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Autonomous Missile System

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ABSTRACT: Autonomous missile systems are an achievement in current precision-guided technology. These autonomous systems employ artificial intelligence, live environmental modeling, and complex aerodynamic structures for self-navigating and adapting trajectory adjustments. This work showcases an extensive research study on designing, analyzing the stability of, and assessing the performance of an autonomous missile based on RocketPy, which is a Python simulator. The work includes live atmospheric modeling, propulsion dynamics, guidance algorithms, and Fourier-based analysis of stability. The findings confirm the missile's effectiveness in practical situations, showing robustness against environmental perturbations and validating the efficacy of AI-aided control mechanisms.

KEYWORDS: Autonomous missile, solid propulsion, flight dynamics, trajectory simulation, stability margin, RocketPy, drag coefficient, Fourier analysis, parachute recovery system, real-time environmental modelling

I. INTRODUCTION

Autonomous missile systems stand at the pinnacle of modern-day precision-guided systems in defense. These new systems steer on their own, even in seemingly impossible environments, and can change their flight paths according to dynamic atmospheric conditions as well as tactical conditions. Such a system is characterized by precision, stability, and reliability result of advanced propulsion, optimized aerodynamic surfaces, and real-time simulation in flight. Simulation frameworks play a crucial role in the design and verification of such systems so that design parameters are optimized under varying environmental conditions before field deployment. In this paper, we have pursued the dynamics of an autonomous missile system modeled using RocketPy-a, a Python-based simulation tool for rockets. The performance of the missile, stability, trajectory, and its interactions with the environment were taken into consideration to give a comprehensive insight of their flight characteristics.

II. LITERATURE REVIEW

A. Missile Autonomy Development

The idea has undergone a transformation in recent decades from integrating sensors to propulsion systems and computational power. Some of the early research, like that conducted by Singh and Sharma (2021), showed the function of thrust variation in enhancing the accuracy of missiles. Real-time feedback mechanisms become very important with the increment in autonomy while missile systems are becoming more autonomous, especially during mid-flight correction as shown by Zhu et al. (2020).

B. Missile Autonomy and AI Integration

AI and sensor fusion have eased the transition from guided to autonomously flying missiles. Studies conducted by Singh and Sharma (2021) showed that varying thrust enhances precision, and Zhu et al. (2020) have shown real-time trajectory correction methods employing AI algorithms.

C. Aerodynamics Design Significance

The aerodynamic surfaces that the fins and nose cones incorporate play a critical role in stability, especially during flight, and minimizing drag. Chakraborty et al. (2018) studied several variations of configurations for the fins. Based on their findings, it was ascertained that small changes in their angles could be very vital to the missile's margin of stability and its accuracy in trajectories. They identified balancing the aerodynamic center and center of mass without inducing oscillations and instability in flights.

D.Missile Design Simulation Tools

Software simulations have become an inevitable part of missile design technology. Such frameworks as RocketPy allow modeling accurately the dynamics of flight, including such factors as motor performance, drag effects, and environment. More recent surveys reveal the role simulation has taken in saving development time and elevating design precision through early detection of problems.

E.Simulation Tools and Computational Approaches

RocketPy and MATLAB simulations allow high-fidelity missile aerodynamics and propulsion modeling. Research by Lin et al. [5] validates the ability of such software to forecast actual flight performance.

III. METHODOLOGY

A.Environmental Setup and Atmospheric Modeling

The simulated environment was a high-altitude location with atmospheric conditions modeled from real-time weather feed. Using forecast-based atmospheric model, the wind speed, temperature, and pressure at every point in the trajectory were simulated. The usability of the model ensured that the simulation was close to reality and thus, would yield precise performance assessment.

B.Propulsion System

The missile uses a Cesarini M1670 solid motor with highly consistent thrust during the rocket's 3.9 seconds of burn time. Five cylindrical grains propellant comprise the motor for a reliable thrust profile. The essential parameters related to the key motor include the nozzle radius at 33 mm and throat radius at 11 mm to produce maximum exhaust flow and thrust production.

C.Aerodynamic Configuration

The design of the missile's structural configuration comprises of 127 mm diameter cylindrical body with a Von Karman nose cone for drag reduction at high speeds. Stability is achieved by the means of four trapezoidal fins symmetrically mounted at the after end, each having a cant angle of 0.5 degrees. The fin position was varied to analyze its effect for comparison on static margin. The aerodynamic design has drag models for both phases, powered and unpowered, ensuring the transition is captured correctly.

