Assignment 1 -> Amphibous Rotor Design

Welcome to the rotor design report! This document contains step by step process taken towards applying basic design theories like Blade Element, Momentum Theory to design a rotor for which a drone can move in air and water.

Contents

Assumptions

- The drone flight is vertical, haven't thought about the implications of forward flight.
- Most of the design is done (table) to cater the Hover scenario, The tools give a chance to vary the Climb Velocity too. Compressibility of the flow is not accounted.
- It is assumed that Cd_water is ~ 10 times that of Cd_air for an airfoil.

Initial Sizing

- The payload mass = 5 kg, I took the total mass to be 15 kg, total Volume to be 0.008 (3 times the volume of the payload).

Rotor Diameter

- By trail and error: 1.7 m . Initial Rough estimation by looking through drone blades Link

Ideal Power

- Air

$T = totalMass * g$

In Hover : $v = \sqrt{\frac{T}{2\rho_a A}}$

$Power = T * v$ ~ 755 W

- Water

  $T = totalMass * g - \rho_w * Vol * g$

  In Hover : $v = \sqrt{\frac{T}{2\rho_w A}}$

  $Power = T * v$ ~ 8.5 W

File Structure

- Rotor Blade Design
  - A1.ipynb
  - Validation.ipynb
  - readme.md
  - blades
    - blade1.py
    - blade2.py
    - blade3.py
  - tools
    - _*init*_.py
    - airfoil.py
    - BET.py
    - BEM.py
  - Images

Code Structure

Working/Algorithm/Logic Flow Diagram of the Tools

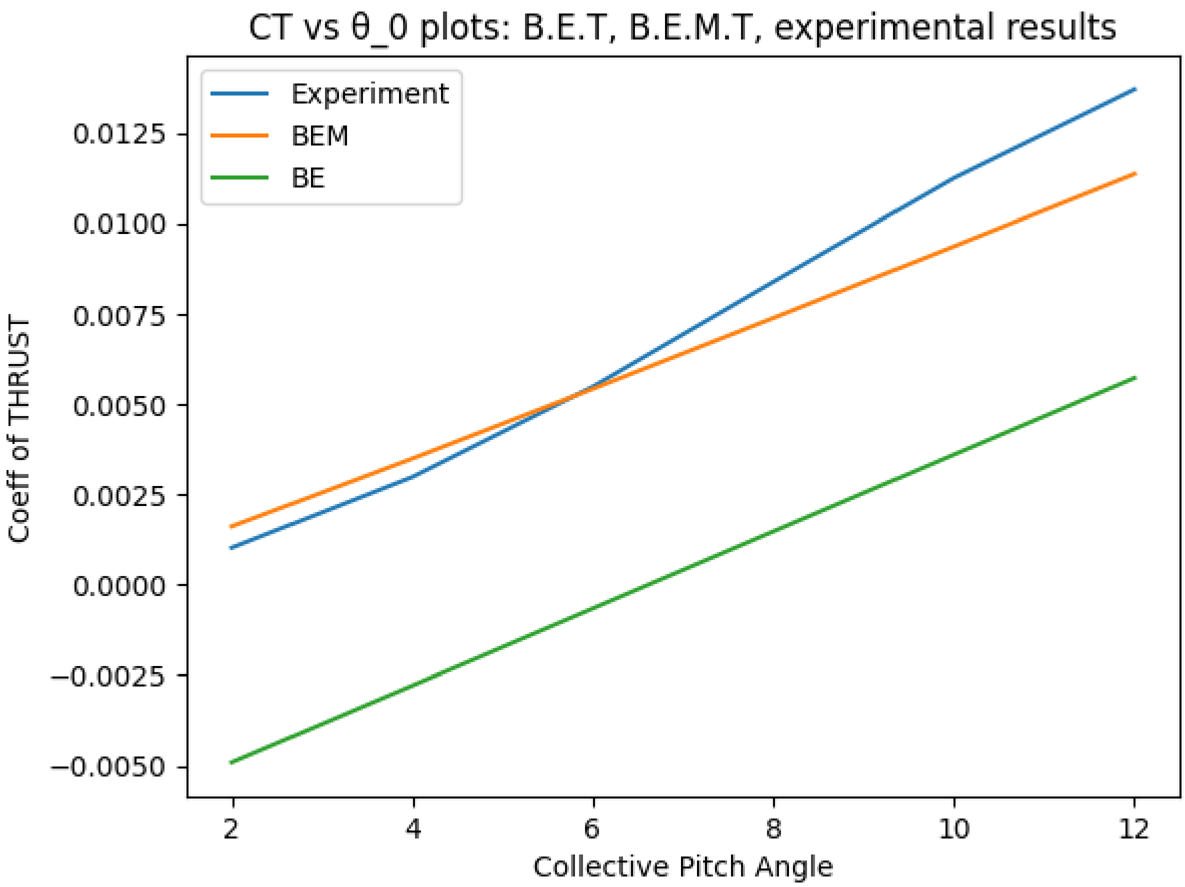
- **Initialization :** The class files in tools folder is initialized with parameters, including the number of blades, angular velocity, rotor radius, lift slope, drag , linear twist, climb velocity, root cutouts, linear taper, and medium (air or water).

