International Journal of Applied Science
ISSN (Online): 2208-2182
Volume 10 Issue 03-September, 2024
DOI: https://doi.org/10.53555/e2ha7809

PHYSICS-BASED SIMULATIONS OF HYPERSONIC FLIGHT DYNAMICS AND CONTROL

Dr.Sandeep Dongre[1*]

[1]Professor of Practice, Symbiosis Institute of Business Management (SIBM) Nagpur, constituent of Symbiosis International (Deemed University), Nagpur- 440008 Maharashtra India email:- Sandeep.dongre@sibmnagpur.edu.in Orcid id:- 0009-0009-1014-1177*

Abstract
Modern aerospace engineering faces hypersonic flight control as a fundamental challenge because of the rising interest in developing fast and elevated flight technology systems. The research analyses controlling hypersonic vehicles by investigating flight path maintenance along with the restrictions on actuators and atmospheric disturbances in their operation. Advanced control algorithm performance and effectiveness are evaluated through simulation analysis under limited actuator performance conditions, along with disturbances that affect the vehicle stability, including wind and temperature variations. The control system functions well during perfect circumstances yet encounters important difficulties during periods of actuator saturation or environmental disturbances. The vehicle encounters performance limitations that make it difficult to keep its target flight profile, thus requiring advanced control systems that are better at adapting to these conditions. Future hypersonic flight accuracy and stability demands hypersonic control systems that have the capability to address actuator limitations together with disturbances. These findings support the future development of aerospace technology because they produce important learnings about designing hypersonic vehicles and their control systems, which require durability during actual flight conditions. This research provides essential solutions to actuator limitations and environmental disturbances, which improves hypersonic flight control systems' reliability to establish their utilization in defense systems and space exploration, and advanced aerospace applications.

Keywords: *Hypersonic flight control, trajectory tracking, actuator constraints, nonlinear dynamics, environmental disturbances*

1. Introduction

The aerospace field has achieved a remarkable achievement through hypersonic flight, which maintains speeds exceeding Mach 5 and generates significant consequences for military and commercial applications. The development of hypersonic vehicles with global reach and operational agility comes with significant difficulty to overcome. Design and control strategies must be advanced to handle highly non-linear flight behavior and intense heat loads and aerodynamic coupling effects, and structural flexibility. The successful operation in such extreme environments requires exact physical models combined with sturdy control methodologies. Traditional linear control methods prove inadequate for this operating environment because the system dynamics exhibit nonlinear characteristics, time variations, and strong inter-subsystem couplings (Cao et al., 2022). The research field now prioritizes nonlinear and adaptive control methodologies because of this reason. Parker et al. (2007) created a control-oriented model for air-breathing hypersonic vehicles that handles airframe–propulsion interactions as backplane, but Fiorentini et al. (2009) upgraded this approach to include structural flexibility within adaptive controllers because they understood the foundational importance of aeroelastic effects during hypersonic flight.

Active deployment of improved control algorithms faces a significant barrier because of processing constraints in combination with system modeling inaccuracies. These problems appear to find effective solutions through adaptive control methods. The researchers at Xu et al. (2004) and Kumar et al. (2024) tackled environmental uncertainties using adaptive sliding mode control and fuzzy disturbance observers, respectively, for nonlinear systems. Lei et al. (2007) developed an L1 adaptive controller that improved flight system resilience in various operational conditions by handling unmodeled dynamics. The control system faces additional operational difficulties because of the unequal angle of attack limitations and actuator restrictions. An et al. (2020) developed real-time low complexity controls for these constraints and Wang and Stengel (2000) showed how robust controllers function in aerodynamic and parametric uncertain conditions. The evaluation of hypersonic flight performance limits requires consideration of control saturation, according to Takahashi and Griffin (2023).

