

SIMULATION CONTROL MODEL MISSILE SURFACE TO SURFACE USING SIMULINK MATLAB

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ABSTRACT

Simulating a model of surface-to-surface missile control using Simulink MATLAB involves creating a model of the missile airframe. The model represents a tail-controlled missile traveling at high speeds and altitudes, with typical angles of attack. The core element of the model is a nonlinear representation of the rigid body dynamics of the airframe. The aerodynamic forces and moments acting on the missile body are generated from coefficients that are non-linear functions of both incidence and Mach number. The guidance system in a surface-to-surface missile is responsible for keeping the missile on its proper flight path and headed towards the target. It performs functions such as target detection and tracking, ensuring the missile stays on the desired trajectory, and making adjustments to maintain accuracy. The guidance system works in conjunction with the control system to make corrective adjustments when there are errors in guidance. To ensure optimal performance, the control system of the missile undergoes testing and tuning. This involves adjusting the proportional and integral gains to minimize steady-state error and settling time. The control system is tested with different setpoints and gains to find the values that result in the fastest settling time and the smallest steady-state error. The guidance system ensures the missile stays on the desired trajectory, while the control system makes corrective adjustments to maintain accuracy. The tuning process is essential to optimize the control system's performance.

Keywords: Simulink Matlab, Trajectory, Missile Guidance, Autopilot

1. INTRODUCTION

Simulating a model of surface-to-surface missile control using Simulink MATLAB involves creating a model of the missile airframe. The missile airframe model is presented in several published papers Elbaoumy, etl (2018). The model represents a tail-controlled missile traveling between Mach 2 and Mach 4, at altitudes ranging between 10,000ft (3,050m) and 60,000ft (18,290m), and with typical angles of attack ranging between +/-20 degrees. The core element of the model is a nonlinear representation of the rigid body dynamics of the airframe. The aerodynamic forces and moments acting on the missile body are generated from coefficients that are non-linear functions of both incidence and Mach number. The model can be created with Simulink and the Aerospace Blockset. The Aerospace Blockset extends Simulink, enabling you to model, simulate, and analyze aerospace vehicle dynamics. You can incorporate vehicle dynamics, validate models of the flight environment, model pilot behavior, and then connect your model to the FlightGear Flight Simulator to visualize simulation results.

The role of the guidance system in a surface-to-surface missile is to keep the missile on its proper flight path and headed towards the target. It is responsible for ensuring that the missile stays on the desired trajectory from the launcher to the target

George M. Siouris.(2004). The guidance system performs several key functions:

- a. Target detection and tracking: The guidance system detects the presence of the target and tracks its position. It uses sensors and tracking algorithms to continuously monitor the target's location.
- b. Course determination: The guidance system determines the desired course or trajectory for the missile to reach the target. It calculates the necessary adjustments to keep the missile on the intended path.
- c. Flight path control: The guidance system provides commands to the control system to steer the missile along the desired flight path. It ensures that the missile stays on track and makes any necessary course corrections.

d.Coordination with control system: The guidance system and the control system work together to determine the flight path and maintain the missile's stability. The guidance system provides commands to the control system, which then moves the control surfaces of the missile to adjust its attitude and direction.

George M. Siouris.(2004) in book missile control system, There are several benefits of using different types of guidance systems in missiles. Some of these benefits are, Accuracy: Different types of guidance systems can provide different levels of accuracy, depending on the type of system used. For example, laser guidance systems can provide very high accuracy, while radar guidance

systems may be less accurate. Flexibility: Different types of guidance systems can be used in different situations, depending on the nature of the target and the environment. For example, heat-seeking guidance systems may be more effective against targets that emit a lot of heat, while radar guidance systems may be more effective against targets that are difficult to detect visually. Countermeasures: Using different types of guidance systems can make it more difficult for an enemy to develop effective countermeasures. If an enemy develops a countermeasure that is effective against one type of guidance system, another type of guidance system can be used instead. And the last is cost: Different types of guidance systems can have different costs associated with them. For example, laser guidance systems may be more expensive than radar guidance systems.

2. MATERIALS AND METHOD

2.1. System Dynamics

A system is a unit of interconnected and interacting components where the state response of one component affects the state of another. Within the scope of the system itself there are several components that affect the state of the system, namely the initial condition, external input (possibly interference) and output. The initial condition of the system is an interpretation of several system states at a given time, which can affect the subsequent state of the system. The input of the system itself is the input given to the system intentionally. Due to the influence of the first two components, the output of the system is the response displayed by system.

In the concept of dynamical systems, the term transient response is also known as response, which is the output that occurs during the transition from the initial state to the final state. In transient response itself are also known several terms that will later be used as a reference in the concept of control in the future, including peak time (rise time, which is the time needed to reach the first peak of the response). Rise time is required to reach 90% of the expected value. Settling time is the time it takes to reach a steady state with a certain tolerance. The latter is the overshoot percentage, which is a comparison between the difference between the peak and the end of the condition itself.

