Generic AOCS/GNC Techniques & Design Framework for FDIR (GAFE)

Space Engineering and Technology Final Presentation Days (SETFPDS) at ESTEC

Airbus Defence & Space, Astos Solutions GmbH, University Stuttgart (IFR)
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Agenda

- Study Objectives and Team
- GAFE Framework
  - GAFE Methodology
  - GAFE Structural Analysis
  - GAFE Simulator
- Examples
- Summary & Status

Study Objectives and Team

Study Title

- Generic AOCS/GNC Techniques & Design Framework for FDIR (GAFE)

Objective

- Develop engineering approach & prototype tools to support AOCS/GNC FDIR design and V&V in early project phases

Study Motivation

- “FDIR engineering for Space Systems is lacking a systematic approach and engineering transparency”
- “FDIR systems design often experiences significant growth in complexity and cost late in the development cycle, causing launch delays or delayed completion of the FDIR capabilities after launch.

Study Team

AIRBUS DEFENCE & SPACE

Astos Solutions

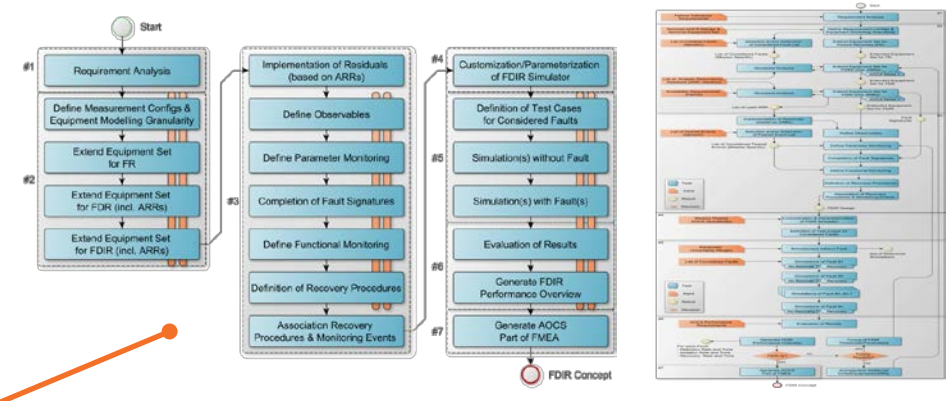
University of Stuttgart Germany

iFR

Initiated by ESA

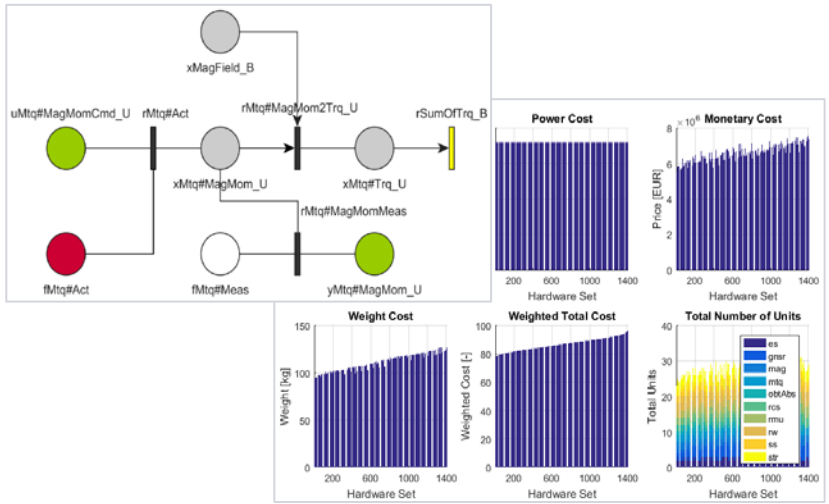
esa European Space Agency

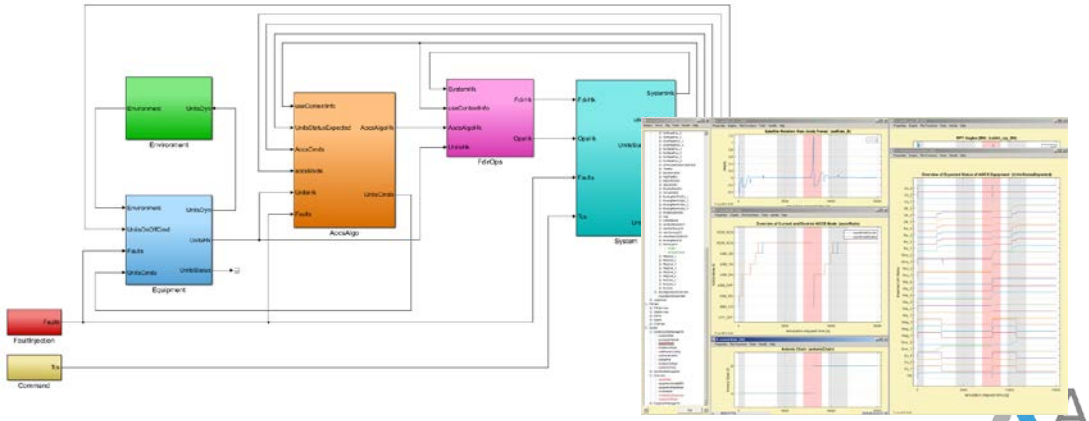
Outcome



GAFE Framework

- GAFE Methodology
- GAFE Structural Analysis
- GAFE Simulator





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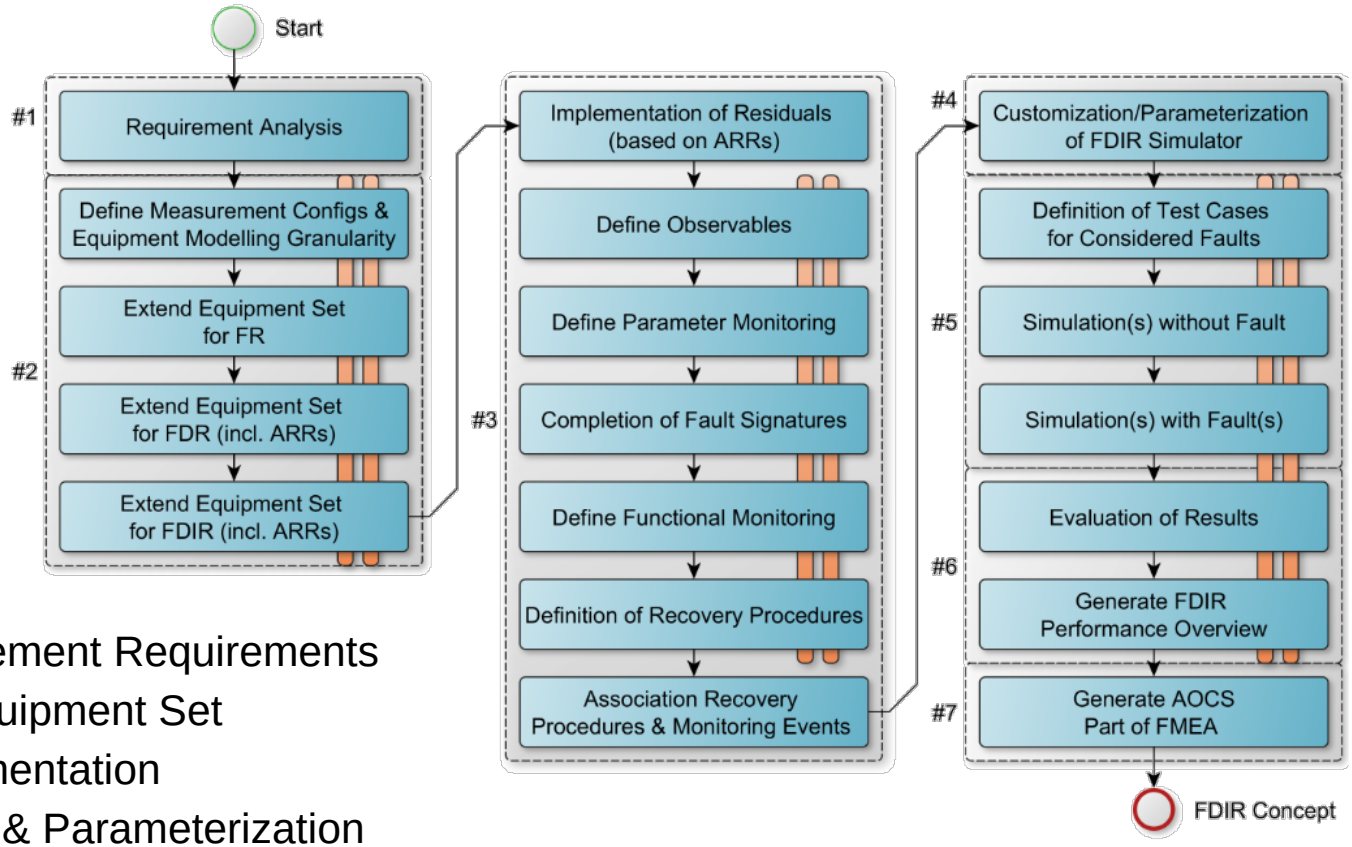
GAFE Methodology

High Level Flow – GAFE Tool Support



GAFE Methodology Tasks:

- #1: Analysis of Fault Management Requirements
- #2: Extension of Nominal Equipment Set
- #3: FDIR Definition & Implementation
- #4: Simulator Customization & Parameterization
- #5: Definition & Simulation of Test Cases
- #6: Evaluation of FDIR Performance
- #7: Generation of FDIR Documentation

GAFE Structural Analysis

Overview

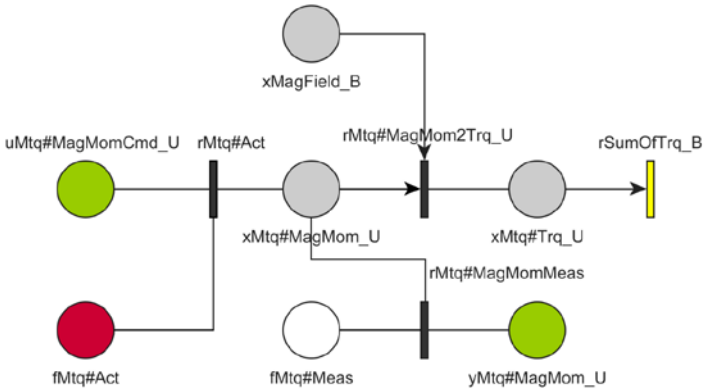
What is a “Structural Analysis”?

