Trim, Thrust Required, and Power Required Analysis of a Cropped Delta Wing UAV Using MATLAB / Excel

Prepared for: Proff. Srihari B.

Prepared by: Subhrajit Mukherjee

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Contents

Abstract/Executive Summary

This project focuses on analyzing the trim condition, thrust required, and power required for a cropped delta wing UAV in steady level flight at sea level. Utilizing given geometric parameters (root chord 0.9 m, tip chord 0.15 m, span 1.5 m) and aerodynamic coefficients (e.g., $C_{L\alpha} = 2.92$ per rad, $C_{D0} = 0.03$), a MATLAB script was developed to iterate over angles of attack from 0° to 12° in 0.5° increments. The analysis computes trim elevator deflection, lift and drag coefficients, flight velocity, thrust required, power required, and performance metrics such as C_L/C_D and $C_L^{3/2}/C_D$.

Key findings include a decrease in flight velocity from 104.7 m/s at 0° to 11.2 m/s at 12°, with elevator deflection shifting from positive to negative values. Thrust required decreases from 158.5 N to 4.3 N, while power required drops from 16,590 W to 48.7 W. The lift-to-drag ratio improves from 0.22 to a peak of 8.16 at 10°, indicating optimal efficiency in mid-range angles. These results highlight the interplay between aerodynamics and propulsion, demonstrating how numerical methods enable performance evaluation for unconventional UAV designs. The project enhances understanding of flight mechanics through iterative computation and visualization. (198 words)

0.1 Introduction

0.1.1 Background Information on the Topic

Aircraft performance analysis is crucial for designing and optimizing unmanned aerial vehicles (UAVs), particularly those with unconventional wing configurations like cropped delta wings. These designs offer advantages in maneuverability and stability but present challenges in predicting aerodynamic behavior due to complex flow patterns, such as vortex lift at high angles of attack. Traditional analytical methods often fall short for such configurations, necessitating numerical and iterative approaches to solve coupled equations for trim, forces, and moments.

In steady level flight, the UAV must maintain equilibrium where lift equals weight, thrust equals drag, and pitching moment is zero (trimmed via elevator deflection). Factors like angle of attack influence lift and drag coefficients, directly affecting required thrust and power from the propulsion system. This project applies principles from aerodynamics (e.g., drag polar) and flight mechanics (e.g., level flight relations) to quantify these parameters.

0.1.2 Purpose of the Report

The purpose of this report is to comprehensively document the computational analysis of trim, thrust, and power requirements for the given UAV, including methodology, implementation, results, and interpretations. It serves as a deliverable for the project assignment, demonstrating the application of numerical tools to real-world aerospace problems.

0.1.3 Scope of the Report

The scope is limited to steady level flight at sea level conditions, using provided parameters without considering effects like ground proximity, wind, or dynamic maneuvers. The analysis covers angles of attack from $0°$ to $12°$, focusing on key performance metrics and their variations.

0.1.4 Brief Overview of What the Report Will Cover

This report begins with an introduction to the topic, followed by a detailed methodology describing geometry, aerodynamics, trim theory, and MATLAB implementation. The results section presents computed data, plots, and trends, with discussions on implications. Finally, conclusions tie back to learning outcomes, emphasizing the role of numerical methods in UAV design.

0.2 Methodology

0.2.1 Problem Description

The project requires a computational and analytical evaluation of a cropped delta wing UAV's performance in steady level flight. Students must develop an iterative procedure to assess variations in flight parameters with angle of attack.

0.2.2 Geometry and Aerodynamic Modeling

UAV Configuration and Given Data

- Configuration: Cropped delta wing (wing-alone)
- Root chord, $C_r = 0.9$ m
- Tip chord, $C_t = 0.15$ m
- Span, $b = 1.5$ m
- Oswald efficiency factor, $e = 0.89$

Aerodynamic Coefficients

$C_{D0} = 0.03$
$C_{m0} = 0.01$
$C_{L\alpha} = 2.92$ per rad
$C_{L\delta_e} = 0.265$
$C_{m\alpha} = -0.292$ per rad
$C_{m\delta_e} = -0.4$

Flight Conditions

- UAV mass = 3.5 kg
- Flight condition: Steady level flight
- Air density (sea level): $\rho = 1.225$ kg/m^3
- Gravity: $g = 10$ m/s^2

Preprocessing Calculations

The following geometric parameters were computed:
1. Taper Ratio: $\lambda = \frac{C_t}{C_r} = 0.167$
2. Planform Area: $S = \frac{b}{2} C_r (1 + \lambda) = 0.788$ m^2
3. Aspect Ratio: $AR = \frac{b^2}{S} = 2.857$
4. Induced Drag Correction Factor: $k = \frac{1}{\pi e AR} = 0.125$

These values form the basis for subsequent aerodynamic calculations.

