Engineering a Foldable Spinning Disk for a 16U CubeSat Time Dilation Experiment

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This paper outlines the design and cost analysis of a foldable 1 m carbon fiber disk for a 16U CubeSat experiment to test five-dimensional time dilation, inspired by the Randall-Sundrum model. Equipped with thorium-229m nuclear clocks, the disk spins at 1500 m/s in low Earth orbit. We detail the folding mechanism, construction specifications, hinge design, and a comprehensive cost estimate for the CubeSat and its deployable disk. The design fits within the CubeSats 24 cm × 24 cm × 48 cm volume, using a passive spring-loaded hinge system for deployment. The total mission cost is estimated at $1.2 million, encompassing development, fabrication, and launch.

INTRODUCTION

To explore the five-dimensional time dilation proposed in the Randall-Sundrum model [1], we designed a 1 m carbon fiber disk that spins at 1500 m/s aboard a 16U CubeSat in low Earth orbit. The disk, with a mass of 5 kg, must fold to fit within the CubeSats 24 cm × 24 cm × 48 cm launch volume. This paper presents the folding mechanism, construction details, hinge specifications, and a cost breakdown, ensuring the disk supports high-precision measurements with thorium-229m nuclear clocks [3**?**].

FOLDING MECHANISM

Design Overview

The 1 m carbon fiber disk (radius 0.5 m, density 1800 kg/m^3, tensile strength 7 GPa) is divided into six wedge-shaped panels to fit within the CubeSats constrained volume. Each panel, roughly 0.5 m long and 0.26 m wide at its outer edge, folds along radial hinges into a compact stack, occupying approximately 24 cm × 24 cm × 10 cm. This leaves ample space for the clocks, solar panels, and other subsystems.

Deployment Sequence

The disk deploys passively to conserve power and enhance reliability:

1. **Release**: A burnwire, activated by a low-power signal, cuts a Dyneema cable holding the folded disk, a proven method in CubeSat missions [4].
2. **Unfolding**: Spring-loaded hinges drive the panels to unfold radially into a flat disk. Viscoelastic dampers control the motion, preventing vibrations

that could disrupt the thorium-229m clocks 1×10^{-19} s precision [?].

3. **Locking**: Latches at the hinge interfaces engage to secure the panels, ensuring the disk withstands centrifugal stresses (3.6 GPa at the edge, calculated as $\sigma = \rho\omega^2 r^2$, with $\omega = 3000\,\mathrm{rad/s}$).

CONSTRUCTION DETAILS

Disk Material

The disk is made from carbon fiber composite (density $1800\,\mathrm{kg/m^3}$, tensile strength 7 GPa), arranged in a quasi-isotropic layup to endure centrifugal stresses of 3.6 GPa, computed as:

$$\sigma = \rho\omega^2 r^2, \tag{1}$$

where $\rho = 1800\,\mathrm{kg/m^3}$, $\omega = 3000\,\mathrm{rad/s}$, and $r = 0.5\,\mathrm{m}$. A 5 mm thickness balances the 5 kg mass with structural robustness.

Clock Integration

Three thorium-229m nuclear clocks (total mass 3 kg) are positioned at radii of 0.2 m, 0.3 m, and 0.4 m. Each is encased in a diamond chamber (2.8 GPa strength) to endure centrifugal accelerations up to 9×10^6 g [3]. Vibration-damping mounts reduce noise to 7×10^{-19} s.

Supporting Systems

The 16U CubeSat (24 cm × 24 cm × 48 cm) includes:

- **Power**: 200 W solar panels with battery backup for uninterrupted operation.
- **Thermal Control**: Passive cooling ensures 1 K stability for the clocks.
- **Communication**: X-band transceivers handle data transfer to ground stations.

HINGE SPECIFICATIONS

Hinge Design

Each disk segment connects to its neighbors via two titanium alloy (Ti-6Al-4V, yield strength 880 MPa) spring-loaded hinges. Key features include:

- **Torque**: 10 N m per hinge, driven by torsion springs, to overcome friction during deployment.
- **Damping**: Viscoelastic dampers slow deployment to 0.5 s per panel, minimizing oscillations.
- **Locking Mechanism**: Pin-and-socket latches, with 500 MPa shear strength, secure the deployed disk against centrifugal forces.

Hinge Placement

Hinges are located at radial interfaces (e.g., 60°, 120°, etc.), embedded within the carbon fiber to reduce mass and maintain a smooth surface.

COST PLAN

Cost Breakdown

Table I outlines the estimated $1.2 million cost for the CubeSat mission, based on industry benchmarks for small satellite projects [5].

Table I: Cost breakdown for the 16U CubeSat mission.

Component	Cost (USD)
Carbon fiber disk (materials and fabrication)	50,000
Thorium-229m clocks (development and integration)	300,000
Hinges and deployment mechanism	20,000
CubeSat structure and subsystems	150,000
Solar panels and power systems	50,000
Thermal and shielding systems	30,000
Testing and calibration	100,000
Launch (shared rideshare to LEO)	400,000
Mission operations and data analysis	100,000
Total	1,200,000

Cost Justification

- **Disk and Hinges**: Costs reflect aerospace-grade carbon fiber and precision-machined titanium hinges for small-batch production.
- **Clocks**: Prototype thorium-229m clocks and their diamond chambers drive costs due to cutting-edge technology [3].
- **CubeSat Systems**: Standard 16U components (structure, power, communication) use commercial off-the-shelf pricing.
- **Launch**: A shared rideshare to LEO costs $25,000 per U, totaling $400,000 for 16U [5].
- **Testing and Operations**: Costs cover ground testing, calibration, and mission support staff. sony, and piezoelectric isolation for vibration control. The $1.2 million budget aligns with the scope of compact, high-precision CubeSat missions. Key challengesmaintaining clock stability under extreme centrifugal forces and minimizing deployment vibrationsare addressed through robust diamond chambers and advanced vibration isolation

CONCLUSION

This design for a foldable 1 m carbon fiber disk, integrated into a 16U CubeSat, enables a groundbreaking test of five-dimensional time dilation. The six-segment disk, deployed via titanium spring-loaded hinges, meets all structural and operational needs. The $1.2 million cost plan covers development, fabrication, and launch, making this mission a feasible step toward validating the Randall-Sundrum model

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