Flight Systems E3 Assignment Report (Digital Servo and MATLAB Assignment)

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Flight Systems E3

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Abstract

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Both safety and efficiency have been significantly improved thanks to the introduction of autopilot systems, which have become an essential aspect of modern aviation. Initially, autopilots were introduced to reduce the flight crew's workload during long-haul flights but over time they have evolved into highly sophisticated systems, which are capable of completing various complex tasks autonomously. One of the different functionalities of autopilots is altitude hold. This feature is of paramount importance for safety and efficiency, as it ensures a steady and controlled flight path is followed, this means that the desired cruising altitude is maintained. Any deviation in the desired cruising altitude could result in serious safety concerns, the aircraft could come into conflict, and cause fuel inefficiencies, thus reducing profit margins for airlines.

The primary function of altitude hold in autopilots is to maintain a specific altitude, autonomously; this allows pilots to focus on other critical aspects of flight, including communicating with air traffic control. This is vitally important for long flights, as small deviations in altitude accumulate over time, resulting in a very significant altitude change (Prasad et al., 2017). This is especially important when flying through turbulence, which can drastically change the aircraft's altitude in a very short period of time, this turbulence is also very frequently encountered between 30kft and 40kft (the altitude range of most modern airliners) (Prasad et al., 2017). Altitude hold systems will automatically account for these altitude changes, returning the aircraft to equilibrium; the best autopilot systems do this quickly and efficiently (with as few oscillations as possible).

2.1 Objectives and Theory

2.1.1 Objectives

The key objectives of any altitude hold system are:

1. To maintain a fixed altitude, which ensures compliance with Air Traffic Control regulations.
2. Minimise pilot workload, by providing automatic altitude maintenance during cruise flight.
3. Enhance flight stability, by reducing oscillations due to atmospheric disturbances and therefore, improving passenger comfort.
4. Creating smooth transitions when changing altitude, which improves fuel efficiency.

2.1.2 Theory

The altitude hold system is modelled using the two degrees of freedom linear equations of motion, which describe aircraft longitudinal dynamics. They are given by

$$\dot{w} = \overline{Z}_w w + V_R q + \overline{Z}_\eta \eta \,, \tag{2.1}$$

$$\dot{q} - \overline{M}_{\dot{w}} \dot{w} = \overline{M}_w w + \overline{M}_q q + \overline{M}_\eta \eta \,, \tag{2.2}$$

$$q = \dot{\theta} \,, \tag{2.3}$$

$$\dot{h} = V_R \theta - w \,, \tag{2.4}$$

These equations describe how the aircraft's vertical velocity (w), pitch rate (q) and altitude (h) change due to control surface deflections (η). From these equations, transfer functions in the laplace domain can be derived

$$G_{\eta}^{q}(s) = \frac{(\overline{M}_{\eta} + \overline{M}_{\dot{w}}\overline{Z}_{\eta})s + (\overline{M}_{w}\overline{Z}_{\eta} - \overline{M}_{\eta}\overline{Z}_{w})}{s^2 - (V_R\overline{M}_{\dot{w}} + \overline{Z}_{w} + \overline{M}_{q})s + (\overline{M}_{q}\overline{Z}_{w} - V_R\overline{M}_{w})}, \tag{2.5}$$

Equation 2.5 describes how elevator deflection affections pitch rate.

$$G_{\eta}^{\theta}(s) = \frac{1}{s} \cdot G_{\eta}^{q}, \tag{2.6}$$

Equation 2.6 describes how elevator deflection affects pitch angle.

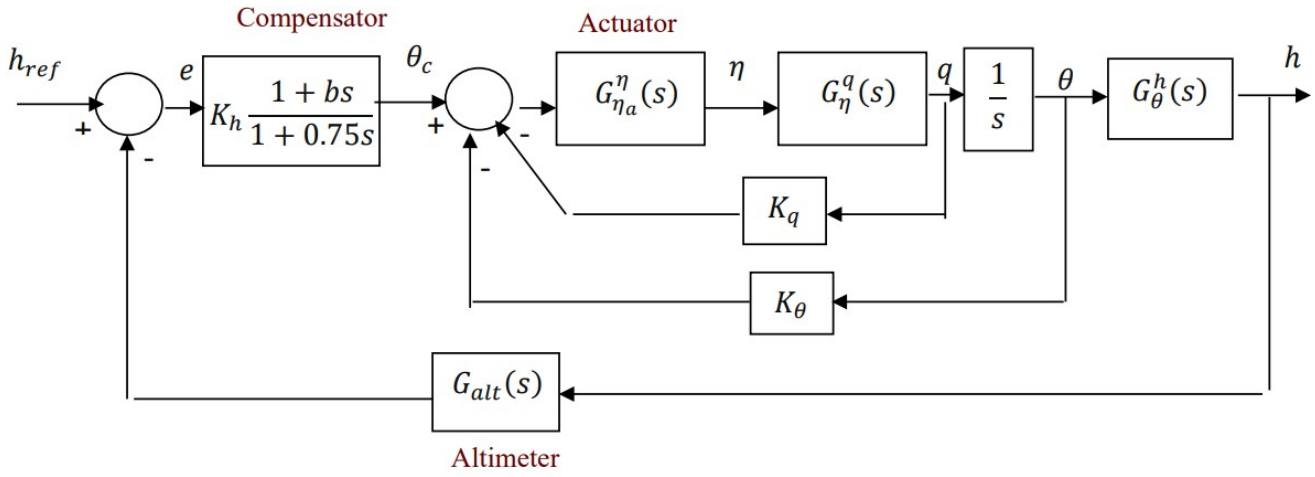
$$G_{\theta}^{h}(s) = \frac{1}{s} \cdot \frac{-\overline{Z}_{\eta}s^2 + (\overline{M}_{q} + V_R\overline{M}_{\dot{w}})\overline{Z}_{\eta}s + V_R(\overline{M}_{w}\overline{Z}_{\eta} - \overline{M}_{\eta}\overline{Z}_{w})}{(\overline{M}_{\eta} + \overline{M}_{\dot{w}}\overline{Z}_{\eta})s + (\overline{M}_{w}\overline{Z}_{\eta} - \overline{M}_{\eta}\overline{Z}_{w})}, \tag{2.7}$$

