flight testing for reliability. Both systems held the stores in flight but the capstone design relied on a questionable interpretation of the competition rules and the balsa prototype exceeded the allowable loading time. After examining and functionality of each design, a third iteration that unquestionably met the rules and easily fell within the loading times was built. This version, seen in Figure 6 used fixed friction clamps made with PVC pipe and Velcro strips to provide the adequate friction necessary to snap the rockets in place and hold them during flight. The lowest rocket was held with a Velcro strap because the PVC quick-release mechanism was too wide to allow the upper rockets to pass without interference.

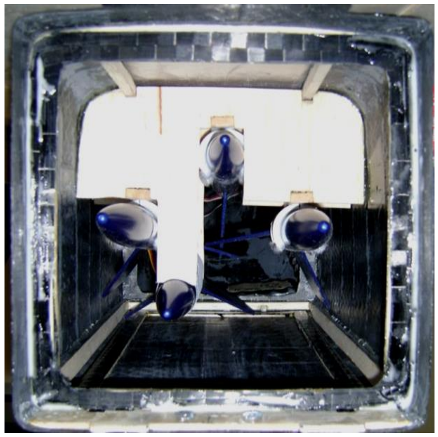

Figure 6: Internal payload

External Payload:

The external payload was carried on pylons mounted to hardpoints located on either side under the wing. Each wing had a variety of potential rocket configurations determined by the number rolled during competition. To provide the necessary versatility of external

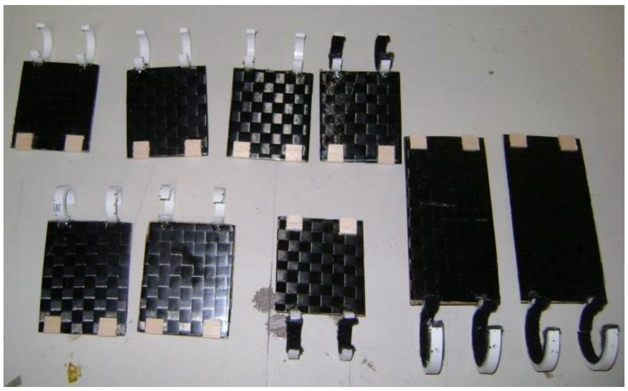

Figure 7: External pylons

payload capacity, the hardpoints for each wing fit a variety of pylons. Any required combination of payload could be carried by selecting the correct pylon configuration. This design was developed for the competition plane testing a similar design on the capstone plane. The capstone plane had the capability to interchange each individual pylon instead of the pair on each wing. This allowed the same versatility with fewer pylons but caused stability problems. It was determined that the added stability created by connecting the two pylons on each wing was worth the extra pylons necessary to comply with all configurations. Figure 7 shows the various pylons before final assembly into their wing pairs. The pylons were made with a sandwich composite consisting of 2 plies of carbon fiber separated by a 1/16" balsa core.

Aerodynamics:

The Aerodynamics team was responsible for the design of general wing parameters such as the wingspan, chord length, aspect ratio, and taper ratio. They also designed the tail surfaces, tail length, and wind tunnel testing procedures. During manufacturing, the aerodynamics team built the wing, stabilizers and the control surfaces. The initial research phase for aerodynamics was spent learning the concepts and equations needed to design an airplane. For the details of their design process, see the 2013 team 21.1 Final report [7].

Wing:

Since short takeoff capability was so critical to the competition, the team chose to sacrifice the speed of the aircraft by choosing a high lift airfoil profile. The aerodynamics capstone team used a Reynolds number of 100,000 to analyze the performance characteristics of various airfoils [7]. Both the capstone prototype and the balsa prototype chose the Eppler 423 airfoil seen in Figure 8 because of its high lift characteristics at low Reynolds numbers.

