Lighter than Air UAV

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Abstract- **ASME competitions challenge the best and brightest engineering students in North America to compete against one another. The competitions are different every year to ensure that student designs are started from scratch. This year's challenge is for student teams to construct an unmanned aerial vehicle or UAV.**

The completed UAV must be able to navigate the ASME course. The course will include two, five meter x two meter gates and a .71m diameter hoop that the UAV must pass through. The UAV will also earn bonus points for carrying a payload and dropping it on a target. The control and propulsion system must be designed by the student team to prevent a team from buying a remote controlled helicopter to enter the Lighter than Air UAV competition.

The UAV constructed by each team must meet the following ASME Lighter than Air UAV requirements:

1. **The vehicle must be powered by batteries.**
2. **The Device must be controlled through a wireless transmitter/receiver radio link.**
3. **A radio transmitter may have its own batteries rechargeable or non-rechargeable.**
4. **The transmitter/receiver radio link may be any commercially available model controller.**
5. **During the trial, the device must be completely controlled via the radio link no other contact, interaction or influence is permitted.**
6. **One team member must control the device throughout the trial.**
7. **All radio controllers will be impounded and shut off during the competition, except during the team's run.**
8. **All devices must have a readily accessible and clearly labeled master shut-off switch.**

The WVU Tech team has made steady progress towards the goal of competing in this competition. Design of the UAV began with the fall semester and the WVU Tech UAV is estimated to be 80% completed. A frame design has been completed and manufactured after verifying our calculations with a finite element analysis. Electronic components have been purchased and mounting fixtures for these components are currently being designed.

I. INTRODUCTION

UAVs were originally developed by the United States Military to execute sorties or flights over hostile areas. The goal was to keep human pilots out of harm's way. UAVs, like the Predator, allow a pilot thousands of miles away to fly a small aircraft in hostile environments.

A UAV can be a fixed or rotary wing aircraft. Well known UAVs, such as the predator, are controlled remotely though a satellite link. Predators and other types of UAVs are becoming more popular with both military and private organizations.

Nonmilitary organizations are gaining an interest in UAVs for other purposes. These companies and organizations foresee several uses for UAVs, such as hurricane hunting, 3D mapping, wildlife protection, and crop dusting.

The purpose of the "lighter than air UAV" is to show that simple and affordable UAVs are possible. Showing that this is possible opens the door to many future possibilities for personal and business uses. The WVU Tech UAV will help UAVs from other schools prove this idea is possible.

II. THEORY

Most people may be able to build a UAV or quad-rotor with the right parts. However, not just anyone can understand how the UAV actually flies and the many calculations that go into figuring the thrust of the propeller/motor combination and the drag force. This section is dedicated to describing some of those equations and what they mean.

The following aerodynamic force equations are used every day in the avionics field and any flight calculations,

Thrust Force;

Is the result of the vertical forces acting on all the blade elements, and is given by the following equation,

$$T = C_T * \rho * A(\Omega * R_{rad})^2 \qquad (1)$$

Where,

T = Thrust Force
C_T=Thrust Force Coefficient
ρ=Density of air
A = Propeller disk area
Ω=Propeller angular rate
R_rad=Rotor radius

Hub Force;

Hub Force is similar to the thrust force, however it is the resultant of all the horizontal forces acting on all of the blade elements and is given by the following equation,

$$H = C_H * \rho * A(\Omega * R_{rad})^2 \qquad (2)$$

Where,
H = Hub Force
C_H=Hub Force Coefficeint
ρ=Density of air
A = Propeller disk area
Ω=Propeller angular rate
R_rad=Rotor radius

Drag Moment;

This moment about the shaft of the rotor is caused by all the forces acting on the blade elements, thrust and hub force, the horizontal forces. However, these forces are multiplied by the moment arm and integrated over the rotor. The drag moment determines how much power it will take to spin the rotor and is given by the following equation,

$$Q = C_Q * \rho * A(\Omega * R_{rad})^2 * R_{rad} \qquad (3)$$

Where,

Q = Drag Moment
C_Q=Drag Coefficeint
ρ=Density of air
A = Propeller disk area
Ω=Propeller angular rate
R_rad=Rotor radius

Rolling Moment;

The rolling moment happens in forward flight, when the most forward blade is making more lift than the retreating one and is given by the following equation;

$$R_m = C_{R_m} * \rho * A(\Omega * R_{rad})^2 * R_{rad} \qquad (4)$$

Where,

R_m = Rolling Moment
C_(R_m)=Rolling Moment Coefficeint
ρ=Density of air
A = Propeller disk area
Ω=Propeller angular rate
R_rad=Rotor radius

The preceding equations and explanations of the equations were obtained from biblion.epfl.ch for a full cite of the author please see the works cited page reference [1] and [2].

