# AC 2009-1765: ALTERNATE FUEL SOURCE TRAINER

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# Alternate Fuel Source Trainer (AFST)

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## Abstract

The scope of the alternate fuel source trainer (AFST) is to provide an effective and competitive trainer aircraft for general aviation flight training, using alternate fuel technologies. To accomplish this the AFST will employ a fuel cell propulsion system in a trainer aircraft. This fuel cell will use hydrogen as its main reactant and water and heat are the only byproducts making it environmentally friendly by eliminating its carbon footprint. This technology as well as how it will be implemented into a trainer aircraft is the basis for this design project.

## I. Introduction

The purpose of the alternate fuel source trainer (AFST) is to provide an effective and competitive training aircraft for general aviation flight training using alternate fuel technologies. With the current economic situation concerning fuel costs and rising oil prices, the alternate fuel source trainer is much needed in today's general aviation industry. AFST's goal is to produce a training aircraft that satisfies all the part FAR 61 training needs for private pilot with an instrument rating, while significantly reducing the aircrafts fuel consumption. This will provide a more inexpensive way for flight schools to operate and for student pilots to obtain FAA ratings. The AFST will also encourage more individuals to pursue aviation. Simultaneously the users will be conscious of the environmentally friendly operation of the airplane.

## II. The Project and the Team

### Mission Profile

The typical flight plan for the AFST begins with the takeoff. After takeoff, the plane will perform a climb to the desired altitude of anywhere between three and six thousand feet. The main part of the flight time is spent in a combination of cruise and practicing basic flight maneuvers. Finally, the aircraft will land at the same airport from which it took off. A further mission is a cross-country flight, during which the aircraft might land at another airport before returning back to original airport. The average cruise speed for the AFST is approximately 90 kts. The following table lists each flight segment and how much time will be spend on an average flight.

**Table 2.1** Block Performance

| **Phase of Flight** | **Time (min)** | **Remaining Energy (min)** |
|---|---|---|
| Taxi | 15 | 165 |
| Takeoff | 1 | 164 |
| Climb Out | 3 | 161 |
| Cruise Climb | 10 | 151 |
| Cruise | 11 | 140 |
| Maneuver | 40 | 100 |
| Cruise | 11 | 89 |
| Descent | 5 | 84 |
| Approach | 7 | 77 |
| Landing | 2 | 75 |
| Taxi | 15 | 60 |
|  | Total Flight Time= 120 min | Energy Remaining = 60 min |

## III. Educational Value

In a world that is suffering from plummeting economies escalated by rising prices in current fossil fuel sources, there is much to be learned from the exploration of alternate fuel sources. Since the project described in this paper is one of the first of its kind, there are still years of research and development to perfect its rudimentary design. The present study is mainly a feasibility study. Also, with the infancy of the concept, it allowed for high levels of creativity and imagination from the design team. There were three main objectives that the team gained from this project. First, the team learned how to work through the design process to achieve a product. Starting from a general idea, a visual of the aircraft, its new power plant, and other design features were researched, engineered, and created over the course of only four months. The second major learning experience was adapting under pressure. The original concept for an alternate fuel source was to create a trainer that ran strictly off of rechargeable batteries. However, after over half of the semester of research and design, including collaboration with electrical engineering students, it was discovered that with the current technology, batteries would not work for powering an aircraft. Therefore, all data collected for the fuel cells had to be put together in a very short time with the same level of accuracy as the work that had taken two months. It had to be correct, as it was going to be presented to industry professionals at the end of the fall semester. Finally, the group learned the different obstacles that present themselves when creating a new product that are beyond just the design of the airframe and propulsion system. In storing a combustible gas, safety regulations and standards have to be met for storage. Also, there is the daunting task of marketing a never before attempted product. Finally, the issue of the infrastructure to support the hydrogen powered trainer would have to be established before any airplane could fly. All of these issues are in the process of being researched to find the most cost effective and rapid solutions for the customer. These three main topics have taught the group more about what it means to be a design engineer working in industry.

## IV. Vehicle

### A. Aircraft Structure

Research was done on ten other existing trainers to get an idea of the necessary design space and parameters. The following table is a sample of the data that was collected on the similar aircraft.

**Table 4.1** Similar Aircraft Comparison Sample

| | **DA20** | **C150** | **C172** |
|---|---|---|---|
| Shaft Horsepower (hp) | 125 | 100 | 160 |
| TO Distance over 50 ft | 1640 | 1385 | 1525 |
| Normal Cruising Speed (kts) | 138 | 107 | 114 |
| Duration (Minutes) | 261 | 225 | 228 |

This research provided the basis for most of the preliminary requirements and assumptions that were made in later sections of this design. Comparing to other trainers on the market allow the design team to build a marketing program for the AFST and make it competitive with the competition. This provided the necessary criteria for the basis of the aircraft structure.

The fuel-cell system that is described in more detail later includes additional structural elements to meet safety and design specifications. At the outset, the structural integrity of the hydrogen storage tanks would have to be addressed. The government has approved 5000 psi tanks and the present analysis will include storage at that pressure. An optimum location for the tanks is in the fuselage. This could pose problems to the overall performance of the aircraft and needs to be addressed. If the weight of the aircraft is increased other structural members will need to be accounted for (i.e. landing gear, critical parts, etc). Also, the structural components of the fuel system will need to be accounted for and safety factors will need to be demonstrated. The center of gravity tradeoffs with the propulsive units will differ slightly and performance characteristics should be evaluated and corrected. Many of these concerns are limited to the design and placement of the hydrogen and cannot be completely evaluated until more details are concluded.

Preliminary three-view drawings are shown below to give an idea for the general design of the aircraft.