In addition to the transient response, it is also called the steady state response, which is the response when the system reaches the final value. In the control concept, the term used in this steady state response is steady state error, which is an error at an undesirable final value.

2.2. Matrices Laboratory (Matlab)

Matlab is a calculation and analysis programming software, which has been widely used in all fields of mathematics applications in

universities and industry in the fields of education and research. By using Matlab, researchers can more easily implement complex mathematical calculations in the program.

Matlab has excellent graphics tools in creating Images in 2D and 3D. In terms of programming, Matlab is similar to the C language, and is even one of the simplest programming languages when writing mathematical programs. Matlab also has several toolboxes that can be used for signal processing, image processing, and so on.

2.3. Autopilot System

To keep the missile in a stable position, the autopilot system ensures it reaches the right orientation angle by adjusting the deflection angle of the missile fin so that the body remains rotating and translating. This autopilot system is a closed loop system that has a reference angle input from the guidance system while the output is in the form of a missile fin deflection angle (δ).

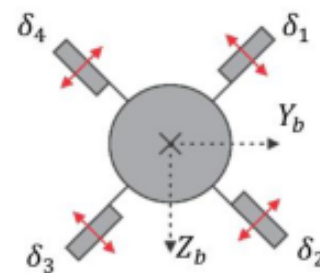


Figure 1. Missile Fin

In Figure 1 above, it can be seen that the missile has 4 cross-shaped fins (X) that are controlled using servo motors. If fin 4 and 2 are mechanically connected, it has a function as an elevator, if the fin has its own servo it is referred to as an aileron. While fins 1 and 3 function as rudders if connected mechanically.

2.4. Guidance System

Each missile consists of an attitude control system and a flight path control system. The attitude control system functions to keep the missile at the desired behavior and on a predetermined path by controlling pitch, roll and yaw. While the function of the flight control system is to determine the flow to be passed and give commands to the attitude control system to maintain the guided missile to fit in a predetermined flow.

Operation of guidance system and control system on the principle of feedback. The control unit makes corrective adjustments to the missile control when a guidance error occurs. The control unit will also perform adjustment control to stabilize the roll, pitch and yaw of the missile.

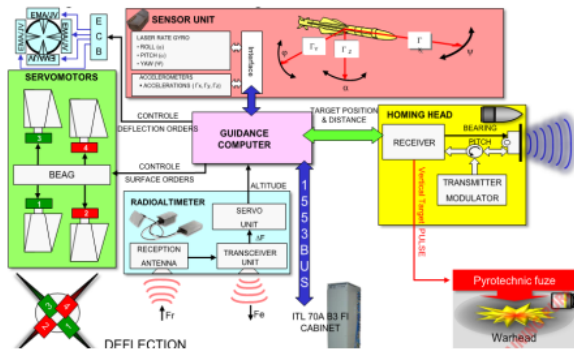


Figure 2 Guidance System Real Missile

The actual model and system picture of the missile is in Figure 2 in general and in the matlab simulation is in Figure 3.

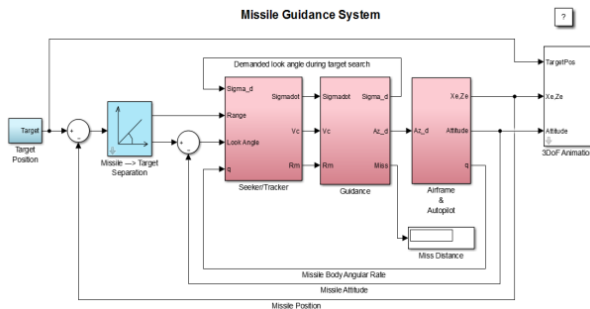


Figure 3. Missile Guidance System In Matlab

In figure 3 is a model made in matlab with simulink. In the simulink diagram on the missile, target position data is entered then the missile moves continuously towards the target according to the guidance in the control box. With all the parameters of the missile entered. That is position, angular velocity and translation. The missile will stop when it hits the target or hits the target.

2.5. Missile kinematics

Kinematics is a science that discusses the displacement, speed and acceleration of the motion of an object and its position by ignoring the force or cause of the movement. Kinematics has a close relationship with coordinate transformations, because kinematics describes the position, velocity, or acceleration of an object relative to a reference and then converts it into another coordinate system.

a. Translational Kinematics

Translational kinematics on a missile is about the presence of translational speed and rotation in the coordinate system of the missile against the earth coordinate system. In the equation below, it can be explained how translational kinematics is obtained.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} c\phi c\psi & s\phi s\theta c\psi - c\phi s\psi & c\phi s\theta c\psi + s\phi s\psi \\ c\phi s\psi & s\phi s\theta s\psi + c\phi c\psi & c\phi s\theta s\psi - s\phi c\psi \\ -s\theta & s\phi c\theta & c\phi c\theta \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$

where:

$\dot{x}\dot{y}\dot{z}$ = Translation speed with respect to earth coordinates.

u, v, w = Translational speed to the coordinates of the missile body.

