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Design and Simulation of Harmonic Control for a Rolling Airframe R-Han 122 Surface-to-Surface Missile Using MATLAB–X-Plane Integration

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A B S T R A C T

Rolling motion in airframe missiles improves gyroscopic stability but may also induce control coupling and oscillatory responses that reduce flight stability. This study aims to design and evaluate a harmonic control strategy for the R-Han 122 surface-to-surface missile by integrating MATLAB and X-Plane 10. A numerical simulation based on a six-degree-of-freedom (6-DOF) flight model was conducted by applying harmonic control with various amplitude and frequency combinations. Flight performance was evaluated using telemetry data, including altitude, ground trajectory, roll, pitch, yaw, velocity, and acceleration. The simulation results indicate that harmonic control effectively compensates for roll-induced control coupling, reduces oscillatory behaviour, and improves flight stability. The proposed simulation framework provides a practical basis for future development of indigenous missile guidance and control systems.

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INTRODUCTION

Missile technology plays an essential role in modern defense systems by enabling precision strikes while reducing the need for direct troop deployment. Unlike conventional artillery rockets that rely solely on ballistic trajectories, guided missiles integrate navigation, guidance, and control systems to maintain flight stability and improve targeting accuracy. Consequently, the development of advanced guidance and control strategies has become an important area of research for enhancing missile performance under various operational conditions.

Indonesia has developed the R-Han 122, a 122-mm surface-to-surface artillery rocket, as part of its indigenous defense technology program. However, the current R-Han 122 configuration operates as an unguided rocket, making its flight trajectory highly dependent on initial launch conditions and susceptible to aerodynamic disturbances. Incorporating an effective guidance and control system into this platform is therefore an important step toward improving missile accuracy and supporting the development of national defense capabilities.

Rolling airframe missiles experience continuous roll motion that enhances aerodynamic stability but also introduces dynamic coupling between the pitch and yaw axes, reducing control effectiveness. Harmonic control addresses this issue by synchronizing the control input with the missile roll motion, allowing the controller to compensate for roll-induced disturbances without eliminating the rotational behaviour of the airframe. This synchronization enables the control surfaces to generate more effective aerodynamic forces despite the continuous rotation of the missile body, thereby improving longitudinal flight stability.

Simulation-based evaluation has become a widely adopted approach for the development of missile guidance and control systems because it enables controller verification under controlled operating conditions while reducing development cost and experimental risk. The integration of MATLAB for control algorithm implementation and X-Plane 10 as a six-degree-of-freedom (6-DOF) flight dynamics simulator provides a flexible platform for analyzing missile behaviour and evaluating controller performance before hardware implementation or flight testing. Such an integrated environment facilitates systematic parameter tuning and performance assessment under various flight scenarios.

Although previous studies have investigated rolling airframe control and missile stabilization, limited research has evaluated the implementation of harmonic control for the R-Han 122 using an integrated MATLAB–X-Plane simulation environment or systematically examined the influence of different harmonic control amplitudes and frequencies on missile flight performance. Therefore, this study investigates the implementation of harmonic control on the R-Han 122 rolling airframe missile through an integrated MATLAB–X-Plane 10 simulation framework.

The proposed approach evaluates the effects of varying harmonic control amplitudes and frequencies on missile flight characteristics, including altitude, ground trajectory, attitude, velocity, acceleration, and overall flight stability. The findings are expected to provide a practical reference for the development and optimization of indigenous missile guidance and control systems.

LITERATURE REVIEW

Flight Dynamics and Control Theory

Flight dynamics and control theory explain that the flight characteristics of a missile are determined by the interaction between aerodynamic forces, moments, propulsion, and control inputs. In a rolling airframe missile, the application of an appropriate control strategy modifies the missile's attitude and translational motion, thereby affecting flight parameters such as altitude, ground trajectory, velocity, and acceleration. Therefore, the implementation of harmonic control is expected to improve the flight performance of the R-Han 122 missile.

