Diagnostics of Avionics Systems Using Causal Models

<u>Raj M. Bharadwaj</u>, Rob McCroskey, Kyusung Kim, Honeywell;
Gautam Biswas, Chetan Kulkarni, ISIS, Vanderbilt University;
COTAR: Adam Sweet, NASA AMES

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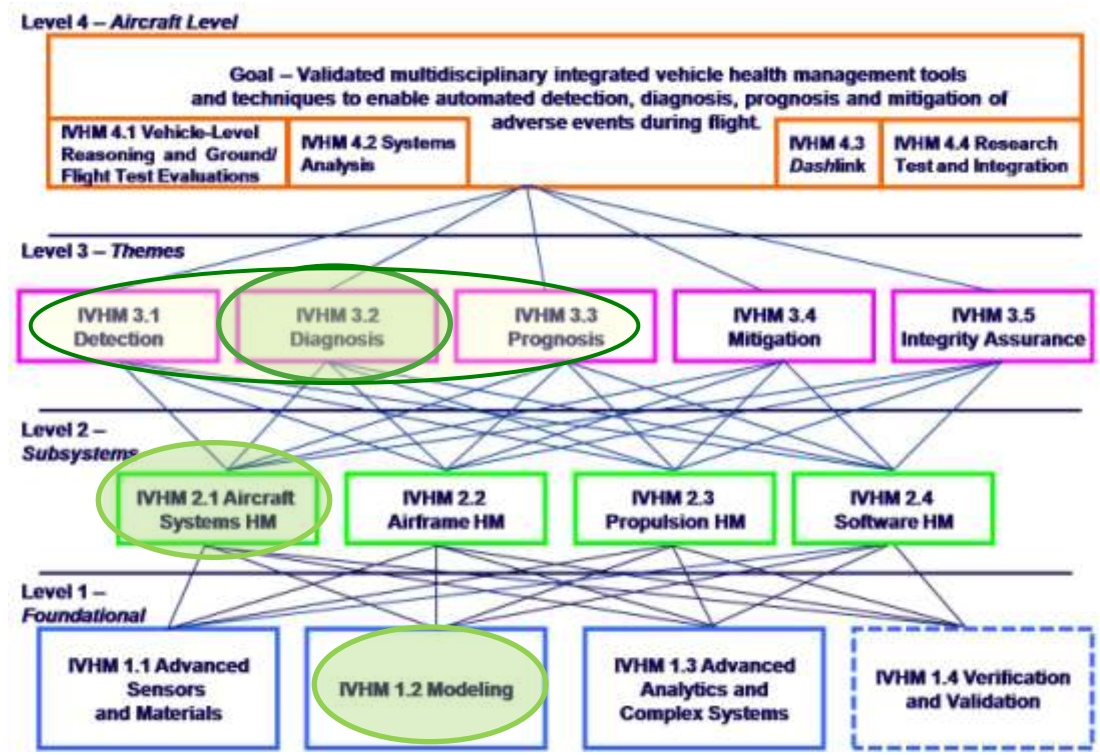
Outline

- Motivation: Avionics related adverse events
- Problem statement, Impact
- IVHM milestones being addressed
- Approach
- Results
- Conclusions
- Next steps



Impacted Themes

Motivation: Avionics Related Adverse Events

Fault	Type	Description
GPS: Satellite vehicle data transmission failure	Discrete, soft, intermittent	Causes loss of lock in all GPS receivers, caused an approach abort during FMS testing
GPS: Satellite vehicle clock drift	Continuous, soft	PRN 23 on 1 January 2004 experienced a clock drift error that grew gradually to a few kilometers.
GPS receiver RF filter failures	Discrete, hard, intermittent	This failure makes it difficult for typical antennae to lock on to signals
GPS receiver delay shift	Continuous, soft, intermittent	Signal delays in the receiver are accounted for in the receiver hardware and/or software. If these delays vary (e.g. with temperature), they can lead to incorrect pseudo-range estimates.
Accelerometer failed high	Discrete	Caused emergency situation on an MAS 777 in 2005 when the flight control system simultaneously thought the aircraft was approaching stall and overspeed due to the failure.
Gyroscope bias/drift	Continuous	Most common gyroscope error and leading cause of position error
Electrolytic capacitor degradation in PSM	Continuous, Degradation	The capacitors have the highest failure rates and the leading cause for breakdowns in PSM. Degradation in the capacitors can be monitored, and using data trending and fault prediction for prognosis can be done.
Power transistor (MOSFET) failure in PSM	Discrete, Degradation, Continuous	Power transistor faults are the second most leading cause of PSM failures. Prior publications mostly discuss the failure in power transistors.

