2008 SAE Aero Design: Cargo Plane

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Executive Summary

This report outlines the proposed SAE cargo plane senior design project for 2008. The main purpose of the project is to design and build an aircraft to compete in the 2008 SAE Aero Design competition. The goal of the competition is to create a radio controlled (RC) aircraft that will lift the most weight and meet a set of preset specifications. This proposal will discuss in detail the project objectives, the issues involved, and the approach the team plans to take to achieve these objectives.

There are a couple of main issues that will be involved during the course of the project. The first are design issues, which may be further broken down into issues of aerodynamics and structures, as well as control systems/electrical and analytical/testing issues. Secondly, there will be organizational issues. These issues may consist of team planning and scheduling difficulties, as well as finding sufficient funding and resources for the project in the time given.

The previously stated design issues arise due to the fact that the team will have to design an aircraft that will perform well aerodynamically using very low Reynolds numbers, as well as design a structure that will support the loads necessary for flight while keeping weight to a minimum, and select a control system that will allow the aircraft to be flown easily by the pilot. The aircraft will be used at Reynolds numbers from about 250,000 to 300,000. Because the aircraft will not carry passengers and weight reduction is critical, the components will be designed with a factor of safety of 1.2-1.5. Part of the competition is also predicting the maximum weight the aircraft will be able to carry, so analysis and testing of the final product will be necessary.

As of this design proposal, the team has decided to pursue a tandem wing design for their aircraft. Both sets of wings will be constructed mainly with balsa wood and plastic sheeting, where the fuselage structure will consist of composite materials. More details regarding the initial concept can be found later in the report.

The organizational issues involved will deal with creating an accurate plan and schedule so that the different phases of the project can be completed at a reasonable time, and the project can stay on track. The team will also have to secure sufficient funding and other non-monetary resources in order to construct the aircraft.

The team is keeping a creative and open mind about the design of the cargo plane but will not over look or ignore the facts put forth by others that have proven successful in the past. The team is dedicated and ready to apply themselves one hundred percent to this project and feel confident that the 2008 SAE cargo plane team will be successful in completing the goals at hand.
Background

The challenge that has been set before the SAE Aero Design competitors is to design and construct a radio control aircraft that can carry a payload successfully. The purpose of this challenge is to offer students an opportunity to apply the knowledge and skills they’ve been supplied with to a real life situation. Each team entry must follow specific guidelines for the construction of their aircraft in order to qualify for competition. This provides experience with working in a design group atmosphere and with following specific instructions and deadlines.

The direct need of the project involves the need to for Florida Tech to enter a team into the competition, and place well. There are other secondary needs of the project as well, particularly those which revolve around the military and civil applications of heavy lifting aircraft in industry. Competing in the design competition acts as an exercise in creating the most efficient and effective design possible, and may also spur innovation and research into new design concepts.

The 2008 Cargo Plane team spoke with the 2007 team to discuss the difficulties that they have faced in their project as well as what their design entailed and their reasoning behind their design decisions.

The 2007 cargo plane team faced time constraint difficulties and failed to stick to their schedule. The team’s construction is late and some parts are still not finished. This is due to the fact that the designing portion was finished past the scheduled time.

The 2007 cargo plane also discussed their design for the plane. An aspect ratio of 15 has been chosen as the best compromise of various factors, the 2008 team will reanalyze this design based on the changed 2008 requirements in order to obtain maximum performance. For practical reasons, the center of gravity of the entire plane should be vertically aligned with the aerodynamic center or with the pressure center of the main wing. The nose then has to be far enough from the center of gravity; this way, the weight which would have to be added in order to compensate the weight of the tail. The size of the current senior team’s plane is due to the elements which have to be placed inside the fuselage, such as the cargo bay, battery pack and receiver from the RC unit, fuel tank, 2 servos for the elevator and the rudder.

Problem Statement and Objectives

This design project has several main objectives that the team will pursue which consist of:

1. Designing and creating an RC aircraft that meets the requirements to compete in the regular class SAE Aero Design 2008 competition.
2. Competing in the SAE Aero Design 2008 competition.

The following are the main design requirements imposed by the competition rules and guidelines supplied by SAE [1].

1. The aircraft must operate using an unmodified OS .61FX engine and E-4010 muffler.
2. The aircraft must be able to take off within a distance of 200 feet and land within a distance of 400 feet at maximum payload.
3. The overall aircraft dimensions (Length + Width + Height) must not exceed 175 inches.
4. The fuselage must be able to fully enclose and support the rectangular cargo box measuring 5x5x10 inches.
5. The aircraft must have a gross weight (including max payload) of no more than 55 pounds.