Equation 2.7 describes how pitch angle affects altitude.

The autopilot system has been designed using a sequential loop closure approach, with two distinct stages. The first is the design of a pitch attitude hold system, which is made up of the two inner loops seen in Figure 2.1. The second is the closure of the feedback loop around the pitch attitude hold system; again as seen in Figure 2.1.

Figure 2.1

Block diagram of an Altitude Hold System.



The first stage (inner loops) is responsible for regulating pitch attitude. It consists of both a pitch rate feedback loop, which damps excessive pitch rate variations, and a pitch angle feedback loop, which ensures the aircraft maintains required altitude by adjusting the elevator control. The closed loop transfer function for the pitch attitude design is derived by root locus design, to achieve a damping ratio of 0.5 and natural frequency of 3 rad/s. This is achieved as follows:

$$s_1 = -\sigma + j\omega_d\,, \tag{2.8}$$

$$\sigma = \zeta\omega_n\,, \tag{2.9}$$

$$\omega_d = \omega_n\sqrt{1-\zeta^2}\,, \tag{2.10}$$

When ζ takes the value of 0.5 and ω_n takes the value of 3, $s_1 = -1.5 + 2.5981j$.

Then, a compensator zero is placed at $s = -a$ so that the desired pole lies on the root locus. This is achieved by first reducing the block diagram shown in Figure 2, by replacing $G^{\eta}_{\eta_a}$ and G^{q}_{η} with transfer function G_p. Finally transfer function G_1 can be found by dividing by s:

$$G_1(s) = \frac{G_p}{s_1}, \tag{2.11}$$

Finally, the value of a can be determined by ensuring that the sum of a and the angle of s_1 multipled by the angle of G_1 is equal to π. This can be expressed mathematically as:

$$\angle((s_1 + a)G_1(s)) = \pi, \tag{2.12}$$

With the compensator pole in place, values of the gains K_q and K_θ can be obtained, so that the closed-loop transfer function of the pitch attitude control system can be found.

$$K_q = \frac{1}{|G_1(s_1)|}, \tag{2.13}$$

$$K_\theta = aK_q, \tag{2.14}$$

So the closed-loop transfer function of the pitch attitude system is:

$$G^{\theta}_{\theta_c} = \frac{G_1(s)}{1 + K_q(s+a)G_1(s)}, \tag{2.15}$$

The denominator of the transfer function in Equation 2.15 is the characteristic equation of the pitch attitude system. This means that the zero of the system is located at $s = -a$, with point s_1 lying on the root locus branch for the open loop transfer function:

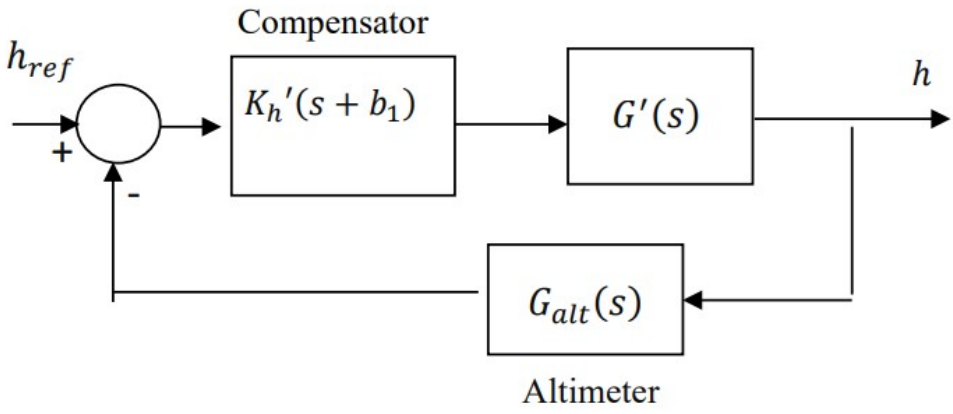
$$G_2(s_1) = (s+a)G_1(s), \tag{2.16}$$

This transfer function should also satisfy the root locus criterion, as the angular value should be exactly equal to π.