ϕ, θ, ψ = Euler angular representation of the rotation of the coordinates of the missile body with respect to the coordinates of the earth.

3. DISCUSSION AND RESULTS

3.1. Missile Model

After determining the shape of the missile and obtaining its mathematical model, the next step is to create a modeling design and the system to be used. The design of this missile model is based on the mathematical form of the missile in the form of a model of dynamics and kinematics that has been obtained. As is known, the model of missile dynamics is in the coordinate system of the missile body, so a model of missile kinematics is needed to carry out the transformation to the earth coordinate system. Therefore, the missile model design step will start from dynamic design, then continue kinematics design.

Based on Newton's law II, an equation is obtained that is the basis for designing the dynamics of a missile with 6DoF (six degrees of freedom) in the form of the sum of forces acting on each axis of the missile's coordinate system. The force in question is aerodynamic force, gravitational force and force that occurs due to the interaction of translational speed with the angular velocity of the missile. If the equations of translational and rotational dynamics are implemented into the functions of the Matlab system, then the design of the function blocks will be seen in Figure 4. The function block is a design to calculate aerodynamic forces and moments with inputs in the form of.

Translational speed of the missile, angular velocity of the missile, angle of orientation of the missile on the coordinate system of the missile body, speed of sound and density. With the input as shown in Figure 4, it is expected that the design will get output in the form of force (F_a) with the equation:

$$F_a = \begin{bmatrix} F_{ax} \\ F_{ay} \\ F_{az} \end{bmatrix} = \begin{bmatrix} q s C_D \\ q s C_S \\ q s C_L \end{bmatrix}$$

with the moment (M_b) of aerodynamics expressed by the equation:

$$M_b = \begin{bmatrix} M_x \\ M_y \\ M_z \end{bmatrix} = \begin{bmatrix} q s C_R \\ q s C_P \\ q s C_Y \end{bmatrix}$$

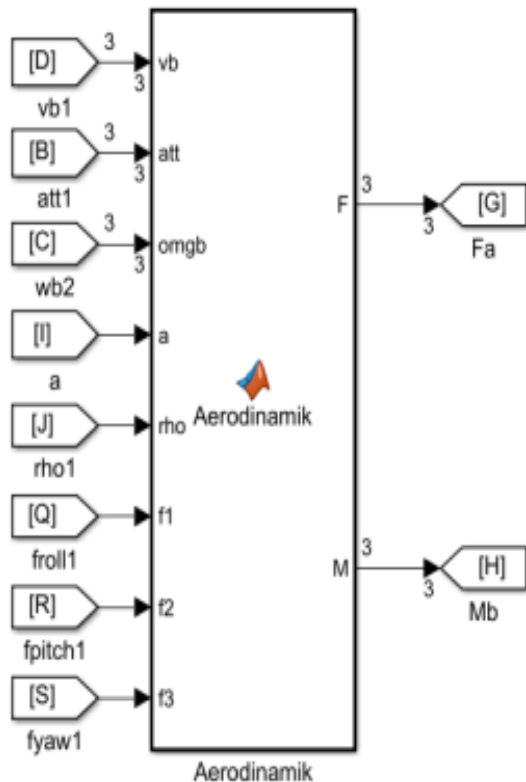


Figure 4. Missile Aerodynamic Function Block Design

After designing the force and aerodynamic moment function block, the next step is to form a function block design kinematics of force and moment acting on the missile with the design form of the function block.

The input function blocks in Figure 5 are the translational velocity of the missile, the angular velocity of the missile, the orientation angle of the total force of the missile and the total moment acting on the missile, the inertial matrix, and the time of its change when there is a difference in the missile's mass and wind speed in the atmosphere around the missile. The total force and moment that input this function block are the aerodynamic forces and moments in the aerodynamic function block and the thruster force of the missile (thruster).

