LOGAN: An Integrated Hypersonic Vehicle Model

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***Abstract* — The development of hypersonic vehicles requires multidisciplinary simulation environments capable of representing the strong coupling between flight mechanics, aerodynamics, propulsion, and control systems. This work presents LOGAN (Large Over-Mach Glider Aircraft New Generation), an integrated hypersonic vehicle model developed in MATLAB/Simulink for system-level analysis of air-breathing hypersonic vehicles. The proposed model combines an atmospheric model, nonlinear six-degree-of-freedom flight mechanics, aerodynamic modeling, one-dimensional scramjet thermodynamics, guidance, navigation, flight control, within a unified and modular simulation environment. To demonstrate the capabilities of the proposed platform, two intercontinental flight missions at different cruise altitudes were simulated until complete fuel depletion. The results demonstrate the consistency of the integrated model in representing the coupled behavior of the vehicle and propulsion system, providing a flexible simulation environment for mission analysis and the development of future hypersonic technologies.**

***Keywords:* Hypersonic Vehicle, Scramjet, Simulation.**

I. INTRODUCTION

Hypersonic vehicles have attracted considerable attention due to their potential applications in space transportation, high-speed flight, and defense systems [1]. Operating at Mach numbers above five introduces complex aerodynamic, structural, thermal, and propulsion phenomena that significantly increase the complexity of vehicle analysis and design. Among the different hypersonic concepts, air-breathing hypersonic vehicles (AHVs), particularly waverider configurations, have been extensively investigated because of the strong interaction between the airframe and the scramjet propulsion system [1–3].

Scramjet engines operate according to the Brayton thermodynamic cycle while maintaining supersonic airflow throughout the combustion chamber [4,5]. This operating condition enables efficient propulsion at hypersonic speeds but also introduces challenges related to combustion stability, thermal choking, and the coupling between propulsion and flight dynamics [6–8]. Therefore, integrated simulation environments have become important tools for the development and evaluation of hypersonic vehicles.

Several mathematical models have been proposed to represent hypersonic vehicle dynamics. Bolender and Doman [9,10] developed first-principle models incorporating aerodynamic, aeroelastic, and propulsion effects, while Parker et al. [11] presented a control-oriented formulation derived from these models. Nonlinear six-degree-of-freedom models were subsequently developed by Keshmiri et al. [12–14], and later extended to include aero-servoelastic and flexible-body effects by Clark et al. [15] and Zhang et al. [16].

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In parallel with advances in mathematical modeling, significant efforts have been devoted to guidance, navigation, trajectory optimization, and flight control, including nonlinear, adaptive, predictive, and artificial intelligence-based approaches [2,17–20]. These developments require simulation environments capable of simultaneously representing aerodynamic, structural, propulsion, and control subsystems.

Although substantial progress has been achieved, many available models have been developed for specific applications, such as flight dynamics analysis, propulsion studies, or controller development. The integration of these disciplines into a unified simulation environment remains an important topic for air-breathing hypersonic vehicles, where the interaction between the airframe and the propulsion system directly influences vehicle performance.

This work presents LOGAN (Large Over-Mach Glider Aircraft New Generation), an integrated hypersonic vehicle model developed in MATLAB/Simulink. The proposed model combines nonlinear six-degree-of-freedom flight dynamics, aerodynamic models, atmospheric representation, scramjet thermodynamic modeling, and control interfaces within a single simulation environment. In addition, the model incorporates visualization capabilities and a modular architecture that facilitates subsystem integration and future developments. The resulting simulation environment provides a platform for multidisciplinary analyses involving vehicle performance, guidance, navigation, flight control, and propulsion under transient hypersonic flight conditions. Figure 1 illustrates the conceptual design of the LOGAN hypersonic vehicle.

Figure 1. LOGAN Conceptual View.

II. LOGAN INTEGRATED SIMULATION MODEL

LOGAN (Large Over-Mach Glider Aircraft New Generation) is an integrated simulation model developed in MATLAB/Simulink for the multidisciplinary analysis of air-breathing hypersonic vehicles. The simulation environment combines flight mechanics, aerodynamics, propulsion, atmosphere, structural dynamics, guidance, navigation, and control within a modular architecture, allowing each subsystem to exchange information during the numerical integration process. The framework has been progressively

developed through a series of studies covering flight dynamics, scramjet thermodynamics, aerodynamic analysis, control systems, and thermal management .