In addition to the design requirements necessary to meet the competition guidelines and rules, the team has defined several self-imposed design requirements:

1. In order to place well in the competition, the final aircraft must be able to achieve a successful flight with at least 25 pounds of payload at sea level density. It will be the main goal of the team to maximize this payload as much as possible while keeping with the design limitations.
2. The aircraft must be able to make a turning radius necessary to make a full circle of the airfield without entering any of the no fly zones.
3. The aircraft must be easy to control, such that an experienced RC pilot can fly the plane with little difficulty and little practice with the aircraft.
4. The aircraft must be able to sustain the extra load factors of the maneuvers necessary to meet the mission requirements of the competition.
5. The aircraft must be able to sustain the impact of landing and maintain its structural integrity.
6. To ensure reliability through the course of the competition, the aircraft must be able to last for at least 50 flights without permanent damage.
7. To score well on the design category of the competition, the team must develop an equation to predict the maximum payload based on density altitude within 2 pounds.

Aerodynamics

The tail is important in the design of the aircraft as it holds the rudder which is used to balance out any yaw created during a rolling maneuver. It also stabilizes the plane during flight. The tail does not produce any lift, but it does produce drag. The design of the tail must eliminate as much drag as possible. One way we plan on reducing drag caused by the tail is by raising it above the wings. This will ensure that the tail stays out of the vortices caused by the wings and will prevent any drag that can be caused by that interaction.

The wing design is extremely important to how an aircraft performs and a great deal of time must be spent to perfect the design. Everything from the shape of the airfoil, the length to surface area ratio of the wing, the twist in the wing, and even how far back the wings are swept must be taken into account for the design.

The camber of a wing is the curved line that connects the leading edge point to the trailing edge point that is exactly halfway between the upper and lower surface of the
airfoil. When an airfoil is said to have a high camber, it means that the camber is more curved. A highly cambered airfoil has a chord line that is at an angle relative to the horizontal. This means that when the airfoil is at an angle of attack of zero, lift will still be produced. The camber of the airfoil determines the lift coefficient at a zero angle of attack. For the purpose of our cargo plane, we want an airfoil with a high camber. We are currently looking at the Selig 1223 airfoil, which is shown in Figure 1. The team compared a couple of different airfoils typically used at the competition, two of which are the Selig 1223 airfoil and the FX63-137 airfoil. A plot comparing the coefficients of lift at a Reynolds number of 300,000 of the Selig 1223 airfoil to the FX63-137 airfoil, shown in Figure 2, was produced by team member, Jeff Gibson, and clearly shows that the Selig 1223 has a higher section lift coefficient, as well as better stall performance.

![Figure 1: Selig 1223 airfoil [2]](image1)

![Figure 2: Comparison of the Selig 1223 and FX63-137 airfoils](image2)

Another important consideration in determining the lift is the aspect ratio of the plane’s wing. The aspect ratio (AR), is the ratio of the wingspan (b), squared to the surface area (S), of the wing and is shown by Equation 1.
A plane with a higher aspect ratio produces more lift than that of a plane with a lower aspect ratio. These planes can fly at higher altitudes, but they do not fly very fast. Planes with a lower aspect ratio have more maneuverability and faster flight speed, but cannot fly as high.[3] For the purposes of our cargo plane, a high aspect ratio is the better choice. Therefore, the wings will be long and not very wide.

Another important consideration in the design of the wing is the stability. In our design, the wings are to be placed on top of the fuselage, such that the fuselage rides underneath the wings. When the aircraft rolls in flight (rolling slightly causes the plane to make a turn) the fuselage forces the plane back into its normal position. This means that the plane is very stable. However, this can be problematic as it makes it more difficult for the plane to maneuver. The solution to this problem is to angle the wings downward. When the wings are angled downward they are called dihedral wings. On a plane where the wings are located at the center of the fuselage, this would cause the plane to become unstable. On our plane where the wings are located at the top of the fuselage, it balances out the extra stability gained from the weight of the fuselage.

Another important consideration is the sweep of the wings. Sweep is the how far back the wings are angled in relation to the incoming wind. A high sweep creates less lift but allows for more speed. It is especially important in supersonic aircraft, as it allows for the plane to remain within the shock cone created at the tip of the fuselage. However, for the purposes of our cargo plane and sweep would not be beneficial. Instead of sacrificing lift for speed and maneuverability, we instead will keep the wings perpendicular to the fuselage.