- **Thrust Power Coefficients :** Thrust, Power equations are written from the respective theories, taken directly from the slides of our Course.
- **Prandtl Tip Loss :** In case of BEM theory Lamda is not constant, depends on r and F(tip loss factor) . Where F in turn depends on r again. So there is a function to keep calculating F, Lamda until they converge.

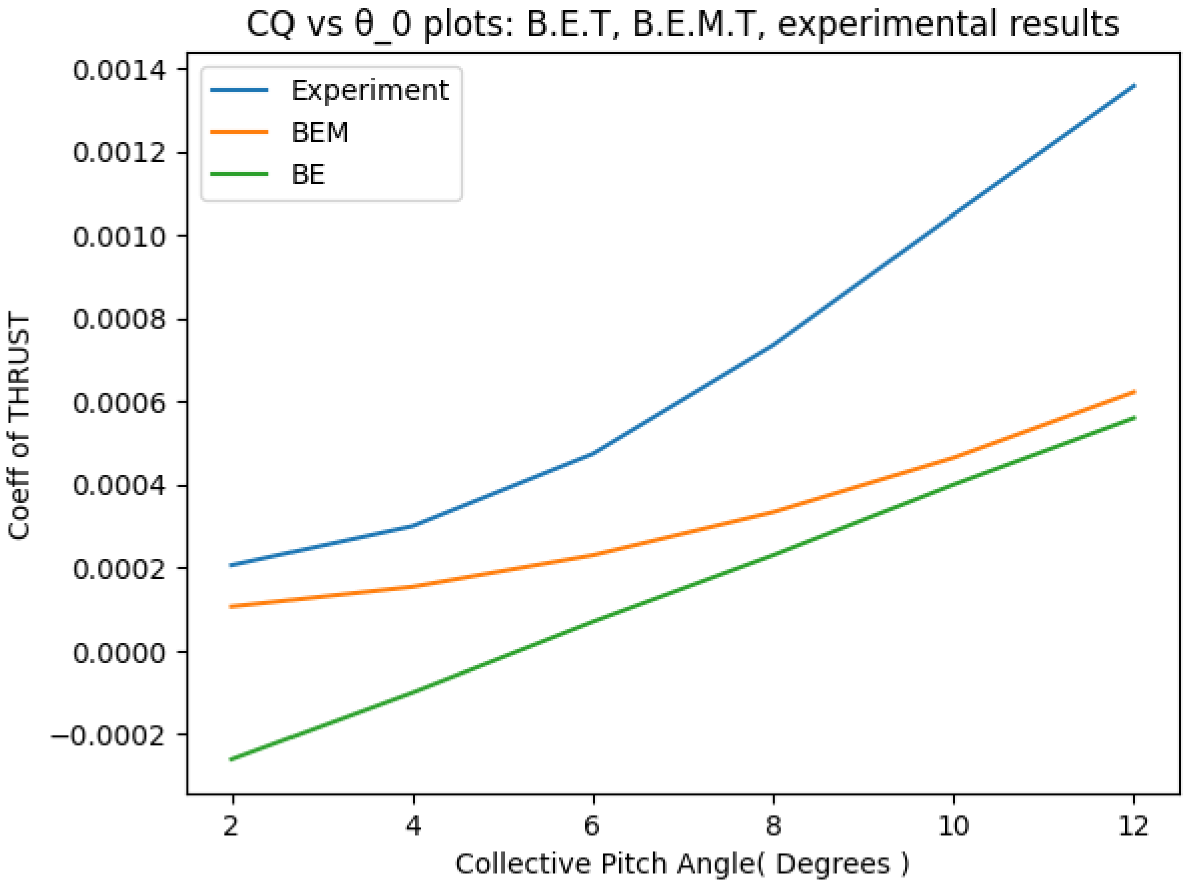
Benchmarking the Tools

Expermental Results are taken from, Where Sigma = 0.0636 ; b = 3

- CT vs θ_0 plots: B.E.T, B.E.M.T, experimental results
  - BE, BEM Thrust values are apart. I think this is atributed to the fact that BEM has varying lamda which helps the phi to adjust so that AoA is optimal at every radius.
  - I varied chord linearly for BEM, took C-mean for BE that can have some influence.