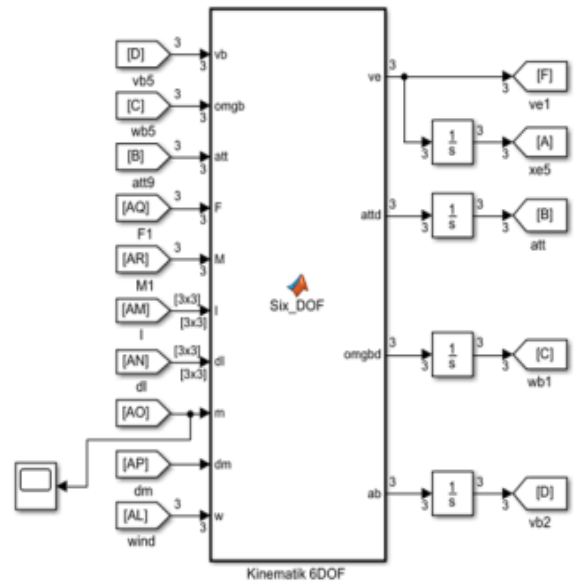


Figure 5. Missile Kinematics Function Block Design

The output of the function block is the translation speed and angular velocity of the missile against the earth coordinate system, the angular acceleration and the acceleration of the translation of the missile against the coordinate system of the missile body, so that the position of the missile against the earth coordinate system is obtained by integrating the translation speed of the missile. To calculate the inertial matrix, the mass of the missile, and the change in its mass as well as the change in inertia during the missile's movement through the air, it takes the input in the form of the missile's mass which will decrease with its movement in the air. Based on this, the approximate matrix will be known. inertia and changes in its inertial matrix. The design of the block diagram of the missile's mass and inertia is shown in Figure 6.

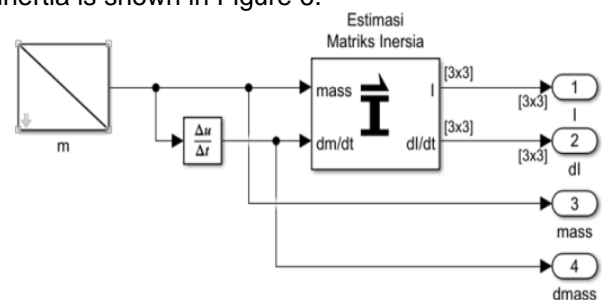


Figure 6. Missile Mass and Inertia Function Block Design

In Figure 7 the design of the function block of the Atmosphere Model whose output is in the form of wind speed (wind direction opposite to the direction of motion of the missile), air density and rapid propagation of sound in the atmosphere around the missile. The output of this design is one of the inputs of the aerodynamic block.

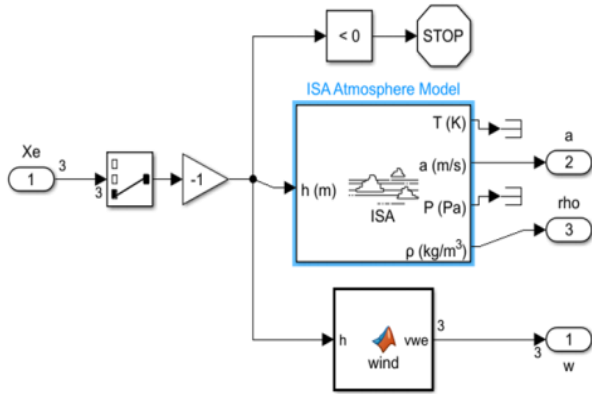


Figure 7. Atmospheric function block design

The next step is to apply the shape of the missile's fins to the design of the missile model. The shape of the C-705 missile's fins is cross (X). Order of conversion fins from ailerons (δ_a), elevators (δ_e) and rudders (δ_r) to (δ_1), (δ_2), (δ_3), and (δ_4) with Equation:

$$\delta_1 = \delta_a + \delta_e - \delta_r$$

$$\delta_2 = \delta_a + \delta_e + \delta_r$$

$$\delta_3 = \delta_a - \delta_e + \delta_r$$

$$\delta_4 = \delta_a - \delta_e - \delta_r$$

In its Simulink block design, the output of the missile's fin actuator dynamics is the deflection angle of the aileron, elevator and rudder which can be seen in Figure 8.

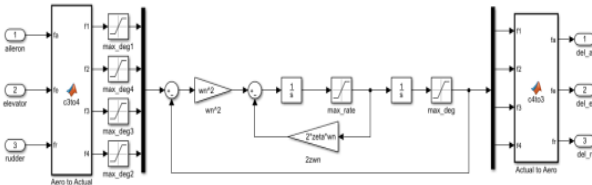


Figure 8. Function Block Missile Fin

3.2 Autopilot System

At the design stage of the autopilot system, the roll, pitch and yaw angles of the missile have their own autopilots. When designing the autopilot system, a cascade P-PI controller will be used that can convert input signals in the form of reference angles into control signals to actuators, in the form of ailerons and missile rudders.

3.2.1 Autopilot Roll

The purpose of designing this autopilot roll is to be able to control roll movement so that it is obtained. The stability of the roll angle on the longitudinal axis of the missile with the fins used is the aileron fin. The reference roll speed value in autopilot roll design is always set to 0 to prevent roll motion on the missile. If implemented into the design, it will appear as in Figure 9.