As part of the rule changes for the 2008 regular class competition, there is no longer a restriction on wing planform area. Instead, the sum of the overall aircraft dimensions (Length + Width + Height) is limited to 175 inches. Because of this change in requirements, the initial design concept has been altered to a tandem wing aircraft. A tandem wing aircraft is one which has a second lifting surface for added lift and stability. This is similar to a canard design, however the front surface is meant to significantly add to the lift of the aircraft. Figure 3 below shows the Rutan Quickie, an example of a tandem wing aircraft.
By adding a tandem wing, the aircraft will have greater lifting capacity, while not significantly increasing the overall dimensions.

The team plans to have the front wing mounted under the fuselage, and the rear wing mounted on top, as far back as possible. This will minimize the effects of downwash from the front wing, and allow the rear wing to produce more lift.

General calculations:

Once more a more accurate representation is found (through computation and/or empirical methods) for the thrust produced by the engine, the team will be able to use the following equations to aid in the overall design and analysis:

For steady level flight:

\[ W_{\text{max}} = \frac{L}{D} \times T_{\text{max}} \]

Velocity necessary for takeoff:

\[ V_{\text{takeoff}} = \sqrt{\frac{2W}{C_{L,\text{max}} \rho S}} \]

To maximize the lifting capacity of the aircraft, the team will have to develop several design alternatives, and select the one that has the largest take off weight for the given take off distance (200ft). After testing the engine, the team will decide on the propeller that provides the maximum work during take off (integral of thrust w/ respect to distance, from 0 to 200ft). This integral will be dependant on the aircraft gross weight, as well as the drag, so a final decision may not be made until the aircraft design is more clearly defined.
Wing Structure and Construction

The material choice for construction of the wings and vertical tail of the plane has been extended this semester. Now the team is not only considering using a foam core with a composite skin, but also balsa wood for the internal construction and MonoKote for the skin.

For the first method, vacuum bagging will press the layers of the skin closer to the core material, reducing the overall weight as the epoxy will be removed from the structure. However, before vacuum bagging can begin, it is necessary to determine the materials to be used for the wing structures. During Structures laboratory, we constructed and tested four different Nomex sandwich specimens, two of which were covered with a single-layer graphite skin on both sides and the remaining two were covered with a three-layer fiberglass skin on both sides. Although the two fiberglass specimens took a higher load, it was determined by the team that Nomex would not be the best choice. Instead, the final choice is between “blue foam” and Spyderfoam.

“Blue foam” is the more common name for extruded polystyrene foam produced by DOW, which boasts a closed cell structure. [4] A closed cell structure allows for a finer trailing edge to be made than with other modeling foams. The density of blue foam ranges from 28 to 45 kg/cu. m, while the easiest and most popular kind, Styrofoam IB, has a density of 28 kg/cu. m. The dense cellular structure of the “blue foam” can be seen in Figure 4. Nomex has a density of 29 kg/cu. m. Based on this information, it is hopeful that the blue foam will be able to hold exactly, if not more, of the load that Nomex can, despite having a lower density.

![Figure 4: Blue Foam Cell Structure detail](image)

The second type of foam considered is Spyderfoam, which is produced by Aerospace Composite Products. The internal structure of the Spyderfoam contains a fine cell structure that when perpendicular to the surface of the wing can create a ridge honeycomb effect which is quite similar to the structural effect of Nomex. Due to this arrangement, Spyderfoam is two times stronger than blue foam, but weighs approximately 10% more than blue foam.[6] However, it is noted that by using a light cover for the wing skin, the wing can be stiffer and lighter. No real information is given about the density of Spyderfoam, but it is assumed that the density is the same as Nomex, despite the former being made from foam instead of Kevlar paper.
Of the two of these, the blue foam is the more probable choice for the wing material, as it will be easier to form the wing shape with a closed cell structure than it would to form the same shape with a honeycomb structure. The skin for the wing will most likely be 200 gsm carbon fiber placed at 45º to the wing edge to increase resistance to torsion.

Once the materials for the wing have been purchased, the actual construction can begin with making the foam core, which is done by filling a wing mold with the foam or by carving the shape of the wing by hand. The mold will be carved out in the machine shop, with the cavity being in the shape of our chosen airfoil. While the wing is being formed, preparation of the work area for the skin lay-up can be started. After the wing is ready and the central carbon fiber spar is inserted into the wing foam, the wing should be wrapped in brown packing tape to provide a flat smooth surface for the skin to attach to. If the skin were attached directly to the surface of the foam core, the epoxy would seep into microscopic imperfections in the foam or into the carbon fiber spar, which has the possibility of cause a warping of the spar.