Problem Statement

- In avionics systems, accurate understanding of the “health state” of the system improves overall flight safety and operational efficiency.
- Undiagnosed/misdiagnosed faults in critical systems, e.g. avionics can lead safety incidents/accidents.
- In integrated avionics the distinction between hardware and software faults is not clear.
- Current systems have extensive Built-In Test (BIT) coverage at the component/LRU level, but little or no knowledge of system interdependence.

Current State of the Art

- Component and Subsystem level BIT
- Central Maintenance Computer (CMC), which uses abductive reasoning to associate cause and effect relationships between faults and symptoms
  - Deployed on Boeing 777, 787

Impact

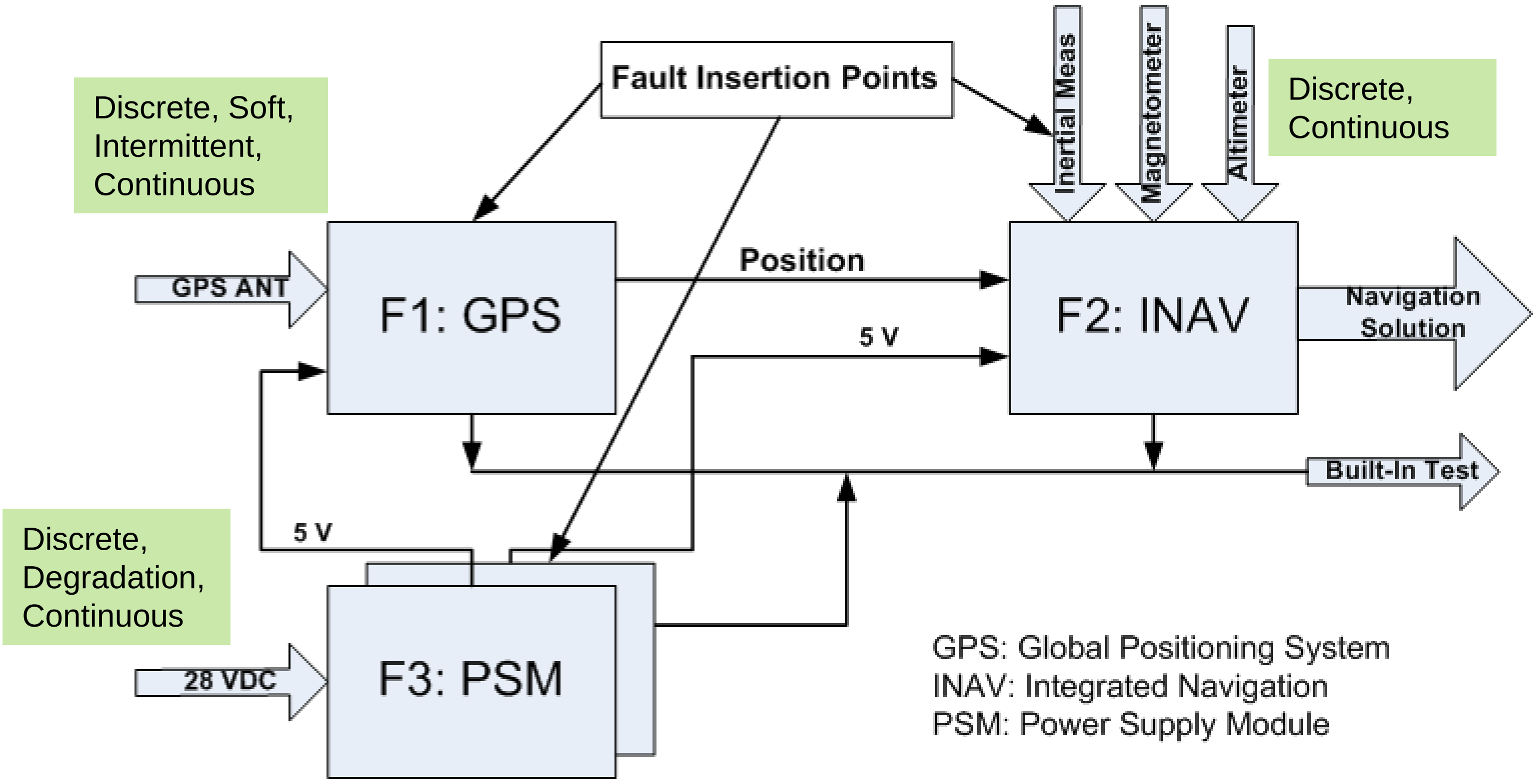
- In this project we have modeled a system with both hardware (power supply, GPS receiver) and software (GPS software, INAV – integrated navigation solution) components
- Our diagnostic approach:
  - Is model-based, which captures the topological and functional dependence among components of the system
  - Captures the causal flow of signals in time
  - Account for causal flow across hardware and software boundaries
- This approach expands the current capability in the following ways:
  - Enables detection of hardware and software faults, as well as faults that can be attributed to the interactions between hardware and software
  - Also, parameterized model can be used to detect small changes in system parameters
- This approach will enable the detection of previously reported safety critical faults
- Finally the capacitor degradation experiments are generating data that will enable DC-DC power supply prognostics