The second stage (outer loop) regulates the aircraft's altitude by adjusting the pitch attitude. The altimeter provides altitude feedback, and a compensator adjusts the pitch command to correct altitude deviations. The altitude loop is only closed after designing the pitch control loop, so that appropriate pitch commands are generated, and then executed by the inner loop. Therefore, since the transfer function for the inner loop has been set (Equation 2.15) the design for the outer loop can be determined by block diagram reduction, as seen in Figure 2.2.

Figure 2.2

Simplified block diagram for the altitude hold loop (outer loop).



Where:

$$G' = \left(\frac{1}{1+0.75s}\right)G^{\theta}_{\theta_c}(s)G^{h}_{\theta}(s), \tag{2.17}$$

And:

$$G^*(s) = G'(s)G_{alt}(s), \tag{2.18}$$

Terms K_h' and b_1 are to be determined, however transfer function $G_{alt}(s)$ has known properties as the performance of the aircraft's elevators have been measured.

$$G_{alt}(s) = \frac{10}{s+10}, \tag{2.19}$$

For the outer loop, an identical method, to what was used in the inner loop, is used to design a root locus. The only difference is that we solve with complex number s_2 by using a ζ of 0.5 and a ω_n of 0.5 rad/s. Therefore, by recalling Equations 2.8, 2.9 and 2.10, the complex number s_2 is found. Therefore, a compensator zero can be placed when $s = b_1$, which can be found by slightly modifying Equation 2.12:

$$\angle((s_2+b_1)G^*(s_2)) = \pi, \tag{2.20}$$

Once a suitable b_1 has been determined, the transfer function $G_3(s_2)$ can be determined, by taking G_{alt} and multiplying by $(s+b_1)$, which now includes our compensator zero in the transfer function. This means that, the value of the gains K_h' and K_h can be found by direct calculation:

$$K_h' = \frac{1}{|G_3(s2)}, \tag{2.21}$$

$$K_h = \frac{K_h'}{b_1}, \tag{2.22}$$

Additionally, just like for $G_2(s_1)$ the angular value of the transfer function $G_3(s2)$ should be exactly equal to π.

Now, all unknown terms have been evaluated, including the gains used in the Compensator block in Figure 2.2. This means that the outer loop can be closed around the

inner loop, completing the theoretical altitude hold design. The simplified closed loop transfer function is:

$$G^{h}_{h_c}(s) = \frac{K'_h(s+b_1)G'}{1+G_3(s_2)K'_h}, \tag{2.23}$$

It's important to note the key relationship between the two loops: the inner loop must be fast and stable to respond effectively to pitch commands from the outer loop, whereas, the outer loop uses the inner loop to influence the altitude, but operates slower to avoid excessive oscillations.

2.2 Modelling and Results

2.2.1 Modelling

The mathematical modelling of the altitude hold system was completed inside of a MATLAB environment, with two distinct scripts (.m files). One of these files is responsible for handling all variables that will be used throughout the course of the design process. The second file contains the mathematical model of the altitude hold system as outlined previously.

Storing the variables in a different script provides a great deal of flexibility, as changing one line of code will enable the user to simulate the autopilot hold system in different conditions, without having to manually change each aerodynamic and control derivative. Variable files are stored in the following format:

```
%%% Stability and Control Derivatives %%%
function [Xu, Zu, Mu, Xw, Zw, Mw, Xw_dot, Zw_dot, Mw_dot, Xq, Zq, Mq,
    Xeta, Zeta, Meta, VR, g] = final_assignment_variables()
     Xu = -1.58E-02;     Zu = -1.442E-01;     Mu = -1.3442E-04;
     Xw_dot = 0;         Zw_dot = -2.2E-03;   Mw_dot = -2.0483E-04;
     Xw = 3.79E-03;      Zw = -8.73E-01;      Mw = -6.0107E-03;
     Xq = 0;             Zq = 0;              Mq = -9.88E-01;
     Xeta = 0;           Zeta = -1.2408E+01;  Meta = -1.153E+01;

     VR = 236; g = 9.8100;
end
%%% END OF VARIABLES %%%
```

