F-35 Class Hovercraft Propulsion

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December 2, 2014

AEM 495

Goal

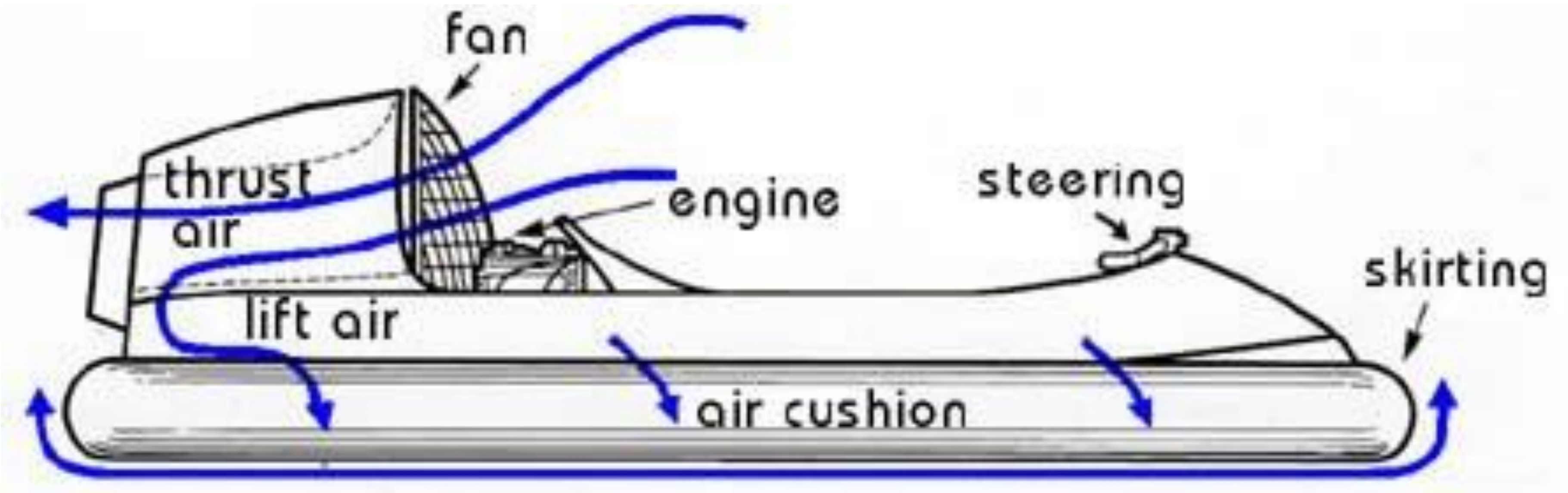
- Determine whether the University of Alabama Hoverteam F-35 Class hovercraft propulsion system should use a non-ducted propeller, a ducted propeller, a non-ducted fan, or a ducted fan