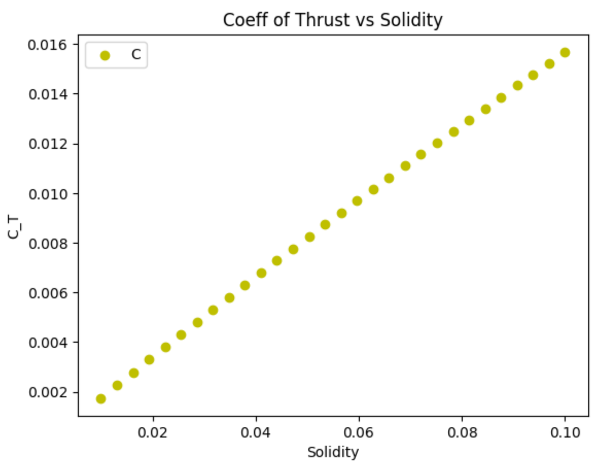


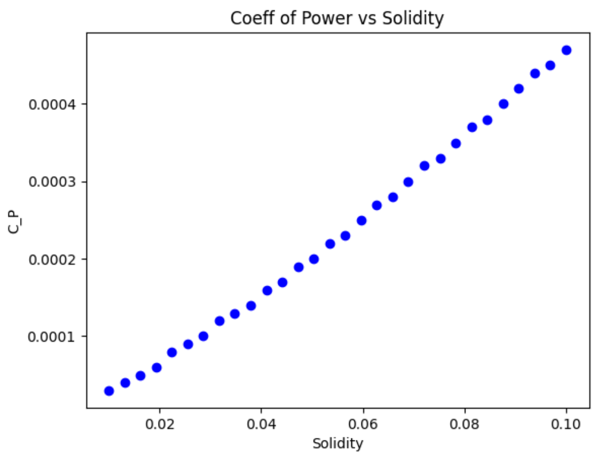
- CQ vs θ_0 plots: B.E.T, B.E.M.T, experimental results



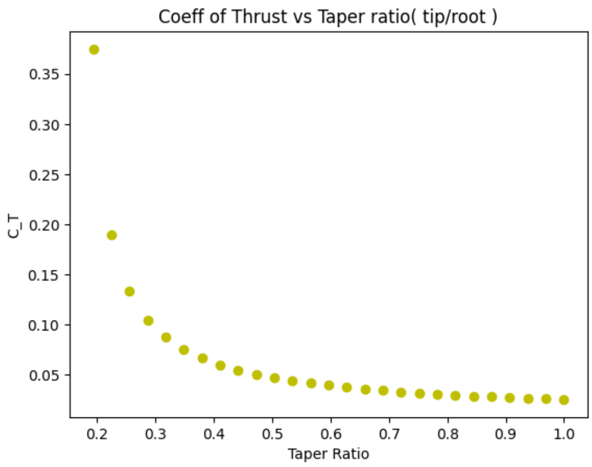
Design Variable Variations

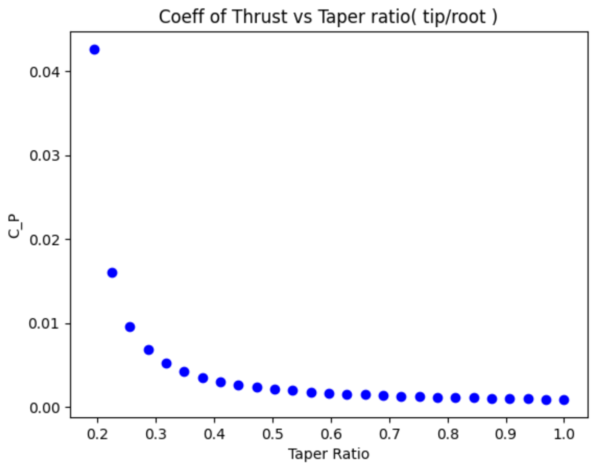
- Coefficients of Thrust and Power vs Solidity
  - It's expected to be linear because the dependency on chord is linear for T and P. solidity = k* chord, in this case b, R weren't changed.



