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Image Segmentation

Introduction

Problem Definition

The purpose of this assignment was to understand how to design homing guidance law by using optimal control theory and to learn how to perform computer simulations with homing guidance law developed by using MATLAB. The homing guidance problem in this assignment is defined as assuming engagement between a missile and a target. The dynamics of the missile and the target are neglected and the movements of them are modelled with kinematics. It is assumed that the missile has constant velocity and the target is not moving.

Part A

Target is assumed as fixed and the velocity of the missile is assumed as constant on the 2-dimensional engagement between the missile and the target. Kinematics of the missile:

$$\dot{x}_M = V_M cos\gamma_M \tag{1}$$

$$\dot{y}_M = V_M sin\gamma_M \tag{2}$$

$$\dot{\gamma}_M = \frac{a_M}{V_M} \tag{3}$$

A-1.

From small angle approximation which means at smaller angles sine value of an angle is equal to itself, of γ gives:

$$\dot{y}_M = v \approx V_M \gamma_m \tag{4}$$

Substitute (4) into (3) occurs:

$$\dot{v} = a_M \tag{5}$$

Under this circumstance, (4) and (5) construct the linearized engagement kinematics. The state variables and the control inputs can be defined as

$$x = [x_1, x_2]^T, u = a_M \tag{6}$$

Linearized engagement kinematics in the form of matrix are given on the assignment file. Homing problem:

$$x_1(t_f) = 0 \tag{7}$$

Impact angle control problem:

$$x_1(t_f) = 0, x_2(t_f) = 0 \tag{8}$$

Time-to-go is defined as $t_{go} = t_f - t$ and for constant vehicle velocity and fixed target, R can be approximated:

$$R \approx V_M t_{go} \tag{9}$$

From (4) and the geometry $\gamma_M = {}^{v}/_{V_M} + \gamma_f$ (10) can be obtained. From the equation (9):

$$\sigma = \gamma_f - \frac{y}{R} = \gamma_f - \frac{y}{V_M t_{go}} \tag{11}$$

Taking derivative of (10) (LOS rate):

$$\dot{\sigma} = -\frac{y + v t_{go}}{V_M t_{go}^2} \tag{12}$$

From (10) and (11) the equation below is also obtained:

$$y = V_M t_{go}(\gamma_f - \sigma) \quad v = V_M(\gamma_m - \gamma_f) \tag{13}$$

A-2.

Performance index is given as:

$$\min_u J = \frac{1}{2}\int_{t_0}^{t_f} u^2 dt \tag{14}$$

Under this circumstance

$$S_f = Q = C = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}, R = 1$$

Terminal conditions from equations (7) and (8)

$$Dx(t_f) = E \tag{15}$$

Step 1: determining S(t) from $\dot{S} = -A^T S - SA + SBB^T S$, where $S(t_f) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$

$$S(t) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \tag{16}$$

Step 2: determining F(t) from $\dot{F} = -[A^T - SBB^T]F$, where $F(t_f) = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$

$$F(t) = \begin{bmatrix} 1 \\ t_f - t \end{bmatrix} \tag{17}$$

Step 3: determining G(t) from $\dot{G} = F^T B B^T F$, where $G(t_f) = 0$

$$G(t) = -\frac{1}{3}(t_f - t)^3 \tag{18}$$

Step 4: determining $\bar{S}(t)$ from $\bar{S} = S - F G^{-1} F^T$,

$$\bar{S}(t) = \begin{bmatrix} \frac{3}{(t_f - t)^3} & \frac{3}{(t_f - t)^2} \\ \frac{3}{(t_f - t)^2} & \frac{3}{t_f - t} \end{bmatrix} \tag{19}$$

Step 5: determining u^* from $u^* = -B^T \bar{S} x$

$$u^* = -\frac{3}{t_{go}^2} x_1 - \frac{3}{t_{go}^2} x_2 \tag{20}$$

Equation (21) can be obtained by converting optimal solutions by using original parameters from (20)

$$a_M = -\frac{3}{t_{go}^2}(y + v t_{go}) \tag{21}$$

A-3.

A guidance law that most guided air-targeted missiles use in one form or another is proportional navigation. Direct line of sight is based on the fact that two vehicles are on collision course when they do not change direction as the distance closes. Proportional navigation specifies that the missile vector should be in the same direction and rotate at a speed comparative to the line-of-sight rotation speed.

The performance index:

$$\min J = \frac{1}{2}\int_{t_0}^{t_f} R(\tau) u^2(\tau) \tau \tag{22}$$

Terminal conditions for homing problem:

$$x_1(t_f) = 0 \tag{23}$$

Schwarz's inequality approach is used to obtain the optimal solution.

Computing optimal solution:

$$x(t_f) = \phi(t_f - t)x(t) + \int_{t_0}^{t_f} \phi(t_f - \tau)B(\tau)u(\tau)d(\tau) \ ,$$
$$where\ \phi(t_f - t) = e^{A(t_f - t)} = \begin{bmatrix} 1 & t_f - t \\ 0 & 1 \end{bmatrix} \tag{24}$$

From equation (24), the final value of $x_1(t_f)$ is obtained as

$x_1(t_f) = f_1 - \int_{t_0}^{t_f} h_1(\tau)u(\tau)d\tau$, where $f_1 = x_1(t) + (t_f - t)\, x\_2(t), h_1(\tau) = -(t_f - \tau)$ (25)

Imposing the terminal constraint gives

$$f_1 = \int_{t_0}^{t_f} h_1(\tau)u(\tau)d\tau \tag{26}$$

Introducing a slack variable $R(\tau)$

$$f_1 = \int_{t_0}^{t_f} h_1 R^{\left(-\frac{1}{2}\right)}(\tau)R^{\frac{1}{2}}(\tau)u(\tau)d\tau \tag{27}$$

Applying Schwarz's inequality to above equation gives

$$f_1^2 \le \int_{t_0}^{t_f} h_1^2(\tau)R^{-1}(\tau)d\tau \int_{t_0}^{t_f} R(\tau)u^2(\tau)d\tau \tag{28}$$

Rearranging the result obtained

$$\frac{f_1^2}{2\int_{t_0}^{t_f} h_1^2(\tau)R^{-1}(\tau)d\tau} \le \frac{1}{2}\int_{t_0}^{t_f} R(\tau)u^2(\tau)d\tau \tag{29}$$

The control input that satisfies the equality condition

$$u(\tau) = K_1 h_1(\tau)R^{-1}(\tau) \tag{30}$$

Substituting (29) into (28) to obtain

$$f_1 = K_1 \int_{t}^{t_f} h_1^2(\tau)R^{-1}(\tau)d\tau \tag{31}$$

Rearranging (31), equation (32) is obtained

$$K_1 = \frac{f_1}{\int_t^{t_f} h_1^2(\tau)R^{-1}(\tau)d\tau} \tag{32}$$

Equation (33) is obtained by substituting (32) into (30)

$$u(\tau) = \frac{f_1 h_1(\tau)R^{-1}(\tau)}{\int_t^{t_f} h_1^2(\tau)R^{-1}(\tau)d\tau} \tag{33}$$

In the time domain, the following result is obtained by using original variables

$$a_M = -\frac{\left(y + vt_{go}\right)t_{go}R^{-1}(\tau)}{\int_t^{t_f}\left(t_f - \tau\right)^2 R^{-1}(\tau)d\tau} \tag{34}$$

It also can be written as

$$a_M = -N'\frac{\left(y+vt_{go}\right)}{t_{go}^2} \text{ where } N' = \frac{t_{go}^3 R^{-1}(t)}{\int_t^{t_f}\left(t_f-\tau\right)^2 R^{-1}(\tau)d\tau} \tag{35}$$

According to equation (21) which is obtained in question number 2, equation (35) and equation (21) are identical when N’ = 3 with time-varying gains and it also is optimal solution.