III.   SAMPLE CALCULATIONS

Thrust Force;

$$F_T = C_T * \rho * A(\Omega * R_{rad})^2$$

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}9.5^2$$
$$A = 70.8822 \ in^2 = 0.04573 \ m^2$$
$$C_T = 0.048$$
$$\rho = 1.20 \ \frac{kg}{m^2}$$
$$\Omega = 8000 \ rpm = 837.758 \ \frac{rad}{s}$$
$$R_{rad} = 4.75 \ in = 0.12065 \ m$$

$$F_T = 0.048 * 1.20$$
$$* 0.04573(837.758 * 0.12065)^2$$
$$F_T = 26.9101 \ N$$

Drag Force;

$$F_D = C_D * \rho * A(\Omega * R_{rad})^2 * R_{rad}$$

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}9.5^2$$
$$A = 70.8822 \ in^2 = 0.04573 \ m^2$$
$$C_D = 0.006$$
$$\rho = 1.20 \ \frac{kg}{m^2}$$
$$\Omega = 8000 \ rpm = 837.758 \ \frac{rad}{s}$$
$$R_{rad} = 4.75 \ in = 0.12065 \ m$$

$$F_D = 0.006 * 1.20$$
$$* 0.04573(837.758 * 0.12065)^2$$
$$* 0.12065$$
$$F_D = 0.40584\ N$$

After performing the calculations the actual thrust force that can be expected at 8000 rpm with a 9.5 in propeller is around 26.5 N. This applies to each motor. After multiplying the actual thrust force by four the total system thrust available at 8000 rpm is about 106 N.

IV. EQUIPMENT

The following table illustrates the component to be used on the UAV. The table includes the price, and the supplier they were received from. However, this is a tentative list of parts and subject to change due to the availability of parts or difficulties applying the part to our application.

Table 1. Parts List and Budget Analysis for UAV Project

Part Name	Quantity	Retailer	Price ($)
350 QX RTF with SAFE Technology by **BLADE** (BLH7800)	1	Ed's RC	409.99

From Table 1 the only item that will be bought for this project is a UAV (quadcopter). The quadcopter chosen has the equivalent parts that are desired for the UAV design. This was a significantly cheaper alternative to buying all of the necessary parts to build the UAV. The strategy has remained the same, but now we must dissect or "can" the parts needed from the pre-built UAV.

More components may be required depending on the outcome of the construction phase. Potential mistakes could result in unserviceable components. Another battery may be purchased. Having an extra battery allows us to test and practice with one battery and compete with a brand new battery. The practice battery will be kept as a spare part for the competition.

Figure 1 shows the pre-built UAV that we will be harvesting the parts from. The blades or propellers will be used along with the motors. Underneath the plastic shell is the flight control board, speed controller, and other electrical components that will be used to construct the prototype UAV.

Some of the other parts included in the pre-built UAV will are the battery, which can be used in our prototype, and the connecting wires for the various electrical components. Figure 1 also shows the pre-built UAV with a camera already installed, however this is an extra item that has to be installed separately. A camera will not be used with our prototype.

The salesman and owner of the retail store where the pre-built UAV was purchased also provided useful insight in to quadcopter technology. Instead of trying to supply the power we need by using a bigger motor, the owner recommended that the propellers be geared. Integrating a gearbox into the design provides more torque to the propeller and in turn more lift.

V. PROCEDURE

The following procedure will be followed as closely as possible for the design, construction, and testing of the UAV.

The procedure is listed in the following steps,

1. Build a competitive UAV according to the ASME Lighter than Air UAV competition rules in order to compete in the competition.
2. Design a frame for the UAV to be light and also strong
3. Make sure the UAV is smaller than 28 inches overall
4. Assign proper components to the UAV and ensure everything functions as a system
5. Achieve flight after the construction of the UAV
6. Be able to effectively control the flight of the UAV
7. Apply an additional payload for the UAV to lift
8. Design a releasing mechanism in order to drop the payload
9. Sustain the flight of the UAV for at least 15 minutes
10. Achieve the best score possible in the competition