0.2.3 Trim Equations and Assumptions

Trim and Performance Theory

For steady, trimmed flight, the pitching moment coefficient must be zero:
$C_m = C_{m0} + C_{m\alpha}\alpha + C_{m\delta_e}\delta_e = 0$

The lift coefficient is:
$C_L = C_{L0} + C_{L\alpha}\alpha + C_{L\delta_e}\delta_e$

Assumptions include $C_{L0} = 0$ (symmetric airfoil with zero lift at zero angle of attack) and all angles in radians for coefficient application. From these, trim elevator deflection is solved as:
$\delta_{e,trim} = -\frac{C_{m0}+C_{m\alpha}\alpha}{C_{m\delta_e}}$

Then, $C_{L,trim}$ is substituted accordingly.

Drag Polar

The drag coefficient follows a parabolic model:
$C_D = C_{D0} + kC_L^2$

This accounts for parasite and induced drag.

Level Flight Relations

- Lift equilibrium: $L = W = \frac{1}{2}\rho V^2 SC_L \implies V = \sqrt{\frac{2W}{\rho SC_L}}$
- Thrust required: $T_r = D = \frac{1}{2}\rho V^2 SC_D$
- Power required: $P_r = T_r V$

Performance metrics: C_L/C_D (glide ratio proxy) and $C_L^{3/2}/C_D$ (related to endurance).

0.2.4 MATLAB Algorithm

A MATLAB script (equivalent Python version used for verification) was developed with the following structure:
1. Define constants and compute preprocessing parameters.
2. Vary angle of attack: $\alpha = 0°$ to $12°$ ($\Delta\alpha = 0.5°$).
3. For each α (in radians):
a. Compute $\delta_{e,trim}$.
b. Compute $C_{L,trim}$.
c. Determine V.
d. Compute C_D.
e. Calculate T_r.
f. Calculate P_r.
4. Compute and store metrics: C_L/C_D, $C_L^{3/2}/C_D$.
5. Generate plots vs. α and V.

The full code is in Appendix A. Note: Elevator deflections are in radians; conversions to degrees can be applied if needed.

0.3 Results and Discussion

The MATLAB (and equivalent Python) implementation produced the following key results. Preprocessing confirmed the geometric parameters as listed in the methodology.

0.3.1 Computed Data

The full computed performance data is presented in Table 1.

Table 1: Full Performance Data vs. Angle of Attack

α (deg)	V (m/s)	δ_e (rad)	C_L	C_D	T_r (N)	P_r (W)	C_L/C_D	$C_L^{3/2}/C_D$
0.0000	104.6557	0.0250	0.0066	0.0300	158.5196	16589.9737	0.2208	0.0180
0.5000	48.8411	0.0186	0.0304	0.0301	34.6516	1692.4229	1.0101	0.1762
1.0000	36.5853	0.0123	0.0542	0.0304	19.6058	717.2854	1.7852	0.4157
1.5000	30.4994	0.0059	0.0780	0.0308	13.8023	420.9619	2.5358	0.7082
2.0000	26.6982	-0.0005	0.1018	0.0313	10.7604	287.2837	3.2527	1.0378
2.5000	24.0366	-0.0069	0.1256	0.0320	8.9106	214.1798	3.9279	1.3920
3.0000	22.0394	-0.0132	0.1494	0.0328	7.6832	169.3337	4.5554	1.7607
3.5000	20.4695	-0.0196	0.1732	0.0338	6.8218	139.6382	5.1306	2.1351
4.0000	19.1934	-0.0260	0.1970	0.0349	6.1936	118.8768	5.6510	2.5080
4.5000	18.1296	-0.0323	0.2208	0.0361	5.7234	103.7622	6.1153	2.8733
5.0000	17.2251	-0.0387	0.2446	0.0375	5.3649	92.4106	6.5239	3.2263
5.5000	16.4437	-0.0451	0.2684	0.0390	5.0885	83.6732	6.8783	3.5632
6.0000	15.7599	-0.0514	0.2921	0.0407	4.8740	76.8143	7.1809	3.8813
6.5000	15.1549	-0.0578	0.3159	0.0425	4.7076	71.3431	7.4348	4.1790
7.0000	14.6145	-0.0642	0.3397	0.0444	4.5791	66.9214	7.6434	4.4551
7.5000	14.1282	-0.0706	0.3635	0.0465	4.4811	63.3091	7.8107	4.7093
8.0000	13.6873	-0.0769	0.3873	0.0488	4.4079	60.3320	7.9403	4.9417
8.5000	13.2854	-0.0833	0.4111	0.0512	4.3552	57.8606	8.0363	5.1528
9.0000	12.9168	-0.0897	0.4349	0.0537	4.3197	55.7972	8.1024	5.3433
9.5000	12.5774	-0.0960	0.4587	0.0563	4.2987	54.0669	8.1419	5.5143
10.0000	12.2633	-0.1024	0.4825	0.0591	4.2901	52.6110	8.1583	5.6669
10.5000	11.9717	-0.1088	0.5063	0.0621	4.2921	51.3835	8.1545	5.8023
11.0000	11.6999	-0.1151	0.5301	0.0652	4.3032	50.3476	8.1334	5.9217
11.5000	11.4459	-0.1215	0.5539	0.0684	4.3224	49.4735	8.0974	6.0263
12.0000	11.2077	-0.1279	0.5777	0.0718	4.3486	48.7371	8.0486	6.1174