IVHM Milestones Being Worked

- This is a three year NRA award. We are currently in the second year.
- Milestone supported:
  - 2.1.2.1 Validated methodologies and tools for the diagnosis of failures associated with aircraft components and subsystems
  - 1.2.2.2 Hybrid model-based fault detection and isolation

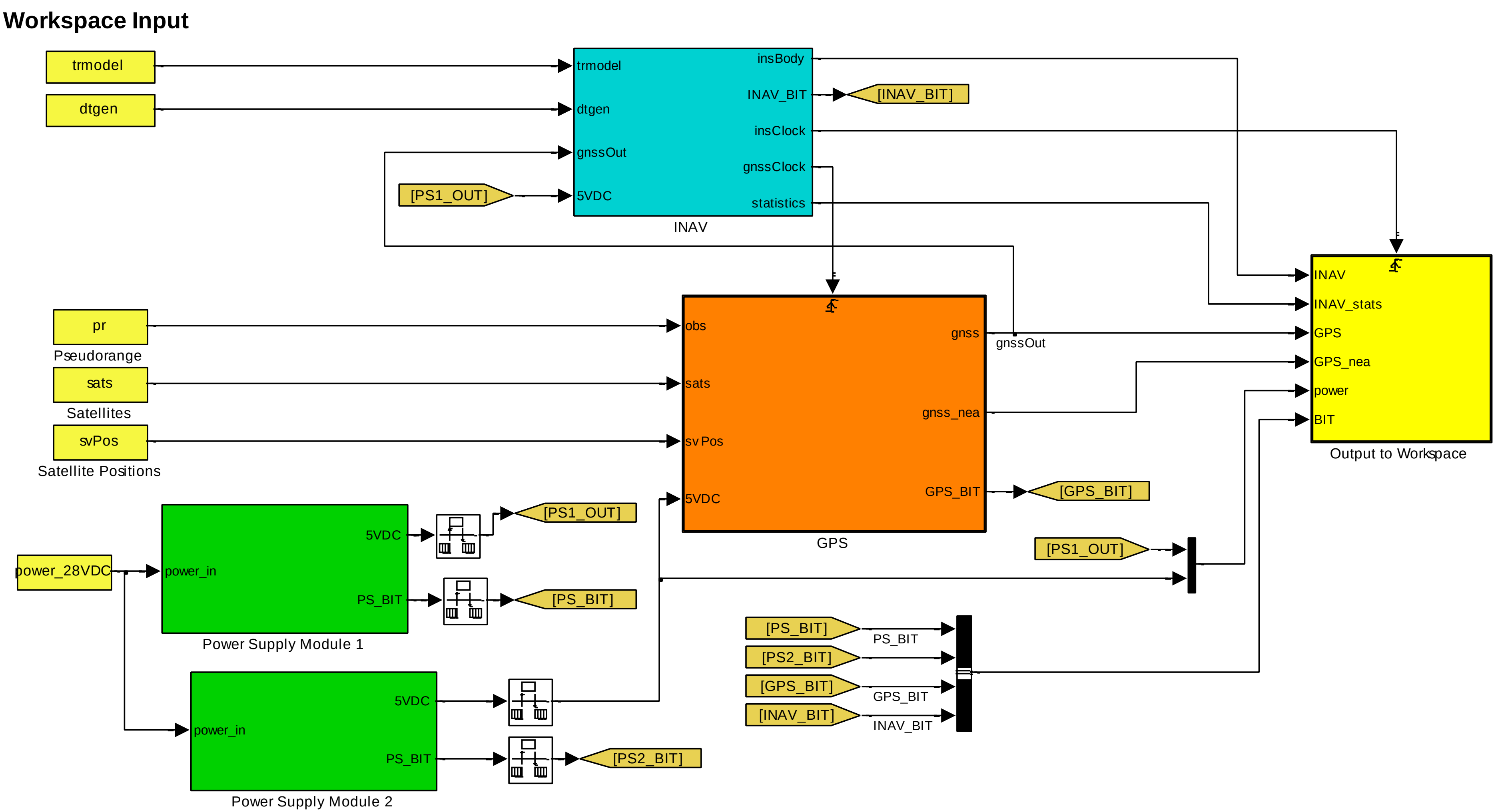
Approach: System Overview

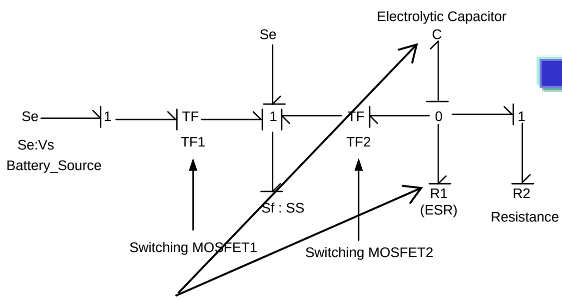
- Nominal behavior of the heterogeneous subsystems are modeled in a common framework (Simulink)
- The integrated system includes the subsystem interactions
- Faults selected linked to real situations
- Demonstrate diagnostic scheme by simulating faulty behavior



