Paper 033 / Application 010

Digital Twins for Capacitor, Cavity, and Cryogenic Subsystem Experiments

A shared simulation and telemetry substrate for frontier physics and space engineering

JMP0X1B Research Group

Working paper draft / June 13, 2026

Abstract

This paper proposes a digital-twin platform spanning three JMP0X1B research domains: electrostatic capacitor nulls, microwave cavity closure audits, and cryogenic superconducting subsystems. The twin combines geometry, fields, thermal behavior, control state, telemetry, artifact ledgers, and failure injection. Its purpose is not to make simulations authoritative; it is to make discrepancies between model and apparatus visible.

Status. Draft manuscript for review and revision. This paper is not an empirical claim of new physics or field-ready technology. It is a structured proposal, theory note, protocol, or application architecture intended to be auditable, falsifiable, and publishable with source.

Contents

1 Problem

Experiments and engineering tests often maintain separate simulation, control, and telemetry systems. That separation hides model drift and weakens review. The problem is to keep a live relationship between expected behavior, measured telemetry, and declared uncertainty without pretending the twin is reality.

2 Model

The twin is an actor graph. Physics actors produce predicted states, instrument actors stream measurements, and reconciliation actors estimate residuals and model drift. Each domain uses the same interface while keeping domain-specific equations.

$$r_t = y_t - h(x_t), \qquad \text{DriftScore} = r_t^T \Sigma_t^{-1} r_t.$$

$$\text{Twin} = \text{Geometry} + \text{Physics} + \text{Controls} + \text{Telemetry} + \text{Ledger}.$$

3 Claims

1. **Claim 1.** A digital twin should report model disagreement, not hide it behind tuned parameters.
2. **Claim 2.** Shared twin infrastructure reduces repeated engineering effort across capacitor, cavity, and cryogenic tracks.
3. **Claim 3.** Failure injection in the twin can test protocol gates before real hardware runs.
4. **Claim 4.** Twins become scientifically useful when their assumptions are published with the paper.

4 Evidence Plan

The evidence plan builds three minimal twins: a capacitor pressure/polarity sequence, a cavity thermal-force audit, and a cryogenic conductor thermal cycle. Each twin is validated against synthetic data with known injected faults and then against bench telemetry when available.

5 JMP0X1B Implementation Surface

JMP0X1B actors provide clear boundaries between model, instrument, control, and reviewer. Effect declarations separate pure simulation from real-world actuation and data acquisition.

Illustrative JMP0X1B-style contract

```
actor Twin<ModelState, Telemetry> {
    fn predict(dt: Duration) -> ModelState effects{Simulation}
    fn ingest(frame: Telemetry) -> Residual effects{Telemetry, Statistics}
    fn fault(kind: Fault) -> Scenario effects{FaultInjection}
}
```

6 Release And Review Plan

Release domain schemas, synthetic traces, fault-injection scenarios, and residual reports. Include a policy that tuned parameters must be versioned and justified.

7 Open Questions

- Which domain should anchor the first end-to-end twin?
- How should uncertainty be propagated across mixed physics and control models?
- Can twins support live safety gates without overtrusting simulation?
- What visualization is most useful to reviewers?

8 Conclusion

Digital twins can turn frontier experiments and space subsystems into continuously auditable systems. The key is humility: the twin is a structured comparison, not an oracle.

References

References

[1] JMP0X1B Research Group. *Ultra-High-Vacuum Null Tests of Electrostatic Projection Couplings with Symmetry-Matched Capacitors*. Working paper, 2026. `https://research.jmp0x1b.com/papers/uhv-electrostatic-null-tests.html`

[2] JMP0X1B Research Group. *Finite-Element Discrimination of Boundary-Flux, Scalar, and Conventional Artifact Forces in Asymmetric Capacitors*. Working paper, 2026. `https://research.jmp0x1b.com/papers/fem-capacitor-force-discrimination.html`

[3] JMP0X1B Research Group. *Energy-Momentum Closure for Microwave Cavity Inertia Claims and Electromagnetic-to-Gravitational Conversion Architectures*. Working paper, 2026. `https://research.jmp0x1b.com/papers/energy-momentum-cavity-hfgw.html`

[4] JMP0X1B Research Group. *From Speculative Superconducting Claims to Practical Spacecraft Power and Magnetic Subsystems*. Working paper, 2026. `https://research.jmp0x1b.com/papers/superconducting-spacecraft-subsystems.html`

[5] JMP0X1B Research Group. *Cryogenic Dielectric and Superconducting Shield Controls for Projection-Electromagnetism Nulls*. Working paper draft, 2026. `https://research.jmp0x1b.com/papers/cryogenic-dielectric-and-superconducting-shield-controls-for-projection-electrom.html`

[6] JMP0X1B Research Group. *AtlasForge: A Differentiable FEM Service for Anomaly-Resistant Apparatus Design*. Working paper draft, 2026. `https://research.jmp0x1b.com/papers/atlasforge-a-differentiable-fem-service-for-anomaly-resistant-apparatus-design.html`

[7] JMP0X1B Research Group. *CryoBus: A Spacecraft Superconducting Power and Magnetic Subsystem Design Toolchain*. Working paper draft, 2026. https://research.jmp0x1b.com/papers/cryobus-a-spacecraft-superconducting-power-and-magnetic-subsystem-design-toolcha.html

[8] JMP0X1B Research Group. *A Mission-Grade Effects Runtime for Local-First Autonomous Systems*. Working paper draft, 2026. https://research.jmp0x1b.com/papers/a-mission-grade-effects-runtime-for-local-first-autonomous-systems.html

[9] A. Logg, K.-A. Mardal, and G. N. Wells, editors. *Automated Solution of Differential Equations by the Finite Element Method*. Springer, 2012.

[10] World Wide Web Consortium. *PROV-DM: The PROV Data Model*. W3C Recommendation, 2013. https://www.w3.org/TR/prov-dm/