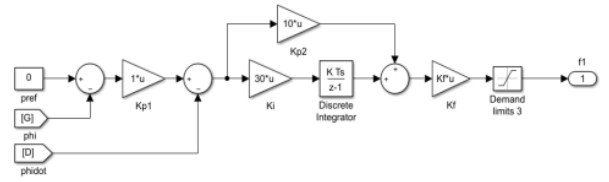


Figure 9. Simulink Autopilot Roll Block

3.2.2 Autopilot Pitch

The purpose of designing this autopilot roll is to be able to control the movement of the rudder fins so that the missile moves according to the desired pitch angle. It has inputs from the missile's guidance system reference pitch angle and outputs that will then be used by the P-PI with the limit range of its elevator fin deflection angle being -17° to 17° (± 0.3 radians). If implemented into the design, it will look like in Figure 10.

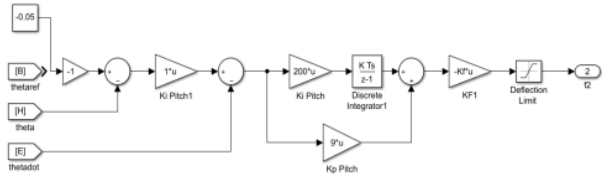


Figure 10. Blok Simulink Autopilot Pitch

3.2.3. Autopilot Yaw

While the purpose of designing this yaw autopilot is to be able to control the movement of the rudder fins so that the missile moves according to the desired yaw angle. The input is the yaw angle error which is the difference between the guidance system's reference yaw angle and the missile's yaw angle. The output itself is a control signal that will be received by the missile's rudder fin. The deflection angle limitation of the missile fin is between -17° and 17° (± 0.3 radians), this limitation is intended to prevent structural damage to the angle of attack that could eliminate acceleration capabilities. If implemented into the design, it will look like in Figure 11.

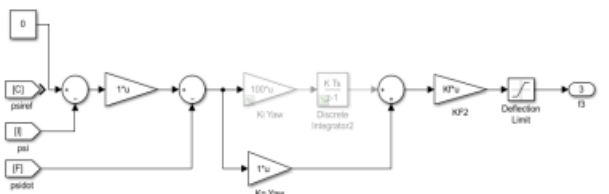


Figure 11. Simulink Block Autopilot Yaw

3.3. Guidance System

In the design of waypoints, initialization of the main points that will become the trajectory of the missile will be carried out. In the waypoint block function, some data will be entered in the form of missile position, waypoint starting point "wpts0", tangent entry point "pen", tangent exit point "pex",

target position "p4", circle center point "c", sampling time "Ts", and total waypoint points that exist "jmlwp".

The difference in distance between the missile's position and the waypoint is marked with the notation d. If the position of the missile is considered to have been at the waypoint, then the distance between the 2 points in 3D space can be calculated by the equation:

$$d = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

The output of this waypoint block function is also the central position (x, y, z) that the missile must achieve in the guidance loop or lottery algorithm. The position of the center of the circle will also be continuously updated until the missile has crossed the entire trajectory. Every Updates at points "WPTS1", "WPTS2" and "CIRCPTS" follow the "K" index, which rises as the value of "D" approaches 0. The block function shape of the waypoint is shown in Figure 12.

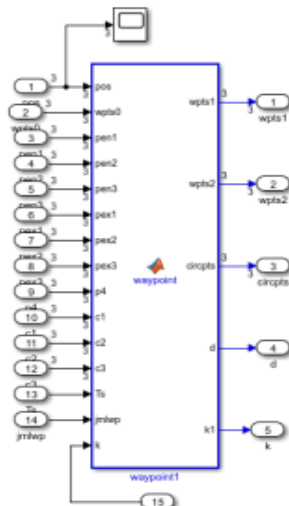


Figure 12. Function block waypoint

3.4. Corkscrew Maneuver

The fin's shape of the missile has a maximum deflection angle of 17 degrees (0.3 radians). In the block diagram, in addition to the orientation angle, the position of the missile against the waypoint will also be used as a reference input for the missile when it will perform maneuvers.

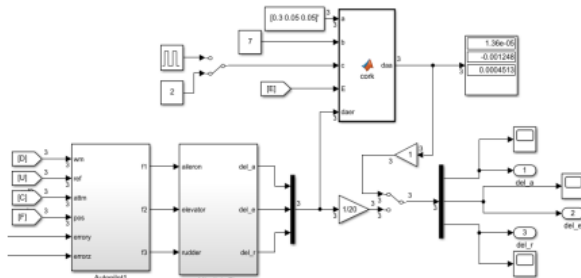


Figure 13. Corkscrew maneuver block diagram

By adjusting the deflection angle deflection of fins (δ) of the ailerons, elevators and rudders on the missile, it is expected to make the missile move in a spiral. This movement will be active at the time of the missile Being at the position "WP = 3", the last waypoint goes to the target position. The input of the missile fin is a constant value assumed to be the deflection angle of the missile fin, as presented in Figure 13.