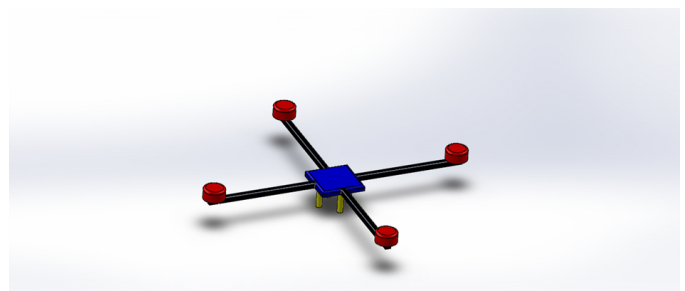

Figure 1. Pre-built UAV (XC 350)
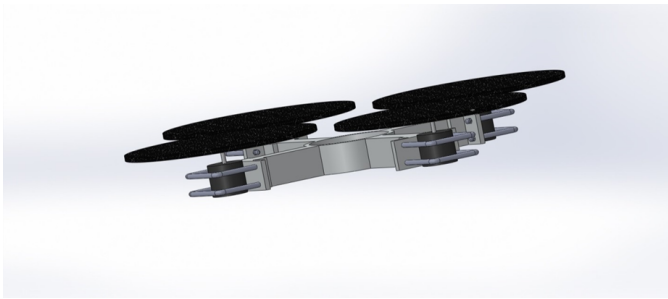

Figure 2. First Design
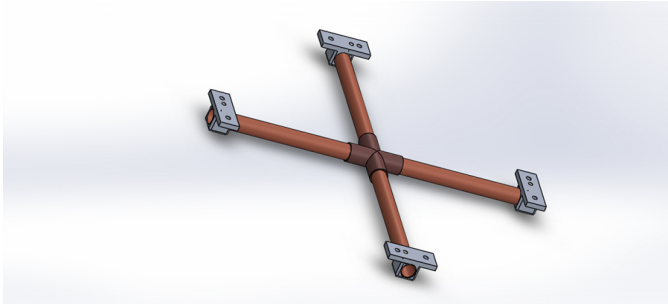
Figure 2. Design as of October 17, 2013

Figure 3. Design as of February 07, 2014

VI. RESULTS

Through our observations we have concluded that the UAV needs to be as light as possible. The UAV will also need to produce the maximum amount of thrust. To do this some sacrifices were made. The equipment we originally selected would create a tremendous amount of heat while consuming the battery supply in a matter of seconds. The team compromised by selecting slightly smaller motors with the same battery setup.

Originally an aluminum frame design was drawn, but after analyzing the calculations a lighter frame was preferred. However, the team was forced to use donated copper tubing for the frame due to lack of funding. According to our calculations this combination will create more than enough trust for a 4000 gram total capacity, and a battery life expectancy of around 30 minutes.

The team created a model drawing of the UAV using the software SolidWorks. Within the model some calculation were completed including:
• Area of rotors
• Moment created from 2kg pay load
• Power loading
• Thrust loading
• Lift
• Shear stress on arms

Table 2: Engineering Parameters

| Engineering Characteristic	Equation	Value
Area of Rotor	$(\pi/4)*$(diameter of rotor)	50.27 in^2
Power Loading	Horsepower of motor/Area of rotor	0.0139 HP/in^2
Thrust Loading	$8.6859 *$ (Power Loading) $^{(- 0.3107)}$	33.4279 in^2/HP
Amount of Lift	Thrust Loading/Horsepower of motor	23.3995 kg/HP
Moment Created from 2kG Pay Load	(2kG pay load)(2.20462) *Length of arm	52.9109 in*lb
Shear Stress on Arms	Moment created on Arm/Area of arm	8.82 lb/in^2
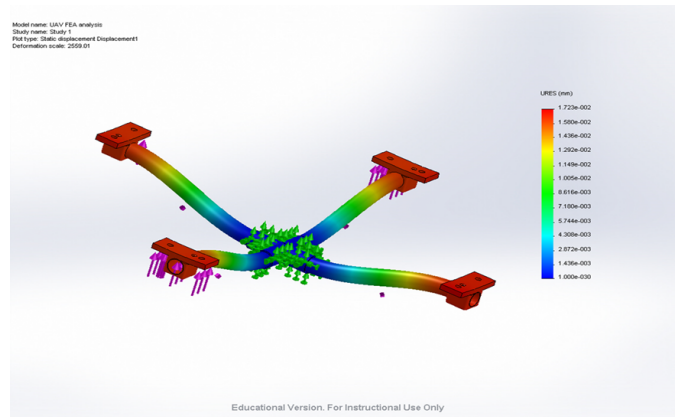
Figure 4. Displacement Diagram
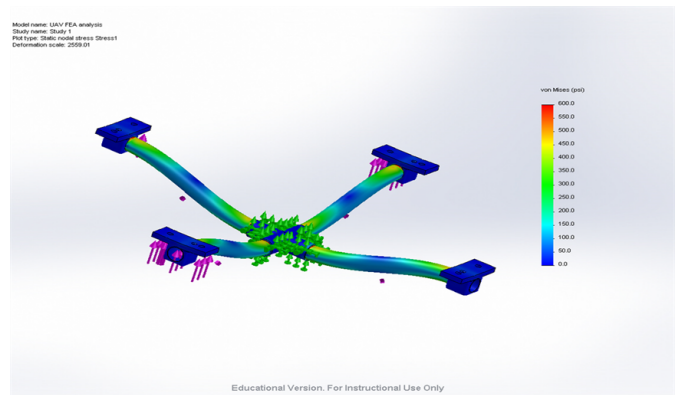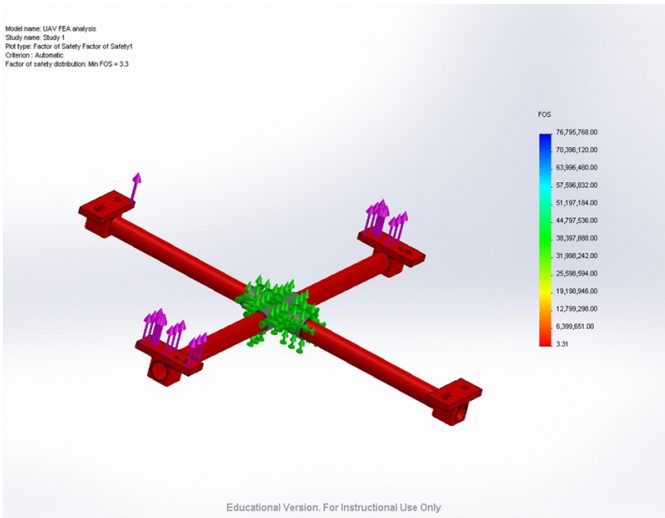