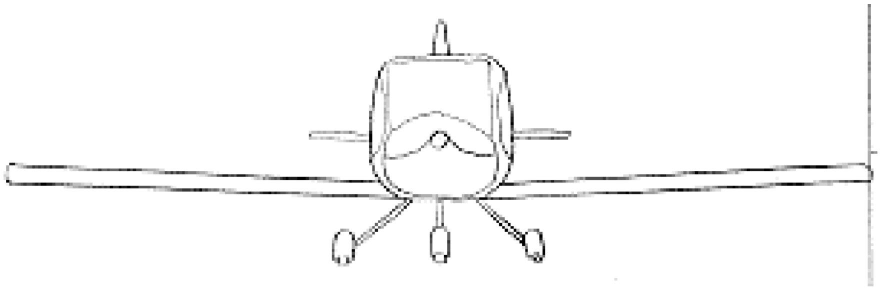


**Fig 4.1 Front View**

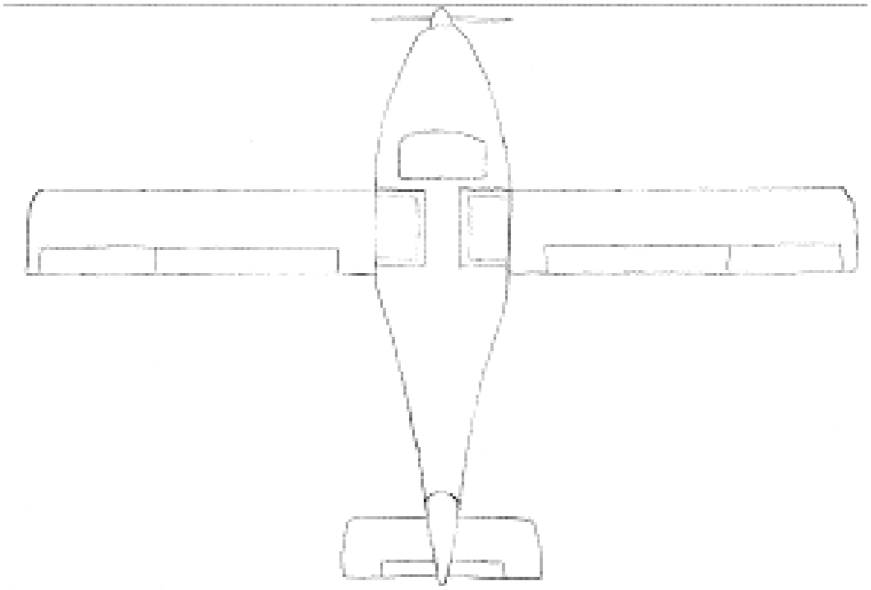


**Fig 4.2 Top View**

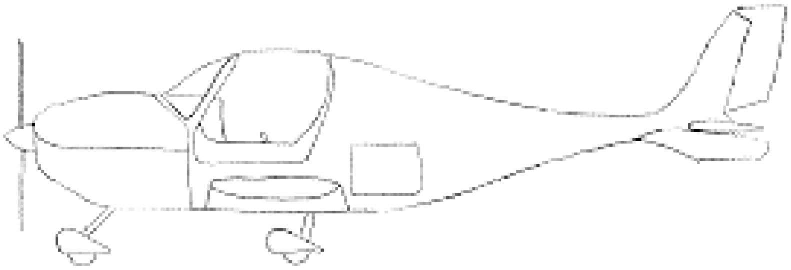


**Fig 4.3 Side View**

## B. Fuel Cell Operation & Electrical Subsystem

The most efficient fuel cell currently being used today is a proton exchange membrane (PEM) fuel cell. The proton exchange membrane fuel cell uses hydrogen and oxygen as reactants to produce a direct electrical current, with only water and heat as a byproduct.

This makes the system environmentally friendly by eliminating the carbon footprint of the vehicle. This attribute is one of the most marketable traits of the AFST. Also this gives a great economical advantage to our aircraft by decreasing the operating cost greatly.

A PEM fuel cell is made up tiny electrochemical cells. Each of these cells is made up of an electrolyte sandwiched between an anode and a cathode. As hydrogen passes through the cell on the anode side, it is catalytically spilt into hydrogen ions, and electrons ( $H_2 \rightarrow 2H^+ + 2e^-$ ). The hydrogen ions react across the electrolyte with the oxygen, absorbed from the air, passing on the cathode side ( $4H^+ + O_2 \rightarrow H_2O$ ). The reaction is a simple oxidation/reduction chemical reaction, where the hydrogen is oxidized, and the oxygen in reduced. The result of this is a negative charge on the anode side, and a positive charge on the cathode side. This electric potential is harnessed as direct current by placing an external circuit for the current to flow. The byproduct of water ($H_2O$) and heat travel out of the electrochemical cell [1]. A PEM fuel cell stack can have a few, to a few hundred of these electrochemical cells depending on the size of the fuel cell. The fuel cell system being used in the AFST can be seen using the diagram below in figure 4.4.

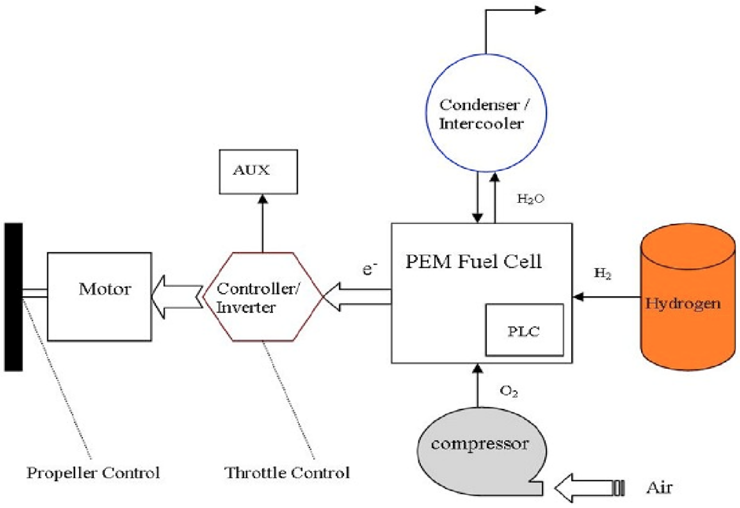


**Figure 4.4** AFST fuel cell system schematic (cite ref)

The PEM fuel cell system for the AFST is run on hydrogen from either a liquid or compressed storage tank system seen on the right side of the schematic. Air is taken from the atmosphere and compressed to increase the efficiency of the fuel cell. Compressing the air means increasing its temperature, which can be a concern for the electrochemical cells of the fuel cell, which already generate a total heat in the range of 100ºC to 800ºC. This means that the air needs to be cooled, either by an air-air cooler or even a water based cooler. The byproducts heat and water pass out of the fuel cell stack to a condenser and intercooler. Here the water is condensed, where it can either be vented overboard, or used in the cooling or humidifying process of the actual fuel cell stack, or other components.