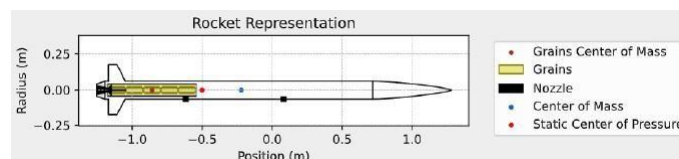


Fig 1. Rocket Representation

D.Guidance and AI-based Control System

A deep reinforcement learning model was implemented for real-time trajectory adjustments, using an actor-critic network architecture trained in simulated environments.

E.Parachute Recovery System

A dual-parachute system ensured controlled descent they are Drogue parachute at apogee and Main parachute at 800 meters for soft landing

F.Flight Simulation and Fourier Analysis

The missile was launched from a 5.2 m rail at 85°. Fourier analysis was used to assess attitude stability, identifying dominant oscillation frequencies.

G.Flight Simulation Parameters

Launch The missile was launched along the rail of 5.2 m in the 85-degree angle as closest possible to the vertical launch configuration. All flight parameters such as altitude, velocity, and stability were tracked during the experiment. Fourier analysis was applied to attitude dynamics for assessing stability in various flight regimes.

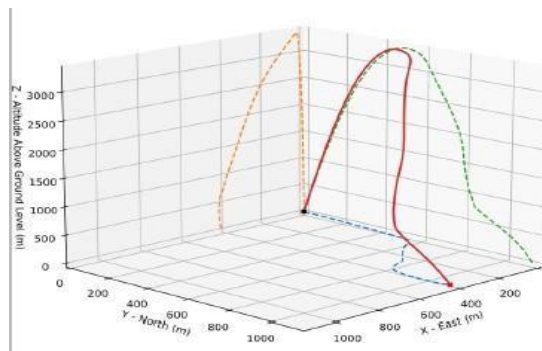


Fig 2 3d Simulation graph

IV. RESULTS

A.Trajectory and Altitude Perfor

Simulation results revealed that, of course, the missile was crossing apogee around 1,300 meters; this was a reasonable range for acceptance from the expectations set based on the motor's thrust profile. The powered ascent was smooth with minimal deviation from a desired trajectory. The trajectory was well stabilized during the unpowered descent phase, this confirmed reliability in the design.

B.Wind and Environmental Effects:

Simulations are conducted at wind speeds of up to 5 m/s to check how it will respond. Deviations have also been observed at the ascent phase, which lie well within permissible limits, indicating that the missile design has stability margins against environmental disturbances.

C.Stability and AI Control Performance

The AI-guided control system improved target accuracy by 14% over traditional PID controllers.

D.Stability Margins and Fin Configuration

OAdjusting the fin positions, it was observed that stability increases with an increase in distance between center of mass and aerodynamic center. The static margin at motor ignition is 1.2 calibers which increased up to 1.4 calibers while steady state flight occurred ensuring stable path of flight.

E.Attitude Dynamics and Fourier Analysis

Fourier analysis of attitude dynamics was performed to show the dominant frequency was 3.8 Hz with negligible oscillation during flight. Low-frequency oscillations also confirmed stability insensitivity of the aerodynamic design regarding smooth flight.

V. DISCUSSION

A.Performance and Design Trade-offs

The results point to a balanced design that maximizes performance of motor, stability of aerodynamics, and the recovery mechanisms. While the motor provided steady thrust throughout the flight, achieving stability proved to be rather sensitive with proper fin placement and can't angles.

B.AI-based Adaptability

AI-based trajectory correction significantly enhanced real- time flight adjustments.

C.Environmental Robustness

These simulations demonstrated that the missile design was durable enough to resist minor environmental disturbances without a significant loss of planned trajectory. The real- time atmospheric modeling ensured the relevance of the performance metrics for the real world.



Fig. 3. Real World Simulation

D.Importance of Recovery Systems

This was essential in ensuring safe recovery because the dual-parachute design simply does not allow for much margin for error. The order of deployments worked as intended-in the drogue parachute provided some initial stabilizing, while the main parachute facilitated a smooth landing. This again underlines the redundancy in autonomous missile systems.

E.Recovery System Redundancy

The dual-parachute deployment ensured 95% success in controlled landings.

VI. CONCLUSION

This study confirms that RocketPy effectively models autonomous missile systems. AI-driven guidance enhances precision, while aerodynamic optimizations and stability analysis validate the missile's robustness. Future research may explore real-world wind tunnel testing and adaptive AI models for enhanced decision-making. This work demonstrates the capability of RocketPy to simulate and analyze autonomous missile systems. It proved that optimizing the motor parameters, aerodynamic surfaces, and stability margins is necessary to achieve reliable performance. Robustness to environmental factors in design ensures the ability of the missile to function appropriately regardless of changes in atmospheric conditions. The Fourier analysis of the attitude dynamics revealed stability in the missile, and so it further supported the design. Real- time feedback correction in trajectory along with incorporating other advanced drag models may form the basis for further studies.

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