A-4.

For impact angle control problem D and E matrices are different than homing problem.

$$D = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \text{ and } E = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Terminal conditions are given as

$$\min_u J = \frac{1}{2}\int_{t_0}^{t_f} u^2 dt$$

$$\gamma_M\left(t_f\right) = \gamma_f$$

Equation for impact angle control problem has the same form with different boundary conditions.

$$u^* = -B^T\bar{S}x$$

$\bar{S} = S - FG^{-1}F$ $\quad\quad$ $\dot{F} = -[A^T - SBB^T]F$, where $F\left(t_f\right) = D^T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

$\dot{S} = -A^T S - SA + SBB^T S$, where $S\left(t_f\right) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$

$G = F^{\dot{T}}BB^T F$, where $G\left(t_f\right) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$

Optimal solution can be obtained as follows in the similar way:

$$u^* = -\frac{6}{t_{go}^2}x_1 - \frac{4}{t_{go}}x_2 \tag{36}$$

Converting optimal solution by using original parameters from (36)

$$a_M = -\frac{6}{t_{go}^2}y - \frac{4}{t_{go}}v \tag{37}$$

Recall equation (13), $v = V_M(\gamma_m - \gamma_f)$. For this case $\gamma_M(t_f) = \gamma_f$, this term becomes zero when this terminal constraint is applied to equation (37). Final optimal solution is:

$$a_m = -\frac{6}{t_{go}^2}y$$

A-5.

Generalized optimal guidance laws for impact angle control problem. Optimal solution is obtained by using Schwarz's inequality approach.

$$\dot{x}(t) = A(t)x(t) + B(t)u(t), x(t_0) = x_0 \tag{38}$$

The general solution of (38) can be expressed as

$$x(t_f) = \phi(t_f - t)x(t) + \int_t^{t_f} \phi(t_f - \tau)B(\tau)u(\tau)d\tau \tag{39}$$

where $\phi(t_f - t) = e^{A(t_f - t)} = \begin{bmatrix} 1 & t_f - t \\ 0 & 1 \end{bmatrix}$

From equation (39), the final values of the state are obtained as

$$x_1(t_f) = f_1 - \int_t^{t_f} h_1(\tau)u(\tau)d\tau \tag{40a}$$

$$x_2(t_f) = f_2 - \int_t^{t_f} h_2(\tau)u(\tau)d\tau) \tag{40b}$$

Imposing terminal constraints $x_1(t_f) = x_2(t_f) = 0$, $\min_u J = \frac{1}{2}\int_{t_0}^{t_f} u^2 dt$ and $\gamma_M(t_f) = \gamma_f$

$$f_1 = \int_t^{t_f} h_1(\tau)u(\tau)d\tau \tag{41a}$$

$$f_2 = \int_t^{t_f} h_2(\tau)u(\tau)d\tau \tag{41b}$$

Introduce Lagrange multiplier λ in order to combine above two equations

$$f_1 - \lambda f_2 = \int_t^{t_f} [h_1(\tau) - \lambda h_2(\tau)]u(\tau)d\tau \tag{42}$$

Here, a slack variable $R(\tau)$ is introduced

$$f_1 - \lambda f_2 = \int_t^{t_f} [h_1(\tau) - \lambda h_2(\tau)]R^{-1}(\tau)R^{\frac{1}{2}}(\tau)u(\tau)d\tau \tag{43}$$

Applying Schwarz's inequality to above equation gives

$$(f_1 - \lambda f_2)^2 \leq \int_t^{t_f} [h_1(\tau) - \lambda h_2(\tau)]^2 R^{-1}(\tau)d\tau \int_t^{t_f} R(\tau)u^2(\tau)d\tau \tag{44}$$

Equation (45) is obtained by rearranging equation (44)

$$\frac{(f_1-\lambda f_2)^2}{2\int_t^{t_f}[h_1(\tau)-\lambda h_2(\tau)]^2R^{-1}(\tau)d\tau} \le \frac{1}{2}\int_t^{t_f}R(\tau)u^2(\tau)d\tau \tag{45}$$

The control input satisfies the equality condition

$$u(\tau)=K_2[h_1(\tau)-\lambda h_2(\tau)]R^{-1}(\tau) \tag{46}$$

Equation (47) can be obtained by substituting (46) into (40a)

$$f_1=K_2\int_t^{t_f}h_1(\tau)[h_1(\tau)-\lambda h_2(\tau)]R^{-1}(\tau)d\tau \tag{47}$$

Equation (48) is obtained by rearranging (47)

$$K_2=\frac{f_1}{\int_t^{t_f}h_1^2(\tau)R^{-1}(\tau)d\tau-\lambda\int_t^{t_f}h_1(\tau)h_2(\tau)R^{-1}(\tau)d\tau} \tag{48}$$

Equation (48) can be rewritten as

$$K_2=\frac{f_1}{g_0-\lambda g_1} \tag{49}$$

By using the shorthand notations are given below

$$g_0=\int_t^{t_f}h_1^2(\tau)R^{-1}(\tau)d\tau$$

$$g_1=\int_t^{t_f}h_1(\tau)h_2(\tau)R^{-1}(\tau)d\tau$$

$$g_2=\int_t^{t_f}h_2^2(\tau)R^{-1}(\tau)d\tau$$

By substituting (49) into (46)

$$u(\tau)=\frac{f_1[h_1(\tau)-\lambda h_2(\tau)]R^{-1}(\tau)}{g_0-\lambda g_1} \tag{50}$$

From (49) and terminal constraints, the minimum value of the performance index is shown below by using shorthand notation

$$J=\frac{(f_1-\lambda f_2)^2}{2(g_0-2\lambda g_1+\lambda^2 g_2)} \tag{51}$$

By imposing $\partial J/\partial\lambda=0$, then λ^* occurs that further minimize J

$$\lambda^*=\frac{f_1g_1-f_2g_0}{f_1g_2-f_2g_1} \tag{52}$$

By substituting (52) into (50) obtain

$$u(\tau)=\frac{\left[f_1h_1(\tau)g_2-g_1\left(f_1h_2(\tau)\right)+f_2h_2(\tau)g_0\right]R^{-1}(\tau)}{g_0g_2-g_1^2} \tag{53}$$