Rather than focusing on a single discipline, the proposed model integrates the principal physical phenomena governing hypersonic flight into a unified simulation environment. Table 1 summarizes the main subsystems currently implemented in LOGAN together with the corresponding mathematical formulations and supporting references.

Table 1. Main modules implemented in the LOGAN integrated simulation model.

Module	Description	References
Atmospheric Model	Extended ISA atmosphere	[21]
Flight Mechanics	Nonlinear rigid-body 6-DOF equations of motion	[21]
Aerodynamic Model	Aerodynamic coefficients and force/moment model	[21]
Scramjet Engine	One-dimensional thermodynamic model based on oblique shock waves, Rayleigh flow and isentropic flow	[22-23]
Longitudinal Control Law	Flight path angle control	[24]
Lateral-Directional Control Law	Roll, yaw and sideslip control	[25]
Scramjet Control Law	Mach number control through fuel flow regulation	[26]
Total Energy Control System (TECS)	Integrated velocity and altitude control	[27]
Autopilot System	Altitude hold and waypoint navigation	[28]
Cooling System	Active thermal management	[29]

Figure 2 presents the LOGAN model integrated architecture. The simulation is composed of coupled mathematical models representing the atmosphere, aerodynamics, flight mechanics, scramjet propulsion, mass variation, actuator dynamics, guidance, navigation, and flight control. The atmospheric model provides the flight condition variables required by the aerodynamic and propulsion model, while the aerodynamic and scramjet models determine the forces and moments acting on the vehicle. These quantities are subsequently considered by the equations of motion, which determine the vehicle states throughout the simulation. The control system receives the relevant flight states and generates the commands required by the actuators, establishing the closed interaction between the vehicle dynamics and the propulsion system. The model also includes the mass variation resulting from fuel consumption, which is incorporated into the vehicle dynamics during the simulated mission. In this manner, the different subsystems operate concurrently and exchange their respective variables at each integration step, allowing the transient behavior of the complete vehicle to be evaluated under the flight conditions. The implementation is modular, with the individual models represented by separate subsystems within the Simulink environment. The complete LOGAN simulation model, including the implemented subsystems and associated files, is publicly available in the project repository [30,31].

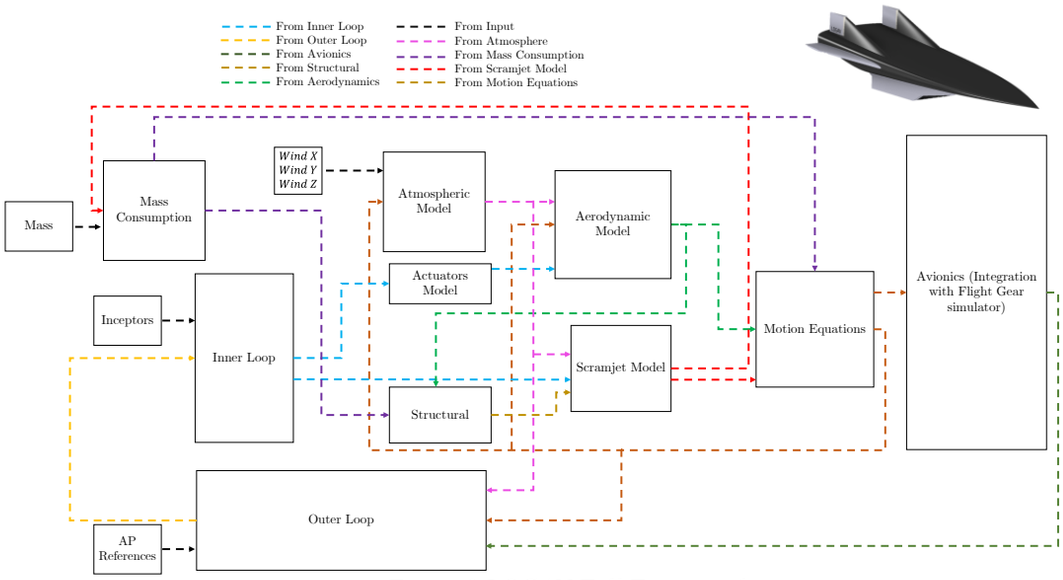

Figure 2.LOGAN Full Framework.

