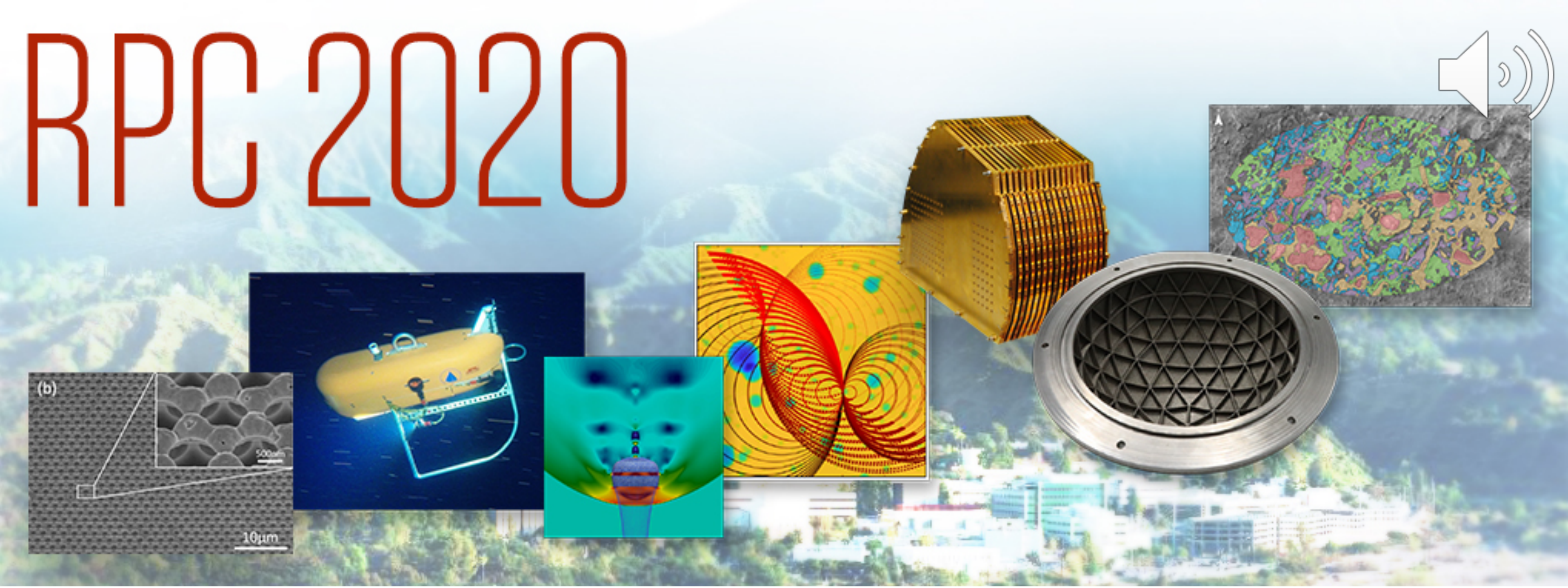

Virtual Research Presentation Conference

On-Board Autonomous Health Assessment

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Program: Strategic Initiative

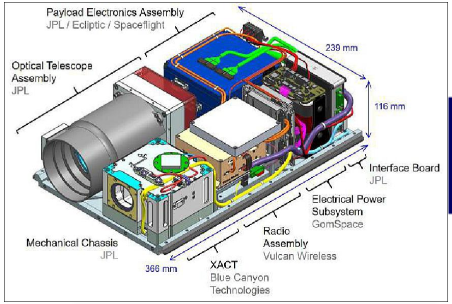
RPC-111

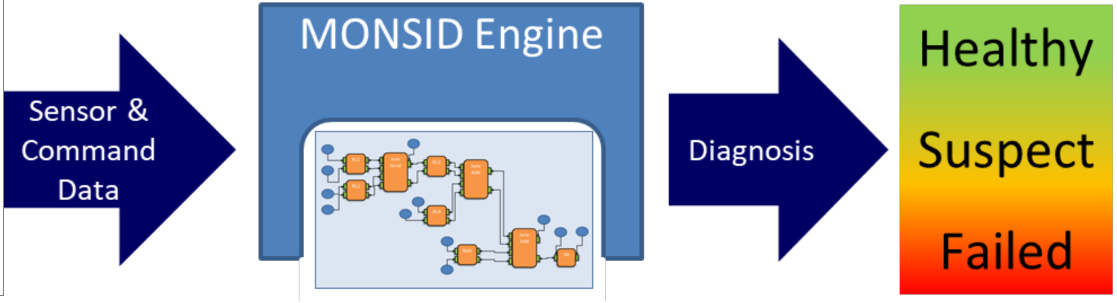
Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract: *The ASTERIA Spacecraft provided a unique opportunity to demonstrate on-board model-based diagnosis of spacecraft systems in support of complete on-board autonomy*