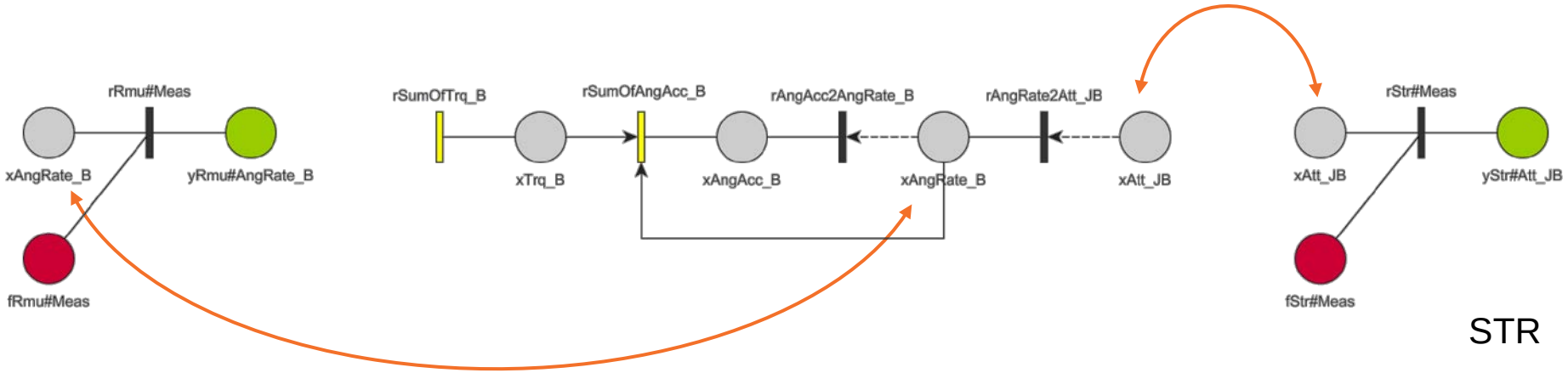
- Mathematical method focused on structural relations between known and unknown “states” of a system

What is a “Structural Model”?

- Abstract model of physical or mathematical relationships

MTQ





RMU

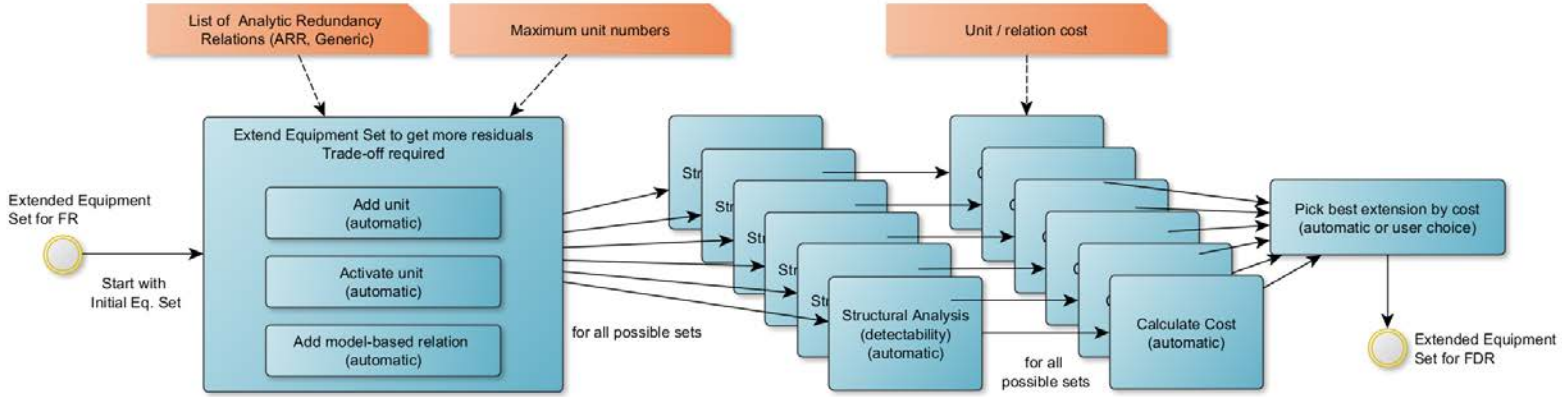
STR

GAFE Structural Analysis

Usage and Outputs

What is the “Structural Analysis” used for?

- To identify if faults in predefined system elements can be detected and/or isolated

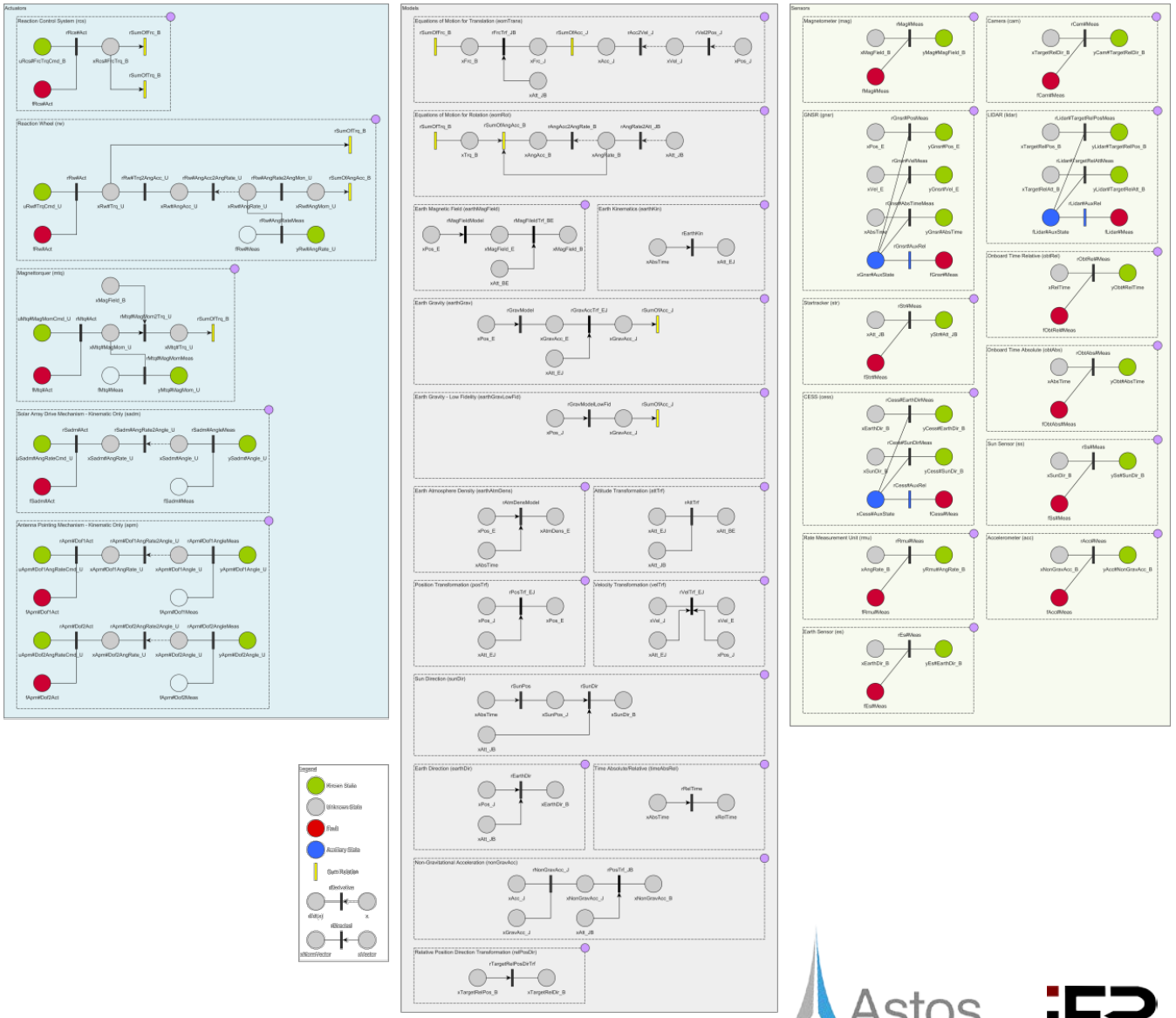


What are the outputs?