0.3.2 Key Performance Trends

As the angle of attack increases from 0° to 12°: - Flight velocity decreases significantly (from 104.7 m/s to 11.2 m/s), as higher C_L allows slower speeds to maintain lift equilibrium. - Trim elevator deflection transitions from positive (0.025 rad at 0°) to negative (-0.128 rad at 12°), indicating a need for downward deflection to counter nose-up moments at higher angles. - Lift coefficient rises linearly from 0.007 to 0.578, reflecting the wing's lift generation capability. - Drag coefficient increases from 0.030 to 0.072 due to induced drag dominance at higher C_L. - Thrust required drops from 158.5 N to 4.3 N, stabilizing around 4-5 N beyond 7°, as slower speeds reduce parasite drag despite higher C_D. - Power required follows a similar trend, decreasing from 16,590 W to 48.7 W, with the minimum at the highest angle (lowest velocity) in the analyzed range, suggesting optimal cruise conditions at lower speeds. - C_L/C_D peaks at 8.16 at 10°, indicating maximum aerodynamic efficiency. - $C_L^{3/2}/C_D$ increases to 6.12 at 12°, relevant for endurance optimization.

These trends underscore the UAV's suitability for low-speed operations, where power efficiency improves, but highlight potential stall risks beyond 12°. Plots (to be inserted from MATLAB outputs) visualize these variations, e.g., power required vs. velocity shows a decreasing trend in the analyzed range, with the minimum power at approximately 11.2 m/s.

