

EAE 130B Project 1 Report:  
Propeller Design and Performance Analysis

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## Introduction

One of the important parameters in aircraft design and performance is the impact of the engines on the flight parameters of the airplane. The aircraft may have a jet engine or a propeller that provides thrust. In this project, a propeller is designed and analyzed for various flight conditions. The aircraft that the designed propeller will be fitted on is a Cessna 152. Therefore, a common Lycoming O-235-L2C engine is used to determine the power output at the cruising altitude of 8,000 ft and the propeller parameters are adjusted to match the engine parameters.

## Methodology

The methodology used in designing and analyzing the propeller is from the lecture notes presented in EAE 130B lectures. The lecture notes are referenced at the end of the paper [1].

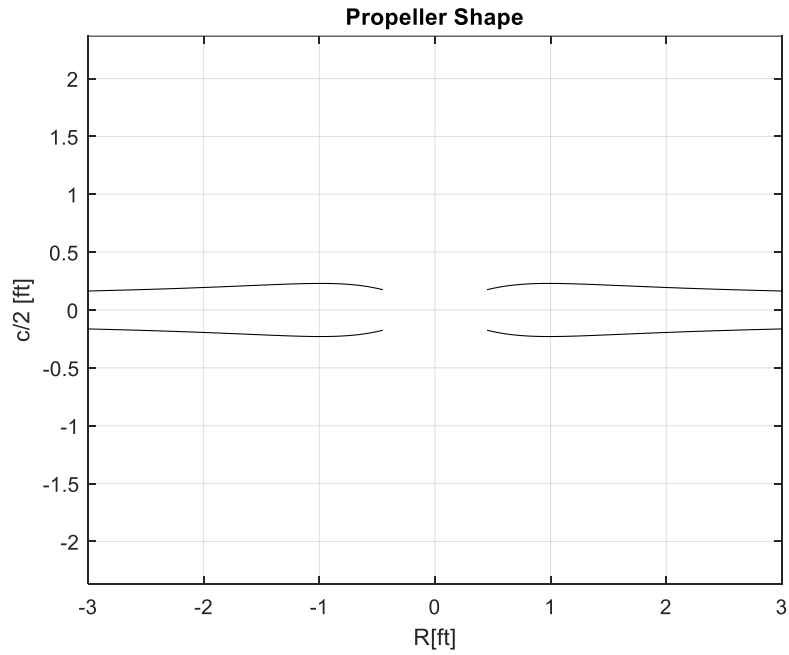
## Results

For the propeller analysis, the engine performance parameters at cruise altitude are found first. The cruise altitude is set as 8,000 ft. The corresponding maximum engine power output is found using the engine performance charts [2] and compared to the maximum engine power rated at sea level.

**Table 1.** Engine Specifications.

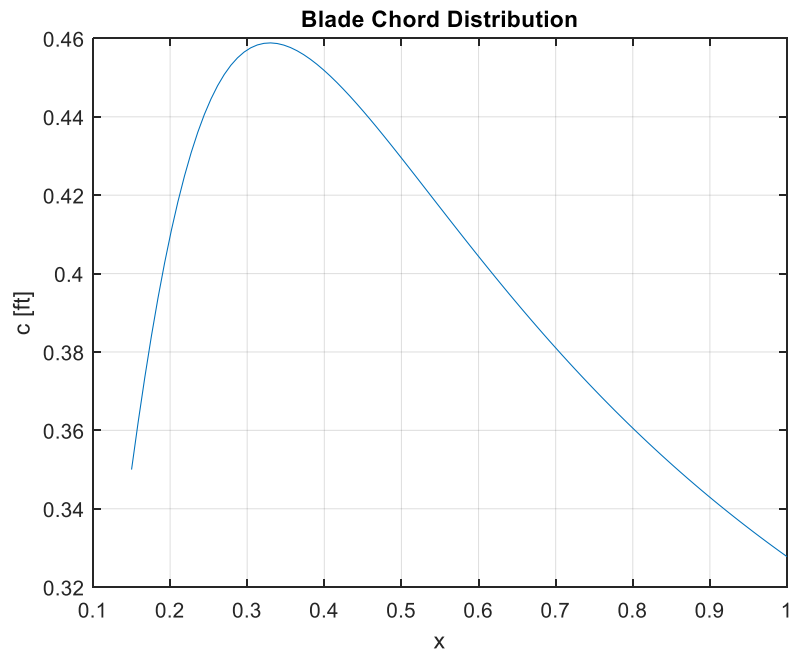
Parameter	Value
Maximum Engine Power Output at 8,000 ft	83.0 hp
Maximum Engine Power Output at SL	110 hp
Percentage of Maximum Power	75.5%

Next, a computer code was generated on MATLAB to design the propeller for Cessna 152 at an altitude of 8,000 ft and airspeed of 107 KTAS and is included in *Appendix A1* and discussed in the discussion section. The designed propeller has the following shape:



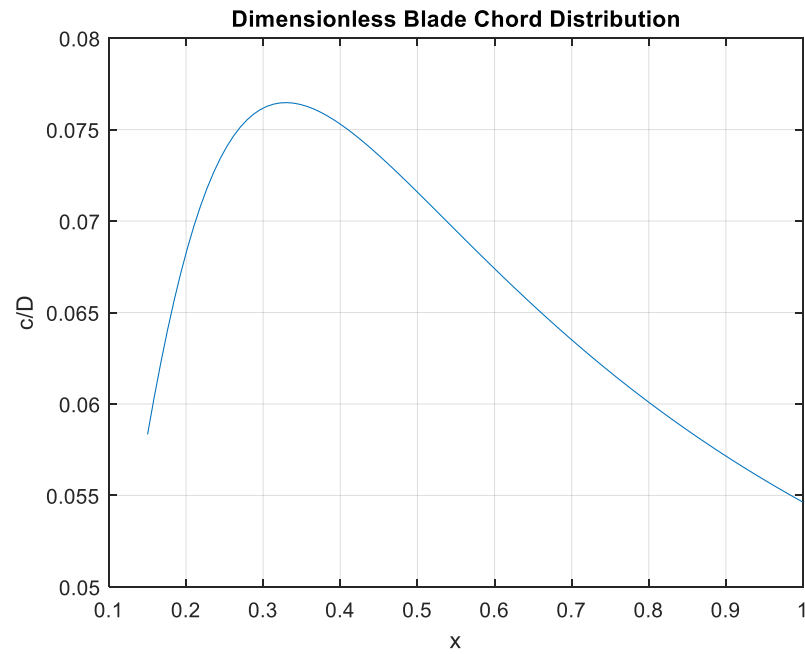
**Figure 1.** Propeller Shape.

The chord distribution of the propeller is shown below:



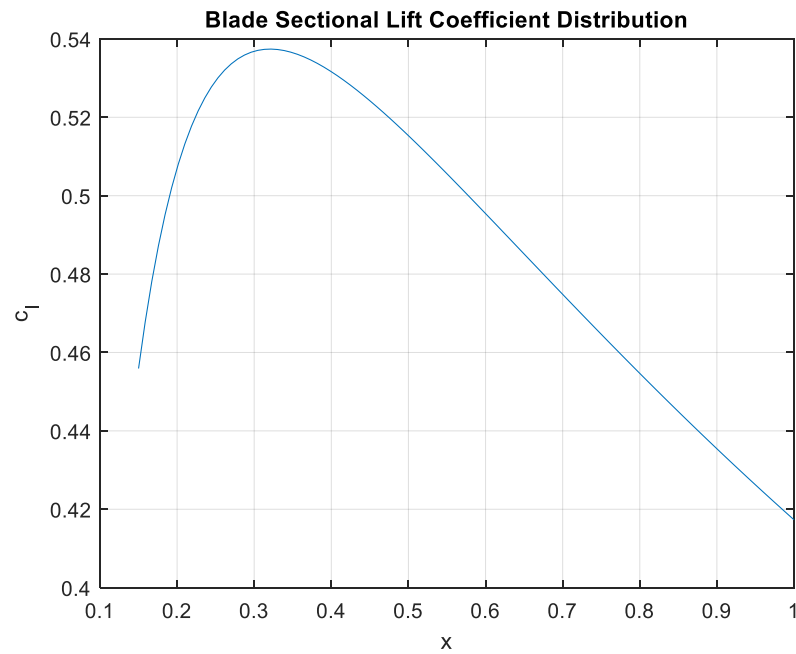
**Figure 2.** Blade Chord Distribution.

The same chord distribution can be non-dimensionalized by dividing by the propeller diameter:



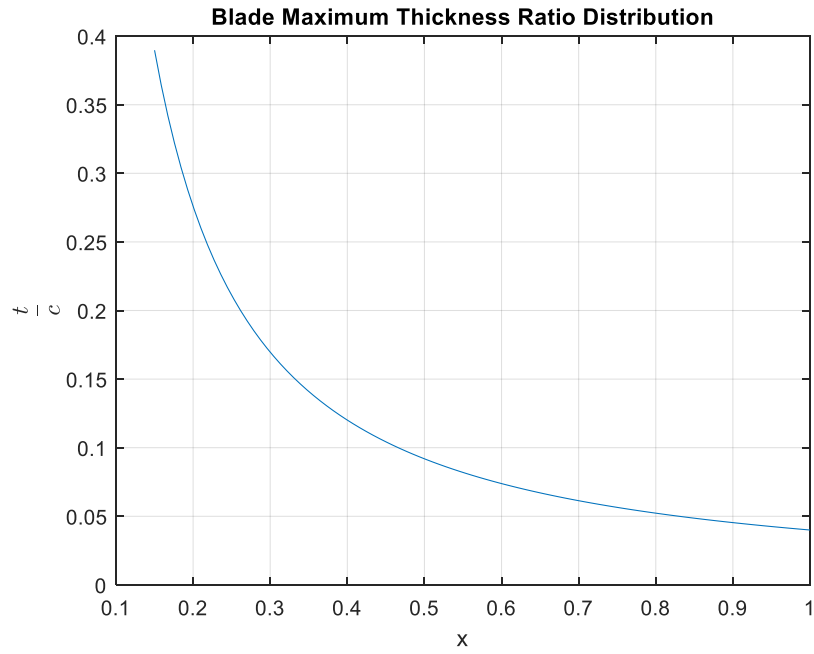
**Figure 3.** Non-dimensionalized Blade Chord Distribution.

Using aerodynamic relations, the design sectional lift coefficient of the propeller can be found:



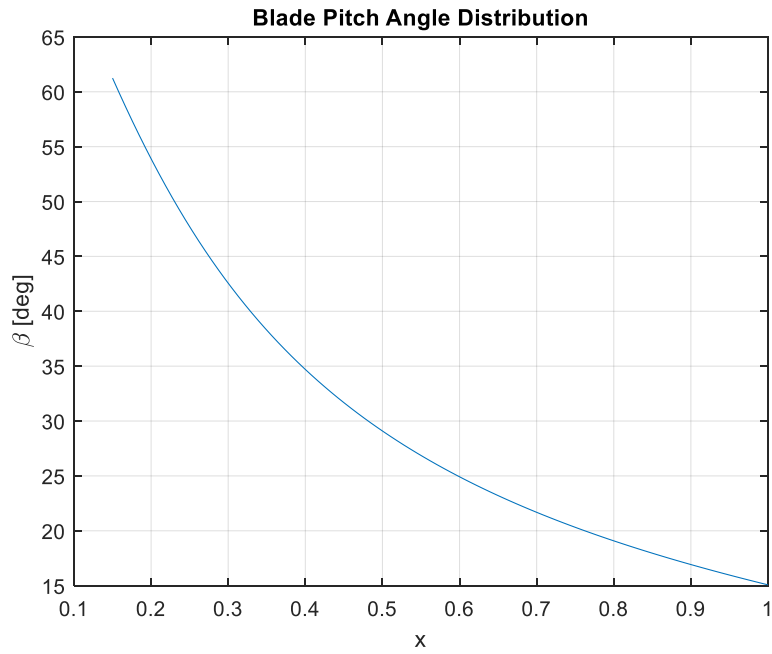
**Figure 4.** Blade Sectional Lift Coefficient Distribution.

The thickness ratio of the designed propeller blade is as follows:



**Figure 5.** Blade Maximum Thickness Ratio Distribution.

The propeller blade pitch angle distribution can also be calculated:



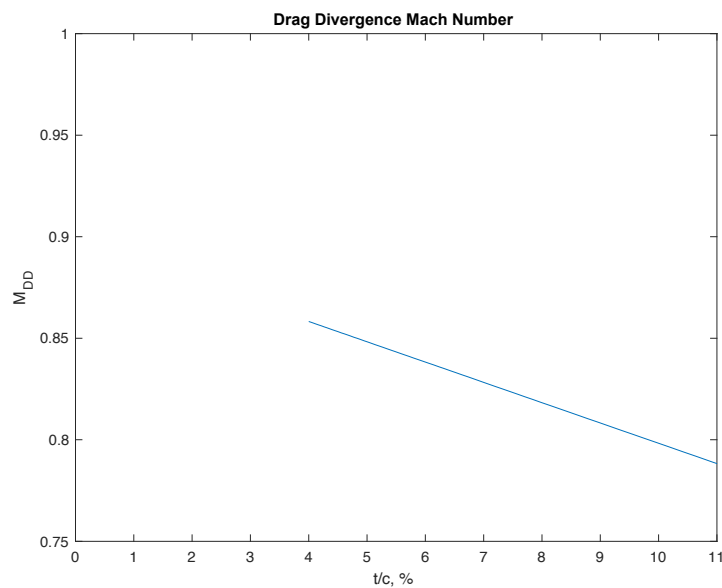
**Figure 6.** Blade Pitch Angle Distribution.