Figure 5. Stress Diagram
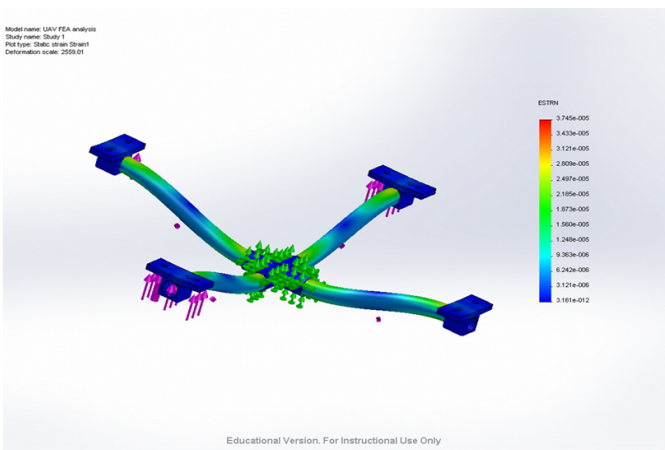
Figure 6. Factor of Safety

Figure 7. Strain Displacement

The preceding figures show a finite element analysis (FEA). A finite element analysis is an analysis that accounts for the stresses, strains, displacement, and factor of safety. Figure 4 shows the displacement diagram and as we figured the ends of the arms of the UAV will move the most.

However, with copper as the material for the frame it is rigid enough barely deflect under the conditions that will be experienced during the competition. These deflections are not enough of see with the naked eye. Figure 5 shows the stress concentrations in the arm of the UAV, as calculated for the highest stress concentrations occur at the bracket and at the cross where the tubing goes into the cross.

Figure 6 shows the factor of safety diagram. This diagram proves that our frame will hold up to the given forces acting on it. The factor is uniform as can be seen in the diagram by the red color that is distributed evenly through the arms. The factor of safety is the lowest in the arms where the reading is around 3 which means that the frame is not going to fail under the tested conditions.

Figure 7 shows the strain diagram. This diagram is a relationship between the elongation and the length of the tubing. This diagram is also shows very good results. As expected the strains are going to be higher where the tubing goes inside the cross and the brackets.

VII. DISCUSSION/CONCLUSION

The group will continue working on, and produce a final design of the unmanned aircraft vehicle (UAV) to compete in the ASME lighter than air competition. The design style chosen is a Quad-Rotor frame. This frame design will provide excellent control and maneuverability. It will also result in a reduced course time. Course time is a major factor in the scoring system.

Overall the design created is a great foundation. Advantages of this design include a 2kg payload capacity. Carrying this large payload will increase the overall score. Team members will continue researching and analyzing the design to find a most efficient assembly. The final goal includes domination of the UAV Lighter than Air competition. The pre-built UAV has been purchased and the construction phase has begun. UAV completion is predicted to be on schedule.

REFERENCES

[1] BOUABDALLAH, Samir. "Design and Control of Quadrotors with Application to Autonomous Flying." Thesis. 2007. pp 20-21 Web.

[2] Gessow, Alfred, and Garry C. Myers. *Aerodynamics of the Helicopter*. New York: F. Ungar Pub., 1967. Print. pp 49,220,324