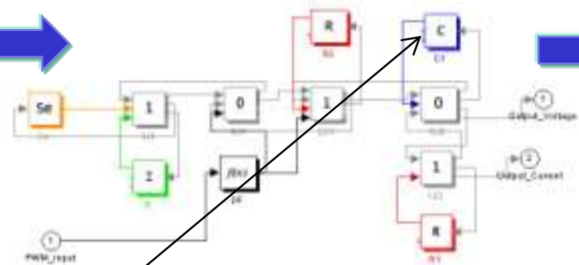
Integrated Simulink Model

Avionics System Model

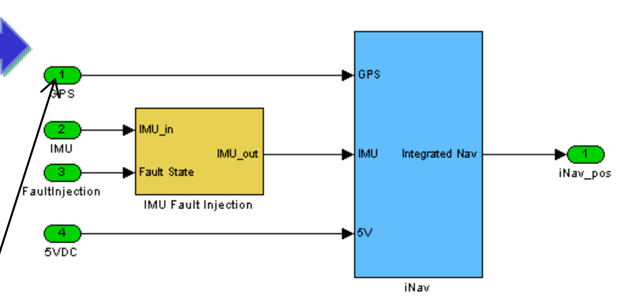




Designate Bond graph parameters corresponding to faults

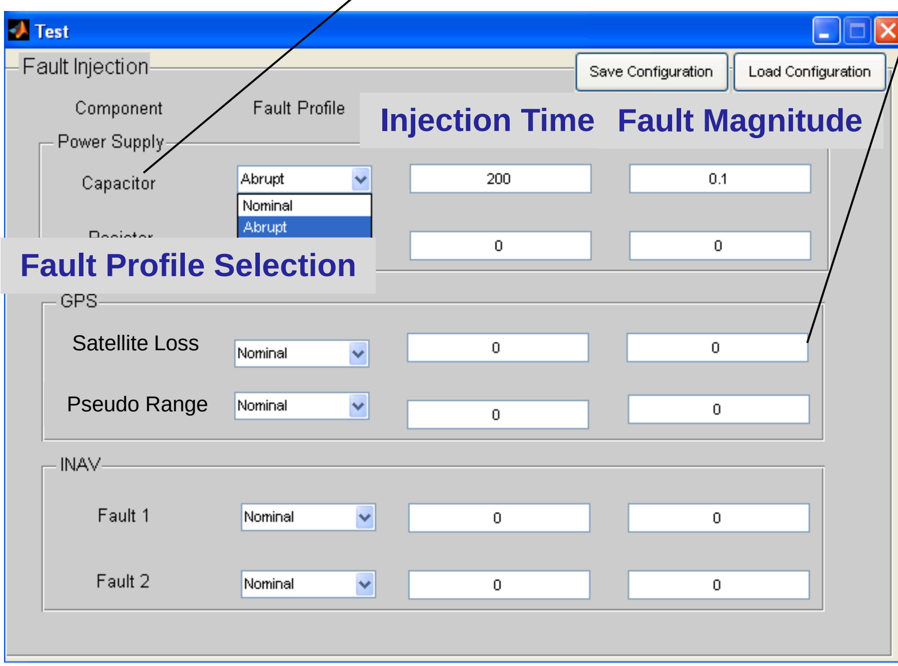


Parameters appear in fault injection GUI.

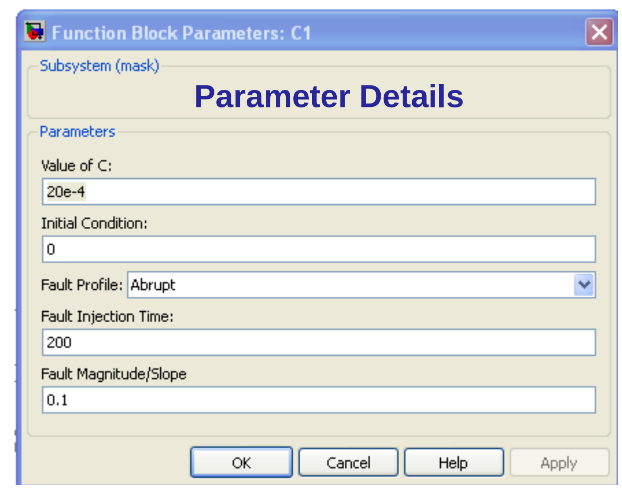


TODO: Add connections in other Simulink modules to allow fault injection from GUI

