Compound Helicopter - Assignment 1

Team Member Contribution

S.No	Roll Number	Name	Contribution Level (0 - 5)	Specifics of contribution
1	25M0016	Vishwa Karthi	5	Performance Estimator, Validation of conceptual design with ref. paper
2	23B0023	Jeet Gurbani	5	Mission Planner, Statistical Design, Code Integration
3	22B0059	Muriki Sree Baruni	5	Mission Planner
4	22B0060	Priyanshu Kumar	5	Engine selection & databasing

Section 1:
Assumptions & Data

1.1 Physics Assumptions

- **Steady, incompressible flow assumed. Compressibility corrections applied using Prandtl-Glauert relations**
- **2D airfoil characteristics applied locally, No spanwise flow**
- **Tip losses approximated using Prandtl's corrections**

1.2 Environmental Assumptions

- **International Standard Atmosphere (ISA) considered.**
- **Flight operations within Troposphere.**

1.3 Vehicle Assumptions

- **Rotor geometry: 4 blades, Linear taper, Linear twist**
- **Airfoil Aerodynamics data drawn from NACA 0015 Experimental results [1]**

1.4 Flight Condition Assumptions

- **Rotor Performance Estimator Benchmarking carried out at SL**
- **Mission Planner Benchmarking carried out at 2000m AMSL**

Section 2:

Algorithm/Logic Flow Diagrams

2.1: Algorithm

1. Input Rotor and Flight parameters

2. Blade Discretisation

- Rotor:
  Geometry:
  - Number of Blades
  - Radius, Root cut
  - Taper, Twist
  - Collective pitch

- Aerodynamics of c/s Airfoils:
  - Cl
  - Cd

ISA Model

- Flight conditions:
  - Altitude
  - Climb velocity

- Blade Geometry:
  Radial
  - Chord variation
  - Twist variation

3. Aerodynamics of sectional airfoils

- Computation of Local flow velocities (magnitude, angle), effective AoA
- Sectional Cl, Cd computation using
  - Aerodynamics of c/s Airfoils:
    - Cl
    - Cd
- Stall limit check
- Local Mach computation and Compressibility Check
- Application of Prandtl-Glauert Compressibility corrections

Outputs:

Cl, Cd, Perpendicular and tangential velocity, flow angle, Effective angle of attack

The function **aerod.py** is repeatedly called to compute velocity inflow, followed by sectional lift, drag and then Thrust, Torque, Power

4. Inflow distribution

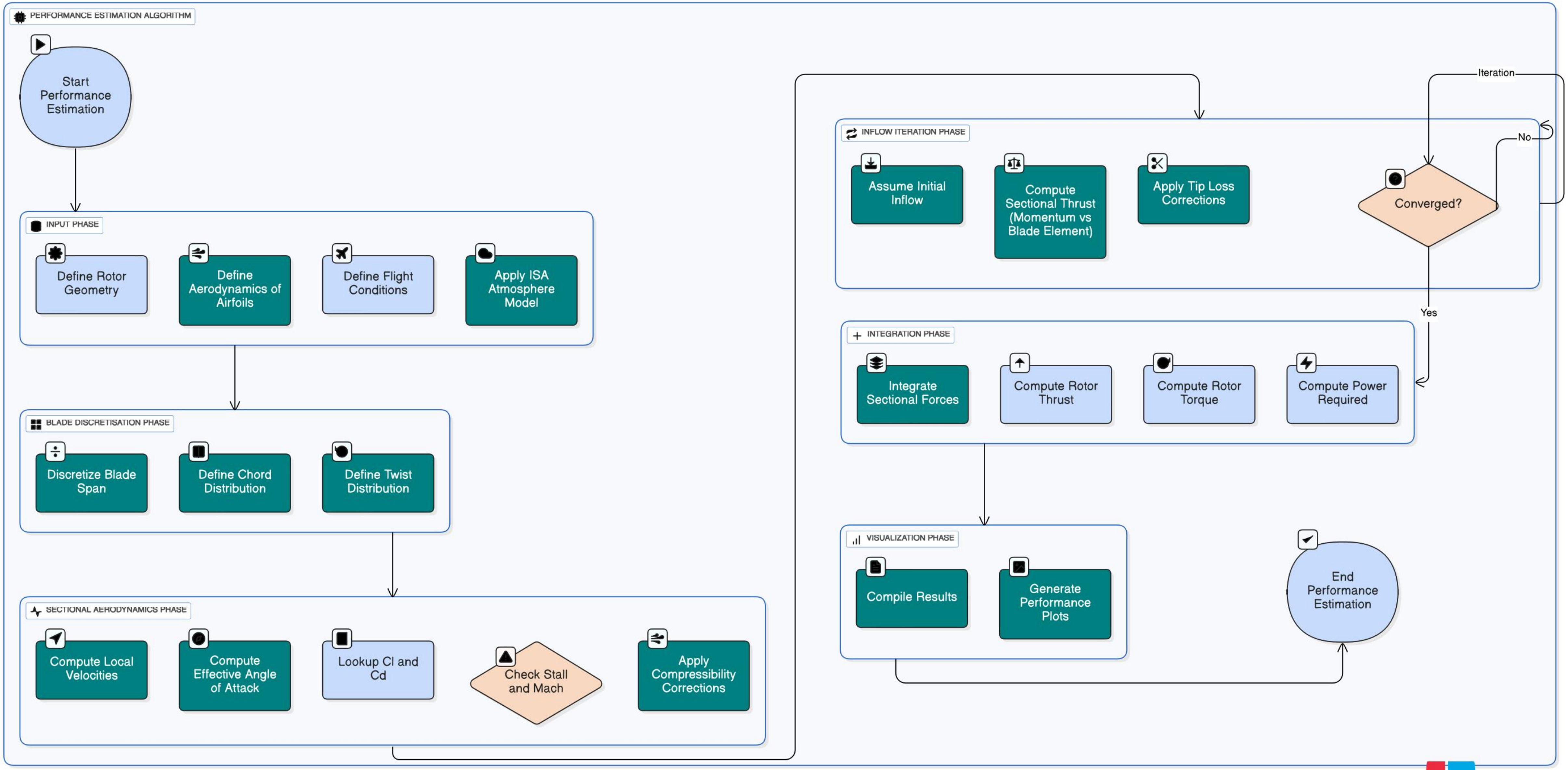
- An initial inflow distribution across blade is assumed
- Sectional thrust computed using Momentum and Blade Element theory are compared. ↓↑ Until convergence
- Inflow is updated and corrected for Tip losses using Prandtl's relation.