Several previous studies have demonstrated that appropriate control strategies significantly improve missile flight performance. Suiçmez and Kutay (2022) developed a robust digital controller for a rolling airframe missile and reported improved flight stability by compensating for roll-induced dynamic coupling. Similarly, Udekwe and Daniel (2025) showed that the implementation of an advanced flight control system enhanced trajectory tracking accuracy and overall aerodynamic performance in precision-guided munitions. These findings support the assumption that the application of harmonic control can improve the flight characteristics of the R-Han 122 rolling airframe missile.

H1: The application of harmonic control improves the flight performance of the R-Han 122 rolling airframe missile by modifying its altitude, ground trajectory, attitude, velocity, and acceleration characteristics.

Harmonic Control Theory

Harmonic control employs sinusoidal control inputs synchronized with the roll motion of a rolling airframe missile. The amplitude determines the magnitude of the control action, whereas the frequency governs its synchronization with the missile roll dynamics.

Different combinations of these parameters produce different control forces and moments, resulting in variations in flight response and stability. Previous studies have also reported that controller parameter selection has a substantial influence on missile dynamic response. Ammar et al. (2026) demonstrated that different control parameter settings produced different roll stabilization performance in a six-degree-of-freedom missile simulation. Likewise, Suiçmez and Kutay (2022) emphasized that control performance depends on proper synchronization between controller inputs and missile roll dynamics.

These findings indicate that variations in the amplitude and frequency of harmonic control signals are expected to produce different flight responses and stability characteristics.

H2: Different combinations of harmonic control amplitude and frequency produce significantly different flight responses and stability characteristics of the R-Han 122 rolling airframe missile.

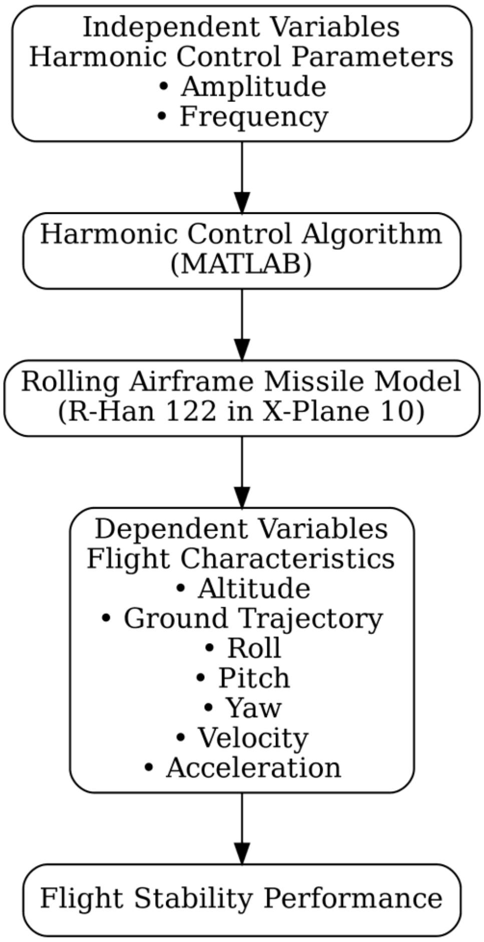

Figure 1. Conceptual Framework

METHODOLOGY

This study employed a quantitative simulation-based research design to evaluate the implementation of harmonic control on the R-Han 122 rolling airframe missile. The simulation integrated MATLAB as the harmonic control algorithm environment with X-Plane 10 as the six-degree-of-freedom (6-DOF) flight dynamics simulator through XPlane. The research object was the R-Han 122 missile model, while the simulation scenarios were conducted by varying the amplitude and frequency of the harmonic control signal under identical initial conditions.

