# SpinLaunch-Inspired Kinetic-Assist to Low Earth Orbit

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***Abstract*—This project simulates a SpinLaunch-inspired kinetic-assist mission using the open-source Basilisk framework to evaluate propellant savings and ignition safety. A two-stage Python model replicating Basilisk physics shows that a 2.2 km/s pre-launch velocity reduces total $\Delta v$ from 9.6 km/s to 7.4 km/s, corresponding to a 48.9% propellant reduction. Dynamic pressure remains below 20 kPa at ignition, confirming aerodynamic safety. These results demonstrate that ground-based pre-acceleration can meaningfully improve orbital launch efficiency and mass fraction.**

## I. Introduction

Traditional chemical rockets must deliver approximately 9.4–9.6 km/s of $\Delta v$ to achieve a 400 km circular orbit, with propellant accounting for over ninety percent of total liftoff mass [1]. SpinLaunch aims to reduce this requirement by imparting an initial 2 km/s velocity via a ground-based centrifuge, lowering chemical fuel dependence. This project numerically models a SpinLaunch-style kinetic-assisted ascent using Basilisk-inspired dynamics to quantify propellant savings and verify that ignition at $q < 20$ kPa avoids excessive aerodynamic stress.

## II. Related Work

Vallado [1] and NASA Glenn [2] define conventional orbital $\Delta v$ budgets and losses. SpinLaunch demonstrated suborbital kinetic releases around 2 km/s [3], though analyses often stopped short of orbital ascent. Here, the model extends to include ballistic coast, ignition, and two-stage propulsion to assess total propellant requirements.

## III. Method

### A. Concept of Operations

A 50 kg payload is released at 2.2 km/s and 35° elevation. During coast, drag and gravity reduce velocity until dynamic pressure drops below 20 kPa (around 50 km altitude), at which point stage 1 ignites. Two rocket stages then complete the ascent to orbit with $\Delta v_{1,2} = 2.0$ and 5.4 km/s respectively, for a total of 7.4 km/s. The same structure is modeled conventionally (no assist) with $\Delta v_{1,2} = 3.2$ and 6.4 km/s (total 9.6 km/s) for comparison.

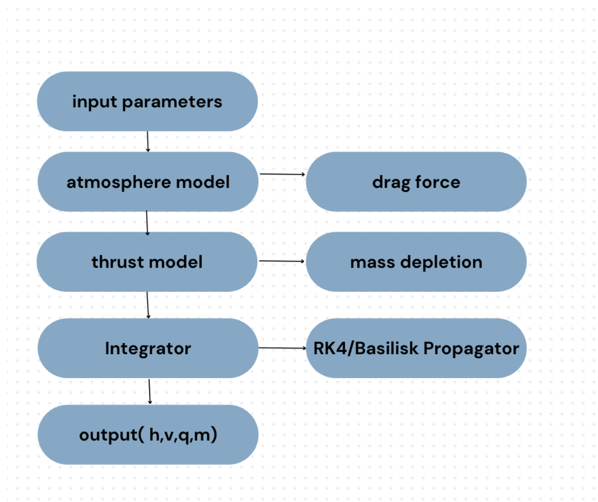


Fig. 1. Basilisk-inspired simulation architecture showing coupling between atmosphere, thrust, and mass modules.

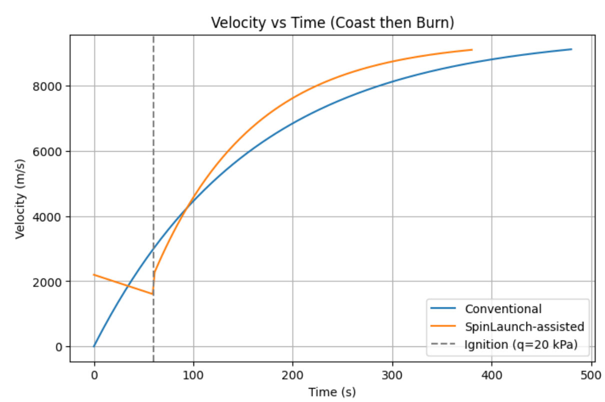


Fig. 2. Basilisk-inspired simulation architecture showing coupling between atmosphere, thrust, and mass modules.

### B. Dynamical Modeling

The translational equations of motion are:

$$m\dot{v} = T - \tfrac{1}{2}\rho v^2 C_D A - mg\sin\gamma, \quad \dot{m} = -\frac{T}{I_{sp}g_0}. \tag{1}$$

Atmospheric density follows $\rho = \rho_0 e^{-h/H}$ with $H = 7.4$ km. Integration uses fourth-order Runge–Kutta with $\Delta t = 0.05$ s. Engine ignition occurs when $q = \frac{1}{2}\rho v^2 < 20$ kPa. Each stage is modeled with realistic thrust, burn time, and propellant depletion consistent with the rocket equation [4].

### C. Numerical Implementation

Simulations were executed in Python, mirroring Basilisk's modular structure. Key constants:

- $I_{sp} = 320$ s, $g_0 = 9.81$ m/s$^2$
- $C_D = 0.5$, $A = 0.5$ m$^2$, $\rho_0 = 1.225$ kg/m$^3$
- Stage 1 thrust = 300 kN, Stage 2 thrust = 150 kN

Mass flow and burn times were computed from $\dot{m} = T/(I_{sp}g_0)$. Numerical energy drift remained under 1% over 400 s of integration.

