When Systems Fail, VANNA Learns to Recover.

1. Executive Summary

Virtually Autonomous Neural Network Applications (VANNA), developed by DeepFlight is a student-driven, long-term research initiative led by engineering undergraduates at Virginia Tech. This project aims to develop an intelligent fallback flight control system for unmanned aerial vehicles (UAVs) operating in complex civilian and public-interest missions, such as search-and-rescue, public safety, and precision agriculture. As UAV usage expands across these sectors, their ability to survive partial failures and maintain mission objectives has become an essential research and engineering challenge.

VANNA addresses this gap by integrating a neural network-based fallback controller trained to recognize unstable flight dynamics and issue corrective thrust commands. It passively monitors system health, activates upon failure detection, and takes over control to stabilize the aircraft, complete the mission, or initiate an autonomous landing. Through subsystems like thrust reallocation logic, a CFD-guided control system, and transition layers for system overrides, VANNA equips UAVs with intelligent post-failure response, a capability conventional PID-based systems cannot deliver.

This business case proposes establishing VANNA as a sustained, student-centered laboratory initiative within the College of Engineering. To accomplish this, the team requests:

- Access to dedicated lab space for long-term development
- Faculty mentorship and advising support
- Financial resources (approximately $10,000) to fund prototyping, simulation platforms, and testing campaigns
- Test space and equipment allocations for validating VANNA across realistic damage scenarios

By supporting VANNA through these resources, Virginia Tech can enable students to build technical expertise in artificial intelligence and flight control, while directly advancing a safer and more resilient future for civilian and public-interest UAV applications.

2. Background

Project Short Title: VANNA

Project Title: Virtually Autonomous Neural Network Applications

Project Overview: VANNA is a neural network–based fallback control system designed to extend the operational survivability of unmanned aerial vehicles (UAVs) following partial system failures. While conventional UAV flight controllers are highly optimized for nominal conditions, they generally cannot recover when severe damage or sensor degradation occurs. As commercial and public safety UAV operations expand, a reliable fallback mechanism becomes vital to prevent mission failure, protect assets, and safeguard human life.

Project Objectives:

- Develop an adaptable contingency control layer that can engage autonomously in the presence of system damage or flight anomalies
- Validate VANNA's fallback logic through high-fidelity simulation and hardware-in-the-loop testing
- Integrate VANNA with common commercial autopilot stacks (e.g., PX4, ArduPilot)
- Provide an engineering research platform for student learning and interdisciplinary collaboration

Project Sponsor / Stakeholder Context:
The VANNA initiative is being developed by Virginia Tech engineering students with the guidance of faculty advisors. Support from the College of Engineering, in the form of lab space, mentorship, funding, and equipment access, will allow the project to progress from its current conceptual stage to a validated, field-deployable solution with significant educational and societal impact.

3. Project Rationale

Maintaining UAV operational capability following a partial system failure is essential in mission-critical civilian and public safety contexts. Search-and-rescue missions, disaster response, and large-scale agricultural surveys increasingly rely on UAVs to perform high-value tasks where even minor flight anomalies can jeopardize objectives and endanger lives. These missions demand dependable and adaptable control solutions that can respond to damage or signal degradation in real time.

Traditional UAV controllers, based on PID algorithms and fixed failsafe routines, function effectively under ideal conditions but cannot adapt to rapidly changing aerodynamic states caused by propeller loss, sensor blackouts, or GPS interference. These legacy architectures lack the capacity to classify abnormal flight conditions or to reconfigure control logic dynamically, transforming otherwise recoverable events into complete mission failures.

The Federal Aviation Administration (FAA), in its 2022 BVLOS Aviation Rulemaking Committee Final Report, states that *"robust risk-based frameworks, including automatic contingency management and reliable detect-and-avoid systems, are essential for scaling commercial UAV operations"* [1]. In public safety missions, where time-sensitive and life-saving operations are at stake, a fallback system capable of real-time adaptive recovery is no longer optional but necessary.

