Gala: A Python package for galactic dynamics

Adrian M. Price-Whelan[1,2*] **and Author Without ORCID**[2*]

1 Lyman Spitzer, Jr. Fellow, Princeton University, United States **2** Institution Name, Country **3** Independent Researcher, Country ***** These authors contributed equally.

DOI: 10.xxxxxx/draft

Software

- Review
- Repository
- Archive

Editor: Open Journals

Reviewers:

- @openjournals

Submitted: 01 January 1970
Published: unpublished

Summary

The forces on stars, galaxies, and dark matter under external gravitational fields lead to the dynamical evolution of structures in the universe. The orbits of these bodies are therefore key to understanding the formation, history, and future state of galaxies. The field of "galactic dynamics," which aims to model the gravitating components of galaxies to study their structure and evolution, is now well-established, commonly taught, and frequently used in astronomy. Aside from toy problems and demonstrations, the majority of problems require efficient numerical tools, many of which require the same base code (e.g., for performing numerical orbit integration).

The development of supersonic civil aviation with an emphasis on enhanced technical and environmental sustainability calls for a comprehensive approach to supersonic aircraft design and performance characterization. These designs must not only meet high-speed flight demands but also accommodate diverse external conditions throughout their missions, requiring optimization across multiple operating points for aerodynamic and propulsive systems **?**. Thus, configuring, optimizing, and investigating a high-speed propulsion system is a pivotal step in realizing supersonic and hypersonic aircraft. In terms of a propulsion system architecture that can comply with the mission definitions of high-speed aircraft, ramjet engines offer significant advantages over rocket engines, as they do not require onboard oxidizer storage or rotating parts. Despite their simpler structure compared to turbo-based aero-engines, the internal flow dynamics of ramjets are complex and must be meticulously studied to ensure system stability and high performance **?**. Accordingly, conceptual design methods using zero- and one-dimensional approaches are therefore necessary cost-effective alternatives to high-fidelity numerical simulations. They allow analysis of the design parameters and operational variables of each major component, as well as assessing propulsive performance metrics such as thrust, specific impulse, and fuel consumption.

Statement of need

In this regard, reduced order models for high-speed propulsion systems, including ramjet and scramjet engine configurations, have been developed and tested since the mid-1960s. Early low-fidelity models analyzed how fuel injection and mixing affect the ramjet/scramjet cycle by simulating flow through intake contours using a two-shock approach **?**. These models examined critical conditions in the combustion chamber, such as pre-ignition states, fuel mixing, ignition methods, and combustor length reduction, while exploring propulsion system characteristics at various altitudes and speeds. To enhance performance and reduce weight of ramjet engines, a numerical approach combining finite-difference solutions with a well-stirred reactor model and finite-rate chemistry was proposed, incorporating a shear layer model to account for viscous effects **?**, **?**. Later studies introduced 1D models with Eulerian-Lagrangian coupling to examine both stable and unstable combustion modes and their impacts on cycle performance **?** and modelling thrust losses due to incomplete fuel burning and entropy losses from irreversibility using aerothermodynamics principles **?**. In subsequent research, O'Brien and colleagues proposed a one-dimensional model for high-speed propulsion flow paths, incorporating finite-rate chemistry to examine how fuel mixing and ignition timescales affect various engine operating conditions **?**. Other studies developed physics-based models to combine low-fidelity propulsion computations with structural integrity considerations for air-breathing hypersonic engines, estimating propulsive performance under different aeroelastic modes **?**, **?**. Similarly, Birzer and Doolan developed a model for a hydrogen-fueled scramjet combustor using a set of one-dimensional ordinary differential equations, validating their approach with experimental data from the Hyshot-II cases **?**. However, these models lacked adequate combustion modeling, failing to consider the aerothermochemical effects of gas mixing and burning in the combustion chamber. In order to resolve these issues, Torrez et al. created a reduced-order engine model for high-speed propulsion systems, simulating mixing and combustion in ramjet and scramjet engines **?**. The authors improved their MASIV numerical tool by coupling it with the Shapiro method to predict the thermal choking position, which is a mathematical singularity in the ramjet engine duct **?**. Additionally, Tian et al. introduced a quasi-1D strength-adaptable shock approach to estimate pre-combustion conditions, modeling the interactions between flow development in the isolator and the combustion modes of dual-mode scramjets or ramjets **?**.

Although there are numerous low-fidelity design and analysis studies aimed at accurately characterizing the performance specifications of ramjet engines, most focus on individual components of the propulsion system rather than a comprehensive methodology. Few studies consider the combined influence of flight conditions and design parameters throughout the entire propulsive flow path. Therefore, this study integrates individual design and analysis approaches for high-speed propulsion components to develop a holistic, low-fidelity design method for cost-efficient characterization of the ramjet engine design space. Accordingly, `RASDAS` is developed.

Research applications

- acta 2022
- hisst 2022 I: ramjet, hisst 2022 II: scramjet
- scitech 2023
- acta 2024
- astec 2024

Citations

Citations to entries in paper.bib should be in rMarkdown format.

If you want to cite a software repository URL (e.g. something on GitHub without a preferred citation) then you can do it with the example BibTeX entry below for Smith et al. (2020).

For a quick reference, the following citation commands can be used: - `@author:2001` -> "Author et al. (2001)" - `[@author:2001]` -> "(Author et al., 2001)" - `[@author1:2001; @author2:2001]` -> "(Author1 et al., 2001; Author2 et al., 2002)"

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme, MORE & LESS (MDO and REgulations for Low-boom and Environmentally Sustainable Supersonic aviation) project under grant agreement No 101006856.

References

Smith, A. M., Thaney, K., & Hahnel, M. (2020). Fidgit: An ungodly union of GitHub and figshare. In *GitHub repository*. GitHub. https://github.com/arfon/fidgit