Conceptual Design Report

EML4551-C Senior Design, Fall 2012, Deliverable

AIAA Design Build Fly Competition
Group # 16 (G16)

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Introduction

The mission of the 2012-2013 AIAA/Raytheon/Cessna Design Build Fly Competition is to design, fabricate and demonstrate the flight capabilities of an unmanned, electric powered, radio controlled aircraft which can best meet the specified mission profile. The goal is a balanced design possessing good demonstrated flight handling qualities and practical and affordable manufacturing requirements while providing a high vehicle performance.

Photo 1: 2010/2011 Design Build Fly Team Working on Air Hercules

Each of the three flight missions requires a different aeronautical skill set to compete successfully. Mission 1 entails a high degree of speed and flight control, the basis of the mission is to fly the largest amount of laps around the flight course in a given amount of time. Mission 2 requires the aircraft to house a number of internal stores (model rockets), the number of which will be decided by the design team, with the flight score being determined by the maximum amount of stores the aircraft can carry for three laps around the flight course. Mission 3 adds the element of external stores (model rockets); the orientation of these stores will be decided by the roll of a dice and is based on the pre-determined orientation chart below. The scoring of this mission is based on the fastest time around the 3-lap flight course.

Competition Overview

General Mission Requirements

The general requirements for this year's competition have several design constraints and specifications as listed below:

- Can be of any configuration other than rotary wing or lighter than air.
- Must be propeller driven and electric powered by NiCad or NiMH batteries.
- Maximum propulsion battery weight of 1.5 lb.
- Maximum current draw of 20 amps.
- Aircraft must take off from a static position for all missions.
- Payloads must be secured; internal payloads must me completely inside the body of the aircraft, and the external payloads must be separated by at least three inches.

The total flight score is calculated from equation 1:

$$Flight\ Score = M1 + M2 + M2 \qquad (1)$$

Where M1 is the flight score from mission one, M2 is the flight score from mission 2, and M3 is the flight score from mission 3. This score comes into the calculation for the absolute total score that will determine the winner of the competition; the equation for the total score is given in equation 2:

$$SCORE = (Written\ Report\ Score) * \left(\frac{\text{Total Flight Score}}{\text{RAC}}\right) \qquad (2)$$

The written score report is determined from the final design report that is due at the latest February 25, 2013, the variable RAC stands for Rated Aircraft Cost and is given by equation 3 :

$$RAC = \frac{\sqrt{\text{EW} * \text{SF}}}{10} \qquad (3)$$

Where EW is the post flight weight with the payloads removed, and SF is the size factor of the aircraft and is determined by equation 4:

$$SF = X_{max} + 2 * Y_{max} \qquad (4)$$

Where X_{max} is the longest possible dimension of the aircraft in the direction of flight and Y_{max} is the longest possible dimension perpendicular to the direction of flight.

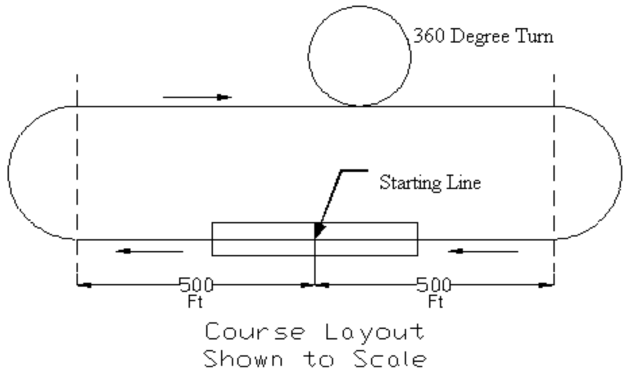


Figure 1: Flight course for all three missions.

Mission 1 - Short Take-off

In mission one the aircraft which has no payload, must start from a static position and from the time that the throttle is advanced forward the plane has to take off from within a thirty foot square on the runway and complete as many laps as possible; the laps must be completed as set by the flight course described in figure 1. The score for mission one is determined by equation 5:

$$M1 = 2 * \left(\frac{N_{Laps\,Flown}}{Max\ N_{Lapsflown}}\right) \qquad (5)$$

Where $N_{Laps\,Flown}$ is the number of laps flown by our team and $Max\ N_{Lapsflown}$ is the maximum number of labs flown by any team. From the criteria of mission 1 the aircraft must be light weight and highly maneuverable.

