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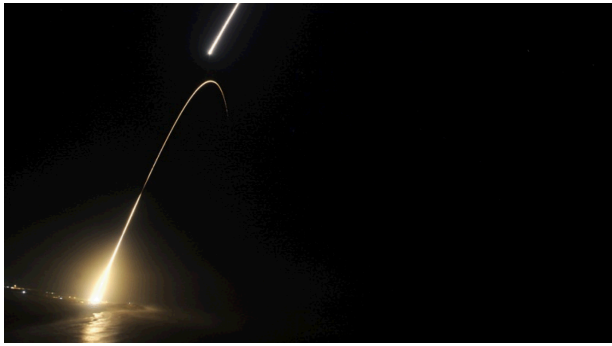

MODEL-BASED DESIGN STRATEGIES FOR REAL-TIME HARDWARE-IN-THE-LOOP ROCKET SYSTEM SIMULATIONS

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AIAA Modeling and Simulation Technologies Conference

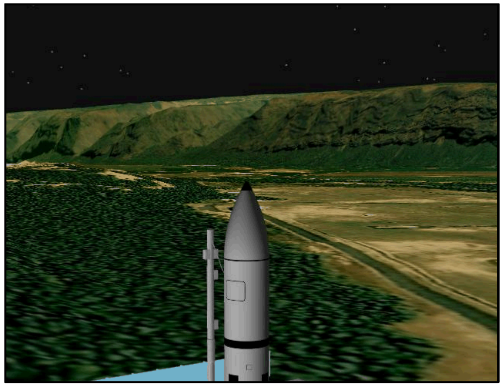
August 13, 2012

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Overview

- Introduction
- Model Based Design
- Model-Based Simulation Design
  - Model-Based Simulation Standards
  - Custom Model-Based Block Libraries
  - Subversion Control
  - Common Model Development Environment
- Real-Time Hardware-in-the-Loop Simulation



Introduction

- SNL NGC Department has been developing model-based simulations of rocket systems for flight code verification and validation purposes
  - Preliminary Studies
  - Monte Carlo analysis
  - Real-Time Hardware-in-the-Loop Simulations
- Over the years we have developed extensive experience simulating rocket systems.
  - Model-in-the-Loop (MIL): model-based representation of the flight computer
  - Software-in-the-Loop (SWIL): flight code implemented in the model-based simulation
  - Hardware-in-the-Loop (HWIL): flight like hardware included in the simulation that emulates actual flight signal streams to and from the flight computer

Model-Based Simulation Activity
- 3 Flown Missions
- 2 Complete V&V Flight Missions
- 3 Flight Missions in Development
- Numerous NGC studies

Model-Based Design

- Benefits (Ref. 1: Hyde, R.A.)
  - A single shared model repository, with model components common to many parts of the process
  - Graphical functional specification aiding, which can aid visibility
  - The idea of successive refinement (i.e. incremental addition of implementation detail)
  - An integrated environment for design, analysis, and testing
- Motivation
  - Reduce development time and cost
    - Implementations developed down-stream in the design process can be re-evaluated by the design team upstream to evaluate potential impacts
- Reality
  - Depending on the circumstances, a poorly implemented model-based design strategy might increase development time and cost as compared with traditional design methods

Good model-based design strategy is **critical** for mission success while trying to achieve the goal of reducing development time and cost.