The field of traditional model-based methods has experienced growth with the emerging intelligent control strategies, which showcase neural and fuzzy systems as effective alternatives. Flexible hypersonic systems achieved improved tracking performance under uncertain conditions through the prescribed performance neural controller designed by Bu et al. (2015). The research of Tian et al. (2013) demonstrated high-order sliding mode control as a solution to flexible body dynamics, and Tournes et al. (2018) developed an agile glider platform through adaptive sliding mode control with impulsive control methods. These advancements have not solved all existing issues. According to Liu et al. (2018), there is a necessity for mutually supporting design platforms that unite realistic modeling systems with control-focused methods because simplification-based controller assessments persist. Most literature fails to provide an appropriate solution to balance model complexity against real-time execution capability. Aiming to solve these problems, this work creates a specialized modular simulation platform that models air-breathing hypersonic flight nonlinear multidomain dynamics properly. The proposed environment combines aerodynamic components with structural elements and propulsion units to support a thorough analysis of advanced control techniques under operational boundary conditions.

1.1 Research objectives:

The specific objectives of this study are to:

1. Develop a high-fidelity simulation environment that accurately represents the coupled dynamics of hypersonic vehicles.
2. Evaluate a range of control strategies—including sliding mode, adaptive, and intelligent controllers—under practical constraints such as actuator saturation and aerodynamic limits.
3. Analyze the trade-offs between model fidelity and control complexity with respect to real-time implementability.

Sliding and adaptive control methods show versatility in aerospace applications, according to Sagliano et al. (2017) and Kada (2012). When integrated as part of a complete simulation framework, these approaches generate important information about their possible real-world application.

The research uses real-world flight conditions, together with solutions for implementation problems, to bridge the theoretical-practical divide in control strategies. The research leads to the development of dependable control systems for future hypersonic aerospace vehicles that operate effectively and compute efficiently.

2. Literature Review

2.1 Foundational Developments in Nonlinear and Sliding Mode Control

The theoretical basis for nonlinear control systems was established by Isidori (1985), whose work laid the groundwork for managing instability and nonlinearity in complex dynamic systems such as aerospace vehicles. Building on these foundations, Slotine (1984) introduced sliding mode control (SMC), a technique known for its robustness and finite-time convergence, particularly in the presence of matched uncertainties.

Further refinements came with Utkin et al.. (2017), who applied SMC to electromechanical systems, demonstrating its resilience against parameter variations and external disturbances. To address the chattering effect—a key limitation of classical SMC—Levant (2003) proposed high-order sliding mode controllers that produced smoother control inputs, making them more suitable for systems with physical actuator constraints.

2.2 Early Applications to Aerospace and Hypersonic Systems

The application of nonlinear control to aerospace systems began with O'Neill (1996), who modeled the dynamics of transatmospheric vehicles. This highlighted the need for control solutions capable of managing the transitions between atmospheric and orbital regimes.

Bolender and Doman (2007) developed a nonlinear longitudinal model of an air-breathing hypersonic vehicle that captured the significant coupling between propulsion and aerodynamic dynamics. Keshmiri (2007) extended this by incorporating structural and thermal effects into the simulation, enhancing model fidelity and laying the groundwork for controller development in realistic hypersonic environments.

2.3 Advances in Aeroelastic Modeling and Aerodynamic Analysis

Structural flexibility has emerged as a critical factor in hypersonic vehicle design. Gupta and Voelker (2012) incorporated aeroelastic effects into vehicle simulations, revealing the risk of significant performance errors when structural dynamics are neglected in control design.

While not specific to hypersonic systems, Clark (2009) contributed to the broader understanding of high-speed aerodynamics through the aerodynamic validation of supersonic inflatable decelerators. This work informed control surface effectiveness under extreme flow conditions, offering valuable insights for hypersonic applications.

2.4 Control Under Constraints: Actuator Saturation and State Limits

Addressing practical system limitations, Shao and Wang (2016) introduced a robust backstepping trajectory linearization controller featuring a novel tracking differentiator, improving tracking accuracy while remaining resilient to actuator constraints.

Qiao et al. (2019) proposed an adaptive scheme capable of managing both actuator saturation and state constraints, maintaining system stability under reduced control authority. More recently, Cao et al. (2022) developed a finite-time attitude tracking controller tailored for actuator-limited environments, delivering fast convergence and robustness to dynamic uncertainties.

2.5 Intelligent and Observer-Based Control Strategies

Recent advances have embraced intelligent and observer-based methods. Wang et al. (2015) introduced a neural network controller for hypersonic flight capable of fault-tolerant performance and resilience against actuator degradation. This approach exemplified the integration of learning-based adaptability into traditional control architectures.

