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Abstract #XXX
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### Title
## Ironbark: Trajectory and Aerodynamic Simulator for High-Power Rockets


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### Abstract
Ironbark is an aerodynamic modelling and trajectory simulator developed by USYD Rocketry Team to model the flight of high-power rockets. Ironbark allows for the accurate trajectory prediction of high-power rocket configurations that are commonly flown at student competitions. Built upon a six-degree-of-freedom flight dynamics model, Ironbark incorporates detailed gravimetric, propulsive, and atmospheric effects. Ironbark's defining feature that separates it from other commercial and open-source trajectory simulators is its in-built aerodynamic modelling capability.

Aerodynamic modelling is implemented through internal coupling with the higher-order open-source panel method PANAIR. PANAIR allows for the prediction of inviscid subsonic and supersonic flows about an arbitrary configuration within the limitations of linear potential flow theory. Ironbark uses this coupling to quickly and efficiently calculate the forces and moments of supported high-power rocket configurations. Because PANAIR is an inviscid solver and viscous effects contribute significantly to drag predictions, additional simulations are required to calculate the viscous drag contribution. Ironbark implements the methods proposed by Mason at Virgina Tech for skin friction drag prediction.

Kriging surrogate models are built for each aerodynamic coefficient using Latin hypercube sampling of Mach number and incidence angles. These surrogate models allow for the reduction of PANAIR evaluations while maintaining a high accuracy. While PANAIR is integrated within Ironbark, other aerodynamic predictive methods like computational fluid dynamics are also supported through a common file input structure.

Ironbark's aerodynamics has been extensively validated against publicly available aerodynamic data, while the trajectory model has also been validated against the extensive flight data collected from USYD Rocketry Team's previous rocket projects (see Figure 8). Ironbark was used to predict the apogee of USYD Rocketry Team's latest Spaceport America Cup entry Bluewren. Aerodynamic coefficients predicted through external computational fluid dynamics modelling were used in this simulation for the highest level of confidence. Using Ironbark, a variable mass ballast incorporated in the rocket was tuned on the flight day resulting in Bluewren reaching within 67ft or 0.2% of the prediction and target altitude of 30,000ft. This ultimately contributed to Bluewren winning its category and the overall competition at the 2022 Spaceport America Cup.

Finally, Ironbark can perform Monte Carlo and sensitivity simulations on several design and environmental variables. Sensitivity analyses are useful in the preliminary design phase of rockets for informing the team of which design parameters have the largest impact on the final apogee. Monte Carlo simulations were used before Spaceport America Cup to determine the expected altitude of the rocket with a confidence interval. It was found that without launch day simulations and modifications to account for local atmospheric conditions, Bluewren had an 82% chance of achieving an apogee within 500ft and a 99% chance of achieving an apogee within 1,000ft of its target (see Figure 12). Monte Carlo simulations are also expected to be utilized in future by the team for landing dispersion analysis for range safety.

Future expansion to Ironbark is planned to incorporate additional modelling capabilities such as flutter, hybrid propulsion, and optimization which are already in varying stages of development and will incorporate other codes already developed by the team.

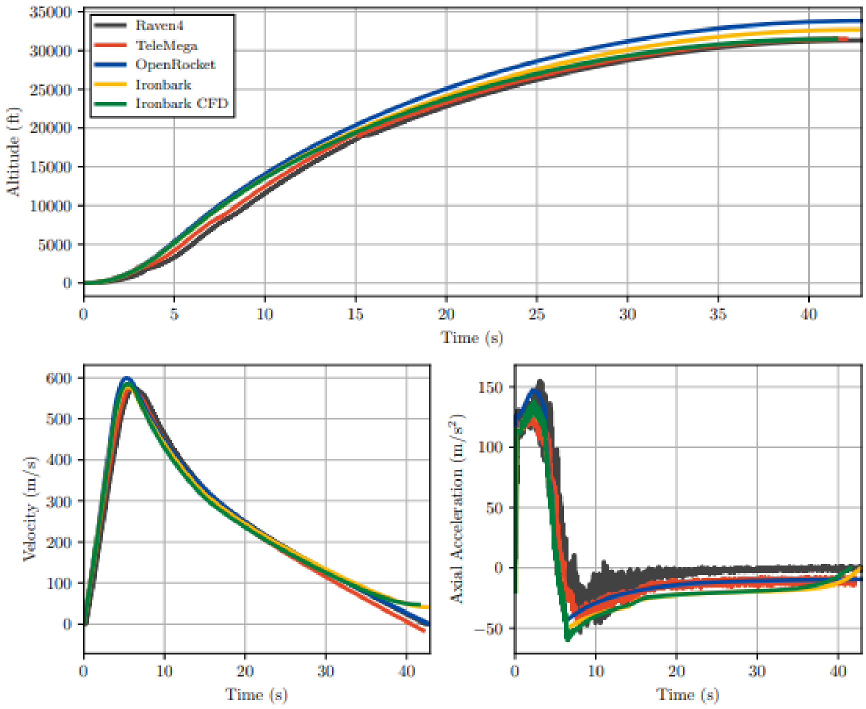


**Fig. 8 Comparison showing values from three flight simulations against the two sets of flight data.**

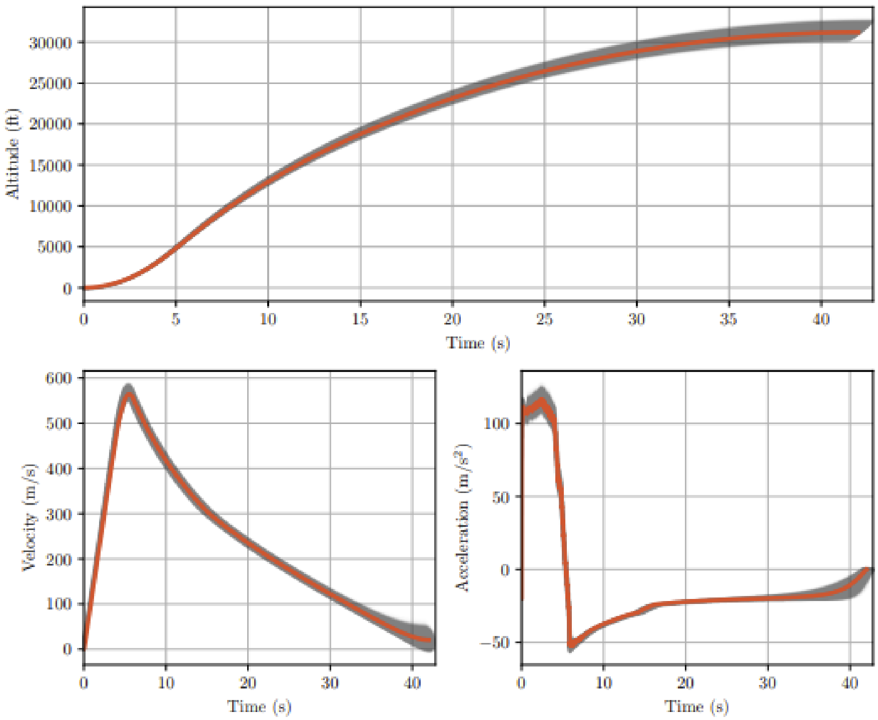


**Fig. 12 Probabilistic dispersion of Bluewren's trajectory after 20,000 simulations.**