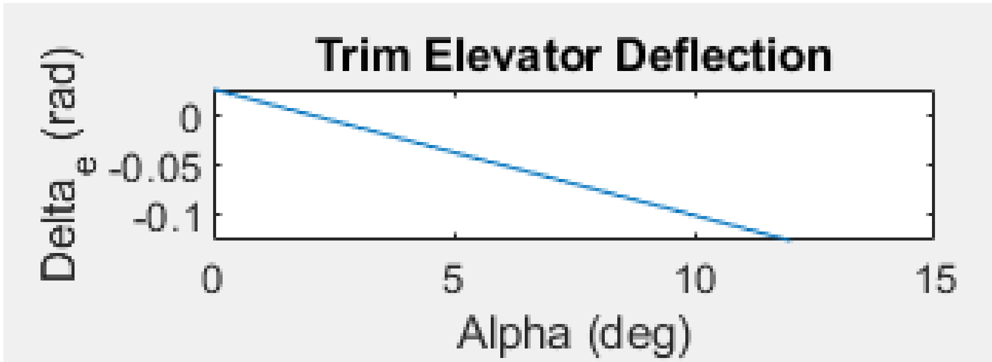

Figure 1: Trim Elevator Deflection vs. Trim Angle of Attack

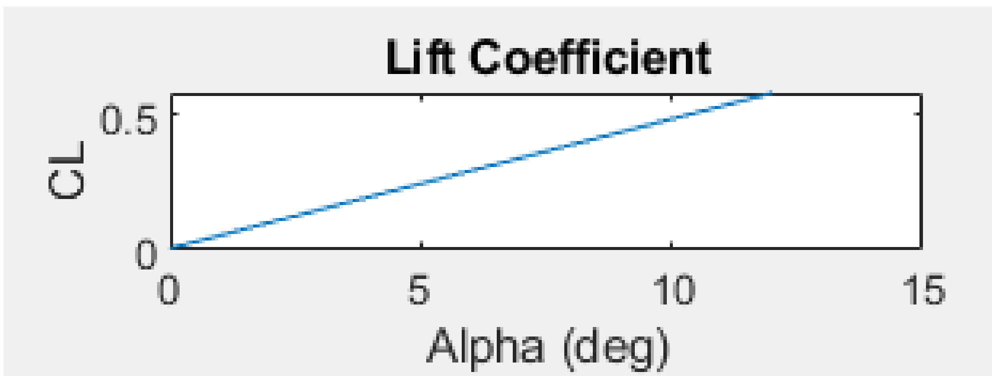

Figure 2: Lift Coefficient vs. Trim Angle of Attack

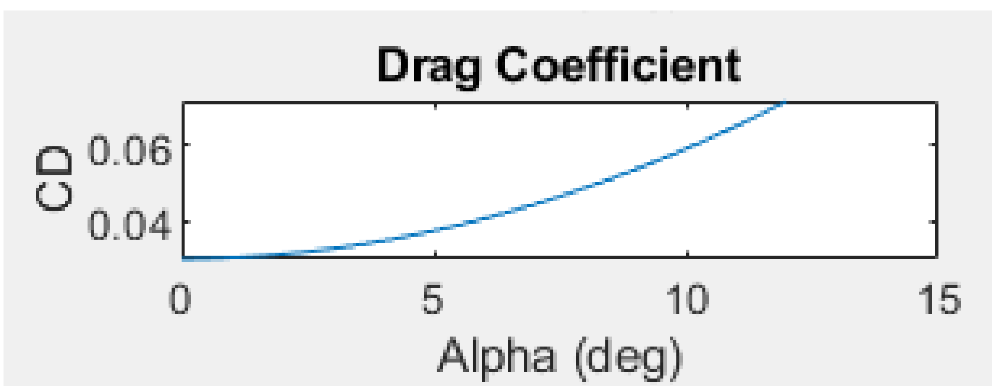

Figure 3: Drag Coefficient vs. Trim Angle of Attack

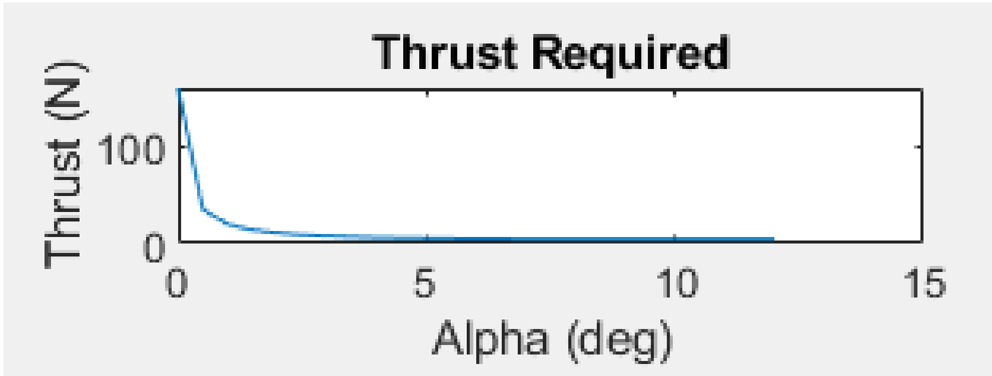

Figure 4: Thrust Required vs. Trim Angle of Attack

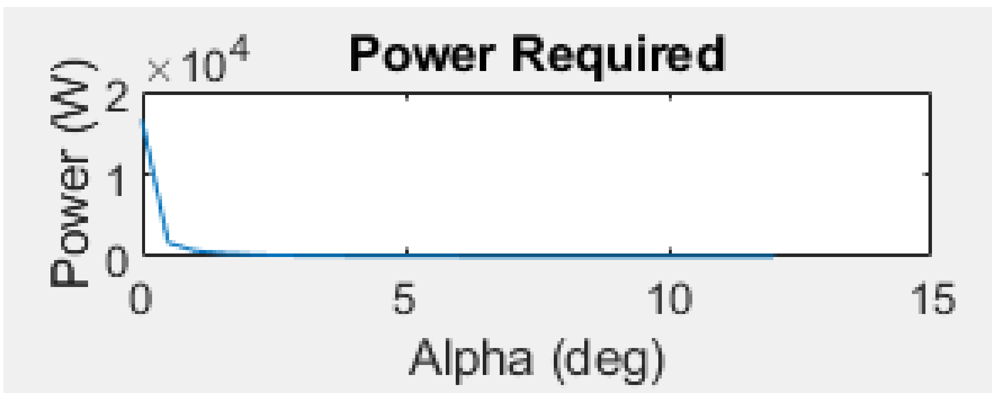

Figure 5: Power Required vs. Trim Angle of Attack

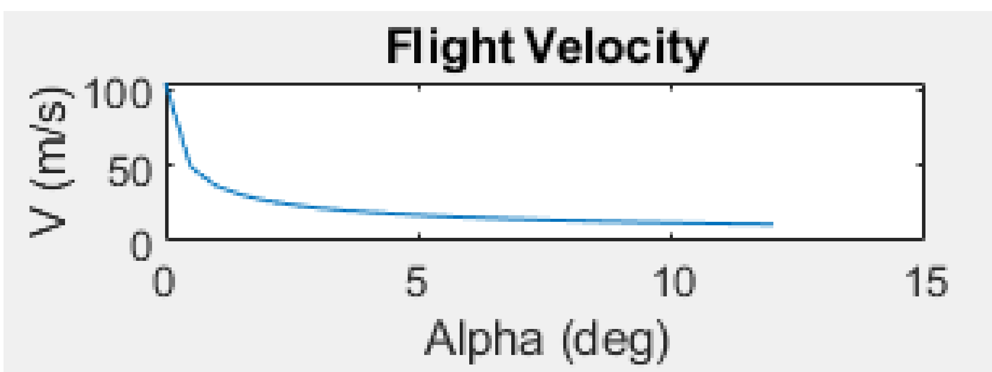