Abrupt
Incipient
Intermittent



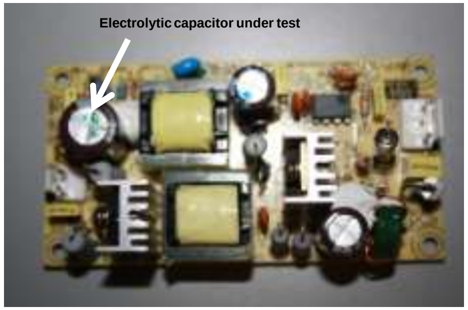
Fault injection interface for component parameters



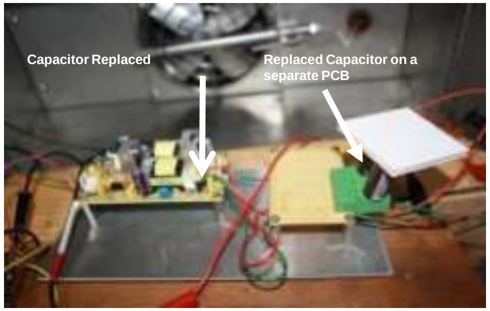
Fault definition interface

PSM- Studying Capacitor Degradation

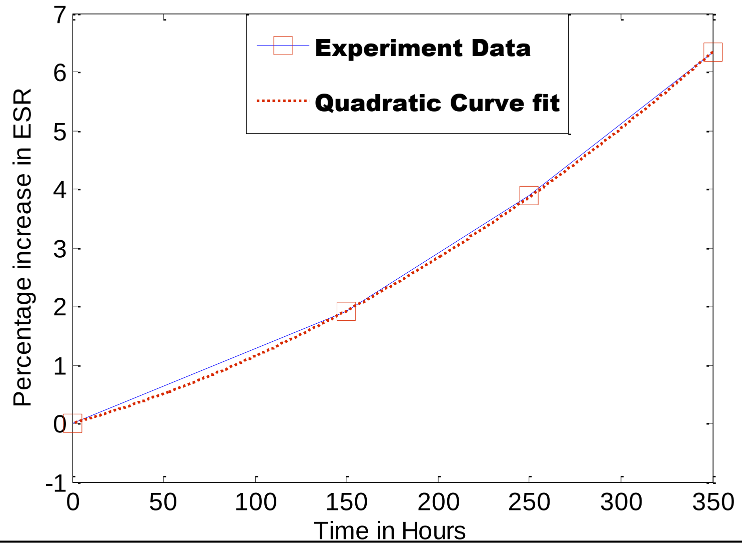
- Degradation in electrolytic capacitors depends on operating conditions – we consider thermal and electrical stressors
- These elevate internal core temperature; <u>cause</u>: electrolyte evaporation; <u>result</u>: capacitor ESR increases gradually and capacitance decreases
- Accelerated Aging Experiment: (1) Run experiment, collect degradation data; (2) Estimate model parameters, validate model