The following result occurs by using original variables in the time domain

$$a_M = -k_1 \frac{y}{t_{go}^2} - k_2 \frac{v}{t_{go}} \tag{54}$$

Where, $k_1 = \left(\frac{g_2 t_{go}^3 - g_1 t_{go}^2}{g_0 g_2 - g_1^2}\right) R^{-1}(t)$, $k_2 = \left(\frac{g_0 t_{go} + g_2 t_{go}^3 - 2 g_1 t_{go}^2}{g_0 g_2 - g_1^2}\right) R^{-1}(t)$,

$g_0 = \int_t^{t_f} \left(t_f - \tau\right)^2 R^{-1}(\tau) d\tau$, $g_1 \int_t^{t_f} \left(t_f - \tau\right) R^{-1}(\tau) d\tau$ and $g_2 = \int_t^{t_f} R^{-1}(\tau) d\tau$

$k_1 = 6$ and $k_2 = 4$ are the energy optimal solution and the guidance gains differ according to choice in R(t). Recall equation (13) again, $v = V_M(\gamma_m - \gamma_f)$. For this case $\gamma_M(t_f) = \gamma_f$, this term becomes zero when this terminal constraint is applied to equation (54). Final optimal solution is:

$$a_m = -k_1 \frac{y}{t_{go}^2}$$

A-6.

Reaching to a target is the aim of guidance. An object position reaches with a target position when getting to a target. Various types of guidance are specified by extra requirements to an object velocity and possibly acceleration. Missile flight consists three phases in the general case; the boost, midcourse and homing stages. The homing stage which is the main part of this assignment parallels to the terminal guidance when the missile-contained system controls the missile flight[1]. Impact angle control problem and homing problem are using the same form but different boundary conditions. Moreover, objective for each case is to minimize control energy during a vehicle reaches a target position. Furthermore, they have similar implementation issue that they need to be converted to nonlinear forms to compensate for the linearisation error. However, homing problem requires vehicle velocity, los rate, time-to-go and flight path while impact angle control problem requires vehicle velocity, time-to-go, los angle and flight path angle[2]. To find solutions of A-2 and A-4, different values of D and E matrices were used according to problem (homing or impact angle) and they have different terminal constraints. This difference caused a Guidance command of homing problem is shown the figure 1. This figure shows that acceleration of energy optimal guidance law and power function weighted optimal guidance laws coincide after some certain time at zero. This means they are arriving their target at the same time, but their starting accelerations differ from each other.

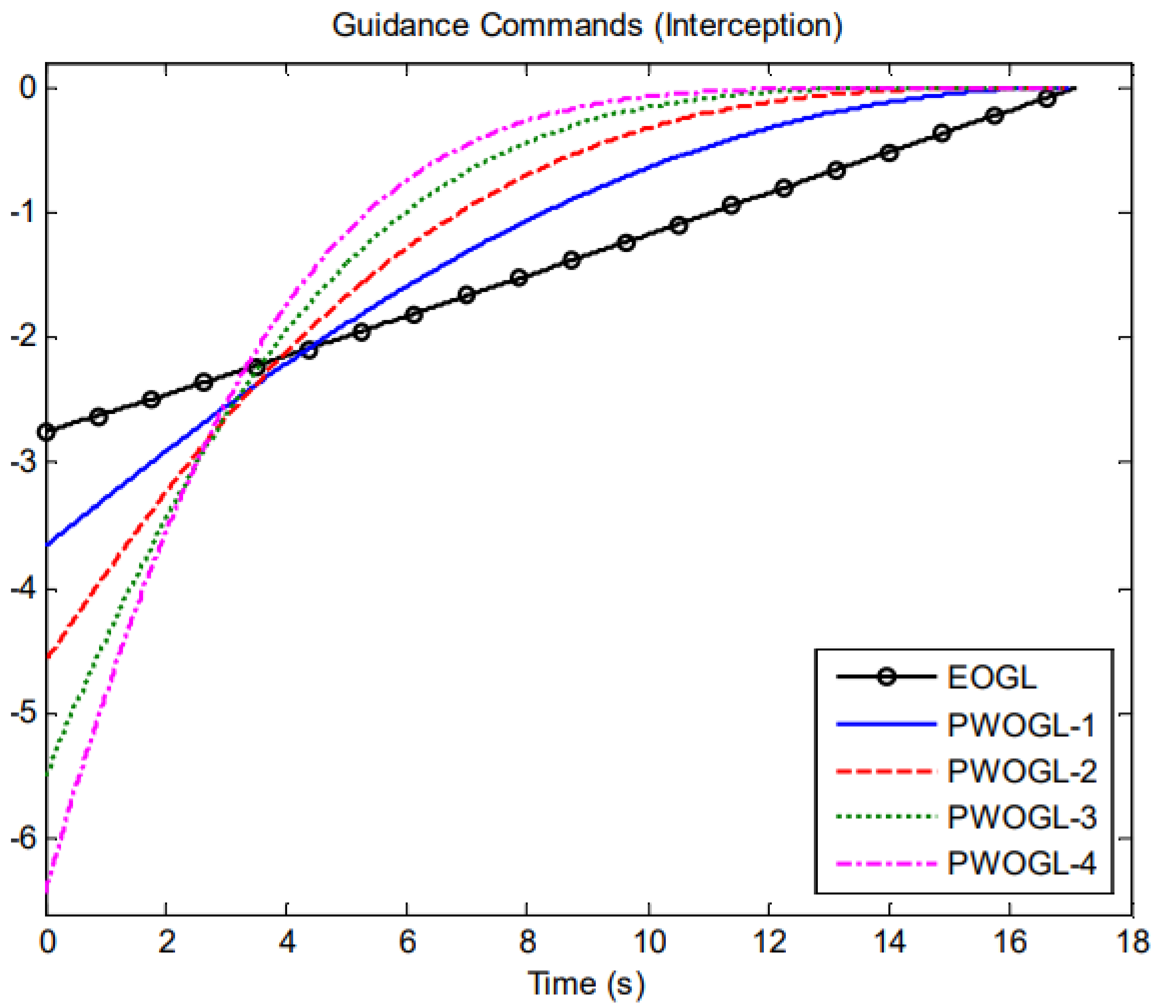

Figure 1 - Guidance Commands of Homing Problem

Guidance commands of impact angle control is in figure 2. This figure shows that energy optimal guidance negatively accelerates over time until seventeenth second at that moment it arrives the target. However, power function weighted optimal guidance laws deaccelerate over time until a curtain time from that point they accelerate, overshot, deaccelerate again, and arrives the target. They show the same trend and have the same time-to-go, but their initial accelerations are not the same.