III. SIMULATION RESULTS

To demonstrate the capabilities of the proposed integrated simulation model, this section presents two representative simulation scenarios involving the LOGAN scramjet-powered hypersonic waverider operating at different flight altitudes.

Figure 3 presents an example of the integration between the LOGAN simulation model and the open-source FlightGear flight simulator, enabling real-time three-dimensional visualization of the vehicle throughout the simulated mission.

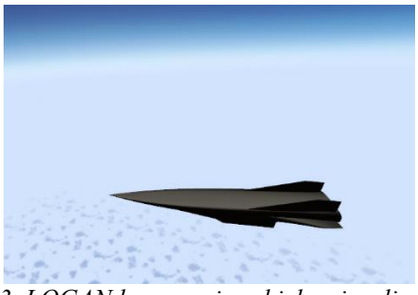

Figure 3. LOGAN hypersonic vehicle, visualized in the FlightGear simulation.

Figures 4 and 5 compare two intercontinental flight missions simulated with the LOGAN model until complete fuel depletion. In the first scenario, the vehicle maintains a constant cruise altitude of 65,000 ft, whereas in the second it performs a continuous climb to 100,000 ft. The higher-altitude mission achieves a greater flight range due to the reduction in aerodynamic drag and the improved propulsion efficiency under lower atmospheric density. These results demonstrate the capability of the integrated simulation model to evaluate different mission profiles and operating conditions.

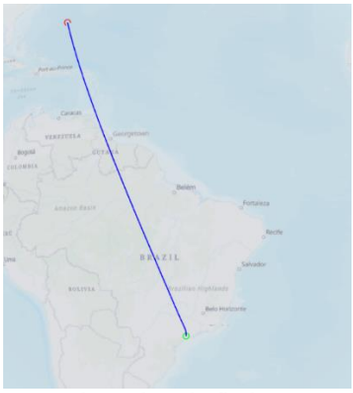

Figure 4. low-altitude flight trajectory.

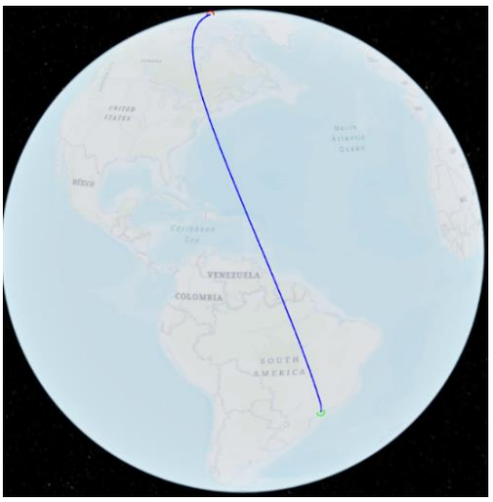

Figure 5. high-altitude flight trajectory.

Figure 6 compares the longitudinal responses of the two intercontinental missions. Subfigure (a) shows the altitude profiles, where one mission remains at 65,000 ft while the other performs a continuous climb to 100,000 ft. The corresponding load factors, shown in (b), remain stable throughout the simulations, with only a small transient during the climb maneuver. The Mach number histories in (c) indicate that both missions start at Mach 10 and gradually decelerate as fuel is depleted. The simulations are terminated when the Mach number falls below Mach 4, which corresponds to the lower validity limit of the aerodynamic and propulsion models. Finally, subfigure (d) presents the calibrated airspeed, showing a slower decay for the high-altitude mission due to the lower aerodynamic drag. Overall, the results indicate that high-altitude cruise extends the hypersonic flight range and endurance.