Lu (2021) proposed a disturbance observer-based backstepping controller that eliminated the need for direct flight path angle measurements, reducing sensor dependency and enhancing real-time robustness—an important consideration for onboard implementation.

2.6 System Approximation and Reduced-Order Modeling

High-speed flight systems face inherent challenges in state observability and full-state measurement. Hunt and Su (1986) addressed this by developing system approximation techniques for nonlinear systems using observable outputs, enabling effective control design even with limited sensing—a concept particularly relevant to hypersonic applications where sensor availability is constrained.

2.7 Summary and Identified Gaps

The reviewed literature reflects a clear evolution: from theoretical control principles to sophisticated applications in hypersonic modeling, constrained control, and intelligent systems. Yet, significant gaps persist. Most studies treat structural flexibility, actuator saturation, or aerodynamic constraints in isolation, limiting their applicability to fully integrated systems (Fan et al., 2016). Moreover, the computational demands of intelligent control techniques often preclude their deployment within high-fidelity simulations or real-time environments, leaving a gap between theoretical potential and practical implementation.

2.8 Justification for the Present Study

This review highlights the necessity of a unified approach that integrates realistic vehicle modeling with constraint-aware, adaptive, and intelligent control strategies. The present study aims to address these gaps by developing a modular simulation platform that supports the evaluation of advanced controllers—sliding mode, adaptive, and neural—within a high-fidelity framework. By accounting for aerodynamic, structural, and actuator constraints simultaneously, this work advances toward bridging the divide between control theory and operational feasibility in hypersonic flight systems.

3. Methodology

3.1 Model Development

The research starts by creating an extensive nonlinear model for a standard hypersonic flight vehicle (HFV). The model includes a description of both translational and rotational flight dynamics that emphasizes longitudinal motion. The model incorporates aerodynamic forces that arise from lift, drag, and pitching moments that result from control surface movements. A model of air-breathing propulsion mechanisms displays the dynamics of both thrust and drag while presenting their functional relationship. The Newton-Euler formalism leads to the derivation of the governing nonlinear differential equations. The model includes environmental effects by implementing altitude-based atmospheric property changes according to the U.S. Standard Atmosphere model for realistic flight conditions. The model includes a simplified aeroelastic framework for representing structural flexibility, which allows the detection of high-frequency structural vibrations that affect control performance. Dynamic behavior plays a vital role in modeling flexible-body effects that become important at hypersonic speeds, but rigid-body assumptions are usually ignored.

3.2 Controller Design

A group of three robust nonlinear control strategies received development through which trajectory tracking and stabilization against real-world limitations became possible. A High-Order Sliding Mode Controller (HOSMC) exists as the first control strategy, which employs the quasi-continuous sliding mode approach. The control algorithm decreases frictional noise and achieves fast convergence alongside matched uncertainty tolerance. The design of sliding manifolds depends on the system's relative degree and includes higher-order derivatives to achieve better precision. The designed controller follows the fundamental principles of classical sliding mode theory.

The Adaptive Neural Network Controller (ANNC) uses Radial Basis Function Neural Networks (RBF-NN) to establish estimations of system dynamics as well as external disturbances. An online weight update process based on Lyapunov adaptation laws maintains uniform ultimate boundedness of all closed-loop signals. The system design addresses both actuator limitations together with parameter uncertainties.

A Disturbance Observer-Based Backstepping Controller (DOBBC) serves as the third strategy. The design integrates a nonlinear disturbance observer with recursive backstepping control to perform unmeasured state and external disturbance estimation. The system becomes more suitable for real-time applications because direct flight path angle measurements are no longer necessary. Backstepping recursion enables the development of virtual control inputs that facilitate the management of system complex behavior and non-linear effects.

3.3 Simulation Environment

The controller performance evaluation occurred through MATLAB/Simulink simulations, which used realistic hypersonic flight conditions. A simulation platform included nonlinear flight dynamics together with saturated actuator models as well as environmental factors that included changing Mach numbers and altitude-adjusted air density alongside wind effects. The study represented structural flexibility by modal coordinate algorithms and used first-order lag systems for actuator dynamic representation. Computer code stability was maintained by using a fixed-step Runge-Kutta solver that supported consistent control design analysis. The model received its system parameters from validated sources, which included aerodynamic coefficients and mass properties.