- Determine the diameter of the propeller/fan

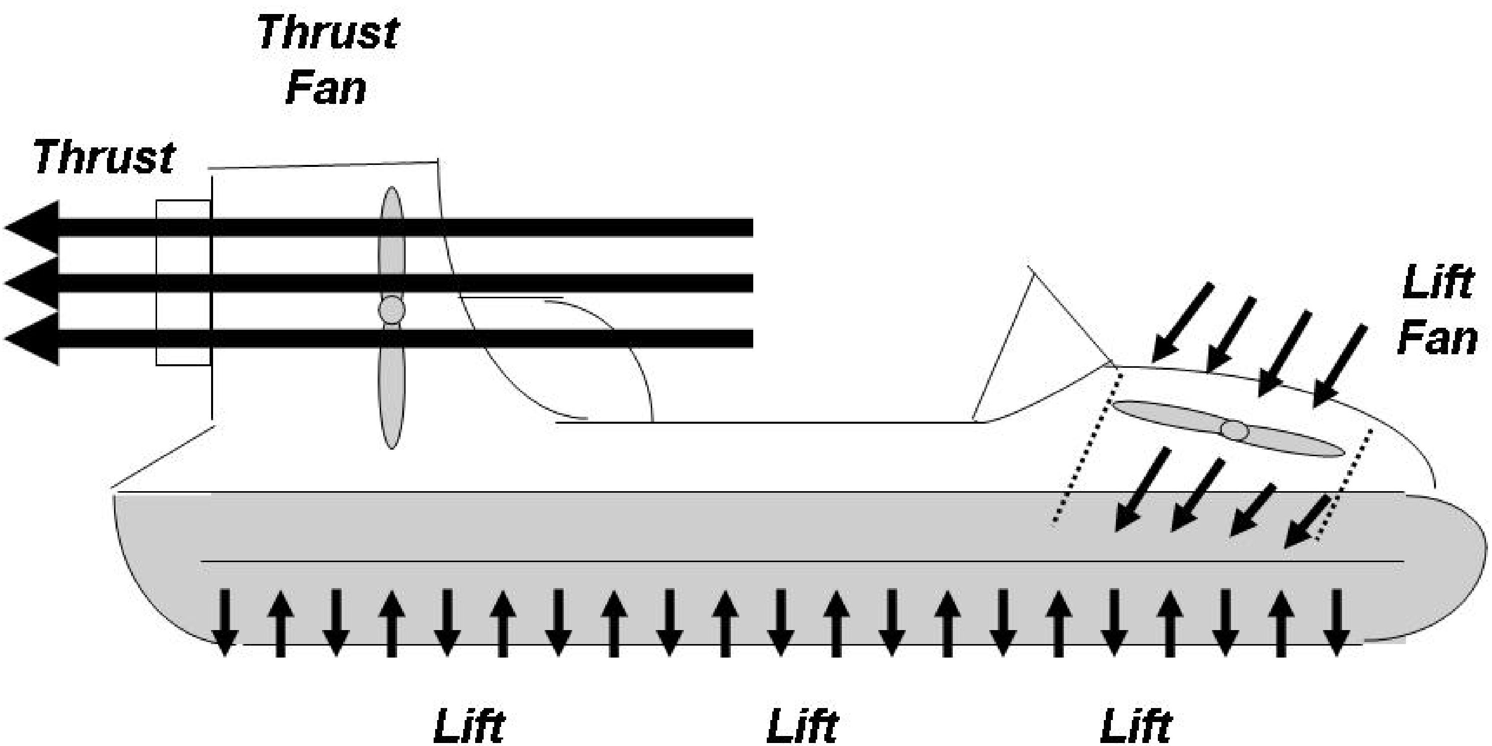
Overview

- 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?