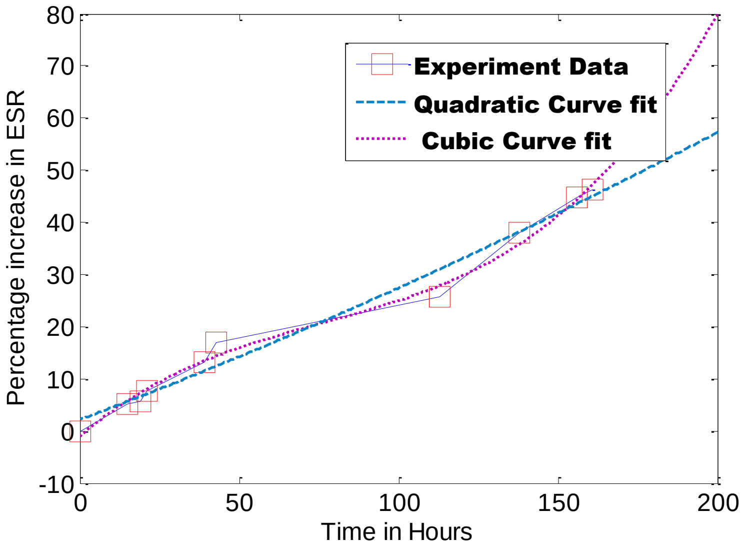


Experimental Setup



Degradation thermal stress





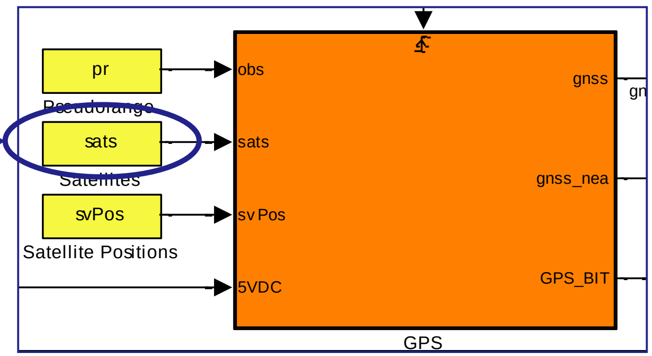
Degradation Electrical stress

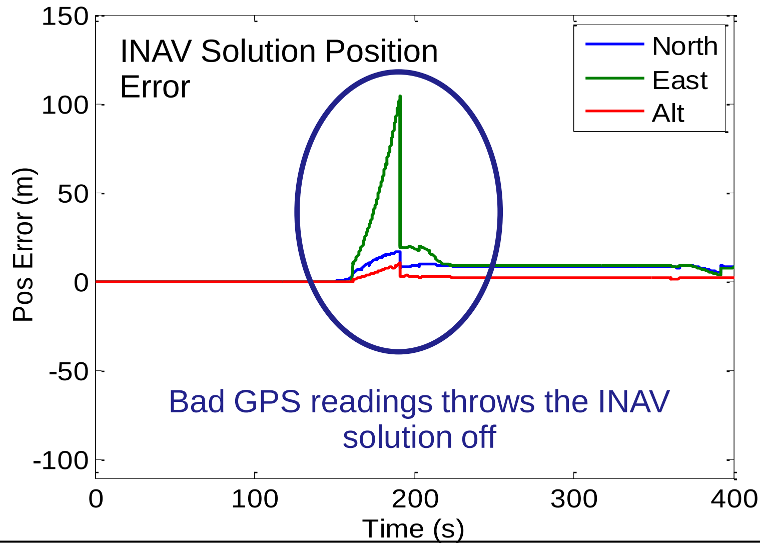
GPS Loss of Satellite Lock

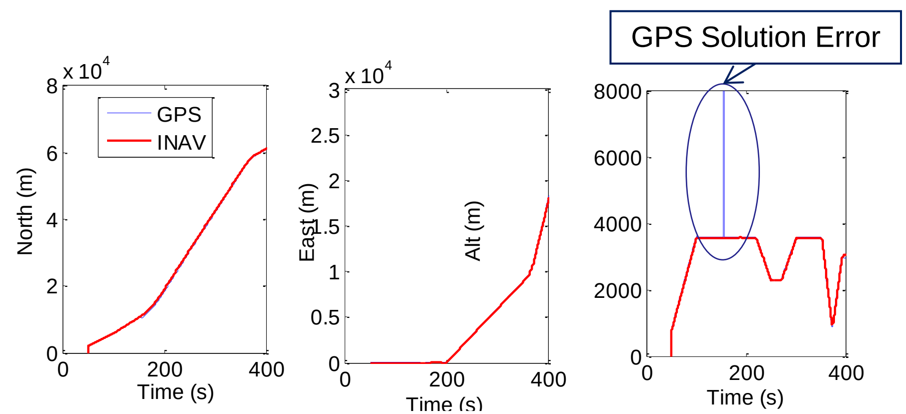
- Objective: Simulating loss of lock in GPS receivers due to fault
- This fault is simulated by changing the sats variable, which represents the number of satellite signals to which the GPS receiver has lock
- At 150 seconds the GPS receiver starts to lose lock to multiple satellites, after 10 seconds the system recovers

149	150	151	152	153	154	155	156	157	158	159	160	*<-Frame*
1	0	0	0	0	0	0	0	0	0	0	1	Sat1
1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	1	Sat2
1	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0	0	1	..
1	1	1	0	0	0	0	1	1	1	1	1	
1	1	1	0	0	0	0	0	0	0	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	
1	1	1	1	1	1	1	1	1	1	1	1	Sat 8

