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Abstract

Due to the many restrictions given to us by the Royal Aeronautical Society, our conceptual design is primarily focused on the general shape of the aircraft necessary to fulfill the mission requirements. These constrains come from environmental concerns, such as the minimum wind requirement, size limits, stemming from trailer stowage, as well as construction methods attributing to assembly time. This report outlines our progress throughout the first and second design iterations. We include our current numbers and sizes for the wing, fuselage, and trailer, and desired characteristics for the drive system, propeller, and empennage. In addition, a baseline pilot training program has been devised.
**Introduction**

We began with the combination of the Sport and Marathon HPA groups into the present configuration. In an effort to maximize our group potential we subdivided into five groups: Wing, Fuselage, Propeller, Trailer, and Simulation. Due to the interdependence of many design aspects, some members worked between groups, and all relevant information was posted online for everyone’s discretion. From this point, each of the groups worked forward from where the original HPA Sport group left off. The Wing group set about designing a planform and method of construction for the wing. The Fuselage group focused mainly on sizing and materials. The Propeller group set out to learn as much as possible due to the class inexperience in this area. Our Trailer group also focused mainly on size and construction methods for our transportation unit. Finally, the Simulation group set out to devise a program to represent flight conditions as accurately as possible. Meanwhile, we also contacted more experience in developing a full training program for our eventual pilot. Currently, we are collectively moving toward the next phase: a full detailed design.

**Wing**

Starting from a parent aircraft approach, primarily using the Musculair 1 & 2 models, a first iteration choice for an airfoil was made, picking a modified version of the FX-76MP with varying thickness from 16% to 14%. Taking characteristics from this airfoil, and taking advantage of our initial weight buildup, the initial sizing of the wing planform was extrapolated. Then, beginning by assuming a take-off weight of 81kg (27kg empty weight), sea-level air density, and using a $C_L$ of 0.8 obtained from the Musculair reports on our chosen airfoil, a range of velocity values were obtained through the Lift Equation,

$$L = \frac{1}{2} \rho V^2 A_{surf} C_L$$ (1)

The accompanying span characteristics are:

<table>
<thead>
<tr>
<th>Velocity (\text{m/s})</th>
<th>Area (\text{m}^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5</td>
<td>12.26</td>
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<tr>
<td>11.6</td>
<td>12.05</td>
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<tr>
<td>11.7</td>
<td>11.85</td>
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<tr>
<td>11.8</td>
<td>11.65</td>
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<td><strong>11.9</strong></td>
<td><strong>11.45</strong></td>
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<td><strong>12.2</strong></td>
<td><strong>10.90</strong></td>
</tr>
<tr>
<td>12.3</td>
<td>10.72</td>
</tr>
<tr>
<td>12.4</td>
<td>10.55</td>
</tr>
<tr>
<td>12.5</td>
<td>10.38</td>
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</tbody>
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Choosing the range highlighted in bold, a range of span and chord lengths that would work for the prescribed areas was determined. Taking a conservative approach in selecting the velocities, trying to take into effect the wind speed requirements for the competition, an optimum velocity of 12.2\text{m/s} resulting in a surface area of 10.90\text{m}^2 was chosen. A relatively even number on the conservative side was assumed for now, for ease of construction, leading to a current span length of 17.5\text{m}. This span length corresponds to a root chord length of 0.73\text{m}. Sizes for the half-span planform with a linear taper are as follows. In addi-
tion, there is a 0.25\textit{m} winglet on each tip. A constant taper is planned throughout the center and outboard sections at this point.

The wings will be supported by a carbon fiber tube spar with the weave oriented at ±45° to sustain torsion loading. The team is currently searching for a potential donor for this piece of the wing. Spar caps will be added to the top and bottom of the tube with a weave oriented at 0°/90° to sustain bending loads. A hardpoint will be fitted to the spar at the point of connection to the fuselage. Design is currently underway for hard points at the connections between wing sections. Such elements would lend themselves to easier construction and quicker assembly/disassembly.

In order to comply with the trailer roadworthy specifications, a multi-section wing is preferred to allow the reaching of the desired span length. Presently, the design is a three-section wing with winglets on both ends. The center section is 6\textit{m} in length. The two outboard sections measure 5.5\textit{m}, and the winglets are each 0.25\textit{m}. A constant taper is planned throughout the center and outboard sections at this point.