Mission 2 - Stealth Mission

In the second mission, the aircraft must complete a takeoff from the takeoff platform described in mission 1 as well as carry a maximized amount of internal stores. The score for mission two is given in equation 6:

$$M2 = 4 * \left(\frac{N_{Stores\,Flown}}{Max\ N_{Storesflown}}\right) \qquad (6)$$

Where $N_{Stores\,Flown}$ is the number of stores flown by our team and $Max\ N_{storesflown}$ is the maximum number of stores flown by any team. The stores that will be flown for mission 2 are the Estes Model Rocket kit Mini-Max which has dimensions of 9.75 inches in length and 0.98 inches in diameter. From the criteria of mission 2 the aircraft must have room to place stores securely inside the body of the aircraft.

Mission 3 - Strike Mission

In the third mission, the aircraft must takeoff with the same requirements listed in mission one, except a random payload configuration is determined by a roll of dice which is shown in figure 2.

Stores Configurations:

Payload Configuration (roll dice)		1	2	3	4	5	6
Internal	Mini-Max	4	-	2	-	-	-
Left Wing	Mini Honest john	-	-	-	2	-	-
	High Flyer	-	1	-	-	1	1
	Der Red Max	1	1	1	-	1	1
Right Wing	Mini Honest john	-	-	2	2	2	1
	High Flyer	-	1	-	-	-	1
	Der Red Max	1	1	-	-	-	-

Figure 2: Flight course for all three missions.

Mission three is timed for three laps, the time starts when the throttle is advanced and stops when the aircraft passes over the finish line in the air for the third time. The flight score for mission three is shown in equation 7:

$$M3 = 6 * \left(\frac{Fastest_{Time\ flown}}{Team\ Time_{flown}}\right) \tag{7}$$

Where Fastest time flown is the fastest time flown out of all competitors for three laps, and Team Time flown is the time that it took for our team to complete three laps.

Subsystems

Our concept generation will be based upon figures of merit determined from mission objectives outlined in the competition rules and through extensive research on aerodynamics and the physical dynamics of radio-controlled model aircraft.

Figures of Merit

• Weight - The weight of each component is very important and must be minimized.

• Drag - Drag opposes the thrust force generated by the motor which determines the amount of energy that must be drawn from the batteries. This is another very important figure that must be minimized.

• Lift - There must be sufficient lift to sustain flight with the maximum desired payload.

• Stability - The aircraft must carry out each required task reliably with very little performance fluctuation.

• Maneuverability - There must be effective control of the aircraft such that each mission can be performed with very little energy consumption or trouble.

• Durability - The aircraft must sustain light to moderate handling and the occasional rough landing.

• Storage Capacity - The payloads must securely store within the fuselage of the aircraft. It is required that the aircraft hold a maximum payload volume for a given design.

• Complexity - All required assembly must be completed with the available expertise.

• Manufacturability - All manufacturing must be completed with the available facilities

• Cost - All components must be made such that they may be replaced during prototype crashes.

Wing

The main wing must be able to accommodate external payloads, as well as the loads of the aircraft itself. Therefore, the main wing must be strong. It must also allow the aircraft to be aerodynamically efficient. The aspect ratio (wingspan to area of the wing platform) and airfoil are the key components when selecting a main wing.

The lifting device that we will implement will be required to develop sufficient lift of the aircraft in order to takeoff in the specified 30 foot square. The lifting device will also have to be limited on the induced drag that it produces such that it will be able perform the above stated task. The lifting device structure will also have to sustain loads on the scale of 2.5 g's in order to pass the preflight test, this will consist of a spar running the length of the lifting device's structure to guarantee that the lifting device can pass the above stated test performed by the competition judges. The material of the lifting device will have to be light enough to reduce weight but strong enough to provide a safe range in order to prevent sufficient damage if an accident does arise.

- **Delta Wing** - Triangular shaped single wing that broadens from tip to tail. Rigid structure and large carrying capacity are two major advantages. Most delta wing aircraft are used in supersonic applications.
- **Monoplane** - A highly conventional single wing which runs normal to the direction of flow across the fuselage.
- **Flying Wing** – Integrated body and wing type aircraft. If constructed ideally, it has very high aerodynamic efficiency. However, it is a difficult type of aircraft to stabilize and store internally, so it is simply wrong for this competition.
- **Canard** - Two smaller wings positioned forward on the aircraft which are intended to provide more lift and more control characteristics.
- **Biplane** - Two full-sized wings placed above one another for greatly increased lift. Greatly increased weight is a concern.