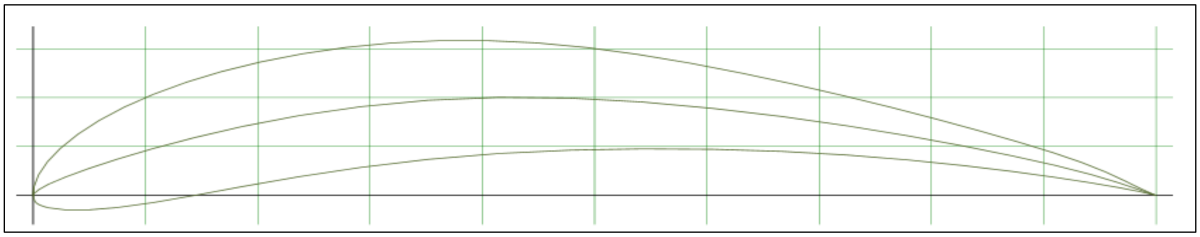

Figure 8: Eppler 423 airfoil [7]

Although the profile of the two prototypes was the same, the other characteristics of the wing varied on each wing. The capstone prototype wing was a tapered wing with a 66 inch wingspan, mean aerodynamic chord of 10 inches, and a taper ratio of 0.8. The balsa plane had a straight wing with a wingspan of 76 inches and a chord of 12 and a 5° dihedral. One aspect of the scoring for the competition is a scoring factor based on the plane's empty weight and exterior dimensions. Since having a shorter wingspan increases the scoring factor of the plane, the final wing was designed to have a shorter wingspan and longer chord length. The competition wing has approximately the same wing surface area as the capstone prototype. During flight testing, the stability provided by the dihedral of the balsa prototype helped improve the handling characteristics enough that a 5° dihedral was built into the competition wing as well. Figure 9 shows the three wings built for the 2013 competition.

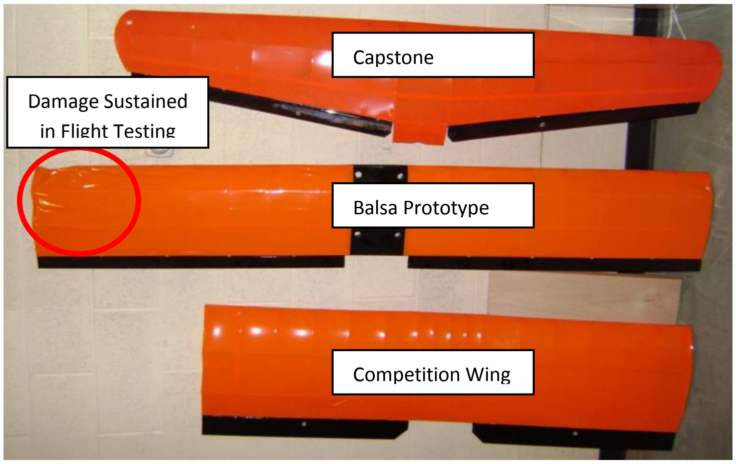

Figure 9: Wing iterations

The long wing from the balsa prototype has visible damage sustained from a crash during flight testing. It is important to consider the ability of the team to remake or repair a wing if needed. During testing and the competition, when planes crashed, it was most often the wings that sustained the most damage. Consider manufacturing an extra set of parts with long lead times such as carbon fiber spars in case a wing is broken during final testing with minimal time before competition. At a minimum, if the wing incorporates composite components, it is nice to have cured sheets of composite materials that can be used as repair patches or reinforcements. These generic sheets were used multiple times during the 2013 competition build as reinforcing materials were needed in parts of the plane.

The shape of the wing was defined by balsa ribs covered in Mylar. Carbon fiber/Balsa sandwich strips made up the main spars along the center of lift which carried most of the bending moment of the wing. Initial calculations concluded that this combination of materials was lighter than a wing made entirely of carbon fiber or balsa/Mylar construction [6].

Full length flapperons were used to provide a large control surface area on each side of the wing. The flapperons were scaled to approximately 20% of the wing chord length on the competition wing. The transmitter was programmed with flap positions at 0°, 15°, and 35°. The Spectrum DX7 transmitter used in the 2013 competition has the capability to control flapperons which gives full use of the flapperons as ailerons even as the flaps are at a lowered position. During initial design phases, a separate flaps/aileron design was considered but the extra weight in adding two servos was not worth the added flexibility of separate control surfaces.