- AOCS/GNC equipment set to be integrated (redundant, FD/FDI)
- Active AOCS/GNC equipment per mode
- Required analytic redundancy models for FDIR purposes
- Residuals to be computed onboard
- Fault signatures required for identification of faults

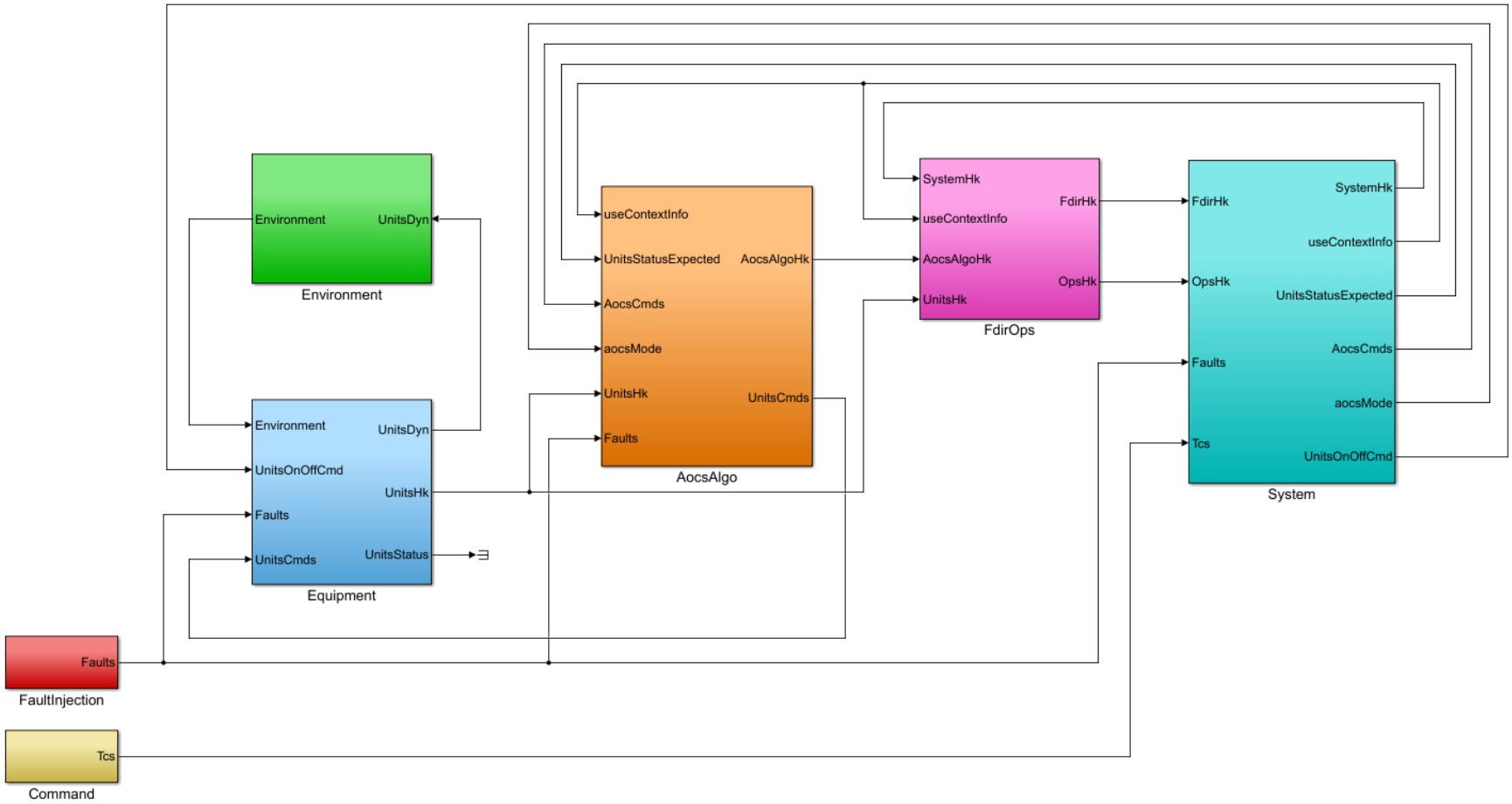
GAFE Structural Analysis

Structural Model Library (5 actuators, 14 analytical modes, 11 sensors)



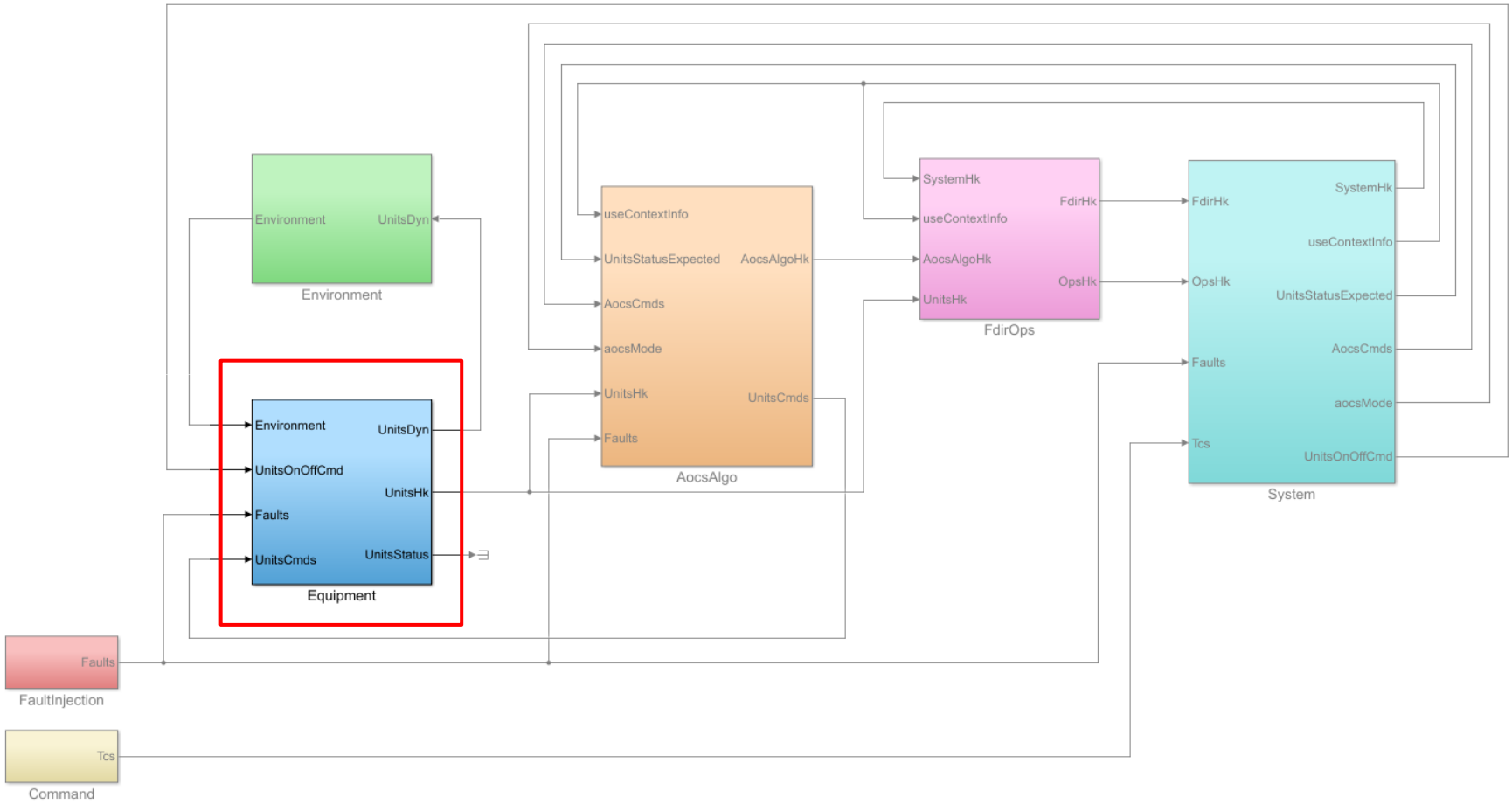
GAFE Simulator

Top-Level Architecture



GAFE Simulator

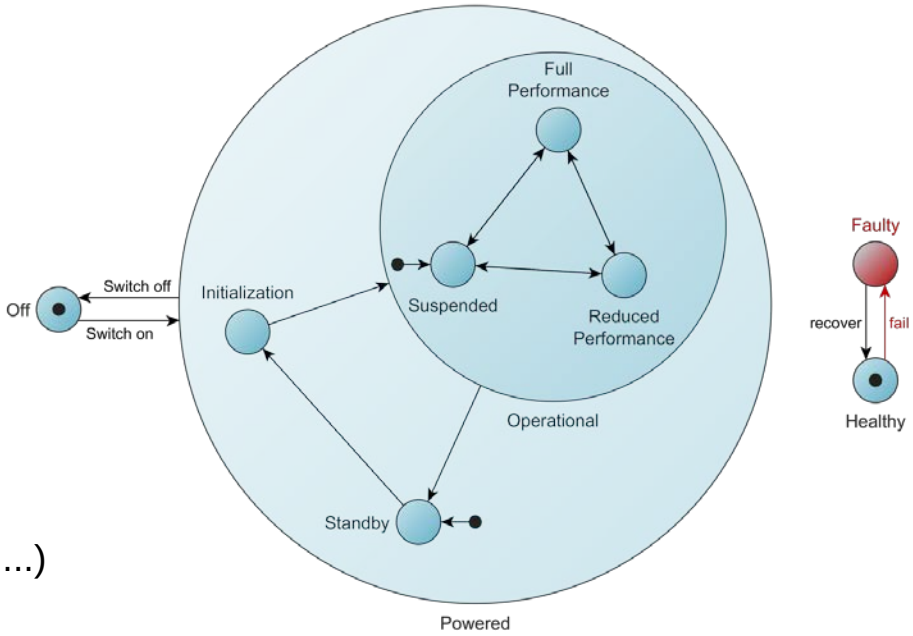
Equipment Module



GAFE Simulator

Generic Equipment Model (GEM)