For the actual bagging, the mold used to form the foam core will be used as the base for the skin and wing, allowing the skin to be pressed closer to the core. The most important thing outlined in the process of vacuum bagging is to put the upper foam bed on the outside of the vacuum bag [7] so that the upper skin is pressed down. If the upper bed were inside the bag, the vacuuming pressure on the edges of the upper foam bed would cause a non-uniform pressure distribution on the foam core. The type of vacuum bag sheeting that is suggested is a 0.48mm polythene sheet and the sealant for the bag can either be vacuum bag caulking, packing tape, or double-sided tape. Once the epoxy is completely dry, which should take about 24 hours, the vacuum bag can be removed and any other modifications that need to be made to the wing can be done.

Before the vertical stabilizer is vacuum bagged, it is necessary to construct the rudder post so the stabilizer will fit after complete. Once the post is prepared, vacuum bagging can be preformed in the same way as for the wing.

The second set of materials, the balsa wood and MonoKote, will require a different manufacturing method. This will include making an internal frame work constructed out of pieces of balsa wood cut to the chosen airfoil shape. The shapes would be cut out by tracing the shape off of a piece of paper using a pen, and then could be cut out of the main sheet of wood using a simple razor blade. A pen (not a ball point pen though) has to be used when tracing the shape because the ink will be able to pass through the paper, and a pencil will leave impressions in the balsa wood that could cause weaknesses in the structural integrity of the part. After the frame is assembled it would be covered with MonoKote by simply tacking the sheet down and then applying heat to it with an iron. The MonoKote provides several advantages over the composite lay up that was discussed previously. First, the MonoKote has a simpler manufacturing process then the composite lay up. Secondly, the composite material is very hard to repair if there is a problem with it, but with the MonoKote all that has to be done is reapplying the heat. If there are wrinkles it is just apply heat, for a hole there is pressure activated MonoKote to apply in the field, and then a patch can be made of the original MonoKote which is then applied with heat.

The team is still finalizing the material choice, but the balsa wood and MonoKote seems more appealing. This is because of the easier manufacturing process, and the fact
that the strength provided from using the foam and composite might not be needed in the wing. The manufacturing process for the composites is currently being considered for the fuselage because that area can use increased strength, and the general shape of the fuselage would be easier to manufacture when compared to the wing.

**Fuselage & Landing Gear**

Another main component of this aircraft is the fuselage. This portion provides the main structure of the aircraft, as well as the cargo bay. Fuselage construction is very important in providing the placement of the center of gravity of the airplane. The location of the center of gravity is crucial in the stability of the aircraft and must be taken into account when performing calculations.

The fuselage holds in place the engine, payload, and servos for the radio controls. The single propeller engine is to be mounted in the very nose of the plane. Behind that is where the payload will be located. The cargo bay must be able to contain the metal weights used for the competition. It needs to be at least 4”x4”x16”, be able to withstand several pounds of weight, and be easy to access for placement and removal of the payload. The payload must also be secured within the cargo bay in order to maintain stability during flight. The payload will be held in the cargo bay using an apparatus as shown in Figure 5.

![Figure 5: Cargo Hold](image)

Besides the payload, the fuselage may also contain the servos for the radio controls. If placed in the fuselage, it would be best if they were located towards the tail end of the fuselage where the controls for the elevators and the rudder would be easily accessed.

The fuselage not only houses the parts mentioned above, but it’s also attached to the wings, landing gear, and tail. In order to perform these tasks, it must be designed with a sturdy structure and areas of reinforcement. The fuselage will have a wooden frame with different sections for each item inside. There are two popular types of wood for model airplanes, Balsa and Basswood. Both are lightweight but provide a good amount of strength. For the frame, the best choice would be the Balsa wood because it is lighter in weight than the Basswood. However, the Basswood is a good option for the platforms for the engine and the payload to rest on. A sheet of basswood on the top and
bottom of the fuselage would also be an option for the mounting of the landing gear and wing supports.

The design for the landing gear is very basic. There are two options for landing gear, dual-wheel or tri-wheel. Both are commonly used in model aircraft, but for this design the best option is most likely the three wheels. The supports are arranged in a triangle layout. One wheel support is mounted towards the front of the fuselage and directly in the center so as to better support the weight of the engine. The other two wheels are placed next to each other and towards the rear of the fuselage. This will better balance and support the wings and the tail, and eliminates the need for a tail wheel.