The water levels inside the fuel cell (to control cooling and humidity) are controlled by a built in programmable logic controller (PLC), which monitors all of the operations of the fuel cell. This includes the flow of the reactants in and out, as well as the water needed for cooling and humidity levels. This controller can be programmed according to the needs of the user, and gives warning when the system is not operating correctly. This is a risk mitigating factor installed in the system. The fuel cell produces DC current which is converted to AC current by an inverter/controller. The inverter/controller is where the amount of electrical power sent to the electric motor is controlled, and thus is the power (or throttle) control station. It also serves the auxiliary power drawing components, such as avionics, compressor, etc. by providing them with there power required also. The electric motor powered by the fuel cell then provides the shaft horsepower needed to power the aircraft. It is of note to state that electric engines are not designed to carry axial loads, and thus a mechanical adaptor needs to be installed in order to transfer the power developed by the propeller to the airframe [7].

## C. Engine and Fuel Cell Selection

When selecting an electric motor, the specific power of the motor, power to weight ratio, was the most important parameter. For the AFST application, the team needed a high power, lightweight electric motor. Appendix D has a listing of electric motors. The motor selected was built by UQM Technologies and designated the Powerphase 100. The specifications of this motor can be seen in table 4.2 below.

**Table 4.2**Electric motor specifications

| **Company** | UQM Technologies |
|---|---|
| **Designation** | PowerPhase 100 |
| **Max Power (Hp)** | 133 |
| **Continuous Power (Hp)** | 74 |
| **Weight (lbs)** | 190 |
| **Diameter (in)** | 16 |
| **Length (in)** | 9.5 |

The inverter/controller specified for this motor weighs approximately 30 lbs. Once the electric motor was selected, the fuel cell could also be selected. The fuel cell was selected based on the same requirements of a high specific power, or high power low weight. The fuel cell selected was designed by General Motors for their work in fuel cell automobiles and is designated as the GM Stack2001. The specifications of this fuel cell are listed in table 4.3 below.

**Table 4.3** Fuel cell specifications

| **Company** | GM |
|---|---|
| **Designation** | Stack2001 |
| **Max Power (Hp)** | 136 |
| **Voltage Range** | 250-380 |
| **Volume (ft^3)** | 2.02 |
| **Weight (lbs)** | 180 |

The hydrogen storage system can be either compressed hydrogen or liquid hydrogen. This is a tradeoff study that needs to be done in the beginning of the next phase of design. Liquid hydrogen will be much heavier, but easier to store. The team has predicted that a liquid hydrogen fuel tank would weight approximately 100 lbs to give the range desired. Compressed hydrogen would require a much smaller tank, and thus less weight, but it is much more difficult to store. Ultimately a risk analysis will be completed to determine the most effective way to store the hydrogen.

## D. Preliminary Weight Sizing

After the power plant system was finalized, the following weights were determined for the new power plant.

**Table 4.4** Weight Estimates for Aircraft Flight Systems

| **New Power Plant Weights** | |
|---|---|
| Electric Motor (lbs) | 190 |
| Inverter/Controller (lbs) | 30 |
| Hydrogen Fuel Tank (lbs) | 405 |
| Fuel Cell (lbs) | 180 |
| *total:* | 805 |

Once the weight of the new power plant was determined, it was added to the estimated empty weight of the AFST without a power plant to give a new empty weight. The empty weight without a power plant was estimated by subtracting the weight of each power plant from the ten aircraft researched. These new values were then averaged to get the empty weight without power plant. The preliminary weight results for the no engine empty weight, and the new empty weight with the addition of the hydrogen fuel cell power plant are summarized in table 4.5 below.

**Table 4.5** AFST Preliminary Weight

| **Ave Weight W/Out Powerplant** | 891 |
|---|---|
| New Power Plant Weight | 805 |
| **New Empty Weight (lbs)** | 1696 |
| Pilot and Passenger (lbs) | 400 |
| Baggage (lbs) | 50 |
| Hydrogen Fuel (lbs) | 54 |
| | |
| **New Max Gross Weight (lbs)** | 2200 |
| HP | 133 |
| | |
| **New HP/W** | 0.06 |

## E. Constraint Analysis

The constraint analysis for the AFST was constructed by varying the wing loading and calculating the corresponding HP/W ratios for takeoff, climb, constant speed-constant altitude, and landing performance of the plane.

The following assumptions which are based off of similar aircraft were made in the calculations:

**Table 4.6** Constraint Analysis Assumptions

| ***Assumptions:*** | |
|---|---|
| $C_{(Lmax)}$ | 1.6 |
| $C_{(Do)}$ | 0.033 |
| take off distance (ft) | 1500 |
| Rate of climb (ft/NM) | 200 |
| Aspect Ratio | 15.4 |
| eta(p) | 0.95 |
| e | 0.8 |
| q(TO) | 12.2 |
| K | 0.0454 |
| V stall (kts) | 45 |