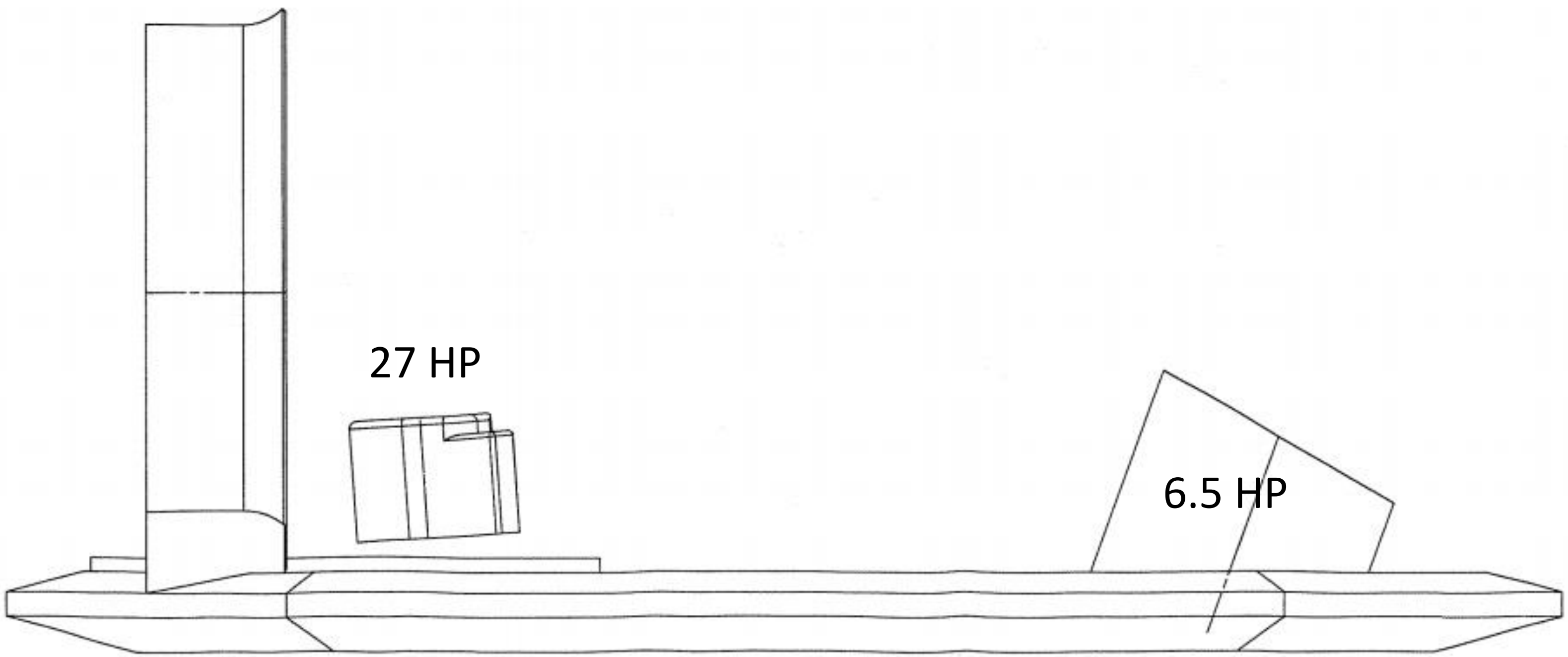
How does a hovercraft work?