The ribs shall be constructed with thin foam, potentially with a layer of fiberglass to add stiffness. A minimal amount of carbon fiber will be applied for structural support. Test and analysis of these configurations are currently being conducted. The placement of lightening holes will be determined later on to reduce weight.

The skin will consist of a Mylar coating over the whole surface, and a thin (≈ 2\textit{mm} thick) sandwich panel that will cover an amount of the wing surface still to be determined. Aerodynamic tradeoffs are currently under consideration in this case.

For the empennage, volume coefficients were used, and scaled from the Musulair II. These were then modified for the HPAs unique mission in that the Musulair’s tail hits the ground and the Zephyrous’s does not. Therefore the vertical tail was placed higher and with most of it projected area above the main boom. Another benefit of reducing the structure needed in the empennage is to improve the aerodynamic shaping compared to that of the Musulair.

![Figure 1: Wing Cross-section](image-url)
Fuselage

Sizing the fuselage began by essentially measuring out a dimension range for the pilot, putting these dimensions in the right orientation, and drawing a fuselage around it. Dimensions were based on a 5’10” (1.778 m) pilot, with the assumption that someone of the necessary weight to fly the aircraft will be no more than this height. From here, a scale drawing (1:75) based on the desired pilot seating configuration was compiled.

![Figure 2: Fuselage Side View](image)

Once the internal characteristics of the fuselage were completed, the external shape was considered. To do this, a minimum volume “bubble” was drawn around the internal structure. The aerodynamic optimization of this shape is underway. Current sizes can be found in the accompanying figures. Constraints considered in this process include minimum widths for pilot comfort, the fuselage-wing connection point, and desired center of gravity of the aircraft.

The internal structural members are designed to firmly hold the seat configuration in place, yet still provide a maximum field of vision for the pilot. Presently the expectation is for these members to be aluminum tubing for weight and workability. Structural members, as well as the wing, attach to the main boom at a primary hardpoint approximately at the fore-aft CG. The chain will rise vertically from the gear to the drive shaft to provide torque to the propeller. A working model design of the hardpoint can be seen below.

![Figure 3: Attachment Hardpoint](image)

The wing must be attached to the main boom of the fuselage, preferably with minimal breaking of the skin of either the wing or fuselage. The most feasible solution to this point is to attach hard points to the main boom as well as the wing spar. The hard points can be attached to the spar using epoxy. To connect the two hard points, U-bolts as well as numerous other devices are under consideration. Specific methods for securing the hard points will be determined later.

The material for the hard points will also be determined later but the preliminary design is to use carbon fiber or aluminum.
The advantages of this method are that neither the fuselage skin or wing skin are load bearing. The attachment is very strong in tension. This is important since lift would correlate to tension in the U-bolts. The disadvantages are that the attachment in torsion will only be as strong as the epoxy holding it to the main boom. Weight may also be an issue depending on the amount of epoxy necessary to hold the boom and attachment brackets in place.

In order to maintain the necessary weight for the fuselage, several lightweight materials will be utilized. The main part of the fuselage cage will be formed from wire. Wire will be used because it can be easily molded to our specifications and assume the desired shape for our pilot. Since it only provides a frame to support the rest of the covering, it will add a minimal amount of weight to the aircraft.

![Figure 4: Fuselage Top View](image)

The bottom of the fuselage will be formed from fiberglass. This is done to ensure a solid foundation for the airplane to rest on while on the ground, and protect the pilot in the event of a crash. The fiberglass will weigh more, but the added safety is a consideration.

The remainder of the fuselage will be made from a combination of Mylar and Lexan. The Mylar will cover most of the fuselage except for where the pilot needs visibility. Lexan will be used as a windshield so the pilot has a clear view of his surroundings.

**Propeller and Drive Train**

The propeller is arguably one of the most important parts of the HPA. Efficiency is paramount because of the limited power available. The low speeds and emphasis on efficiency make propeller design for an HPA markedly different from other applications. As such, it must be designed with care and precision. Currently the propeller is in only the earliest design stages.

For help with this design, Dr. Mark Drela of MIT was contacted regarding the use of his program XRotor. As of this date we have not had a response.

XRotor will ideally be used for the design and analysis of our propeller. This program will take the propeller radius, number of blades, airspeed, and rotational speed as inputs. XRotor will then output advance ratio, twist, and chord distribution.