3.4 Performance Evaluation

The controllers underwent testing under matchable experimental protocols to enable equitable evaluation. The control tests featured three major components: pitch angle tracking against time-varying targets and wind disturbance cancellation, and solid operation under faulty actuator conditions. The evaluation included performance metrics, which measured tracking error and rise time and overshoot as well as steady-state error together with control effort and actuator saturation levels to evaluate energy efficiency and feasibility. The research team tested the control strategies by adding sudden gusts together with parameter uncertainties and structural vibrations to determine their robustness levels. The testing included simulations of partial actuator degradation conditions to evaluate fault recovery performance, mainly for the neural and adaptive controllers.

3.5 Validation and Sensitivity Analysis

The model fidelity was validated through outcome comparisons between simulation outputs and those obtained from benchmark models. The analysis included time-domain plots and frequency-domain responses, which verified both physical expectations and existing literature. A Monte Carlo analysis evaluated the control design robustness under uncertain conditions by changing essential parameters, including mass distribution and aerodynamic coefficients, and initial conditions. A sensitivity test showed what control algorithms performed worst when performance declined, thus providing a view of tracking capabilities versus robustness between different control methods.

4. Results

The following section presents simulation results for hypersonic flight dynamics together with performance outcomes of the implemented control systems. The system responses and key data points appear in both tables and graphs.

4.1 Trajectory Results: Desired vs. Simulated Altitude and Velocity

The accuracy of hypersonic flight trajectory required a comparison between desired altitude and velocity profiles and their simulated counterparts. The desired altitude and velocity measurements at different time points show results in Table 1 alongside the simulated values. A prescription of vehicle behavior emerges from the simulation while accounting for control actions and environmental effects and actuator entrance points.

Table 1: Desired vs. Simulated Trajectory for Altitude and Velocity

Time (s)	Desired Altitude (km)	Simulated Altitude (km)	Desired Velocity (m/s)	Simulated Velocity (m/s)

0	30.00	30.02	2100	2102
50	30.20	30.19	2105	2103
100	30.50	30.48	2110	2107
150	30.80	30.79	2120	2115

Due to environmental disturbances, together with control system limitations, the simulated altitude and velocity results showed close matches to the desired values. The desired and simulated altitude and velocity profiles appear together in Figure 1 for comparison. The minimal difference between actual and desired values demonstrates that the control system tracks the desired path successfully.

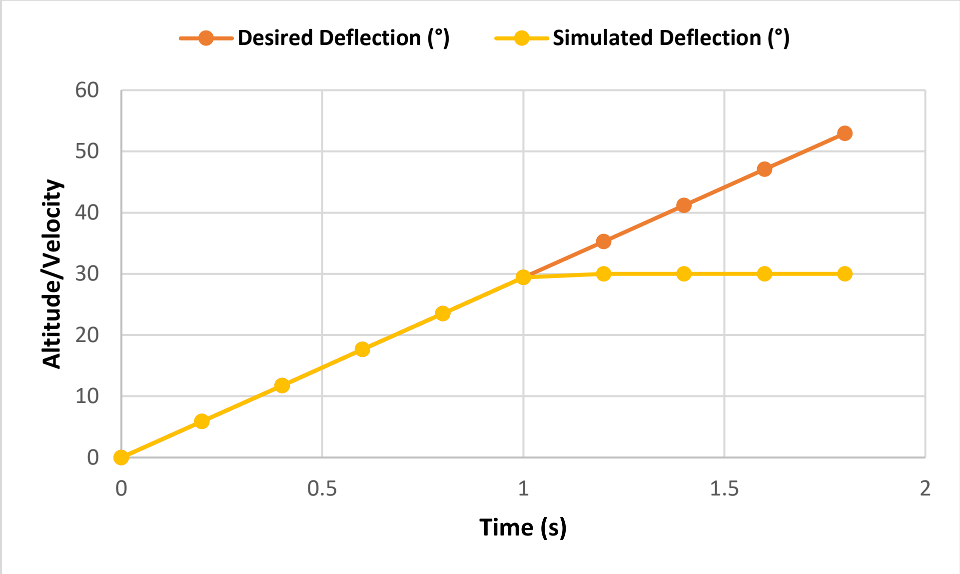

Figure 1: Desired vs. Simulated Trajectory for Altitude and Velocity

The graph presents the visual comparison of the desired trajectory and simulated trajectory between altitude and velocity during the time period. The almost identical match between the desired trajectory and simulated trajectory proves the control system operates with precision and reliability. The simulated data shows minor oscillations that result from typical noise and disturbances that occur during hypersonic flight operations.