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

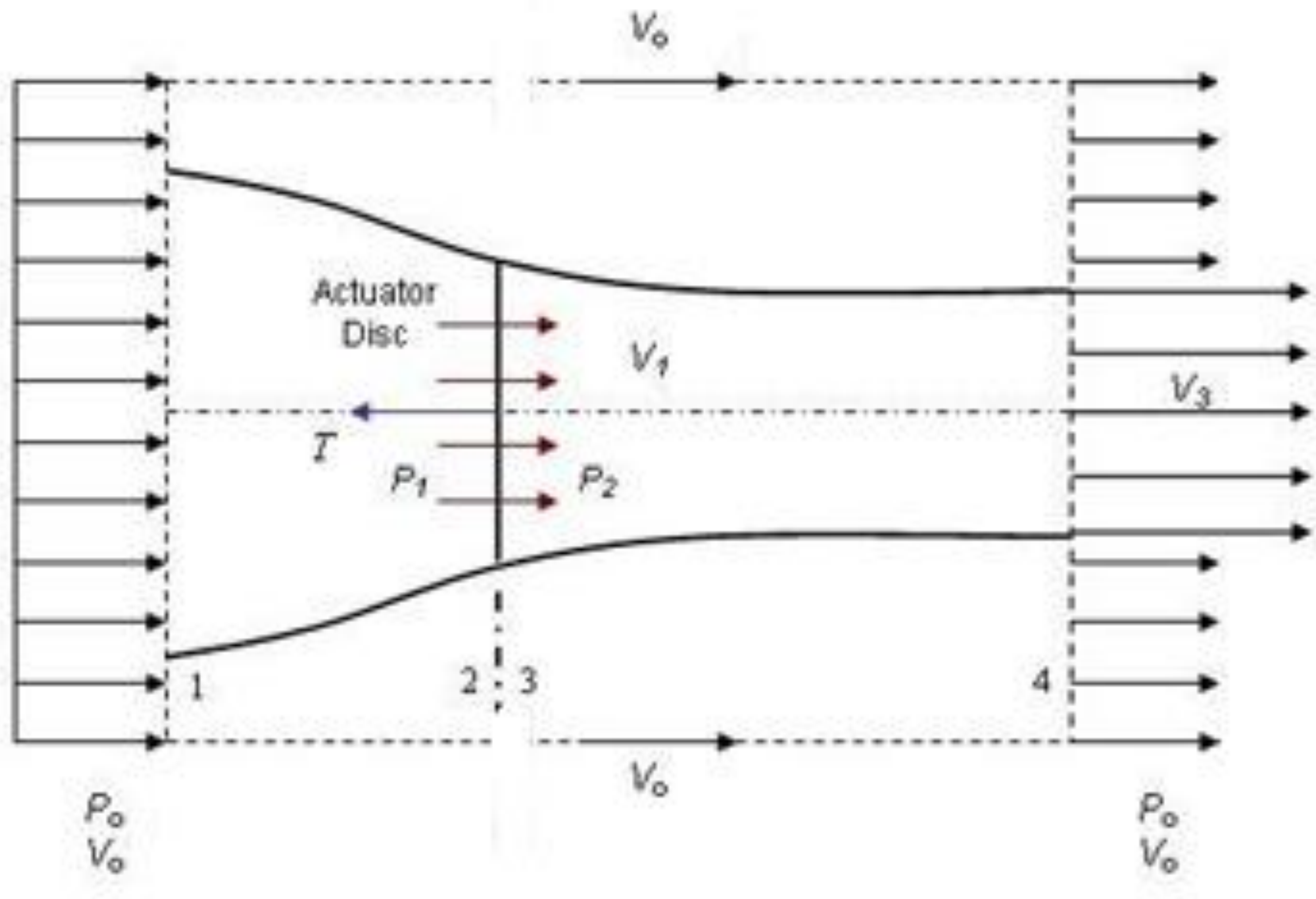
Configurations Considered

- 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
  - $P = 26.5\ hp = 14575\ \frac{ft*lb}{s}$
  - $\rho = 0.0023769\ \frac{slugs}{ft^3}$
- Assumptions made:
  - Steady flow
  - Incompressible flow
  - Neglect rotation imparted to flow
  - Air at standard temperature and pressure

Momentum Theory



Non-ducted Thrust Calculation

- Determine V_1 using propeller efficiency
  - Ideal propeller efficiency ($n_{pr_{ideal}}$) is about 0.8
  - $n_{pr_{ideal}} = \frac{V_0}{V_1}$
  - $n_{pr} = 0.85 * n_{pr_{ideal}} = 0.85 * 0.8 = 0.68$
  - $0.68 = 0.85 * n_{pr_{ideal}} = 0.85 * \frac{V_0}{V_1}$
  - $\boldsymbol{V_1 = 1.25 * V_0}$