VANNA directly addresses this gap by providing an intelligent fallback controller that:

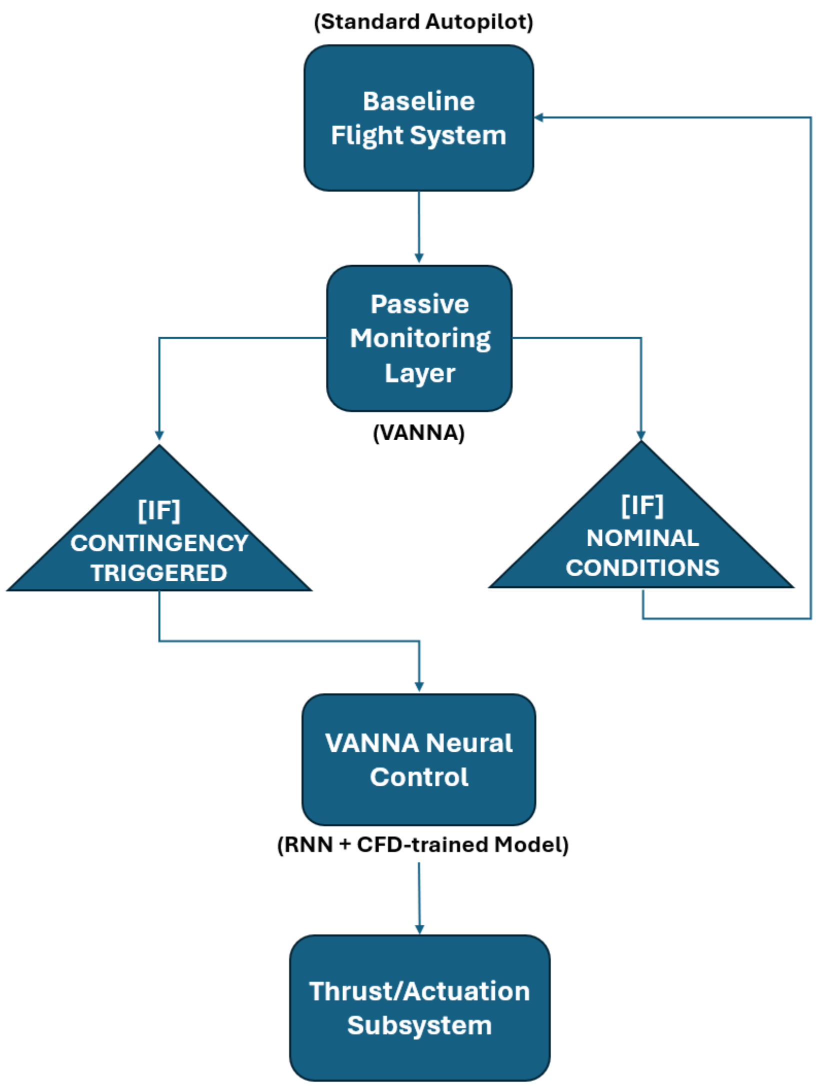
- Passively monitors UAV system state during nominal conditions
- Detects and classifies partial failure events (e.g., propeller loss, sensor failure, etc.)
- Engages to stabilize the aircraft and continue or safely terminate the mission

4. Solution Overview

VANNA is a fallback control system designed to extend UAV mission survivability following partial system failure. Operating as a contingency layer, VANNA remains passive under nominal conditions but activates when the UAV suffers critical disruptions. Once engaged, VANNA overrides conventional control logic to stabilize the aircraft and complete the mission or initiate a safe autonomous landing. VANNA utilizes an adaptable engine trained in a high-fidelity simulation environment. This engine allows the system to recognize damage-induced aerodynamic changes and dynamically issue new thrust commands.

Figure 4-1 provides a visual breakdown of the VANNA system architecture, illustrating how to control transitions from the baseline autopilot to VANNA under failure conditions.

Figure 4-1 – VANNA System Diagram



VANNA Integration Strategy & Risks/Mitigations:

To execute this contingency response, VANNA is structured into **five subsystems.** Each component plays a critical role in detecting instability, evaluating conditions, and issuing corrective control outputs.