Output: Sectional Induced velocity

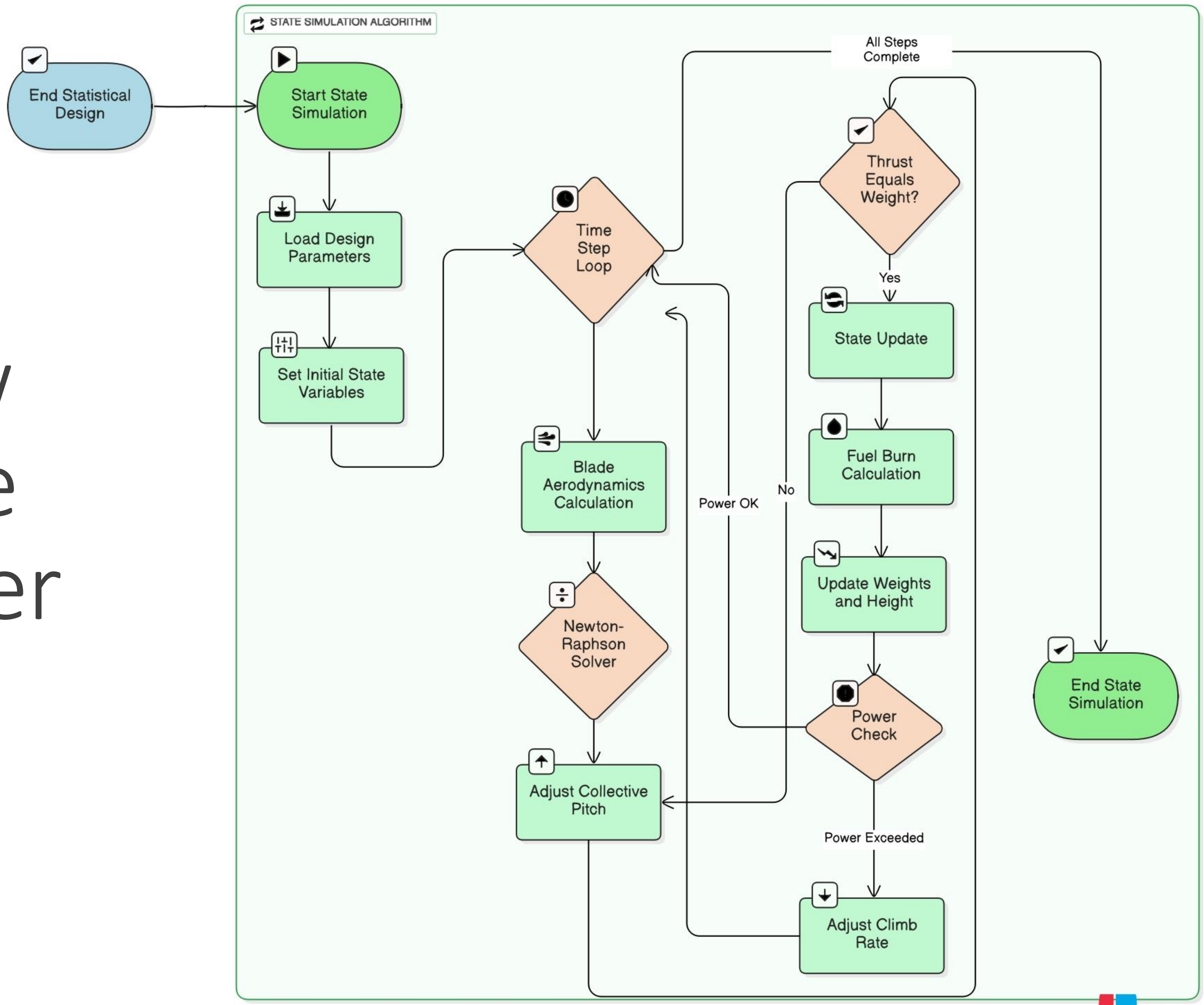
5. Performance Integration

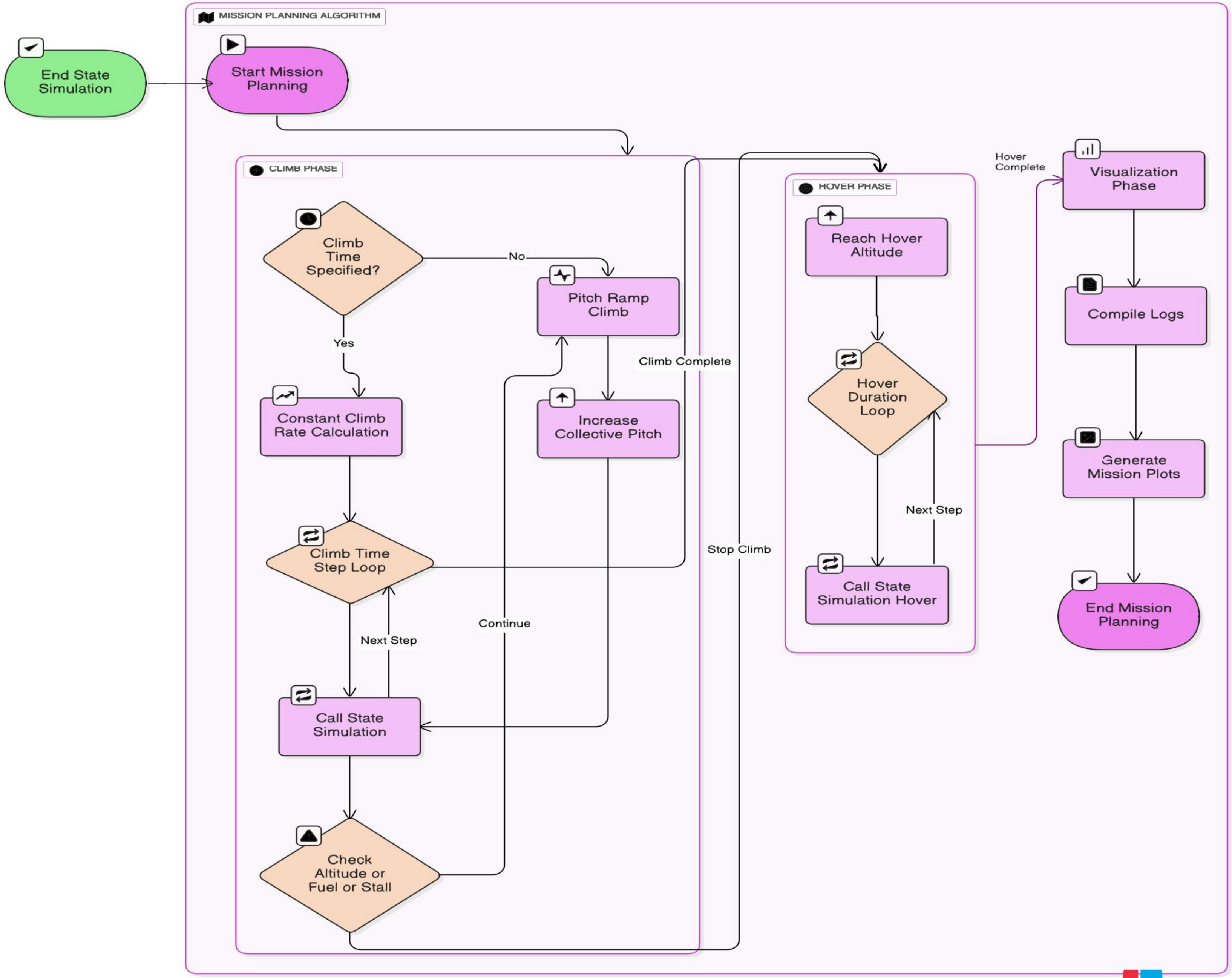
- Section inflow and airfoil characteristics called sequentially to computed blade element performances
- Sectional Thrust generated, Torque produced and power consumed are integrated from hub to tip of blades and scaled for identical blades assumed

Output: Rotor Thrust, Torque, Power


PERFORMANCE ESTIMATION ALGORITHM
Start Performance Estimation
INPUT PHASE
Define Rotor Geometry
Define Aerodynamics of Airfoils
Define Flight Conditions
Apply ISA Atmosphere Model
BLADE DISCRETISATION PHASE
Discretize Blade Span
Define Chord Distribution
Define Twist Distribution
SECTIONAL AERODYNAMICS PHASE
Compute Local Velocities
Compute Effective Angle of Attack
Lookup Cl and Cd
Check Stall and Mach
Apply Compressibility Corrections
INFLOW ITERATION PHASE
Assume Initial Inflow
Compute Sectional Thrust (Momentum vs Blade Element)
Apply Tip Loss Corrections
Converged?
Iteration
No
Yes
INTEGRATION PHASE
Integrate Sectional Forces
Compute Rotor Thrust
Compute Rotor Torque
Compute Power Required
VISUALIZATION PHASE
Compile Results
Generate Performance Plots
End Performance Estimation

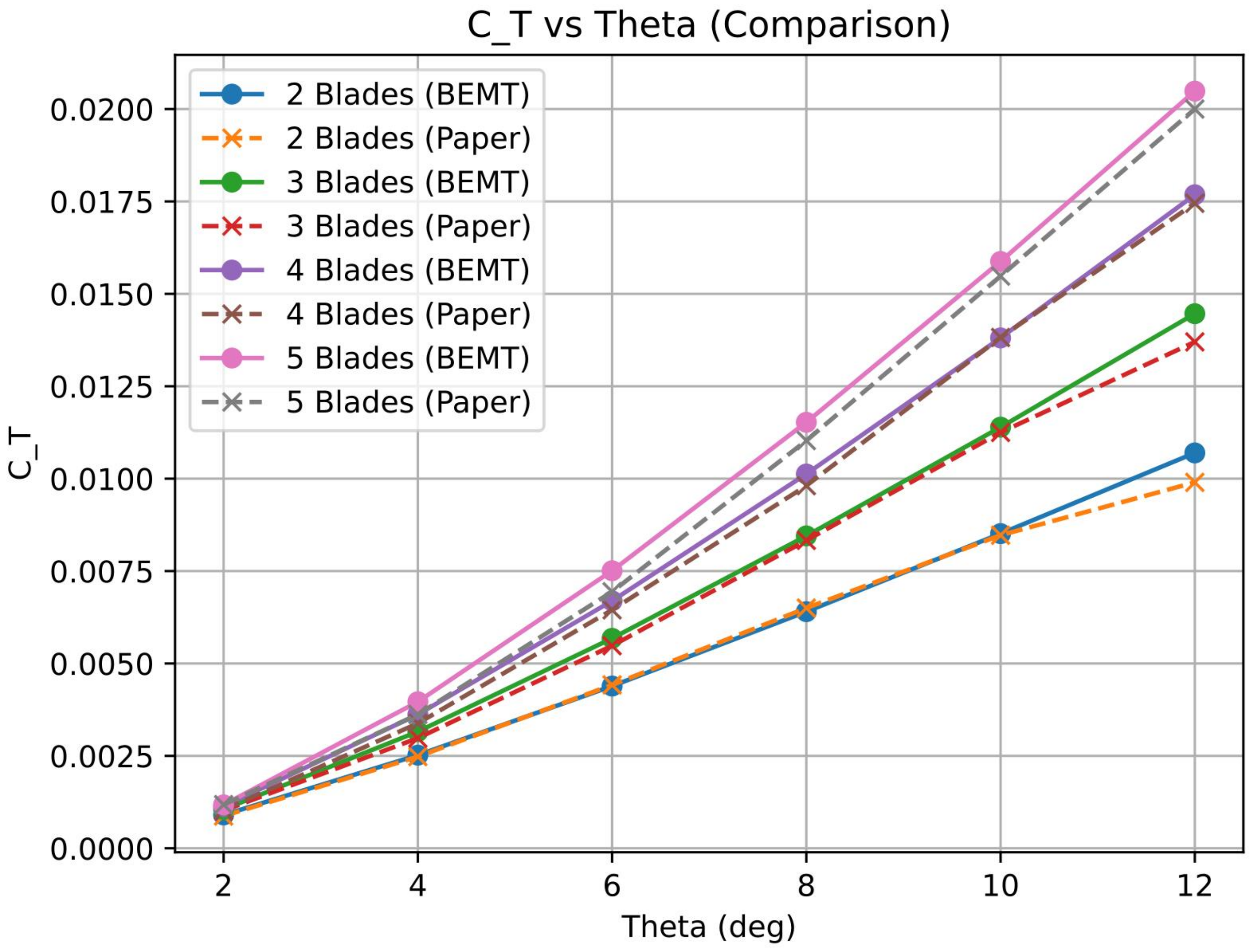
2.2: Logic Flow Diagram of the Mission Planner



