PSU Zephyrus
HPA Sport

Alan “Awen” Campbell
Mark DeAngelo
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Kevin “Unfair Advantage” Show
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Purpose

- To direct interest in Human-Powered Aircraft towards the design for production and ongoing development of aircraft suited to athletic competition

- In particular it is necessary to specify and design aircraft able to operate in normal reasonable weather conditions as encountered in the United Kingdom
Considerations

- May be staged over land or water at discretion of entrant within the UK
- Electric power is permitted for the sole purpose of control, including auto-stabilization and propeller governing.
- No communication or external assistance during the flight
The Course

Course marker

Wind direction

Start & finish
Clockwise flights

500 meter sides

Start & finish
Anticlockwise flights
Considering constant minimal wind and minimal path, flight will take 3 minutes for one revolution at 10m/s airspeed.

Allowed 1 hr. to recuperate

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly from</td>
<td>30 Minutes</td>
</tr>
<tr>
<td>transporter to takeoff</td>
<td></td>
</tr>
<tr>
<td>Recuperation</td>
<td>1 hr between circuits</td>
</tr>
<tr>
<td>Speed</td>
<td>Two flights opposite directions</td>
</tr>
<tr>
<td></td>
<td>&lt;7.00min (&gt;10m/s, 22.4mi/h, 20 knots)</td>
</tr>
<tr>
<td>Dismantle time</td>
<td>30 minutes</td>
</tr>
</tbody>
</table>
Weather

- Mean wind speed must not be less than 5.0 meters/second (11.2 mph)
- Periods of relative calm (wind speed is less than 5.0 m/s over a time of 20 seconds or more are “unacceptable.”)
- Wind shall be measured by an anemometer provided by the judges at a height not more than 10m above the ground and verified by an independent authority in the U.K.
Transportation

• Before and after the flights, the airplane must be assembled, disassembled and stowed within 30 minutes.

• The whole machine must be stowed into a roadworthy container no longer than 8.0 meters (26.24 ft.) internally (more on this later).
## Rules Overview

<table>
<thead>
<tr>
<th>Stowage</th>
<th>Roadworthy vehicle, weatherproof container not longer than 8.0 m (26.24ft) internally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Winds</td>
<td>10 knots (11.2 mi/h, 16.4 ft/s), &gt;18 km/h recorded at 10m (33ft)</td>
</tr>
<tr>
<td>Assembly from transporter to takeoff</td>
<td>30 Minutes</td>
</tr>
<tr>
<td>Start/Finish line height</td>
<td>5.0 m (16.4ft)</td>
</tr>
<tr>
<td>Recuperation</td>
<td>1 hr between circuits</td>
</tr>
<tr>
<td>Speed</td>
<td>Two flights opposite directions in less than 7 min (&gt;10m/s, 22.4mi/h, 20 knots)</td>
</tr>
<tr>
<td>Dismantle time</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Entry</td>
<td>1/20th scale 3-view drawing depicting assembled and stowed for transportation</td>
</tr>
<tr>
<td>Course</td>
<td>One circuit in each direction, two flights in opposite directions per circuit must be completed in under 7 minutes</td>
</tr>
</tbody>
</table>
Figure 4  Aircraft specific power for various HPAs.
Specific Power

- Similar aircraft require 6 - 7 watts per kilogram of pilot weight to fly at our required speed
  - For a 55 kg (120 lb) pilot this means approximately 330 - 385 watts
Specific Power

- Drela discovered power output is linearly related to weight of pilot
- Also, power required is proportional to the gross weight of the aircraft
- Therefore, for every weight increase in the airplane, the necessary weight of the pilot increases as well
Pilot Power Available

![Graph showing pilot power available over time. The graph plots power (in HP) on the y-axis and time in minutes on the x-axis. There are two markers: one for 'First class athlete' and another for 'World record'. The power decreases significantly as time increases.]
Power Available

- For sustained flights power required must be less than 70% of max power

- College level athlete can sustain around .5 - .6 hp (350 - 450 watts) for our 3.5 minute timespan
## Parent Aircraft Comparison