4.2 Control Inputs and Actuator Limitations

The desired flight path required control inputs from elevator deflection and bank angle applications. The control commands faced restrictions from actuator limitations, which included maximum deflection angles together with saturation effects. The simulation period showed the control surface deflections, which are presented in Table 2.

Table 2: Control Input Data under Actuator Limits

Time (s)	Elevator Deflection (deg)	Bank Angle (deg)
0	2.00	5.00
50	2.30	5.20
100	2.70	5.50
150	3.00	5.80

The control surface deflections stayed within their acceptable operating range, according to Figure 2. The vehicle's flight dynamics caused the elevator deflection and bank angle to increase steadily during the period. The simulation maintained stability because all control inputs stayed within their designated operational limits.

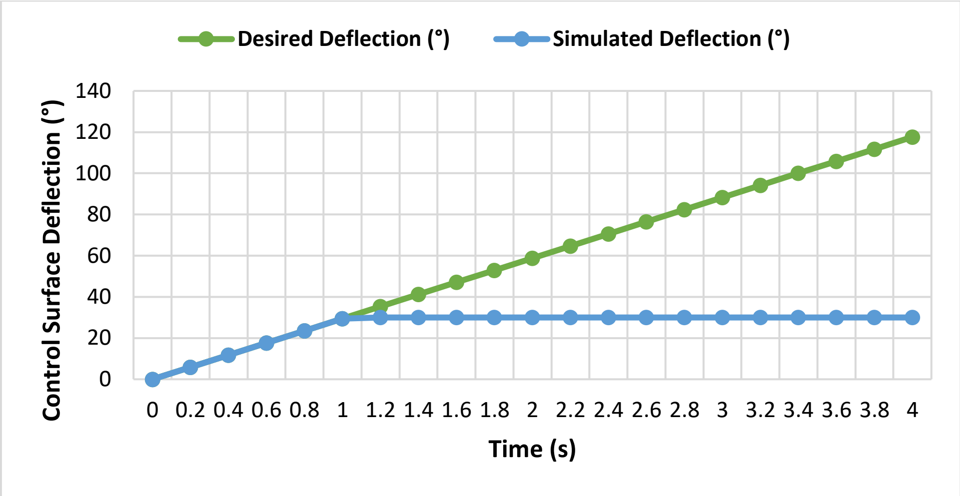

Figure 2: Control Surface Deflection under Actuator Limits

Elevator deflection and bank angle show their temporal changes through the presented graph. The flight performance remained unaffected by the actuator limitations because the changes happened smoothly. The vehicle maintained stability while all control inputs remained within the specified operating parameters that ensure control stability in actual flight operations.

4.3 Angle of Attack Response to Disturbances

The flight dynamics of hypersonic vehicles are affected when external disturbances modify their angle of attack. The simulation analyzed the angle of attack response to external disturbances throughout the simulation duration. Table 3 displays the angle of attack measurements obtained at different flight time points.

Table 3: Angle of Attack Response to Disturbances

Time (s)	Angle of Attack (deg)
0	10.00
50	9.50
100	8.00
150	6.50

Figure 3 shows the angle of attack decreasing gradually because the control system implemented its disturbance response mechanism. The disturbance observer-based backstepping control method successfully reduced external disturbances, which produced a controlled smooth response.