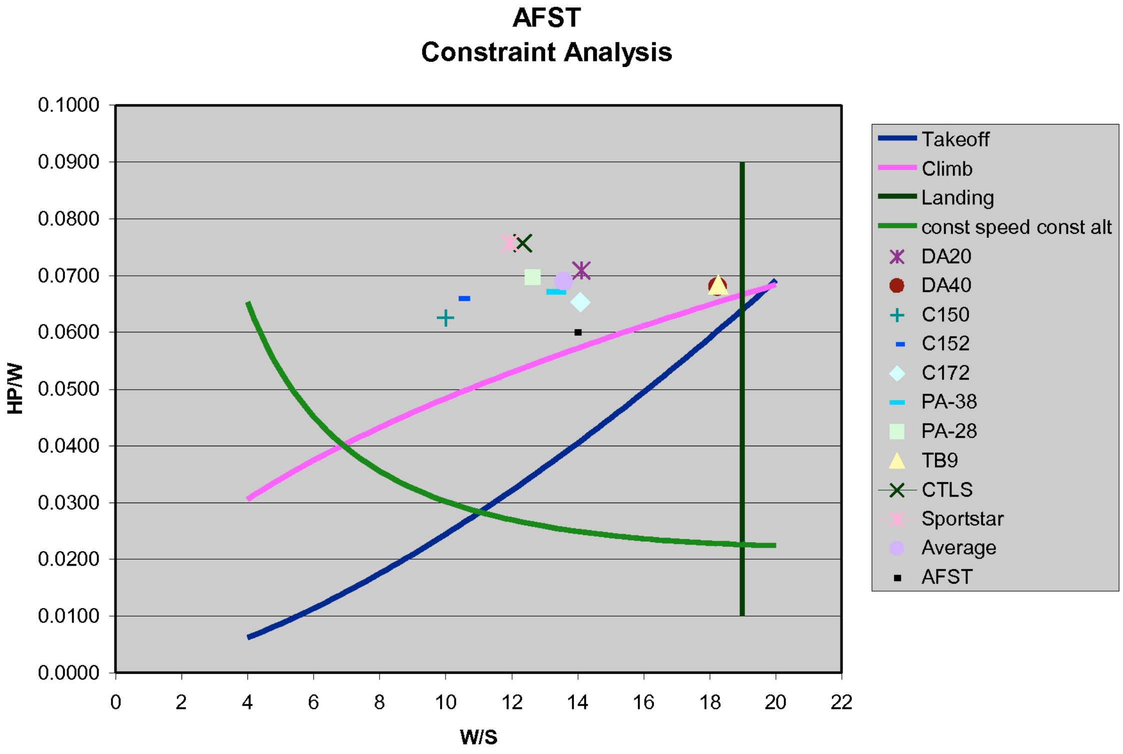


**Figure 4.5** Constraint Analysis

After completing the constraint analysis in figure 4.5, the wing loading could then be analyzed based on the current power to weight ratio. With the power to weight ration of 0.068 (seen above in table 4.6) a wing loading of 12 psf was chosen. This wing loading is well within our design space, and allows the design of the wing with a small enough area to make the structural design feasible. Also shown on the constraint analysis is the data for similar airplanes in service. The other points in the graph represent similar aircraft and where they fall in our constraint analysis. These parameters were then used to make initial calculations on the drag and performance of the AFST described in the next section.

## F. Wing Geometry

The data listed below in table 4.7 is based on the results of the constraint analysis shown in Fig.4.5 as well as references [4], [5], and [6]. The airfoil chosen by the group for the AFST is the NLF(1)-0416 airfoil. The wing loading value of 10 was chosen from the constraint analysis graph. This particular value was decided upon due to the groups want to have the AFST have better performance in takeoff and climb rather than be simply a faster airplane. Important values are shown in table 4.7 below.

**Table 4.7** Wing Characteristics

| Description | Value |
|---|---|
| Geometric MAC | 4.74 ft |
| Cl max | 1.66 |
| Lift Curve Slope | 0.05 / deg |
| W/S | 12 |
| S | 157 ft^2 |
| b | 40 ft |
| AR | 10.2 |

One of the main considerations that were made in the conceptual design of the AFST was whether it would use a high wing or a low wing configuration. The advantages of a high wing are increased visibility downward, making it easier for students to learn how to fly using the earth as a reference. Disadvantages of the high wing are stability issues, as well as structural issues. The low wing design offers increased visibility upward, and has more stable characteristics. The biggest advantage to the low wing design is the structural aspect. For the low wing design, the wing spar passes through underneath the fuselage, increasing the strength of whole structure. Since our design calls for a heavier power plant, the structure needs to be able to support it, and thus a low wing configuration was chosen for its strength characteristics.

## G. Drag Polar Data

The following drag data was calculated using the information given in table 4.7. Table 4.8 below lists the critical velocities and drag information. The velocity vs. drag graph for sea level is shown in figure 4.6 below.

In addition, the Power Required, Glide Performance, and the Coefficient of Lift vs. Coefficient of Drag are listed in Appendix C. All calculations were done at maximum gross weight.

**Table 4.8** Drag Polar Data Summary

| Description | Velocity |
|---|---|
| **Minimum Drag, SL** | 70 kts |
| **Best Glide Airspeed** | 68 kts |
| **Best L/D, SL** | 24 |