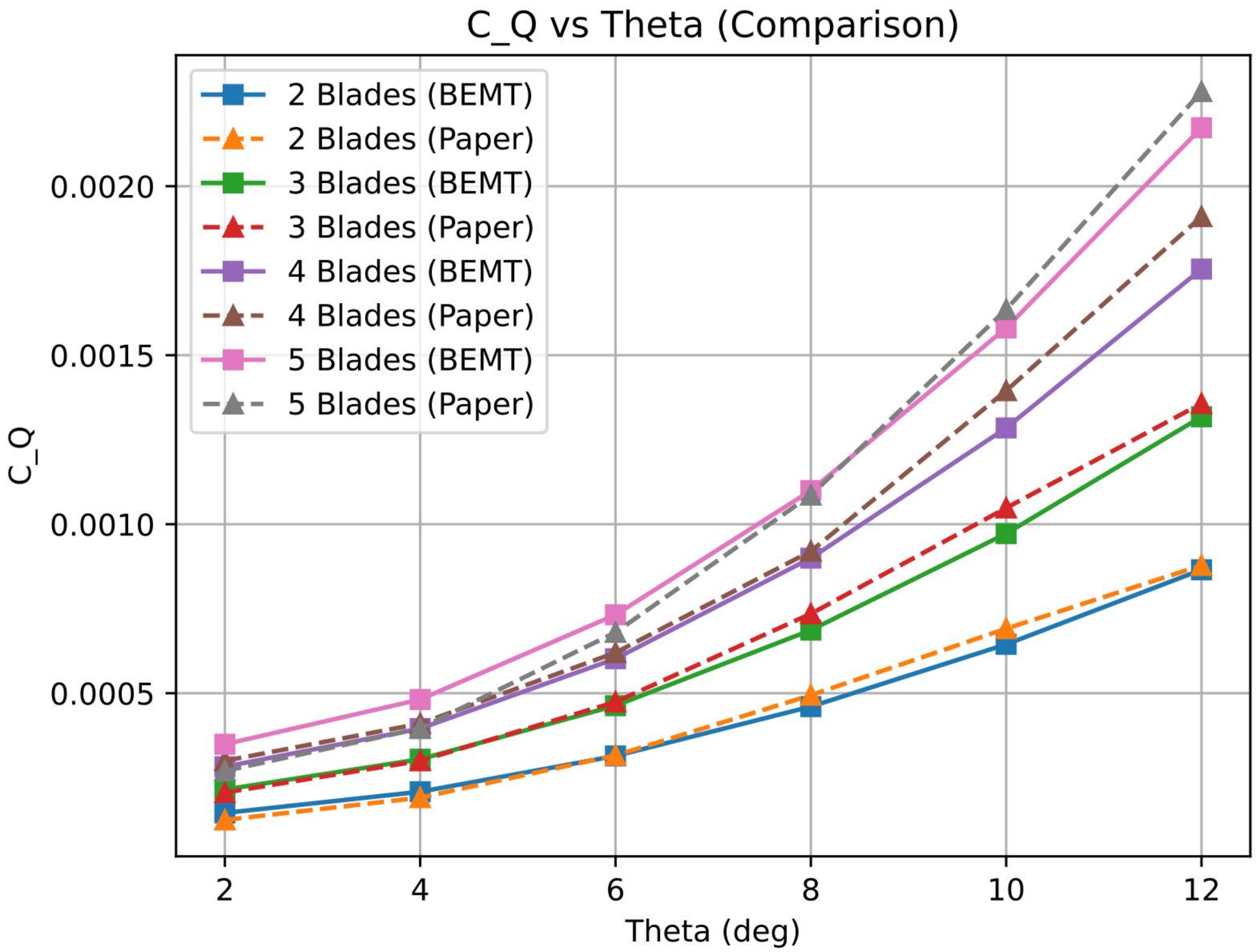

MISSION PLANNING ALGORITHM
End State Simulation
Start Mission Planning
CLIMB PHASE
Climb Time Specified?
No
Yes
Pitch Ramp Climb
Constant Climb Rate Calculation
Increase Collective Pitch
Climb Complete
Climb Time Step Loop
Next Step
Continue
Call State Simulation
Check Altitude or Fuel or Stall
Stop Climb
HOVER PHASE
Reach Hover Altitude
Hover Duration Loop
Next Step
Call State Simulation Hover
Hover Complete
Visualization Phase
Compile Logs
Generate Mission Plots
End Mission Planning