NGC Simulation Objectives

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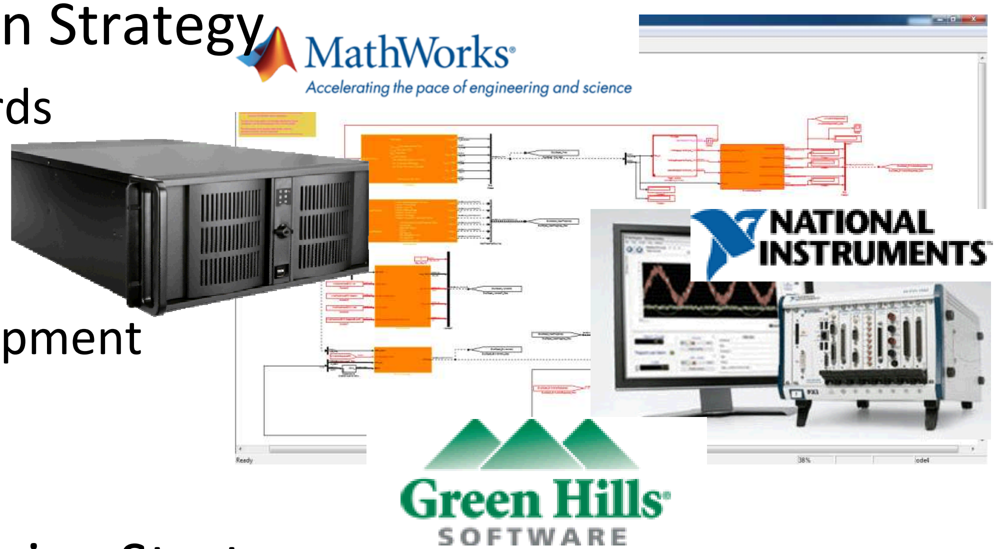
- Simulation Platform that allows for Responsive Prototyping
  - Simulation and Tools that allow the Simulation Engineer to Quickly Respond or React Appropriately
    - Changing Mission Requirements
    - Various Fidelity Levels
    - Complete Re-configuration of the Simulation
- High Fidelity Simulation Capability to Analyze NGC performance through Monte Carlo Analysis
- Simulation Capability for Evaluating Range Safety
- High Fidelity Real-Rime Simulation with Flight Replica Lab Hardware Components to Verify *Flight Software Binary* meets System Level Design Requirements
  - Nominal flight
  - Off-nominal flight
  - Failure mode conditions
- Simulation to Support System Level Testing

- High Fidelity Simulations to Evaluate NGC Performance
- Test Platform that Emulates Actual Flight Signal Streams to and from Flight Computer

NGC Simulation Approach

- NGC Department has Developed a Strategy for Responsive Simulation Prototyping
  - Model-Based Simulation
  - Real-Time HWIL Simulation Activities
- Model-Based Simulation Design Strategy
  - Model-Based Simulation Standards
  - Custom Simulink Libraries
  - Subversion Control
  - Common Simulink Model Development Environment
  - Tool: Mathworks Simulink
- Real-Time HWIL Simulation Design Strategy
  - Common Hardware Interface Platform
  - Tools: Mathworks xPC Target, National Instruments Veristand, Green Hills MULTI



Model-Based Simulation Standards

- Model-Based Simulation Standards are Critical
  - Working in a Collaborative Environment
  - Maintaining the Model over an Extended Period of Time.
- Published Simulink Model-Based Design Standards
  - Matlab Automotive Advisory Board (MAAB) ``Control Algorithm Modeling Guidelines Using Matlab, Simulink, and Stateflow“
  - Japan Matlab Automotive Advisory Board (JMAAB) ``Control Algorithm Modeling Guidelines Using Matlab, Simulink, and Stateflow“
  - NASA ``Orion GN&C: Matlab and Simulink Standards"
- NGC Standards
  - Simulink Block Color Scheme
  - All Units are ft-lb-s
  - All Subsystems are Documented using Masks
  - Use only 1-D Vectors
  - Blocks Read Left to Right
  - Continuous Integrators have Continuous Signals

NGC Department has decided that the standards are not intended to be an exhaustive list of best practices for using Simulink, but help simulation developers/users work more efficiently together, while still giving the model developer flexibility within their subsystems.