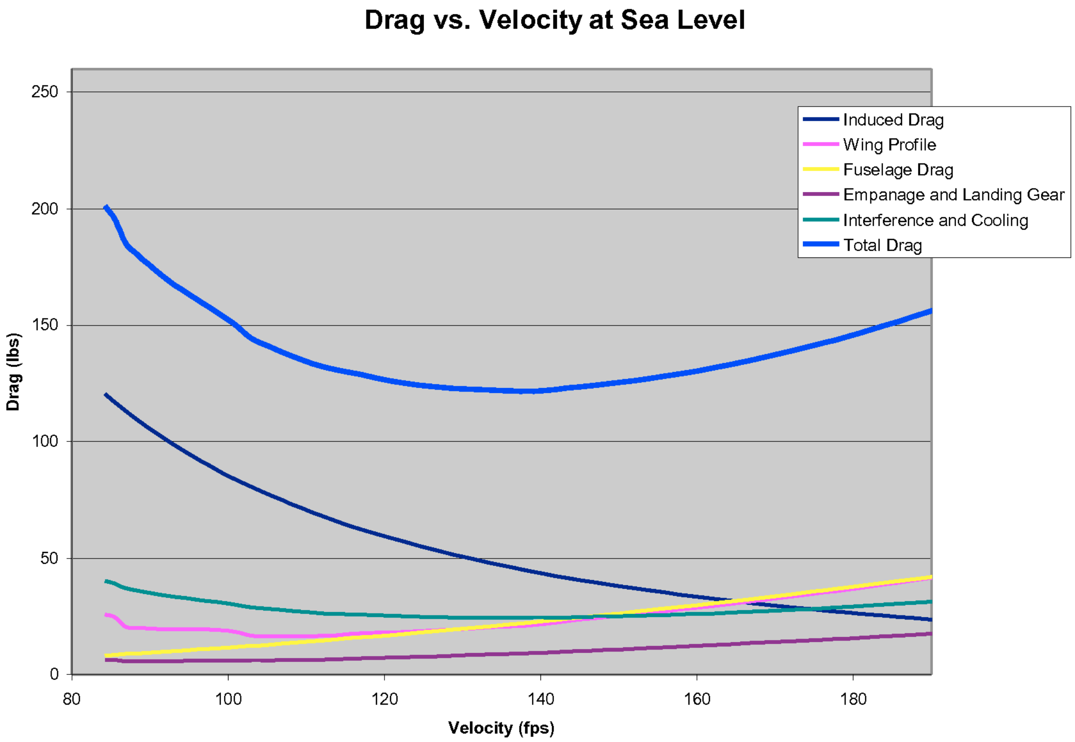


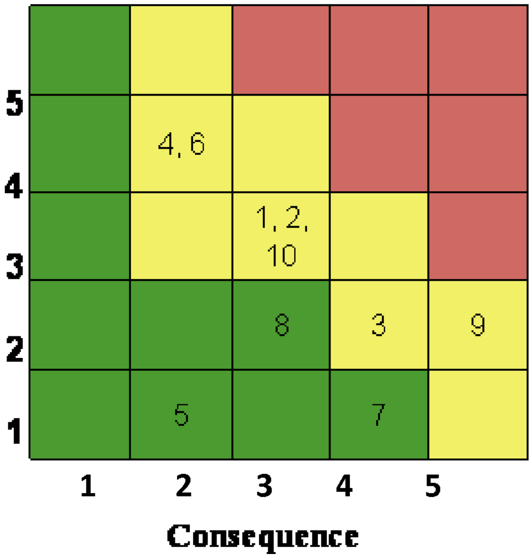
**Figure 4.6** Drag vs. Velocity, total drag and component drags.

## H. Risk Analysis

To be a responsible and ethical engineer one must look at any possible risks involved in new projects. In the case of the Avaridis H2 there are many risks that need to be documented and mitigated due to the newer technology being used. Some of the risks associated with the hydrogen technology come about due to the storage tank. There could be an external leak in the tank, high impact to the tank, a leak of the hydrogen tank into the cabin, the hydrogen igniting, the fuel cell failing, and a failure due to cold ambient temperatures. The highest consequence risk out of those is the hydrogen igniting however the likelihood is quite low. Some of the other risks that the Avaridis H2 could come across are those risks that are standard to most all trainer aircraft. These are a hard landing, bird strike, turbulence, and control surface failures. These risks are ones that come along with a trainer aircraft due to the nature of the pilot. It will be a student pilot and therefore hard landings will have a higher likelihood. The consequences and likelihoods for these many risks are shown in figures 4.7 and 4.8. These risks will be further mitigated to lessen the consequence or likelihood to thus make the aircraft safer for use.

| RISK CHART | | | |
|---|---|---|---|
| | | (1-5) | (1-5) |
| # | RISK | CONSEQUENCE | LIKELIHOOD |
| 1 | External Leak of Hydrogen Tank (Wing) | 3 | 3 |
| 2 | Fuel Cell Failure | 3 | 3 |
| 3 | High Impact to Hydrogen Tank (Wing) | 4 | 2 |
| 4 | Hard Landing | 2 | 4 |
| 5 | Bird Strike | 2 | 1 |
| 6 | Turbulence | 2 | 4 |
| 7 | Control Surface Failure | 4 | 1 |
| 8 | Hydrogen Leak into Cabin | 3 | 2 |
| 9 | Hydrogen Igniting | 5 | 2 |
| 10 | Failures Due to Cold Ambient Temperatures | 3 | 3 |

**Table 4.9** Risk Chart



| | | | | | |
|---|---|---|---|---|---|
| 5 | 🟩 | 🟨 | 🟥 | 🟥 | 🟥 |
| 4 | 🟩 | 🟨 4, 6 | 🟨 | 🟥 | 🟥 |
| 3 | 🟩 | 🟨 | 🟨 1, 2, 10 | 🟨 | 🟥 |
| 2 | 🟩 | 🟩 | 🟩 8 | 🟨 3 | 🟨 9 |
| 1 | 🟩 | 🟩 5 | 🟩 | 🟩 7 | 🟨 |
| | 1 | 2 | 3 | 4 | 5 |

**Consequence**

| | Likelihood | Consequence |
|---|---|---|
| 1 | Not Likely | Minimal or no impact |
| 2 | Low Likelihood | Minor performance shortfall |
| 3 | Likely | Moderate Performance shortfall |
| 4 | Highly Likely | Unacceptable, but workarounds Available |
| 5 | Near Certainty | Unacceptable, no alternatives exist |

**Figure 4.7** Likelihood v. Consequence Risk Visualization

## I. Hydrogen Storage

The storage tank was constrained by the amount of hydrogen needed during the entire mission profile and a certain amount in excess for precautionary measures. The estimate established a hydrogen mass of 54 lbs. Using the ideal gas law (equation 4.1) with a pressure of 5000 psi (which is a typical industry pressure for composite pressure vessels) a value of 30 $ft^3$ was calculated for the required volume of the tank.

The positioning of the tank was to be arranged behind the wings in the fuselage to balance the weight of the fuel cells and its' devices in the nose. From this we decided on a basic geometry of a sphere to allow for evenly distributed pressures; this could be changed to adjust to the contours of the fuselage itself in later versions. Then using a high strength carbon fiber material, CFRP (Carbon Fiber Reinforced Composites) allowed for a smaller radius and lighter overall weight for the configuration.

**CFRP Material Properties**

| | |
|---|---|
| Strength | 79.8 ksi |
| Density | 99.9 $lb/ft^3$ |
| Cost | $18.2-20 per lb |

**Table 4.10** CFRP material properties (conservative estimate) used for calculations.

$$
\begin{aligned}
&PV = mRT \\
&where \\
&R = 5.322\frac{psi\cdot ft^3}{lbm\cdot {}^\circ R} \\
&T = 519^\circ R \\
&m = 54 lbm \\
&P = 5000 psi \\
&thus \\
&V = 29.8 ft^3
\end{aligned}
$$

**Equation 4.1** Ideal gas law for required volume of tank; sea level temperature for conservative estimate.

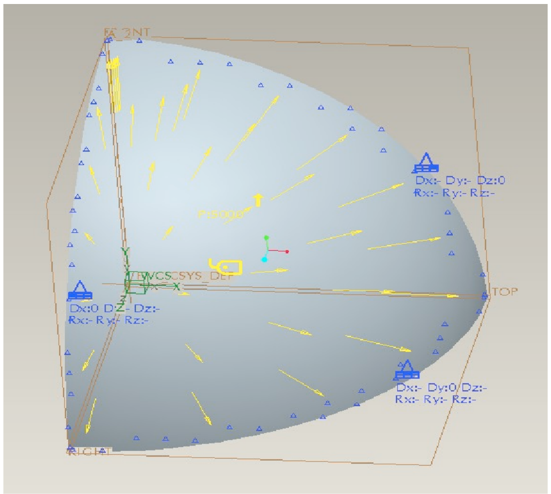
$$
\begin{aligned}
&V = \frac{4}{3}\pi r^3 \\
&where \\
&V = 29.8 ft^3 \\
&thus \\
&R = 23 in
\end{aligned}
$$