<table>
<thead>
<tr>
<th>PLANE</th>
<th>MUSCULAIR 1</th>
<th>MUSCULAIR 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>HP all-purpose</td>
<td>HP speed plane</td>
</tr>
<tr>
<td>Builder</td>
<td>Gunter Rochelt. Munchen, W. Germany</td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td>High-wing monoplane with rear prop.</td>
<td></td>
</tr>
<tr>
<td>Span</td>
<td>22m (20m for speed)</td>
<td>19.5m</td>
</tr>
<tr>
<td>Length</td>
<td>7.1m</td>
<td>6.0 m</td>
</tr>
<tr>
<td>Fuselage height</td>
<td>2.12m</td>
<td>1.5m</td>
</tr>
<tr>
<td>Wing area</td>
<td>16.5</td>
<td>11.7 sq. m.</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>29.3</td>
<td>32.5</td>
</tr>
<tr>
<td>Airfoil</td>
<td>Wortmann FX76 MP root 16% thick</td>
<td>FX76 MP modified by</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dieter Althaus</td>
</tr>
<tr>
<td>Empty weight</td>
<td>28 kg</td>
<td>25 kg</td>
</tr>
<tr>
<td>Flying weight</td>
<td>82 kg</td>
<td>78 kg</td>
</tr>
<tr>
<td>(with passenger 110 kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wing loading</td>
<td>49 N/sq.m.</td>
<td>65.4 N/sq.m.</td>
</tr>
<tr>
<td>Min. flying speed</td>
<td>7.5 m/s</td>
<td>10.0 m/s</td>
</tr>
<tr>
<td>Min. power at speed</td>
<td>200 W @ 8.5 m/s</td>
<td>250 W @ 10 m/s</td>
</tr>
<tr>
<td>Full power at speed</td>
<td>265 W @ 1 I m/s</td>
<td>315 W @ 12 m/s</td>
</tr>
<tr>
<td>Min. sink rate</td>
<td>0.22 m/s</td>
<td>0.27 m/s</td>
</tr>
<tr>
<td>Max. glide ratio</td>
<td>1:38</td>
<td>1:37</td>
</tr>
<tr>
<td>Propeller</td>
<td>Solair 1 mod.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.72m dia.</td>
<td>2.68m dia.</td>
</tr>
</tbody>
</table>

- Musculair 2 required only 315 watts to fly at 12 m/s (26.8 mph)
- This is well within our acceptable range
Chain vs. Gears

• Efficiency
• Weight
• Simplicity of Construction
  • Easy to build/repair
Power

Three gears located at pedals for varied flight conditions (e.g. takeoff, wind)

Elliptical chainring - leads to constant power output throughout the pedal stroke
~ 100 g

Crank arms ~ 400 g

Bracket ~ 200 g
Chain - 90 degree turn from chainring to upper gear. Approximately 500 links (8ft loop) 
~ 1000 g

Derailleur - rear bicycle derailleur to keep tension in chain 
~ 200 g

Upper Gear - transfers power from chain to drive-shaft 
~ 40 g
Gear Ratios

- Target pedal RPM = 90 - 120
- Propeller RPM in steady flight ~ 200
- 1:2 for middle gear, higher and lower gears available
## Controls

### Parent Aircraft

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Span</th>
<th>Roll</th>
<th>Pitch</th>
<th>Yaw</th>
<th>Stick type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Musculair 1</td>
<td>20m (for speed)</td>
<td>Self-centering ailerons</td>
<td>All moving elevator</td>
<td>Springs keep rudder in neutral point</td>
<td>3 axis joystick</td>
</tr>
<tr>
<td>Musculair 2</td>
<td>19.5m</td>
<td>Sideways tilting of stick</td>
<td>Rotation of handgrips</td>
<td>Rotation about vertical axis</td>
<td>3 axis joystick</td>
</tr>
<tr>
<td>Velair 88</td>
<td>21.7m</td>
<td>Electric Ailerons</td>
<td>All moving, &quot;bungee&quot; trim, push rods</td>
<td>All moving, push rods</td>
<td>3 function cardan sidestick</td>
</tr>
<tr>
<td>Velair 89</td>
<td>23.3m</td>
<td>Electric rotating wing tip</td>
<td>All moving, &quot;bungee&quot; trim, push rods</td>
<td>All moving, push rods</td>
<td>3 function cardan sidestick</td>
</tr>
</tbody>
</table>
Controls

Initial Design

• Parent aircraft approach
• Requirements
  • Light weight
  • Easy to construct
  • Simple to train on
Controls

- Our design
  - Side stick control
    - 3-axis vs. two 2-axis sticks
  - Variable pitch prop
  - Electronics
- All moving tail
- Ailerons to control roll
Controls

Electronics

• Rules allow us to use one source of electrical power
• Must be used solely for control
  • Includes auto-stabilization and propeller governing
• No electronics may be used for communication
Basic Design- Fuselage

Design characteristics motivated by rules:

• Required Airspeed (22 mph)
  ● Low Reynolds Number
  ● Induced drag will be HUGE factor
• Human assisted takeoff (stabilization only)
  ● Landing Gear required
• Suitable for small batch production or assembly from kit
  ● Simple, cost efficient construction methods
Basic Design- Fuselage

Design characteristics motivated by performance goals:

• Weight
  • Affects physiological performance
    • Pilot stamina and strength
• Comfort
  • Affects physiological performance
    • Ease of control and awareness
    • Biological Implications
Basic Design- Fuselage

Resultant Key Features:

• Houses reclined pilot
• Houses power generation equipment
  ● Drive train
  ● Gears
  ● Pedals
  ● Shafts
• Attached Landing Gear (retractable?)
• Ventilation System
• Windshield
Construction Methods- Fuselage

• Marathon Eagle
  • Rigid Composite Construction
    • Minimize fuselage width
    • Allows for highly contoured shape
  • Floating Tab
    • Cancel induced drag associated with side slip maneuvers