The performance parameters of the designed propeller blade are calculated and tabulated below:

**Table 2.** Designed Propeller Performance Specifications.

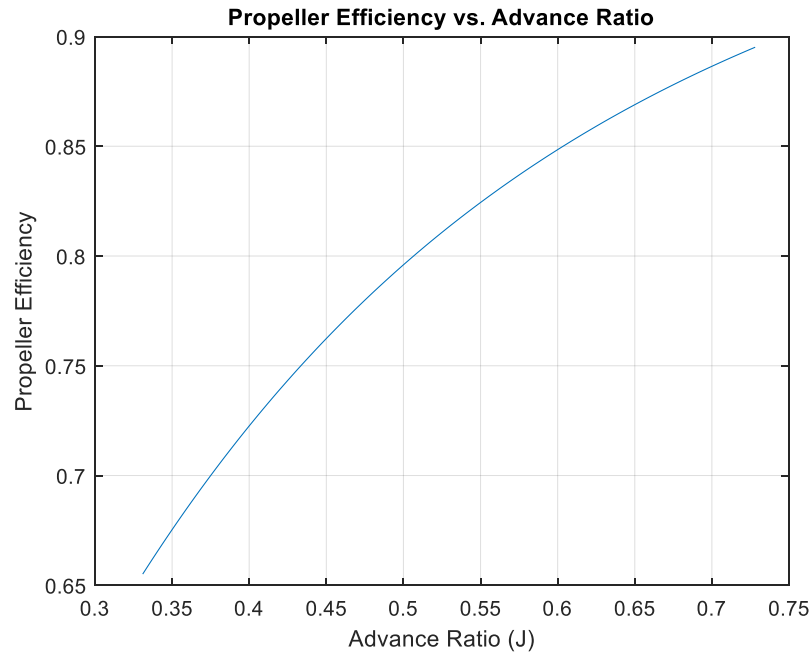
Parameter	Value
Number of Blades, $B$	2
Blade Diameter, $D$	6.0 ft
Advance Ratio, $J$	0.71
Propeller Efficiency, $\eta_P$	87%
Torque Coefficient, $C_Q$	0.00649
Power Coefficient, $C_P$	0.04077
Thrust Coefficient, $C_T$	0.04989
Propeller Power, $P$	82.68 hp
Propeller Thrust, $T$	218.18 lbs
Blade Activity Factor, $AF$	94.55
Blade Pitch Angle at 0.75R, $\beta_{0.75R}$	20.31°
Blade Design Lift Coefficient, $C_L$	0.45

The Mach number of the propeller tip has also been calculated to ensure that it does not exceed the divergence Mach number [4] [5]. The Mach Divergence plot can be seen below:

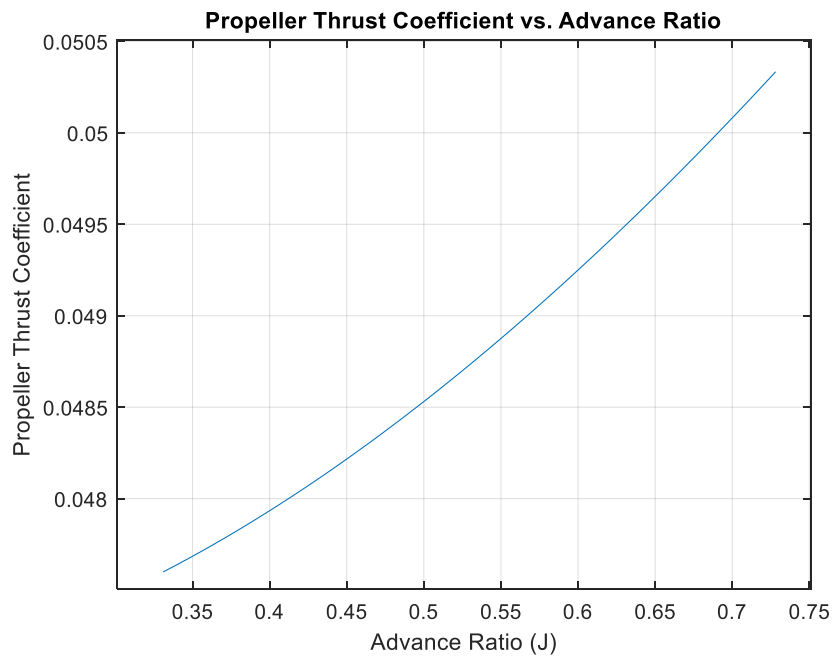


**Figure 7.** Drag Divergence Mach Number Graph.

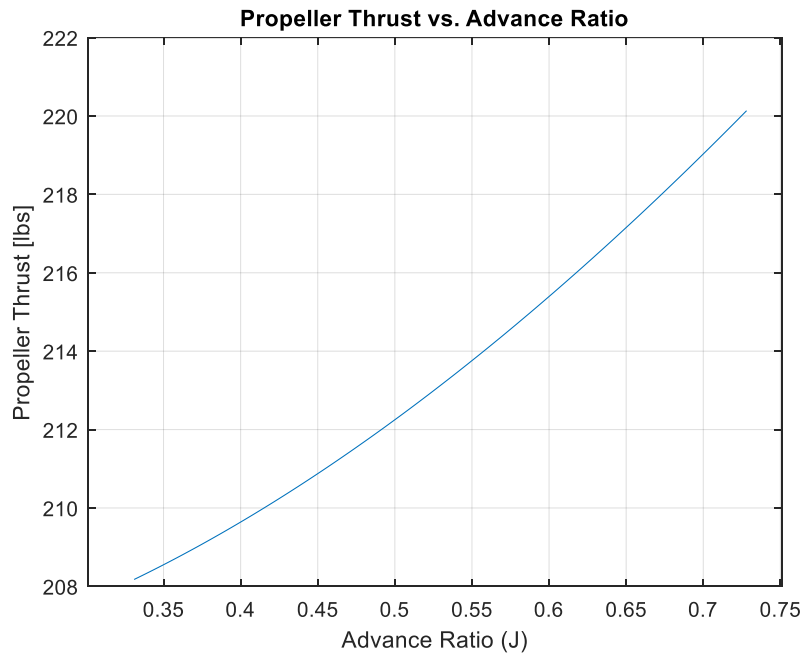
Following the design of the propeller, the performance of the propeller is analyzed for off-design airspeeds. The range for the airspeed is 50 to 110 KTAS. The resulting performance parameters are presented as a function of the advance ratio,  $J$ .



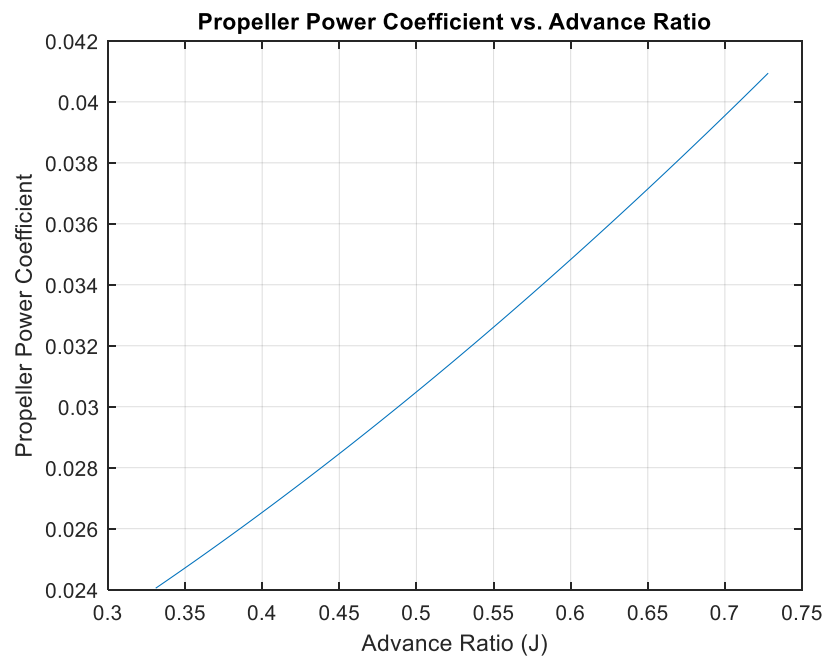
**Figure 8.** Propeller Efficiency vs. Advance Ratio.



**Figure 9.** Propeller Thrust Coefficient vs. Advance Ratio.

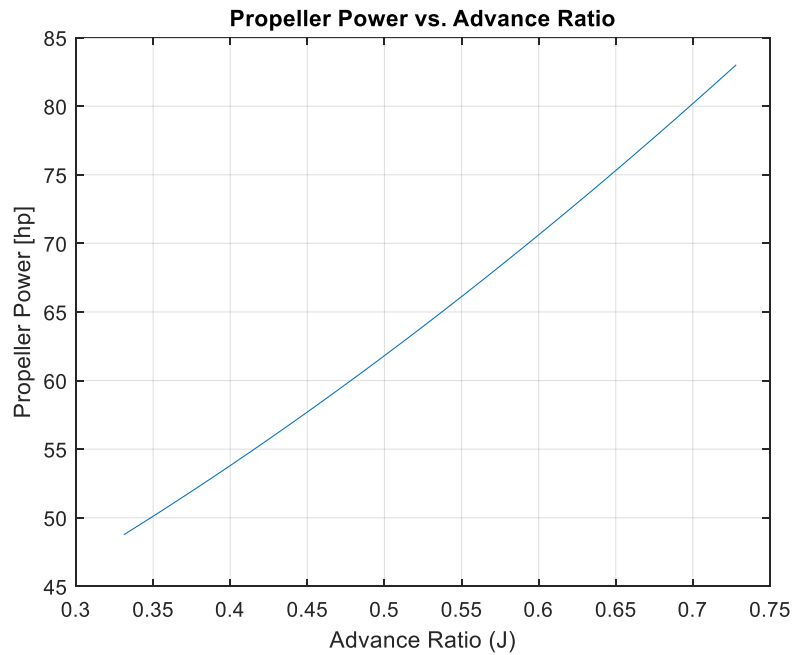


**Figure 10.** Propeller Thrust vs. Advance Ratio.



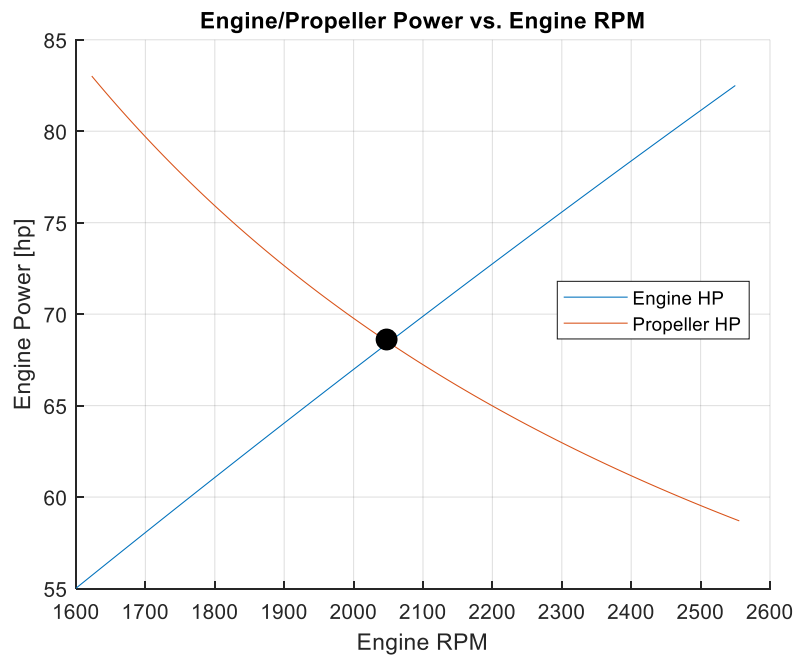
**Figure 11.** Propeller Power Coefficient vs. Advance Ratio.





**Figure 12.** Propeller Power vs. Advance Ratio.

While Cessna 152 does not have a variable pitch propeller, for informational purposes, the designed propeller is analyzed for a variety of variable pitch angles to investigate its effect on propeller thrust and propeller efficiency.



**Figure 13.** Engine/Propeller Power vs. RPM.

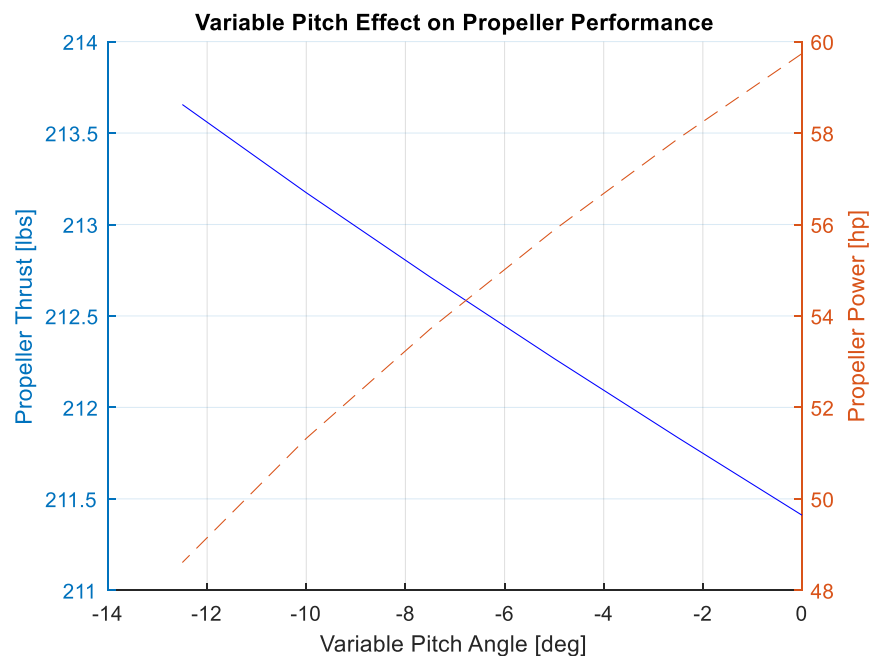
First, as the 2550 RPM limit was set for the designed airspeed of 107 KTAS, the RPM at the variable pitch angle analysis airspeed (70 KTAS) was calculated by matching the engine power to the propeller power. The calculated RPM match was at 2500 RPM. Then, the respective advance ratio was calculated, and the variable pitch angle was added to the pitch angle distribution of the propeller to calculate the propeller thrust, propeller power, and propeller efficiency.

The results are tabulated below:

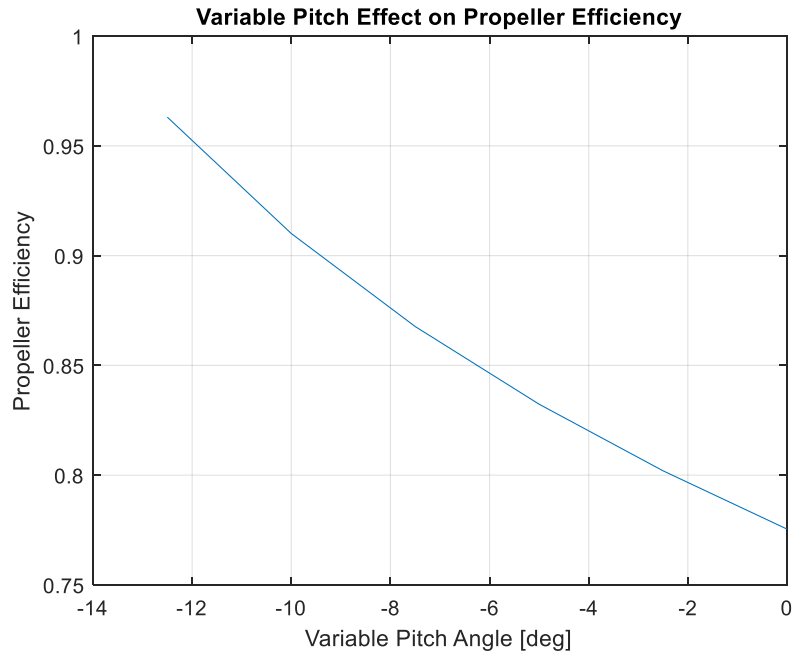
**Table 3.** Variable Pitch Effect on Propeller Performance.

Variable Pitch Angle ( $\Delta\beta$ )	Propeller Thrust	Propeller Power	Propeller Efficiency
0.0°	211.18 lbs	59.74 hp	77.02%
-2.5°	211.60 lbs	57.88 hp	79.67%
-5.0°	212.02 lbs	55.88 hp	82.71%
-7.5°	212.46 lbs	53.71 hp	86.24%
-10.0°	212.91 lbs	51.32 hp	90.48%
-12.5°	213.38 lbs	48.61 hp	95.76%

The data presented in the table can also be plotted as a function of the variable pitch angle:



**Figure 14.** Variable Pitch Angle vs. Propeller Performance.



**Figure 15.** Variable Pitch Angle vs. Propeller Efficiency.

These values and trends will be further discussed in the next section.

## Discussion

In the project, a propeller was designed for Cessna 152 for an altitude of 8,000 ft and airspeed of 107 KTAS. To design and analyze the propeller, the combined momentum and blade theory was used. Following the design of the propeller, the propeller performance was evaluated at design and off-design conditions, along with a variable pitch effect analysis.