The main substance of the Autopilot script has been broken down into 17 steps, each aiming to accomplish a specific design goal. The MATLAB code is as follows:

```
%%% Workspace Cleanup %%%
clc;
clear;
close all;

s = tf('s');
%%% Stability and Control Derivatives and Flight Condition %%%
[Xu, Zu, Mu, Xw, Zw, Mw, Xw_dot, Zw_dot, Mw_dot, Xq, Zq, Mq, Xeta, Zeta
    , Meta, VR, g] = final_assignment_variables(); % Change the name of
    this function to to run this system with different variable values.

%%% Actuator and Altimeter Dynamics %%%
G_etaA_eta = -4/(s+4);
G_etaA_eta_Numerator = cell2mat(G_etaA_eta.Numerator); % Gets numerator
     in appropriate form for Simulink
G_etaA_eta_Denominator = cell2mat(G_etaA_eta.Denominator); % Gets
    denominator in appropriate form for Simulink
G_alt = 10/(s+10);
G_alt_Numerator = cell2mat(G_alt.Numerator);
G_alt_Denominator = cell2mat(G_alt.Denominator);

%%% Transfer Functions - TASK 1 %%%
G_eta_q = ((Meta + (Mw_dot*Zeta))*s + ((Mw*Zeta) - (Meta*Zw)) )/((s^2)
    - ((VR*Mw_dot) + Zw + Mq)*s +((Mq*Zw) - (VR*Mw)));
G_eta_q_Numerator = cell2mat(G_eta_q.Numerator); % Gets numerator in
    appropriate form for Simulink
G_eta_q_Denominator = cell2mat(G_eta_q.Denominator); % Gets denominator
     in appropriate form for Simulink
G_eta_theta = 1/s * G_eta_q;
G_theta_h = 1/s * ((-Zeta*(s^2))+ Zeta*s*(Mq+VR*Mw_dot) + VR*(Mw*Zeta-
    Meta*Zw))/(s*(Meta+Mw_dot*Zeta) + (Mw*Zeta-Meta*Zw));
Gp = G_etaA_eta*G_eta_q;
G1 = Gp/s;
```

```
26
27 %%% Root Locus Design for Pitch Control - TASK 2 %%%
28 Wn = 3;
29 zeta = 0.5;
30 sigma = zeta*Wn;
31 Wd = Wn*sqrt(1-zeta^2);
32 s1 = -sigma + 1i * Wd;
33
34 %%% Plot The Root Locus for Pitch Control - TASK 3 %%%
35 figure;
36 rlocus(G1)
37 hold on;
38 plot(real(s1), imag(s1), 'rx', 'MarkerSize', 10, 'LineWidth', 2);
39 title('Root Locus of G1(s) - Pitch Control');
40 grid off;
41
42 %%% Evaluating the Complex Number of G1 - TASK 4 %%%
43 G1_s1 = evalfr(G1, s1);
44 mag_G1_s1 = abs(G1_s1);
45 angle_G1_s1 = angle(G1_s1);
46
47 %%% Find the location of the compensating Zero - TASK 5 %%%
48 alpha_c = pi - angle_G1_s1;
49 a = sigma + Wd / tan(alpha_c); % Finds the zero location, a, by
     accounting for the phase shortfall at point s1.
50
51 %%% Define G2 and show the point s1 on it's Root Locus Plot - TASK 6
     %%%
52 G2 = (s+a)*G1;
53 G2_s1 = evalfr(G2, s1);
54 angle_G2_s1 = angle(G2_s1); % May output a value close to, but not
     exactly pi - the criterion should still be met.
55 fprintf('The phase of G2 at s1 is: %.4f radians\n', abs(angle_G2_s1));
56 figure;
57 rlocus(G2);
```

```
hold on;
plot(real(s1), imag(s1), 'rx', 'MarkerSize', 10, 'LineWidth', 2);
title('Root Locus of G2(s) - Pitch Control');
grid off;

%%% Check to see if the angle criterion is satisfied %%%
if abs(abs(angle_G2_s1) - pi) < 1e-3
    disp('The angle criterion has been satisfied for G2 at s1 - the
        phase is approximately pi.');
else
    disp('The angle criterion has not been satisfied.');
end

%%% Calculating the Gains - TASK 7 %%%
Kq = 1/(abs(G2_s1)); % Kq*mag_G1_s1 = 1. This satisfies the magnitude
    condition at s1. This means the CL pole will be at s1.
Ktheta = a*Kq; % Therefore, Krg = Kq.

%%% Determine the CLTF and find the Zeros and Poles - TASK 8 %%%
G_theta_c = feedback(G1,Kq*(s+a));

info = stepinfo(G_theta_c*5); % Gets the properties from the CLTF with
    a step change of 5 degrees.
overshoot = info.Overshoot;       % Percentage overshoot of CLTF
settlingTime = info.SettlingTime;   % Settling time in seconds of CLTF
finalValue = dcgain(G_theta_c*5);      % Final value of CLTF

figure;
[response, time] = step(G_theta_c*5);
plot(time, response, 'LineWidth',2);

[maxVal, maxIdx] = max(response);
maxTime = time(maxIdx); % Find the maximum response value and its time

grid on;
```

```
90 title('Step Response of Pitch Attitude Control - Pitch Control');
91
92 annotationStr = sprintf('Maximum Overshoot: %.2f%%\nSettling Time: %.2f
       s\nFinal Value: %.2f', overshoot, settlingTime, finalValue); %