The independent variables consisted of harmonic control parameters (amplitude and frequency), whereas the dependent variables included missile flight characteristics, namely altitude, ground trajectory, attitude (roll, pitch, and yaw), velocity, acceleration, and overall flight stability. The simulation procedure consisted of implementing the harmonic control algorithm, executing flight simulations, acquiring telemetry data, and evaluating missile performance. Flight characteristics obtained from each simulation scenario were analysed descriptively by comparing the effects of different harmonic control parameter combinations. The controller performance was assessed through graphical visualization and telemetry analysis to determine the effectiveness of harmonic control in improving the stability of the R-Han 122 rolling airframe missile.

RESULTS AND DISCUSSION

Missile Modelling and Integrated Simulation Environment

The R-Han 122 rolling airframe missile was modeled using Plane Maker and implemented in the X-Plane 10 environment to represent the aerodynamic characteristics of the actual missile. Minor modifications were introduced to the canard geometry to accommodate the harmonic control mechanism without altering the overall missile configuration. The developed model was integrated with MATLAB through XPlaneConnect, enabling real-time communication between the harmonic control algorithm and the six-degree-of-freedom (6-DOF) flight dynamics simulator. This integrated simulation environment allowed the controller to continuously exchange telemetry and control commands during flight simulation.

Table 1. Specifications of the R-Han 122 Missile Model

Parameter	Value
Caliber	122 mm
Total Weight	33 lb
Length	2.8 m
Diameter	122 mm
Semi Length	0.56 ft
Arm Length	6.56 ft
Maximum Weight	301 lb

Harmonic Control Implementation

The harmonic control algorithm was first evaluated in MATLAB to verify its capability to compensate for roll-induced dynamic coupling before integration with the flight simulator. Three simulation conditions were considered: (1) a baseline model without roll effect, (2) a rolling airframe model without harmonic control, and (3) a rolling airframe model with harmonic control. The baseline simulation demonstrated a stable response without significant oscillation. Introducing roll motion without harmonic compensation increased oscillatory behaviour due to the continuous rotation of the body frame, which periodically altered the direction of the control force. After implementing harmonic control based on rotational coordinate transformation, the controller successfully synchronized the control input with the missile roll motion, thereby maintaining control effectiveness and reducing oscillatory responses.