First, the engine power output at the design altitude was found using the Lycoming engine specifications chart [2]. The resulting engine power at 8,000 ft was 83.0 hp, which is 75.5% of the maximum rated power of 110 hp for the selected engine.

For the propeller design, propeller diameter and number of blades were selected to start the design process. The propeller diameter was selected to be 6.0 ft, which is a close value compared to a real

Cessna 152 propeller seen at University Airport. The propeller was designed to incorporate two blades because three blades was considered to be unnecessary given the power of the engine.

After selecting the design components, air properties were found for the cruise altitude of 8,000 ft for US Standard Atmosphere [3]. Then, velocity components associated with the propeller cross-section were found as a function of  $x = r/R$ . Then, sectional lift curve slope was calculated while avoiding the Mach divergence of  $Ma > 0.9$ .

Using the Betz condition for optimal blade loading, the induced angle of the propeller was calculated. The sectional lift coefficient was assumed to be constant along the span of the propeller and local solidity ratio and chord distribution are calculated. Then, combined momentum and blade theory was used to find the corresponding propeller performance parameters. However, the propeller power (hp) is required to match the engine power (hp), therefore, the process was iterated to find the correct value for induced velocity ( $v_i=v_o$ ) that would result in a matching propeller and engine power. This concludes the performance analysis process at the design conditions.

The obtained propeller shape looks realistic as the chord length distribution and diameter of the propeller is close to the real propeller used in the Cessna 152 at University Airport. The resulting chord distribution, Figure 2, shows that it starts around 0.35 ft reaches a maximum of 0.46 ft around  $x=0.3$ , where it starts to decrease again. The root chord length seems reasonable in terms of structural considerations. The sectional lift coefficient distribution of the propeller was obtained using the chord distribution and Figure 4 shows that  $c_l$  varies from 0.46 to 0.54 to 0.42, which is within the limit for drag divergence. The drag divergence plot can also be seen in Figure 7. The blade maximum thickness ratio distribution of the propeller decreases with the span, shown in Figure 5. The result of the propeller design indicates that the blade pitch angle distribution of the propeller varies from  $60^\circ$  at the root and  $15^\circ$  at the tip, seen in Figure 6. The resulting propeller design has a propeller efficiency of 87%, a propeller power of 82.68 hp, and a propeller thrust of 218.18 lbs. These values along with other design point performance parameters can be found in Table 2.

While the previous performance parameters were for the design point of 107 KTAS, the aircraft is expected to operate within a range of airspeeds outside the design conditions. Therefore, the propeller performance was analyzed for an airspeed range of 50-110 KTAS and the results were graphed as a function of advance ratio ( $J$ ). As the engine RPM and propeller blade diameter are

constant, the x-axis of the graphs can be interpreted as the range of airspeeds. It is seen in Figure 8 that propeller efficiency increases with an increase in advance ratio, therefore, an increase in airspeed. Figures 9 and 10 show that propeller thrust and thrust coefficient increase with advance ratio. Propeller power and power coefficient are also directly proportional to the advance ratio of the propeller, seen in Figure 10 and 11.

The nonideal performance of the propeller at low speeds means that at speeds which the aircraft is expected to take off, the propeller operates with lower efficiency and lower thrust. This problem can be solved by using a variable pitch propeller. Cessna 152 does not have a variable pitch propeller; however, it is expected that such a system would increase the efficiency of the aircraft by optimizing the pitch angle for the flight conditions.

First, the engine and propeller power were matched for the off-design condition of 70 KTAS, which is the speed of the aircraft at maximum rate of climb. The RPM of propeller/engine is found for the intersection point on Figure 13. Using the decreased 2500 RPM, a new advance ratio was calculated for 70 KTAS. Then, the previous propeller performance parameters were obtained for various variable pitch angle values by adding  $\Delta\beta$  to the pitch angle distribution of the propeller. By plotting the thrust and power of the propeller with respect to the variable pitch angle, it was seen that the thrust of the propeller increased while propeller power decreased for a smaller pitch angle. Propeller efficiency also increased for a smaller pitch angle. Therefore, a more negative variable pitch angle would increase the performance of the aircraft and optimize the aircraft for lower speeds when rate of climb is maximum.

## References

- [1] van Dam, C.P. *EAE 130B – Aircraft Performance & Design – Propeller BEM Equations*. 31 March 2020.
- [2] Lycoming, "Operator's Manual Lycoming O-235 and O-290 Series," 5th Edition, Part No. 60297-9, January 2007.
- [3] Yechout, Thomas R., et al. *Introduction to Aircraft Flight Mechanics*. American Institute of Aeronautics and Astronautics, 2014. p. 573.
- [4] Harris, C.D., "NASA Supercritical Airfoils," NASA TP 2969, March 1990.
- [5] Boppe, C.W., "CFD Drag Prediction for Aerodynamic Design," *Technical Status Review on Drag Prediction and Analysis from Computational Fluid Dynamics: State of the Art*, AGARD AR 256, June 1989, pp. 8-1 – 8-27.

## **Appendices**

### **Appendix A1. MATLAB Codes for Propeller Design**

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## Table of Contents

.....	1
Part 1 - Engine Performance .....	1
Part 2a - Propeller Design .....	1
iterations .....	5

```
% EAE 130B - Project 1
% Propeller Design Program
% Emre Mengi
% ID: 913707050
clc; clear all; close all; % housekeeping
```

## Part 1 - Engine Performance

```
rpm_e = 2550; % engine max RPM
% sea level parameters
bhp_sl = 110; % engine power at sea level conditions, obtained from
Fig 2

% cruise parameters (h = 8,000 ft)
bhp_c = 83; % engine power at cruise, obtained from Fig 2

p_eng = bhp_c/bhp_sl*100; % engine power percentage of the max rating

fprintf('Maximum engine power output at cruise (h=8,000ft) is %1.1f
BHP and %1.1f %% of maximum rated power.\n', bhp_c, p_eng)

Maximum engine power output at cruise (h=8,000ft) is 83.0 BHP and 75.5
% of maximum rated power.
```

## Part 2a - Propeller Design

```
N = 100; %solution resolution
% propeller design parameters
D = 6; % propeller diameter [ft]
B = 2; % number of blades
x = linspace(0.15,1,N); % radial sections of the propeller
t_c = 0.04 ./ (x.^(1.2)); % maximum thickness to chord distribution
R = D / 2; % radius of propeller [ft]
r = x .* R; % local radius of the blade

n = rpm_e / 60; % rotations per second

% air properties
a = 1085.3; % speed of sound at 8,000 ft cruise
rho = 1.8683e-3; % density of air at 8,000 ft cruise

% given parameters
alpha_0 = -1 / 180 * pi; % zero lift angle of attack [rad]
V_inf = 107 * 1.68781; % speed for design condition [ft/s]
```



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```

w = n * 2 * pi; % angular velocity of propeller [rad/s]
V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
V_R = V_loc; % assumption
M = V_loc ./ a; % local Mach number

J = V_inf / (n * D); % advance ratio of propeller
%sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 * pi / sqrt(1-0.90^2);
    else
        m_0(i) = 2 * pi / sqrt(1-M(i)^2);
    end
end

% Optimum blade loading

% optimal induced angle
v_o = 0.001 * V_inf; % induced velocity - INITIAL ASSUMPTION
theta = atan2(V_inf + v_o, 2.*pi.*n.*r) - phi; % optimal induced angle
c_l = 0.4 * ones(1,N); % sectional lift coefficient initial assumption
%c_l = linspace(0.2, 0.6,N);

% drag divergence check
K = 0.94;
M_DD = K - t_c - min(c_l) / 10; % drag divergence Mach number
figure(1)
plot(t_c*100, M_DD)
grid on
title('Drag Divergence Mach Number')
xlabel('t/c, %')
ylabel('M_{DD}')
ylim([0.75,1]);
xlim([0, 11]);

sig = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ c_l;
c = sig .* pi .* R ./ B;
r_c = (5.5/12)/max(c); % Cessna 152 propeller max chord length was
    measured to be 5.5 inches
c = r_c .* c;
a_c = (0.35)-c(1);
c = a_c + c;

% for i = 23:N
%     a = (0.25-c(23))/((x(N))^3-(x(23))^3);
%     b = 0.25 - a*((x(N))^3);
%     c(i) = a*x(i)^5+b;
% end
%
```

---

---

```

% % for i = 1:23
% %     a = (0.25-c(23))/((x(1))^3-(x(23))^3);
% %     b = 0.25 - a*((x(1))^3);
% %     c(i) = a.*x(i)^3+b;
% % end
%
% for i = 1:22
%     c(23-i)=c(23+i);
% end

sig = B .* c ./ (pi .* R);
c_l = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ sig;
sig = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ c_l;
c = sig .* pi .* R ./ B;

alpha = c_l ./ m_0 + alpha_0; % angle of attack of blade element
beta = alpha + phi + theta; % pitch angle

% sectional drag polar
c_d_min = 0.01;
k = 0.004;
c_l_min = 0.1;
c_d = c_d_min + k .* (c_l - c_l_min).^2;

% drag divergence check
K = 0.94;
M_DD = K - t_c - min(c_l) / 10; % drag divergence Mach number
figure(2)
plot(t_c*100, M_DD)
grid on
title('Drag Divergence Mach Number')
xlabel('t/c, %')
ylabel('M_{DD}')
ylim([0.75,1]);
xlim([0, 11]);

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

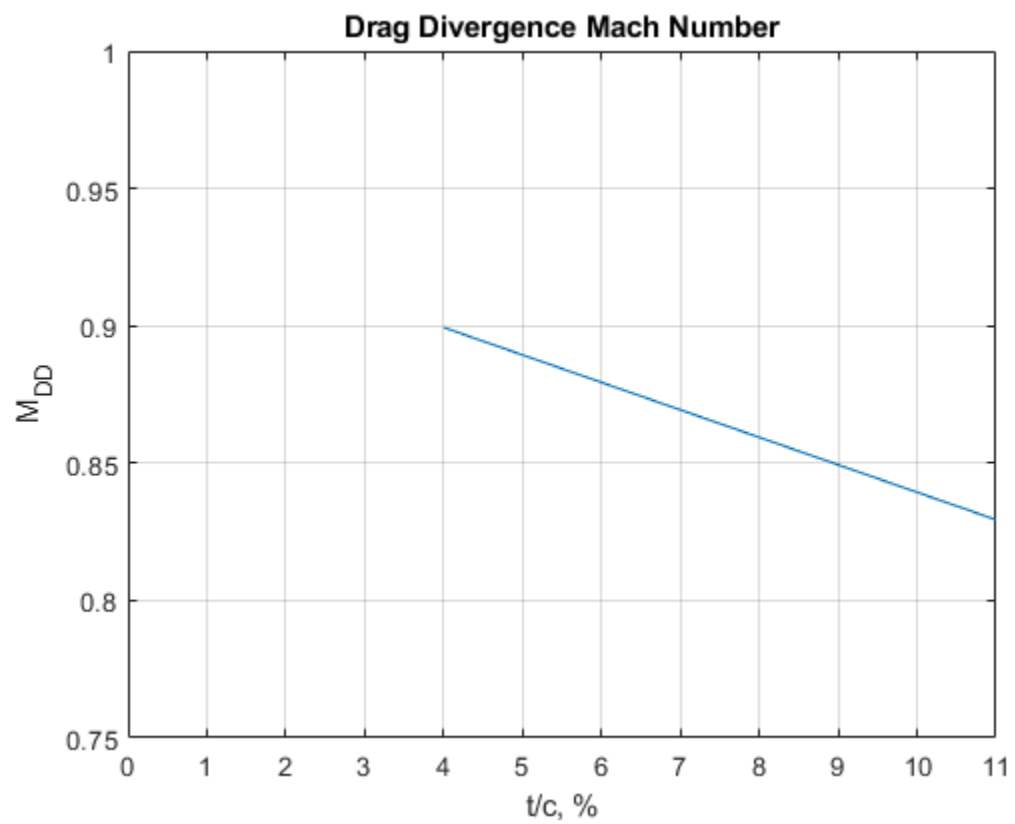
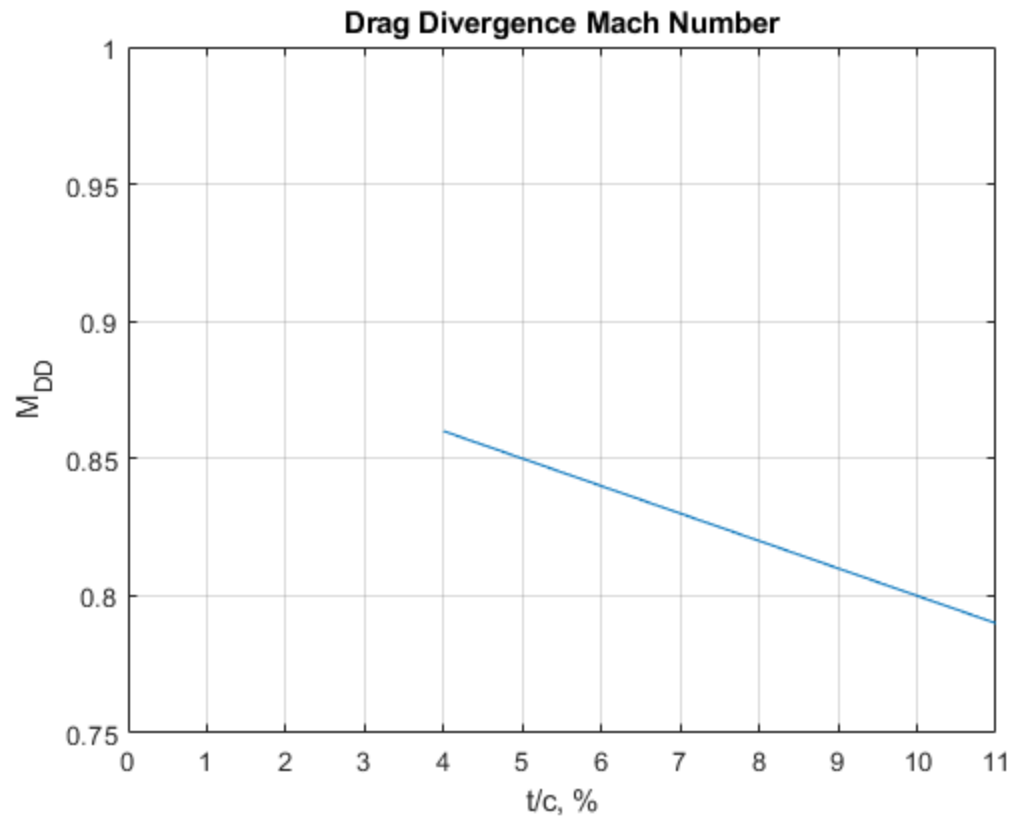
C_P = 2*pi*C_Q;
eta_P = C_T / (2*pi*C_Q)*J;

P_prop = C_P * rho * n^3 * D^5 / 550;

T_prop = C_T * rho * n^2 * D^4;

```

---



---

# iterations

Loop function for matching propeller hp to engine hp

```
d = 0.01; % increase in v_o per loop

while (abs(P_prop - bhp_c)/bhp_c * 100)>1
    % Optimum blade loading

    % optimal induced angle

    v_o = (0.001 + d) * V_inf; % induced velocity - INITIAL ASSUMPTION
    theta = atan2(V_inf + v_o, 2.*pi.*n.*r) - phi; % optimal induced
    angle