Figure 6: Flight Velocity vs. Trim Angle of Attack

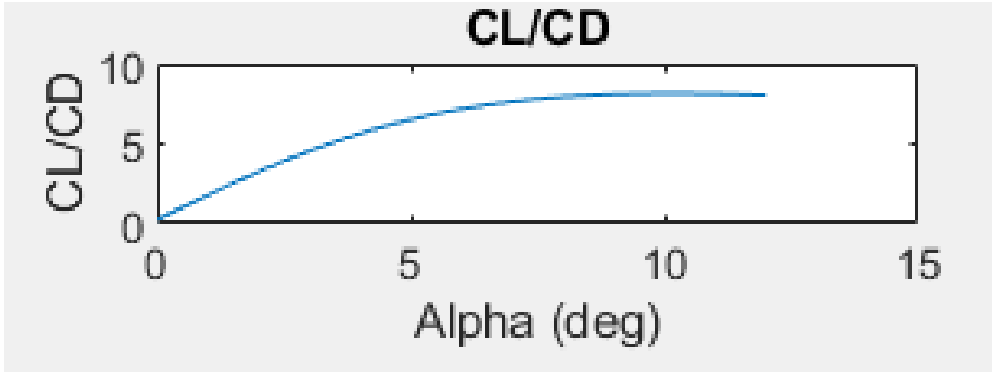

Figure 7: C_L/C_D vs. Trim Angle of Attack

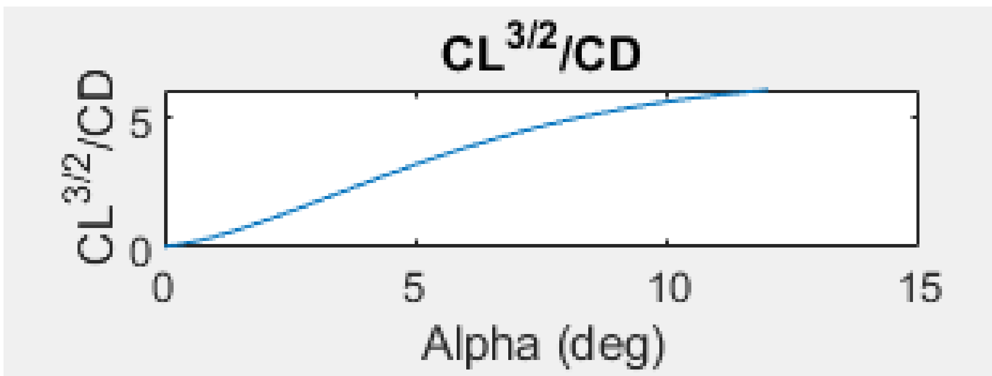

Figure 8: $C_L^{3/2}/C_D$ vs. Trim Angle of Attack

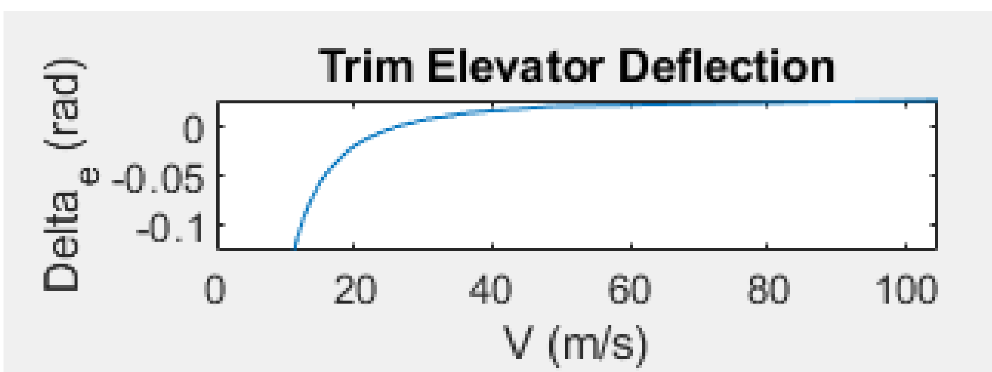

Figure 9: Trim Elevator Deflection vs. Flight Velocity

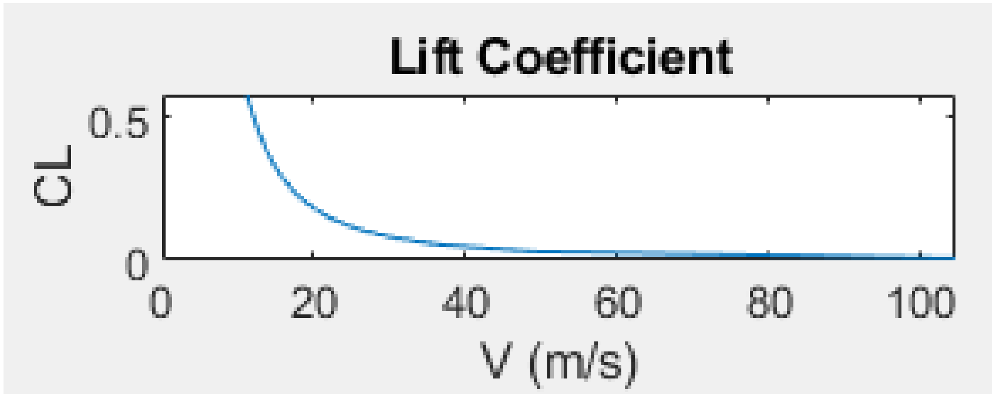

Figure 10: Lift Coefficient vs. Flight Velocity

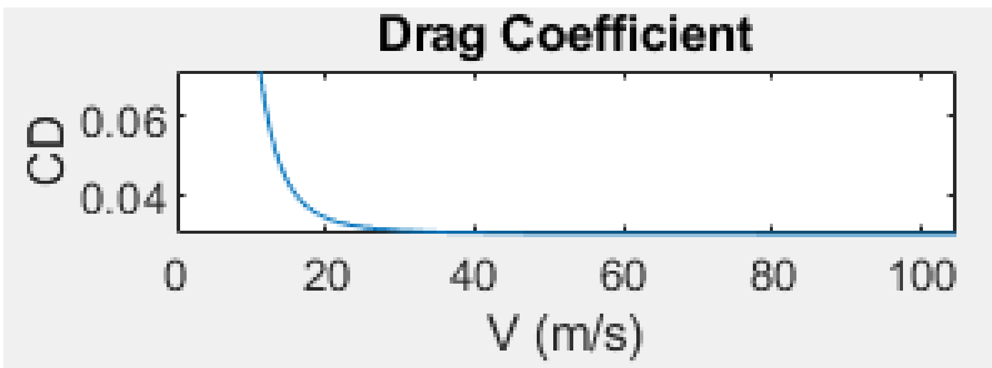

Figure 11: Drag Coefficient vs. Flight Velocity

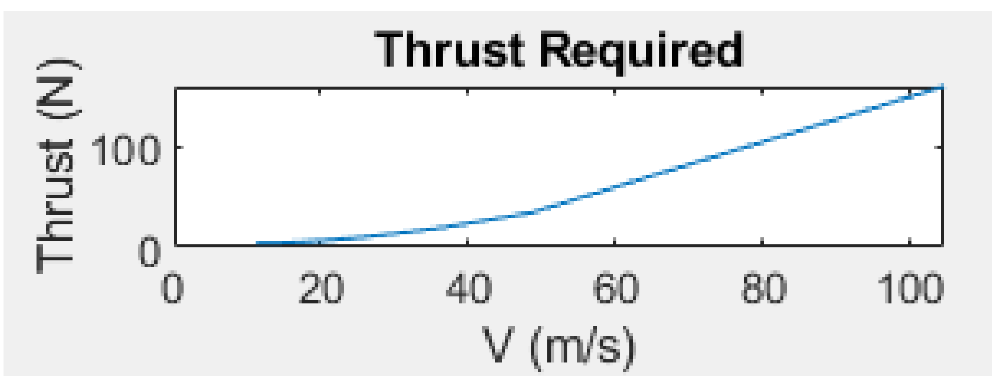