Tail Section:

All three planes built for the 2013 competition used a conventional tail consisting of a vertical stabilizer/rudder and horizontal stabilizer/elevator combination. This configuration allows the elevator and rudder to both be attached to the tail boom instead of a T-tail where the elevator is attached at the top of the rudder. V-tail designs were also considered but were not pursued because the conventional tail offered easier mounting of the control rods during assembly. The balsa prototype was built with the carbon fiber boom ending at the leading edge of the stabilizer surfaces. The connection between the boom and tail surfaces involved a balsa rod extending into the boom. This balsa rod broke during initial testing of the plane causing minor damage to other components during the crash. During design of the tail surfaces it is critical to ensure there is adequate structure to handle the loads incurred. The competition plane was built with the boom extending 3" into the stabilizer surfaces to help support the flight loads on the tail.

Propulsion/Controls:

The Propulsion/Controls team was responsible for the design, assembly, and testing of the plane's propulsion system, the radio transmission system, and the wiring of the control servos. It was determined that these components are readily available in the R/C market. The purchased components fulfill the necessary tasks sufficiently and provide an easy platform for changing components during testing. R/C controls systems offer little need to experiment or optimize but the performance of the propulsion system is critical to a strong flight score in competition.

Propulsion System:

While observing the various aircraft submitted for the 2013 competition, it became apparent that the motor choice was extremely important to overall performance. The planes with higher flight scores had the highest total power ratings as well. The competition rules regulate several key aspects of the propulsion system including the maximum current draw, battery weight, and battery material. The contest rules limit the batteries to Ni-Cd and Ni-Mh batteries [4]. The team chose to use Ni-Mh batteries and in conversation with other teams at the 2013 competition, it was apparent that Ni-Mh are used almost exclusively.

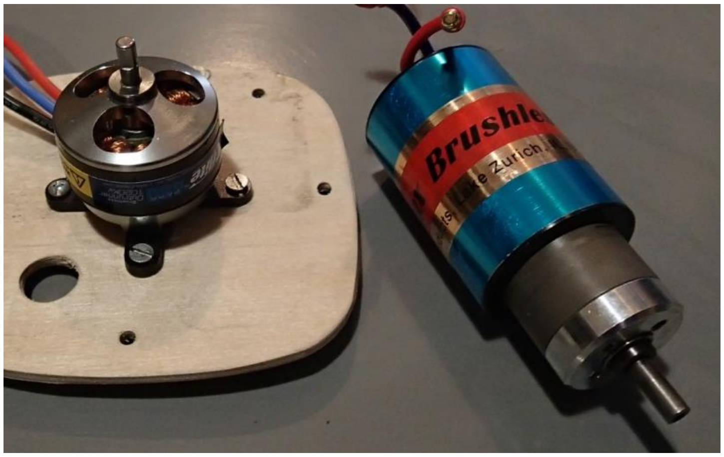

Figure 10: Motors

The capstone team used a small motor and battery pack to keep the total weight of the plane small. During testing, this method failed to sufficiently propel the plane out of ground effect. The balsa plane used a larger motor designed to run on high voltage and low current. Both motors can be seen in Figure 10. Since the contest rules limit the current but not the voltage, the high voltage, low current motor allows a higher total power than feasible with standard hobby motors. The higher power motor used in the balsa prototype was used in the competition plane. At full throttle, the competition motor and batteries had an output of 535 Watts which produced 5lbs 9oz of thrust with the APC-E 15X8.

Oregon State's DBF team chose to use a single high powered motor to achieve high thrust but some other teams adopted the multiple motor method. The limiting factor in either design becomes the battery weight limit if the right motor is used. The fastest 3 teams in the competition used a single motor tractor design similar to Oregon State's [1].

Control System:

Servos use the electricity in a given circuit from the receiver to rotate an arm that can be used to move components on the airplane. The receiver energizes specific circuits in relation to a channel of communication with the transmitter. This allows the plane to maneuver in flight from pilot inputs on the ground. The receiver also controls a speed controller which uses the lower power inputs from the receiver to control the high power circuit that runs the motor. Figure 11 shows a standard control setup for an aileron or flapperon.