    % % drag divergence check
    % K = 0.94;
    % M_DD = K - t_c - max(c_l) / 10; % drag divergence Mach number
    % figure(1)
    % plot(t_c*100, M_DD)
    % grid on
    % title('Initial Drag Divergence Mach Number')
    % xlabel('t/c, %')
    % ylabel('M_{DD}')
    % ylim([0.75,1]);
    % xlim([0, 11]);

    sig = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ c_l;
    c = sig .* pi .* R ./ B;
    r_c = (5.5/12)/max(c); % Cessna 152 propeller max chord length was
    measured to be 5.5 inches
    c = r_c .* c;
    a_c = (0.35)-c(1);
    c = a_c + c;

    % for i = 23:N
    %     a = (0.25-c(23))/((x(N))^3-(x(23))^3);
    %     b = 0.25 - a*((x(N))^3);
    %     c(i) = a*x(i)^5+b;
    % end
    %
    % % for i = 1:23
    % %     a = (0.25-c(23))/((x(1))^3-(x(23))^3);
    % %     b = 0.25 - a*((x(1))^3);
    % %     c(i) = a.*x(i)^3+b;
    % % end
    %
    % for i = 1:22
    %     c(23-i)=c(23+i);
    % end

    sig = B .* c ./ (pi .* R);
    c_l = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ sig;
```

---

---

```

sig = 8 .* x .* theta .* cos(phi) .* tan(theta + phi) ./ c_l;
c = sig .* pi .* R ./ B;

alpha = c_l ./ m_0 + alpha_0; % angle of attack of blade element
beta = alpha + phi + theta; % pitch angle

% sectional drag polar
c_d_min = 0.01;
k = 0.004;
c_l_min = 0.1;
c_d = c_d_min + k .* (c_l - c_l_min).^2;

% % drag divergence check
% K = 0.94;
% M_DD = K - t_c - min(c_l) / 10; % drag divergence Mach number
% figure(3)
% plot(t_c*100, M_DD)
% grid on
% title('Final Drag Divergence Mach Number')
% xlabel('t/c, %')
% ylabel('M_{DD}')
% ylim([0.75,1]);
% xlim([0, 11]);

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2*pi*C_Q;
eta_P = C_T / (2*pi*C_Q)*J;

P_prop = C_P * rho * n^3 * D^5 / 550;

T_prop = C_T * rho * n^2 * D^4;

d = 0.001 + d; % increase in v_o per loop

end

% drag divergence check
K = 0.94;
M_DD = K - t_c - min(c_l) / 10; % drag divergence Mach number
figure(3)
plot(t_c*100, M_DD)
grid on
title('Final Drag Divergence Mach Number')
xlabel('t/c, %')
ylabel('M_{DD}')
%ylim([0.75,1]);

```

---

---

```

    %xlim([0, 11]);

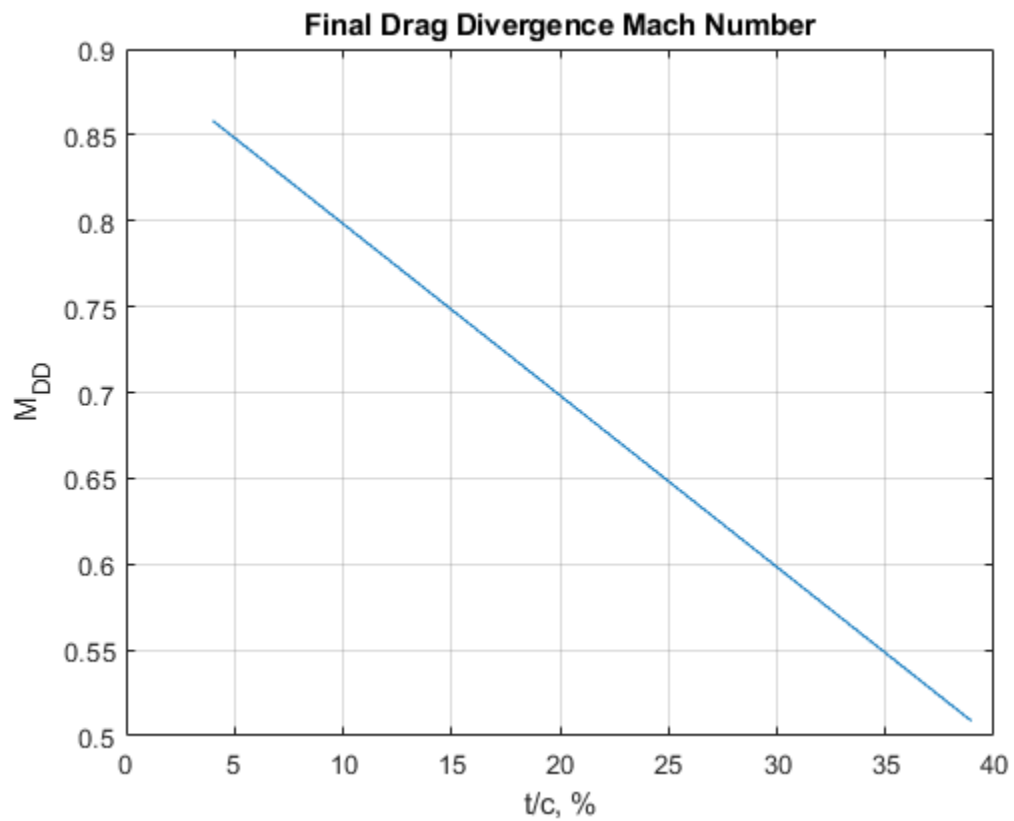
    c_l = m_0.*(alpha-alpha_0);

    % Induced angle calculations

    %A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).*tan(phi);
    %A_1 = V_inf ./ V_R + ((beta - phi - alpha_0) .* tan(phi) + 1) .*
        (sig .* m_0 ./ 8 .* x);
    %A_0 = -(beta - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

    %theta = (-A_1 + sqrt(A_1^2 - 4 * A_2 * A_0)) / (2 * A_2); % induced
    angle

```



*Published with MATLAB® R2019a*

## **Appendix A2.** MATLAB Codes for Propeller Performance Analysis

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## Table of Contents

.....	1
Design blade chord distribution, c and c/D vs. x .....	1
Design ?, t/c, cl vs. x .....	4
Design J, ?P, CQ, CP, CT .....	6
Design B, AF, CLd, D .....	6
Propeller Analysis for Range of Airspeeds .....	7
Analysis of Airspeed Sweep Results .....	9
Variable Pitch Propeller .....	13

```
% EAE 130B - Project 1
% Propeller Analysis Program
% Emre Mengi
% ID: 913707050
```

```
clc; clear all; close all; % housekeeping
```

```
EmreMENGI_EAE130B_Project1_PropellerDesign % importing design
parameters
close all;
```

*Maximum engine power output at cruise (h=8,000ft) is 83.0 BHP and 75.5 % of maximum rated power.*

## Design blade chord distribution, c and c/D vs. x

```
figure(1)
plot(x, c)
grid on
title('Blade Chord Distribution')
xlabel('x')
ylabel('c [ft]')
%ylim([0.3,0.5])
```

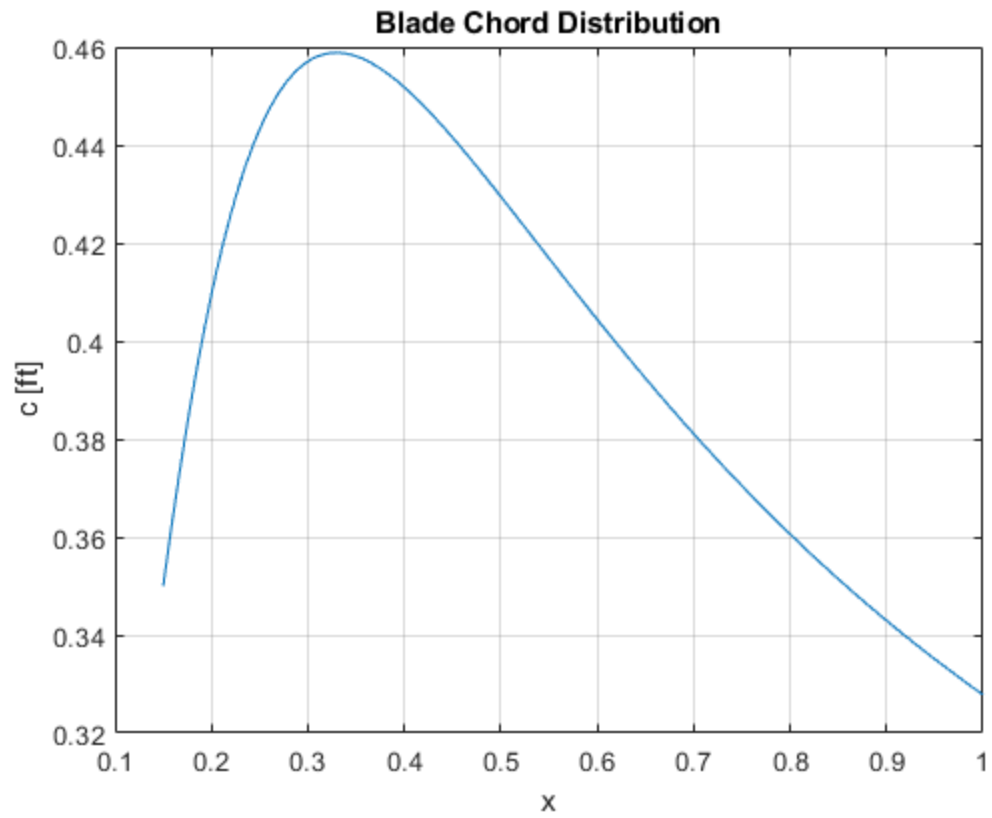
```
figure(2)
plot(x*R, c/2, 'k')
hold on
plot(x*R, -c/2, 'k')
plot(-x*R, c/2, 'k')
plot(-x*R, -c/2, 'k')
grid on
title('Propeller Shape')
xlabel('R[ft]')
ylabel('c/2 [ft]')
axis equal
hold off
```

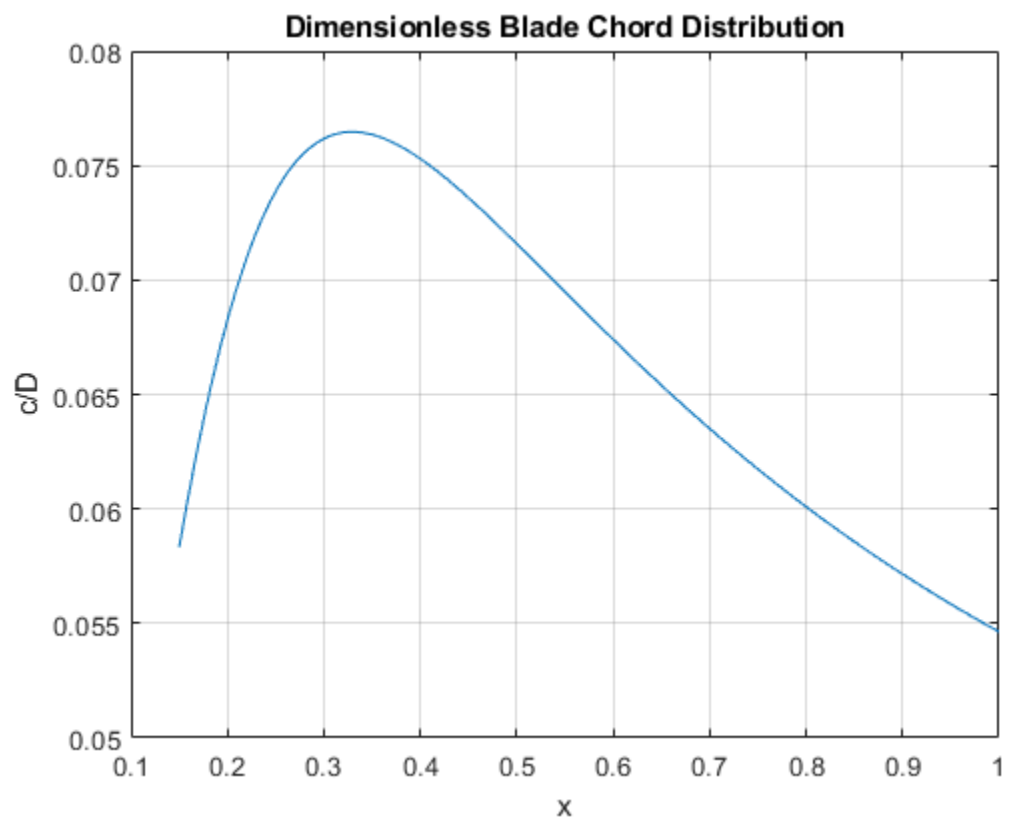
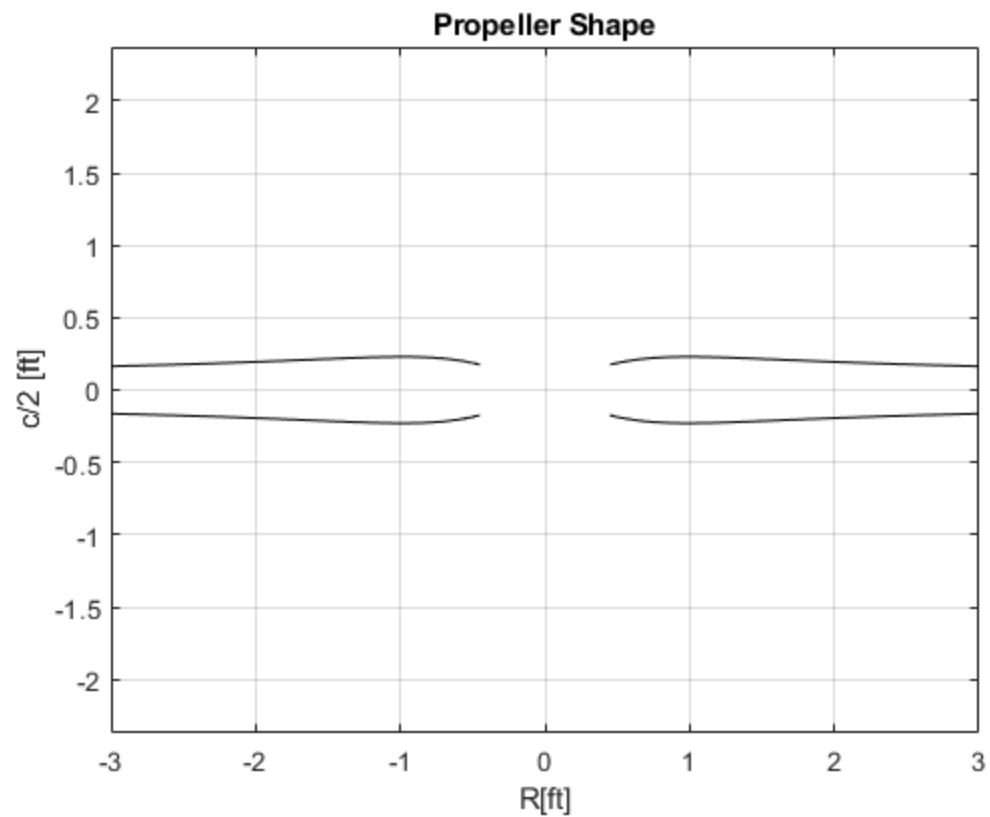
```
figure(3)
plot(x, c./D)
```



---