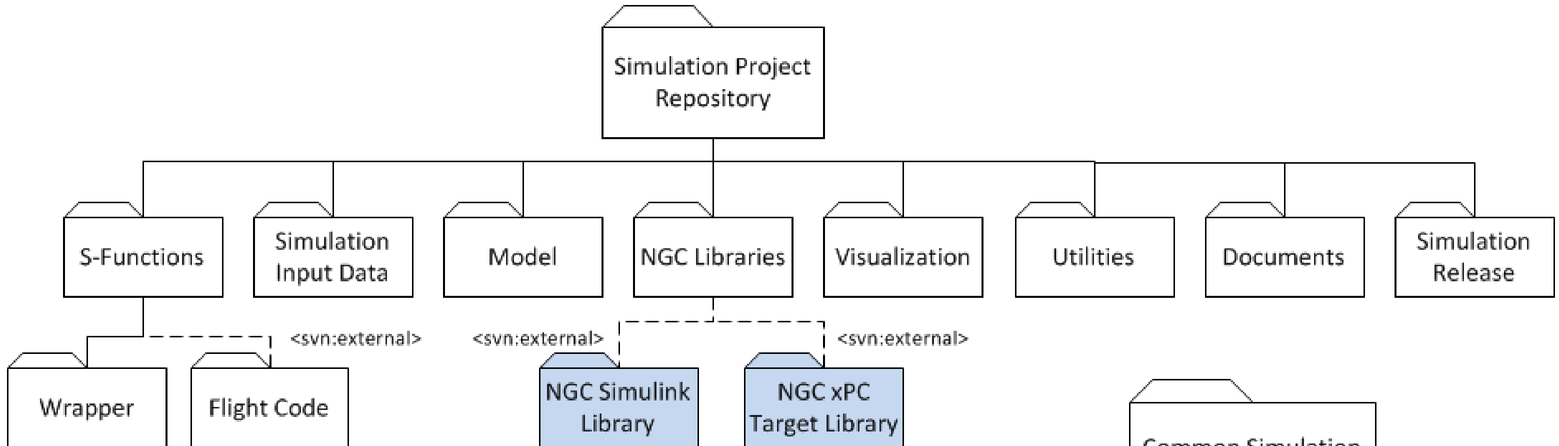
Custom Simulink Libraries

- Common Blocks or Subsystems for Multiple Projects
- Simulink Library Models that are well Vetted with Strictly Controlled Changes
  - Test Models for each Library Block
  - Library Block Modification
    - Block must Pass the Test Conditions before being Committed to the Repository/Released for Use
- Developed SNL NGC Simulink Library and SNL NGC xPC Target Library.
  - aerodynamic, coordinate transformations, environment, equations of motion, mass properties, propulsion, sensors, thrusters, utility blocks

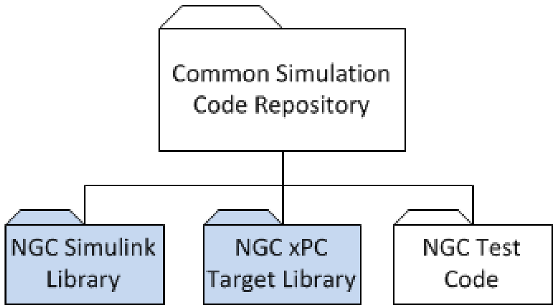
Debugging model-based simulations can require a huge time effort, thus having bug free library models can potentially *decrease* the simulation development time

Subversion Control

- Apache Subversion 1.7.x
- Starting Mathworks Products R2011b
  - XML Compare Tool for Simulink Models
  - Simulink Project
- Standardized Simulation Project Repository