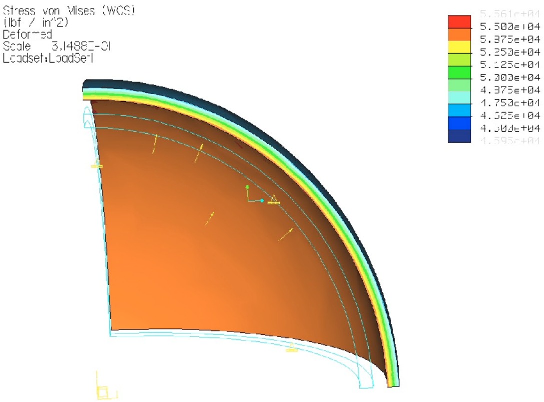
**Equation 4.2** Sphere volume calculation to find radius of 23 in.

$$
\begin{aligned}
&\sigma = \frac{\Pr^2}{2\left(r+\frac{t}{2}\right)t} \\
&where \\
&\sigma = 53.2 ksi \\
&r = 23 in \\
&P = 5000 psi \\
&thus \\
&t = 1.102 in
\end{aligned}
$$

**Equation 4.3** Sphere pressure vessel stress equation for thickness of tank. A factor of safety of 1.5 was used for the composite strength.

Equations 4.2 and 4.3 then gave a thickness of 1.102 in and thus a mass of 405 lbs using the density of the material for the necessary spherical tank. The stresses using Pro-Mechanica on the geometry were consistent with the ultimate stresses established of the material with the safety factor. The results showed gave a factor of safety of 1.44 due to slightly higher stresses of 58.4 ksi. This could be a result of slight variances in the values established for the model.





**Figures 4.8 and 4.9** ProMechanica analysis for the spherical pressure vessel using the CFRP material properties and pressure loads.

## J. Design Freeze

In order to freeze the design to continue with the modeling and testing a number of factors needed to be considered. After deciding on the type of fuel cell and electric motor that will be used, see section C, the next step was to determine exactly how much hydrogen would be needed and how to store it. The amount of hydrogen was determined to be 54 lbs (see section I). Next the storage tank for the hydrogen was designed and determined to be 405 lbs (see section I). Once these new weights were determined they were added into the preliminary weight sizing done previously. The results gave the final weight and power to weight ratio seen below in table 4.11.

| **New Power Plant Weights** | |
|---|---|
| Electric Motor (lbs) | 190 |
| Inverter/Controller (lbs) | 30 |
| Hydrogen Fuel Tank (lbs) | 405 |
| Fuel Cell (lbs) | 180 |
| *total:* | 805 |

| **Weight W/Out Powerplant** | 891 |
|---|---|
| New Power Plant Weight | 805 |
| **New Empty Weight (lbs)** | 1696 |
| Pilot and Passenger (lbs) | 400 |
| Baggage (lbs) | 50 |
| Hydrogen Fuel (lbs) | 54 |
| | |
| **New Max Gross Weight (lbs)** | 2200 |
| HP | 133 |
| | |
| **New HP/W** | 0.060 |

**Table 4.11.** Final weight sizing

Once the final weight and final power to weight ratio were determined the process of freezing the design was a matter of trade offs. Using the drag buildup and constraint analysis (see sections E and G) completed earlier with the final weight information the area and span of the wing were determined. Using the constraints the team decided on a higher power to weight ratio in order to minimize the wing area needed. This was done in order to make the wingspan more manageable structurally as well as easier to produce and store. After the wing design was frozen, the horizontal and vertical tail areas as well as the distance between the center of gravity and the horizontal and vertical tail aerodynamic centers (assumed to be quarter cord), $l_h$ and $l_v$ respectively, was determined using a method found in Raymer's design book[4].. The final geometric design values for the wing, horizontal and vertical tails can be seen below in table 4.12.

| **Final Geometric Design** | |
|---|---|
| Aspect Ratio | 10.2 |
| Wing Loading | 14 |
| Wing Area | 157.3 ft$^2$ |
| Wing Span | 40 ft |
| | |
| Vertical Tail Area | 27.5 ft$^2$ |
| Vertical Tail Span | 6.64 ft |
| Vertical Tail Aspect Ratio | 1.6 |
| Length Verical Tail (lv) | 16 ft |
| | |
| Horizontal Tail Area | 30.9ft$^2$ |
| Horizontal Tail Span | 12.4 ft |
| Horizontal Tail Aspect Ratio | 5 |
| Length Horizontal Tail (lh) | 16 ft |

**Table 4.12.** Final geometric design of wing and tail

## K. Propeller Sizing

Propeller sizing for an aircraft is limited by the propeller tip Mach number. This number needs to be below one so that super sonic effects are not felt by the tips of the propeller. The ideal tip Mach number is approximately 0.88. To solve for the propeller diameter the design group worked backwards from the ideal tip Mach number. The propeller diameter is also based on the rpm that the motor will be running at. This was also taken into account when designing the propeller. The rpm's were varied on a range from 1500-4000 to find the ideal value. The graph of propeller diameter v. tip Mach number with those varying rpm values is shown in figure 4.10. After looking at the different values that could satisfy the specified tip Mach number two options were found. The first being a diameter of 64 in with an rpm of 3500, and the second being a diameter of 56 in at an rpm of 4000. The first option was chosen due to the longer propeller as well as the lower rpm value.