- Serves as "host" for specific equipment models (SEM)
  - Behavioural model
    - Generic states with generic functionality
  - Fault handling
    - Injection
    - Ejection
    - Persistency
    - Performance impact
      (noise increase, drift, bias, stale data, random walk, ...)
  - Instantiation of Units
    - Number of units via parameter
    - User specifies just the differences



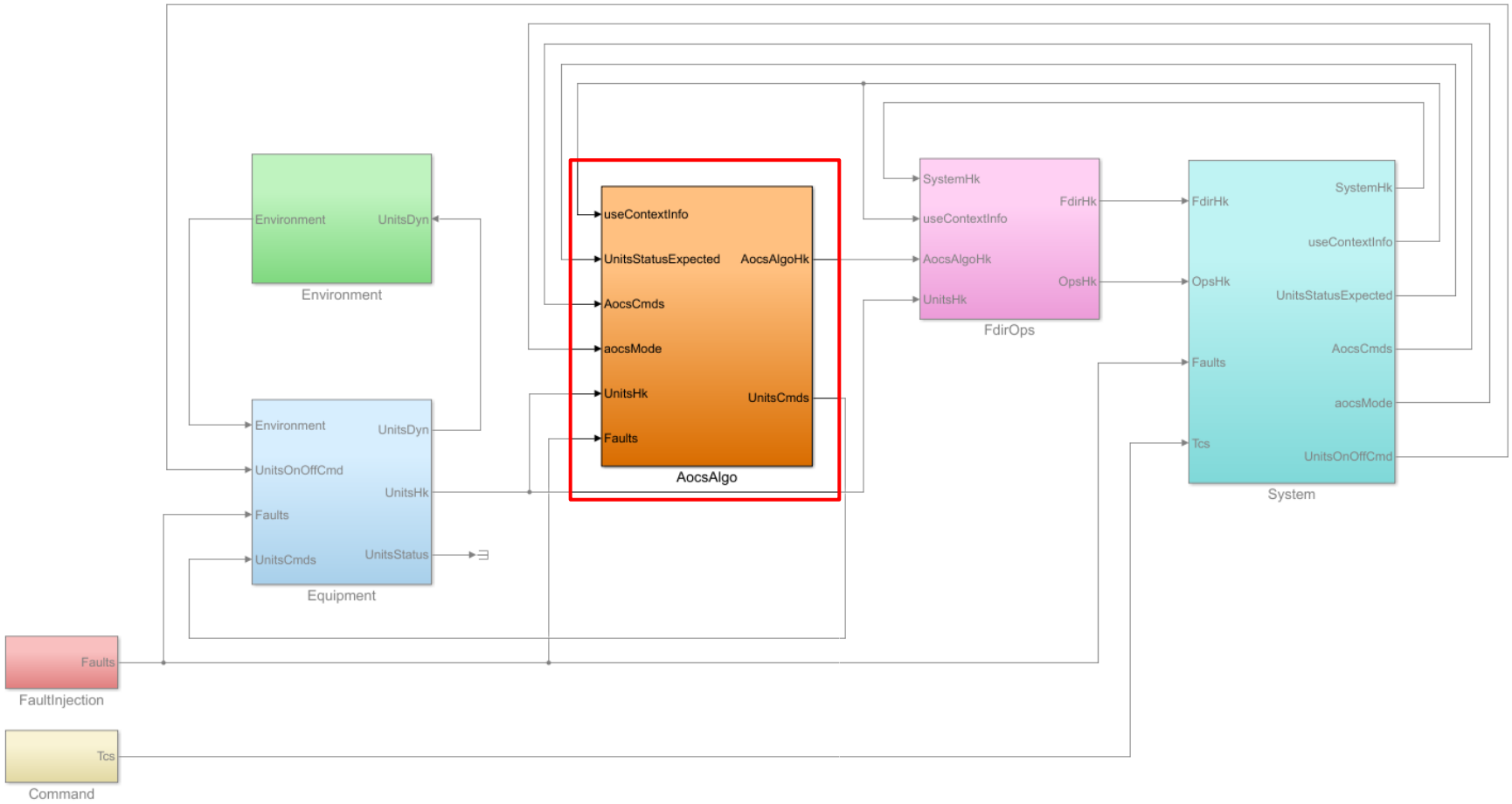
GAFE Simulator

Specific Equipment Models - Library

- Sensors
  - Magnetometer
  - Earth Sensor
  - Sun Sensor
  - Startracker
  - GNSR
  - Lidar
  - Camera
  - Clock
  - Rate Measurement Unit
  - Accelerometer
- Actuators
  - Magnetorquer
  - Reaction Wheel
  - Reaction Control System (Thrusters)
- Non-AOCS/GNC Actuators
  - Solar Array Drive Mechanism
  - Antenna Pointing Mechanism

GAFE Simulator

AOCS/GNC Algorithms Module



GAFE Simulator

AOCS/GNC Algorithms - Concepts

- Modularity on AOCS/GNC Algorithmic „Component“ level
  - e.g. rmuMeasProc, oop, nomAcqCtrl, rcsCmd
- Parametric configurability
- Identical interface of all „Components“
  - Data => intra Component
  - Status => for FDIR / OPS
  - States
  - Parameters
- Status Flag concept
  - „isValid“ Status Flag from one „Component“ to the next
  - Tristate logic: NOTEVAL, OK, NOK
  - „Common“ and „Individual“ flags
- Systematic collection of all States
  - all States accessible
  - States reset overall, of single Components or even selectable individually (SGM)
- Sampling
  - sample time and offset
  - reset/hold Output and States