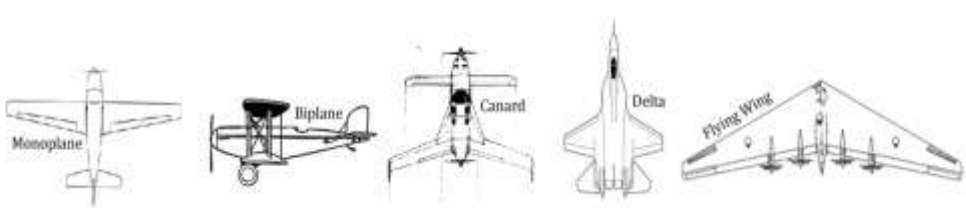


Figure 3: Wing Layout

FOM	Weight Value	Wing Types				
		Mono	Flying Wing	Delta Wing	Biplane	Carnard
Weight	0.2	4	1	4	1	3
Drag	0.2	4	3	1	2	2
Lift	0.3	3	4	3	5	4
Stability	0.15	4	5	3	5	3
Complexity	0.15	5	1	3	4	2
Total	1	3.85	2.9	2.8	3.45	2.95

Table 1: Wing Type Decision Matrix

Table 1 illustrates the most effective wing type for our aircraft design is the monowing type because of the simplicity in the design and the overall high score that it received in our decision matrix.

Fuselage

Figure 4: Fuselage Configurations

The fuselage contains its own subsystem set. They include a payload area, an electronics/control systems bay, and other possible servo areas. The payload area will be strictly dependent upon the minimum amount of payloads (4) that we must fit inside of the aircraft, while maintaining a low structural weight. The electronics bay is where the propulsion battery pack, motor (all battery packs must have a combined weight of no more than 1.5 pounds) and fuse should be located outside of the body of the aircraft.

FOM	Weight Value	Fuselage Types		
		Single Boom	Double Boom	Blended Body
Weight	0.4	3	1	4
Drag	0.2	4	2	5
Durability	0.1	4	3	5
Storage Capactiy	0.3	4	5	1
Total	1	3.6	2.6	3.4

Table 2: Fuselage Type Decision Matrix

Table 2 demonstrates that the most effective fuselage type for this year's competition is the single boom configuration because the design has relatively high storage capacity and durability while maintaining low drag as shown by the decision matrix.

Tail Section

The tail is largely responsible for climb rate and pitch control. Its selection is a function of balancing the lift and other moments generated by the rest of the aircraft. In a word, stability is the job of the tail. The tail needs to be rigid as to prevent any tail-induced instability of the aircraft in flight. Weight is not as important here because in comparison to the entire aircraft, the tail section is relatively light.

- **Conventional** – Rudder normal to wing, vertical stabilizer parallel to wing.
- **T-Tail** – Rudder normal to wing, vertical stabilizer above rudder
- **Twin Tail** – Dual Rudder, vertical stabilizer at bottom between rudders
- **V-Tail** – Rudder and vertical stabilizer blended into two V-configured rudders.

Figure 5: Tail Layouts

FOM	Weight Value	Tail Types			
		T-Tail	V-Tail	Twin Tail	Conventional
Weight	0.15	3	4	3	3
Drag	0.2	3	5	3	4
Stability	0.35	3	2	3	5
Control	0.2	4	2	4	5
Complexity	0.1	3	2	3	4
Total	1	3.2	2.9	3.2	4.4

Table 3: Tail Type Decision Matrix

Table 3 gives the decision matrix for selecting the best tail configuration given the constraints and requirements for this year's competition, the conventional tail type exhibited high stability and control which are very important in the above described missions.

Electronics and Propulsion

Propulsion System

The propulsion system should include a battery pack, motor, and propeller. The propulsion system is where the thrust for the aircraft will come from. The thrust greatly affects the speed and climb rate of the aircraft.

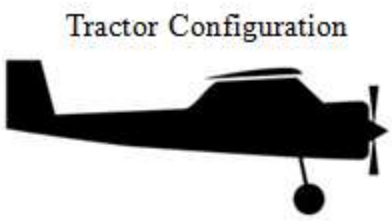
The propulsion of the aircraft will be required to develop enough thrust in order to get the aircraft up to speed within the allotted space. The propulsion system will consist of a motor, a battery pack to power the motor and a propeller that the motor will turn which will develop the thrust needed. The maximum allowed current draw for propulsion is 20Amps.

Control Surfaces

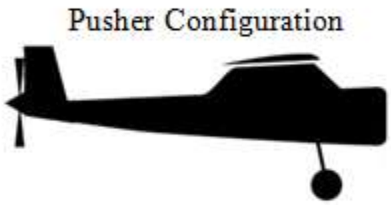
For the control system, there is a radio controller and receiver, transmitter, as well as a speed controller. The radio controller allows the aircraft to use the required fail-safe mechanism, which is required by competition rules, and causes the aircraft to enter a descending spin to the ground for safety reasons. There are multiple servos that will control different parts of the aircraft such as the rudder, elevator, and aileron.