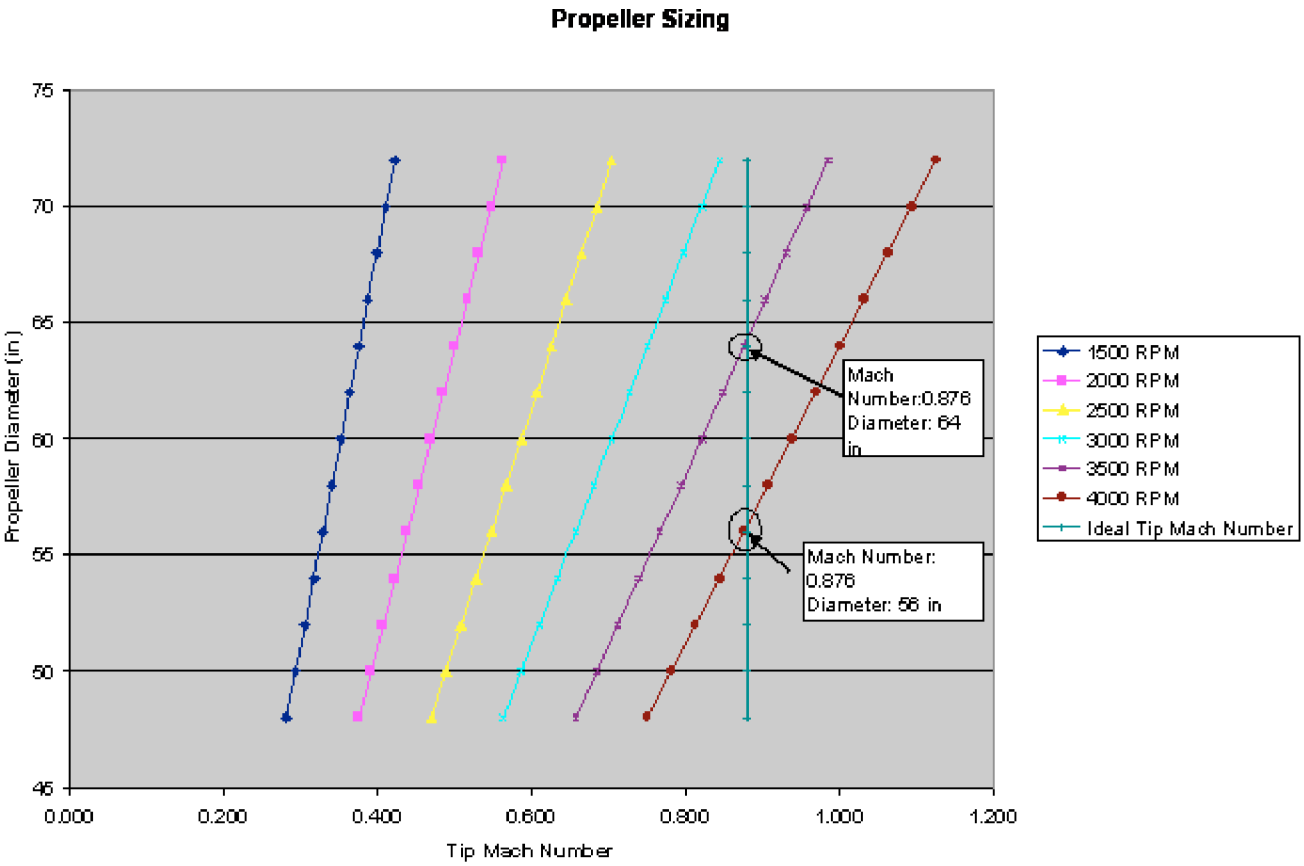


**Figure 4.10** Propeller Sizing graph

## L. Weights and Balance

The weight and balance of the AFST was determined by creating a table of each component listing its station location, weight and moment. These were then summed together to determine an empty weight center of gravity location, a max takeoff weight center of gravity location, as well as a landing weight center of gravity location. The following table lists each component and its station using the tip of the nose cone as the datum plane.

| **Component** | **Weight (lbs)** | **Station (in)** | **Moment (inlbs)** |
|---|---|---|---|
| Propeller | 38 | 4 | 152 |
| Gear Box/Governer | 35 | 7 | 245 |
| Electric Motor | 190 | 12 | 2280 |
| Controller | 30 | 15 | 450 |
| Fuel Cell | 180 | 50 | 9000 |
| Compressor | 30 | 30 | 900 |
| Condensor | 15 | 35 | 525 |
| AUX Battery | 18 | 35 | 630 |
| Avionics | 20 | 64 | 1280 |
| Nose Wheel | 40 | 35 | 1400 |
| Forward Fuselage | 40 | 32 | 1280 |
| Cabin | 130 | 90 | 11700 |
| Hydrogen Tank | 405 | 148 | 59940 |
| Wing Assembly | 250 | 90 | 22500 |
| Main Landing Gear | 60 | 90 | 5400 |
| Aft Fuselage | 90 | 160 | 14400 |
| Horizontal Tail | 65 | 280 | 18200 |
| Vertical Tail | 60 | 280 | 16800 |
| | | | |
| **Total Empty Weight:** | 1696 | 98.52 | 167082 |
| | | | |
| Pilot | 200 | 90 | 18000 |
| Passenger | 200 | 90 | 18000 |
| Baggage | 50 | 120 | 6000 |
| Hydrogen | 54 | 148 | 7992 |
| | | | |
| **Takeoff Weight:** | 2200 | 98.67 | 217074 |
| | | | |
| Hydrogen Burn | -54 | 148 | -7992 |
| | | | |
| **Landing Weight:** | 2146 | 97.43 | 209082 |

**Table 4.13.** Component breakdown of weight, arm and moments

The following table lists all of the important center of gravity locations which will be used in the stability and control calculations of the AFST.

| **Total Empty Weight** | **Empty Weight C.G. Location** |
|---|---|
| 1696 | 98.52 in |
| | |
| **Max Takeoff Weight** | **Max Takeoff Weight CG Location** |
| 2200 | 98.67 in |
| | |
| **Landing Weight** | **Landing Weight CG Location** |
| 2146 | 97.43 in |

**Table 4.14.** Weight and balance summary

## M. Stability and Control

The static stability calculations were performed by using a MATLAB code, which is shown in Appendix F. It proves that the aircraft is statically stable because the slope of the moment coefficient versus the lift coefficient is negative. Also in the program are calculated the values of the wing and tail contributions to the lift coefficient, and the total drag coefficient. The group has future plans for this program to include calculations to show the dynamic stability of the trainer, as well as more stability derivatives to help in the sizing of the control surfaces. Below is a table consisting of the assumed or measured values in the calculations and also the results of the MATLAB program.