When looking at previous HPA's, it is worth noting that the Musculair 1 had a larger propeller diameter (2.72m) than did the faster Musculair 2 (2.68m). This fact alone may indicate a preference for a smaller propeller, but further investigation will have to be performed to confirm this. The final design size will almost certainly put our diameter between 2.5 and 3.0m. If
a larger propeller happens to be the best choice, our aircraft’s structure may allow for it.

Construction of our propeller will ideally be done on-site. A method for doing this would resemble that of building a wing with a foam core and covering it with a durable material (e.g. Kevlar or carbon fiber). We would prefer that each blade weighs less than one pound, a very reasonable value if careful construction methods are used.

Because of associated difficulties in design and construction, a variable pitch propeller is being avoided. Also, as this aircraft is designed to be flown at its maximum speed (and therefore maximum thrust) at all points during flight, gearing between the pedals and the propeller are currently considered superfluous. Therefore, our aircraft will be powered much like a fixed gear bicycle with the pedals connected to the propeller through a single fixed gearing. If it is determined at a later date that gearing is required, only minimal modifications to these parts will be required due to the modified chain. The total weight, feet to propeller (pedals, gears, hub, chain, drive-shaft), will be under 2.7kg.

Simulation

The flight simulator group was formed to develop a human powered simulator as a training aid. The ability to understand how our aircraft will perform in the conditions specified by the competition will be gained by creating a working simulator model.

Initial research began by meeting with Dr. Joseph Horn, who oversees one of the graduate simulator projects. During the meeting Dr. Horn described several different methods to modeling an aircraft and integrating a pedal powered throttle control. His graduate students use a program called Flight Gear for their models. The main benefit of using this program is that it is completely open source and free to download. Being open source it would be easy to program and integrate the pedal powered throttle.

After meeting with Dr. Horn, one of
his students, Sade Sparbanie, met with the group to show how Flight Gear works on the simulator. She gave a brief overview of Dr. Horn’s code and how to modify it. While learning how to use the software, several disadvantages of Flight Gear were discovered. The two main problems were that Flight Gear does not incorporate wind or ground effect, both of which are crucial to the performance of our particular aircraft.

Dr. Horn gave us a few different options to working around these problems. First, the group could program both wind effects and ground into Flight Gear. The second option would be to use a different flight simulator program. Dr. Horn suggested either Microsoft Flight Simulator or X-Plane. Both are very accurate at modeling aircraft. MS Flight Simulator, however, has an open source code that would allow us to integrate a human powered throttle.

After working with MS Flight Simulator 2004, it was found that its modeling software is difficult and somewhat confusing. X-Plane 8.0 uses a much more straightforward model builder. With every modification in X-Plane, flight characteristics change to accurately match the model. The only problem with this program is that it is not open source and would be very difficult to integrate the pedal powered throttle. More research on the feasibility of using X-plane is needed.

Ongoing and future work consists of continuing to develop models in both MS Flight Simulator 2004 and X-Plane 8.0. The group hopes to have a full working model to be tested using standard controls shortly following the semester break. Once the model is complete, research and fabrication of the human powered throttle will begin. By working closely with graduate students and engineers of different concentrations, the plan is to have this project finished by mid-spring semester to begin training.

**Power and Training**

In addition to flight training, the pilot must also undergo an extensive physical training regimen. To help with the design of this program, the help of Ashley Sustakoski, a Honors Kinesiology student here at Penn State, was enlisted to increase our knowledge of this subject matter. The goal of this program is to best prepare the pilot for the actual flight conditions. The most important aspects of this is to increase the pilot’s ability to output as much power as possible over the time of flight. A secondary concern is to increase his/her core strength to improve stability in flight.

Due to the intermediate (approximately three-and-a-half minute per lap) flight time, both sprint and endurance components must be included in the training. One way to do this quite effectively is to focus efforts using interval training methods. Interval training involves numerous sets, each for an equal amount of time, alternating between sets at full power or resistance and sets at low power or resistance. For example, on a resistance bicycle, the pilot could undergo a series starting with a set at full resistance (or whatever resistance correlates to our goals) for three minutes followed by a three minute "rest" set at zero resistance before another full resistance period.