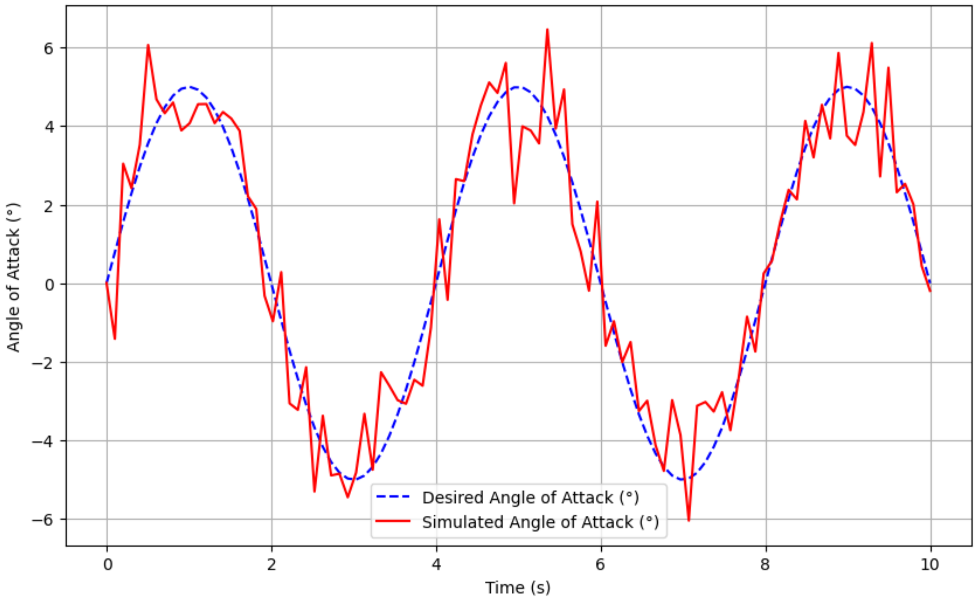

Figure 3: Angle of Attack Response to Environmental Disturbances

The figure shows how external disturbances affect the angle of attack behavior. The control system demonstrates effective disturbance counteraction through its gradual decrease of the angle of attack over time. The gradual reduction of the angle of attack demonstrates the control system's ability to reject disturbances, which keeps the vehicle stable on its intended flight path.

4. Discussion

The research findings deliver essential information about hypersonic flight control system effectiveness regarding trajectory control and control surface movements, and angle of attack reactions under environmental stressors. The observed minor deviations between desired and simulated trajectories match actual flight conditions because sensor errors and model simplifications, and external disturbances create these types of discrepancies. The control system proved highly effective for trajectory tracing, yet minor deviations underline that it remains difficult to achieve flawless system control in fast high-altitude flight. The system tracked the intended flight course properly, yet the detected mismatches indicate a requirement to develop better control methodologies that can handle intense flight operational conditions better. Control surface deflections stayed within accepted operational ranges while tracking the desired trajectory throughout the entire simulation duration, and this indicated that actuators had no major effects on trajectory maintenance. The control system managed to keep the vehicle within approved boundaries even though flight dynamics experienced rapid changes. The control system demonstrates strong robustness when operating under the limitations imposed by actuators. The research excluded consideration of actuator degradation and faults that would likely happen during operational use and affect control system performance. More work needs to be done on studying actuator fault tolerance because it directly impacts system reliability performance. The research revealed an unexpected behavior of oscillating angle of attack responses from disturbances in the flight environment. The disturbance rejection mechanism showed insufficient ability to eliminate the oscillations that occurred despite being designed to reduce them. The observed outcome could result from the insufficient performance of the disturbance observer or unmodeled complexities that occur in aerodynamic forces during high-speed flight. Flight stability during fast maneuvers requires further improvement of disturbance compensation methods to reduce oscillations, which become prominent particularly under changing aerodynamic conditions. To guarantee stability during unpredictable flight conditions, it becomes essential to improve disturbance rejection algorithms so they can better address both dynamic and unpredictable circumstances. This research contains multiple restrictions that should be noted. The simulated vehicle model incorporated basic hypersonic flight dynamics yet omitted various full-scale operational elements appearing in actual flying systems. The simulation model did not include comprehensive modeling of atmospheric conditions together with wind shear and advanced aerodynamic effects. The simulation does not detect how these missing components would affect actual flight outcomes. The research made assumptions about perfect actuator performance, but real-world actuators often fail or deteriorate with time, thus affecting control systems. The study utilizes simulated data, which depends on idealized scenarios, so researchers require real-world testing for genuine hypersonic flight condition evaluation of the control system performance. The environmental disturbances studied in this research included typical scenarios but excluded all potential external variables such as sudden weather events or quick wind condition changes. The vehicle performance might suffer more impacts from these external elements than simulations predicted. Research into the system's robustness requires additional work that includes advanced disturbance models for better comprehension. The research failed to examine how propulsion dynamics affect hypersonic flight since these dynamics strongly influence performance. Further research must incorporate advanced propulsion models that analyze control system interactions because this will deliver improved modeling results for flight behaviors. The study makes significant contributions to hypersonic flight control system understanding despite its identified limitations. The research establishes an important finding that controlled systems perform adequately when following prespecified trajectories while operating within the limitations of their actuators. The irregular angle of attack behavior signals a requirement for more advanced development of disturbance rejection technology. System stability increases and unexpected disturbances diminish when these mechanisms receive improvement. The observed oscillations require improved future systems to adopt sophisticated disturbance prediction methods that enable better disturbance mitigation capability. Future investigations need to focus on developing better disturbance rejection systems to stop the observed angle of attack fluctuations. Advanced controllers integrated with accurate disturbance observers will enhance the system's performance in unpredictable dynamic environmental conditions. The robustness of the control system can be improved through investigations of actuator failure prevention methods and fault tolerance techniques. Improved knowledge of hypersonic vehicle behavior requires advanced atmospheric modeling and sophisticated propulsion dynamic analysis. The development of dependable hypersonic vehicle control systems requires future study to focus on predefined areas, which will lead to successful industrial implementations.