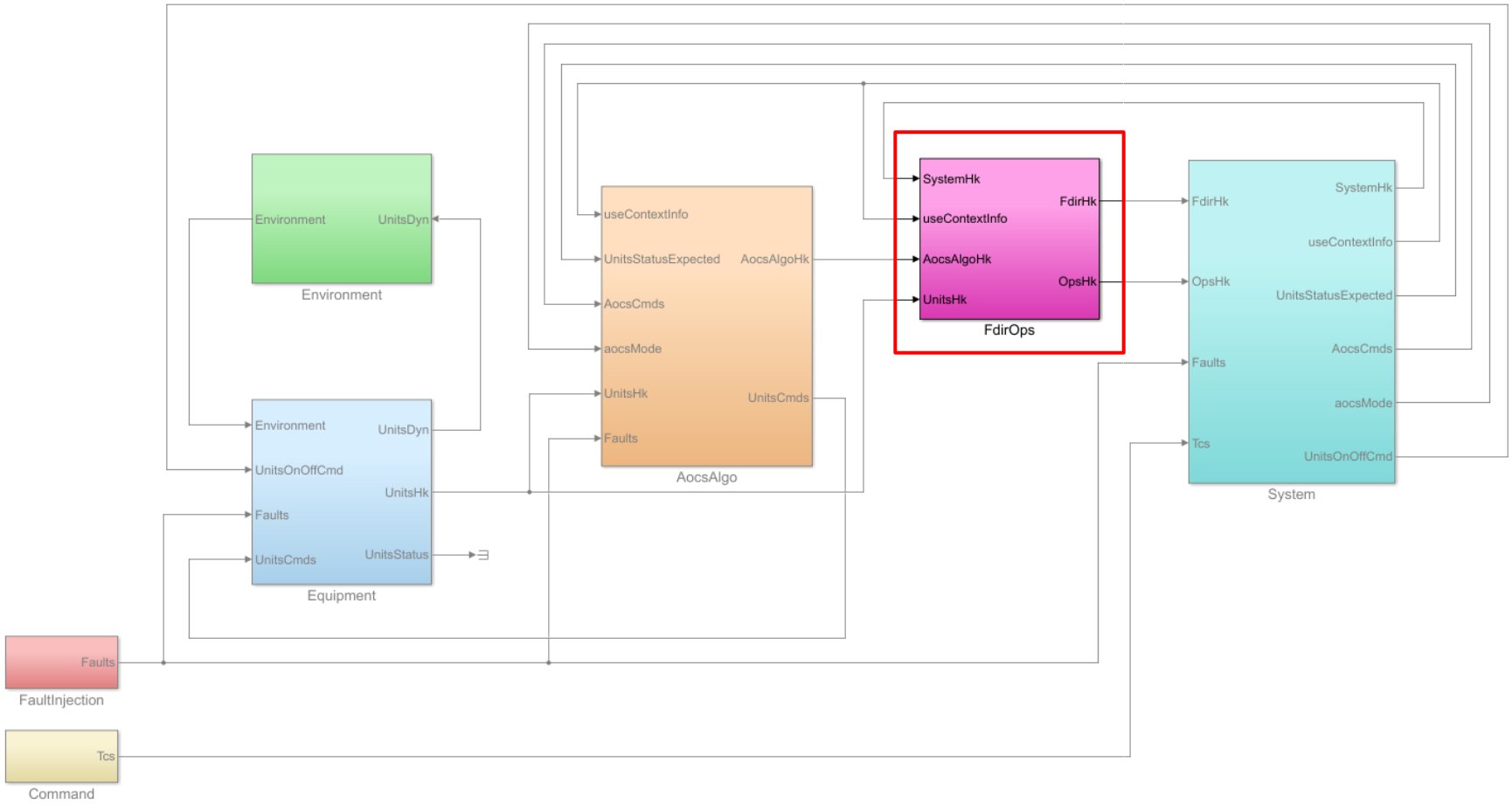
GAFE Simulator

AOCS/GNC Algorithms – Components Library

- Sensor Processing
  - Magnetometer
  - Earth Sensor
  - Sun Sensor
  - Startracker
  - GNSR
  - Lidar
  - Camera
  - Clock
  - Rate Measurement Unit
  - Reaction Wheel
- Determination functions
  - Satellite attitude and rate
  - Earth direction
  - Sun direction
  - Magnetic field and rate,
  - Orbit (OOP),
  - Earth ephemeris,
  - Reaction Wheel friction estimation
  - Relative position and orbital elements (to target)
- Controller
  - Rate Damping
  - Attitude Acquisition and Safe Mode
  - Nominal Mode, ...
- Actuator Commanding
  - Magnetorquer
  - Reaction Wheel
  - Reaction Control System (Thrusters)

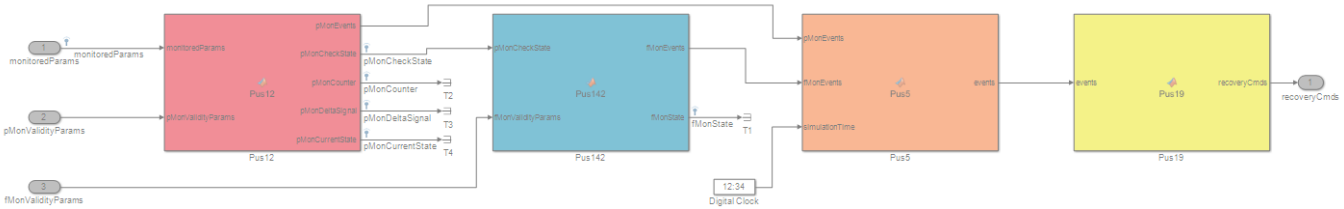
GAFE Simulator

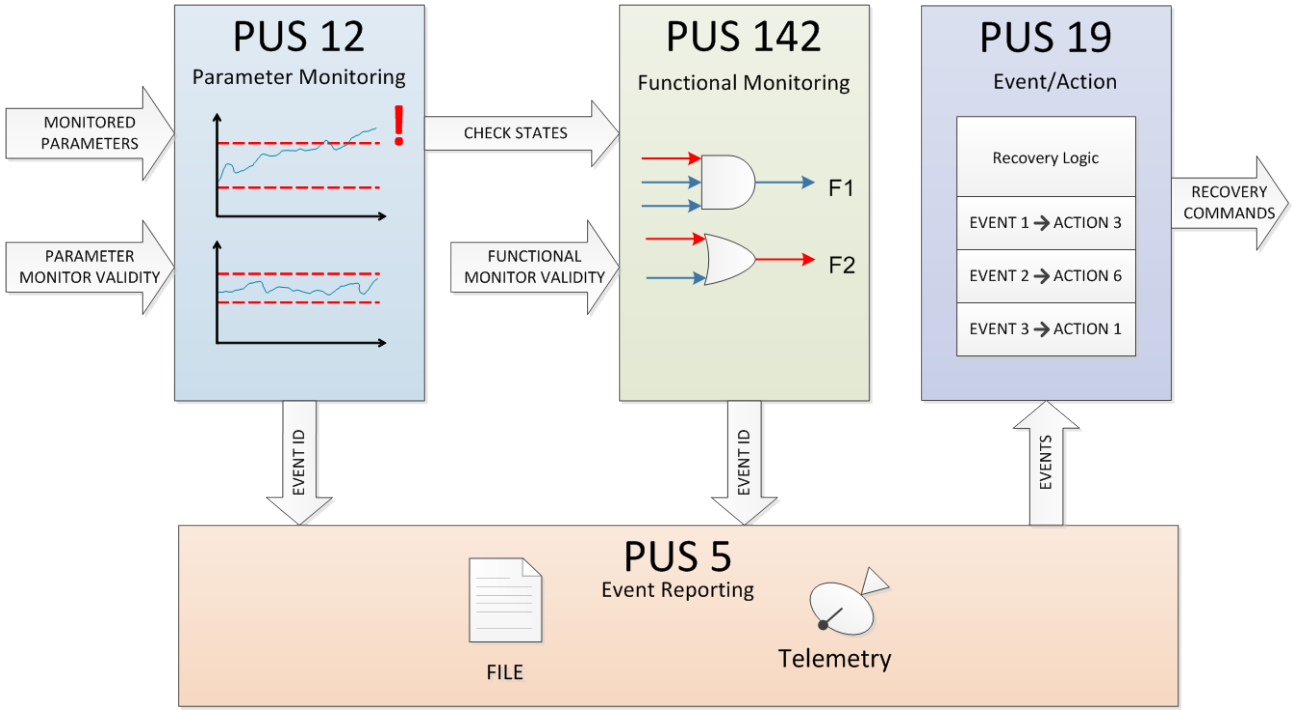
FDIR/OPS Module



GAFE Simulator

FDIR/OPS Module – PUS Services



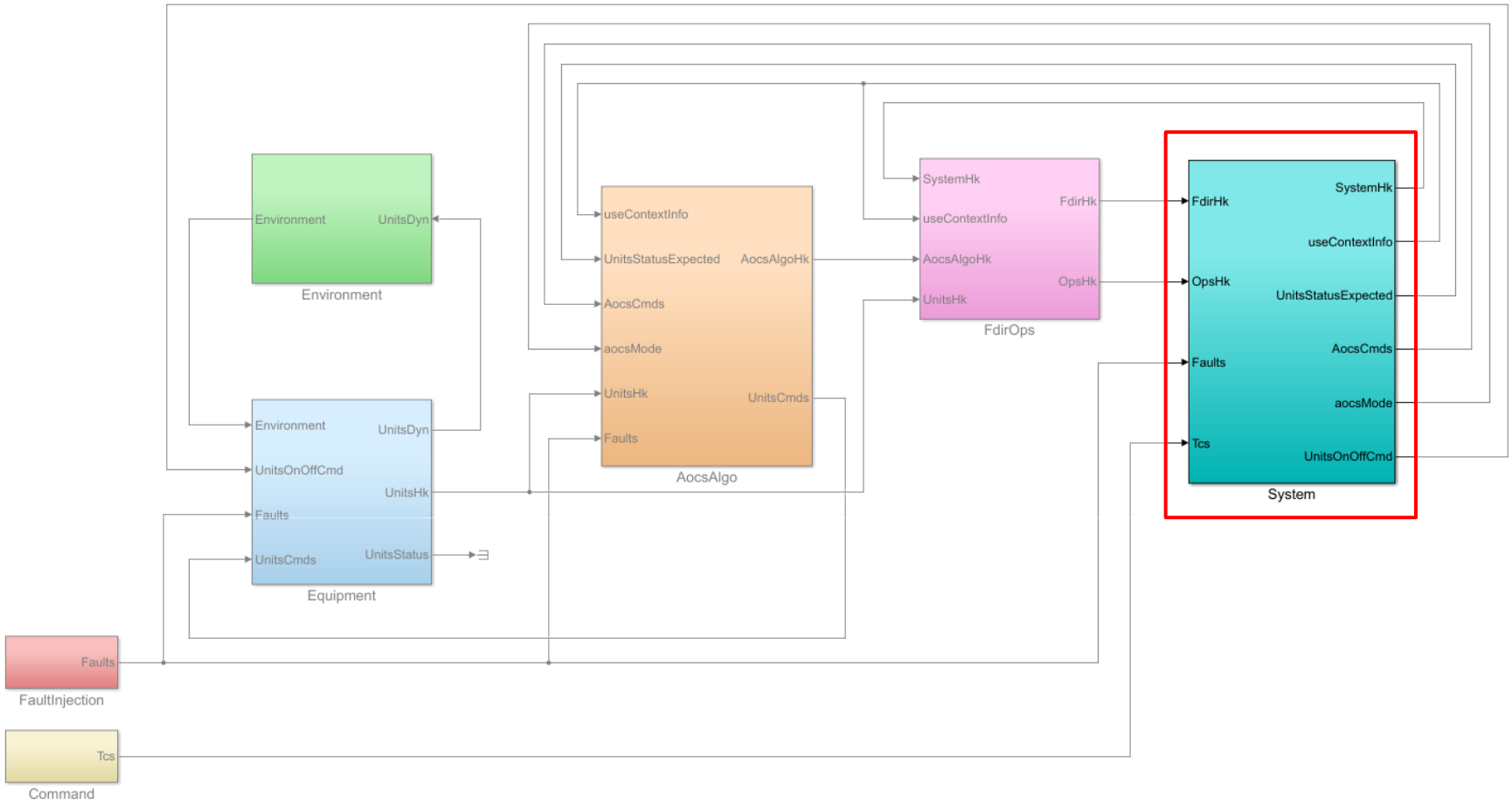


for FDIR purposes

New:
for OPS purposes
=> AOCS/GNC mode management

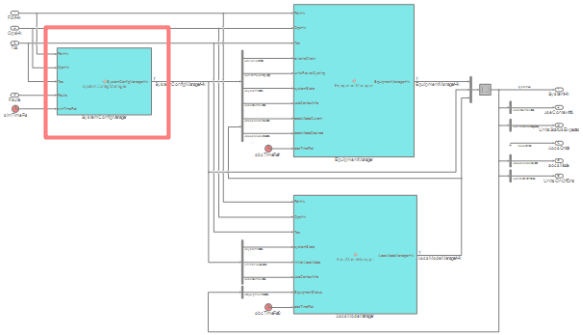
GAFE Simulator

System Module



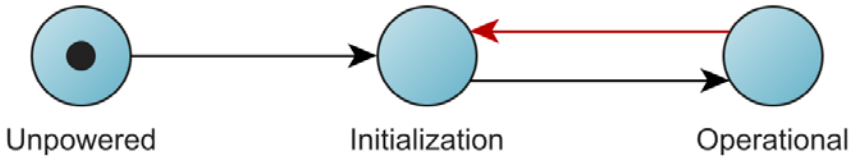
GAFE Simulator

System – System Configuration Manager



Tasks:

- Models operational state of OBC

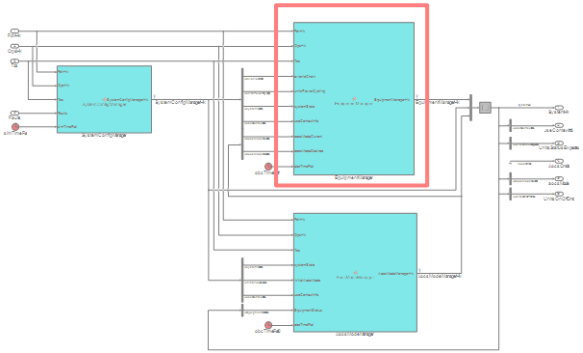


- Handles OBC (re)boots
- Maintains and distributes System Configuration
  - Processor module
  - Avionic chain
  - Initial AOCS mode to use
  - Equipment power-cycling
  - Use of context information from non-volatile memory (SGM, RAM)
  - Enable/disable FDIR
  - Next system configuration

System Config	Processor Module	Avionic Chain	Initial AOCS Mode	Units Power Cycling	Use Context Info	Enable FDIR	Next System Config
1	A	A	ASM	No	Yes	Yes	2
2	A	B	ASM	No	Yes	Yes	3
3	B	A	SAME	Yes	Yes	Yes	4
4	B	B	ASM	Yes	No	Yes	5
5	A	A	ASM	Yes	No	Yes	6
6	B	A	ASM	Yes	No	No	1

GAFE Simulator

System – Equipment Manager



Tasks:

- Equipment Configuration using ECT
  - Mode setup
  - Mode transition
  - Reconfiguration
- Unit Health Status
  - Keeps record and handles “unitFailed” notification

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GAFE Simulator - Examples

Scenario & Demonstration Cases

Scenario:

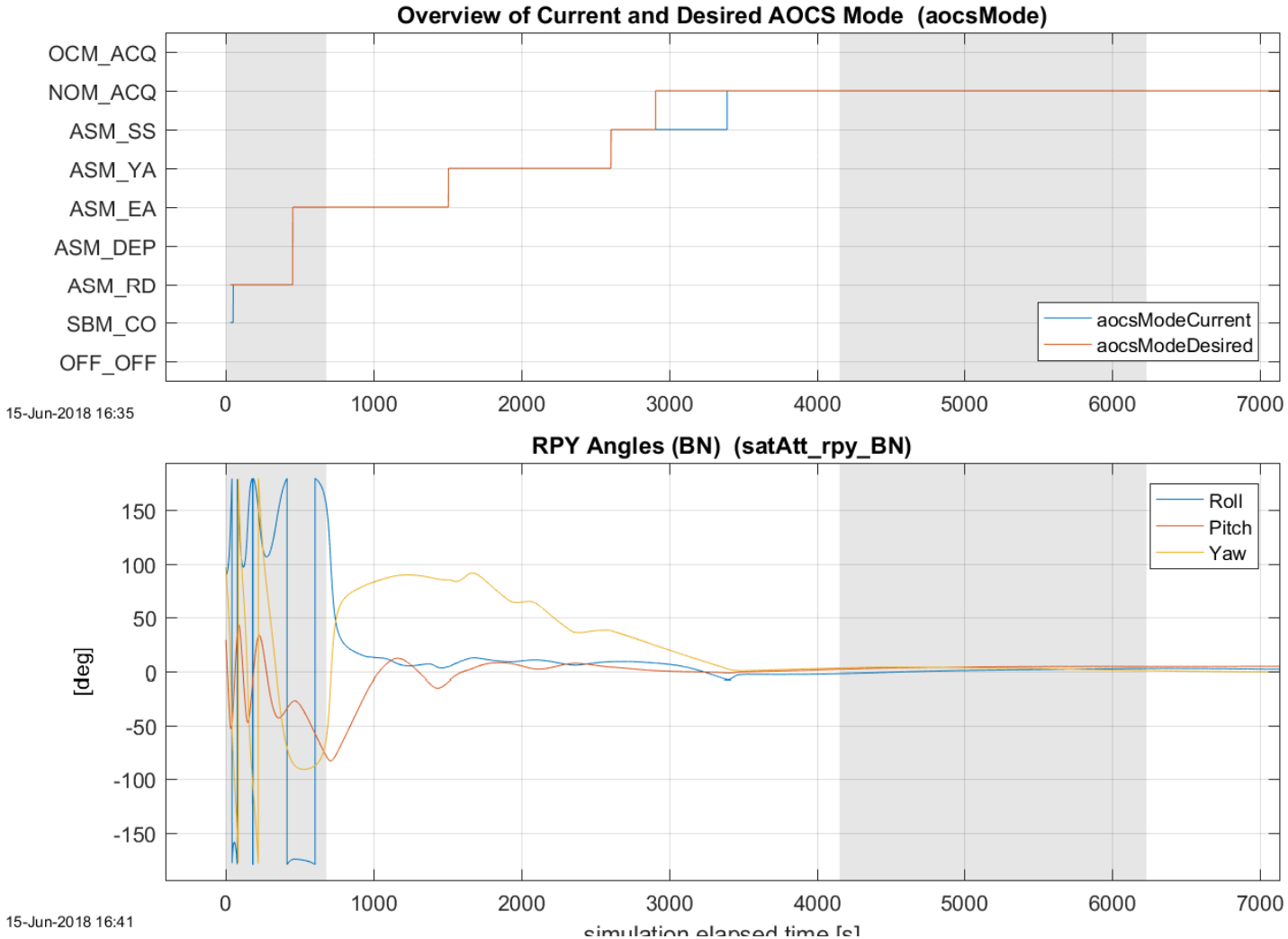
- EarthCARE (from the re-engineered study case):
  - Wakeup in Acquisition & Safe Mode, transition to Nominal Mode

Demonstration Cases:

- Nominal Part: No faults
- Fault Case 1:
  - Fault: Star Tracker Unit 2 – Drift
  - Injection time: 4700s & 5450s
- Fault Case 2:
  - Fault: Reaction Control System – Thruster Stuck Open
  - Injection times: between 7000s and 9000s (Monte-Carlo)