3.5. Test Results

3.5.1 Missile Test Results

The initial stage of the simulation is to determine the exact initial configuration so that the missile does not fall as long as the missile is in the booster phase. The initial configuration is x_e, y_e, z_e data which is the initial position of the missile, u, v, w data is the translational speed data of the missile, ϕ, θ, ψ data is the orientation angle of the missile and p, q, r is the angular velocity data of rotation. The missile's current status $t = 3$ seconds is the completion of the booster phase and the missile's position is [461 8.5 -29.1]. Thus, the missile has an orientation angle that leads to the first waypoint reference point [10000 100 -300] as seen in the graphic below.

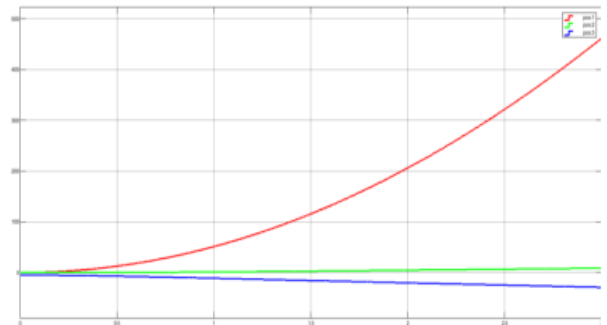


Figure 14. Configuration [0 0.245 0.0251]

In comparison, if the initial configuration scenario of the orientation angle (pitch and yaw angle) is changed to [0 0.1 0], then what happens to the missile when $t = 3$ is the position where the missile falls to the surface as shown in the figure below.

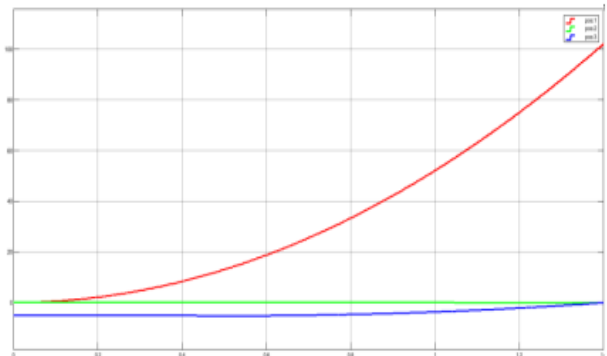


Figure 15. Configuration [0 0.1 0]

In comparison, if the scenario of the initial configuration of the angle of orientation (pitch and yaw angles) is changed to $[0 \ 0.1 \ 0]$, then what happens to the missile when $t = 3$ is the position where the missile falls to the surface as seen in Figure 16.

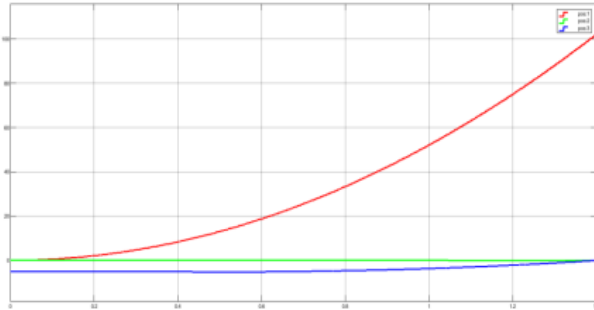


Figure 16. Configuration $[0 \ 0.1 \ 0]$

3.5.2. Autopilot Testing

Because this system uses an integral proportional controller, a test is needed system for obtaining the values of the gain parameter. The amount of gain value is obtained through tuning using procedural methods.

The initial step using this method is tuning the inner loop control followed by tuning the outer loop control. When carrying out the inner loop tuning procedure, the condition of the missile has been completed in the booster phase with its initial position being $[0 \ 0 \ -5]$ and its orientation angle $[0 \ 0.245 \ 0.0251]$. These tuning aims to analyze the closed-loop response by changing the proportional and integral gains of the autopilot roll, pitch, and yaw to reduce steady-state errors until a minimum value is obtained. The outer loop tuning procedure is only performed for proportional control with the aim of speeding up system response. When carrying out a response analysis with this procedure, the allowable settling time value is $\pm 2\%$.

a. Tuning Inner Loop Autopilot Pitch

Before performing autopilot pitch tuning, the setpoint values of the roll and yaw controllers are zero. At this tuning stage, what is done is to analyze the closed loop response when added with proportional gain given a constant value of pitch angle.

When performing tuning, the pitch angle is given a value of 0.05 radians. The test was conducted by changing the value of gain from $K_p = 3$ (a value below it would not be enough to raise the pitch that would cause the missile to fall) to $K_p = 9$ (a value above it would cause oscillations that resulted in system instability). It is known that if K_p is given a small value, then the settling time will be long and the steady state error value will be large. In contrast, $K_p = 9$ responds with a settling time and a small steady-state error. The response looks like in the image below.