Locked satellites





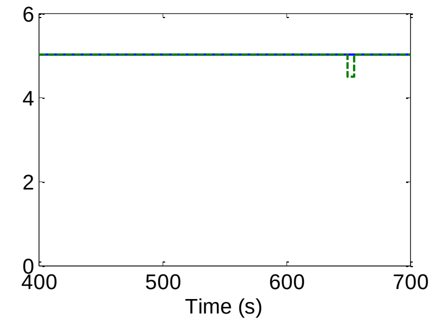


Power Supply Glitch Cascading though the GPS

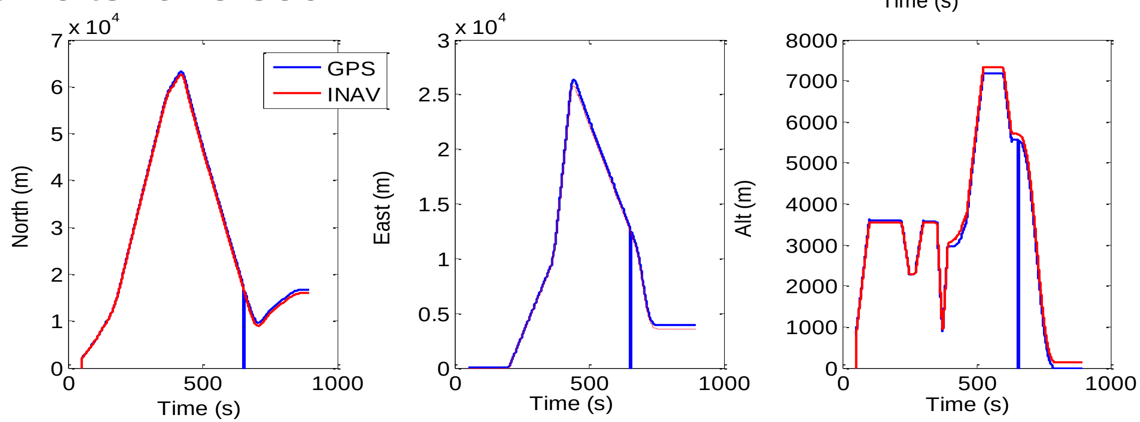
Objective: Simulating GPS receivers reset due to power supply fault

Simulation scenario:

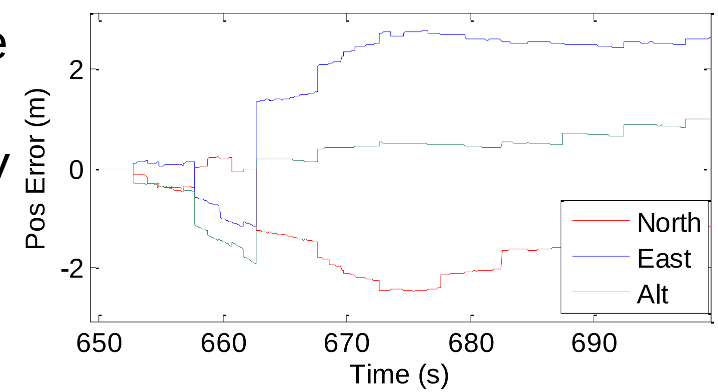
- Glitch in the GPS PSM at 650 sec, the power supply voltage drops to 4.5 volts for 5 sec



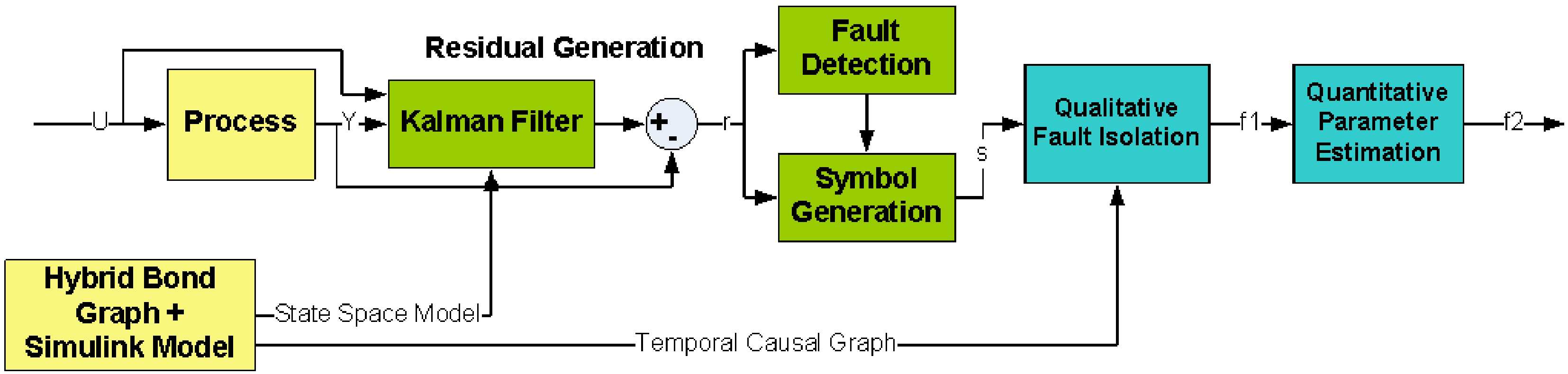
- The GPS receiver resets



- The INAV solution starts to diverge due to the loss GPS signal
- Once the GPS output fully recovers, the INAV solutions will converge
- We are investigating the conditions under which the INAV solution would not converge