Non-ducted Thrust Calculation

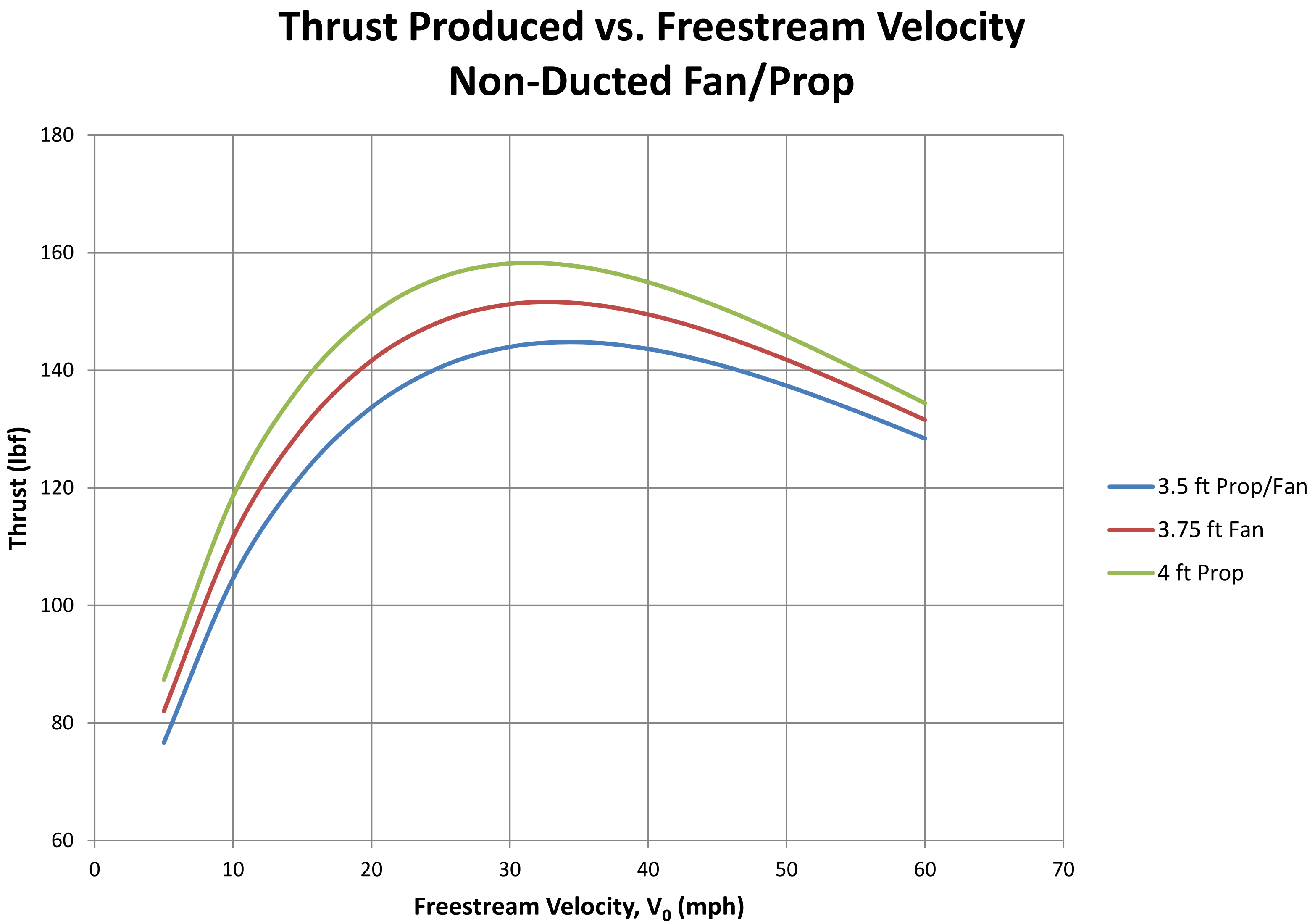
- Find V_3 using power equation
  - $P = \dot{m}\left(\frac{{V_3}^2}{2} - \frac{{V_0}^2}{2}\right) = \rho V_1 A_{disk}\left(\frac{{V_3}^2}{2} - \frac{{V_0}^2}{2}\right)$
  - Solve for $\boldsymbol{V_3} = \sqrt{\frac{\mathbf{2}\boldsymbol{P}}{\boldsymbol{\rho V_1 A_{disk}}} + \boldsymbol{V_0}^{\mathbf{2}}}$