- Integrate MONSID (Model-based Off Nominal State Isolation and Detection) health assessment approach, developed under SBIR by Okean Solutions, with ASTERIA flight software. This involves creation of new F Prime FSW components to manage MONSID libraries, handle data interfaces, and interpret commands and parameters sent from ground or from on-board autonomy components.
- Develop a MONSID model of the ASTERIA XACT Attitude and Control Subsystem, relating relevant system state variables and their behavior through mathematical constraints, and associating constraints with XACT functional elements.
- Perform robustness and flight readiness tests of the MONSID-infused flight software, maturing verification and validation approaches for model-based software, including peer reviews of the MONSID model and certification of the MONSID flight software.
- Test MONSID model performance against captured ASTERIA XACT full-rate engineering data, and benchmark computing resources required for execution. Demonstrate MONSID operation in real time on ASTERIA System Testbed (in-flight demonstration not completed due to early loss of ASTERIA spacecraft)
- Finally, integrate MONSID with MEXEC planning/execution engine and AutoNav on-board orbit estimation, and support a (testbed) joint demonstration of closed-loop autonomy.





Problem Description

a) Context (Why this problem and why now):

Model-based Fault Management is an enabling capability for future autonomous missions. Legacy fault protection lacks flexibility to respond to unanticipated faults / environmental interaction, and focuses on "fail-safe" behavior instead of "fail-operational" autonomous recovery. This obstructs infusion of system autonomy (e.g., MEXEC) as it relies upon accurate, timely assessment of system capability. MBFM can also leverage common system models (supports) MBSE, and can support spacecraft development and testing as well as spaceflight operations.

MONSID, developed under SBIR (2015-2019) proved its value in experiments on rover and small spacecraft testbeds (Athena and SSDT), leading up to a full-scale mission test. The ASTERIA spacecraft extended mission provided a unique opportunity to host this demonstration, supporting development with representative subsystems, mature testbeds and processes, and operational flexibility permissive of engineering data capture and "software as payload" experiments.

b) SOA (Comparison or advancement over current state-of-the-art):

DS1 Remote Agent MIR: MONSID improves upon the Remote Agent MIR approach through a more physics-grounded modeling approach, enabling straightforward modeling and testing, faster execution on board, more detailed diagnosis

Traditional Fault Protection: MONSID dramatically improves response to unanticipated problems, provides positive evidence of correct behavior or repair, and supports closed-loop autonomy

c) Relevance to NASA and JPL (Impact on current or future programs):

Leverage system models, improve spacecraft V&V, reduce ops risks / costs, improve science throughput, enable autonomy

Methodology

a) Formulation

Model creation: Identify key system state variables, especially those available from telemetry, and define model topology with inputs / outputs to each component

Draft forward constraints (outputs as function of inputs) and reverse constraints (inputs as a function of outputs) based on first principles or existing system models

Unit test model components individually using simulated or captured data, define node tolerances (thresholds), and update constraints as needed

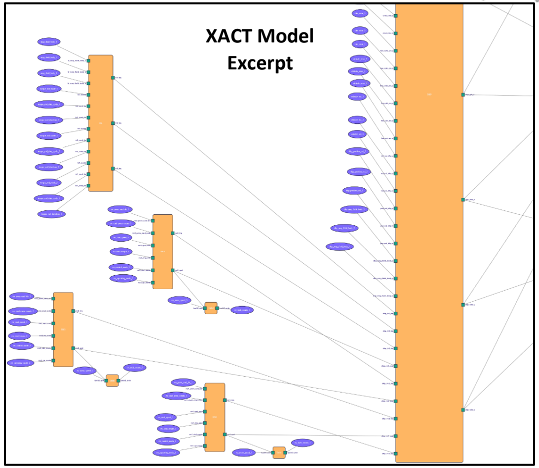
Assemble finished model and test against captured system data, complete validation