```
grid on
title('Dimensionless Blade Chord Distribution')
xlabel('x')
ylabel('c/D')
```





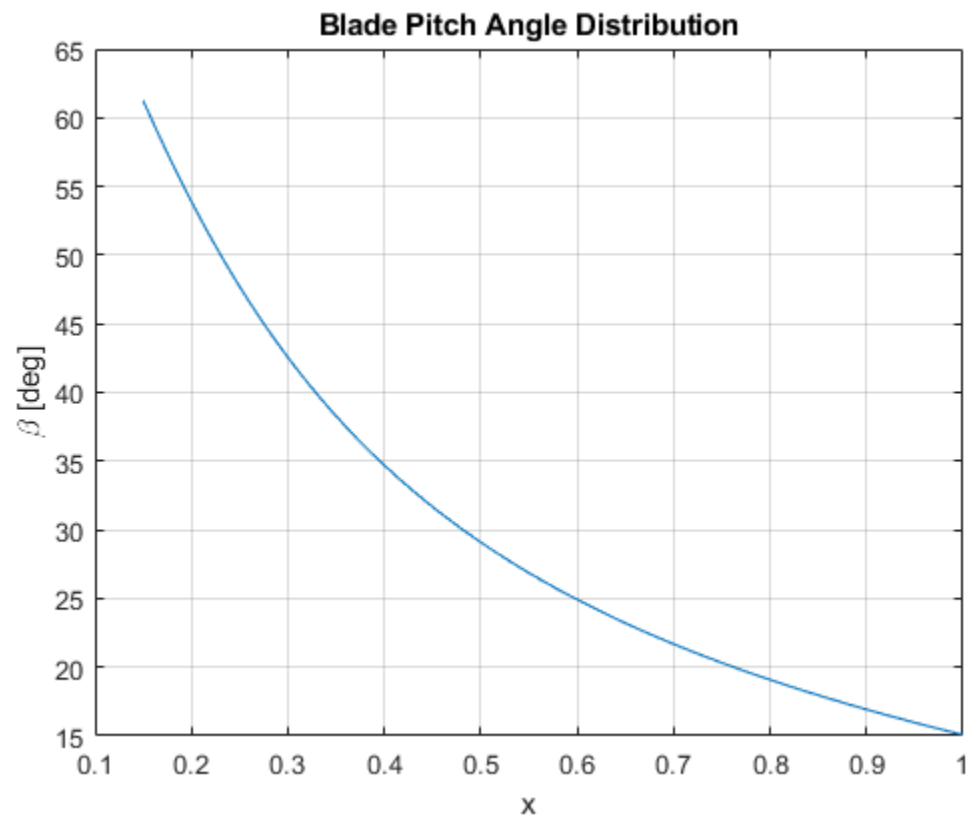
---

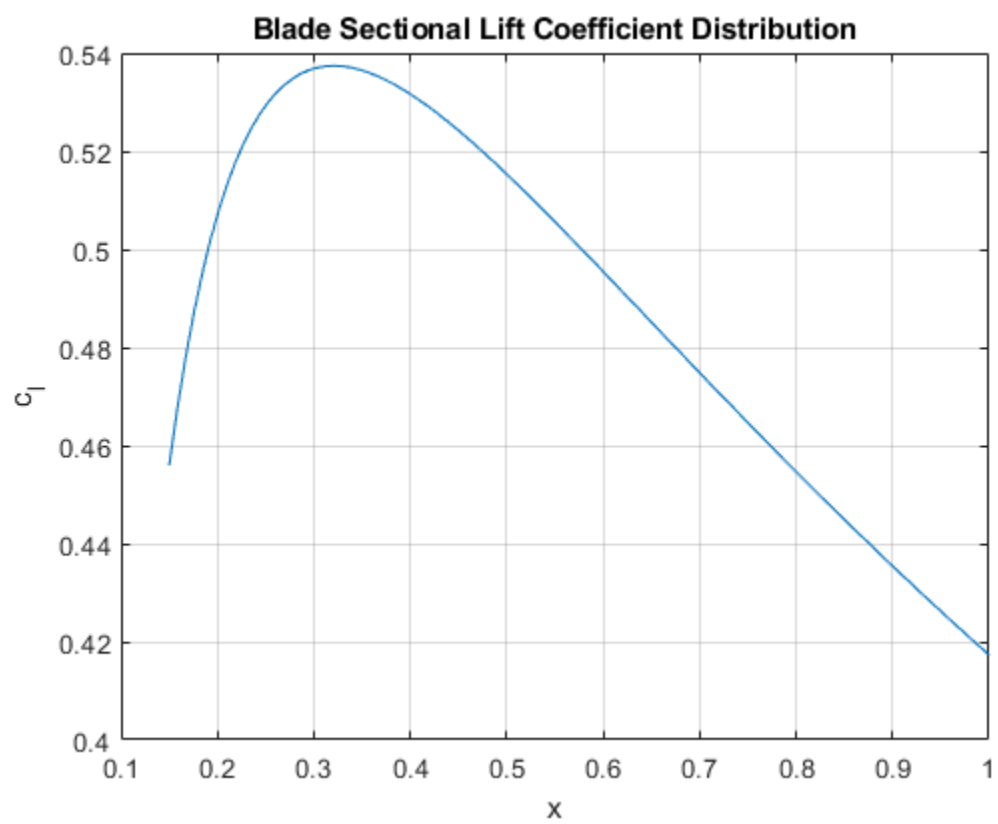
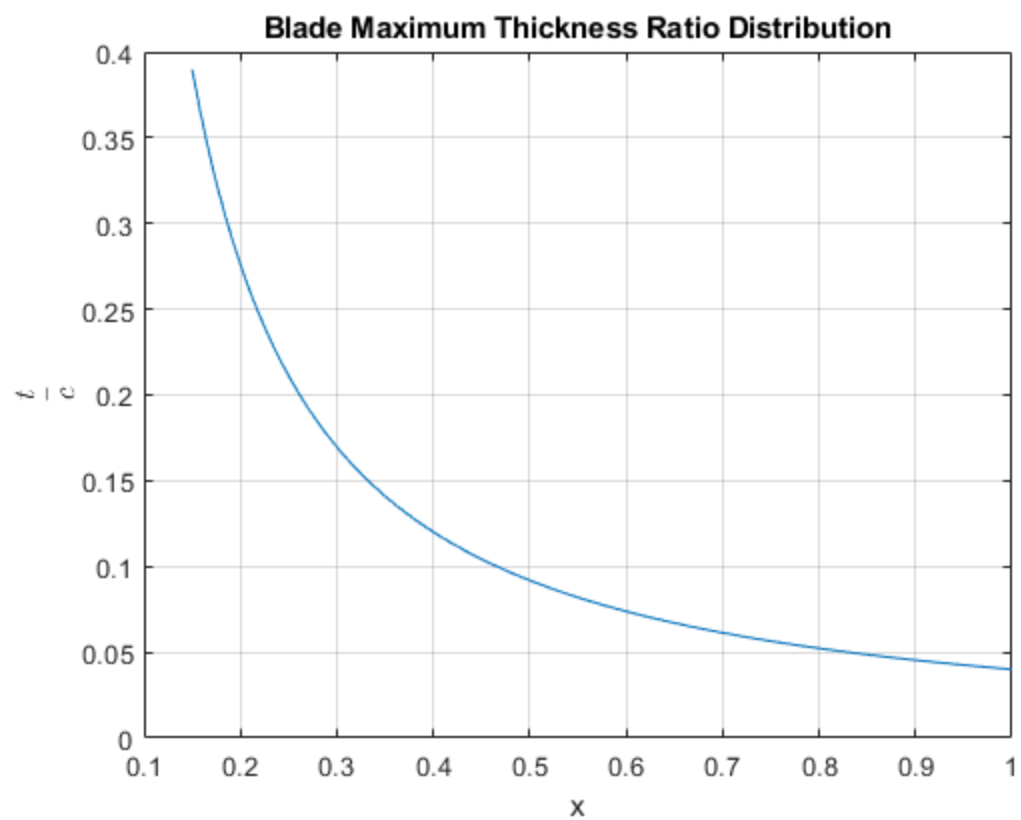
## Design ?, t/c, cl vs. x

```
figure(4)
plot(x, beta.*180./pi)
grid on
title('Blade Pitch Angle Distribution')
xlabel('x')
ylabel('\beta [deg]')

figure(5)
plot(x, t_c)
grid on
title('Blade Maximum Thickness Ratio Distribution')
xlabel('x')
ylabel('$$\frac{t}{c}$$', 'interpreter', 'latex')

figure(6)
plot(x, c_l)
grid on
title('Blade Sectional Lift Coefficient Distribution')
xlabel('x')
ylabel('c_l')
```





---

## Design J, $\eta_P$ , $C_Q$ , $C_P$ , $C_T$

```
% Advance Ratio
fprintf('Advance Ratio ( $\eta$ ) of the propeller is %1.2f.\n',  $\eta$ )

% Propeller Efficiency
fprintf('Propeller Efficiency of the propeller is %1.2f.\n',  $\eta_P$ )

% Torque Coefficient
fprintf('Torque Coefficient ( $C_Q$ ) of the propeller is %1.5f.\n',  $C_Q$ )

% Propeller Power
fprintf('Power of the propeller is %1.2f hp.\n',  $P_{prop}$ )

% Power Coefficient
fprintf('Power Coefficient ( $C_P$ ) of the propeller is %1.5f.\n',  $C_P$ )

% Propeller Thrust
fprintf('Thrust of the propeller is %1.2f lbs.\n',  $T_{prop}$ )

% Thrust Coefficient
fprintf('Thrust Coefficient ( $C_T$ ) of the propeller is %1.5f.\n',  $C_T$ )

Advance Ratio ( $\eta$ ) of the propeller is 0.71.
Propeller Efficiency of the propeller is 0.87.
Torque Coefficient ( $C_Q$ ) of the propeller is 0.00649.
Power of the propeller is 82.68 hp.
Power Coefficient ( $C_P$ ) of the propeller is 0.04077.
Thrust of the propeller is 218.18 lbs.
Thrust Coefficient ( $C_T$ ) of the propeller is 0.04989.
```

## Design B, $AF$ , $CL_d$ , $D$

```
% Number of Blades
fprintf('Number of blades on the propeller is %1.0f.\n',  $B$ )

% Blade Activity Factor
 $y_{AF} = (c ./ D) .* x.^3$ ;
 $AF = ((10^5)/16)*trapz(x, y_{AF})$ ;
fprintf('Blade Activity Factor ( $AF$ ) of the propeller is %1.2f.\n',  $AF$ )

% Blade Design Lift Coefficient
 $y_{CL} = (c_l) .* x.^3$ ;
 $CL = (4)*trapz(x, y_{CL})$ ;
fprintf('Blade Design Lift Coefficient of the propeller is %1.2f.\n',
         $CL$ )

% Blade Diameter
fprintf('Blade Diameter of the propeller is %1.1f ft.\n',  $D$ )

% Blade Pitch Angle at 0.75R
 $p = 2*\pi.*r.*\tan(\beta)$ ;
```

---

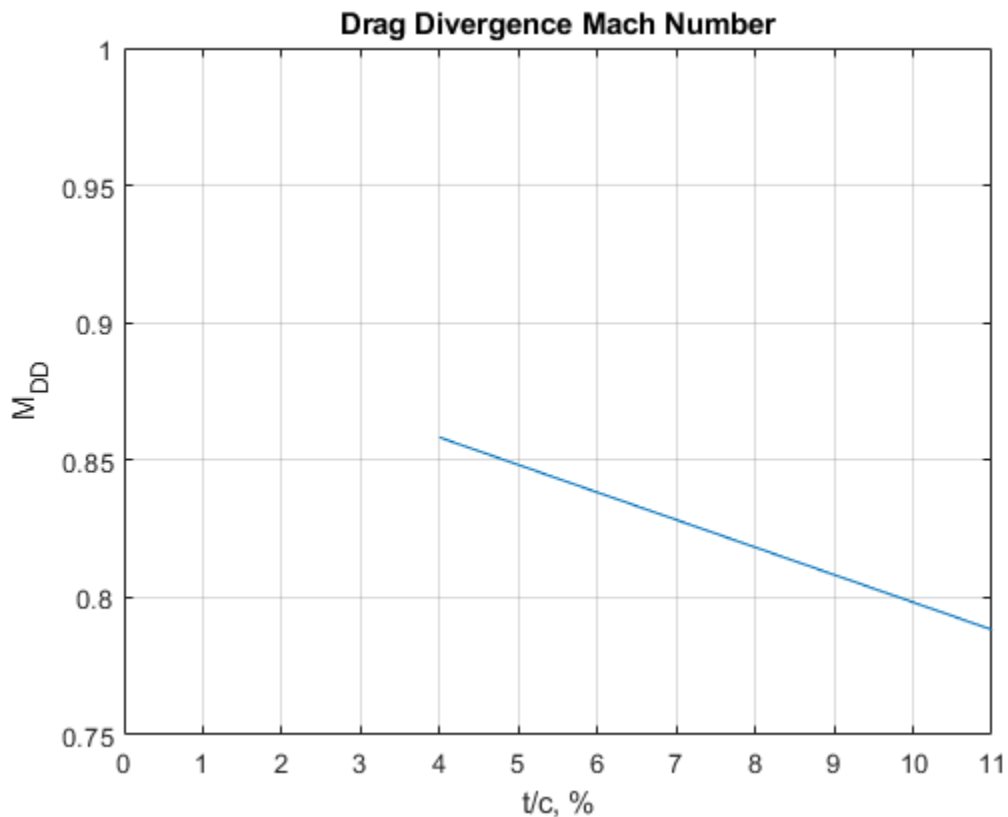
```

i_r = round((0.75-0.15)/((1-0.15)/N)+1);
beta_075R = atan2(4*p(i_r),3*pi*D);
fprintf('Blade Pitch Angle at 75%R is %1.2f degrees.\n',
    beta_075R*180/pi)

% drag divergence check
K = 0.94;
M_DD = K - t_c - min(c_l) / 10; % drag divergence Mach number
figure(15)
plot(t_c*100, M_DD)
grid on
title('Drag Divergence Mach Number')
xlabel('t/c, %')
ylabel('M_{DD}')
ylim([0.75,1]);
xlim([0, 11]);

```

Number of blades on the propeller is 2.  
 Blade Activity Factor (AF) of the propeller is 94.55.  
 Blade Design Lift Coefficient of the propeller is 0.45.  
 Blade Diameter of the propeller is 6.0 ft.  
 Blade Pitch Angle at 75%R is 20.31 degrees.



## Propeller Analysis for Range of Airspeeds

```

N2 = 128; % sweep resolution

```

---

```

V_inf = linspace(50,110,N2).* 1.68781; % range of airspeeds [ft/s]

J = V_inf ./ (n .* D); % advance ratio of propeller
alpha = ones(N2,N);

for z=1:length(V_inf)
    V_loc(z,:) = sqrt(V_inf(z)^2 + (w .* r).^2); % local velocity at
    the section of the propeller
    M(z,:) = V_loc(z,:) ./ a; % local Mach number
    sig(z,:) = B .* c ./ (pi .* R); % local solidity ratio
    phi(z,:) = atan2(J(z), pi .* x); % blade angle
    %V_R(z,:) = V_inf(z) .* sin(phi(z,:)); % resultant velocity
    V_R(z,:)=V_loc(z,:);