- 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

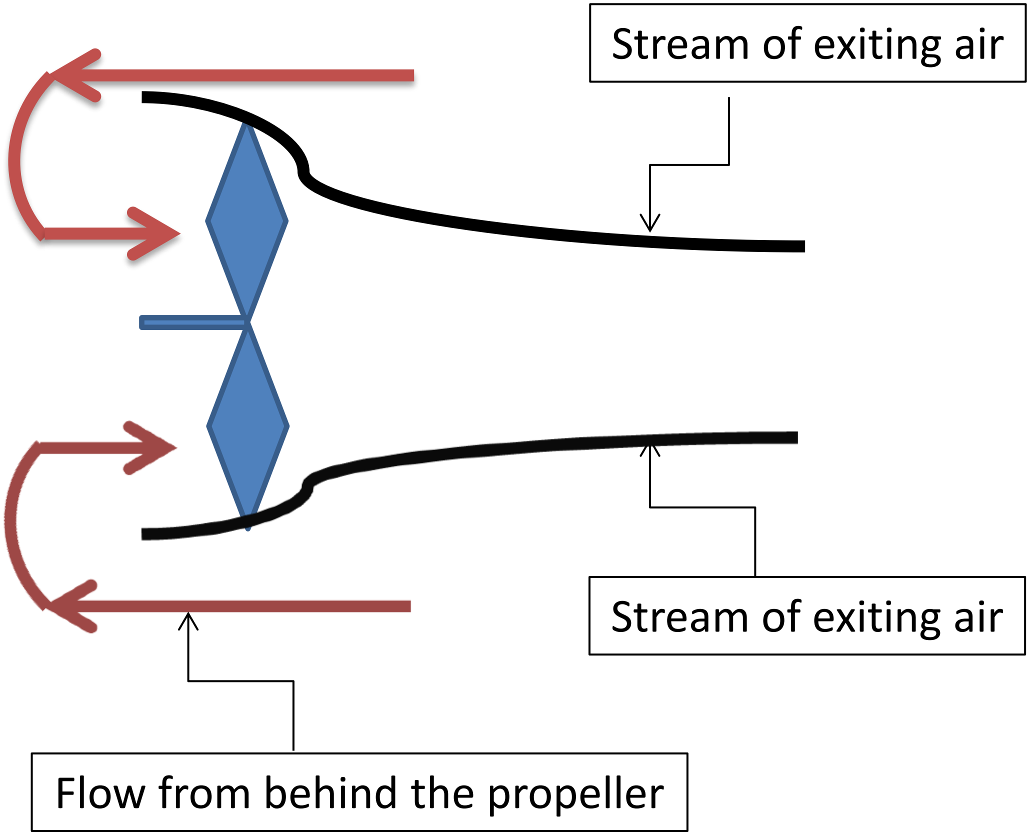


Why is a duct helpful?