| **Stability and Control** | | | | |
|---|---|---|---|---|
| **Constants** | | | | |
| eta | 1 | | Sht (ft^2) | 30.867 |
| ARw | 10.1726 | | Svt (ft^2) | 27.525 |
| ARht | 5 | | lt (ft) | 16 |
| ARvt | 1.6 | | aow | 9.35/rad |
| rho | 0.00237 | | aot | 6.44/rad |
| V (fps) | 140 | | xcg (in) | 98.67 |
| alpha (deg) | 0 | | xac (in) | 96 |
| Sw (ft^2) | 157.28 | | V1 | 0.8 |
| chord (ft) | 3.932 | | V2 | 0.07 |
| | | | | |
| **Calculated Values** | | | | |
| CLw | 0.3343 | | CD | 0.0377 |
| CLt | 0.0237 | | dCm/dCl | -0.287 |
| Cltotal | 0.3469 | | Dcm/dalpha | -1.967 |

**Table 4.15.** Stability and Control Derivatives

## N. Computer Aided Design Model

The model was developed using ProEngineer design software. The model was constrained by the aircraft characteristics, this included the location of the storage tank and fuel cell parts, the necessary wing, tail, and propeller dimensions found through sizing and performance. The fuselage was driven by other trainer models and creating as aerodynamic a body as possible. Ongoing work is being conducted for the control surfaces and constant modifications.

**Model Dimensions/Constraints**

| STRAIGHT WING | |
|---|---|
| Aspect Ratio | 10.2 |
| Area | 157 ft$^2$ |
| Span | 40 ft |
| Dihedral | 3 degrees |
| Chord | 3.93 ft |
| Airfoil | NLF(1)-0416 |

| HORIZONTAL TAIL | |
|---|---|
| Area | 30.9 ft |
| Aspect Ratio | 5 |
| Span | 12.4 ft |
| Airfoil | NACA0015 |

| VERTICAL TAIL | |
|---|---|
| $L_v$ | 16 ft |
| Area | 27.5 ft$^2$ |
| Aspect Ratio | 1.6 |
| Span | 6.64 ft |
| Airfoil | NLF(1)-0416 |

| PROPELLER (ft) | |
|---|---|
| Diameter | 5.33 |

| SPHERICAL HYDROGEN TANK (ft) | |
|---|---|
| Radius | 1.92 ft |

| FUEL CELL (ft) | |
|---|---|
| Length | 1.35 |
| Width | 0.83 |
| Depth | 0.23 |

| MOTOR (ft) | |
|---|---|
| Diameter | 0.67 |
| Length | 0.40 |

**Table 4.16** Current model constraints and various considerations for development of the aircraft.

**Figure 4.11** The current CAD model.

## O. Marketing and Public Relations

Two important issues of nowadays are the challenges posed by the current economy and how to develop products that are more environmentally acceptable. This innovative idea will not pull us out of the recession, nor solve the energy and pollution issues. It will, however, be a symbol of lowering costs for eager, minded individuals learning to fly, and also be a small step forward in the ongoing struggle against pollution. This aircraft would expel pure water and could be a stepping stone to greater achievements in clean, reliable, propulsive technology. The initial cost of this aircraft will be greater, but the operating cost will be quite less giving the AFST a large economic advantage.

## V. Decision Making and Design Process

The design process can be summed up as an iterative process that continues to take one idea and improve on it for the next to reach the desired outcome. Decision making and the design process are directly related, as our team learned, was the case throughout the semester's design project. Each decision we made was made in the belief that it was the best decision for our product at the time. The design process began with identifying a problem and creating mission requirements, a mission profile and finally a mission statement for our vehicle. The original problem identified is the rising cost of petroleum based fuel and the need for a cleaner and more economical aircraft for use in the training role. From there our team specified exactly what the vehicle needed to be able to accomplish. Once that was done the physical design of the vehicle began.

As the design moved forward, many decisions originally made had to be adjusted to accommodate newly arising issues. This is what made it an iterative process. For example after conducting an initial trade off study on the different types of power sources available, the team decided to choose battery power as the primary power source. This decision was made because it seemed to be the correct decision at the time in the design process. It was the most economical for its power output. However, once more information about the batteries and its capabilities were found the group decided that there would have to be too many batteries to sustain the airplane for the mission requirements stated above. This led to make a decision to scrap the battery idea and try the hydrogen fuel cell idea. In doing so, the design process also had to take the necessary steps back to re-design around the new unit. This process was repeated over a number of iterations on a number of different issues to get the final product described above.

Since designing an aircraft involves designing many different components that are all related, effective communication between team members working on each individual component is paramount. For example, when the propulsion engineer decided to switch from battery power to fuel cells that greatly affected the total weight, forcing the aerodynamic and structural engineers also needed to make changes. Without effective team communication the project would not be possible. The team learned how cooperative teamwork equals project success, and just how to make that teamwork happens in the decision making and design processes of this project.

## VI. Conclusion

The AFST is a very complex design and has provided the students with great exposure to many different facets of engineering throughout their work thus far. This trainer is capable of offering an inexpensive source of energy in hydrogen fuel. Based on the trade off studies discussed above, hydrogen fuel is the least expensive source of energy that is able to power an aircraft. This design is one of the first of its kind and will only introduce a competition in industry. The outcome of this competition is going to be the best possible and most sophisticated technology available. Hydrogen provides a simple means to accomplishing our basic mission requirements without bringing increasing fuel costs into the equation.

There is still much work that is needed on this design project and will be completed in the following three to four months. In the future, the safety of using compressed hydrogen in an aircraft will be a major part of the study. Other things that are going to be introduced into the design are the weight and balance, stability and control analysis, and structural calculations for the aircraft. Using computer drawing programs, a model prototype will be fabricated and tested in the wind tunnel. Another major issue that needs to be addressed in the future is how to provide a ground based hydrogen source for the aircraft. This problem needs to be addressed and solved in order to make a hydrogen powered airplane feasible and something that the consumer will desire.

As is shown by these students' research, the world is not far away from having such an advanced technology to power aircraft. It will not only provide a quality trainer airplane for students to pursue flying in, but will combat the ever increasing oil prices as well as helping to preserve our environment.

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