Section 3:
Performance Estimator Tool Benchmarking

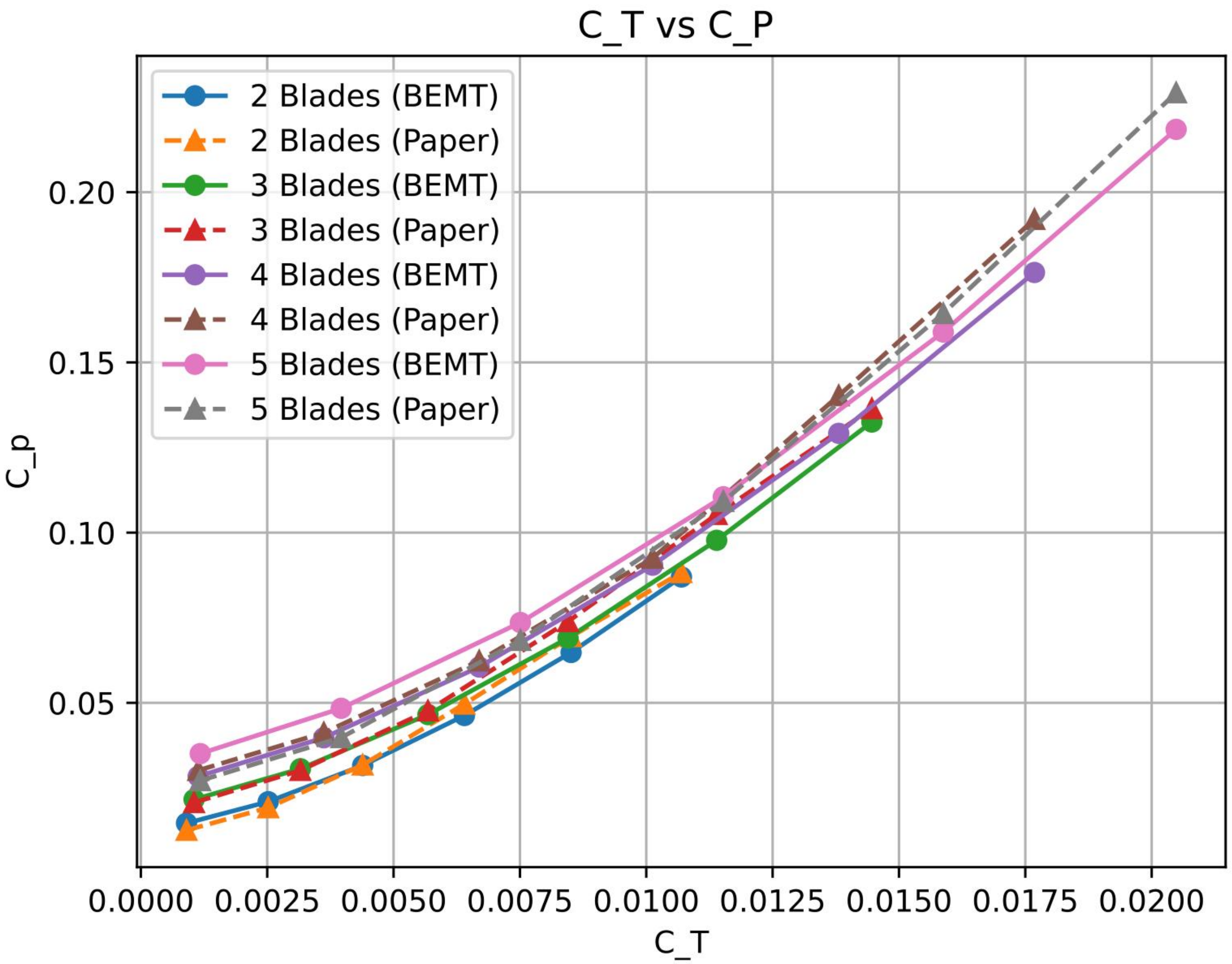
3.1: Thrust vs θ plots



3.2: Torque vs θ plots



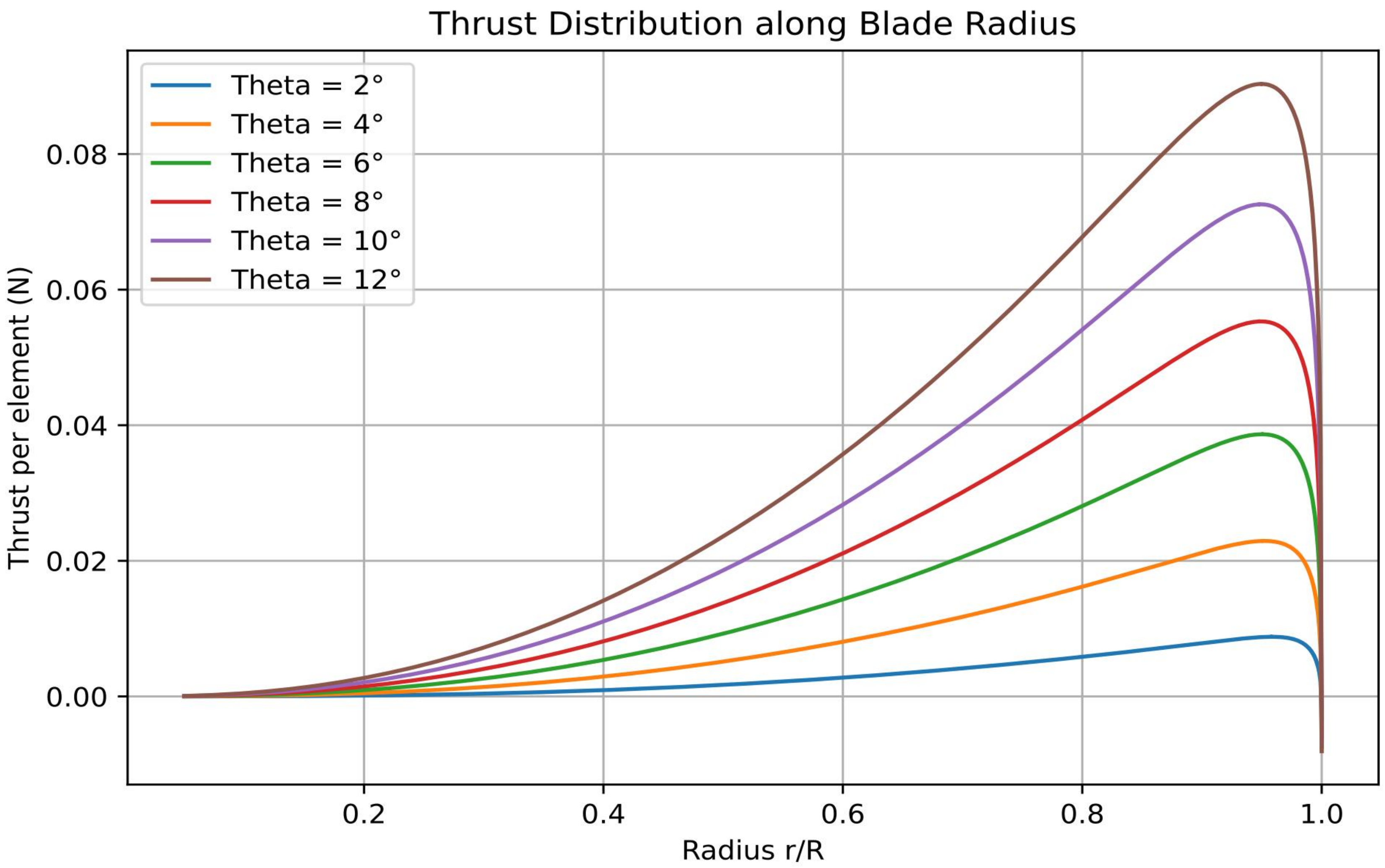
3.3: Thrust vs Power plots



3.4: Observations from the above plots

	Plots	Comments / Observations
3.1	Thrust vs θ	• Ct increases (~linearly) with increasing theta for all blade counts. • Close agreement with expt. results, however, thrust is overestimated by BEMT arising from neglected swirl losses, 3D effects.
3.2	Torque vs θ	• Cq increases with increasing theta for all blade counts. • Close agreement with expt. results, however, torque (reflecting power requirement) is underestimated by BEMT due to discrepancies in capturing swirl, tip losses, profile drag.
3.3	Thrust vs Power	• Ct and Cp show a nearly linear relationship, with good agreement between BEMT and experimental reference data. • However, BEMT slightly underpredicts power requirement at a given thrust (especially at higher loading) arising from simplifications and neglected losses that occur in real world.