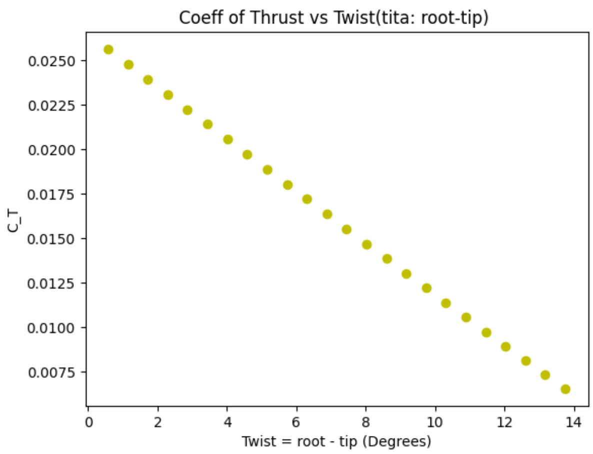


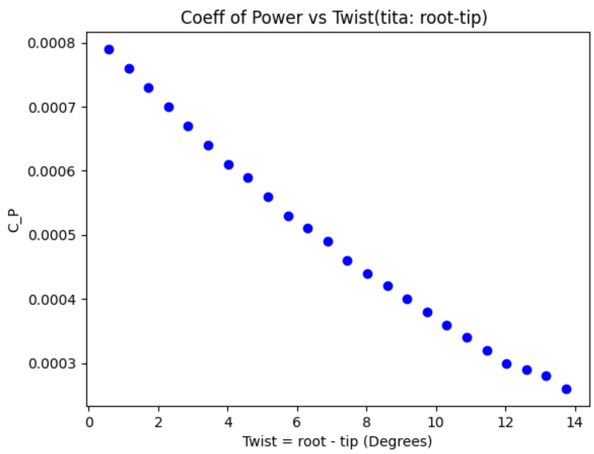
- Coefficients of Thrust and Power vs Taper ratio
  - Chord = A - B*r , A = 0.12m and B was calculated with help of taper ratio.
  - It has to decrease because with decrease in chord , Lift Decreases.





- Coefficients of Thrust and Power vs Twist
  - linear_twist = 0.3 - b*r; where b is varied with regard to the twist.
  - Higher twist implies if tita_root is constant, the tita_tip is decreading => AoA is decreasing causing the lift to decrease.





Rotor Design & Performance

Design Parameter	Design 1	Design 2	Design 3
Airfoil	NACA 2412	NACA 2412	NACA 0024
Rotor Radius	0.85	1.18	1
No of Blades	3	2	3
Chord Length Variation	0.12 - 0.02*r	0.1 - 0.03*r	0.15 - 0.02*r
Root Cutout	0.15	0.2	0.2

Design Parameter	Design 1	Design 2	Design 3
Operating Condition			
Rotor Speed in Air (rpm)	750	700	650
Rotor Speed in Water (rpm)	25	28	25
Collective pitch in Air (degrees)	7	6	6
Collective pitch in Water (degrees)	8	4	5
Steady Hover Performance Estimates			
Thrust in Air	150.578	150.803	167.423
Power in Air	350.101	372.901	428.948
Ideal Power in Air	755.786	544.422	642.418
Thrust in Water	75.725	69.137	69.1585
Ideal Power in Water	8.433	6.075	7.168
Power in Water	85.565	181.474	143.183
Performance Limits (RPM constant, varying collective pitch only)			
Stall Collective Pitch Angle in Air	14	13	12
Maximum Thrust Before Stall in Air	320.066	341.459	358.236
Power at Max Thrust in Air	695.164	665.880	804.954
Stall Collective Pitch Angle in Water	20	16	17
Maximum Thrust Before Stall in Water	267.908	406.959	389.654
Power at Max Thrust in Water	144.405	267.0623	240.1076

Acknowledgement

- To Taha my classmate, we had a lot of the discussion to understand why things are varying in a certain way.
- To Prof Dwanil Shukla , He helped me with doubts I had in the way to approach this Assignment

Reference

- Knight, M., & Hefner, R. A. (1937). Static thrust analysis of the lifting airscrew.
- Airfoil Data
- Example Rotors used in current Drones

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