    % sectional lift curve slope calculation
    for i = 1:length(M(z,:))
        if M(z,i)>0.90
            m_0(z,i) = 2 .* pi ./ sqrt(1-0.90^2);
        else
            m_0(z,i) = 2 .* pi ./ sqrt(1-M(z,i).^2);
        end
    end

    alpha(z,:) = c_l ./ m_0(z,:) + alpha_0; % angle of attack of blade
    element
    % Induced angle calculations

    A_2(z,:) = cos(phi(z,:)) - (sig(z,:) .* m_0(z,:) ./ 8 .*
    x).*tan(phi(z,:));
    A_1(z,:) = V_inf(z) ./ V_R(z,:) + ((beta - phi(z,:) - alpha_0) .*
    tan(phi(z,:)) + 1) .* (sig(z,:) .* m_0(z,:) ./ 8 .* x);
    A_0(z,:) = -(beta - phi(z,:) - alpha_0) .* (sig(z,:) .*
    m_0(z,:) ./ 8 .* x);

    theta(z,:) = (-A_1(z,:) + sqrt(A_1(z,).^2 - 4 .* A_2(z,:) .*
    A_0(z,:))) ./ (2 .* A_2(z,:)); % induced angle

    y_T(z,:) = sig(z,:) .* pi.^3 .* x.^2 ./ 8 .* ((1./
    cos(phi(z,)).^2) .* (c_l .* cos(phi(z,:) + theta(z,:)) - c_d .*
    sin(phi(z,:) + theta(z,:))));
    C_T(z,:) = trapz(x, y_T(z,:));

    y_Q(z,:) = sig(z,:) .* pi.^3 .* x.^3 ./ 16 .* ((1./
    cos(phi(z,)).^2) .* (c_l .* sin(phi(z,:) + theta(z,:)) + c_d .*
    cos(phi(z,:) + theta(z,:))));
    C_Q(z,:) = trapz(x, y_Q(z,:));

    C_P(z,:) = 2.*pi.*C_Q(z,:);
    eta_P(z) = C_T(z) ./ (2.*pi.*C_Q(z,:)).*J(z);

    P_prop(z) = C_P(z) .* rho .* n.^3 .* D.^5 ./ 550;
    T_prop(z) = C_T(z) .* rho .* n.^2 .* D.^4;

```

---

---

end

## Analysis of Airspeed Sweep Results

```
figure(7)
plot(J, P_prop)
grid on
title('Propeller Power vs. Advance Ratio')
xlabel('Advance Ratio (J)')
ylabel('Propeller Power [hp]')

figure(8)
plot(J, C_P)
grid on
title('Propeller Power Coefficient vs. Advance Ratio')
xlabel('Advance Ratio (J)')
ylabel('Propeller Power Coefficient')

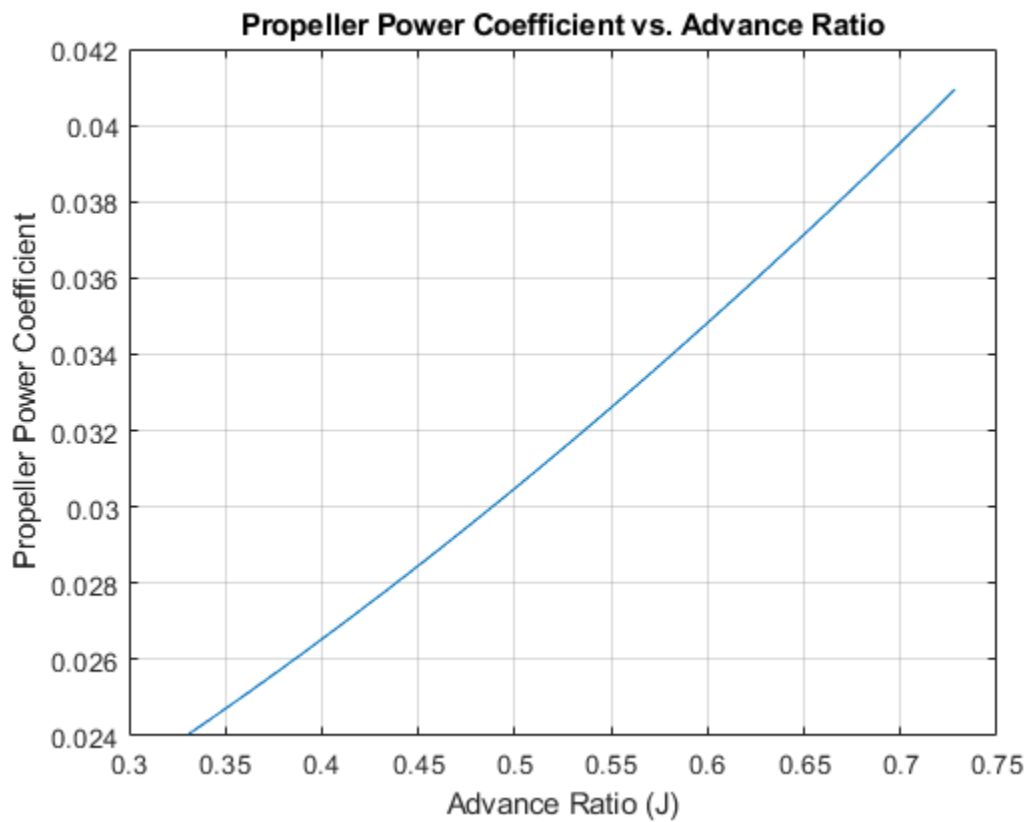
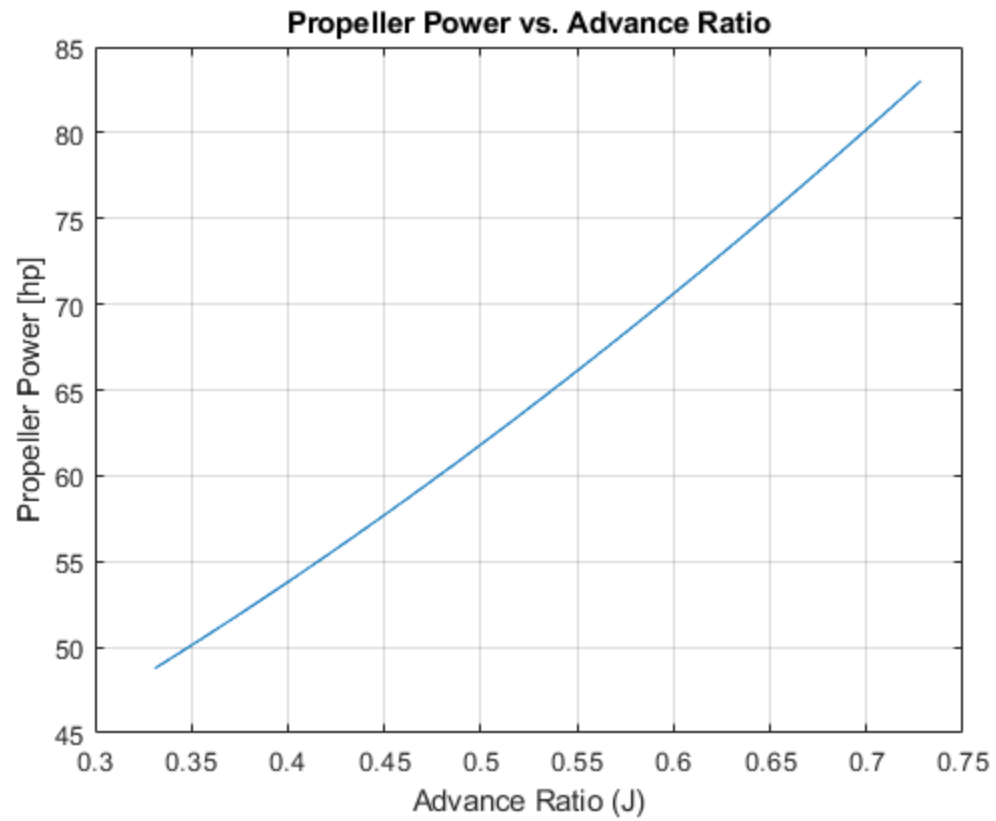
figure(9)
plot(J, T_prop)
grid on
title('Propeller Thrust vs. Advance Ratio')
xlabel('Advance Ratio (J)')
ylabel('Propeller Thrust [lbs]')

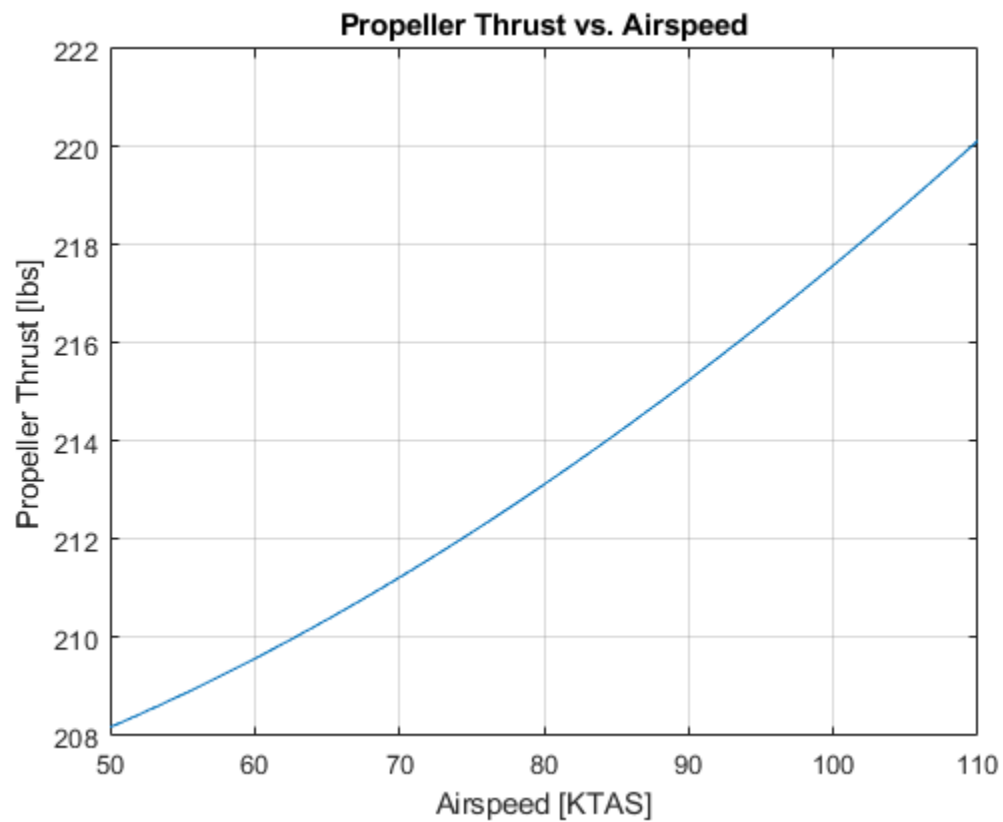
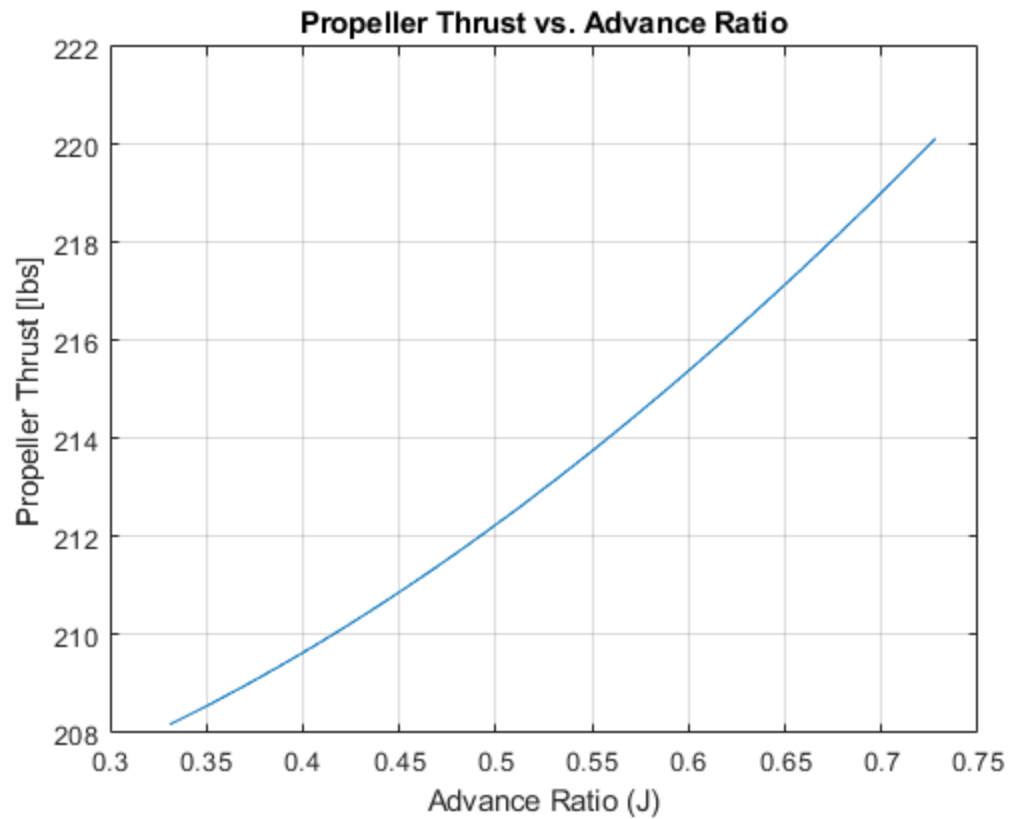
figure(10)
plot(V_inf./1.68781, T_prop)
grid on
title('Propeller Thrust vs. Airspeed')
xlabel('Airspeed [KTAS]')
ylabel('Propeller Thrust [lbs]')