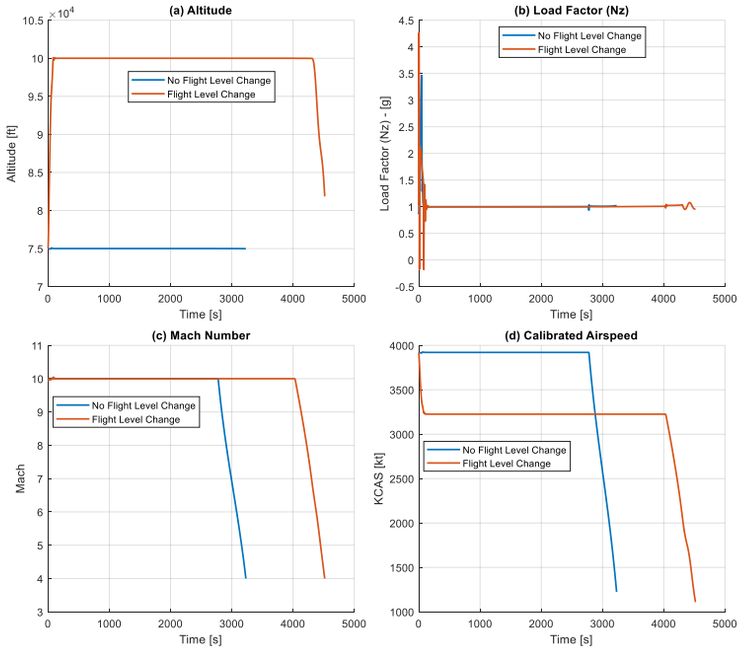

Figure 6. Comparison of longitudinal flight response with and without flight level change during intercontinental mission.

Figure 7 compares the scramjet performance for the two intercontinental missions. Subfigure (a) shows the total irreversibility, which decreases throughout the flight in both cases as fuel flow is progressively reduced, with consistently lower values for the high-altitude mission. The exergetic, thermal, and propulsive efficiencies, presented in (b)–(d), indicate superior propulsion performance during high-altitude cruise, although a degradation is observed near the end of the mission as the vehicle approaches the lower operating limit of the hypersonic regime. Subfigures (e) and (f) show the specific impulse and fuel flow rate, respectively, demonstrating that the high-altitude mission achieves higher specific impulse while requiring a lower fuel flow throughout most of the flight. Finally, subfigures (g) and (h) present the inlet compression ramp angles, which remain nearly constant during cruise and increase only near the end of the mission as the propulsion control system compensates for the reduction in engine performance. Overall, the results demonstrate the thermodynamic and propulsive benefits of high-altitude hypersonic cruise.

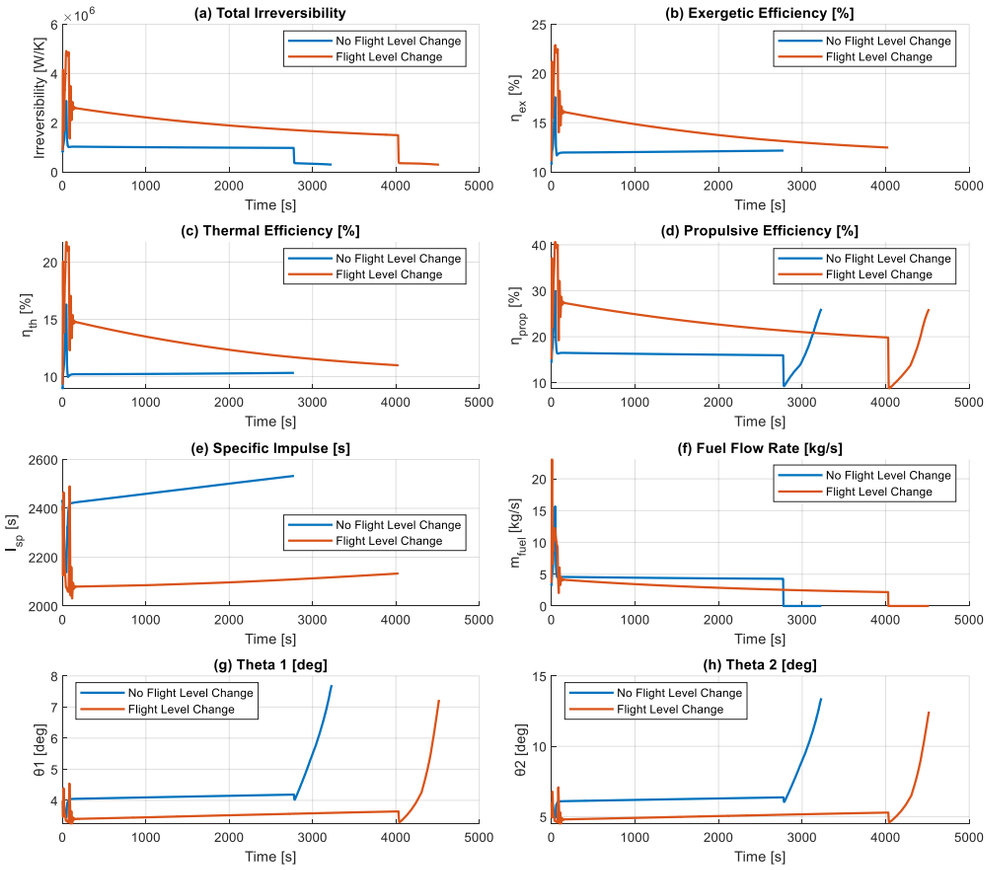

Figure 7. Comparison of scramjet performance with and without flight level change during intercontinental mission.

