Physics-Guided Multifidelity Learning for Characterization of Blunt-Body Dynamic Stability

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Research Objectives

Goal: Establish advanced physics-guided models to enable predictive dynamic stability simulations of atmospheric entry vehicles in the entire Mach regime of interest (Mach 2.5 – Mach 0.3) with embedded uncertainty relevant landing conditions.

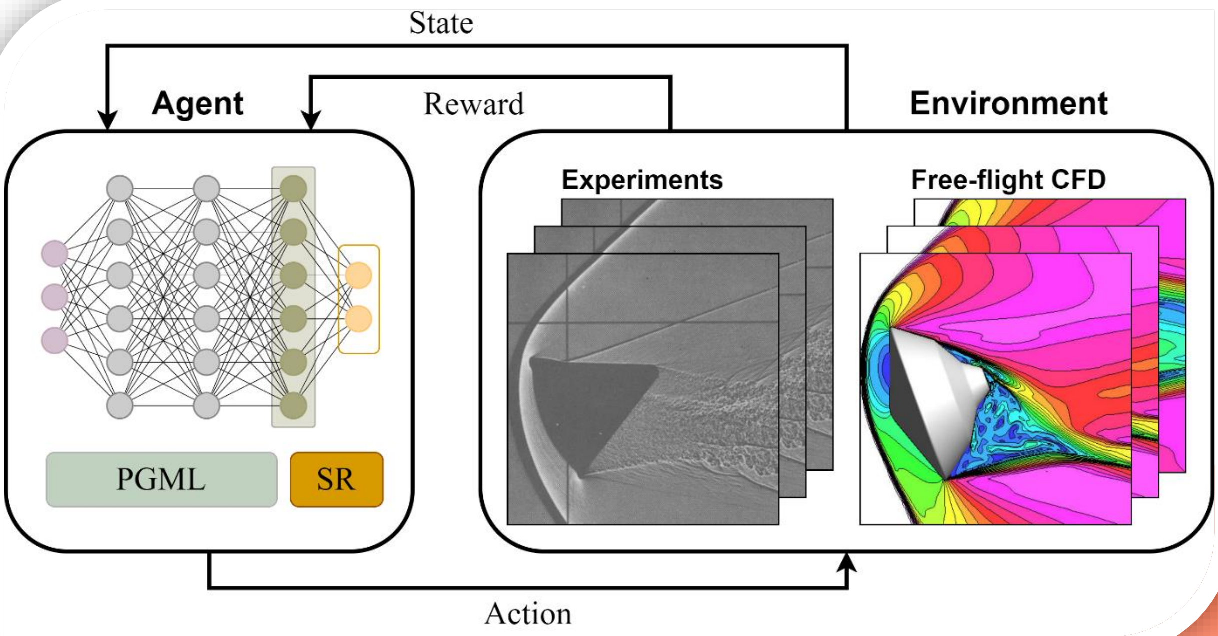
Key Innovations:

- **Address long-standing limitations in vehicle dynamics** at supersonic and transonic Mach numbers and Reynolds numbers through a physics guided learning approach that connects the reduction of experimental and computational data to development of an improved aerodynamic model.
- **Uncertainty in modeling parameters will be characterized through data** (experimental and computational) using multifidelity learning and scalable inference techniques.

Comparison to SOA: An end-to-end hybrid dynamic and learning framework for synthesizing multimodal experimental and numerical data sets to generate optimal parameters for vehicle dynamics does not currently exist.
Start TRL 1: Formulating the proposed framework.
End TRL 3: Data-driven models validated against high fidelity simulations and experimental data sets with quantified uncertainties.

Approach

- **Formulate** a reinforcement learning framework for discovery of new insights into **vehicle dynamic behavior** of free flight relevant environment.
- **Develop** Physics Guided Multifidelity Learning (PGML) approaches for aerodynamic characterization with reduced uncertainties.
- **Integrate** PGML with reinforcement learning to improve generalizability, interpretability, and trustworthiness of data driven learning computational modules backward compatible with existing numerical and experimental databases as well as prior theoretical and empirical knowledge and models.
- **Use** symbolic regression (SR) tools to **discover** new functional forms of vehicle dynamic stability parameters that can be embedded in existing NASA codes.



Potential Impact

The success of future space missions will require accurate modeling of reentry vehicle dynamic stability (STMD, EVT)

This ESI Project will enable predictive modeling capabilities to support NASA missions relevant to atmospheric entry vehicle design activities.

- The PGML technology will create revolutionary data reduction and aerodynamic modeling capabilities to enable rapid, safe, and expanded access to diverse surface destinations.
- The PGML technology will (a) allow the synthesis of existing heterogeneous multimodal experimental and simulation data sets and (b) forge novel hybrid dynamics and data-centric model fusion approaches to accelerate the analysis, design, and development of planetary entry vehicle technologies.