The tail itself will be attached to the fuselage by a long hollow tube. The tube will most likely be made of strong carbon fiber and will carry the wires from the servos to the elevators in the tail of the plane.

The frame of the fuselage must also be encased in a hard skin to protect everything inside. The material must be sturdy and light weight. Carbon fiber is one option for the skin. It is resilient and can be easily molded to the shape of the frame. There is also another plastic-like material known as Monokote. Monokote is a plastic film that is applied through the process of heat shrinking. It is self-adhesive and is designed to be placed over porous materials. However, Monokote is meant to be a tightly sealed skin and is not recommended for use where a lot of additional strength and support is needed. Therefore, the use of this material would be best finalized once a final design for the plane is set. Also, when considering both materials, it must be taken into account that an opening in the side must be present to allow for access to the inside to add the payload or adjust the parts of the control systems that have been placed in the fuselage.

Control Systems

In all remote controlled planes the control systems are very important for the propulsion and maneuverability of the aircraft. The control system of an RC plane is the mechanical and electrical (see Figure 6, below) parts that control the throttle, and the movement of the ailerons, elevators, and rudder. The control systems are a set of electronics and mechanisms including:

- Remote controller
- Digital servos
- Pushrods/linkages
- Battery packs
- Wires switches
The remote controller will be a typical RC plane four channel controller that has a channel each for all three degrees of freedom (pitch, up/down, left/right) experienced by the airplane and a final channel controlling the throttle. It will be necessary to make sure that the joystick motions for flying are setup in a typical manner to make it familiar for the pilot to operate. The standard setup used in the US is currently ailerons and elevators controlled by the right joystick and throttle and rudder controlled by the left joystick. The competition rules require that the controller transmit according to the FCC and Academy of Model Aeronautics 1991 standards and recommend a 2.4 GHz system to avoid interference. The standards consist of a list of frequencies for different channels in the 72 MHz, and 2.4-2.48 GHz bands, while the average controller available for purchase is generally in the 72 MHz band. The controller will determine the rotation of a set of servos controlling each degree of freedom for the aircraft. There will need to be one servo for the throttle, two for the rudder, one for each elevator, and one or two for each aileron depending on the size and expected forces working the ailerons, the total being 7-9 servos depending on aileron size.

Servos are small electric motors than can be digitally programmed to have an output rotation of a specific degree and are controlled by the joysticks on the remote controller. This means that if an object to be moved, such as a rudder, only needs to move a small amount it is not necessary to have a motor that rotates a complete 360 degrees. If a motor that rotates 360 degrees is used a complicated four bar crank rocker mechanism would have to be designed in order to get a small output motion. The servos that are going to be used can be programmed to rotate a certain degree setting to provide the small output movement of the rudder. The servos are programmed by a handheld servo programmer that allows the user to easily and digitally set the specific rotation angles of the servos.

The servos will most likely be purchased from or donated by a local hobby shop. The servos available for purchase have a torque output range of 76-333 oz-in for operation using a six volt battery. The respective weights for the servos are respectively
1.4-2.2 oz and are of varying dimensions and prices. The placement of the servos and which size will depend on how much torque needs to be used and for how long that torque needs to be applied. For instance the rudder will be operating a lot of the time during flight and as the power drains from the batteries the torque output will drop considerably. It will probably be necessary to test the actual torque output and its change over time using a setup similar to that seen below in Figure 7.

![Figure 7: Servo torque test setup [16]](image)

Servo placement will consist of one servo connected to the engines throttle, which will open and close the intake valve to increase or decrease the power output of the engine. The servo for the throttle will be located inside the fuselage directly behind the motor. The servos for the elevators will be located on the underside of each of the horizontal sections of the tail and will be connected to the elevators using pushrods and linkages. The two servos for the plane’s rudder will be located low, on both sides of the vertical section of the tail. The rudder needs two servos in order to allow it to cover the full area of rotation necessary for the planes handling. Two or more additional servos will be necessary for ailerons and will have to be located within the wing’s cross-section, most likely on a fortified rib.