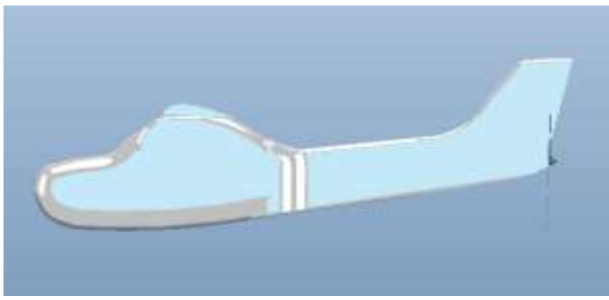
There will have to be at least three main control surfaces: aileron, rudder, and elevator. Flaps are an additional option if that design concept is accepted. The ailerons will be attached to the trailing edge of the lifting device and will be responsible for producing more lift on one wing while decreasing the lift on the other wing; this will result in a banking effect of the aircraft. The rudder will be conjoined with the vertical stabilizer in order to direct air in one direction which will produce a yaw effect on the plane; this effect in turn with the bank created by the ailerons will control the horizontal movement of the aircraft from side to side. The elevator will be conjoined behind the horizontal stabilizer in order to produce a moment about the tail of the aircraft in order to pitch the aircraft up or down depending upon the desired movement of the aircraft and thus will produce more lift or less lift depending upon the angle of attack. Flaps are an additional option which would help in developing lift on the takeoff roll and would increase the rate of descent without increasing the airspeed of the aircraft.

Engine Configuration



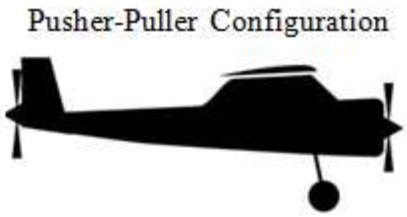
The tractor design has several distinct advantages. The thrust produced by the most forward part of the plane has the tendency to stay in the direction of flight making them naturally stable and having a positive dynamic stability. The weight of the engine and all components that make up the engine being focused at the front of the body tends to shorten the fore body which allows for a smaller tail area and additional improved stability, this also leads for a balanced center of gravity needed for flight whether the gyro is lightly loaded or is at full gross weight. The location of the tractor allows for the propeller to operate in undisturbed air allowing for more efficient thrust. When the propeller is set up in the tractor configuration it prevents the chance of ground contact and thus damage to the propeller while in the landing or takeoff sequence of flight, this also allows for use of a bigger size of propeller which adds to better performance.

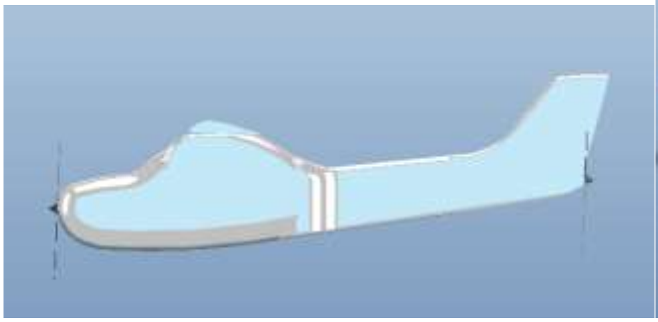


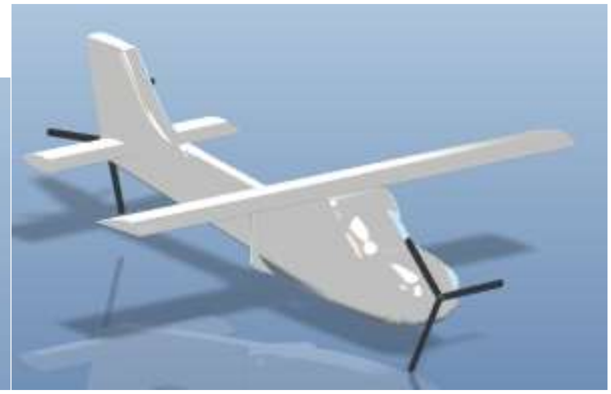


A “pusher” type plane is defined as having the propeller behind the engine as well as to the rear of the main lifting surface as shown in the depiction above. This specific positioning has been used on many different planes throughout history including the Wright brother’s “Wright Flyer”.

