F-35 Class Hovercraft Propulsion

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AEM 495
Goal

• Determine whether the University of Alabama Hoverteam F-35 Class hovercraft propulsion system should use a non-ducted propeller, a ducted propeller, a non-ducted fan, or a ducted fan

• Determine the diameter of the propeller/fan
Overview

• How does a hovercraft work
• Hovercraft racing classes
• Hoverteam craft design
• Factors/Configurations to consider
• Non-Ducted Thrust Calculations
• Ducted Thrust Calculations
• Weight Calculations
• Selection of propulsion system
How does a hovercraft work?
How does a hovercraft work?
Hovercraft Racing Classes

- **Formula 1** – no upper limit on size or # of engines

- **Formula 2** – no limit on # of engines, upper limit on engine size

- **Formula S** – single engine, fan, duct, no engine size limit

- **Formula 50** – single engine, fan, duct, 50 HP

- **Formula 35** – no limit on # of engines, total of 35 HP
Hoverteam Craft Design

- Formula 35 class
- 27 HP thrust engine
- 6.5 HP lift engine
Factors to Consider

• Manufacturer availability

• Thrust/Weight – would like this to be high

• Safety – HCA guidelines

• Ability to change from fan to propeller

• Noise – HCA guidelines
Configurations Considered

• Non-ducted propeller
  – 2 blades
  – 3.5 ft.
  – 4 ft.

• Ducted propeller
  – 2 blades
  – 3.5 ft.
  – 4 ft.

• Non-ducted fan
  – 5 blades
  – 3.5 ft.
  – 3.75 ft.

• Ducted fan
  – 5 blades
  – 3.5 ft.
  – 3.75 ft.
Thrust Calculation

• Momentum theory will be used

• Constants
  – \( P = 26.5 \text{ hp} = 14575 \frac{\text{ft}\times\text{lb}}{\text{s}} \)
  – \( \rho = 0.0023769 \frac{\text{slugs}}{\text{ft}^3} \)

• Assumptions made:
  – Steady flow
  – Incompressible flow
  – Neglect rotation imparted to flow
  – Air at standard temperature and pressure
Momentum Theory

![Diagram showing momentum theory concept with labeled areas and arrows indicating flow and pressure changes.]
Non-ducted Thrust Calculation

• Determine $V_1$ using propeller efficiency
  
  – Ideal propeller efficiency ($n_{pr_{ideal}}$) is about 0.8

  
  $n_{pr_{ideal}} = \frac{V_0}{V_1}$

  $n_{pr} = 0.85 \times n_{pr_{ideal}} = 0.85 \times 0.8 = 0.68$

  $0.68 = 0.85 \times n_{pr_{ideal}} = 0.85 \times \frac{V_0}{V_1}$

  $V_1 = 1.25 \times V_0$
Non-ducted Thrust Calculation

• Find $V_3$ using power equation

\[-P = \dot{m} \left( \frac{V_3^2}{2} - \frac{V_0^2}{2} \right) = \rho V_1 A_{disk} \left( \frac{V_3^2}{2} - \frac{V_0^2}{2} \right)\]

\[-\text{Solve for } V_3 = \sqrt{\frac{2P}{\rho V_1 A_{disk}}} + V_0^2\]

• Solve for thrust

\[-T = \dot{m}(V_3 - V_0) = \rho V_1 A_{disk}(V_3 - V_0)\]
Non-ducted Thrust Calculation

• Calculations are performed for values of $V_0$ ranging from 5 mph to 60 mph

• 60 mph is the approximate top speed of the craft

• Unlikely that the craft will be going this fast during a race
Non-Ducted Thrust Comparison

Thrust Produced vs. Freestream Velocity
Non-Ducted Fan/Prop

Freestream Velocity, $V_0$ (mph)

Thrust (lbf)

3.5 ft Prop/Fan
3.75 ft Fan
4 ft Prop
Why is a duct helpful?

• Helps prevent pressure tip vortices from forming

• Decreases noise due to reduction of tip vortices

• Essentially has the same effect as if you were increasing the diameter of the prop/fan
Why is a duct helpful?