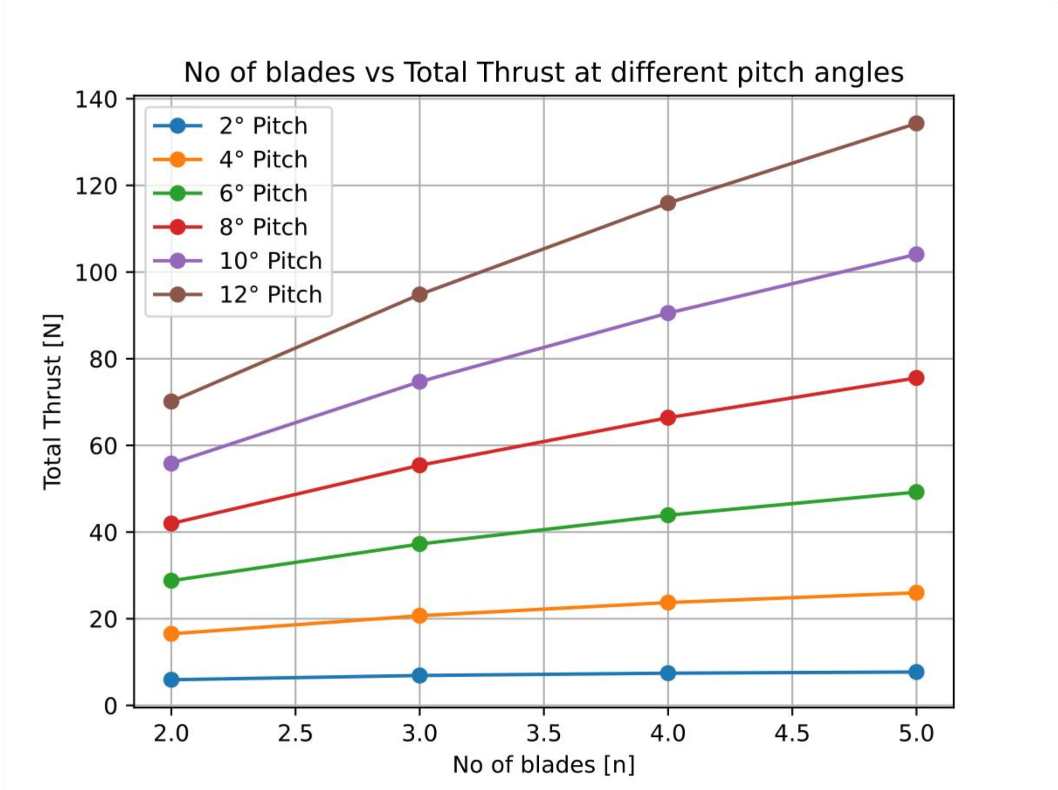
4.1: Sectional thrust from BEMT

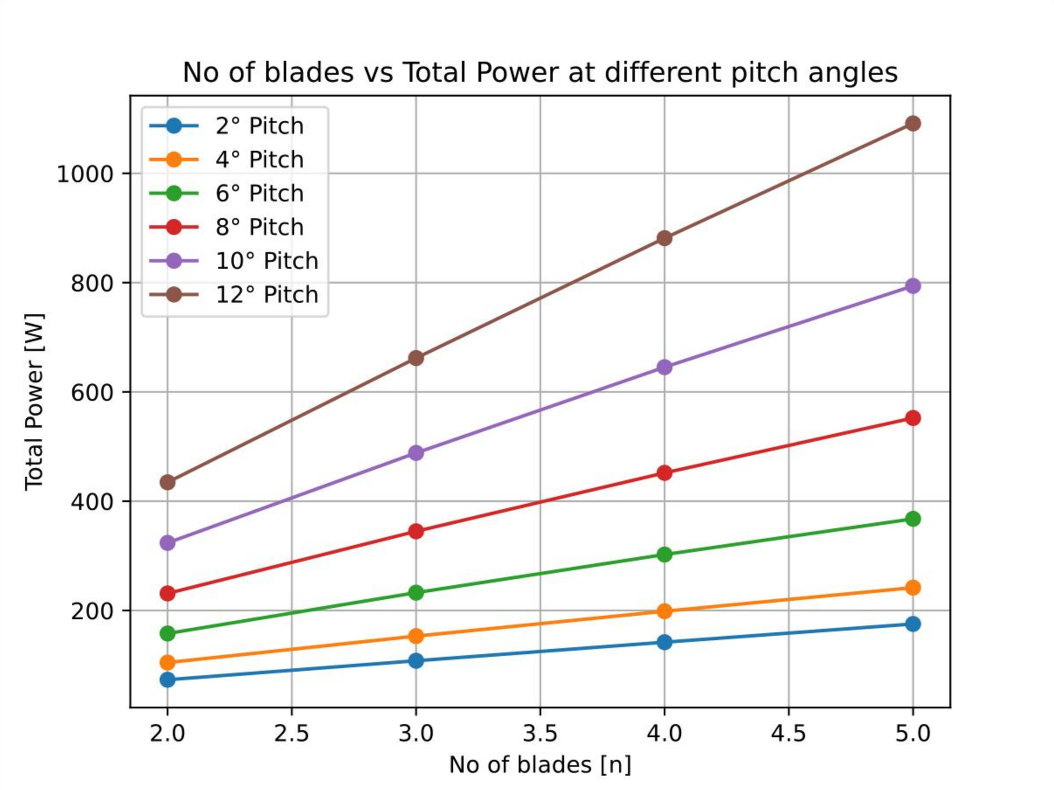


Section 5:

Design Variable Variations

5.1: Thrust vs Blades & Power vs Blades

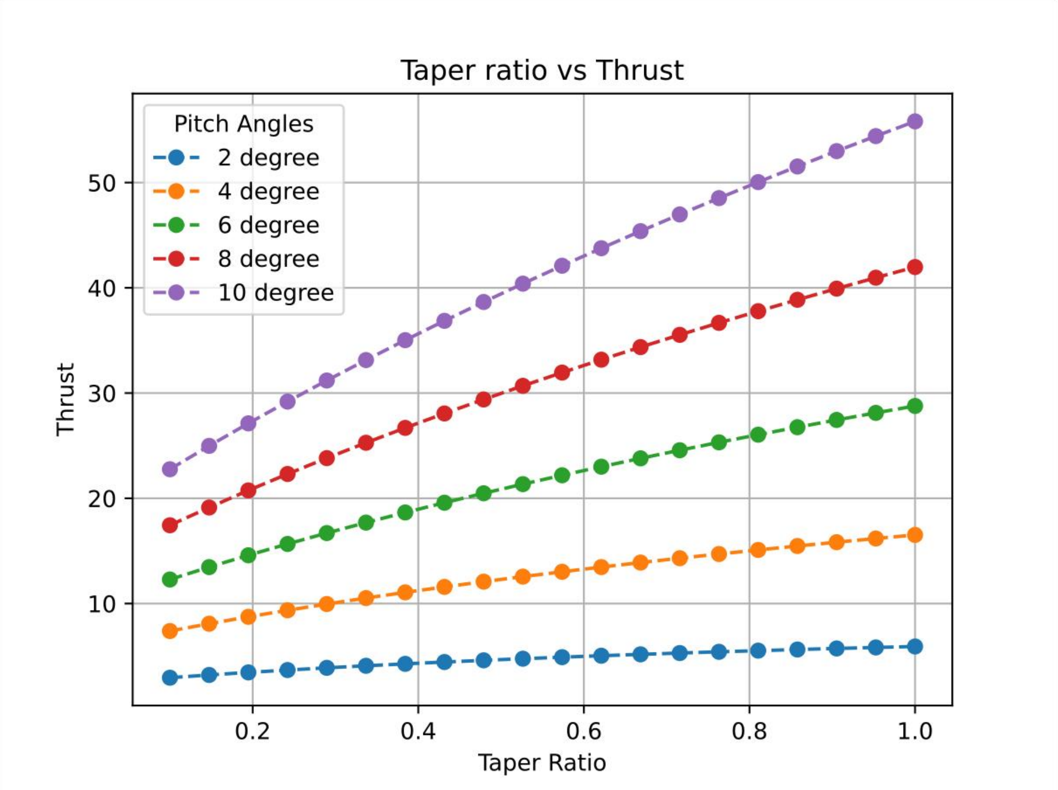


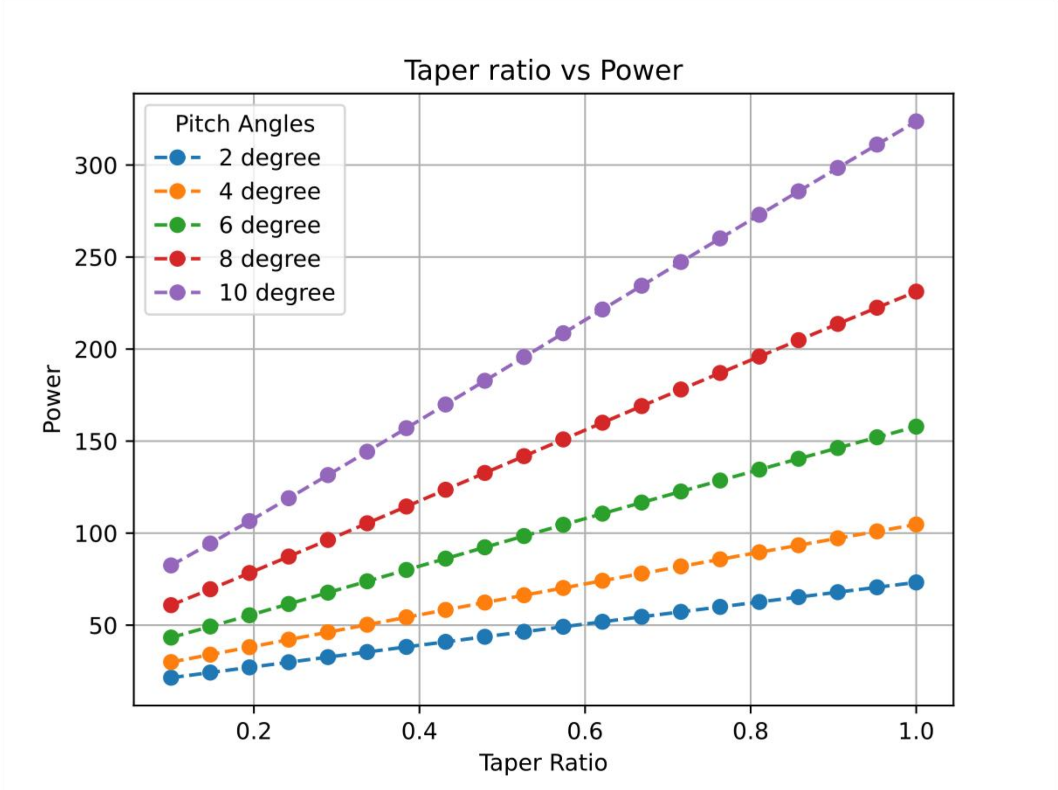


Discussion / Interpretation

- **Thrust generation and Power requirement increase with number of blades due to increased number of lifting surfaces.** Beyond a certain blade number, **efficiency gain diminishes**, as added blades mainly add drag and power loss rather than proportional thrust benefit.