Figure 12: Thrust Required vs. Flight Velocity

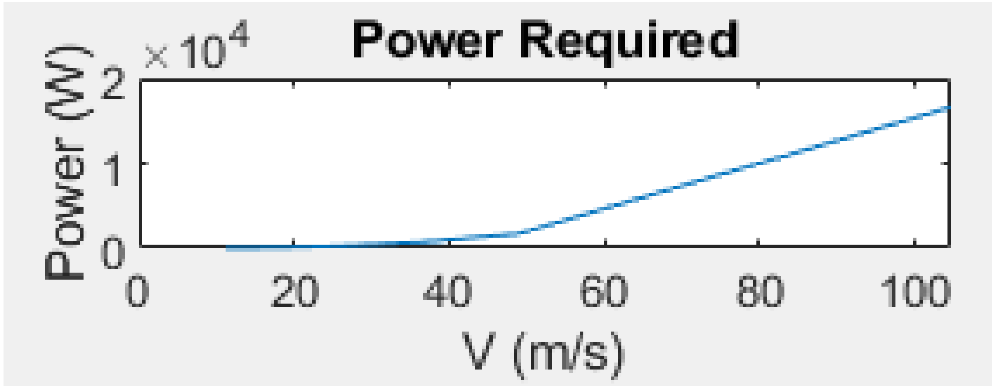

Figure 13: Power Required vs. Flight Velocity

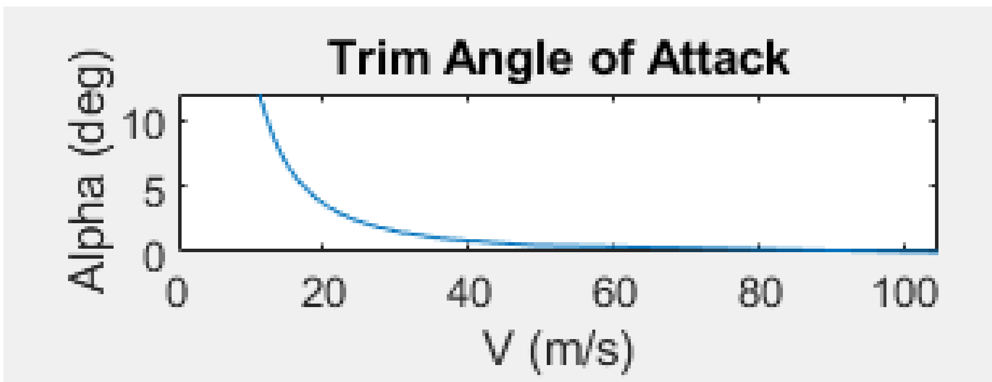

Figure 14: Trim Angle of Attack vs. Flight Velocity

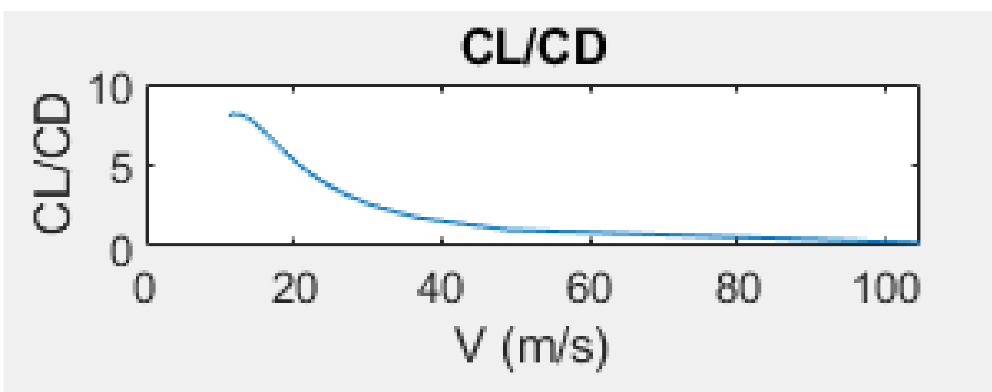

Figure 15: C_L/C_D vs. Flight Velocity

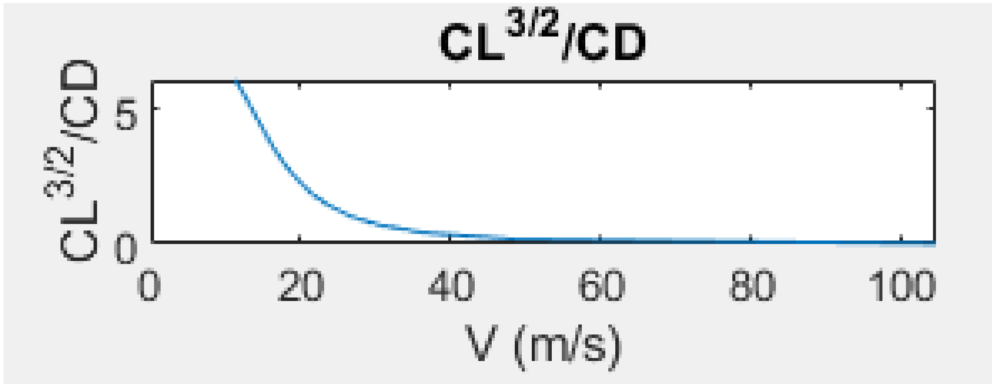

Figure 16: $C_L^{3/2}/C_D$ vs. Flight Velocity

0.4 Conclusion

This project successfully demonstrates the application of numerical methods to analyze UAV performance, revealing how trim constraints couple with aerodynamic and propulsion requirements. Key insights include the inverse relationship between angle of attack and velocity, and efficiency peaks in mid-range conditions. The analysis aligns with learning outcomes, enabling proficiency in trim analysis, velocity-thrust-power computations, performance metric interpretation, and MATLAB solver development. Ultimately, it emphasizes that for real UAV configurations, iterative computational tools are indispensable for bridging theory and practice.