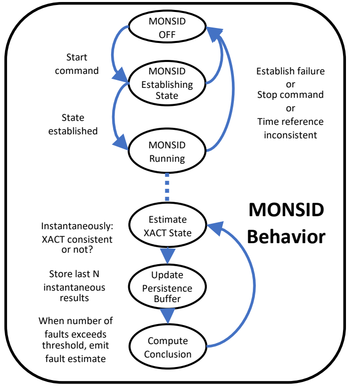
Flight Software Infusion (F Prime): Develop an F Prime component to receive XACT telemetry, correct timing errors or repeated samples, handle commands to start/stop/reset the MONSID engine, and output telemetry, EVRs, and detailed logs

b) Innovation and advancement

Include a safe fault injection capability for random fault testing, in testbed or flight

Develop F Prime components consistent with FRESCO architecture (3XA R&TD) and Principles of Autonomy (Rasmussen, Nesnas) to enable integration with other on-board autonomy technologies





Results

a) Accomplishments: **Except for losing our on-board test opportunity, all goals were met**

MONSID model construction and validation successful: Discovered a discrepancy between XACT control models and flight magnetorquer / magnetic field interaction – fixed by replacing XACT prediction with on-board magnetometer data

Diagnostic performance: Discovered several examples of benign but previously unknown transient fault behavior in ASTERIA operations (intermittent Star Tracker false tracks, Reaction Wheel tach noise and errors)

System-Level Autonomy: Successfully drove integrated demonstration of reliable task completion with MEXEC and AutoNav, using injected faults to drive different planning decisions and mitigation tests

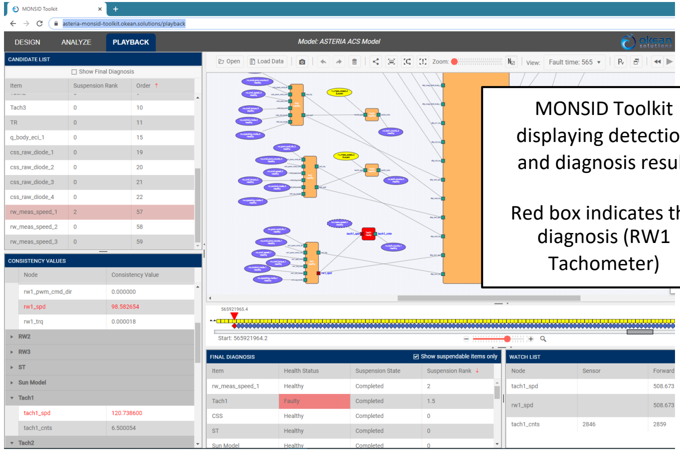
b) Significance

Proved MONSID maturity and validated 3XA R&TD Autonomy Architecture (FRESCO) through experiment, completed reusable software and model components, benchmarked performance / resource requirements

c) Next steps

Develop for future mission in support roles – assist system V&V, analyze mission data on ground, on-board shadow mode?

MONSID prototypes for Lunar Flashlight ACS and IRIS Radio currently under development



MONSID Toolkit displaying detection and diagnosis result

Red box indicates the diagnosis (RW1 Tachometer)

Publications and References

Conference Publications

A. Nikora, M. Aleem, R. Mackey, L. Fesq, “Demonstrating Assurance of Model-Based Fault Diagnosis Systems on an Operational Mission”, 2020 IEEE Aerospace Conference

R. Mackey, C. Altenbuchner, M. Sievers, A. Nikora, L. Fesq, K. Kolcio, M. Prather, M. Litke, “On-Board Model Based Fault Diagnosis for Cubesat Attitude Control Subsystem: Flight Data Results,” in preparation (abstract accepted to 2021 IEEE Aerospace Conference)

M. Feather, B. Kennedy, R. Mackey, M. Troesch, C. Altenbuchner, R. Bocchino, P. Doran, L. Fesq, R. Hughes, F. Mirza, A. Nikora, P. Beauchamp, K. Koclio, M. Prather, M. Litke, “System Level Autonomy – A Demonstration,” in preparation (abstract accepted to 2021 IEEE Aerospace Conference)

New Technology Report

NTR-51554, Diagnostic model of CubeSat Attitude Control Subsystem using MONSID technology

Software Description Document

Design documentation archived at https://github.jpl.nasa.gov/ASTERIA/MONSID-FSW/wiki/Design