Pushrods are metal dowels, of a small diameter, that are used to convert the rotation of the servo to the output motion needed for the object it is attached to. The pushrods that are going to be used are going to be made using a small diameter aluminum dowel that well be cut to the necessary size. The pushrods are connected to the servos and the flaps by linkages. The pushrods are bent at the end where they connect to the servo and are placed in a hole in the linkage that is glued to the output shaft of the servo. The other end of the pushrod is glued into the linkage that is connected to the flap. The linkages that are going to be used on the plane are going to be prefabricated, store purchased, or donated, typical RC plane linkages. They are typically made of plastic and are connected to the plane by screws, adhesive or a combination of the two. The connection of the flap, by the use of linkages and pushrods, to the servo are shown in Figure 8.
Figure 8: Connection of a flap to a servo using linkages and a pushrod [?]

The battery packs and wiring are going to be store bought or donated and have to be at least 500 mA-h, as stipulated by the SAE requirements. For the initial design it is expected that two 6 volt, NiMH battery packs will be used to power the five servos. The battery packs will be located in the fuselage and will be connected to the servos by the wiring harness. It is also expected that a third battery pack of a different voltage will be used in the remote controller.

Design considerations that will need to be taken into account to prevent failure will be the possible overload of the batteries when multiple servos are operated together. For instance when turning the rudder and ailerons will be used simultaneously, and draw a load for four to six servos at the same time. If the batteries are over loaded the servos won’t operate correctly and loss of control could occur. Also, the placement will have to be precise in order to have balance and minimize vibrations. Because there is also a “slop” test performed by the judges prior to each flight to make sure that there is no give in the controls the linkages will have to be tight and properly put together. There is also a requirement for servo testing in the design report that will be turned into SAE prior to competition.

Note: Some of the items discussed in this section, as stated, are going to be prefabricated, store purchased, or donated items in order to save the team time and money.

**Possible Design Modifications**

The basic airfoil shape and design should essentially provide the lift required to provide acceptable lift to drag ratios. However through the projected tests to the airfoil sections, additions to or modifications of the airfoil may be required to increase the effectiveness of the wing. In this section, possible design modifications and design alternatives will be discussed to promote a more efficient design using the given parameters of the SAE Aero Design competition.

Beginning at the leading edge, a possible modification to the wing is the addition and use of fixed slats, referred to as slots. Slats, as a general description, are small aerodynamic surfaces on the leading edge of the wings of fixed-wing aircraft which, when deployed, allow the wing to operate at a higher angle of attack [9]. For the wing
design proposed, a moving slat would add additional weight and increase the level of complexity to the wing design that is undesirable, so the use of the fixed slat or slot, would be the desired version of this modification.

Essentially the slot pulls air from high pressure flow underneath the wing after separation, and pulls it up to the boundary layer of the low pressure as shown in Figure 9. This action produced by the “venturi effect” [10] accelerates the air between the wing and the slot increasing the longevity of the boundary layer. According to Zenithair, the addition of slots can increase the stall angle of attack up to 30 degrees. This increase in the stall angle allows for a much steeper and quicker ascent, which for planes taking off on very short runways, such as in Africa or jungle clearings, is very advantageous. A significant drawback to the use of slots is the increase in drag at cruise speed. However, in the course of this SAE competition the cruise speed is not judged in value or efficiency. The use of slots for increased lift at takeoff would be very advantageous for the limited takeoff space required to produce a good showing at the competition.

![Figure 9: Flow diversion by slots [10]](image)

Traveling across the wing surface to roughly the trailing edge provides another possible addition to the wing in the interest of flow efficiency. A blown flap is a “small amount of the compressed air produced by the jet engine is ‘bled’ off of the compressor stage and piped to channels running along the rear of the wing. There it is forced through slots in the wing flaps of the aircraft when the flaps reach certain angles. This air follows the flap profile, aimed downward to provide more lift. The bleed air prevents the boundary layer (slow-moving air that accumulates on the airframe surface) on the upper surface of the flap from stagnating, further improving lift.”[11]

The use of the blown flap would be achieved by the redirection of the exhaust from the engine to the wings, as shown in Figure 10. This modification is assumed to be an allowed modification to the airplane. Because the preliminary design does not include fully operational flaps, this concept would be adapted to the trailing edge of the wing. Through the course of future wind tunnel tests, the placement of the holes/exhaust points on the wing surface would be determined to increase the maximum efficiency and the reduction of air stagnation on the upper portion of the wing. The successful adaptation of this concept would: 1) increase the efficiency of the airfoil; 2) increase the attack angles utilized during takeoff; and 3) decrease the speed required for successful landing leading to better control and a more accurate pinpoint landing.
However there is a significant drawback to the use of blown flaps, especially if used from the straight exhaust of the engine. In designs used by Lockheed in their F-104 Starfighter, issues with clogging occurred, creating a maintenance nightmare. In the scope of this design, before each run and test, a flush of the ports would be recommended to eliminate failure. As a fail safe, a blow off valve could be used in the event of a major clog to prevent the engine from failing mid-flight.