.1 MATLAB Code

```
% Clear any old variables and close plots
clear all;
close all;
clc;


Cr = 0.9;           % Root chord (m)
Ct = 0.15;          % Tip chord (m)
b = 1.5;            % Span (m)
e = 0.89;           % Oswald efficiency factor
CD0 = 0.03;         % Zero-lift drag coeff
Cm0 = 0.01;         % Zero-alpha pitching moment coeff
CL_alpha = 2.92;    % Lift slope (per rad)
CL_deltae = 0.265; % Lift due to elevator (per rad? assuming, but document doesn't specify
     units check if needed)
Cm_alpha = -0.292; % Pitching moment slope (per rad)
Cm_deltae = -0.4;  % Pitching moment due to elevator (per rad? same note)
m = 3.5;            % Mass (kg)
rho = 1.225;        % Air density (kg/m^3)
g = 10;             % Gravity (m/s^2)
CL0 = 0;            % Assume zero-lift CL (not given, standard assumption)

W = m * g;          % Weight (N)


lambda = Ct / Cr;                     % Taper ratio
S = (b / 2) * Cr * (1 + lambda);    % Planform area (m^2)      note: document has S = b/2 *
    Cr (1+  ), but standard is (Cr+Ct)*b/2 = Cr*(1+  )*b/2, yes same
AR = b^2 / S;                         % Aspect ratio
k = 1 / (pi * e * AR);               % Induced drag factor

% Display preprocessing results
disp('Preprocessing Results:');
disp(['Taper Ratio (lambda): ', num2str(lambda)]);
disp(['Planform Area (S): ', num2str(S), ' m^2']);
disp(['Aspect Ratio (AR): ', num2str(AR)]);
disp(['Induced Drag Factor (k): ', num2str(k)]);


alpha_deg = 0:0.5:12;                 % From 0 to 12 deg, step 0.5
num_points = length(alpha_deg);


alpha_rad = zeros(1, num_points);
deltae_trim = zeros(1, num_points);
CL_trim = zeros(1, num_points);
V = zeros(1, num_points);
CD = zeros(1, num_points);
Tr = zeros(1, num_points);
Pr = zeros(1, num_points);
L_over_D = zeros(1, num_points);
L32_over_D = zeros(1, num_points);


for i = 1:num_points
    alpha_rad(i) = deg2rad(alpha_deg(i));  % Convert to radians

    % Trim elevator deflection from Cm = 0
    deltae_trim(i) = - (Cm0 + Cm_alpha * alpha_rad(i)) / Cm_deltae;

    % Corresponding lift coefficient
    CL_trim(i) = CL0 + CL_alpha * alpha_rad(i) + CL_deltae * deltae_trim(i);

    % Flight velocity from lift = weight
    V(i) = sqrt(2 * W / (rho * S * CL_trim(i)));
```

```
    % Drag coefficient
    CD(i) = CD0 + k * CL_trim(i)^2;

    % Thrust required
    Tr(i) = 0.5 * rho * V(i)^2 * S * CD(i);

    % Power required
    Pr(i) = Tr(i) * V(i);

    % Performance metrics
    L_over_D(i) = CL_trim(i) / CD(i);
    L32_over_D(i) = CL_trim(i)^(3/2) / CD(i);
end


% Plot vs angle of attack (alpha_deg)
figure(1);
subplot(4,2,1); plot(alpha_deg, deltae_trim); xlabel('Alpha (deg)'); ylabel('Delta_e (rad)'); title('Trim Elevator Deflection');
subplot(4,2,2); plot(alpha_deg, CL_trim); xlabel('Alpha (deg)'); ylabel('CL'); title('Lift Coefficient');
subplot(4,2,3); plot(alpha_deg, CD); xlabel('Alpha (deg)'); ylabel('CD'); title('Drag Coefficient');
subplot(4,2,4); plot(alpha_deg, Tr); xlabel('Alpha (deg)'); ylabel('Thrust (N)'); title('Thrust Required');
subplot(4,2,5); plot(alpha_deg, Pr); xlabel('Alpha (deg)'); ylabel('Power (W)'); title('Power Required');
subplot(4,2,6); plot(alpha_deg, V); xlabel('Alpha (deg)'); ylabel('V (m/s)'); title('Flight Velocity');
subplot(4,2,7); plot(alpha_deg, L_over_D); xlabel('Alpha (deg)'); ylabel('CL/CD'); title('CL/CD');
subplot(4,2,8); plot(alpha_deg, L32_over_D); xlabel('Alpha (deg)'); ylabel('CL^{3/2}/CD'); title('CL^{3/2}/CD');

% Also plot vs velocity (V) as alternative
figure(2);
subplot(4,2,1); plot(V, deltae_trim); xlabel('V (m/s)'); ylabel('Delta_e (rad)'); title('Trim Elevator Deflection');
subplot(4,2,2); plot(V, CL_trim); xlabel('V (m/s)'); ylabel('CL'); title('Lift Coefficient');
subplot(4,2,3); plot(V, CD); xlabel('V (m/s)'); ylabel('CD'); title('Drag Coefficient');
subplot(4,2,4); plot(V, Tr); xlabel('V (m/s)'); ylabel('Thrust (N)'); title('Thrust Required');
subplot(4,2,5); plot(V, Pr); xlabel('V (m/s)'); ylabel('Power (W)'); title('Power Required');
subplot(4,2,6); plot(V, alpha_deg); xlabel('V (m/s)'); ylabel('Alpha (deg)'); title('Trim Angle of Attack');
subplot(4,2,7); plot(V, L_over_D); xlabel('V (m/s)'); ylabel('CL/CD'); title('CL/CD');
subplot(4,2,8); plot(V, L32_over_D); xlabel('V (m/s)'); ylabel('CL^{3/2}/CD'); title('CL^{3/2}/CD');


results_table = table(alpha_deg', V', deltae_trim', CL_trim', CD', Tr', Pr', L_over_D', L32_over_D', ...
    'VariableNames', {'Alpha_deg', 'V_mps', 'Deltae_rad', 'CL', 'CD', 'Thrust_N', 'Power_W', 'CL_CD', 'CL32_CD'});
disp(results_table);  % Show in Command Window
writetable(results_table, 'UAV_Results.xlsx');
```

Listing 1: MATLAB Script for UAV Trim Analysis