Figures 8 and 9 compare the fuel flow rate and cumulative fuel consumption for the two intercontinental missions. Subfigure (a) shows that the mission with flight level change requires a higher fuel flow during the initial climb to 100,000 ft. However, after reaching cruise altitude, the fuel flow decreases and remains below that of the 65,000 ft mission owing to the lower aerodynamic drag. The cumulative fuel consumption, shown in subfigure (b), confirms that the high-altitude mission consumes less fuel throughout the flight, despite the initial climb penalty. Consequently, the reduced fuel consumption extends the flight range and endurance, demonstrating the operational advantages of high-altitude hypersonic cruise.

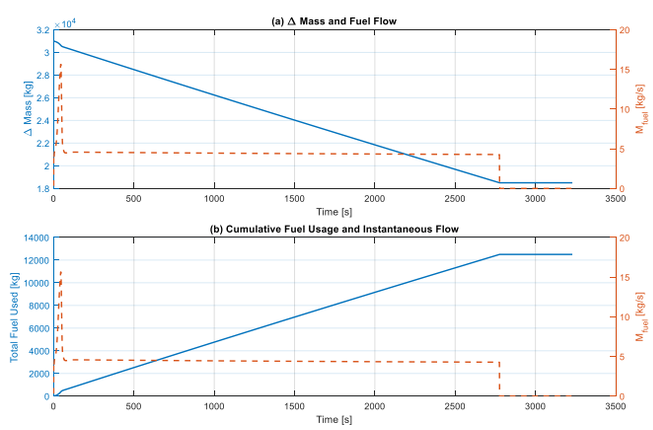

Figure 8. Mass depletion and fuel flow response without flight level change during low-altitude (65,000 ft) intercontinental mission.

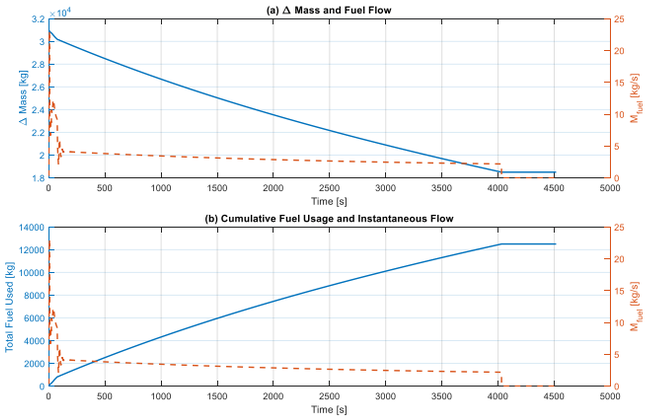

Figure 9. Mass depletion and fuel flow response with flight level change to 100,000 ft during intercontinental mission.

IV. CONCLUSIONS

This paper presented LOGAN (Large Over-Mach Glider Aircraft New Generation), an integrated simulation model developed in MATLAB/Simulink for air-breathing hypersonic vehicles. The proposed environment combines atmospheric, aerodynamic, flight mechanics, scramjet propulsion, guidance, navigation, control within a modular architecture, providing a unified platform for multidisciplinary hypersonic vehicle analysis.

The capabilities of the proposed model were demonstrated through two intercontinental flight missions performed under different cruise altitudes. The simulation results showed that the integrated environment consistently captures the interactions between vehicle dynamics and propulsion throughout the mission. The comparison between the two flight profiles indicated that high-altitude cruise provides greater flight range, lower fuel consumption, and improved propulsion performance due to the reduction in aerodynamic drag.

The modular organization adopted in LOGAN allows individual subsystems to be independently extended or replaced without affecting the remaining simulation architecture. Consequently, the proposed model provides a flexible platform for future developments involving advanced guidance, control, propulsion, thermal management, optimization, and autonomous flight strategies for hypersonic vehicles, enabling civil and military applications.

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