A staple in most modern aircraft design is the use of ailerons on the trailing edge. Ailerons are small hinged sections on the outboard portion of a wing. Ailerons usually work in opposition: as the right aileron is deflected upward, the left is deflected downward, and vice versa as illustrated in Figure 11. Ailerons adjust the roll of the aircraft. This modification is advantageous for sharper turns, by using the lift created by the wings to help turn the aircraft.

The usage of ailerons on the cargo plane would be advantageous to the aerodynamic stability of the aircraft. However, the use of ailerons could become a repetitive factor through the use of independently controlled elevators (normally control
the pitch of the aircraft) in the tail. This concept and assumption will need to be field tested during the course of the final test phase in the Spring 2008 semester. The drawback to this addition is weight that would be concentrated at the wing tips which would further limit the aspect ratio available for the wings.

Winglets

Winglets were originally designed by Frederick W. Lanchester in 1897. The initial concept was created to control the vortices off of the wingtips. The concept was further refined by Richard T. Whitcomb, of the NASA Langley Research Center, in the late 1970s in response to the oil crisis of 1973. The wing tip is most commonly seen on fixed wing aircraft such as the Boeing 747 Shuttle Carrier Aircraft.

The winglet allows for a greater lift-to-drag ratio by limiting the effect of wingtip vortices, thus reducing the lift induced drag. The addition of the winglet also increases the aspect ration without greatly increasing the wingspan.

![Figure 12: Blended winglet of a Boeing 737-800](image)

The winglet dimensions however must be controlled and unique to the airplane design. Consideration as to the angle of the winglet in relation to the wing and the size of the winglet must be determined before implementation. A drawback to the winglet is it increases the parasitic drag, requiring an additional lateral reinforcement of the wing.

For the airplane considered in this project, the winglets would be a readily available design addition that would assist in the goal of a high aspect ratio. The benefits would include a more efficient wing design, shorter takeoff distance, and greater range of the aircraft.

Raked Wingtip

An addition to the wing that is very similar in purpose to the winglets is the raked wingtip design. The raked wingtip increases the range of an aircraft as well as the climb performance and shortens the takeoff field length. According to test conducted by NASA in conjunction with Boeing, raked wingtips reduce the induced drag by up to 5.5% as opposed to winglets at 3.5% - 4.5%. (1) The main advantage over the winglet is that in addiction to reducing drag it also adds lift, because of the increase in wingspan.
The use of the raked wingtip for this project would also be a good addition to the design because of the increase in the aspect ratio, and by shortening the takeoff distance the aircraft should be able to lift more, given the constraints of the competition.

**Plan of Execution**

The team will be following the initial schedule shown in Table A-1 in Appendix I. In order to achieve success in the project, the team will work to secure funding early on, as well as perform testing of materials and aerodynamics as soon as possible. The research will include computational modeling of the aerodynamics and structure, as well as testing the engine and possible materials, before construction begins.

**Budget**

<table>
<thead>
<tr>
<th>Description</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration fee</td>
<td>$350.00</td>
</tr>
<tr>
<td>Control systems/electronics</td>
<td>$600.00</td>
</tr>
<tr>
<td>High density foam</td>
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<tr>
<td>Balsa wood</td>
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<tr>
<td>Coverite 21st Century Film</td>
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<tr>
<td>Epoxy &amp; Carbon Fiber</td>
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<tr>
<td>Miscellaneous Supplies</td>
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<tr>
<td>Travel Costs</td>
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</tr>
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</table>

**Table 1: Team Budget**

Table 1 is the current estimate on the building costs required for this project. The primary spending that will occur is the Registration Fee, which is needed at the time of registration. The remaining expenses cover the cost of building. We did receive the motor used by the previous SAE team, allowing us to have a motor to use during testing. The high density foam will be used as the airplane’s fuselage, while the balsa wood will make up the wings and cargo box. The Coverite 21st Century Film is a plastic shrink covering which will be used to cover the wings and possibly the fuselage, providing a tough skin to the airplane’s structure from getting puncture damage.