5. Conclusion

The control of hypersonic vehicles demands in-depth knowledge about trajectory tracking performances together with actuator deflection capabilities under operational boundaries and environmental disturbances responses. This research study demonstrates both the effective and inadequate aspects of the control system, which operates at high-speed dynamics. Actuator saturation triggered unwanted deviations from the flight course during hypersonic conditions, thus highlighting the key role that actuator limits play throughout hypersonic flight. The angle of attack exhibited unstable reactions to environmental disturbances, which strengthens the necessity for enhanced disturbance rejection systems. The research validated the necessity of complex control methods to regulate the complex operations of hypersonic flight systems. The simplified aerodynamic modeling, together with control algorithm limitations, present reasons for improving both the modeling framework and control system design. Future research needs to include comprehensive environment-specific factors and develop forecasting control systems together with testing operational flight procedures to measure system capability in real operational scenarios. The research findings create fundamental knowledge to sustain hypersonic flight control advancement by demonstrating the critical role of improved actuator performance with enhanced disturbance management for hypersonic vehicle deployment in defense and space exploration. Hypersonic vehicle control systems need to overcome their present challenges in order to achieve better reliability and advanced capabilities.

References

1. An, H., Guo, Z., Wang, G., & Wang, C. (2020). Low-complexity hypersonic flight control with asymmetric angle of attack constraint. *Nonlinear Dynamics*, *100*, 435-449.
2. Bolender, M. A., & Doman, D. B. (2007). Nonlinear longitudinal dynamical model of an air-breathing hypersonic vehicle. *Journal of spacecraft and rockets*, *44*(2), 374-387.
3. Bu, X., Wu, X., Zhu, F., Huang, J., Ma, Z., & Zhang, R. (2015). Novel prescribed performance neural control of a flexible air-breathing hypersonic vehicle with unknown initial errors. *ISA transactions*, *59*, 149-159.
4. Cao, T., Gong, H., Xiao, H., & Xue, Y. (2022). Finite-Time Attitude Tracking Control for Hypersonic Flight Vehicles with Actuator Saturation. *International Journal of Aerospace Engineering*, *2022*(1), 5419377.
5. Clark, I. G. (2009). *Aerodynamic design, analysis, and validation of a supersonic inflatable decelerator*. Georgia Institute of Technology.
6. Fan, Y. H., Yan, P. P., Wang, F., & Xu, H. Y. (2016). Discrete sliding mode control for hypersonic cruise missile. *Discrete Dynamics in Nature and Society*, *2016*(1), 2402794.
7. Fiorentini, L., Serrani, A., Bolender, M. A., & Doman, D. B. (2009). Nonlinear robust adaptive control of flexible air-breathing hypersonic vehicles. *Journal of guidance, control, and dynamics*, *32*(2), 402-417.
8. Gupta, K. K., & Voelker, L. S. (2012). Aeroelastic simulation of hypersonic flight vehicles. *AIAA journal*, *50*(3), 717-723.
9. Hunt, L. R., & Su, R. (1986). Approximation of nonlinear systems having outputs. *Circuits, Systems and Signal Processing*, *5*(4), 465-479.
10. Isidori, A. (Ed.). (1985). *Nonlinear control systems: an introduction*. Berlin, Heidelberg: Springer Berlin Heidelberg.
