National Aeronautics and Space Administration

FY25 Strategic University Research Partnership (SURP)

Simulating Fault Protection and GNC Interactions for System-Level Behavior Assessments

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Objectives:
- Develop a proving ground to explore autonomous fault protection (FP) capabilities that can provide **graceful degradation** of system performance in presence of faults.
  - Current FDIR systems are traditionally designed for only single-fault tolerance
  - The use of redundant components allows for multi-fault tolerance in many cases
  - Safing when not necessary negatively impacts mission performance
- This project lays the foundation to assess the viability of new FP approaches that incorporate fault diagnosis to autonomously handle in-flight anomalies

Background:
Current FP architecture is not sustainable as increased autonomy is desired. We propose a low cost test environment for new FP approaches by merging two existing technologies.

MONSID [2]
- Model-based fault detection and identification
- C++ API
- Relies on software models of physical system hardware and dynamics
- Constraint suspension used to identify source of fault at component level

Syssim [1]
- Component-level simulation with interconnection (c.f. Simulink)
- General purpose dynamics simulation in *Python*
- Expressive API for injecting user defined faults into the simulation
- Open sourced

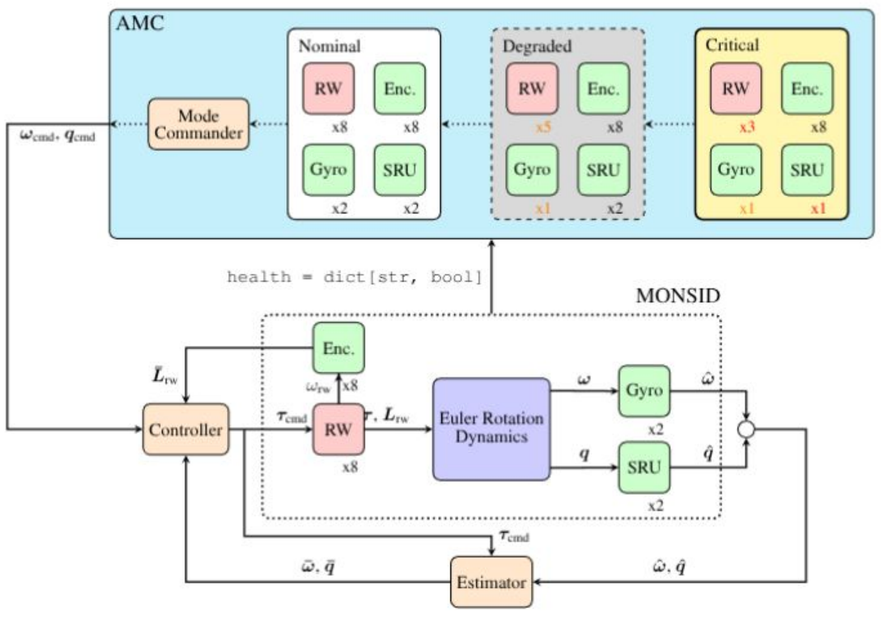

Figure 1: Simulation block diagram

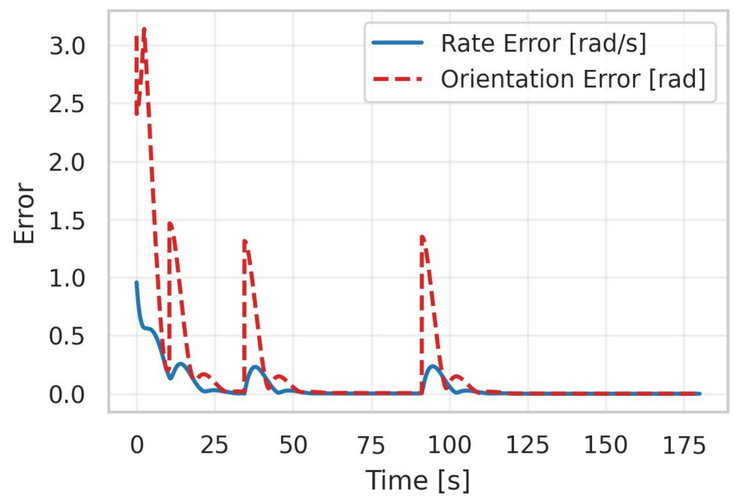

Figure 3: Command tracking errors

FY25 Approach and Results:

Integrate model-based fault detection and identification approach with a dynamics simulation with fault injection to prototype robust, multi-fault tolerant autonomy
- ACS simulation with redundant actuators and sensors (**Figure 1**)
- *MONSID* integrated with *syssim* with parallel hardware model of ACS
- *MONSID* provides diagnosis in the loop (**Figure 2**)
- Autonomous mode commander provides graceful degradation using a minimum capability heuristic (e.g., are there enough redundant components to maintain control authority?) to maintain control (**Figure 3**)