- 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

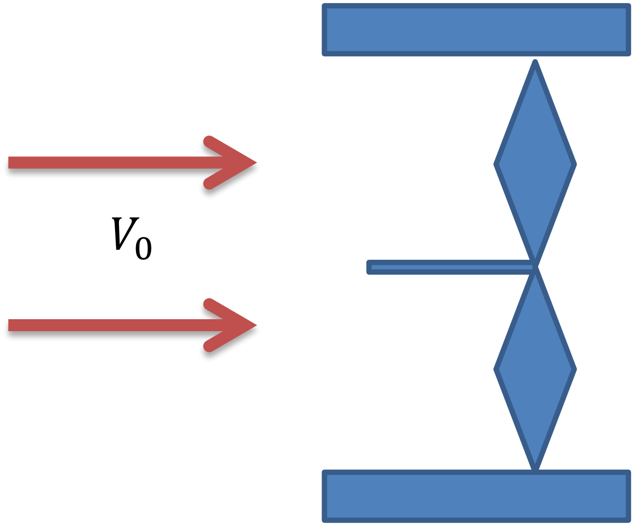


Ducted Thrust Calculation

- 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

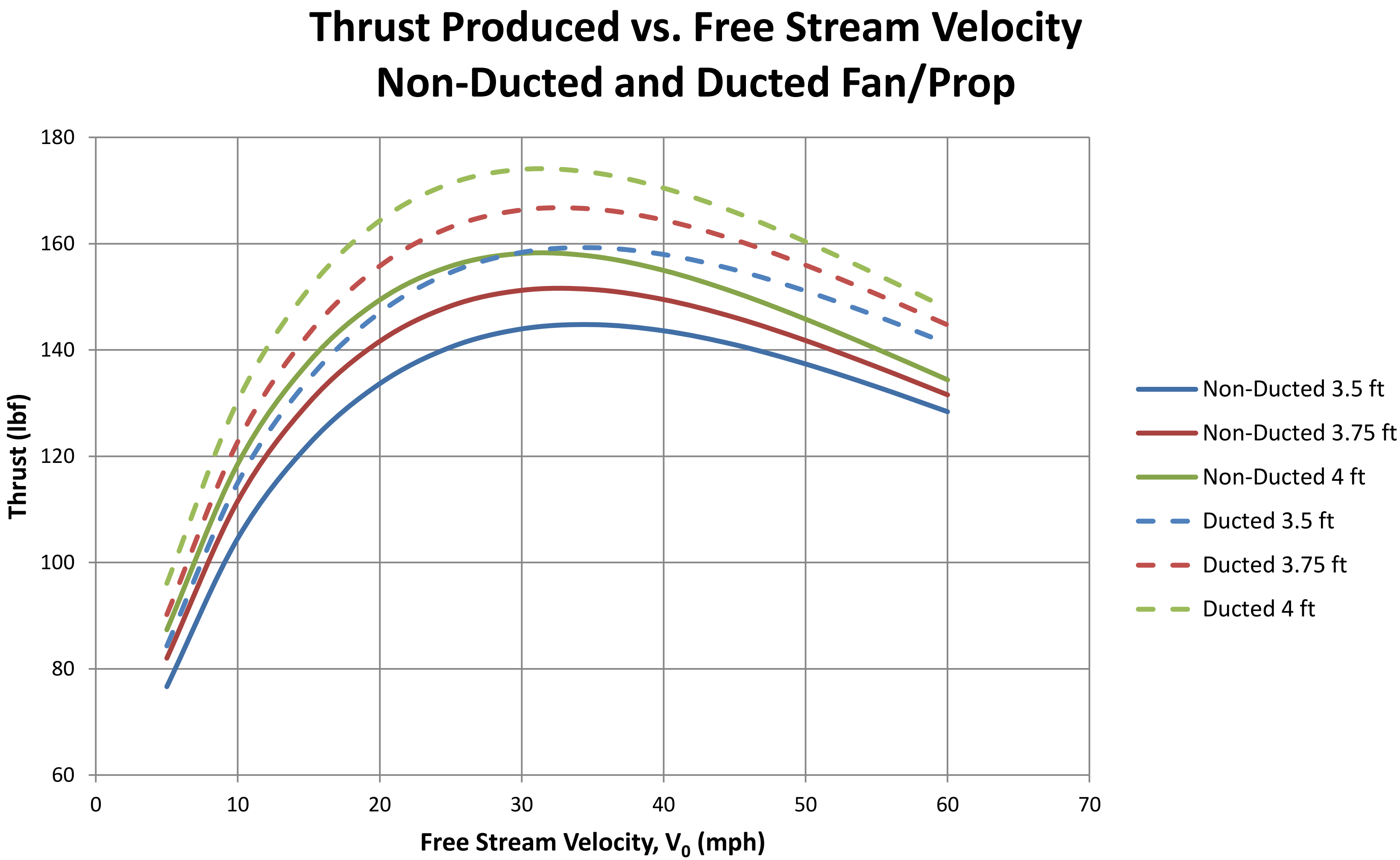
- Assumptions
  - Duct does not converge or diverge



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
  - $T_{ducted} = 1.10 * T_{non-ducted}$

Ducted Thrust Comparison



Propeller Weight Calculation

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

Diameter (ft)	Fan/Prop	Total Weight (lbs)
3.5	Propeller	4.55
4	Propeller	5.20

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 → 0.635 lbs/ft
- A five bladed fan will be used for calculations
  - $W = 3.5 + 0.635 * 5 * \left(\frac{Diameter - 0.916}{2}\right)$

Diameter (ft)	Fan/Prop	Total Weight (lbs)
3.5	Fan	7.60
3.75	Fan	8.00

Duct Weight Calculation

- Mid range Styrofoam density is 2.275 lbs/ft^3
- Duct assumed perfectly cylindrical, 18" in height, and 3" thick
  - $W = 2.275 * (\pi {r_{outer}}^2 h - \pi {r_{inner}}^2 h)$