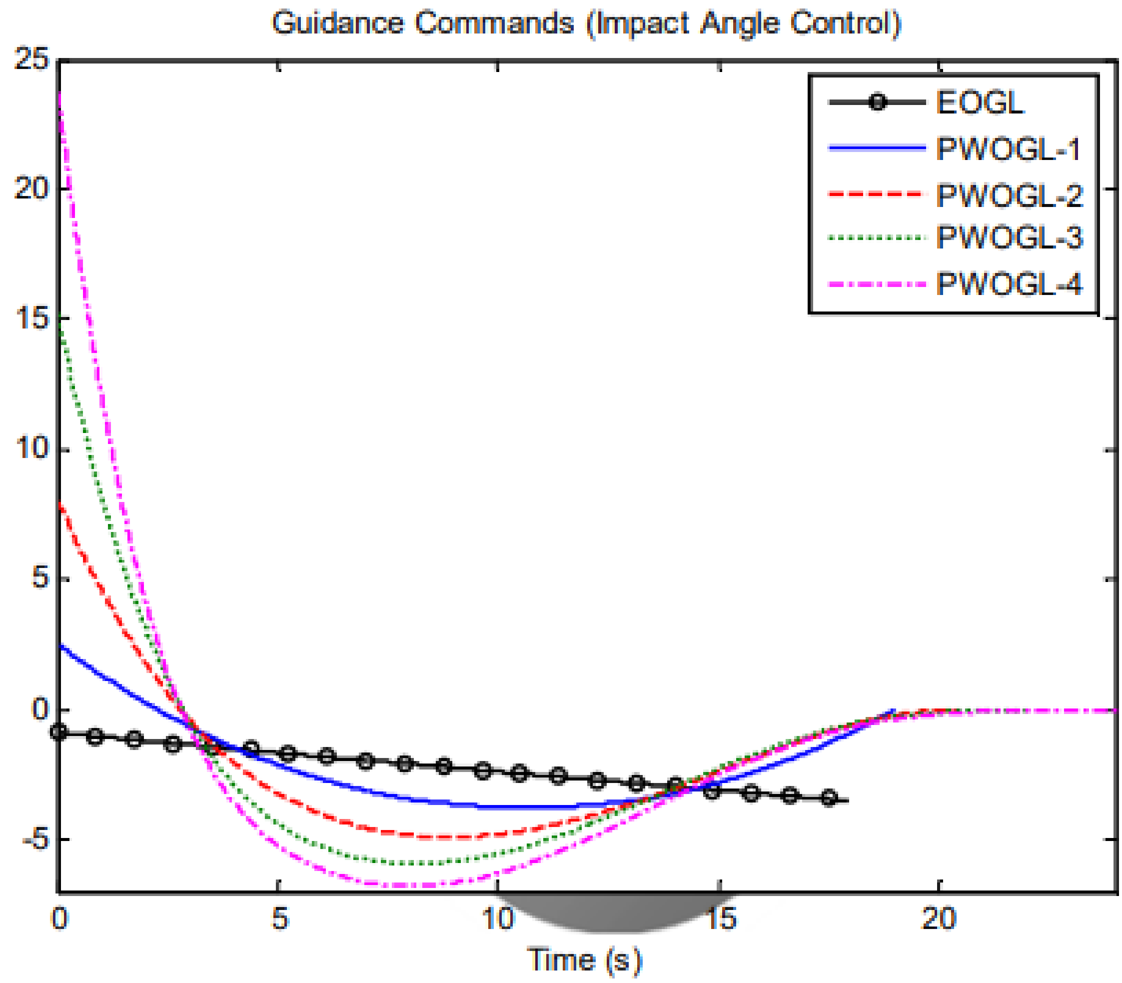

Figure 2 - Guidance Commands of Impact Angle Control

Trajectories of homing problem is shown in figure 3. This figure states that EOGL goes higher compare to PWOGLs. They are taking the same distance horizontally that means EOGL takes more distance. Trajectories of impact angle control case are shown in figure 4. It is directly reverse of the homing case. Moreover, impact angle control case has more constraints that specify the target more specific. This is because the weakest point of the target is the actual target of the missile, so missile hit the target at a specific point and a specific angle. Thus, impact angle control case has better performance than homing case.

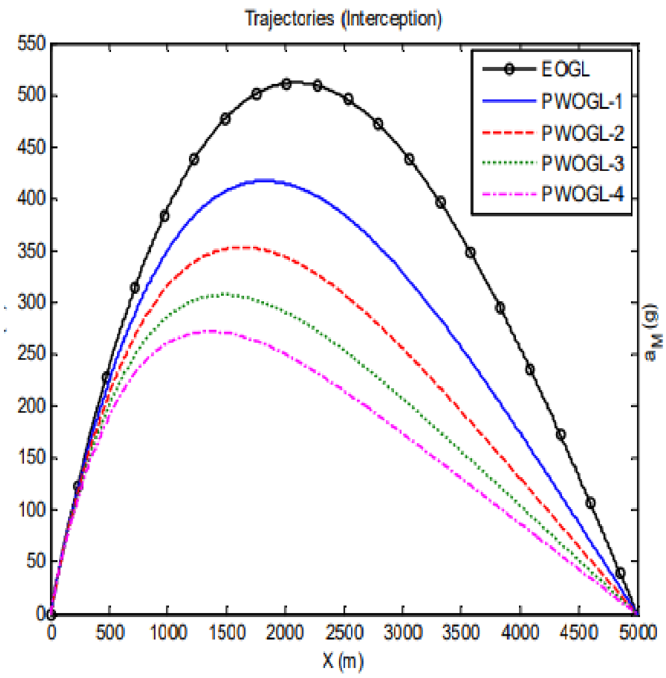

Figure 3 - Trajectories of Homing Case

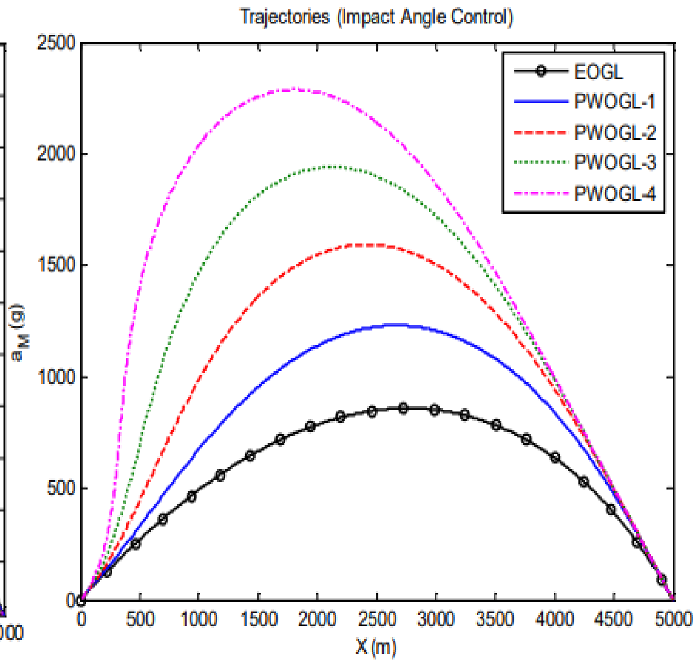

Figure 4 - Trajectories of Impact Angle Control Case

Recall solutions obtained in question A-4 and A-5 relatively:

$$a_m = -\frac{6}{t_{go}^2} y$$

$$a_m = -k_1 \frac{y}{t_{go}^2}$$

For A-5, $k_1 = 6$ is energy optimal solution that means solutions are very similar, but they are identical under one condition. k_1 and k_2 are functions of a

$$k_1 = (a+2)(a+3)$$

$$k_2 = 2x(a+2)$$

For this case a is equal to 2, so k_1 is equal to 20. The only condition that makes these algorithms identical is a = 0. However, in this assignment a is equal to 2, so they differ from each other. Thus, their normalised inverse of power weighting functions supposed to be different. In fact, there is no power for a is equal to 0 case and there suppose to be no graph for that case see the figure 5.