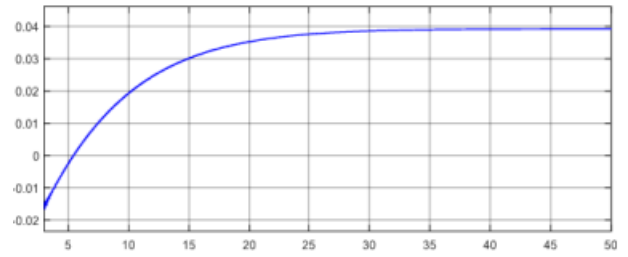


Figure 17. Respond pitch when $K_p = 9$

To reduce the presence of steady-state errors in this system, an additional gain integral K_i is needed. By increasing the integral gain, it will speed up settling time and steady-state errors. Several experiments have been carried out to get the best response, obtaining values $K_p = 9$ and $K_i = 200$ as illustrated in the figure below.

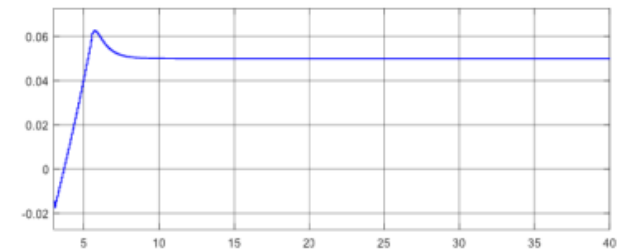


Figure 18. Respond pitch when $K_p = 9$, $K_i = 200$

b. Tuning Inner Loop Autopilot Roll

When performing this tuning, the autopilot roll setpoint value must be zero in order to maintain the roll speed and pitch setpoint with a value of 0.05 radians to simulate the missile flying over the surface. The purpose of this tuning is to analyze the response of the closed loop when added with proportional gain. If there is a steady state error, then to minimize it can be added integral gain. The test is carried out by changing the value of the proportional gain starting from $K_p = 1$ to $K_p = 16$ (the rest will cause oscillations that have an impact on system instability). Based on these tests, the value that produces the fastest settling time and the smallest steady state error value is when gain is given a value of $K_p = 10$.

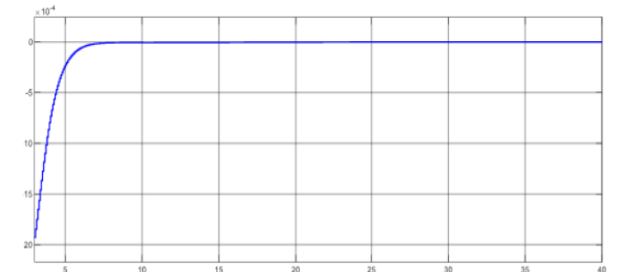


Figure 19. Respond roll when $K_p = 10$ $K_i=50$

To minimize steady-state errors, an integral controller will be added and find the right integral gain value by testing with a gain value range of 1 to 50. In this test, it is known that the gain with a value

of $K_i = 50$ has the fastest settling time, the smallest steady-state error, and the lowest overshoot.

c. Tuning Inner Loop Autopilot Yaw

To be able to analyze the closed loop autopilot yaw response, the autopilot pitch and roll setpoints must be given a constant value. To reduce if there is a steady state error, an integral gain will be added. Just like the previous test, this test is carried out starting with finding a proportional gain value followed by integral gain. The setpoint gain to be tested starts from the value of $K_p = 3$ (the value below is not enough to control the angle of yaw that makes the missile fall) to the value of $K_p = 11$ (the value above makes the yaw angular response will oscillate and make the system unstable).

To reduce steady-state errors that occur, it is necessary to add the gain integral K_i . In this study, tests were carried out with a range of values from 1 to 200, when the values of $K_i = 50$ and $K_i = 100$ both have the fastest settling time but have different steady-state errors. In consideration of the smaller percentage of steady-state errors, the value of $K_i = 100$ will be used as seen in Figure 20.

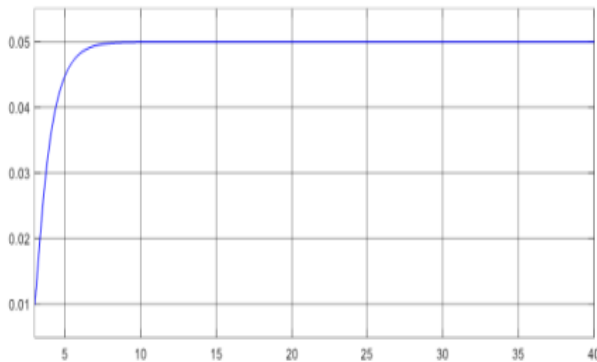


Figure 20. Respond yaw when $K_p = 11$, $K_i = 100$

3.5.3 Guidance System Testing

To find out the movement and direction of the missile during flight, it is necessary to have a trajectory to determine the consistency of the missile in the air. With this need, a straight-line guidance system was formed as a missile guidance system. This track system is created by Connecting several points as a waypoint, the missile will turn up to the last point, which is the position of the virtual target. Since the guidance system and autopilot are active after the booster phase is completed, the starting point of the trajectory is the missile's position at the time $t = 3$ at the point $[462 \ 8.85 \ -29.13]$.