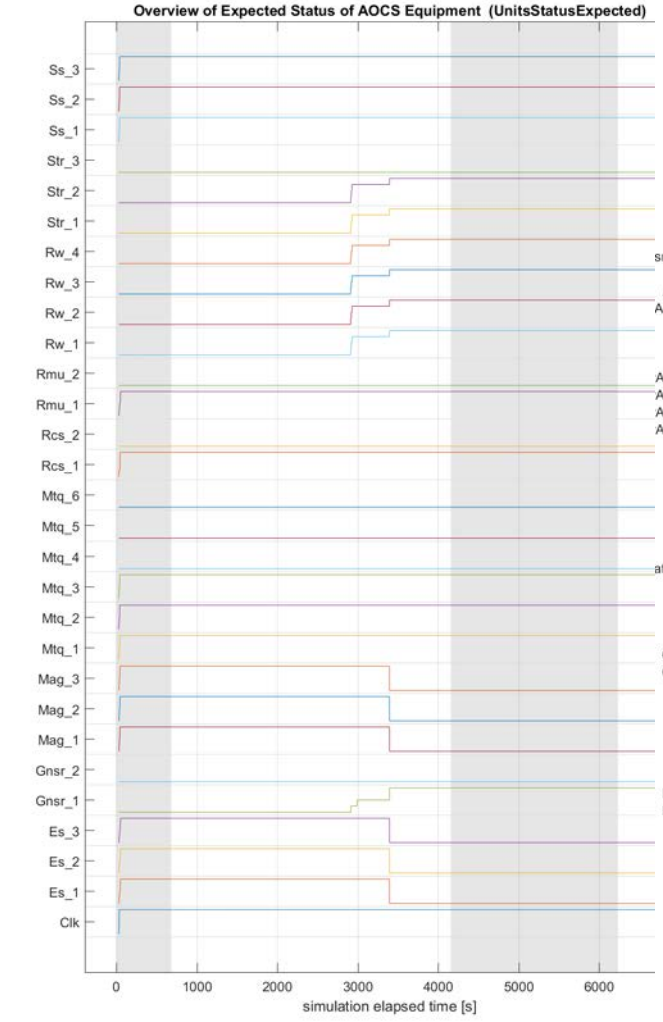
GAFE Simulator - Examples

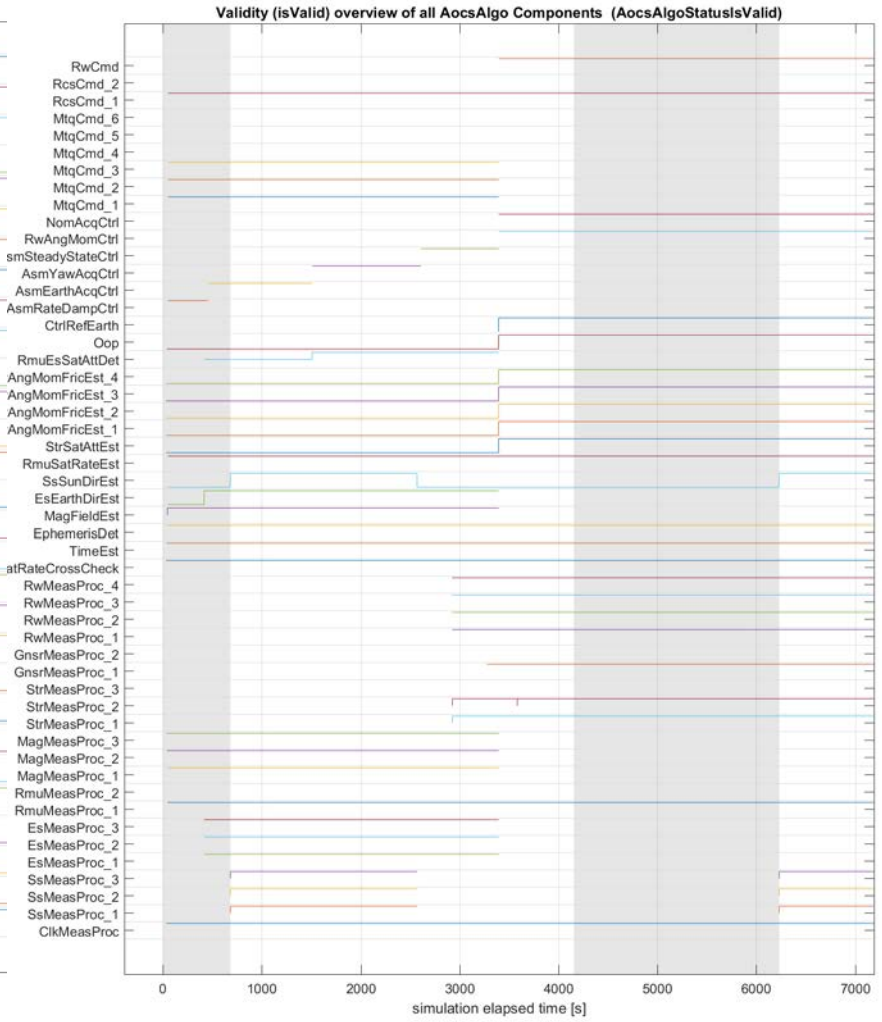
Nominal Part – No Faults



GAFE Simulator - Examples

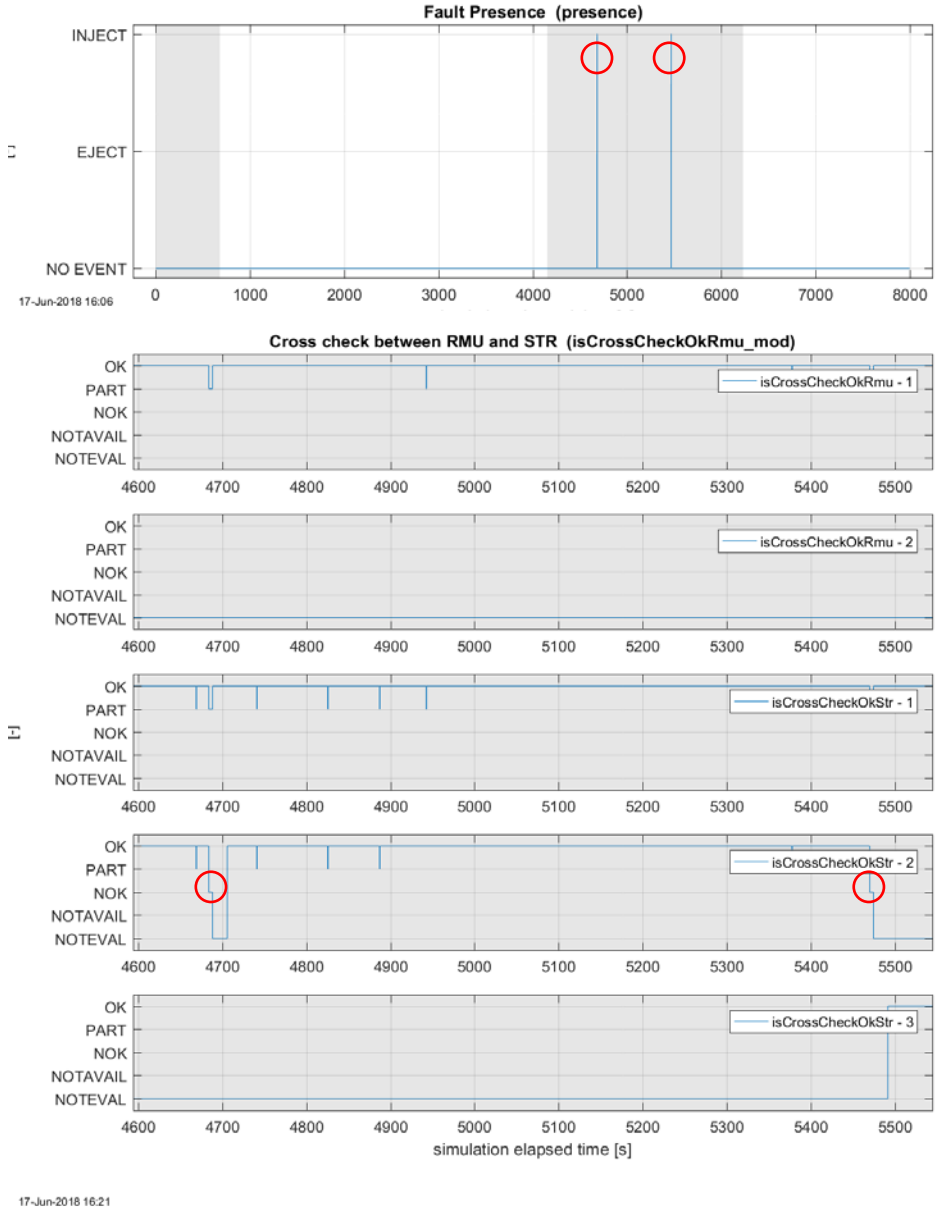
Nominal Part – No Faults

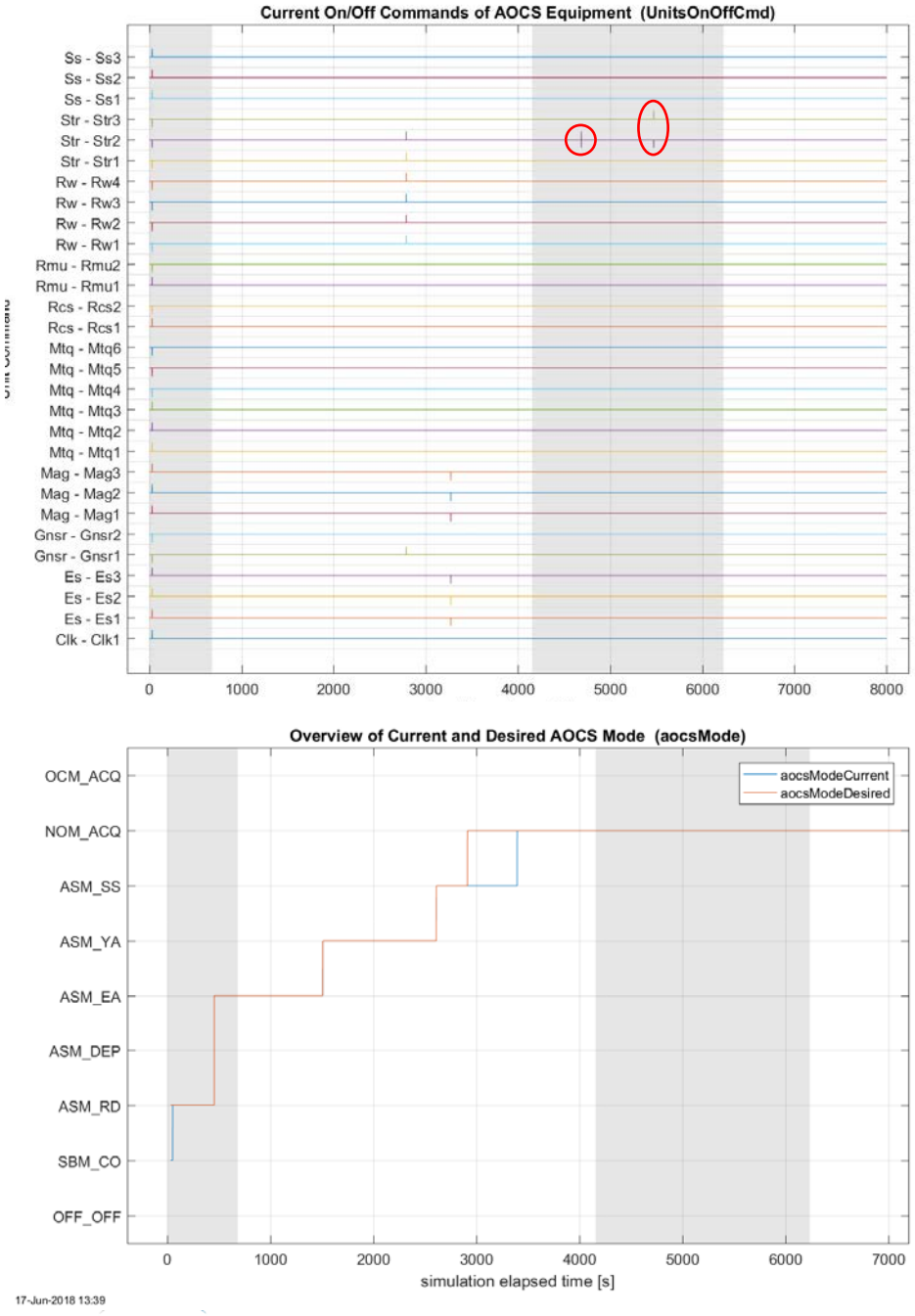




GAFE Simulator - Examples

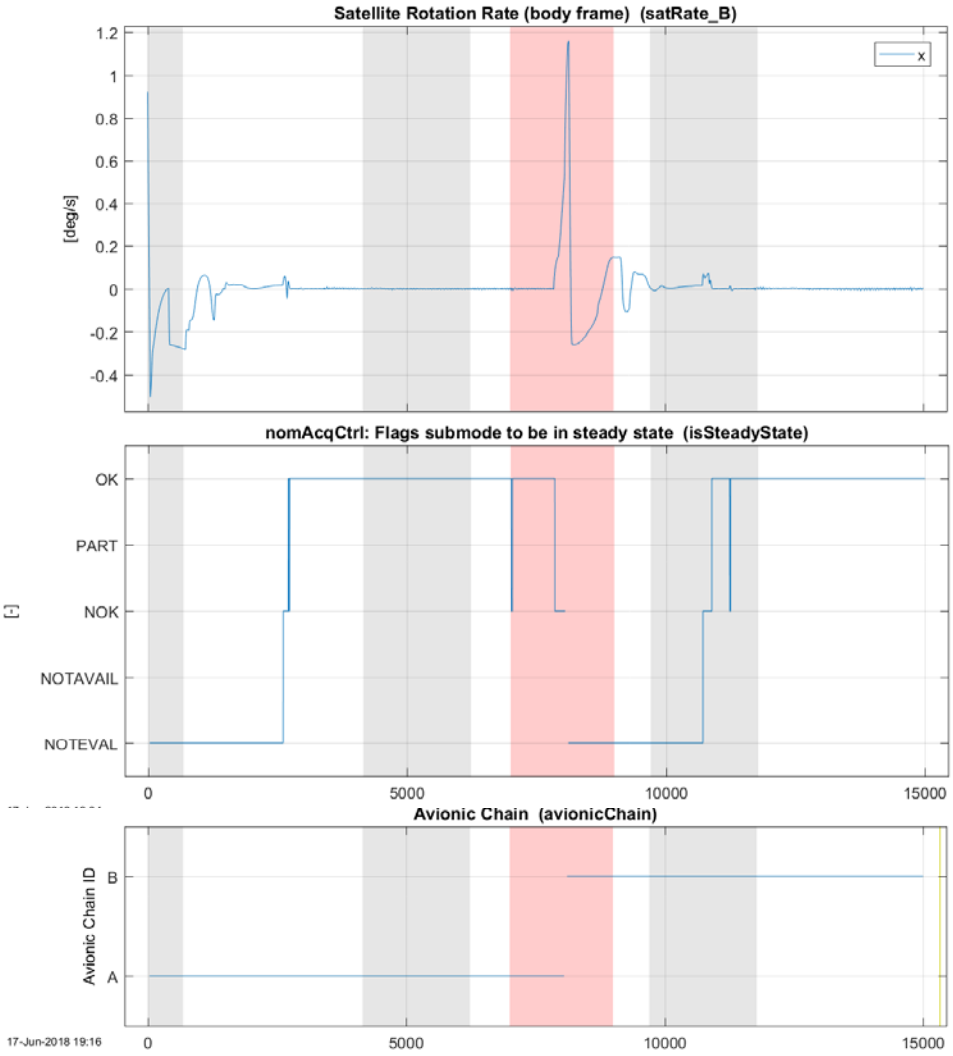
Fault Case 1: Star Tracker Unit 2 – Drift

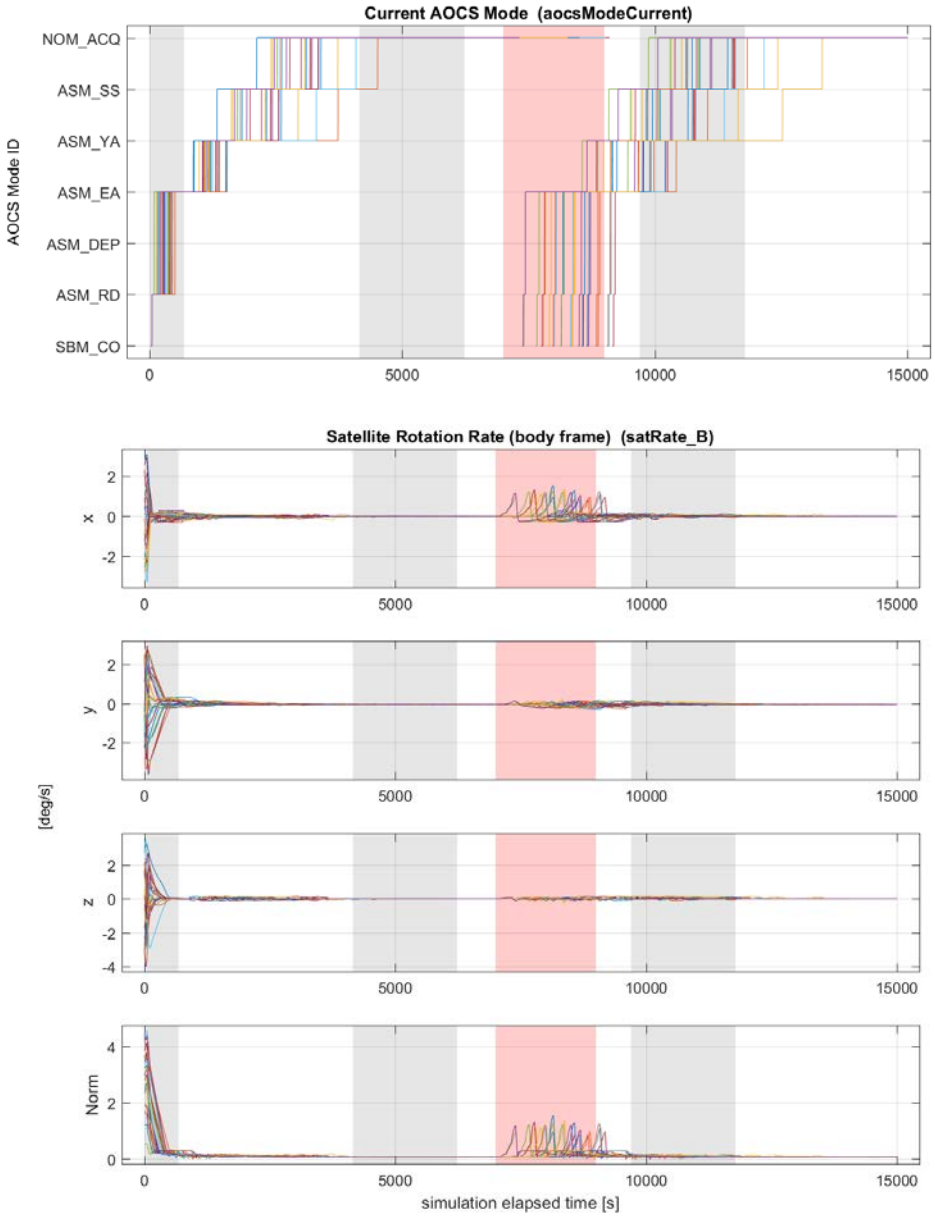




GAFE Simulator - Examples

Fault Case 2: RCS - Thruster Stuck Open





Summary & Status

- GAFE Framework
  - Ready-to-use for european space industry
  - TRL level 3
  - Requires MATLAB Release 2016b + Simulink

- Website and Download at: https://gafe.estec.esa.int

- Contact Points
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  - ESA:
    Alvaro Martinez Barrio, Alvaro.Martinez.Barrio@esa.int

- Outlook
  - Include electrical & communication layers RIU, PCDU, MilBus and cross-strappings
  - Extend the „libraries“ with more analytical models
  - Add high-level automatic configuration capabilities
  - Upgrade to PUS-C
  - Increase automatisation level for post-processing
  - Include event-based fault injection
  - ...

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