In addition to interval training, it would also be beneficial to alternate in road endurance sessions (for example on a hill
course) to familiarize the pilot with motion characteristics. For this aspect, it would be to the pilot’s advantage to build a recumbent seat bicycle with similar riding characteristics as what will eventually be implemented in the aircraft. Making sure the pilot is optimally challenged by the training regimen is vital to its success. Our primary way to do this is to make sure the pilot is receiving the maximum benefit by the workouts. This can be done using a heart-rate monitoring system to check to see if the trainee’s heart rate is in the ideal range. Also, as a way to self-monitor the program and the pilot’s progress, we should have occasional (e.g. monthly) tests which would consist of the actual competition characteristics.

Another component of the program is pyramidal training sessions. These consist of a series of sets beginning with a low power output over a longer period of time, with successive sets decreasing the amount of time and increasing the power output until a maximum is reached, after which successive sets work their way back toward the start.

The pilot’s stability is a concern because he/she needs to be able to control the aircraft and maintain optimal flight attitude in addition to powering it. To improve this, medicine balls should be implemented into workouts for an effective core routine. Finally, a simple strength training routine for the pilot must be devised to maintain a well-rounded, healthy physique.

**Trailer**

The trailer for the Human Powered Aircraft Sport Competition has to meet several regulations. One regulation states, “The whole machine shall stow into a roadworthy vehicle supporting a weatherproof container not longer than 8.0m (26.24 ft) internally.” Another line stipulates a time requirement: “At the commencement of the proceedings the HPA shall be removed from its transporter, and assembled ready for flight with crew onboard and ready to start, within an observed time of 30 minutes.” This requires the trailer to be easily accessible to the ground crew.

In addition to the Kremer rules, the trailer also has to be transportable on U.S. and U.K. roads and therefore has to follow their regulations. The U.K. regulates the width of a trailer to 2.55m externally with a towing vehicle over 3.5 tonnes, which is
more restrictive than PennDot regulations. Likewise, since the trailer needs to pass under bridges and lower overhangs, the height needs to be limited to 3m externally. Given these restrictions and an average wall thickness of 10cm, the inside of the trailer is restricted to $8m \times 2.35m \times 2.8m$ or $52.6m^3$.

With these in mind, a visit to the gliderport to view existing glider trailers, which would be the closest thing to our needs, was planned. Two viable design types of interest were found: the closed box configuration and the open trailer configuration. The open trailer design is a series of racks and shelves that the aircraft pieces are set on. This design would have to be modified with a canvas top or some sort of covering due to the Kremer requirements. The box trailer is already weatherproof and allows the mounting of pieces or tools to the walls and ceiling of the trailer. Also sliders, wheels, shelves, or other devices to aid in the unloading process must be added to meet the Kremer time requirement. It may also be beneficial to add a side door to facilitate unloading.

![Figure 7: Dimensioned Rear View of Trailer](image)

![Figure 8: Isometric View of Trailer](image)

Based on what was viewed at the gliderport and our restrictions, a box trailer is the preferred option at this point. If an open trailer were chosen, it would have to be heavily customized. However, the box trailer can be tailored to our specific dimensions and is already weatherproof. It can also be mounted to an existing trailer base or chassis for ease of construction. The sides would most likely be aluminum with a metal chassis. The floor and walls would have plywood attached to them which would make it easier to drill into the walls for hanging purposes.

Future work and concerns involve finalizing the design as the aircraft dimensions change, optimizing the design for unloading time, and figuring out the logistics of transporting the trailer across the ocean. After that, we should start building the trailer so we can store the completed components inside. Building the trailer will allow the focus to be exclusively on the construction of the aircraft itself.
Future Work

It seems as though the aircraft design process is well on its way. There is, however, still a long way to go. The next steps are to continue on the current path, continually refining our numbers. Once more accurate dimensions are known, an existing drag build-up must be modified and ran to acquire performance estimates for the aircraft. Also, further research and testing in human power availability must be done in order for appropriate analysis.

In order to actually construct the aircraft, material testing and analysis should be done on key components, as well as the finalization of construction methods. Once this is done, materials can be ordered and construction can begin. At some point in the not-so-distant future, the entry procedure should begin, and also the piloting situation needs to be determined. It also would not hurt to begin study of possible competition sites at the earliest opportunity.

Clearly, it is a long and difficult road toward our goal. It seems, though, that we are off to a solid start. We must prepare for every scenario that we can come up with, and if this is done, then our goal may be in reach.