Based on Figure 21, it is known that the point between 2 straight lines is still in the form of a broken trajectory. If the missile moves in this trajectory, it will result in unstable missile movement and increase the missile's relative distance error on the trajectory.

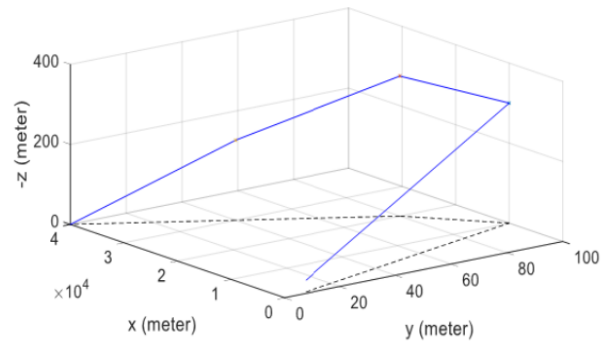


Figure 21. Track with 3 waypoints

To overcome this problem, the track design added reference trajectory planning using the Dubins curve method. The process that needs to be done is to design the meeting point of the waypoint by changing the curvature.

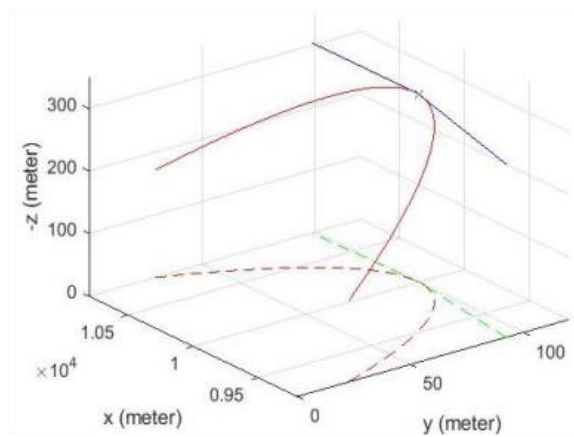


Figure 22. Dubins curve at the waypoint

3.5.4 Corkscrew Maneuver Testing

Using the open loop control system method, this test was carried out by changing the reference deflection angle of the missile until the correct input was obtained. Several experiments will be conducted to obtain the exact deflection angle, with missile angle deflection values $[0.3 \ 0 \ 0]$, $[0.3 \ 0.05 \ 0.1]$, $[0.3 \ 0.1 \ 0.05]$, and $[0.3 \ 0.05 \ 0.05]$. If δ given a value of $[0.3 \ 0.05 \ 0.1]$ then the missile appears to have moved in a spiral with a fairly sharp dive angle with a small amount of spiral motion.

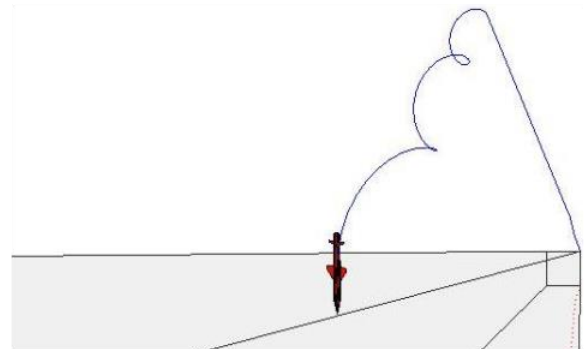


Figure 23. Missile Current $\Delta = [0.3 \ 0.05 \ 0.1]$

When δ values are given [0.3, 0.1, 0.05] and [0.3, 0.1, 0.05], it will make the angle of the missile dive slower with a greater amount of spiral movement. In this experiment, the behavior exhibited by the missile would look almost the same.

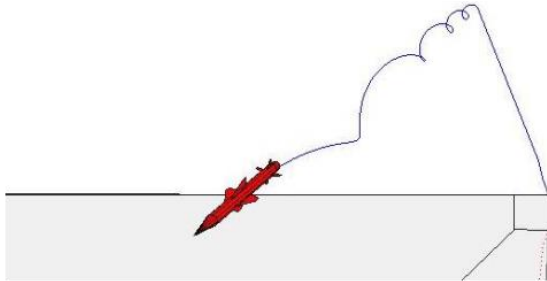


Figure 24. Missile current $\delta = [0.3 \ 0.05 \ 0.05]$

4. CONCLUSION

Based on the result and discussions, we can take some conclusions are:

- The Dubins curve method is quite optimal and efficient to reduce error when the missile turns at the inflection point of a straight-line trajectory.
- The advantage of using an integrative proportional controller as missile control is that procedural tuning of the system design circuit can be performed.
- Based on the experiments conducted, the missile can move in a spiral manner when the missile fin is $\delta = [0.3 \ 0.05 \ 0.1]$ and $\delta = [0.3 \ 0.05 \ 0.05]$

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