Figure 11: Servo and control rod

Manufacturing Techniques:

Fall term for the capstone class is devoted to the design of the airplane, which leaves the manufacturing and testing of the airplane for winter term. Because the design is completely separate from the manufacturing and testing, the second two phases of the project must be carefully considered in the design phase. The use of composite materials for components of the plane accentuates the need for careful consideration of the manufacturability of the design. The manufacturing techniques for composite materials such as carbon fiber are complex enough that taking a class on carbon fiber manufacturing is recommended before attempting to build airplane parts with it. The structures team kept a composites manufacturing log while producing the first carbon fiber prototype fuselage which can be seen in Appendix C.

Fuselage:

The competition fuselage was built as a single carbon fiber component from the back of the nose cone to the end of the tail boom. This one piece construction increased rigidity and decreased the weight compared to a multiple piece design by eliminating the need for joints. The bulkheads were manufactured separately from the main fuselage on a flat mold. By curing the bulkheads on the same flat aluminum mold as the external pylons and repair strips, the team was able to use one vacuum bag for the batch of parts and save time in the vacuum bagging process.

The main fuselage mold was fabricated out of kiln dried alder. It is important that any wood used as a mold be kiln dried and sealed because moisture is a large problem in composites manufacturing. Wood that has not been dried and sealed will likely release water vapor during curing that can weaken the bonds between laminates. The mold was initially made with 1.75 inch sections that were machined in 1/8 inch steps on the CNC Bridgeport machine in the Oregon State University's MIME Machining and Project Realization Lab. The mold was then assembled and hand sanded to the final dimensions. Figure 12 shows the process of planning the mold sections and Figure 13 shows the rough cut sections of the mold being assembled.

Figure 12: sizing mold sections

Figure 13: Assembling rough cut mold

Once the mold was sanded to final dimensions, it was sealed with high temperature paint and coated in mold release. Low draft angles such as those found on the main fuselage can cause difficulties in the de-molding process. To aid the de-molding process, holes were drilled in the mold that allow compressed air blown into holes on the exposed mold surface to create a cushion of air between the mold and part. This method eased the de-molding of the part significantly.

Laminate Tools, a computer program for composite materials design, was used to create the flat panels for the carbon fiber nose cone and main fuselage. This program was useful to design the size of panels that would prevent excessive drape. Once the carbon fiber was cut using templates from Laminate tools as seen in Figure 14, they were placed in the proper locations on the mold.

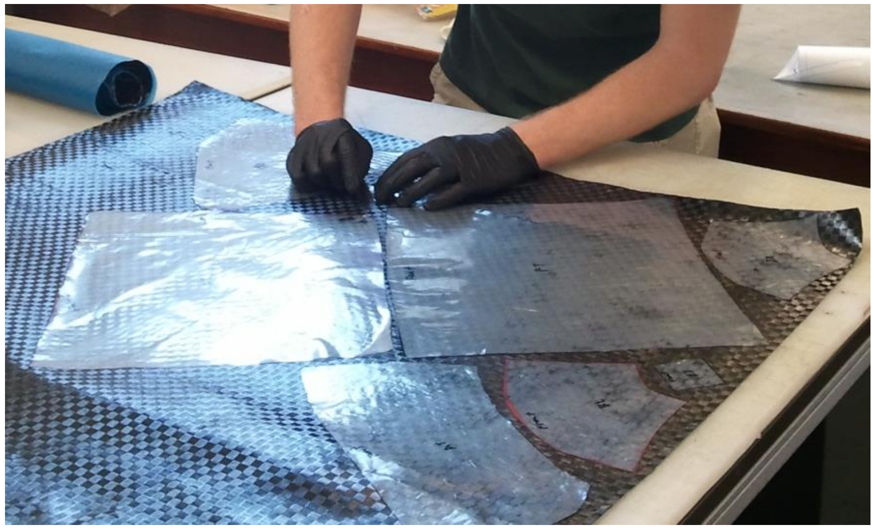

Figure 14: cutting carbon fiber

Labeling the individual pieces of carbon fiber as they were cut with their location and direction was useful when placing them on the mold. Enclosing the mold in vacuum bagging material was difficult with the curved mold shape.

Nose Cone:

The Nose cone was manufactured using the techniques listed above with minor changes to the mold and bagging techniques. The mold was entirely shaped by hand to save money on shop fees. Due to the smaller size and larger draft angle, the nose cone mold also did not include any air holes to help the de-molding process. These would have likely made de-molding quicker but were not completely necessary. Instead of being placed in its own bag, the nose cone was placed on a flat aluminum mold and bagged with other parts to reduce the total manufacturing time.