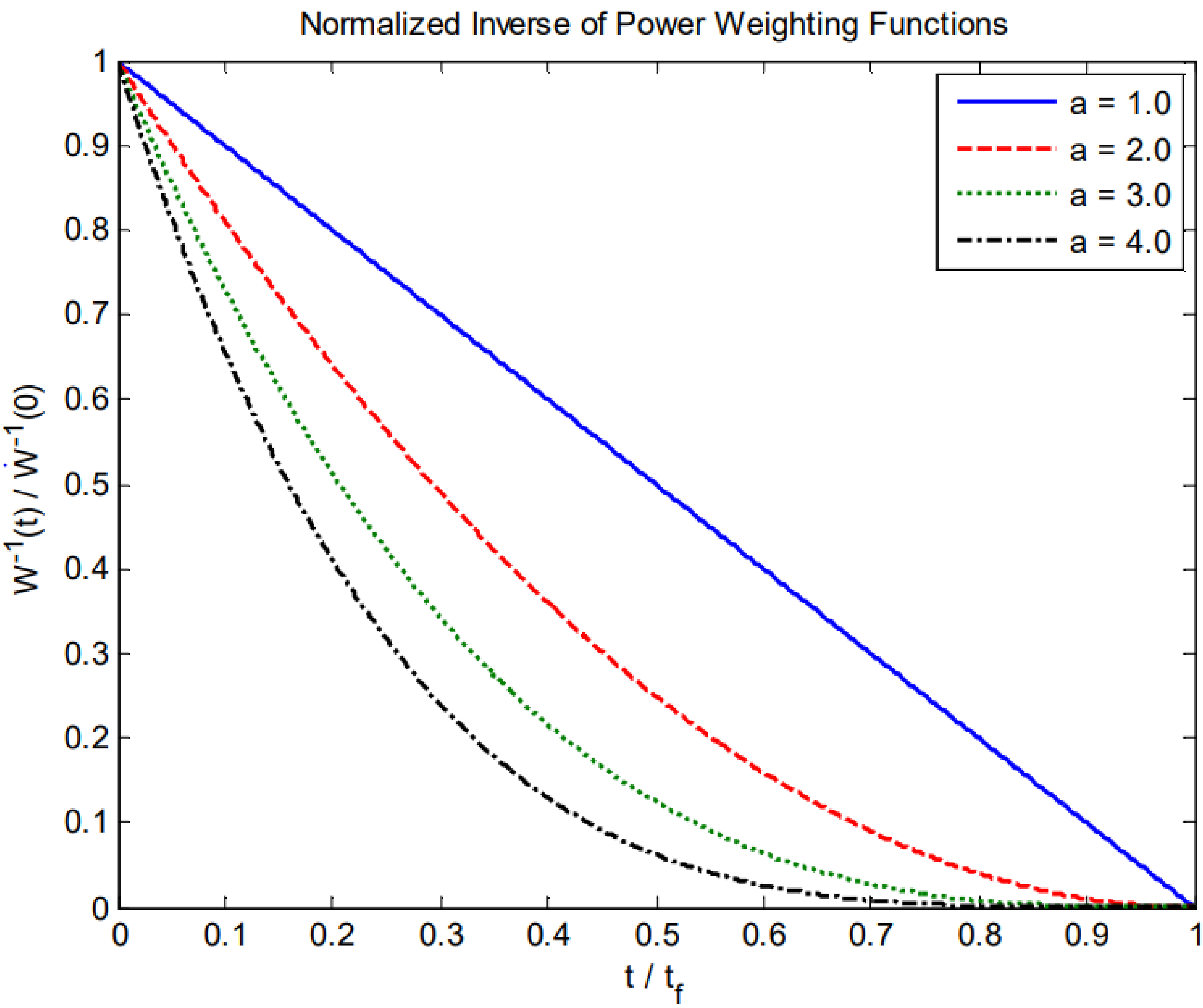

Figure 5 - Normalised Inverse of Power Weighting Functions

Part B

For this part of assignment initial parameters of missile are

$x_M(t_0) = 0$, $y_M(t_0) = 0$, $\gamma_M(t_0) = 20°$, $V_M = 10$

The target is fixed and its position is

$$x_T = 20, y_T = 0$$

B-1.

According to given parameters, relative distance between missile and target, line-of-sight angle from missile to target, flight path angle of missile and line-of-sight angle rate were calculated by using formulas given below on MATLAB.