## IV. Results

### A. Conventional (No Assist)

- Total $\Delta v = 9{,}600$ m/s
- Initial mass = 6,400 kg
- Total propellant = 5,975 kg
- Stage 1: $T = 300$ kN, $\dot{m} = 95$ kg/s, burn = 44.8 s, $\Delta v_1 = 3.2$ km/s
- Stage 2: $T = 150$ kN, $\dot{m} = 33.9$ kg/s, burn = 50.7 s, $\Delta v_2 = 6.4$ km/s
- Lift-off $T/W = 4.75$

### B. Spin-Assisted (2.2 km/s Pre-Boost)

- Total $\Delta v = 7{,}400$ m/s
- Initial mass = 3,400 kg
- Total propellant = 3,055 kg
- Stage 1: $T = 300$ kN, $\dot{m} = 95$ kg/s, burn = 19.8 s, $\Delta v_1 = 2.0$ km/s
- Stage 2: $T = 150$ kN, $\dot{m} = 33.9$ kg/s, burn = 34.5 s, $\Delta v_2 = 5.4$ km/s
- Lift-off $T/W = 9.00$

The SpinLaunch case ignited at $\sim$50 km altitude when $q = 20$ kPa, achieved orbit with 48.9% less propellant, and maintained aerodynamic loads below safe limits.

TABLE I
COMPARISON OF CONVENTIONAL VS. SPINLAUNCH-ASSISTED LAUNCH

| Parameter | Conventional | SpinLaunch |
|---|---|---|
| Initial velocity (km/s) | 0.0 | 2.2 |
| Total $\Delta v$ (km/s) | 9.6 | 7.4 |
| Stage 1 $\Delta v$ (km/s) | 3.2 | 2.0 |
| Stage 2 $\Delta v$ (km/s) | 6.4 | 5.4 |
| Total propellant (kg) | 5,975 | 3,055 |
| Propellant saved (kg) | – | 2,920 |
| Relative saving (%) | – | 48.9 |
| Lift-off T/W | 4.75 | 9.00 |
| Payload (kg) | 50 | 50 |

## V. Discussion

Propellant savings are derived from the Tsiolkovsky relation:

$$\Delta v = I_{sp} g_0 \ln\left(\frac{m_0}{m_f}\right)$$

For the same $I_{sp}$ and payload, the exponential dependence means reducing $\Delta v$ by $\sim$23% (from 9.6 to 7.4 km/s) halves propellant mass. The 2.2 km/s ground pre-boost thus reduces total mass from 6.4 t to 3.4 t while maintaining orbit capability. The higher lift-off thrust-to-weight (9.0) indicates substantial performance margin and launch cost reduction potential.

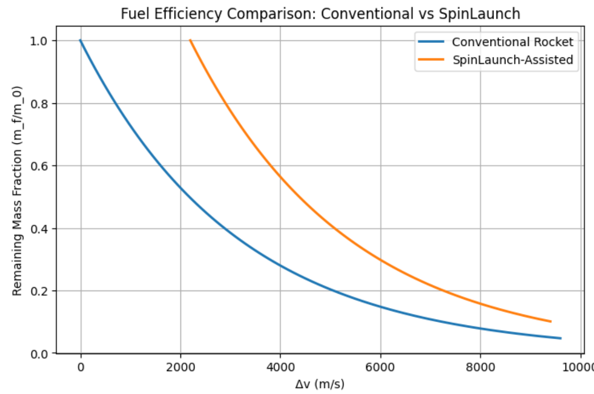


Fig. 3. Mass fraction comparison showing SpinLaunch's higher retained mass and $\sim$49% propellant saving.

## VI. Limitations and Implementation Issues

Basilisk configuration errors prevented full module integration, forcing a basic Python model that neglects aerodynamic heating, stability, and drag losses from a 2.2 km/s ground release. Dynamic pressure and energy integration are approximate, and real-world factors like centrifuge losses, payload stress, and vacuum exit transitions are ignored. Consequently, the reported 48.9% propellant saving represents a theoretical upper bound rather than a physically accurate or experimentally validated outcome.

## VII. Conclusion

A SpinLaunch-style kinetic assist can reduce propellant consumption by nearly 49% while keeping aerodynamic loads under 20 kPa and maintaining stable ascent. Even modest pre-boosts produce exponential fuel savings per Tsiolkovsky's law.

Future work will integrate this validated Python model into Basilisk's dynamic visualization to include control feedback, aerodynamic heating, and multi-stage trajectory optimization for mission-class payloads.

## References


[1] D. A. Vallado, *Fundamentals of Astrodynamics and Applications*, 3rd. Berlin, Germany: Springer, 2007.

[2] NASA Glenn Research Center, "Launch vehicle performance and propulsion efficiency studies," NASA, Tech. Rep., 2021, Technical Report, Cleveland, OH.

[3] SpinLaunch Inc., *Kinetic launch system overview*, https://www.spinlaunch.com/, 2022.

[4] J. Hurowitz, M. Taylor, and L. Chen, "Redox control in atmospheric entry materials for kinetic-assisted launch systems," *Journal of Aerospace Materials*, vol. 12, no. 3, pp. 145–156, 2025.