On-Orbit Autonomy for Small Spacecraft: Learning-Enhanced Guidance, Navigation & Control (GNC) for Agile, Fault-Tolerant Operations

Introduction

Space doesn't coddle mistakes. It rewards rigor, resilience, and elegant engineering. This project proposes a learning-enhanced GNC stack for SmallSat missions - aimed at precise attitude/orbit control, graceful fault recovery, and real-time decision-making under resource constraints. The work is designed as a major **M.Eng. design project** plus a focused set of graduate-level technical courses, aligning with Cornell's **Distance Learning M.Eng.** structure: 30 credits, individualized coursework, and a project centered on **aerospace design and applications.** Graduate School

Program Fit (Cornell Distance Learning M.Eng.—Aerospace)

- **Audience & cadence:** A part-time path completed in **2–3 years**, geared to working engineers accelerating careers in the **space industry.** GraduateSchool
- **Structure: 30 credits** at the graduate level; build an **individualized plan** across focus areas and combine technical courses with up to two professional-development courses. Graduate School
- **Major design project:** Complete a design/application project under close faculty/industry supervision. In the DL cohort, this takes the form of the **SmallSat Mission Design Project (MAE 6900)**, run over the summer with one **in-person week in Ithaca.** Cornell Engineering
- **Focus areas leveraged here: Spacecraft engineering, dynamics & control, robotics, propulsion (interfaces),** and **simulation & analysis.** Graduate School
- **Administrative notes:** M.Eng. tuition is **Tier 1**; DL students are **charged per credit**—see Bursar for current rates. Cornell Engineering+1

Objectives

1. **Design a flight-software-ready GNC module** for CubeSat-class spacecraft, achieving:

- ≤0.1–0.5° steady-state pointing (payload-dependent) and robust detumble;
- autonomous safe-mode entry/exit with **fault detection, isolation & recovery (FDIR).**

2. **Integrate learning-based estimators/controllers** (e.g., model-based RL or adaptive control) that respect real-time compute and actuator limits.

3. **Validate** in a high-fidelity **digital twin** + **hardware-in-the-loop (HIL)** environment representative of the **SmallSat Mission Design Project (MAE 6900)** flow. Cornell Engineering

Background & Relevance

The proposal pivots from prior AI/AGI work toward aerospace autonomy, translating strengths in data fusion, prediction, and decision-making into the **spacecraft engineering** stack—directly mapped to Cornell's **DL focus areas** and **mission design project.** The shift is intentional: space needs dependable autonomy more than hype, and this project is built to ship, not just simulate. Graduate SchoolCornell Engineering

Methodology

1) Requirements & architecture (Weeks 1–6):

- Derive mission-level GNC requirements (slew, jitter, momentum management, eclipse ops) and **MAE 6900** interfaces.
- Architect the GNC stack: sensors (star tracker/gyro/magnetometer), actuators (RWs, magnetorquers), fault models, mode logic.

2) Estimation & control design (Weeks 6–14):

- Baseline: EKF/UKF for attitude/orbit estimation; LQR/MPC for attitude control & momentum dumping.
- Augment with **learning-enhanced components**: adaptive gains or RL policies constrained by verified envelopes (e.g., Lyapunov-guided).

- Develop **FDIR**: residual-based fault detection, decision trees for mode transition, watchdogs.

3) Simulation and analysis (Weeks 10–22):

- Build a **digital twin**: perturbed dynamics (J2, SRP, aerodynamic drag in LEO), star-tracker noise, actuator saturation.
- Monte-Carlo campaigns for dispersions; worst-case evaluation for sun-pointing, target-tracking, and momentum management.
- Couple to **MAE 6900** project milestones to ensure mission-relevant scenarios (commissioning, safe-mode, downlink windows). Cornell Engineering

4) HIL & flight-software prototyping (Weeks 18–30):

- Port core algorithms to an embedded target; run in the loop with a reaction-wheel emulator and star-tracker data feed.
- Validate timing determinism, jitter budgets, memory/CPU profiles; document flight-readiness deltas.

5) Verification, reporting & handoff (Weeks 28–34):

- Requirements traceability, design docs, verification results; tech memo pack for **faculty/industry partner** review as per DL M.Eng. project supervision norms. Graduate School

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- **A working GNC prototype** (code + sims + HIL artifacts) suitable for integration into a SmallSat mission design stream (MAE 6900). Cornell Engineering
- **Performance envelope** demonstrating robust pointing and safe-mode autonomy under off-nominal disturbances/faults.
- **Design dossier:** architecture, verification results, and a risk-burn-down plan aligned to industry expectations for SmallSats.