Wing:

Since the wing spars run the entire wingspan, they were manufactured first. The balsa core of the spars was cut and glued to shape then wrapped with prepreg carbon fiber. The spars were then vacuum bagged and cured in the oven for the curing cycle specified for the resin used. Once the spars were cured, they were used as a guide to hold the ribs in place during assembly of the wing structure. The ribs were cut by hand using templates developed on Solidworks. Manufacturing the ribs in stacks as seen in Figure 15 shortened manufacturing time. Components of the wing such as the servo mounts, hardpoints for external payload, and wing/body join studs were attached to the wing structure before covering. Careful consideration was taken to ensure proper transfer of loads for each of these components. Since the spars were built to carry the main load of the wing, the load bearing components such as hard points were directly connected to the spar if possible. The wing structure was covered with Mylar once all necessary components were added. Mylar covering material is heat sensitive so application of heat causes the material to adhere to surfaces and shrink. Once a piece of Mylar is cut slightly oversize for its desired location, the covering is placed on the wing and tacked down along its edges. By using an iron or heat gun, the Mylar can be fully adhered to the structure and shrunk to provide a tight covering without wrinkles.

Figure 15: Ribs

Conclusions:

The structure of a team such as Oregon State's DBF team is critical to the success of the program. Implementing the changes suggested in this report should improve the organization of the DBF team and provide positive changes to the team's competition results. Adding a chief engineer and a project manager to the team structure will help define the multi-team components of the plane and facilitate a better integration of the designs. A fourth team consisting of both mechanical engineering students and industrial engineering students will be created and given responsibility for the payload system and managing the aircraft's center of gravity. The responsibilities of the existing three teams will be changed slightly with the addition of the payload team which will result in a more even distribution of work.

The report is a significant aspect of the overall competition score and was Oregon State's lowest score at the competition. This score can be improved by adjusting the capstone report to more closely match the DBF competition report requirements. This will prevent redundant work and allow the team to focus on producing a higher quality report and plane.

An effective structure can improve the long term success of the team when coupled with proper documentation for future reference. The advantage an established team has over a new one is the previous knowledge which is only beneficial if it is transferred each year. Including younger team members who will be able to contribute for multiple years is one way to ensure this retention of knowledge. The other solution is proper documentation of all aspects of the competition. The design, manufacturing, and competition should all be well documented each year to maximize knowledge transfer. By doing this, Oregon State University's DBF program can propel themselves into a thriving program that is consistently in the top tier of competition.

Appendix A: Proposed Competition Schedule

Dates used are for the 2013-2014 school year	Fall Term Schedule									
	October				November				December	
	1	2	3	4	1	2	3	4	1	2
Task	Week of the Term									
	1	2	3	4	5	6	7	8	9	10
Point Analysis										
Airfoil/Wing Style										
Pick a wing style										
Wing Parameters										
Wing Structure										
Wind Tunnel Testing										
Results Analysis										
Order Parts										
Point Analysis										
Fuselage/Wing Style										
Fuselage Parameters										
Fuselage Design										
Landing Gear										
Matl. Testing										
Fuselage Iteration										
Order Parts										
Point Analysis										
Motors/Empenage										
Empenage Design										
Motor Location										
Control Surfaces										
Battery Life Testing										
Motor Selection										
Order Parts										
Point Analysis										
Payload Grouping										
Initial CG										
Payload location										
Wing/Pylon										
Payload Structure										
Storage										
Order Parts										

Dates used are for the 2013-2014 school year	Winter Term Schedule									
	January			Febuary				March		
	2	3	4	1	2	3	4	1	2	3
Task	Week of the Term									
	1	2	3	4	5	6	7	8	9	10
Manufacture Mold		■								
Wing structure		■	■							
Interface devices				■						
Wing Covering				■						
Assemble Prototype					■	■				
Flight Test						■	■	■		
Iterative Design						■	■	■	■	
Mfg. Mold		■	■							
Cure Fuselage			■							
Post Process Fuselage				■						
Mfg. Landing gear				■						
Assemble Prototype					■	■				
Flight Test						■	■	■		
Iterative Design						■	■	■	■	
Mfg. Batteries		■								
Mfg Empenage			■							
Test Battery life			■	■	■					
Mount Motor				■						
Assemble Prototype				■	■					
Flight Test						■	■	■		
Iterative Design						■	■	■	■	
Mfg. Payload		■	■							
Mfg crate			■	■						
Integrate Payload				■						
Assemble Prototype				■	■					
Flight Test						■	■	■		
Iterative Design						■	■	■	■	