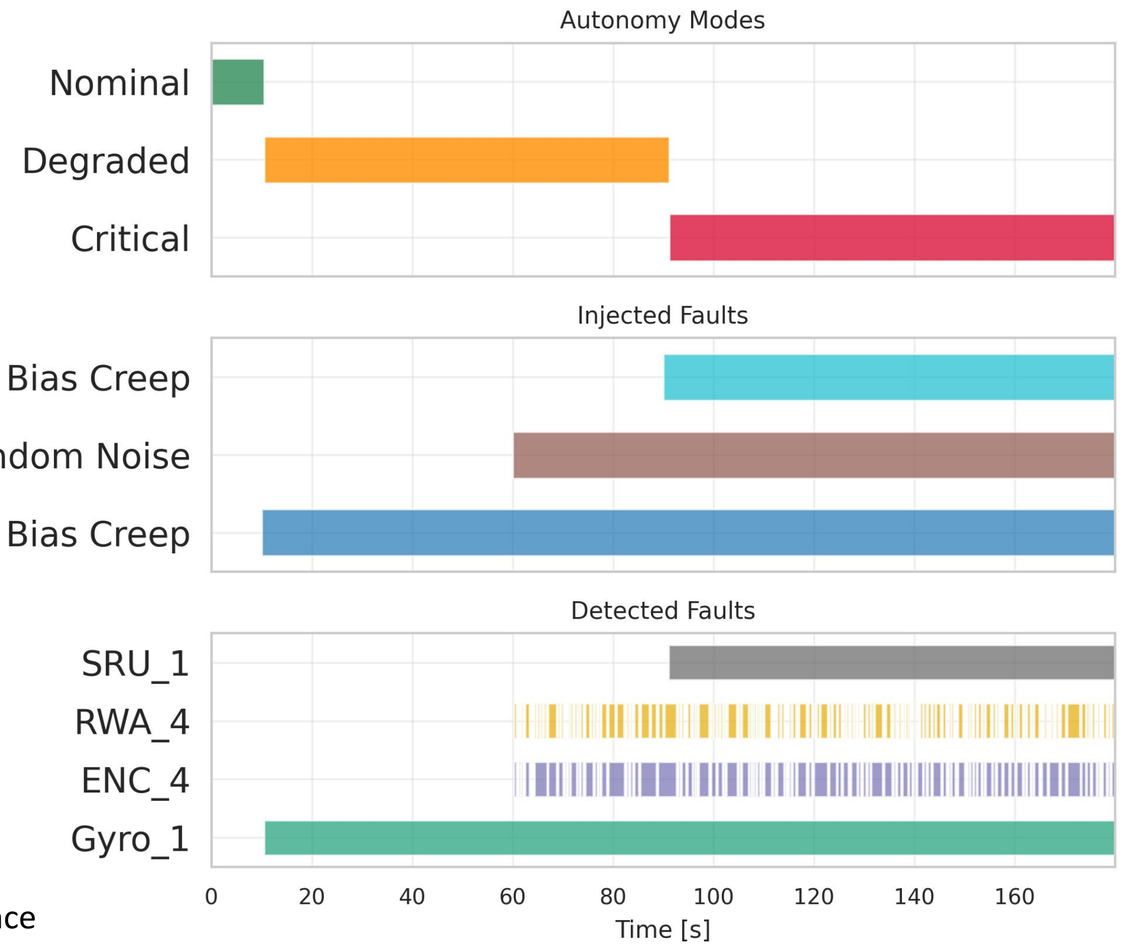

Figure 2: Mode and fault timeline

Significance/Benefits to JPL and NASA:

Provides a test environment for advanced autonomous spacecraft fault response
- Shows a baseline implementation of graceful degradation of spacecraft performance in the presence of multiple simultaneous faults
- Autonomous fault diagnosis (vs detection) will reduce testing time as well as spacecraft downtime during recovery

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Publications:

Josef Biberstein, et al., “Graceful Degradation of Spacecraft Capabilities with Simulated Component Failure,” IEEE Aerospace Conference, Big Sky, MT, Mar 7-14, 2026.

References:

[1] Josef Biberstein, et al., “Simulation Framework for Architecting Autonomous Fault Protection”, IEEE Aerospace Conference, Big Sky, MT, Mar 2-9, 2024, DOI: 10.1109/AERO58975.2024.10521101.
[2] Ksenia Kolcio, Lorraine Fesq, “Model-Based Off-Nominal State Identification and Detection for Autonomous Fault Management,” IEEE Aerospace Conference Proceedings, Big Sky, MT, Mar 6-12, 2016, DOI: 10.1109/AERO.2016.7500793.

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