      Creates the annotation text with variable placeholders.
93
94 annotation('textbox', [0.3, 0.3, 0.3, 0.2], 'String', annotationStr, '
      FitBoxToText', 'on', 'BackgroundColor', '#ADD8E6', 'EdgeColor', '
      black', 'FontSize', 50); % Creates the annotation with a text box.
95
96 pole_G_altitude = pole(G_theta_c);
97 zero_G_altitude = zero(G_theta_c);
98 disp('The poles of G_theta_c are:');
99 disp(pole_G_altitude);
100 disp('The zeros of G_theta_c are:');
101 disp(zero_G_altitude);
102
103 %%% Define Altitude Loop Transfer Functions - TASK 9 %%%
104 a_c = 0.75;
105 G_prime = (1 / (1 + a_c*s)) * G_theta_c * G_theta_h;
106 G_star = G_prime * G_alt;
107
108 %%% Root Locus Design for Altitude Control - TASK 10 %%%
109 Wn_2 = 0.5;
110 zeta_2 = 0.5;
111 sigma_2 = zeta_2*Wn_2;
112 Wd_2 = Wn_2*sqrt(1-zeta_2^2);
113 s2 = -sigma_2 + 1i * Wd_2;
114
115 %%% Plot the Root Locus for Altitude Control - TASK 11 %%%
116 figure;
117 rlocus(G_star);
118 hold on;
119 plot(real(s2), imag(s2), 'rx', 'MarkerSize', 10, 'LineWidth', 2);
120 title('Root Locus of G*(s) - Altitude Control');
```

```
121 grid off;
122
123 %%% Evaluating the Complex Number of G_star - TASK 12 %%%
124 G_star_s2 = evalfr(G_star, s2);
125 mag_G_star_s2 = abs(G_star_s2);
126 angle_G_star_s2 = angle(G_star_s2);
127
128 %%% Compute Zero Location for Altitude Control - TASK 13 %%%
129 alpha_c_prime = pi - angle_G_star_s2;
130 b1 = sigma_2 + Wd_2 / tan(alpha_c_prime);
131
132 %%% Define G3(s) and Root Locus Plot for Altitude Control - TASK 14 %%%
133 G3 = (s + b1) * G_star;
134 G3_s2 = evalfr(G3, s2);
135 angle_G3_s2 = angle(G3_s2);
136 fprintf('The phase of G3 at s2 is: %.4f radians\n', abs(angle_G3_s2));
137 figure;
138 rlocus(G3);
139 hold on;
140 plot(real(s2), imag(s2), 'rx', 'MarkerSize', 10, 'LineWidth', 2);
141 title('Root Locus of G3(s) - Altitude Control');
142 grid off;
143
144 %%% Check to see if the angle criterion is satisfied %%%
145 if abs(abs(angle_G3_s2) - pi) < 1e-3
146     disp('The angle criterion has been satisfied for G3 at s2 - the
        phase is approximately pi.');
147 else
148     disp('The angle criterion has not been satisfied.');
149 end
150
151 %%% Calculate the gain Kh_prime - TASK 15 %%%
152 kh_prime = 1/abs(G3_s2);
153
154 %%% Calculate the gain Kh - TASK 16 %%%
```

```
155 kh = kh_prime * b1;
156
157 %%% Compute Closed Loop Transfer Function - TASK 17 %%%
158 G_altitude = feedback(kh*(s+b1)*G_prime, G_alt);
159
160 info_2 = stepinfo(50 * G_altitude); % Gets the properties from the CLTF
      with a step change of 5 degrees.
161 overshoot_2 = info_2.Overshoot;       % Percentage overshoot of CLTF
162 settlingTime_2 = info_2.SettlingTime;   % Settling time in seconds of
    CLTF
163 finalValue_2 = dcgain(G_altitude*50);      % Final value of CLTF
164
165 figure;
166 [response_2, time_2] = step(50 * G_altitude);
167 plot(time_2, response_2, 'LineWidth',2);
168
169 [maxVal_2, maxIdx_2] = max(response);
170 maxTime_2 = time(maxIdx_2); % Find the maximum response value and its
    time
171
172 title('Step Response of Altitude Hold System - Altitude Control');
173 grid on;
174
175 annotationStr_2 = sprintf('Maximum Overshoot: %.2f%%\nSettling Time:
    %.2f s\nFinal Value: %.2f', overshoot_2, settlingTime_2,
    finalValue_2); % Creates the annotation text with variable
    placeholders.
176
177 annotation('textbox', [0.3, 0.3, 0.3, 0.2], 'String', annotationStr_2,
    'FitBoxToText', 'on', 'BackgroundColor', '#ADD8E6', 'EdgeColor', '
    black', 'FontSize', 50); % Creates the annotation with a text box.
178
179 pole_G_altitude = pole(G_altitude);
180 zero_G_altitude = zero(G_altitude);
181 disp('The poles of G_altitude are:');
```

```
182 disp(pole_G_altitude);
183 disp('The zeros of G_altitude are:');
184 disp(zero_G_altitude);
185
186 %%% Get the compensator and G_prime block for Simulink %%%
187
188 overallBlock = G_prime * kh_prime*(s+b1);
189 overallBlock_Numerator = cell2mat(overallBlock.Numerator);
190 overallBlock_Denominator = cell2mat(overallBlock.Denominator);
191
192 %%% END OF SCRIPT %%%
```