Relative distance (R1): $R = \sqrt{((y_t - y_m)^2 + (x_t - x_m)^2)}$

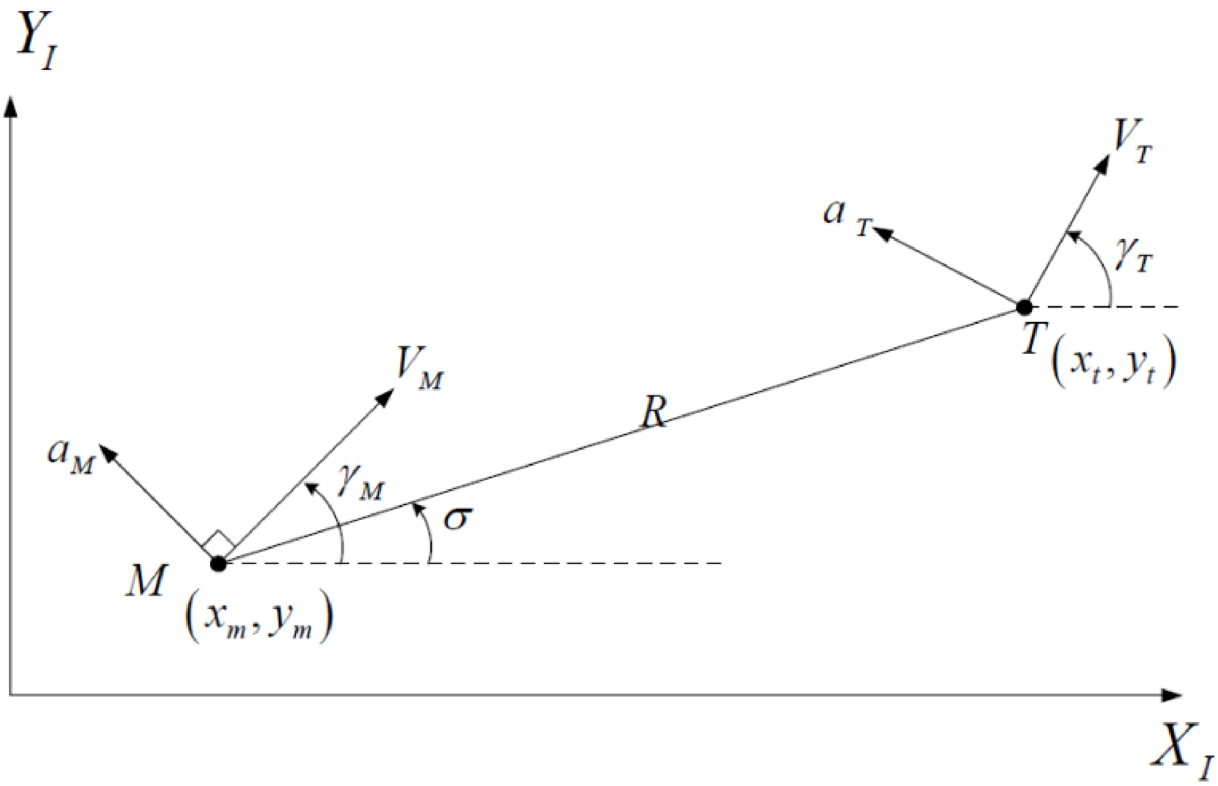

Figure 6 - 2D Target and Missile

Line-of-sight angle from missile to target (SIG1): $\sigma = \tan^{-1}\left(\frac{y_T - y_M}{x_T - x_M}\right)$

Flight path angle of missile (GAM1): $\gamma_M = \tan^{-1}\left(\frac{\dot{y}_M}{\dot{x}_M}\right)$

Line-of-sight angle rate (SIGR1): $\dot{\sigma} = \frac{V_T \sin(\gamma_T - \sigma) - V_M \sin(\gamma_M - \sigma)}{R}$

B-2.

For this part of assignment, formulas derived in A-1 are used to find 'y' and 'v'.

Recall equation (13): $y = V_M t_{go}(\gamma_f - \sigma)$ $\;v = V_M(\gamma_m - \gamma_f)$

Velocity is equal to distance travelled over time, after doing some manipulations, time-to-go was calculated by using the formula given below:

$$t_{go} = \frac{R}{V_M}$$

B-3.

Homing guidance law designed in A-2 worked for the provided engagement scenario by using MATLAB simulation. Graphs obtained from the simulation are given below.

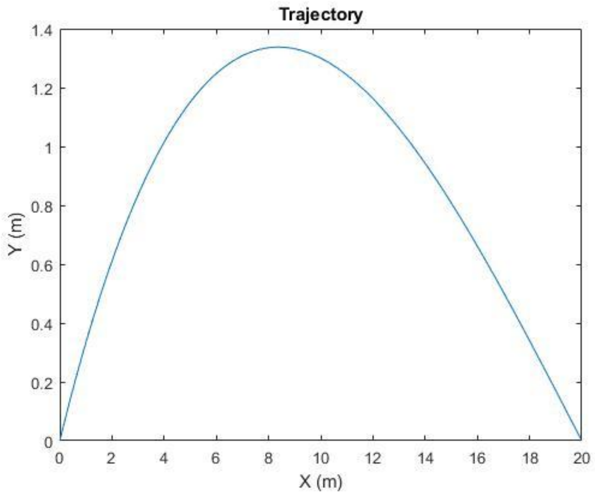

Figure 7 – Engagement Trajectory of Homing Problem

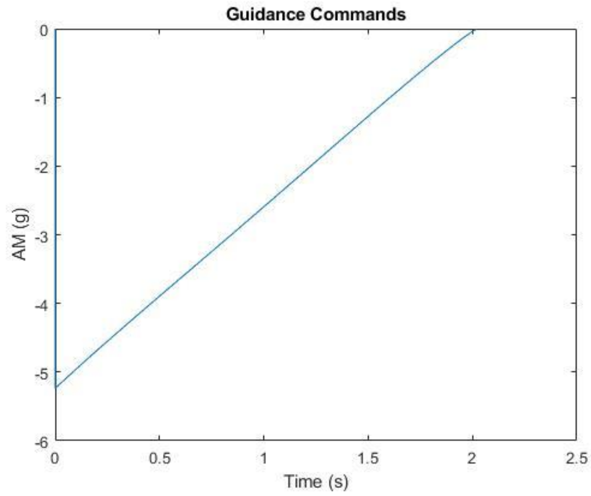

Figure 8 – Guidance Commands of Homing Problem

It is easily to see from figure 7, the missile starts its move from 0 and goes up until some curtain point to aim to the target, after that point it descends directly to the target to hit it. As it is shown in the figure 8, the missile deaccelerates as it gets closer to the target and its final acceleration is 0.

B-4.

Recall the formula derived in A-4:

$$a_M = -\frac{6}{t_{go}^2}y - \frac{4}{t_{go}}v$$

The missile was simulated for this acceleration formula according to given flight path angle as 0°, -45° and -90°. Results obtained from 0° flight path angle are shown in figures 9 and 10

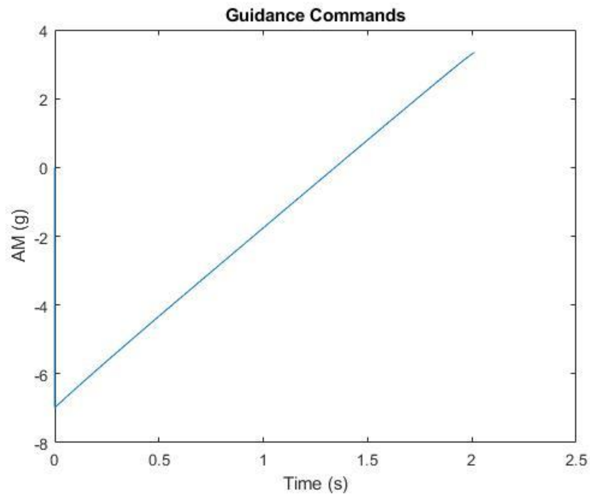

Figure 9 – Guidance Command of Impact Angle Problem for 0° (A-4)

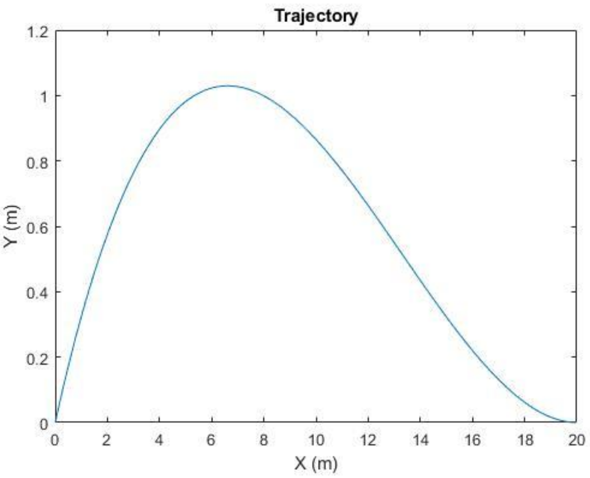

Figure 10 – Engagement Trajectory of Impact Angle Problem for 0° (A-4)

It can be easily seen from the figure 9, the missile deaccelerates for a while and accelerates. As it was mentioned before, impact angle aims and hits the weakest point of the target. It tries to find that weakest point of the target and accelerates to hit that point. Figure 10 shows the engagement trajectory of the guidance law designed in A-2. Flight path angle 0° means missile strikes the target at 0° and that is why it does not go very high; it rises around 1 metre and descents. Thus, for this strike required time is relatively low and at the final point it has positive acceleration.