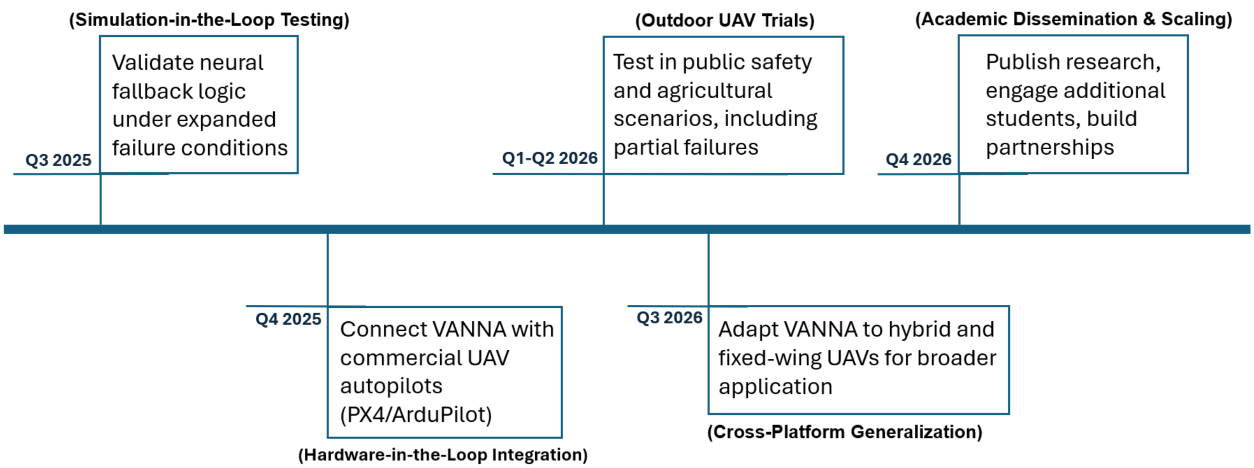
- **State Monitoring Module:** Detects anomalies by tracking IMU, GPS, and power data for rotor drop, signal loss, etc.
- **CFD-Guided Neural Control:** Predicts control commands using a neural network trained on simulated flight data.
- **Thrust Reallocation Logic:** Redistributes thrust to compensate for asymmetric conditions (e.g., damaged propeller).
- **Control Transition Layer:** Switches control from the default autopilot to VANNA when failure thresholds are passed.
- **Simulation-to-Reality Transfer Pipeline:** Refines VANNA behavior by blending synthetic data with real-world flight feedback.

Table 4-2 – VANNA Risks & Mitigations

Risk	Impact	Mitigation
AI doesn't respond well to unexpected damage	May fail to stabilize the UAV if the damage type wasn't seen during training	Keep improving the AI using real flight data to teach it how to handle more damage types
Triggers fallback mode when there's no real issue	Could override a healthy autopilot and cause instability	Use better thresholds and combine data from multiple sensors to avoid false alarms
Slow reaction time after failure	May not correct the issue fast enough, risking a crash	Optimize code and hardware to reduce delay when switching to fallback mode

5. Future Direction

Although VANNA's initial development and simulation testing have validated the feasibility of its fallback control concept, transitioning to a reliable field-ready platform will require continued, sustained research over multiple semesters. The following phased approach is proposed to mature the technology and maximize its educational impact:



These milestones will establish VANNA as a recognized, long-term student-centered engineering initiative at Virginia Tech. Over time, the lab environment and faculty mentorship will position the project as a unique research opportunity for undergraduates and graduate students across robotics, autonomy, artificial intelligence, and aerospace systems.

6. Resource Needs

To transition VANNA from its current design and simulation stage to a validated and field-deployable system, the following resources are requested from the College of Engineering:

- **Lab Space**: A dedicated laboratory environment for multi-semester hardware integration and testing
- **Faculty Mentorship**: Guidance and advising to support the student team in technical development and research publication
- **Financial Support**: Approximately $10,000 to cover prototyping materials, simulation tools, and student stipends
- **Test Infrastructure**: Access to UAV test areas, safety equipment, and supporting facilities

7. Conclusion

VANNA represents a unique opportunity to build a student-driven, research-focused, and long-term engineering initiative directly aligned with Virginia Tech's mission of hands-on, experiential learning. By combining advanced neural-network–based controls with rigorous engineering principles, VANNA not only addresses a critical gap in UAV resiliency but also creates a high-impact educational platform for students.

The project team is committed to collaborating closely with faculty, building partnerships, and maintaining a culture of excellence as VANNA moves forward. With the college's support, this initiative can make a significant contribution to safer, more reliable, and more autonomous UAV operations for public benefit.

8. References

1. https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/UAS_BVLOS_ARC_FINAL_REPORT_03102022.pdf