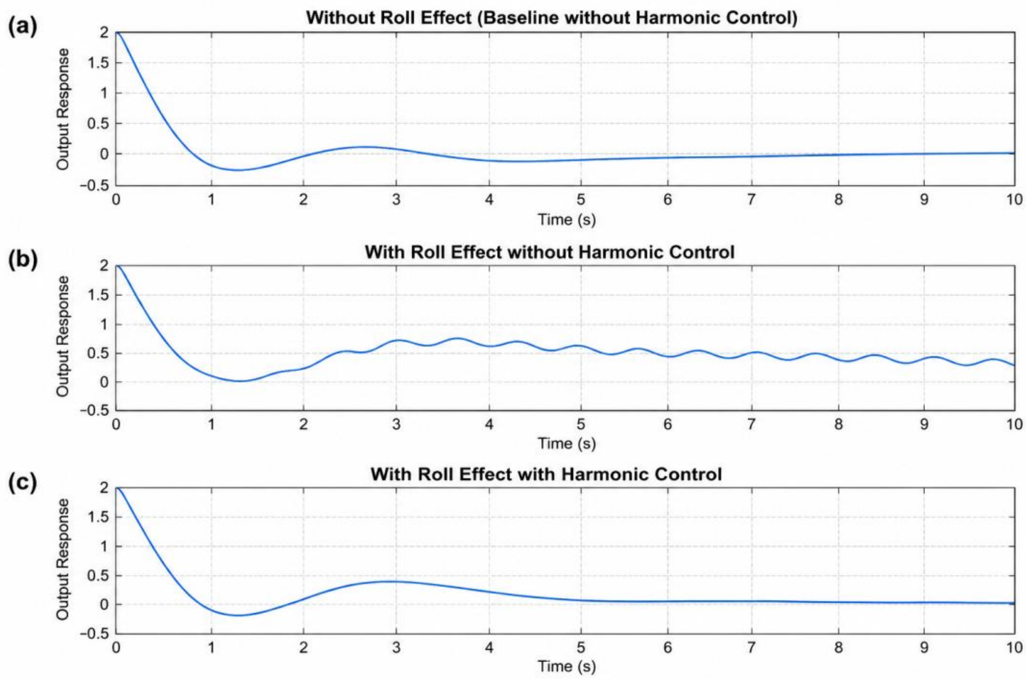

Figure 2. MATLAB Simulation Results under Different Harmonic Control Conditions: (a) without roll effect, (b) with roll effect, and (c) with harmonic control

Effect of Harmonic Control Parameters

Following controller validation, integrated MATLAB–X-Plane simulations were performed by varying the harmonic control amplitude (0, 0.1, 0.5, and 1.0) and frequency (0.3, 0.5, and 0.8 Hz). Flight performance was evaluated using the minimum and maximum pitch angles, pitch peak-to-peak values, and maximum altitude. The simulation results demonstrated that both amplitude and frequency affected the missile's longitudinal response and flight stability. At frequencies of 0.3 Hz and 0.5 Hz, increasing the control amplitude generally reduced the pitch peak-to-peak value, indicating a decrease in longitudinal oscillation. Conversely, at 0.8 Hz, the oscillation initially decreased but increased again at higher amplitudes, indicating that excessive excitation reduced control effectiveness.

Table 2. Summary of Harmonic Control Performance

Frequency (Hz)	Amplitude	Pitch Min (°)	Pitch Max (°)	Peak to Peak (°)	Max. Altitude (m)
0.3	0.0	-45.082	45.000	90.082	3625.1
0.3	0.1	-44.198	45.000	89.198	3455.2
0.3	0.5	-36.830	45.000	81.830	2314.7
0.3	1.0	-43.538	45.000	88.538	3310.1
0.5	0.0	-44.697	45.000	89.697	3528.8
0.5	0.1	-42.737	45.000	87.737	3223.8
0.5	0.5	-24.049	45.000	69.049	3074.8
0.5	1.0	-25.444	45.000	70.444	3502.8

Frequency (Hz)	Amplitude	Pitch Min (°)	Pitch Max (°)	Peak to Peak (°)	Max. Altitude (m)
0.8	0.0	-43.129	45.000	88.129	3592.1
0.8	0.1	-41.926	45.000	86.926	3579.6
0.8	0.5	-22.738	45.000	67.738	3680.5
0.8	1.0	-25.244	45.000	70.244	3647.9

To facilitate comparison among all simulation scenarios, the optimum harmonic control parameter at each frequency was identified based on the minimum pitch peak-to-peak value.

Table 3. Optimum Harmonic Control Parameters

Frequency (Hz)	OptimumAmplitude	Minimum Peak to Peak (°)	Maximum Altitude (m)	Performance
0.3	0.5	81.830	2314.7	Stable
0.5	0.5	69.049	3074.8	Most Stable
0.8	0.5	67.738	3680.5	Reduced oscillation, but oscillatory behaviour reappeared at higher amplitude

Telemetry Analysis

Telemetry data obtained from the X-Plane simulation consisted of altitude, ground trajectory, roll, pitch, yaw, forward velocity, forward acceleration, and harmonic control input for each simulation scenario. Overall, the missile maintained continuous and controllable flight trajectories throughout all simulations, indicating that the implemented harmonic control algorithm ensured stable flight under the tested operating conditions. Among the evaluated flight parameters, the pitch response exhibited the most significant variation and therefore served as the primary indicator of longitudinal flight stability. Low harmonic control amplitudes produced relatively small improvements in pitch oscillation, whereas a moderate amplitude (A = 0.5) consistently reduced the pitch peak-to-peak response while maintaining stable altitude, velocity, and ground trajectory profiles across the tested frequencies. Increasing the amplitude beyond this value resulted in larger oscillatory responses, although no divergent flight behaviour or loss of control was observed during the simulation period. Since all simulation scenarios exhibited similar telemetry trends, presenting every telemetry output would introduce substantial redundancy without providing additional analytical value. Therefore, only the representative telemetry responses corresponding to the optimum harmonic control amplitude (A = 0.5) at each excitation frequency (0.3, 0.5, and 0.8 Hz) are presented in Figures 3–5, while the complete telemetry dataset was used in the quantitative analysis and performance evaluation.