Appendix B: Competition Packing List

Emergency repair
[ ] adhesives
    { } CA
    { } Epoxy
        -5 min
        -15 min
    {} Tape

[ ] Skin repair
    { } Exact-o knife
    { } Mon-o-kote iron
    { } spare covering
        -orange
        -black
[ ] Hand tools
    { } Screw drivers (just the case of mini screw drivers will be sufficient.)
        Philips and flat head
        -#0
        -#1
        -#2
    { } Socket driver for sing nuts
    { } Pliers
        Needle nose
        Big pliers
    { } modeling saw
[ ] Spare parts
    { } carbon scraps
    { } Spare rib(s)
    { } ¼ balsa sheet
    { } stripping tool
    { } plywood scraps

For flight
[ ] Plane
[ ] Transmitter
[ ] Batter packs
    { } flight packs 4 sets of 2
    { } receiver packs 2 or 3
[ ] Battery chargers
    { } Transmitter charger
    { } large charger for flight packs

For Missions
[ ] Missiles – Payload
[ ] various wing pylons

For Pit Crew at Table
[] camp chairs
[] wheel chocks
[] cooling fan for plane
[] OSU AIAA banner and USA flag
[] 2-way radios

Flight Line Kit
[] spare fuses
[] small roll of strong tape
[] socket driver
[] pliers

Items to maintain an able and enthusiastic crew
[] sunscreen
[] snacks
[] RedBull – it gives you fuselage (or something like that)
[] shelter for spectator seating
[] centralized clipboard for general information

Appendix C: Composites Manufacturing Log for Prototype 1

Final mold prep-Fuselage and Nose cone molds

Mold material: Kiln dried alder planed to 1.75" layers

Mold use: Prepreg carbon fiber to be vacuum bagged and cured in an oven at 275˚F for 4 hours.

Molds were sanded to smooth finish and any voids were filled with 3M fire block sealant. All mold surfaces were roughed up with a red Scotch Brite pad to improve paint adhesion. The mold was given 3 coats of Dupli-Color ceramic Engine Enamel which is rated to 500˚ F then allowed to sit overnight. The following day, the mold was sanded with 150 grit paper to further smooth the surface then prepped with Scotch Brite and painted again with 3 more coats of Dupli-Color Engine Enamel. After again curing overnight, the mold was coated with 4 coats of Frekote mold release. Air holes were added to the fuselage mold as a method to ease demolding. The holes which start at the open face of the mold travel back toward the tail and are intersected by holes that go to the surface of the mold along the fuselage. These holes were covered with release film to allow air to escape without allowing resin to fill the holes during curing.

Mold Prep – Leading Edge of wing

Mold material: Wet-layup fiberglass weave

Mold use: Prepreg carbon fiber to be vacuum bagged and cured in an oven at 275˚F for 4 hours.

The plug for this mold was cut with a hot wire out of 2" Foamular pink insulation foam. The shape of the plug was defined with metal templates cut on the CNC Bridgeport machine in the OSU product realization laboratory. The fiberglass was laid over the plug with a 3" flange around the outside of the flat section of the mold for rigidity. After curing for approximately 36 hours, the plug material was removed from the mold using lost foam deposition. By pouring acetone into the mold, we were able to dissolve the majority of the foam and scrape it out of the mold. This method did leave a lot of hard foam residue left on the mold but this was able to be sanded out later before laying up the carbon fiber. Once the mold was smooth and the rough edges of the flange were cut off, the mold was coated with 4 coats of mold release.

1/31 – Layup of first prototype

Fuselage and Nose Cone

Materials: *Toray 600 12K Weave prepreg carbon fiber*

3" strips of uni carbon fiber gathered in 3 ply strips and debulked before use.