- Decreases turbulence at the blade tip

Flow from behind the propeller

Stream of exiting air
Ducted Thrust Calculation

• For this propeller/fan size range, a duct **can** cause an increase in thrust of up to 25%

• Generally, a hovercraft thrust duct will increase the total thrust output by 10-15%

• For calculations, assume a 10% increase in total thrust output
Ducted Thrust Calculation

• Assumptions
  – Duct does not converge or diverge

\[ V_0 \]
Ducted Thrust Calculation

• Multiply thrust values found for non-ducted propeller/fan by 1.1 to show a 10% increase in total thrust output
  – Assumptions (incompressible, steady, etc.) still apply
  – \( T_{ducted} = 1.10 \times T_{non-ducted} \)
Ducted Thrust Comparison

Thrust Produced vs. Free Stream Velocity
Non-Ducted and Ducted Fan/Prop

Thrust (lbf)

Free Stream Velocity, $V_0$ (mph)
Propeller Weight Calculation

- 4 ft. propeller weighs 5.2 lbs. $\rightarrow$ 1.3 lbs/ft
  - Propeller in the hovercraft lab was weighed
  - $W = 1.3 \times Diameter$

<table>
<thead>
<tr>
<th>Diameter (ft)</th>
<th>Fan/Prop</th>
<th>Total Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>Propeller</td>
<td>4.55</td>
</tr>
<tr>
<td>4</td>
<td>Propeller</td>
<td>5.20</td>
</tr>
</tbody>
</table>
Fan Weight Calculation

- Fan hub weighs about 3.5 lbs and is 11” in diameter
- Each blade for a 45” fan weighs 0.9 lbs and is 17” long $\Rightarrow$ 0.635 lbs/ft
- A five bladed fan will be used for calculations

$$W = 3.5 + 0.635 \times 5 \times \left( \frac{\text{Diameter} - 0.916}{2} \right)$$

<table>
<thead>
<tr>
<th>Diameter (ft)</th>
<th>Fan/Prop</th>
<th>Total Weight (lbs)</th>
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</thead>
<tbody>
<tr>
<td>3.5</td>
<td>Fan</td>
<td>7.60</td>
</tr>
<tr>
<td>3.75</td>
<td>Fan</td>
<td>8.00</td>
</tr>
</tbody>
</table>
Duct Weight Calculation

• Mid range Styrofoam density is 2.275 lbs/ft³

• Duct assumed perfectly cylindrical, 18” in height, and 3” thick
  \[ W = 2.275 \times (\pi r_{outer}^2 h - \pi r_{inner}^2 h) \]

<table>
<thead>
<tr>
<th>Diameter (ft)</th>
<th>Weight (lbs)</th>
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<tbody>
<tr>
<td>3.5</td>
<td>8.71</td>
</tr>
<tr>
<td>3.75</td>
<td>9.38</td>
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<tr>
<td>4</td>
<td>10.05</td>
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## Total Assembly Weight

<table>
<thead>
<tr>
<th>Diameter (ft)</th>
<th>Fan/Prop</th>
<th>Duct/Non</th>
<th>Total Weight (lbs)</th>
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</thead>
<tbody>
<tr>
<td>3.5</td>
<td>Propeller</td>
<td>Non</td>
<td>4.55</td>
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<tr>
<td>4</td>
<td>Propeller</td>
<td>Non</td>
<td>5.20</td>
</tr>
<tr>
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<td>Non</td>
<td>7.60</td>
</tr>
<tr>
<td>3.75</td>
<td>Fan</td>
<td>Non</td>
<td>8.00</td>
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<tr>
<td>3.5</td>
<td>Propeller</td>
<td>Duct</td>
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<tr>
<td>4</td>
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<td>Duct</td>
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<tr>
<td>3.5</td>
<td>Fan</td>
<td>Duct</td>
<td>16.31</td>
</tr>
<tr>
<td>3.75</td>
<td>Fan</td>
<td>Duct</td>
<td>17.38</td>
</tr>
</tbody>
</table>
Final Decision

- HCA mandates that a duct be installed on the craft for safety reasons
  - For this reason, non-ducted propellers and fans must be eliminated from consideration
  - Noise will be reduced with the addition of the duct
Thrust/Weight Comparison

Thrust/Weight vs. Free Stream Velocity
Ducted Fan/Prop

Free Stream Velocity, \( V_0 \) (mph)

<table>
<thead>
<tr>
<th>Thrust/Weight</th>
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</thead>
<tbody>
<tr>
<td>3.5 ft Ducted Prop</td>
</tr>
<tr>
<td>4 ft Ducted Prop</td>
</tr>
<tr>
<td>3.5 ft Ducted Fan</td>
</tr>
<tr>
<td>3.75 ft Ducted Fan</td>
</tr>
</tbody>
</table>
## Final Decision

<table>
<thead>
<tr>
<th>Factor</th>
<th>Best Choice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust/Weight</td>
<td>3.5 ft. Ducted Propeller</td>
</tr>
<tr>
<td>Safety</td>
<td>Any Ducted Propeller</td>
</tr>
<tr>
<td>Interchangeable</td>
<td>3.5 ft. Ducted Fan/Propeller</td>
</tr>
<tr>
<td>Noise</td>
<td>4 ft. Ducted Propeller</td>
</tr>
</tbody>
</table>

Best Choice: 3.5 foot ducted propeller