5.2: Thrust vs Taper ratio & Power vs Taper ratio

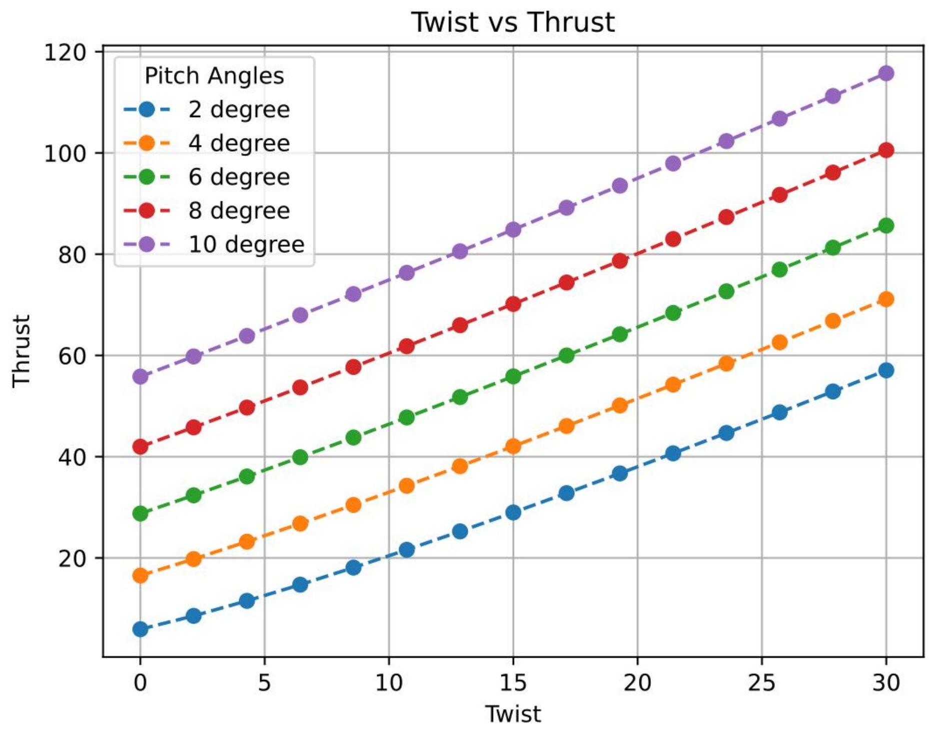


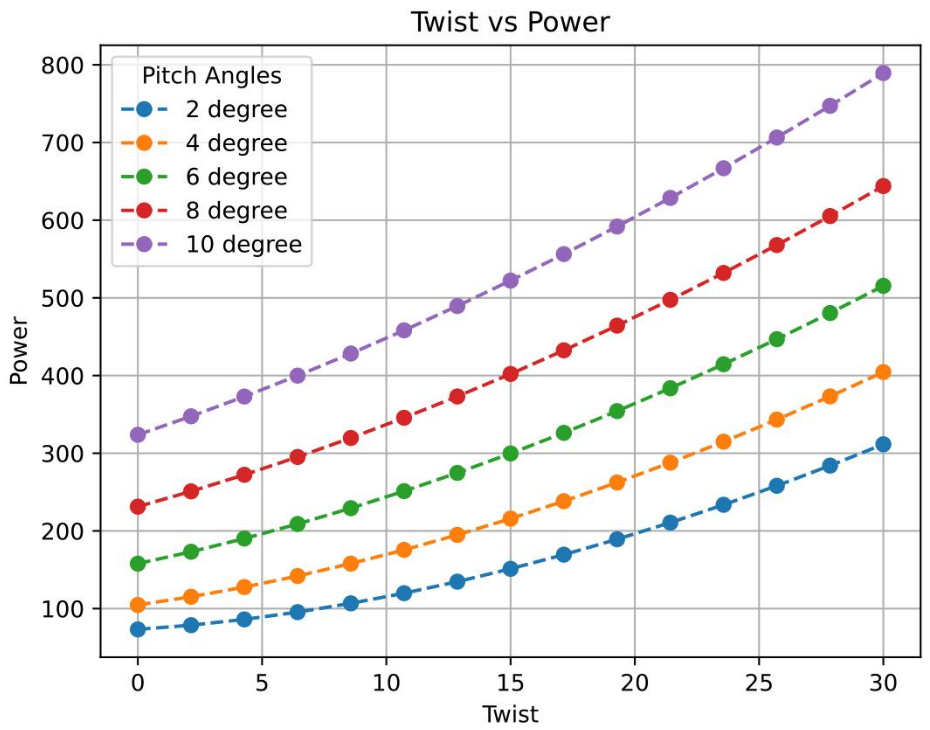


Discussion / Interpretation

- Both thrust and power rise with taper ratio. An optimal taper ratio is needed to balance thrust gains against power penalties.

5.2: Thrust vs Taper ratio & Power vs Taper ratio



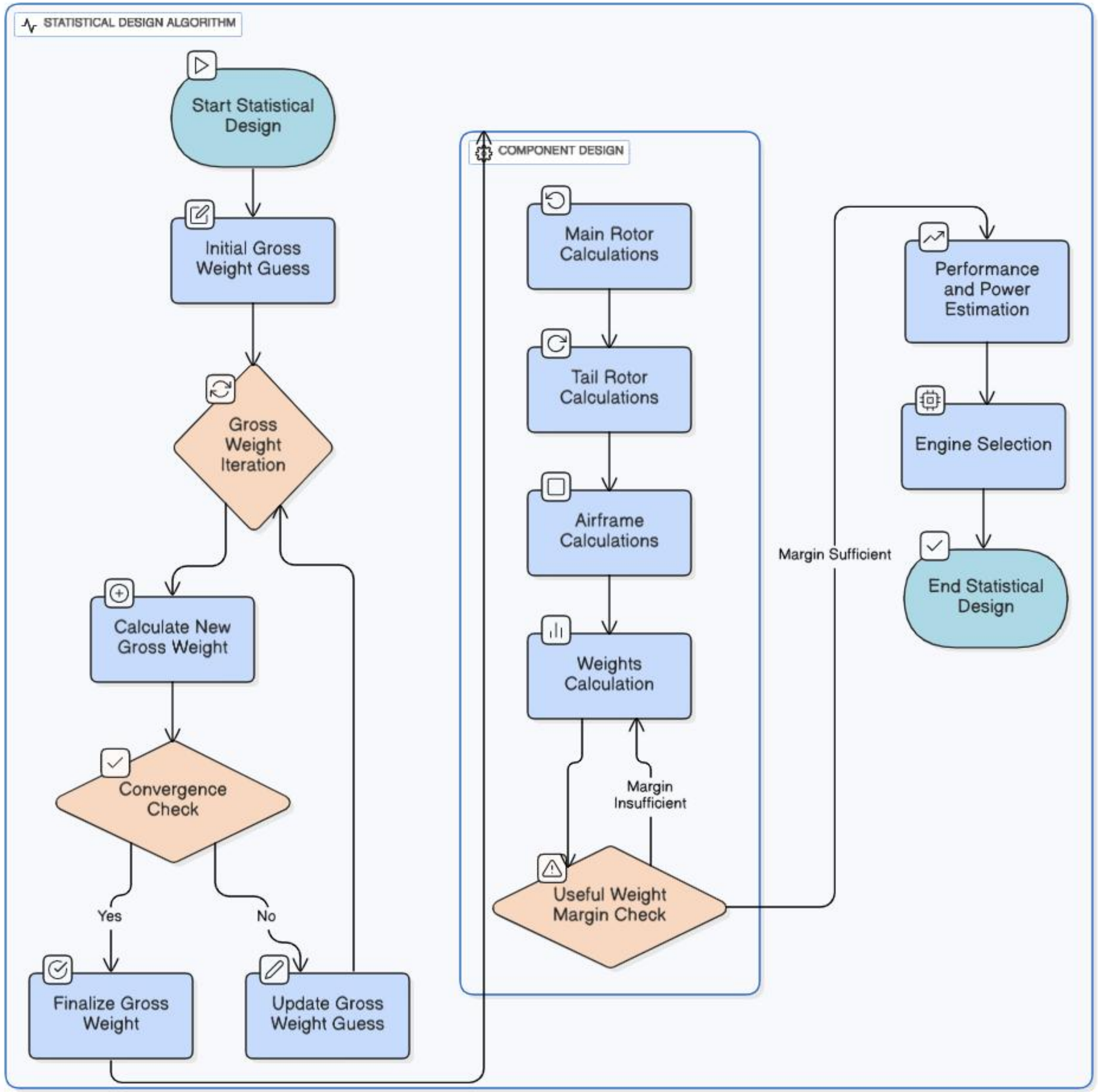


Discussion / Interpretation

- **More twist improves thrust**, but **also increases power consumption disproportionately**. The root moves slower than the tip (lower tangential speed), so increasing its angle of attack helps it contribute more lift. **Too much twist is inefficient**, as it loads the root excessively.