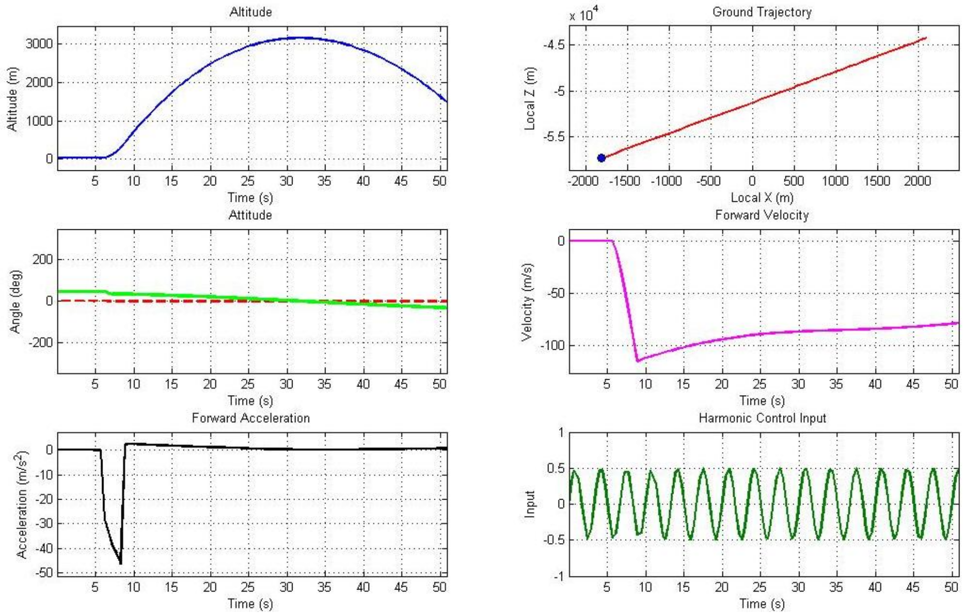

Figure 3. Telemetry Response A=0.5; F=0.3

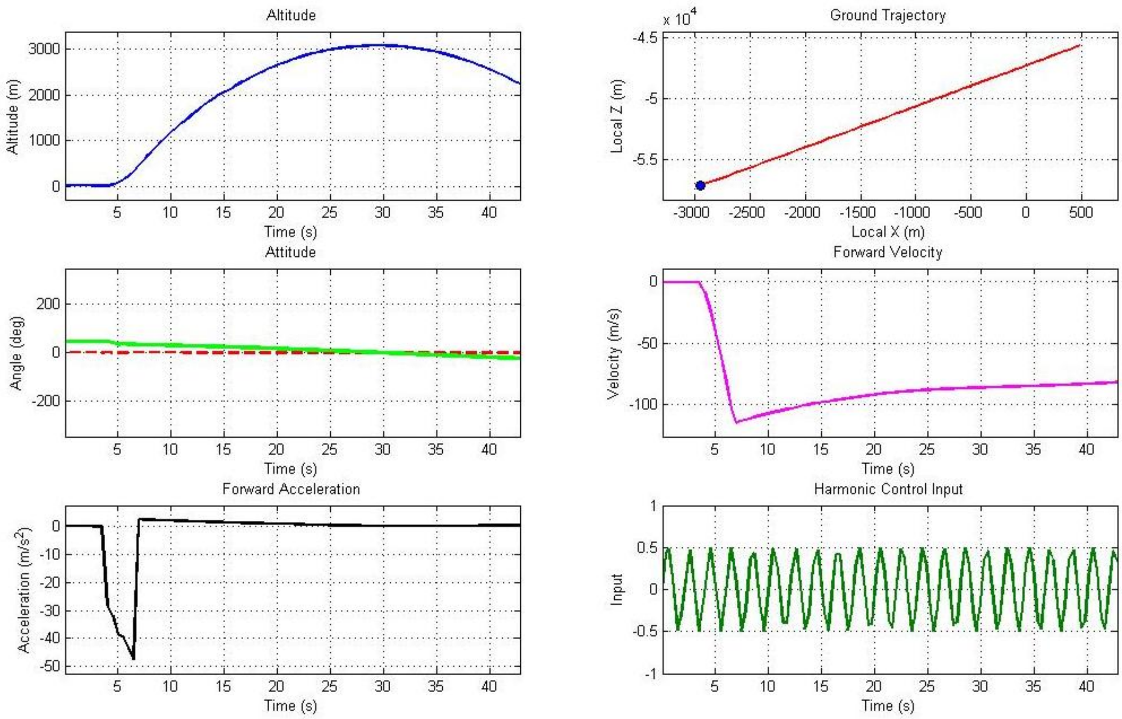

Figure 4. Telemetry Response A=0.5; F=0.5

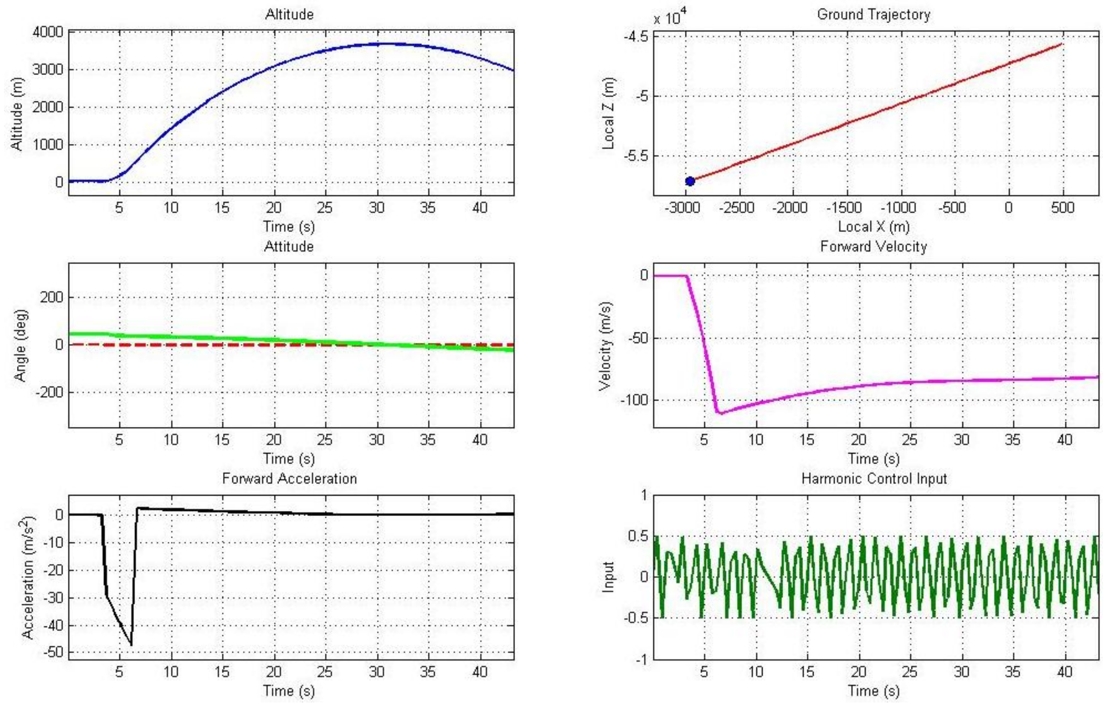

Figure 5. Telemetry Response A=0.5; F=0.8

The results demonstrate that the implementation of harmonic control significantly improved the longitudinal flight performance of the R-Han 122 rolling airframe missile by reducing the adverse effects of roll-induced dynamic coupling. Compared with the uncontrolled rolling condition, the harmonic control algorithm-maintained synchronization between the control input and the missile roll motion, thereby reducing pitch oscillation while preserving stable altitude, trajectory, velocity, and overall flight behaviour. These findings support the first hypothesis and are consistent with the principles of Missile Flight Dynamics Theory and Control System Theory, which state that synchronized control inputs are essential for maintaining stability in rolling airframe missiles. By continuously transforming the control commands into the rotating body frame, harmonic control compensates for the changing orientation of the control surfaces and enables more effective aerodynamic force generation throughout the flight.

The simulation results further indicate that controller performance was strongly influenced by the selected harmonic control parameters. Among all tested scenarios, an amplitude of 0.5 consistently produced the lowest pitch peak-to-peak response across the tested excitation frequencies, indicating the most favourable balance between control effectiveness and flight stability. Lower amplitudes provided insufficient