Results obtained from -45° are shown in figures 11 and 12

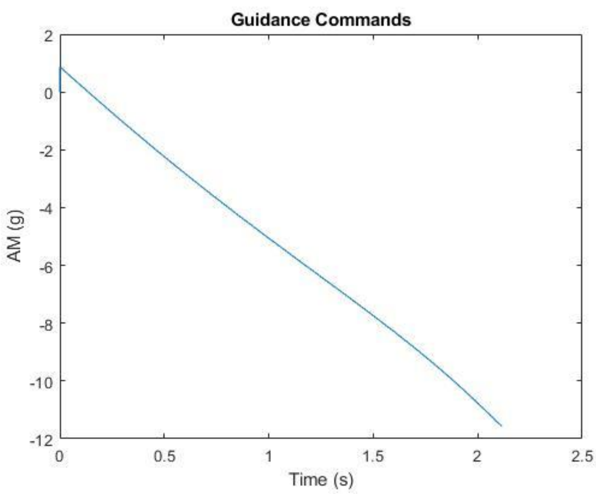

Figure 11 – Guidance Command of Impact Angle Problem for -45° (A-4)

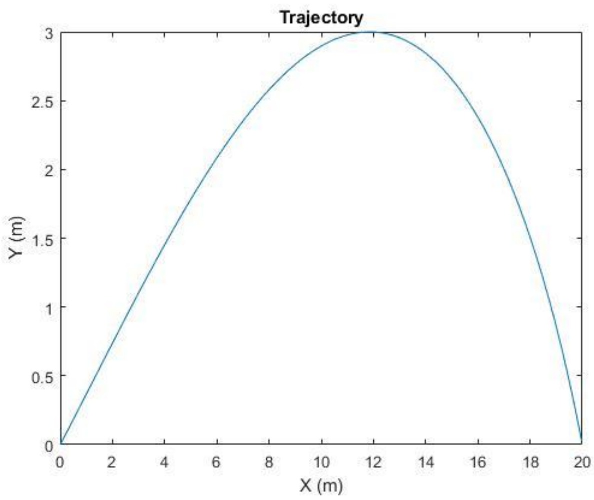

Figure 12 – Engagement Trajectory of Impact Angle Problem for -45° (A-4)

The missile tries to engage with target at -45°, to have this angle it changes its position that is why its acceleration turns to negative can be understood from figure 11. Its engagement trajectory is shown in figure 12 and it can be said that to have the correct flight path angle it goes higher than 0° flight path angle. Thus, it takes more time to collide with target compare to 0° case. The same comments can be done on -90° case as well. It takes the most time to collide with target because having the correct flight angle is much higher than the other cases. While doing that it gains much more acceleration because it need corrections. This also affects the engagement trajectory; it takes much of the distance after a certain point.

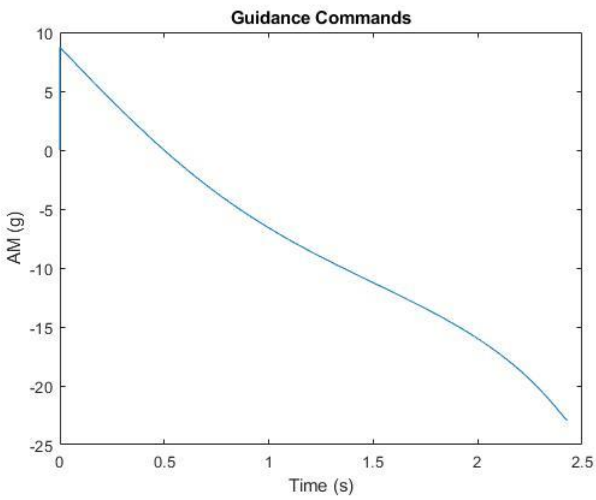

Figure 13 – Guidance Command of Impact Angle Problem for -90° (A-4)

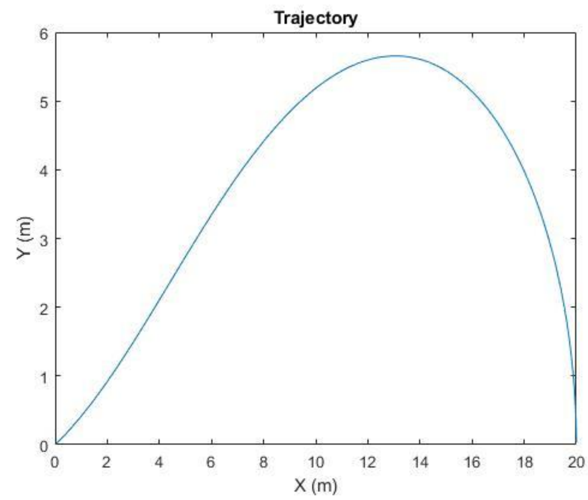

Figure 14 – Engagement Trajectory of Impact Angle Problem for -90° (A-4)

B-5.

In this part, B-2 was repeated according to impact angle law designed in A-5. Recall equation derived in A-4:

$$a_M = -k_1 \frac{y}{t_{go}^2} - k_2 \frac{v}{t_{go}}$$

For this case, given terminal constraints mention that a = 2 and k_1 and k_2 values are functions of a:

$$k_1 = (a+2)x(a+3)$$

$$k_2 = 2x(a+2)$$

This was simulated on MATLAB with flight path angle $\gamma_f = 0°, -45°, -90°$.

For 0° the results obtained from simulation are shown in the figure 15 and 16. From figure 15, it can be said that the missile's final acceleration value is zero which means it does not need any correction during this period and it has same angle as its initial condition, so it does not require too much high to get the correct flight path angle to collide with the target.