Originally, a requirement for this assignment was to also complete separate simulations inside of SIMULINK, but this element of the assessment has been subsequently removed. All the code relating to this part of the assessment remains in the script above.

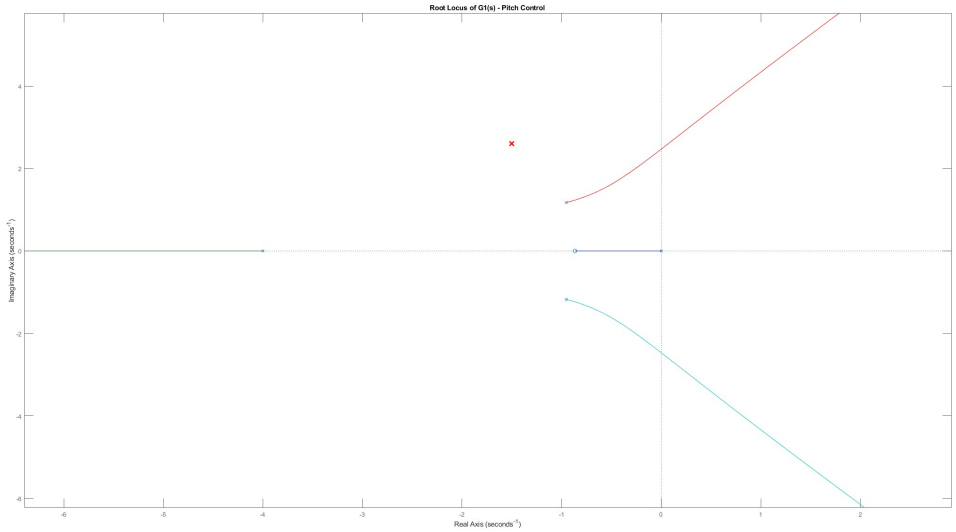
Tasks 3, 6, 8, 11, 14 and 17 each provide a major output, or result, which can be used to monitor the progress of the simulation.

2.2.2 Results

First of all, the results from Task 3 will be discussed. Task 3 outputs a root locus plot, as seen in Figure 2.3.

Figure 2.3

The Root Locus of $G_1(s)$ - Pitch Control

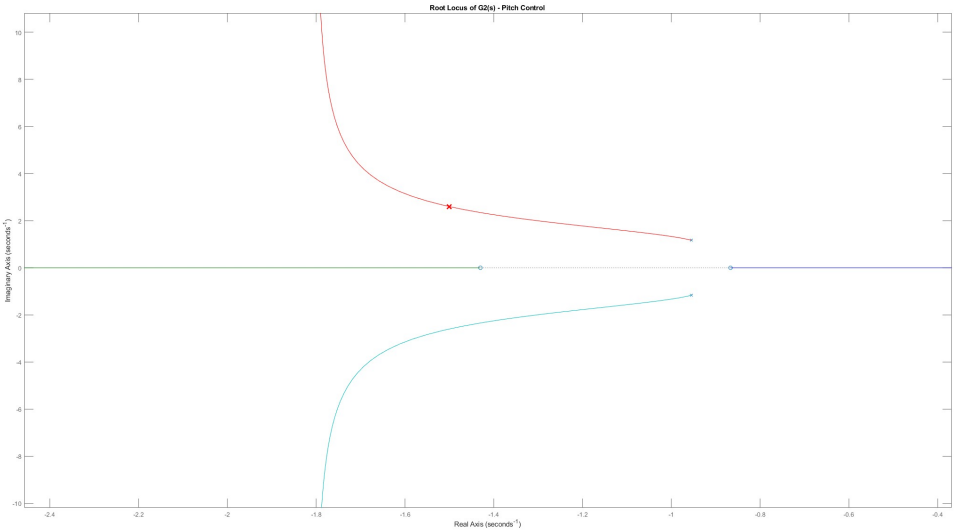


We can recall the equation of transfer function $G_1(s)$ in Equation 2.11. The root locus of G_1 has been plotted along side the complex number s_1. However, the complex number does not lie upon a branch of the root locus. This complex number must lie on a branch for the system to function correctly as they represent the location of the system's closed-loop poles. This is why in following tasks, the location of a compensating zero is found. When all the criteria are met, a compensating zero will move the branches of the root locus so that the complex number will lie upon them.

Task 6 acts a check for this, as it outputs the root locus plot of transfer function $G_2(s_1)$, Equation 2.16 shows it's mathematical representation. The important difference between $G_1(s)$ and $G_2(s_1)$ is that $G_2(s_1)$ has been compensated with a new zero. This results in the the plot shown in Figure 2.4.

Figure 2.4

The Root Locus of $G_2(s_1)$ - Pitch Control



As seen in Figure 2.4, the root locus plot now intersects with the complex number s_1. This means that an acceptable closed-loop pole of the system has been found. Therefore, the step response of the pitch attitude system can be plotted. For this particular simulation, the aircraft experiences a 5° change to it's pitch attitude. The output of this step response is seen in Figure 2.5.

Figure 2.5

Step Response of Pitch Attidude System.