The rearward pusher propeller design offers many advantages, however the most important in our considerations would likely be the increased cargo space inside the front-most area of the fuselage. The absence of the front engine allows for more open area in the largest portion of the plane’s fuselage, which would enable our plane to carry more internal stores than a plane of similar size using a tractor layout. Another advantage comes from the increased protection of the propeller during a possible crash, since the prop is not extending forward from the airframe as in a tractor style aircraft; it stands a better chance of surviving a rough landing.

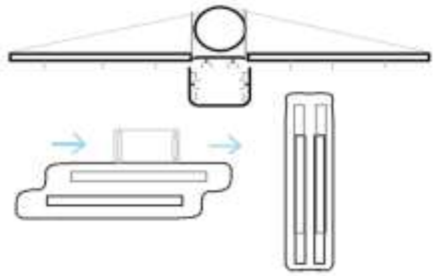


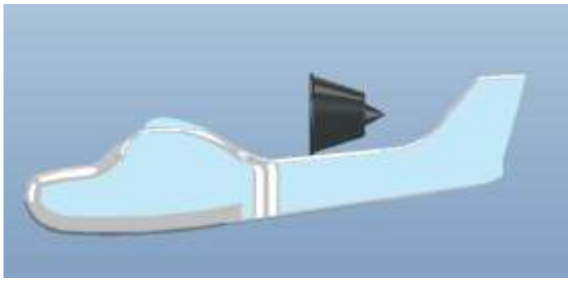


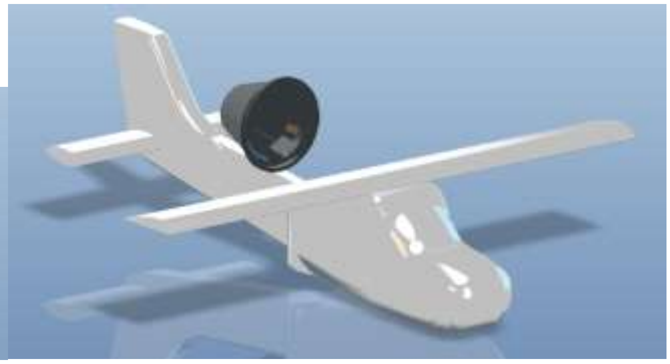


The concept of the pusher-puller aircraft is to have the tractor (puller) propeller mounted on the front of the plane, with an additional "pusher" propeller mounted on the back of the aircraft near the tail. This is known as the 'center line thrust' configuration as well. Using this configuration has a few advantages.

The first benefit of this layout is a reduced frontal area. Additionally, any problems associated with engine failure can be eliminated due to there being multiple engines involved. If one fails, the other would take over fully. Engine power would be maximized along the plane center line, creating greater thrust and therefore more speed from the plane. This also enables the aircraft to be more aerodynamically efficient as well. Meaning reduced drag over the wings and the plane still having a good amount of maneuverability as well.







A ducted fan, aside from simply serving as a propulsion option, would serve several other functions on this aircraft. The reason to consider a ducted fan in this design is primarily to move the flow trajectory due to the thruster out of the line of motion of the fuselage. By mounting the ducted fan, the thrust will not be scattered by the bulky cargo-carrying fuselage. Another useful function of a top-mounted ducted fan is the opportunity for an inverted strut. If we have a ducted fan, we must mount it using plates. Those plates can potentially be fastened to a wire which would add support to the wings from the top. The benefit of eliminating bottom struts is to remove interference with payload mounted on wing hard points. The addition of these mounting plates and support wire would cost virtually no additional drag or weight when compared with under wing struts.

FOM	Weight Value	Engine Configuration			
		Tractor	Pusher	Tractor-Pusher	Ducted Top-Mounted Tractor
Weight/Balance	0.4	5	4	5	2
Efficiency	0.4	4	4	3	3
Complexity	0.2	5	4	2	3
Total	1	4.6	4	3.6	2.6

Table 5: Engine Configuration Decision Matrix

Table 5 illustrates the decision matrix for selecting the most efficient engine configuration for the competition; the tractor was selected because of the well maintained weight and balance of the aircraft and the simplicity in the design as well as providing the propeller with clean air for high efficiency.

Conclusion

Although our research is not yet complete, the project appears to look like some of the illustrations shown. The aircraft will likely take on traditional high-wing single-prop monoplane characteristics in order to achieve efficient, stable, and controllable flight. Furthermore, with the basic decisions made from the information in this report, we intend to proceed by designing specific geometry. This geometry will be custom fit to efficiently carry the payloads required by the competition. The specifications will all be iteratively tailored in order to create the greatest possible advantage in each specific mission.

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