Fault Detection and Isolation Approach

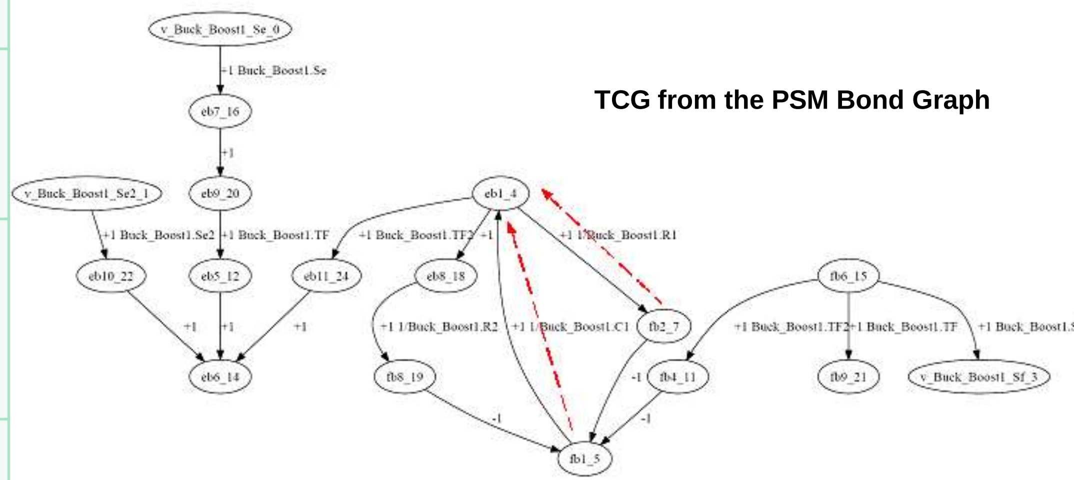


- "Process" block: Simulated system data (faulty behavior)
  - Integrated model with and without the injected faults is used to generate training data
- State space model (for Kalman filter) and temporal causal graph (for diagnosis) are
  - Auto-generated from HBG (physical processes) or Simulink model (software/hybrid processes)
  - For Simulink only models, the state equations and TCG need to be generated by synthesis of simulated cases (with and without fault)
  - Detector compares nominal behavior from model versus process data – discrepancy signals fault
  - Discrepancies converted to symbols and compared to fault signatures for fault isolation
- High fidelity GPS and NAV simulation will be used to generate the validation data

PSM Fault Detection and Isolation

- Example: Capacitor faults in the DC-DC power converters; Fault profile
  - Abrupt: Instantaneous (step) change in the system parameter value. These are caused due to instantaneous high voltage surges in the system.
  - Incipient: Gradually changing parameter value over time. These are caused due to the degradation in the capacitor over the period of time. i.e., increase in the ESR with time.

Fault Hypothesis	Fault Signature	Signal Deviation from Nominal
ESR increase (ESR+): abrupt or incipient	(0,–)	A gradual increase in the ESR will cause a gradual decrease the output voltage of the converter.
Capacitance decrease (C–): abrupt	(+,–)	Abrupt decrease in the capacitance will cause a jump then a decrease in the output voltage of the converter.
Capacitance decrease (C–): incipient	(0,+)	A gradual (incipient) decrease in the capacitance will cause a gradual increase in the output voltage of the converter.



TCG from the PSM Bond Graph

An abrupt fault introduced earlier in the capacitor will generate the (+,-) as shown in the table derived from the TCG .

Summary and Contributions

- Summary
  - Delivered the integrated simulation with power supply, GPS and INAV modules
    - The integrated simulation leverages Honeywell's expertise and prior developed INAV software
    - The fault detection software plans to use NASA and Vanderbilt's experience on ADAPT
  - Identified the list of relevant faults for the integrated system
  - Demonstrated the ability to simulate injected GPS and power supply faults
  - Showed results for select fault injection scenarios
  - We are currently running aging experiments on the power supply capacitor, which can be used for power supply prognostics

- Key Contributions
  - Modeling of heterogeneous systems (hardware + software) in common modeling framework; demonstrated propagation of faults between subsystems
  - Developed fault detection and isolation algorithms for combined system based on causal graphs and qualitative analysis of signals
  - Combining prognosis and diagnosis into common framework for degradation and performance analysis

Milestones & Next Steps

- Upcoming Milestones
  - Description of the faults' effect on system – Jan. 2010
    - Finalize the fault integration interface
    - Characterize all system faults using integrated fault simulation
  - Hybrid diagnosis algorithms and data sets – Feb. 2010
- Next Steps
  - Simulate fault injection cases with varying injection time and NAV trajectories
  - Generate the temporal fault signatures for the GPS and INAV modules
  - Enable fault detection and isolation for the integrated system and evaluate the diagnostics performance
  - Provide requirements and data to NASA's Vehicle Level Reasoner System program