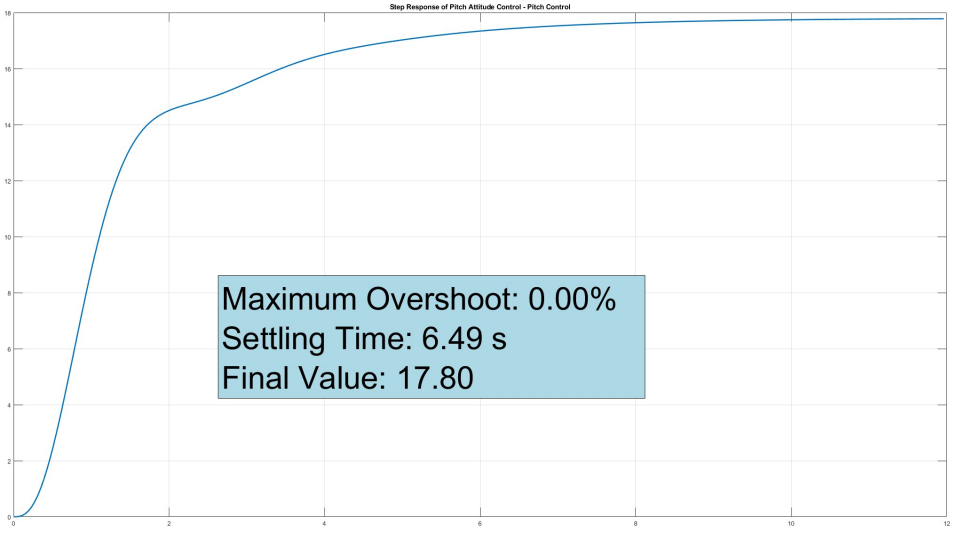
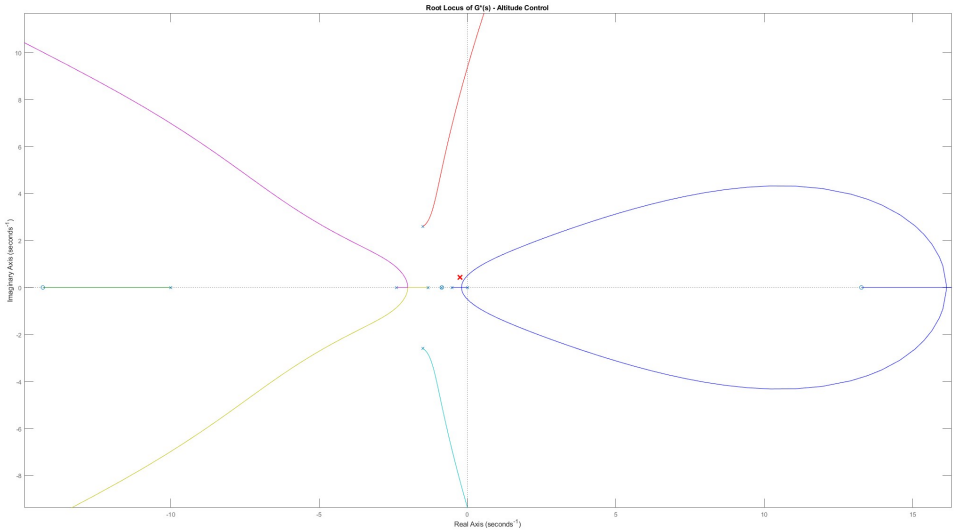


Figure 2.5 shows that the pitch control system responds to the 5° change by sending a pitch correction command to the altitude hold system after 6.49 seconds. The pitch needed to correct is 17.8°. All tasks from this point onwards are for the altitude hold section.

Tasks 11 and 14 are identical to tasks 3 and 6 in terms of their basic function. However, the root locus is designed for transfer function G^{*} which is defined in Equation 2.18. Therefore, the initial root locus plot is produced, for complex number s_2, as seen in Figure 2.6.

Figure 2.6

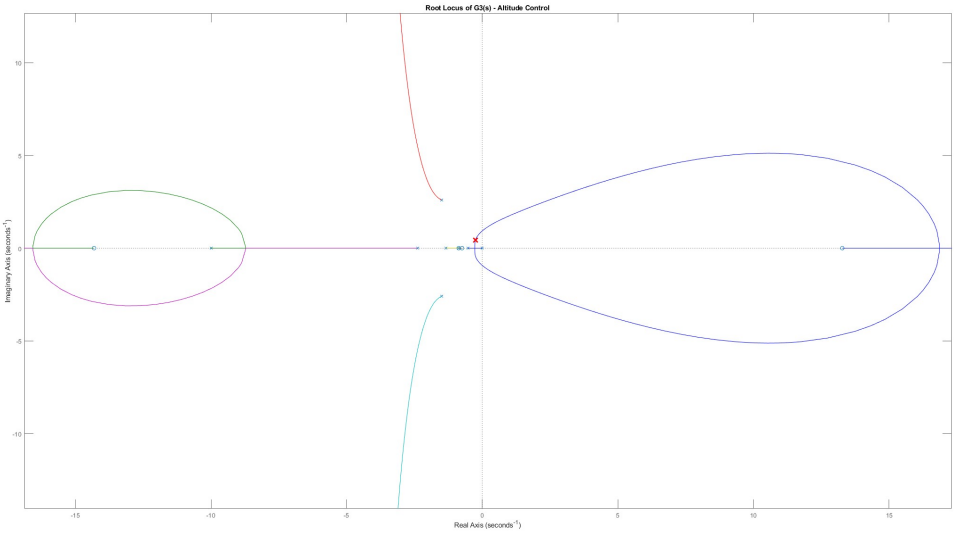
Root Locus Design for G^*.



Just as in task 3, the complex number does not lie on a branch for the root locus design. Therefore, by the method outlined in the theory, it is moved onto a branch, in an identical method to task 6. The result of task 14 can be seen in Figure 2.7

Figure 2.7

Root Locus Design for $G_3(s_2)$.