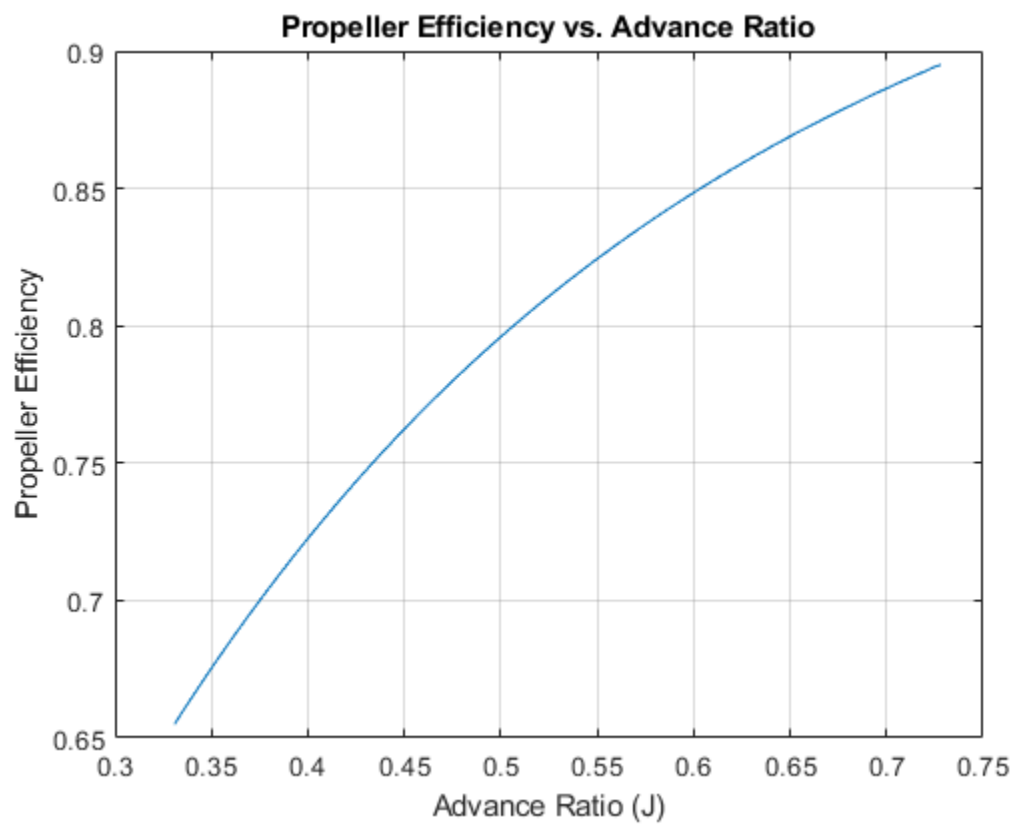
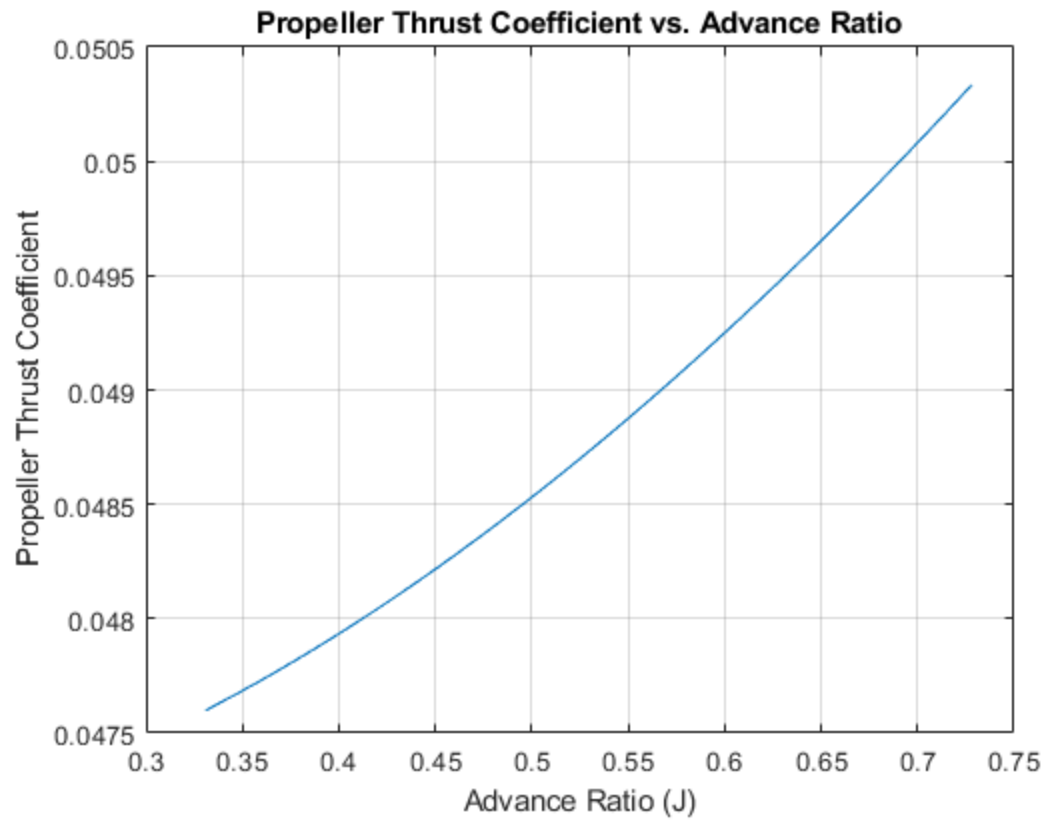
figure(11)
plot(J, C_T)
grid on
title('Propeller Thrust Coefficient vs. Advance Ratio')
xlabel('Advance Ratio (J)')
ylabel('Propeller Thrust Coefficient')

figure(12)
plot(J, eta_P)
grid on
title('Propeller Efficiency vs. Advance Ratio')
xlabel('Advance Ratio (J)')
ylabel('Propeller Efficiency')
```









---

# Variable Pitch Propeller

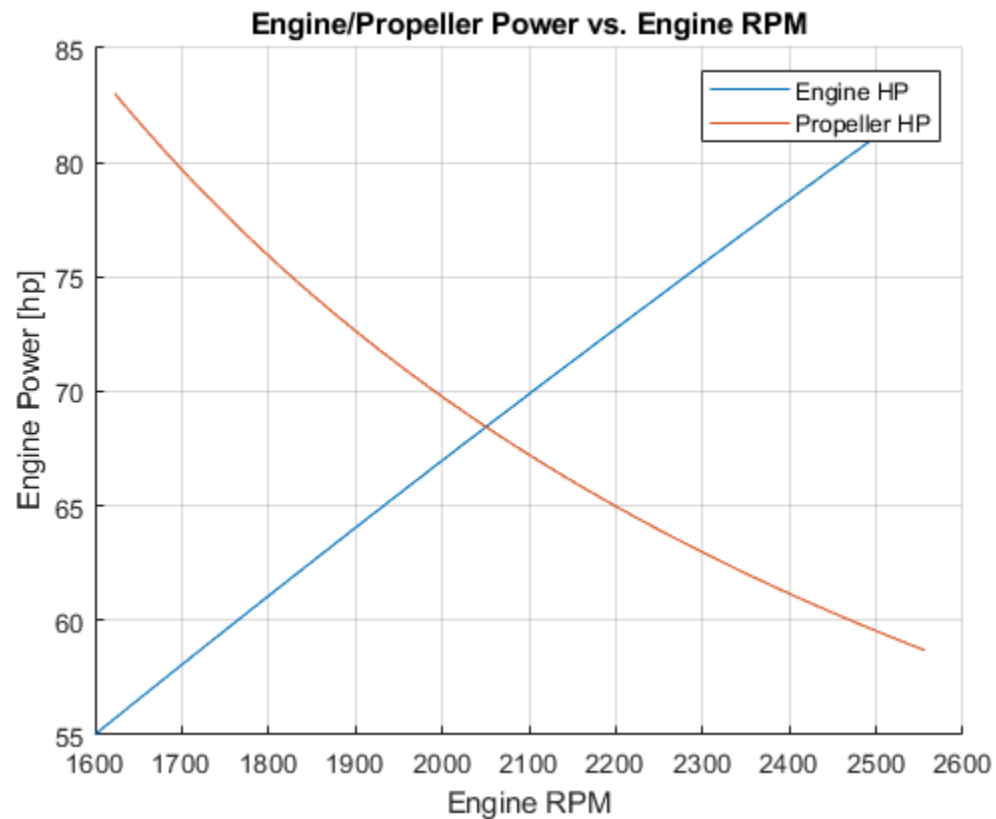
run the first section and airspeed sweep section before running this section

```
% matching RPM
RPM = linspace(1600,2550,1000);
bhp_fix = 0.75.*(1.9286+0.048452.*RPM-0.000002381.*RPM.^2);

RPM_P = 70 .* 1.68781 ./ (D .* J) .* 60;

figure(13)
hold on
plot(RPM, bhp_fix)
plot(RPM_P(43:128), P_prop(43:128))
grid on
title('Engine/Propeller Power vs. Engine RPM')
xlabel('Engine RPM')
ylabel('Engine Power [hp]')
legend('Engine HP', 'Propeller HP')
hold off

n1 = 2500/60;
```



```
clear all;
EmreMENGI_EAE130B_Project1_PropellerDesign % importing design
parameters
```

---

```

n1 = 2500/60;
% delta_b = 0 deg
betal = beta + (0/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).tan(phi);
A_1 = V_inf ./ V_R + ((betal - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(betal - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop1 = T_prop;
eta_P1 = eta_P;
P_prop1 = P_prop;

```

---

---

```

% delta_b = -2.5
beta2 = beta + (-2.5/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).tan(phi);
A_1 = V_inf ./ V_R + ((beta2 - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(beta2 - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop2 = T_prop;
eta_P2 = eta_P;
P_prop2 = P_prop;

```

---

---

```

% delta_b = -5
beta3 = beta + (-5/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).*tan(phi);
A_1 = V_inf ./ V_R + ((beta3 - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(beta3 - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop3 = T_prop;
eta_P3 = eta_P;
P_prop3 = P_prop;

```

---

---

```

% delta_b = -7.5 deg
beta4 = beta + (-7.5/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).tan(phi);
A_1 = V_inf ./ V_R + ((beta4 - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(beta4 - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop4 = T_prop;
eta_P4 = eta_P;
P_prop4 = P_prop;

```

---



---

```

% delta_b = -10 deg
beta5 = beta + (-10/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).*tan(phi);
A_1 = V_inf ./ V_R + ((beta5 - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(beta5 - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop5 = T_prop;
eta_P5 = eta_P;
P_prop5 = P_prop;

```

---

---

```

% delta_b = -12.5 deg
beta6 = beta + (-12.5/180*pi);
V_inf = 70* 1.68781; % airspeed at max rate of climb [ft/s]

J = V_inf ./ (n1 .* D); % advance ratio of propeller

V_loc = sqrt(V_inf^2 + (w .* r).^2); % local velocity at the section
    of the propeller
M = V_loc ./ a; % local Mach number
sig = B .* c ./ (pi .* R); % local solidity ratio
phi = atan2(J, pi .* x); % blade angle
%V_R = V_inf .* sin(phi); % resultant velocity

% sectional lift curve slope calculation
for i = 1:length(M)
    if M(i)>0.90
        m_0(i) = 2 .* pi ./ sqrt(1-0.90^2);
    else
        m_0(i) = 2 .* pi ./ sqrt(1-M(i).^2);
    end
end

alpha2 = c_l ./ m_0 + alpha_0; % angle of attack of blade element
% Induced angle calculations

A_2 = cos(phi) - (sig .* m_0 ./ 8 .* x).*tan(phi);
A_1 = V_inf ./ V_R + ((beta6 - phi - alpha_0) .* tan(phi) + 1) .*
    (sig .* m_0 ./ 8 .* x);
A_0 = -(beta6 - phi - alpha_0) .* (sig .* m_0 ./ 8 .* x);

theta = (-A_1 + sqrt(A_1.^2 - 4 .* A_2 .* A_0)) ./ (2 .* A_2); %
    induced angle

%beta = alpha + phi + theta; % pitch angle

y_T = sig .* pi.^3 .* x.^2 ./ 8 .* ((1./cos(phi)).^2) .* (c_l .*
    cos(phi + theta) - c_d .* sin(phi + theta));
C_T = trapz(x, y_T);

y_Q = sig .* pi.^3 .* x.^3 ./ 16 .* ((1./cos(phi)).^2) .* (c_l .*
    sin(phi + theta) + c_d .* cos(phi + theta));
C_Q = trapz(x, y_Q);

C_P = 2.*pi.*C_Q;
eta_P = C_T ./ (2.*pi.*C_Q).*J;

P_prop = C_P .* rho .* n.^3 .* D.^5 ./ 550;
T_prop = C_T .* rho .* n.^2 .* D.^4;

T_prop6 = T_prop;
eta_P6 = eta_P;
P_prop6 = P_prop;

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% Propeller Thrust, d_beta = 0 deg
fprintf('Thrust of the propeller with variable pitch angle of 0
degrees is %1.2f lbs.\n', T_prop1)

% Propeller Thrust, d_beta = -2.5 deg
fprintf('Thrust of the propeller with variable pitch angle of -2.5
degrees is %1.2f lbs.\n', T_prop2)

% Propeller Thrust, d_beta = -5 deg
fprintf('Thrust of the propeller with variable pitch angle of -5
degrees is %1.2f lbs.\n', T_prop3)

% Propeller Thrust, d_beta = -7.5 deg
fprintf('Thrust of the propeller with variable pitch angle of -7.5
degrees is %1.2f lbs.\n', T_prop4)

% Propeller Thrust, d_beta = -10 deg
fprintf('Thrust of the propeller with variable pitch angle of -10
degrees is %1.2f lbs.\n', T_prop5)

% Propeller Thrust, d_beta = -12.5 deg
fprintf('Thrust of the propeller with variable pitch angle of -12.5
degrees is %1.2f lbs.\n', T_prop6)

% Propeller Power, d_beta = 0 deg
fprintf('Power of the propeller with variable pitch angle of 0 degrees
is %1.2f hp.\n', P_prop1)

% Propeller Power, d_beta = -2.5 deg
fprintf('Power of the propeller with variable pitch angle of -2.5
degrees is %1.2f hp.\n', P_prop2)

% Propeller Power, d_beta = -5 deg
fprintf('Power of the propeller with variable pitch angle of -5
degrees is %1.2f hp.\n', P_prop3)

% Propeller Power, d_beta = -7.5 deg
fprintf('Power of the propeller with variable pitch angle of -7.5
degrees is %1.2f hp.\n', P_prop4)

% Propeller Power, d_beta = -10 deg
fprintf('Power of the propeller with variable pitch angle of -10
degrees is %1.2f hp.\n', P_prop5)

% Propeller Power, d_beta = -12.5 deg
fprintf('Power of the propeller with variable pitch angle of -12.5
degrees is %1.2f hp.\n', P_prop6)

% Propeller Efficiency, d_beta = 0 deg
fprintf('Propeller efficiency with variable pitch angle of 0 degrees
is %1.2f%%.\n', eta_P1*100)

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% Propeller Efficiency, d_beta = -2.5 deg
fprintf('Propeller efficiency with variable pitch angle of -2.5
degrees is %1.2f%%.\n', eta_P2*100)

% Propeller Efficiency, d_beta = -5 deg
fprintf('Propeller efficiency with variable pitch angle of -5 degrees
is %1.2f%%.\n', eta_P3*100)

% Propeller Efficiency, d_beta = -7.5 deg
fprintf('Propeller efficiency with variable pitch angle of -7.5
degrees is %1.2f%%.\n', eta_P4*100)

% Propeller Efficiency, d_beta = -10 deg
fprintf('Propeller efficiency with variable pitch angle of -10 degrees
is %1.2f%%.\n', eta_P5*100)

% Propeller Efficiency, d_beta = -12.5 deg
fprintf('Propeller efficiency with variable pitch angle of -12.5
degrees is %1.2f%%.\n', eta_P6*100)

beta_a = [0 -2.5 -5 -7.5 -10 -12.5]+20.31;
eta_P_a = [eta_P1 eta_P2 eta_P3 eta_P4 eta_P5 eta_P6];
T_prop_a = [T_prop1 T_prop2 T_prop3 T_prop4 T_prop5 T_prop6];
P_prop_a = [P_prop1 P_prop2 P_prop3 P_prop4 P_prop5 P_prop6];

beta_b = [0 -2.5 -5 -7.5 -10 -12.5];

figure(14)
hold on
yyaxis left
ylabel('Propeller Thrust [lbs]')
plot(beta_b, T_prop_a, 'b-')
yyaxis right
ylabel('Propeller Power [hp]')
plot(beta_b, P_prop_a, '--')
xlabel('Variable Pitch Angle [deg]')
grid on
title('Variable Pitch Effect on Propeller Performance')
hold off

figure(15)
plot(beta_b, eta_P_a)
grid on
title('Variable Pitch Effect on Propeller Efficiency')
xlabel('Variable Pitch Angle [deg]')
ylabel('Propeller Efficiency')

Maximum engine power output at cruise (h=8,000ft) is 83.0 BHP and 75.5
% of maximum rated power.
Thrust of the propeller with variable pitch angle of 0 degrees is
211.41 lbs.