control authority to fully compensate for roll-induced disturbances, whereas higher amplitudes generated larger oscillatory responses due to excessive control action. This behaviour reflects the fundamental characteristics of closed-loop control systems, where controller performance depends on the appropriate selection of control parameters to avoid under-compensation or excessive oscillation. Therefore, the second hypothesis is also supported, confirming that different combinations of harmonic control amplitude and frequency produce different flight responses and stability characteristics.

These findings are consistent with previous studies reporting that synchronized control strategies improve the stability of rolling airframe missiles by reducing dynamic coupling and maintaining effective control throughout the flight. However, unlike previous research that primarily focused on controller development or theoretical analysis, this study evaluated harmonic control using an integrated MATLAB–X-Plane simulation environment based on the R-Han 122 missile model. Furthermore, the systematic evaluation of multiple amplitude and frequency combinations enabled the identification of the optimum harmonic control parameter for the investigated configuration. This study therefore contributes to the development of simulation-based guidance and control systems for indigenous missile technology by providing practical insights into harmonic controller implementation and parameter optimization before experimental or flight-test validation.

CONCLUSIONS AND RECOMMENDATIONS

This study evaluated the implementation of harmonic control on the R-Han 122 rolling airframe missile through an integrated MATLAB–X-Plane simulation environment. The simulation results demonstrate that harmonic control effectively reduced the adverse effects of roll-induced dynamic coupling, resulting in improved longitudinal flight stability while maintaining stable altitude, trajectory, velocity, and overall flight performance. Furthermore, the performance of the controller was strongly influenced by the selected harmonic control parameters. Among the evaluated scenarios, an amplitude of 0.5 consistently produced the lowest pitch peak-to-peak response across the tested excitation frequencies, indicating the optimum balance between control effectiveness and flight stability. These findings confirm that harmonic control is a promising guidance and control strategy for improving the performance of the R-Han 122 rolling airframe missile and provide practical references for future missile control system development.

ADVANCED RESEARCH

This study was limited to simulation-based evaluation using an integrated MATLAB–X-Plane environment under predefined flight conditions. Factors such as aerodynamic uncertainties, environmental disturbances, actuator dynamics, sensor noise, and hardware implementation were not considered. Therefore, future research should validate the proposed harmonic control algorithm through hardware-in-the-loop (HIL) simulations or experimental flight testing. In addition, advanced control approaches, such as adaptive, robust, or intelligent control algorithms, may be investigated and compared with harmonic control to further improve the stability and guidance performance of rolling airframe missiles.

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