Section 6:
Mission Planner Test

Helicopter design (Conceptual)



Helicopter Parameters Overview

Parameter	Value
Disc Loading (kg/m²)	26.56
Diameter (m)	11.2
Chord (m)	0.42
Tip Speed (m/s)	211.61
Angular Velocity (rad/s)	37.79
blades	2

Main Rotor

Parameter	Value
Diameter (m)	1.84
Arm (m)	6.63
Tip Speed (m/s)	202.11
Angular Velocity (rad/s)	219.79
Chord (m)	0.17
bladdes	2

Tail Rotor

Parameter	Value
Fuselage Length (m)	10.56
Rotor-to-Tail-End Length (m)	13.12
Helicopter Height (m)	3.29
Helicopter Width (m)	2.35
Horizontal Tail Arm (m)	5.30
Horizontal Tail Surface Area (m²)	0.73
Vertical Tail Arm (m)	6.54
Avg. Vertical Tail Chord (m)	0.46

Parameter	Value
Gross Weight (kg)	2246.78
Useful Weight (kg)	1022.35
Fuel Weight (kg)	322.35
Empty Weight (kg)	1224.43

Parameter	Value (kW)
Take-off Power (P_to)	527.6
Take-off Transmission (T_to)	418.04
Main Continuous Power (P_mc)	891.22
Main Continuous Transmission (T_mc)	810.9

Parameter	Value
Never Exceed Speed (m/s)	221.05
Long Range Speed (m/s)	176.31

	Plots	Value
6.1	Maximum Take Off Weight based on blade stall at 2000 m AMSL	4553.65 kgf
6.2	Maximum Take Off Weight based on power requirement at 2000 m AMSL	3511.74 kgf

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--- 3.1: Max Take-off Weight based on blade stall at 2000m AMSL ---
Stalling at 18.00 deg, alpha = 12.02 deg.
Stall pitch for main rotor found at 18.00 deg max_alpha = 12.02 deg
Maximum Take-Off Weight (Stall) at 2000.0m AMSL: 4553.65 kg

--- 3.2: Max Take-off Weight based on power requirement at 2000m AMSL ---
Maximum Take-Off Weight (Power) at 2000.0m AMSL: 3511.74 kg
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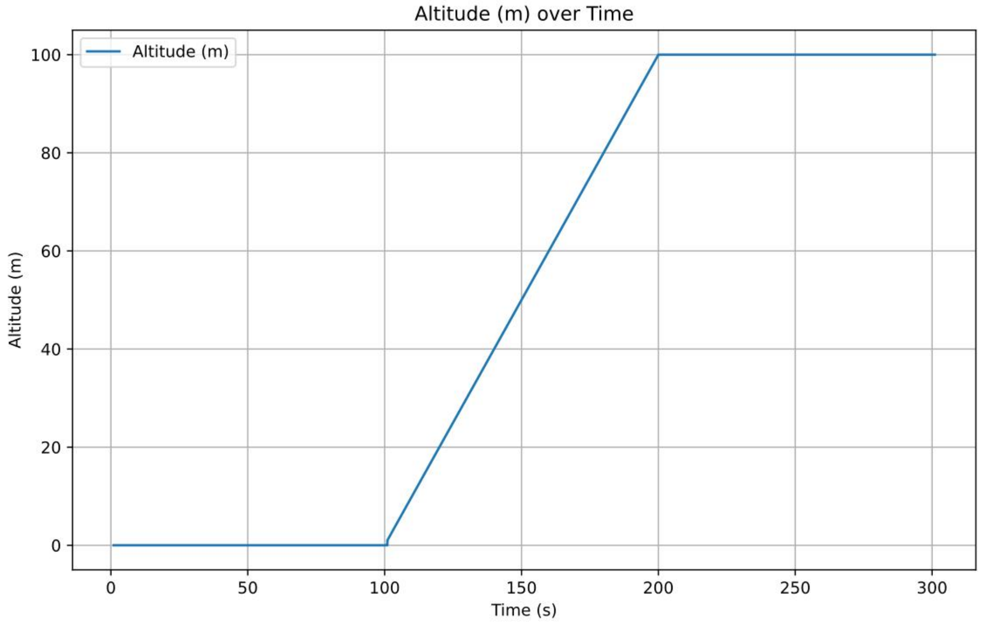
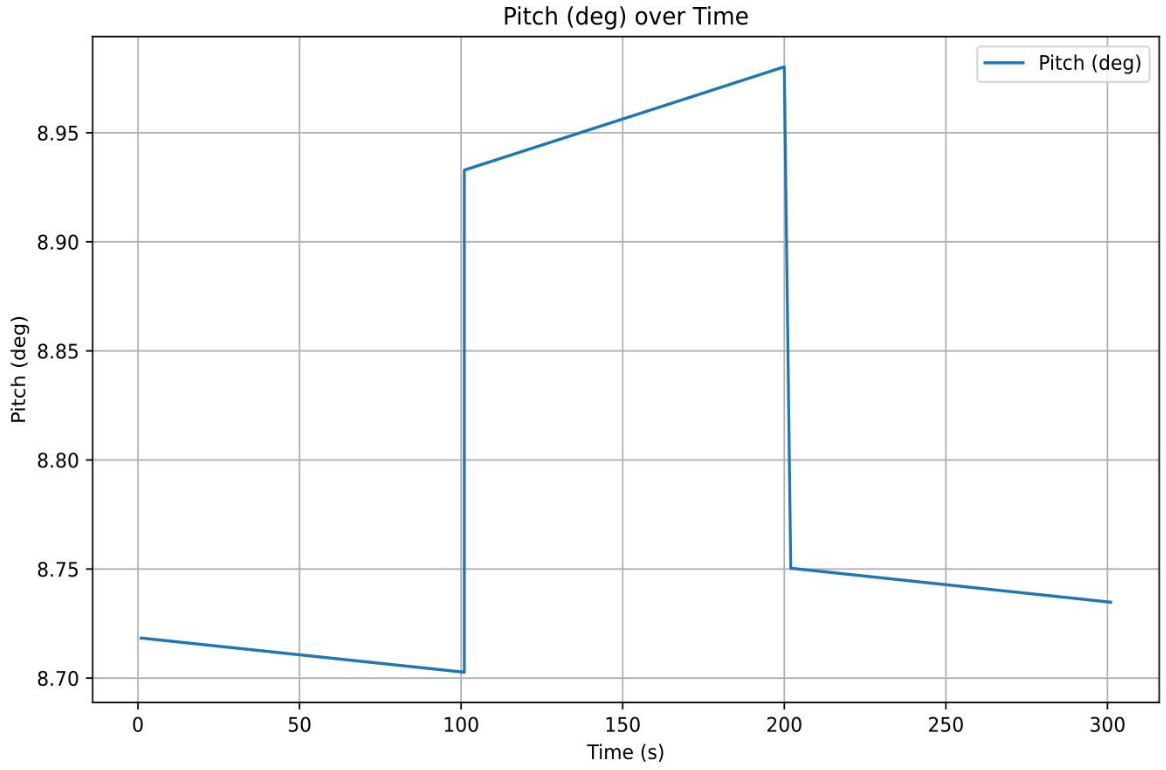
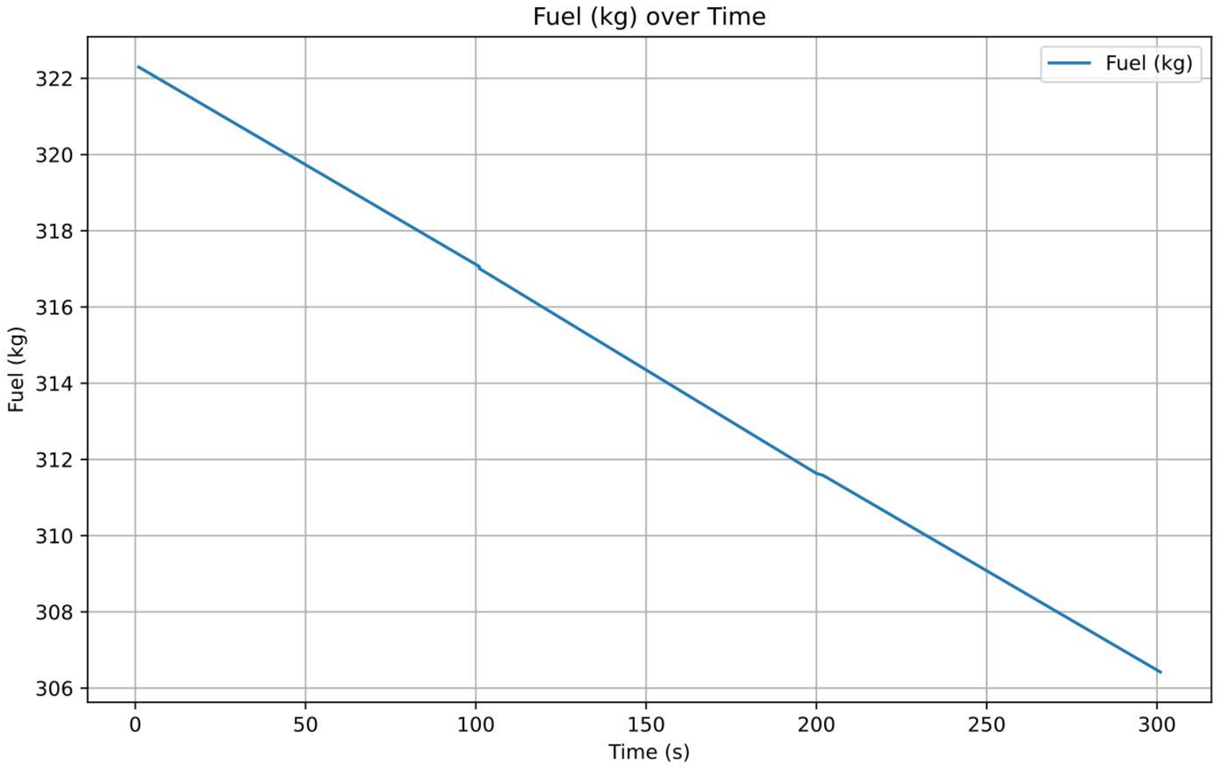
S. No.	Flight Segment	Altitude	Duration
1	Hover	0 m	100s
2	Vertical Climb	0 - 100m	100s
3	Hover	100m	100s