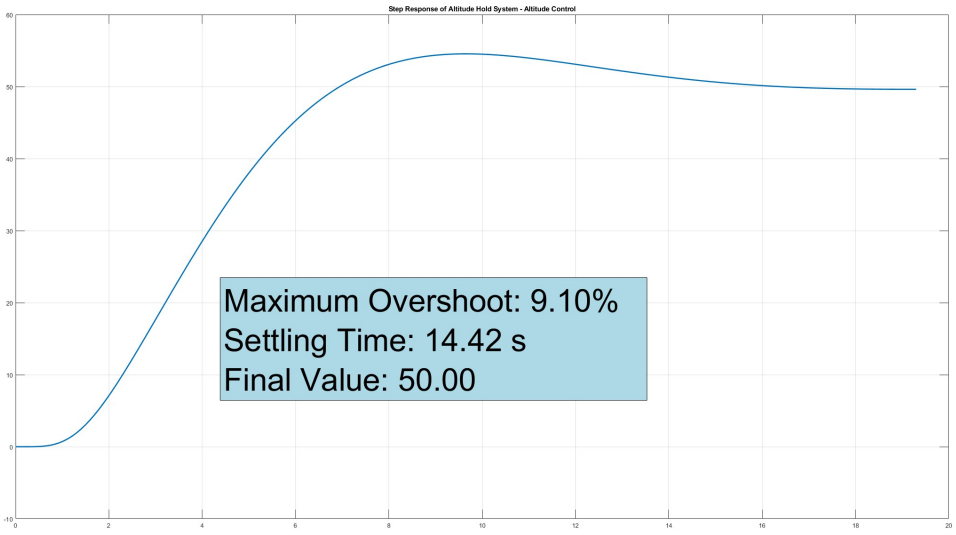


This means that the final design has been completed for the altitude hold system.

Therefore, the step response can be plotted in task 17. The following simulation shows the response, assuming the aircraft experienced an altitude change of 50m due to the pitch change discussed in task 8. The step response can be seen in Figure 2.8.

Figure 2.8

Step Response of Altitude Hold System.



As seen in this step response, after 14.42 seconds, the aircraft has returned exactly to it's original height (the difference between the altitude change and final value is zero). There is a slight oscillation, as the aircraft initially over-corrects before returning to the original value.

2.3 Discussion

Before discussing the performance of the altitude hold system as a whole, its vitally important to mention the design steps, especially the root locus design. Primarily, this can bee seen in Tasks 3 and 6 for the inner loop and Tasks 11 and 14 for the outer loop, these relate to Figures 2.3, 2.4, 2.6 and 2.7 respectively. These figures successfully show how a compensator can be identified by physically moving the root locus branch to lie up on the position of complex numbers s_1 and s_2 (Equation 2.8), which is determined based on two control parameters; the Damping Ratio and the Natural Frequency. Changing these parameters would result in an Altitude Hold system with a very different performance. However, the most important results obtained are thanks to Tasks 8 and 17, which produce Figures 2.5 and 2.8

respectively. First of all, the result from Figure 2.5 (Task 8) will be discussed. Figure 8 shows the step response for the pitch attitude system, namely the response of a system when a 5° pitch change is experienced by the aircraft. The response successfully meets the design criteria as it responds in a fast (6.49 seconds) and stable (zero overshoot) manner. This is exactly what is required for a successful altitude hold system as the inner loop must respond quickly and efficiently to pitch commands, so that altitude corrections can be made in a timely manner. The correcting pitch angle has been determined as 17.8° and once this is known, the autopilot systems can execute the correcting pitch motion, which will have an impact on the altitude of the aircraft. Task 17 and Figure 2.8 discuss how the altitude changes due to this correcting pitch angle previously mentioned. The simulation has been run assuming a step change of 50m in height. The plot in Figure 2.8 successfully meets the design criteria as the aircraft responds in a safe manner, returning to the original altitude after 14.42 seconds. As discussed previously, the altitude response will be significantly slower than the pitch response, this is intentional to avoid excessive oscillations, which creates a more comfortable experience for passengers onboard an aircraft. There is however one oscillation, which can be seen both in the plot response, but also as the maximum overshoot is 9.10%. This means that the aircraft initially over-corrects before returning to the original altitude. This likely occurs due to a time lag in the correcting the pitch angle once again to maintain the original altitude.

2.4 Conclusions

In summary, the design of the simple altitude hold system was successful. A mathematical model was created inside of the MATLAB environment and simulations were run to show how this model would handle sudden changes in pitch for an aircraft. This model of course offers a completely ideal simulation, assuming the aircraft's elevators and actuators are working perfectly and the aircraft only experiences one sudden change in pitch, not several small changes in quick succession. However, within the scope of this investigation the model performed as expected, matching up with all the requirements for an altitude hold system for aircraft.

List of Figures

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List of Equations

References

Prasad, S., Ivanco, M. L., Ivanco, T. G., & Ancel, E. (2017). Nasa technical reports server [Accessed: 2025-03-11]. https://ntrs.nasa.gov/api/citations/20170005878/downloads/20170005878.pdf