National Aeronautics and
Space Administration

TECHNOLOGY SOLUTION

**Information Technology and Software**

# Enhancing Fault Isolation and Detection for Electric Powertrains of UAVs

## Embedding Failure Mode and Effect Analysis (FMEA) and Bayesian Framework for Real-time diagnostics/ prognostics

NASA's System-Wide Safety (SWS) project is developing innovative data solutions to assure safe, rapid, and repeatable access to a transformed National Airspace System. The increasing number of electric propulsion systems that will enter the airspace will require systems that ensure high safety standards in the low-altitude airspace. One element that can help ensure safety is proper diagnosis of failures via Fault Detection and Isolation (FDI). NASA Ames has developed a fault isolation approach for electric powertrains of unmanned aerial vehicles. It leverages a combination of Failure Mode and Effect Analysis (FMEA) and Bayesian Networks (BN) to create a dependability structure within a diagnostic framework-mapping fault and failure events from the FMEA within a BN. This framework helps the fault isolation process by identifying the probability of occurrence of specific fault or root causes given evidence observed through sensor signals.

### BENEFITS

- Method for rapidly understanding, isolating, and informing response to faults in a complex system
- Scalable to a larger system and the size is co-related to the schematic interactions between the different nodes
- Real-time diagnostics/ prognostics feedback that increases safety, decreases machine downtime, and improves profitability of a system
- Incorporates the age, usage rate, and specifications for components into decision making. The failure probabilities are updated based on these factors over the life of the component/ sub-system
- Can be adapted to a variety of components (including batteries, speed controllers, etc.) to provide value. The system is not overly constrained by a finite set of compliant hardware
- Generalizable to a broad spectrum of industry domains and use cases
- Enables timely observation of faults in mission critical scenarios (e.g., determining if UAV must land immediately or may proceed to destination)
- Automates the identification and pinpointing of faults in systems – saving labor hours and enabling faster understanding of and reaction to faults

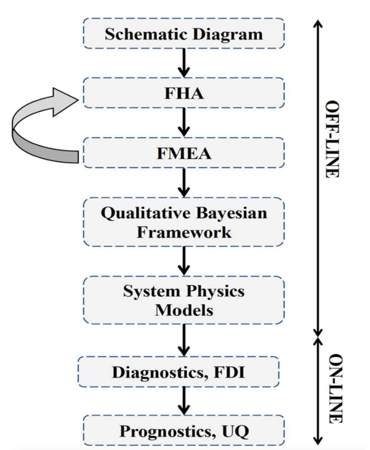
## THE TECHNOLOGY

The tool developed through this work merges information from the electric propulsion system design phase with diagnostic tools. Information from the failure mode and effect analysis (FMEA) from the system design phase is embedded within a Bayesian network (BN). Each node in the network can represent either a fault, failure mode, root cause or effect, and the causal relationships between different elements are described through the connecting edges.

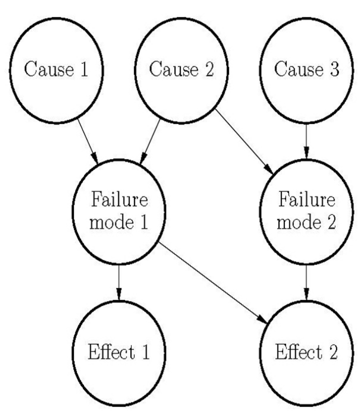
This novel approach can help Fault Detection and Isolation (FDI), producing a framework capable of isolating the cause of sub-system level fault and degradation.

This system:
• Identifies and quantifies the effects of the identified hazards, the severity and probability of their effects, their root cause, and the likelihood of each cause;
• Uses a Bayesian framework for fault detection and isolation (FDI);
• Based on the FDI output, estimates health of the faulty component and predicts the remaining useful life (RUL) by also performing uncertainty quantification (UQ);
• Identifies potential electric powertrain hazards and performs a functional hazard analysis (FHA) for unmanned aerial vehicles (UAVs)/Urban Air Mobility (UAM) vehicles.

Despite being developed for and demonstrated with an application to an electric UAV, the methodology is generalized and can be implemented in other domains, ranging from manufacturing facilities to various autonomous vehicles.




Process Flow Chart of the implemented approach to UAV Health Management




Example of a simple BN structure build from FMEA

## APPLICATIONS

The technology has several potential applications:

- Fault Diagnostics and Prognostics for Vehicle Systems Health Management
- Industrial Internet of Things (IIoTs)
- Aviation - Unmanned Aerial Vehicles (UAVs)
- Drone/Unmanned Aircraft Management (UAM) industry
- Automotive industry
- Commercial R&D for prognostic health management /condition-based maintenance
- Companies developing software products for system health management
- Aviation ground support
- Space industry (satellites)
- Manufacturing and factory settings (e.g., CNC machine monitoring), power plants, gas turbines, drilling system, and wind turbines

## PUBLICATIONS

Chetan S. Kulkarni, Matteo Corbetta, Elinirina I. Robinson. Enhancing Fault Isolation for Health Monitoring of Electric Aircraft Propulsion by Embedding Failure Mode and Effect Analysis into Bayesian Networks. Proceedings of the Annual Conference of the Prognostics and Health Management Society, 12(1), Virtual, 2020.

Chetan S. Kulkarni, Matteo Corbetta, Elinirina I. Robinson. System Health Monitoring: Integrating FMEA into Bayesian Networks. IEEE Aerospace Conference, Virtual, 2021.

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## More Information

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