The fuselage and nose cone layup schedules were made using laminate tools. This gave accurate flat templates to cut the carbon with. This step was very successful and saved hours of work in the shop later trying to size the plies in a way that would drape correctly.

The first step to the process for this prototype was making a cage structure of unidirectional strips. This cage consisted of a single .75” strip along each face of the fuselage from the nose of the plane to the tail. The top and bottom strips were centered to the nose and the tail while the side strips were centered with the tail only. This is due to the tail centerline being even horizontally but being higher than the nose centerline vertically. 3 hoops were placed around the fuselage with their center axis parallel to the direction of flight. One hoop was located in the front of the payload bay, one was located behind the payload bay, and one was near the midpoint of the tail cone. 1.5” strip was also wrapped at the very end of the fuselage to provide a strong mounting point for the tail boom.

The carbon sheets were placed on the mold consecutively from the tail to the nose. This order makes the seams smooth from the direction of the nose to the tail which is the airflow direction. Because of the careful planning of shapes using computer software, there was minimal overlap on the plies. It was very helpful to have notes written on the plastic covering on the carbon such as the plane centerline and overlap edges in the correct orientation of the sheet.

The reinforcement on the nose cone consisted of a strip along each face, a band on the nose-fuselage join section, and a pair of strips against the front face. The front of the nose cone is at too steep of an angle to allow for a strip to be wrapped so this band consisted of two strips that wrap halfway around the front radius of the cone with their tails angled back towards the fuselage. The front face of the nose cone was covered with one ply of weave. For the nose cone, we had to cut small slits in the carbon in select places to allow the material to lay down smooth over the mold. Future nose cones might incorporate more than 2 pieces to reduce the need for relief cuts.

Wing Lay-Up

Material: *Toray 600 12K Weave prepreg carbon fiber*

The wing leading edge was made with two strips of weave oriented at ±45˚ with a 6” overlap of the 2 strips in the middle of the wing section. The end of the wings are left open as there were no end caps placed on this prototype.

2/1 - Curing:

Fuselage: The fuselage mold was placed face down on an aluminum plate. The bag was wrapped around the fuselage with the bottom of the bag tacked to the plate. We left off the peel ply on the fuselage to provide a smoother surface with more resin to seal off the holes. The breather was run along the corners of the fuselage running from nose to tail. The air fitting was placed on the aluminum plate near the base of the fuselage. Robert Story mentioned that it might be better to bag the entire plane without a plate.

Nose Cone: The nose cone was placed on an aluminum plate and shared a bag with the stringers since the oven only has 3 vacuum fittings. The nose cone was bagged without a peel ply for the same reasons as the main fuselage. The release film was in direct contact to the carbon fiber with the breather running up the 4 corners of the nose.

Stringers: The stringers were laid up on the same aluminum sheet as the nose cone. They were covered with peel ply and release film with strips of breather and bagged.

Leading Edge:

The leading edge was initially bagged with the bag sealed against the mold with tack but we were unable to maintain a vacuum with this technique. To compensate for the mold not holding a vacuum, the entire mold was surrounded by a sealed vacuum bag.

2/2 – Demolding

Nose Cone: The nose cone came off its mold fairly easily. The nose cone mold did separate into two pieces at a joint due to the epoxy not holding though. The overall finish without the peel ply turned out very good. There were some ridges where the bag was not flat but the overall surface finish was acceptable. With some finish work, the full surface will be good.

Fuselage: The fuselage took a lot of work to separate. The air holes drilled into the mold worked great. The release film kept the resin out of the holes so that when air was blown into the mold, it formed a cushion of air between the mold and carbon. The problem with the mold was that the tail cone and boom attachment points were stuck. These areas did not have air holes due to dimensional constraints. The tail boom section was particularly difficult. The mold was actually removed in pieces as parts of the mold separated because of the weak epoxy bonds. The support rods for the mold were driven out until they were no longer in the smallest mold section. At this point, the larger part of the mold was removed out the large opening in the part leaving the final small round piece. This piece was driven out using a rod and a hammer out of the smaller opening of the part.

Leading Edge: The leading edge part did not come out successfully. While in the oven, parts of the leading edge collapsed which caused deformations to the desired shape. We think this was due to the pressure of the bag around the whole mold collapsing it inward.

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