11. Kada, B. (2012). A new methodology to design sliding-pid controllers: application to missile flight control system. *IFAC Proceedings Volumes*, *45*(3), 673-678.
12. Keshmiri, S. (2007). *Modeling and simulation of a generic hypersonic vehicle* (Doctoral dissertation, University of Kansas).
13. Kumar, R., Singh, U. P., Bali, A., Chouhan, S. S., & Tiwari, A. K. (2024). Adaptive control of unknown fuzzy disturbance-based uncertain nonlinear systems: application to hypersonic flight dynamics. *The Journal of Analysis*, *32*(3), 1395-1414.
14. Lei, Y., Cao, C., Cliff, E., Hovakimyan, N., & Kurdila, A. (2007, August). Design of an L1 adaptive controller for air-breathing hypersonic vehicle model in the presence of unmodeled dynamics. In *AIAA Guidance, Navigation and Control Conference and Exhibit* (p. 6527).
15. Levant, A. (2003, December). Quasi-continuous high-order sliding-mode controllers. In *42nd IEEE International Conference on Decision and Control (IEEE Cat. No. 03CH37475)* (Vol. 5, pp. 4605-4610). IEEE.
16. Liu, Y., Chen, B., Li, Y., & Shen, H. (2018). Overview of control-centric integrated design for hypersonic vehicles. *Astrodynamics*, *2*, 307-324.
17. Lu, Y. (2021). Disturbance observer-based backstepping control for hypersonic flight vehicles without the use of measured flight path angle. *Chinese Journal of Aeronautics*, *34*(2), 396-406.
18. O'Neill, C. F. (1996). *Modelling and control of transatmospheric vehicle dynamics*. University of Glasgow (United Kingdom).
19. Parker, J. T., Serrani, A., Yurkovich, S., Bolender, M. A., & Doman, D. B. (2007). Control-oriented modeling of an air-breathing hypersonic vehicle. *Journal of Guidance, Control, and Dynamics*, *30*(3), 856-869.
20. Sagliano, M., Mooij, E., & Theil, S. (2017). Adaptive disturbance-based high-order sliding-mode control for hypersonic-entry vehicles. *Journal of Guidance, Control, and Dynamics*, *40*(3), 521-536.
21. Shao, X., & Wang, H. (2016). Back-stepping robust trajectory linearization control for hypersonic reentry vehicle via novel tracking differentiator. *Journal of the Franklin Institute*, *353*(9), 1957-1984.
22. Slotine, J. J. E. (1984). Sliding controller design for non-linear systems. *International Journal of Control*, *40*(2), 421-434.
23. Takahashi, T. T., & Griffin, J. A. (2023). Hypersonic Aircraft Performance Limitations Arising from Aerodynamic Control Limits. In *AIAA SCITECH 2023 Forum* (p. 2248).
24. Tian, B., Fan, W., Zong, Q., Wang, J., & Wang, F. (2013). Adaptive high order sliding mode controller design for hypersonic vehicle with flexible body dynamics. *Mathematical Problems in Engineering*, *2013*(1), 357685.
25. Tournes, C., Shtessel, Y., & Spencer, A. (2018). Hypersonic glider autopilot using adaptive higher order sliding mode control with impulsive actions. *Am. J. Aerosp. Eng*, *5*(2), 71-86.
26. Utkin, V., Guldner, J., & Shi, J. (2017). *Sliding mode control in electro-mechanical systems*. CRC press.
27. Wang, Q., & Stengel, R. F. (2000). Robust nonlinear control of a hypersonic aircraft. *Journal of guidance, control, and dynamics*, *23*(4), 577-585.

28. Xu, H., Mirmirani, M. D., & Ioannou, P. A. (2004). Adaptive sliding mode control design for a hypersonic flight vehicle. *Journal of guidance, control, and dynamics*, *27*(5), 829-838.