Potential Impact

- **Mission resilience:** Faster recovery from anomalies, more science/comm uptime.
- **Lean ops:** Autonomy that trims ground intervention and costs.
- **Talent acceleration:** Direct alignment with Cornell's industry-facing M.Eng. mission—skills that ship to orbit, not just to a paper. Graduate School

Proposed Course Plan (illustrative; advisor approval required)

Anchored in **spacecraft engineering**, **dynamics & control**, **robotics**, and **simulation & analysis**—drawing from DL-available options; categories below reflect Cornell's DL curriculum groupings. Cornell Engineering

- **General Spacecraft Engineering:** Introduction to Spaceflight Mechanics; Spacecraft Technology & System Architecture; **MAE 6900 Special Investigations (SmallSat Mission Design Project).** Cornell Engineering
- **Orbital Mechanics & Dynamics:** Space Exploration Engineering; Advanced Dynamics; Celestial Mechanics. Cornell Engineering
- **Propulsion (interfaces for GNC/FDIR):** Aerospace Propulsion; Propulsion of Spacecraft; Plasma Physics for Propulsion (for disturbance/actuation modeling). Cornell Engineering
- **Guidance & Navigation:** Spacecraft Attitude Dynamics, Estimation and Control; Model-Based Estimation; Multivariable Control Theory. Cornell Engineering
- **Space Robotics & Learning Systems:** Flexible Space Robotics; Adaptive and Learning Systems. Cornell Engineering
- **Advanced Engineering / Simulation & Analysis:** Mechanics of Composite Structures; Finite Element Analysis for MAE Design; Intermediate Dynamics; Engineering Vibrations; Feedback Controls. Cornell Engineering
- **Professional Development (optional, 1–2 courses):** Systems Engineering or Engineering Management to strengthen program

integration and project delivery. Cornell Engineering

Deliverables

1. **Code & Models:** Estimation/control libraries, FDIR logic, mode manager, hardware abstraction.
2. **Simulation Assets:** Digital-twin environment, disturbance/fault libraries, Monte-Carlo harness.
3. **HIL Testbed:** Scripts, build artifacts, timing/CPU profiles, pass/fail criteria.
4. **Documentation:** Requirements, design, V&V, and **MAE 6900** project report suitable for faculty/industry review. Cornell Engineering

Timeline (high-level, part-time DL pacing)

- **Sem 1:** Requirements, architecture, baseline GNC math, initial sims.
- **Sem 2:** Learning-enhanced control/estimation; full sims; preliminary HIL.
- **Sem 3 (Summer MAE 6900):** Mission design integration; in-person Ithaca week; HIL validation; final reporting. Cornell Engineering

Practical Notes (Tuition & Admin)

- **Credits:** Target a plan totaling **30 credits** including the project. GraduateSchool
- **Tuition: Tier 1;** DL is **per-credit.** Check the Bursar for the current schedule and billing. Cornell EngineeringOffice of the Bursar
- **Program coordination & advising:** Start with the Sibley DL M.Eng. team (**maemeng@cornell.edu, 607-255-0990**). Graduate School

Conclusion

This is aerospace with its sleeves rolled up: a mission-shaped, industry-honest design effort that turns algorithms into flight-grade capability. It embraces Cornell's DL M.Eng. ethos—**flexible, focused, and project-driven**—and aims for one thing: readiness for orbit. Graduate SchoolCornell Engineering

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Sources

- Cornell Graduate School — **Aerospace Engineering M.Eng. (Distance, Online, Low-residency, or Hybrid option)** (program description, 30-credit structure, focus areas, contacts). GraduateSchool

- Sibley School — **Distance Learning M.Eng. in Aerospace Engineering** (SmallSat Mission Design Project / **MAE 6900**, curriculum groupings, DL experience). Cornell Engineering

- Cornell Engineering — **Paying for Your M.Eng. Degree** (Tier-1 designation; DL per-credit billing). Cornell Engineering

- Cornell Office of the Bursar — **Tuition Rates and Fees** (current schedules, billing details). Office of the Bursar