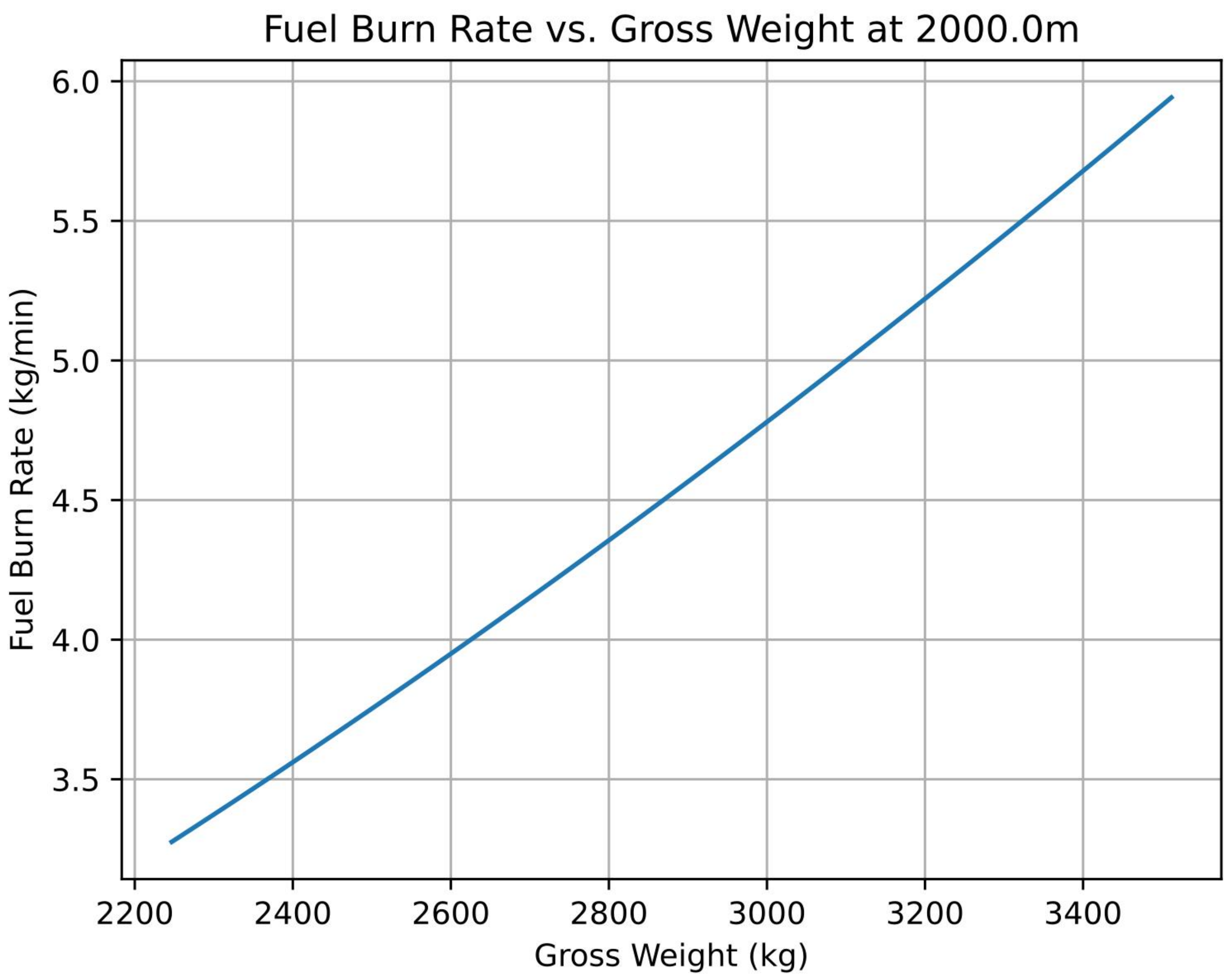


Pitch (deg) over Time
Pitch (deg)
8.95
8.90
8.85
8.80
8.75
8.70
0
50
100
150
200
250
300
Time (s)

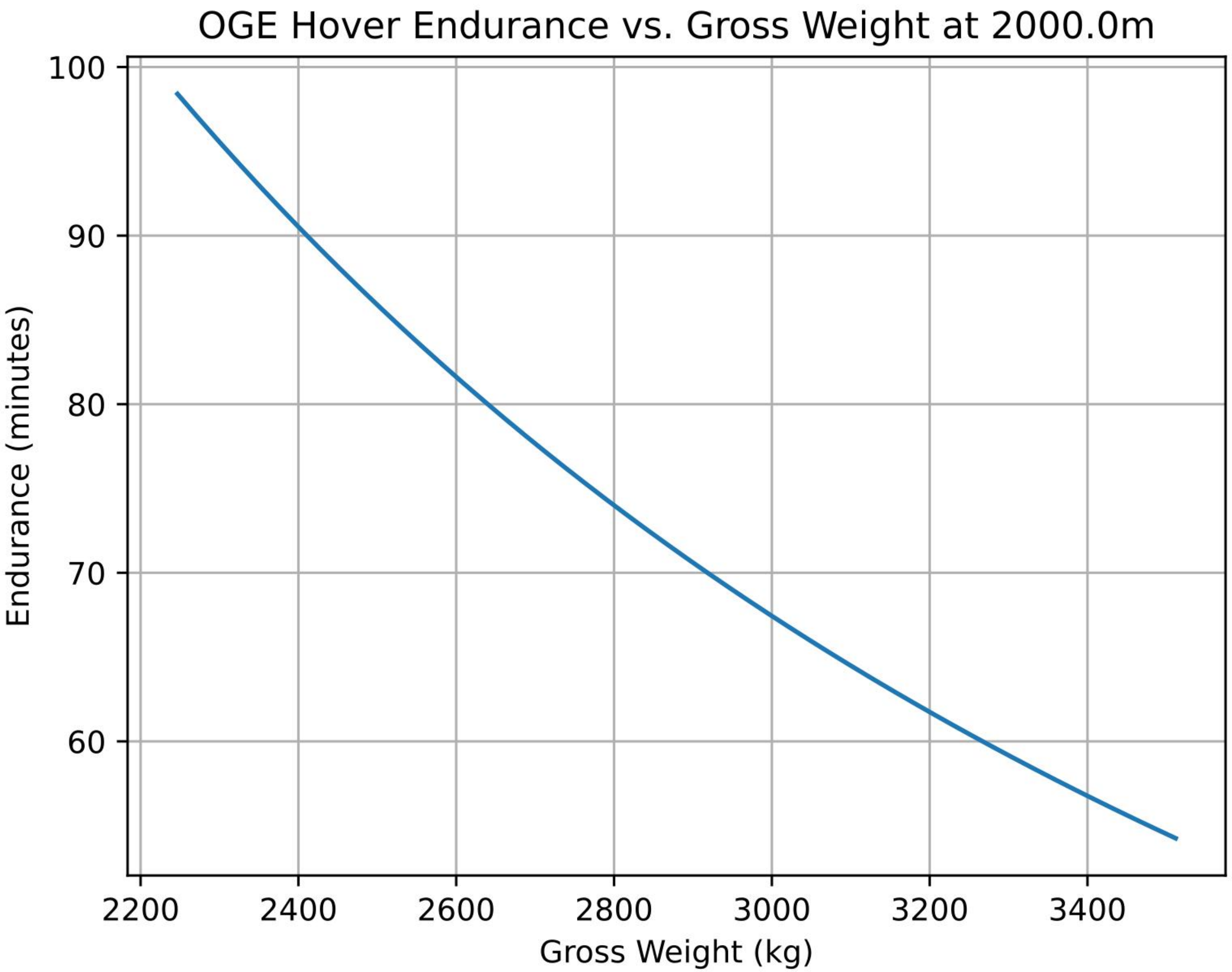


Fuel (kg) over Time
Fuel (kg)
322
320
318
316
314
312
310
308
306
0
50
100
150
200
250
300
Time (s)

6.3: Fuel Burn Rate vs Gross Weight Plot



6.4: OGE Hover Endurance vs Take-Off-Weight plot



Acknowledgement

References

[1] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19930081433.pdf

[2] Fundamentals of Helicopter Dynamics