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Thrust of the propeller with variable pitch angle of -2.5 degrees is 211.83 lbs.

Thrust of the propeller with variable pitch angle of -5 degrees is 212.27 lbs.

Thrust of the propeller with variable pitch angle of -7.5 degrees is 212.71 lbs.

Thrust of the propeller with variable pitch angle of -10 degrees is 213.17 lbs.

Thrust of the propeller with variable pitch angle of -12.5 degrees is 213.66 lbs.

Power of the propeller with variable pitch angle of 0 degrees is 59.74 hp.

Power of the propeller with variable pitch angle of -2.5 degrees is 57.88 hp.

Power of the propeller with variable pitch angle of -5 degrees is 55.88 hp.

Power of the propeller with variable pitch angle of -7.5 degrees is 53.71 hp.

Power of the propeller with variable pitch angle of -10 degrees is 51.32 hp.

Power of the propeller with variable pitch angle of -12.5 degrees is 48.61 hp.

Propeller efficiency with variable pitch angle of 0 degrees is 77.54%.

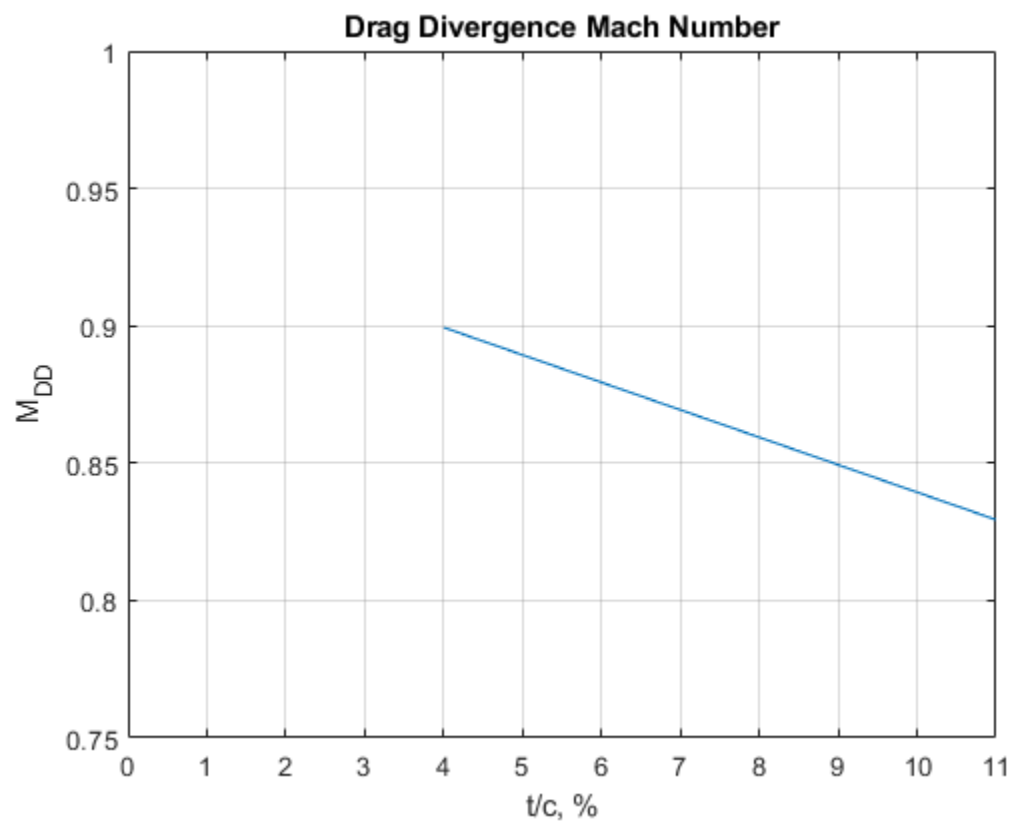
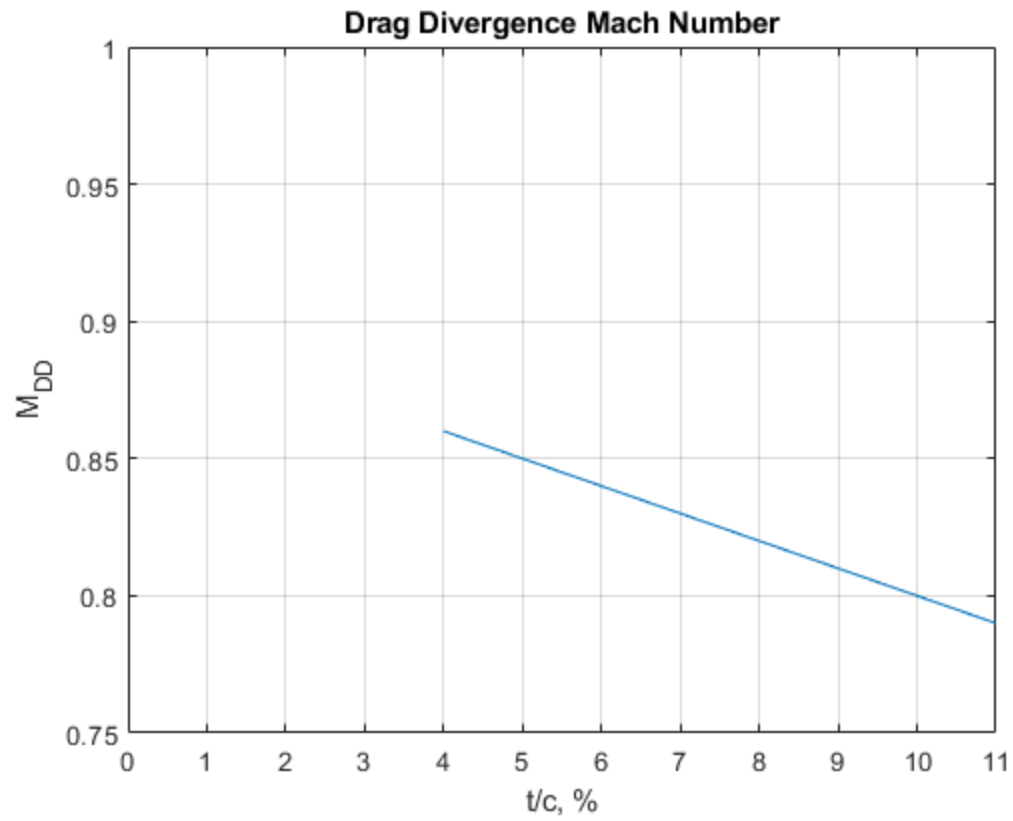
Propeller efficiency with variable pitch angle of -2.5 degrees is 80.20%.

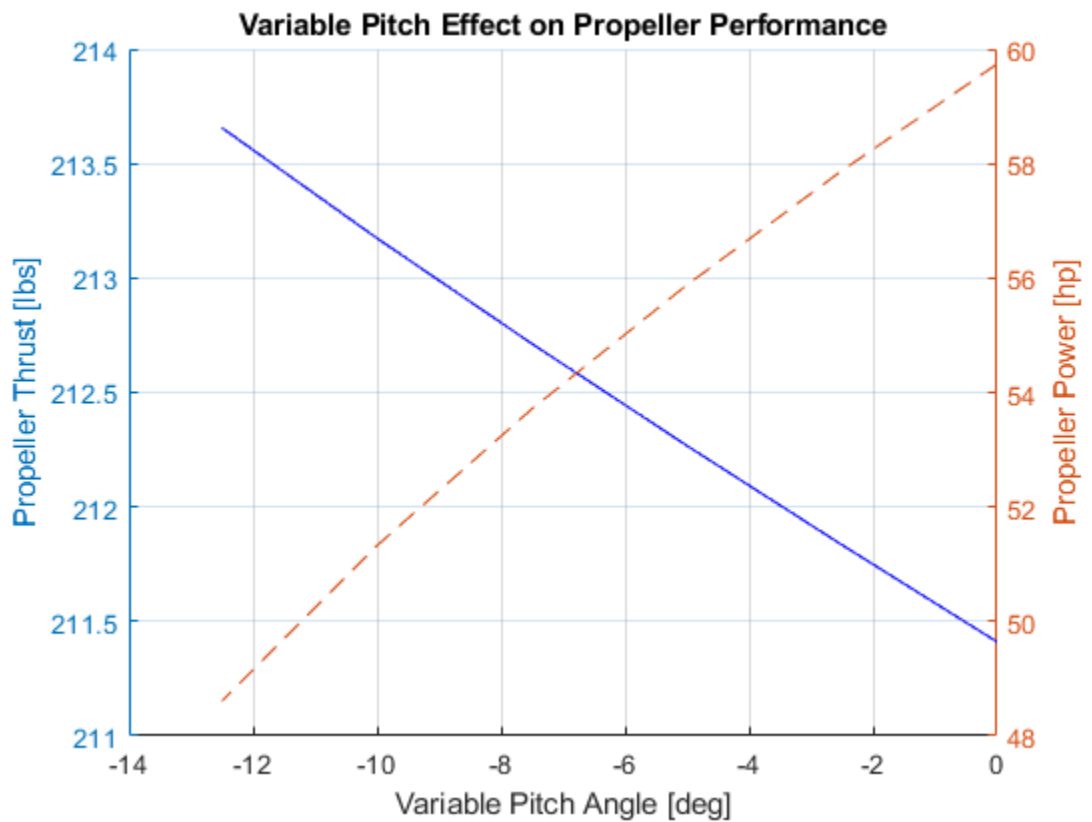
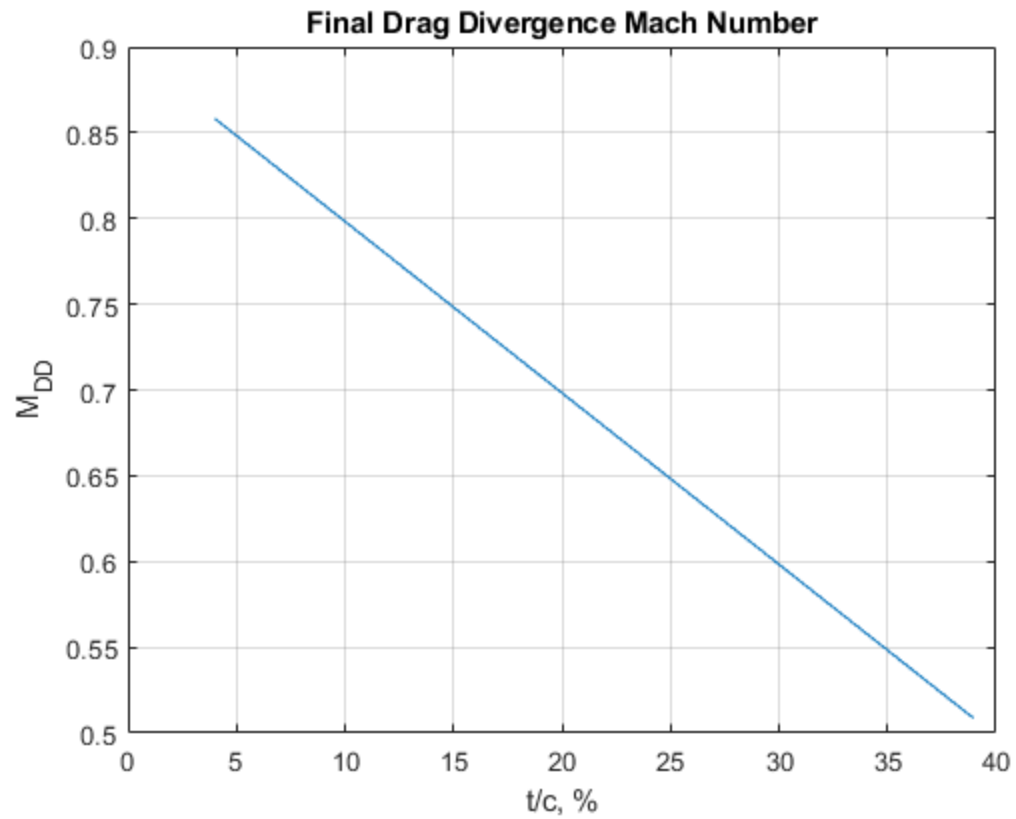
Propeller efficiency with variable pitch angle of -5 degrees is 83.23%.

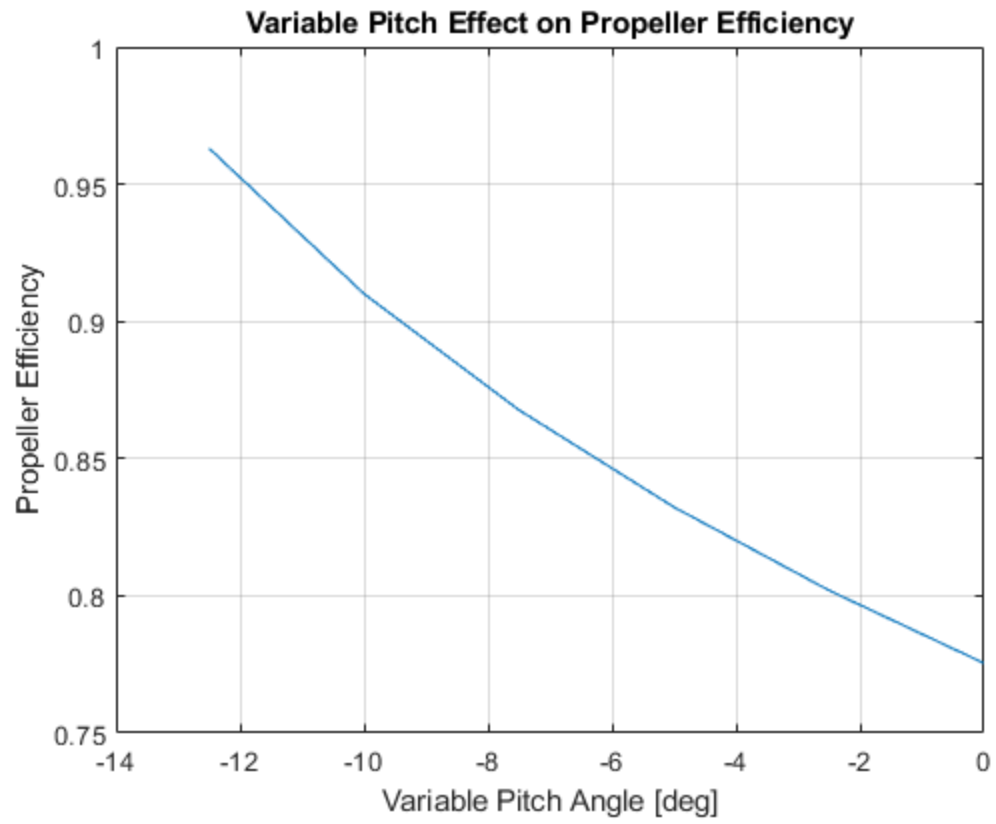
Propeller efficiency with variable pitch angle of -7.5 degrees is 86.77%.

Propeller efficiency with variable pitch angle of -10 degrees is 91.01%.

Propeller efficiency with variable pitch angle of -12.5 degrees is 96.31%.







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