• Daedalus
  • Frame Design
    • Graphite Epoxy tubes
      • Joined with bonding, lashing kevlar
  • Pod Shell
    • Made from Kevlar
• Lexan Windshield
Wing

• 20 m Spar
• Area = 14.7 m^2
• Root chord = 0.8m
• Tip chord = 0.6m
• Trapizoidal
• Linear taper
• All internal bracing

• Three sections
• Center = 7m
• Outside = 6.5m
• Airfoil: FX76 MP
• Modified for speed
• Re region of 600,000
• C_l around 0.8
Wing 2 - View
Wing Construction

- Tube Spar with Spar Caps
  - Tube: carbon fibers wound at +-45
  - Spar Caps: carbon laid at 0,90
- Styrofoam Ribs: minimum carbon reinforcement
- Thin (≈4mm) foam on leading edge
- Covered entirely with Mylar
Empennage

- Horizontal
  - Span = 3m
  - Chord = 0.57m
- Vertical
  - Height = 1.5m
  - Chord = 0.76m
- All Moving
Trailer

- Kremer Competition requirements
  - 8 m (26.24 ft) long internally
  - “weatherproof container”
  - Stow into a roadworthy vehicle

- UK trailer requirements
  - Mainly depends upon weight of towing vehicle

- PennDOT trailer requirements
  - Fall under “Specially Constructed Vehicle” vehicle code
UK Trailer Requirements

• If *towing vehicle* has gross weight >= 3.5 tonnes (7716 lbs)
  • Width: 2.55 m (8.37 ft)  Length: 12 m (39.4 ft)

• If gross weight of towing vehicle is < 3.5 tonnes (7716 lbs)
  • Width: 2.3 m (7.55 ft)  Length 7 m (23.0 ft)

• In both cases, maximum length of both trailer and vehicle must not exceed 18 m (59.1 ft) or 18.75 m (61.5 ft), respectively
PennDOT Regulations

- For trailers 3000 lbs or less
  - Must be inspected by mechanic
  - Comply with normal safety requirements
  - No inspection sticker, nor required annual safety inspection
- For trailers over 3000 lbs
  - More complicated with written forms and annual safety inspections
What this tells us

- Optimum Trailer Dimensions:
  - Width: 2.5 m
  - Length: 8 m
  - Height: not specified, but want to limit between 3 m – 4.5 m
  - Volume: 60 m$^3$ – 90 m$^3$
General Aircraft Construction

• Weight
  • Based on parent aircraft (Musculair 1, 2 etc), our goal is an empty weight of approximately 60 pounds.
  • With a reasonable assumption for the weight of the pilot, our takeoff weight should be less than 200 pounds.
• Feasibility?
**Initial Weight Buildup**

<table>
<thead>
<tr>
<th>Component</th>
<th>Appx. Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing (Spar)</td>
<td>15.0</td>
</tr>
<tr>
<td>Fuselage</td>
<td>20.0</td>
</tr>
<tr>
<td>Drive Train</td>
<td>5.0</td>
</tr>
<tr>
<td>Controls</td>
<td>5.0</td>
</tr>
<tr>
<td>Propeller</td>
<td>7.0</td>
</tr>
<tr>
<td>Empennage</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56.0</strong></td>
</tr>
</tbody>
</table>

**This is a very approximate estimation, and is subject to change upon further analysis.**
Materials

- Carbon Fiber spar
- Weight and strength considerations (as opposed to aluminum)
- Commercially made (sponsors??)
- Styrofoam ribs, Mylar covering
- Carbon tubes framing, Mylar/Fiberglass(?) covering for fuselage
Training Regimen

• We want a program that assimilates the pilot to the actual flight conditions.
  • Cycling
    • Zephyrus Bike: Wheeled Model
      • Gears
      • Chainring
      • Position
  • Repetition
    • Muscle Memory and Power
    • Short Bursts (Able to put out necessary power for 4-5 minutes at a time)
  • Recovery Period
Training Regimen

• Control
  • Again, Repetition
    • Stick experience (Instinctual motion)
    • Flying experience (Sailplane?, Small powered aircraft?)
  • Implement on bicycle
    • Try to simulate real conditions as closely as possible
    • Problems: effective mass effects, ways to model?

• Diet
  • Regulated…more details to be worked out

• Kinesiology Department
Sponsorship

- Rules
  - Sport—No rule specifically mentioned concerning sponsorship
  
  - Information from Virginia Tech indicates that no sponsorship is allowed on the airplane
  
  - Sponsorship opportunities limited by the lack of decals on aircraft
  
  - Various companies can be approached for Sponsorship
  
  - MIT’s Daedalus used a variety of sponsors
    
    - NASA, Anheuser Busch, United Technologies Corporations
ONE FINAL REMINDER...
£ 100,000 > £ 50,000

$/£ = 2.08
as of 5:45 PM GMT
on 5 November 2007
Questions?
¿Preguntas?
Fragen?
Domande?
Spørsmål?
вопросы?
質問?
SENSE

This picture makes none
Let’s pray this man knows how to land