**Organization and Capabilities**

Table 2 shows the members of our team, as well as the members’ field of engineering, areas of responsibility, and qualifications. This information is based on the courses taken by the team members as well as their past experiences and workings dealing with the engineering field.
<table>
<thead>
<tr>
<th>Team Member</th>
<th>Area of Responsibility</th>
<th>Qualifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jeff Gibson (AE)</td>
<td>Leader, Structures</td>
<td>Previous leadership experience in freshman design, structures knowledge</td>
</tr>
<tr>
<td>Steven Tucker (AE)</td>
<td>Aerodynamics, Structures</td>
<td>Aerodynamics and structures knowledge</td>
</tr>
<tr>
<td></td>
<td></td>
<td>public relations experience</td>
</tr>
<tr>
<td>Ray Klingerman (ME)</td>
<td>Control Systems, Structures, Computer Modeling</td>
<td>Knowledge of circuits and control systems, expertise in CAE, CAD, and drafting</td>
</tr>
<tr>
<td>Joe Walk (AE)</td>
<td>Aerodynamics, Testing</td>
<td>Knowledge of aerodynamics, lab testing and research skills</td>
</tr>
<tr>
<td>Sarah Lagerquist (AE)</td>
<td>Structures, Materials, Testing</td>
<td>Structures and materials knowledge, research and testing experience</td>
</tr>
<tr>
<td>Jennifer Allison (AE)</td>
<td>Structures, Materials, Funding</td>
<td>Structures and materials knowledge, experience with public relations</td>
</tr>
<tr>
<td>Dan Denmark (ME)</td>
<td>Control Systems, Structures, Computer Modeling</td>
<td>Experience in CAE, CAD, structural analysis</td>
</tr>
<tr>
<td>Kathleen Murray</td>
<td>Structures, Master Builder</td>
<td>Expertise in structural design, machine shop certified</td>
</tr>
</tbody>
</table>

Table 2: Team Members, responsibilities, and qualifications

Progress

As of the date of this report, the team has made the following progress:
- Finalized the type of materials that will be used (balsa for the wing structure, composites for the fuselage).
- Narrowed overall dimensions down to several design options based on the size requirements.
- Decided to pursue a tandem wing design for increased lift and stability.
- Completed and submitted a more accurate budget to the school.
- Created plans for the mounting plate necessary to use the R/C engine test stand.

In the next few weeks, the team will attempt to accomplish the following goals:
- Test the engine in the wind tunnel with various propellers to determine which is best suited for our application, and to determine the maximum thrust each can produce at various speeds.
- Develop and analyze designs for the internal wing and fuselage structure.
- Research analysis methods pertaining to the downwash effects on the rear wing.
- Begin actively requesting funding/support from outside sources.
- Develop and analyze designs pertaining to aerodynamics (wing size, placement) based on data obtained regarding engine thrust.
Summary

The main purpose of this project is to design and create an aircraft that will compete and place well in the 2008 regular class SAE Aero Design competition. The proposed design is an aircraft with a high aspect ratio wing and high lift airfoil. The aircraft will be constructed mainly with composite materials, and use “off the shelf” control system components. Success will be achieved by performing extensive testing and optimization of the design, and by perfecting the construction of the final aircraft. Because part of the competition involves presentation of the design, analysis will be conducted such that the team can accurately predict the capabilities of the design, and be able to evaluate its merit. The expected result of the design project is that Florida Tech will enter the competition for the first time in several years and enter it with a design that will perform well against the other competing schools.
References


#### Table A-1: Initial Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>Start</th>
<th>End</th>
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<tbody>
<tr>
<td>2 Preliminary Design</td>
<td>8/31/2007</td>
<td>9/14/2007</td>
</tr>
<tr>
<td>5 Funding Support</td>
<td>8/31/2007</td>
<td>9/14/2007</td>
</tr>
<tr>
<td>6 Submit Final Budget</td>
<td>9/7/2007</td>
<td>11/12/2007</td>
</tr>
<tr>
<td>11 Written Proposal</td>
<td>9/7/2007</td>
<td>9/14/2007</td>
</tr>
<tr>
<td>13 Draft - Final</td>
<td>9/7/2007</td>
<td>9/14/2007</td>
</tr>
<tr>
<td>14 Final - Final</td>
<td>9/7/2007</td>
<td>9/14/2007</td>
</tr>
<tr>
<td>16 Construction</td>
<td>1/7/2008</td>
<td>3/10/2008</td>
</tr>
<tr>
<td>17 Testing/Redesign</td>
<td>3/10/2008</td>
<td>4/12/2008</td>
</tr>
<tr>
<td>18 Competition</td>
<td>4/12/2008</td>
<td>4/12/2008</td>
</tr>
</tbody>
</table>