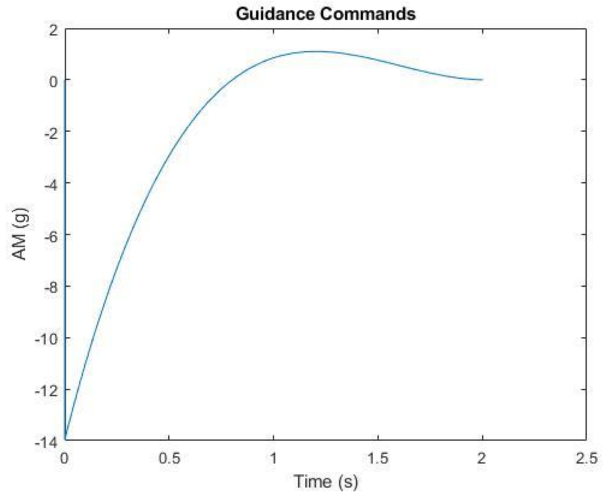

Figure 15 – Guidance Command of Impact Angle Problem for 0° (A-5)

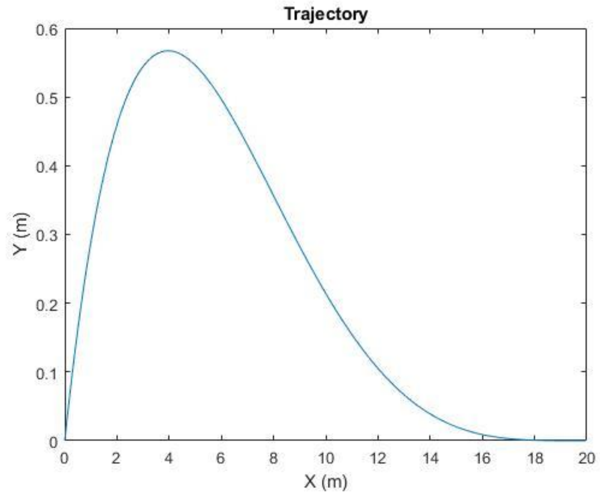

Figure 16 – Engagement Trajectory of Impact Angle Problem for 0° (A-5)

For -45°, final acceleration reaches to 0 as 0° case and that means it does not require any correction. However, its flight path angle is -45° and this causes more hight and more time-to-go compared to 0°

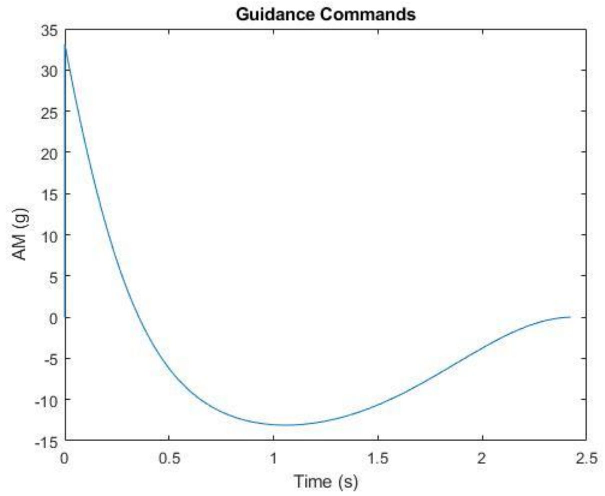

Figure 17 – Guidance Command of Impact Angle Problem for -45° (A-5)

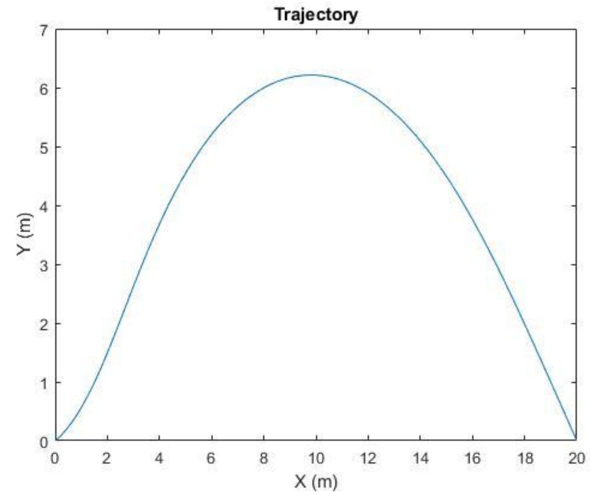

Figure 18 – Engagement Trajectory of Impact Angle Problem for -45° (A-5)

The same comments are valid for -90°, its acceleration goes to zero which means it does not need any correction. Nevertheless, its flight path angle is the highest one and it requires more time-to-go to have correct flight path angle, so it causes more hight compare to the others.

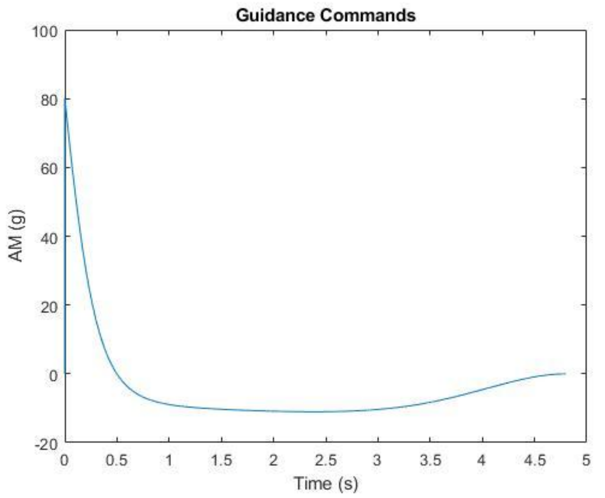

Figure 19 – Guidance Command of Impact Angle Problem for -90° (A-5)

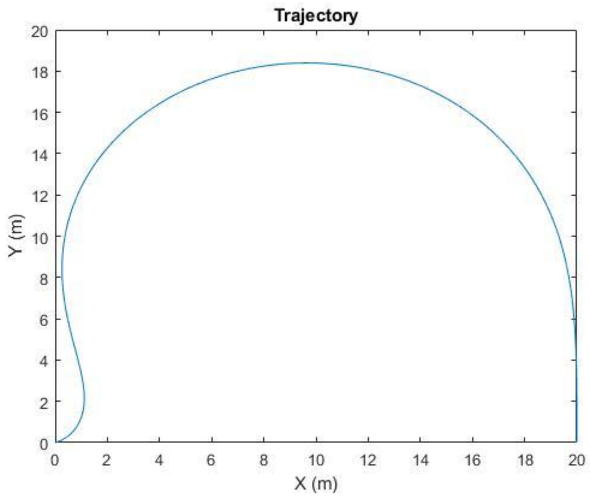

Figure 20 – Engagement Trajectory of Impact Angle Problem for -90° (A-5)

B-6.

Differences between B-4 and B-5 are trajectories and guidance commands, but the main difference is guidance commands. In B-5, guidance commands in every case goes to zero which means missile does not need any correction. However, the missile in every case in B-4 needs correction because guidance commands have non-zero final values. Nevertheless, B-3 is almost totally different from the others because it has no specific flight path angle, it is not its interest, but its guidance command has very similar trend as B-4 for 0° flight path angle guidance command. This happens because substituting 0 for γ_f in equation (37), there is not too much difference between equations (37) and (21).

Reference

[1] R. Yanushevsky, “GUIDANCE OF UNMANNED AERIAL VEHICLES,” 2011.

[2] M.-G. Seo, H.-S. Shin, P. Chang, and -Hun Lee, “Optimal Guidance Laws,” 2021.