Diameter (ft)	Weight(lbs)
3.5	8.71
3.75	9.38
4	10.05

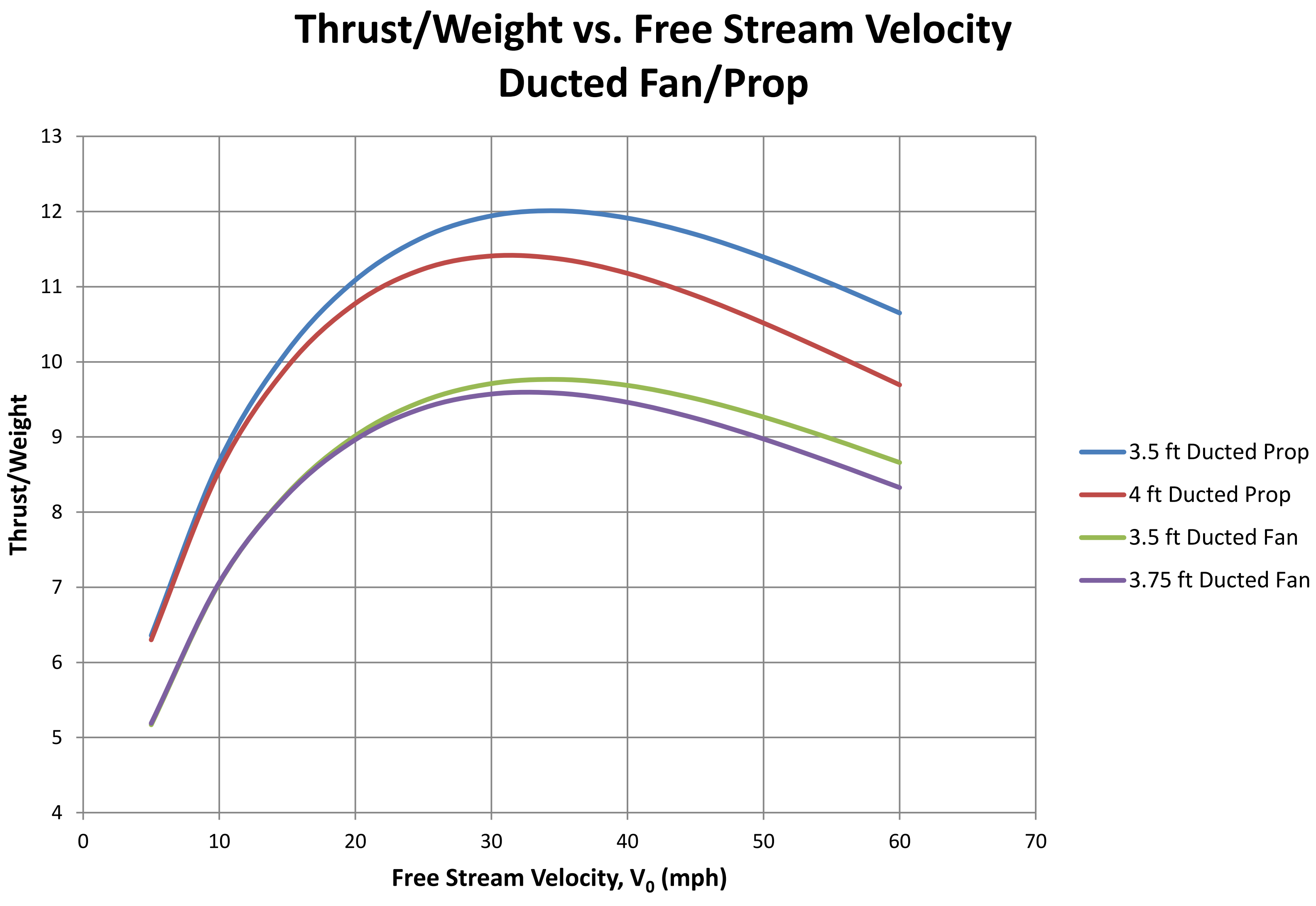
Total Assembly Weight

Diameter (ft)	Fan/Prop	Duct/Non	Total Weight (lbs)
3.5	Propeller	Non	4.55
4	Propeller	Non	5.20
3.5	Fan	Non	7.60
3.75	Fan	Non	8.00
3.5	Propeller	Duct	13.26
4	Propeller	Duct	15.25
3.5	Fan	Duct	16.31
3.75	Fan	Duct	17.38

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



Final Decision

Factor	Best Choice
Thrust/Weight	3.5 ft. Ducted Propeller
Safety	Any Ducted Propeller
Interchangeable	3.5 ft. Ducted Fan/Propeller
Noise	4 ft. Ducted Propeller

Best Choice: 3.5 foot ducted propeller