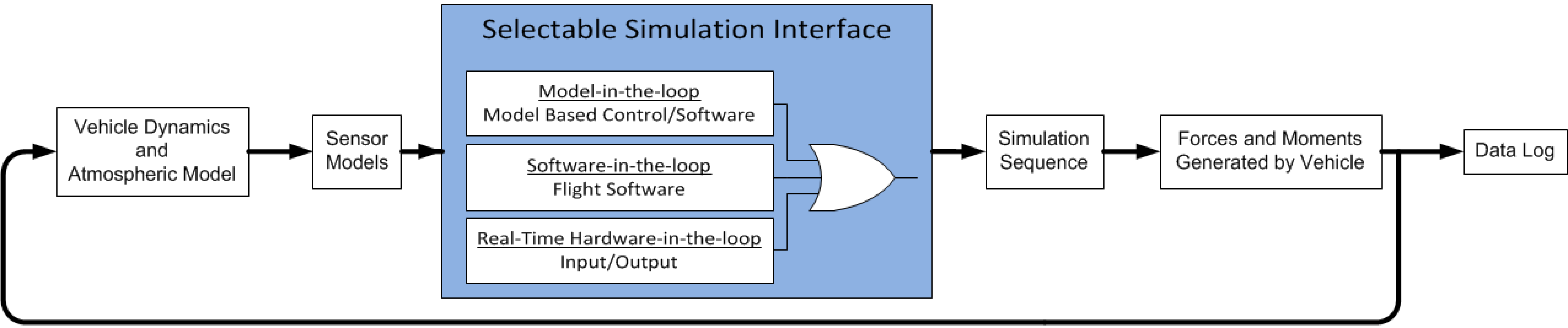


- Version number for each SVN external



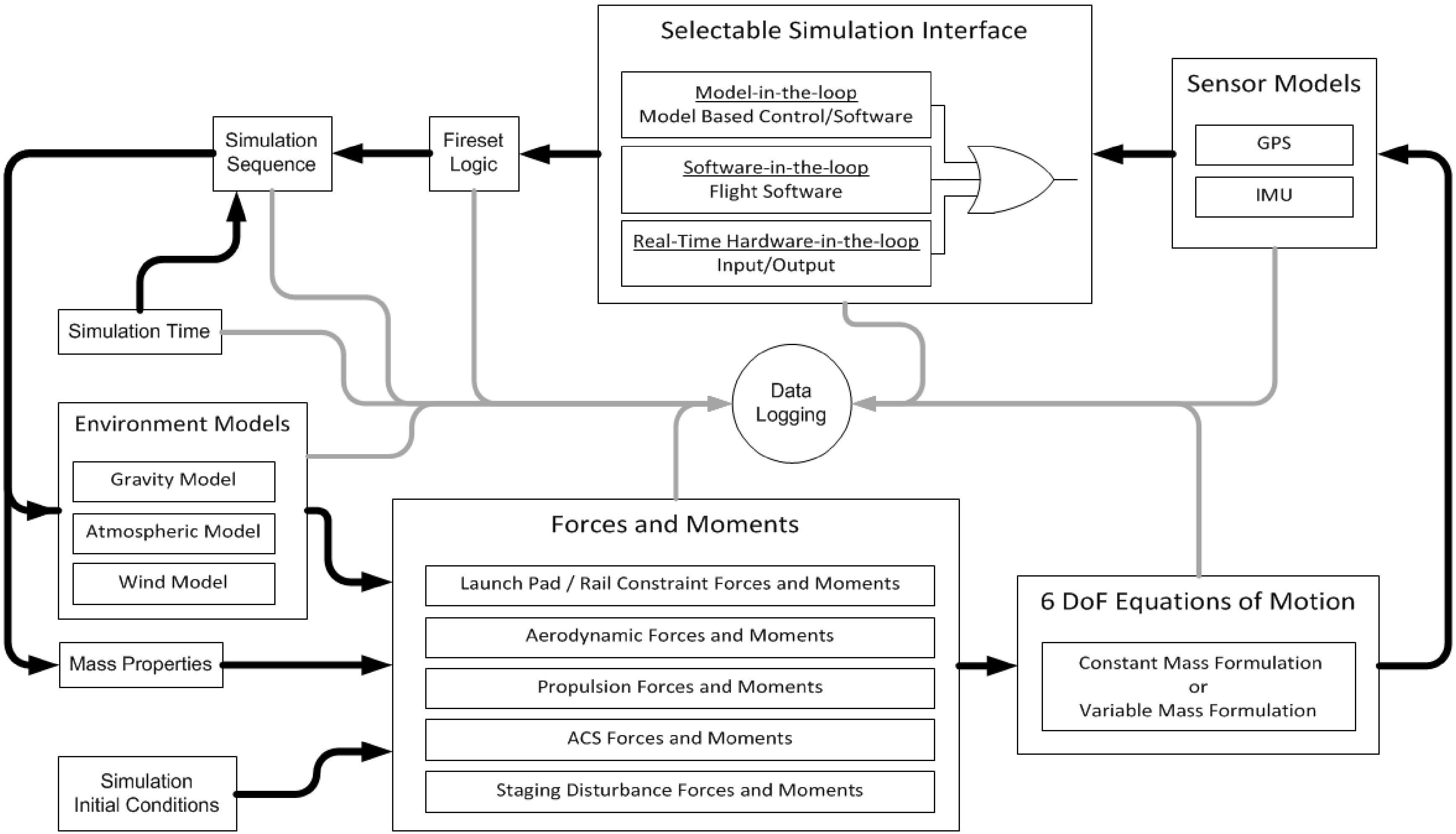
Common Simulink Model Development Environment

- Same Core Simulation Blocks are used for MIL, SWIL and HWIL Simulation
- Variant Subsystems Instead of Model Reference
  - Allow for Continuous Signals

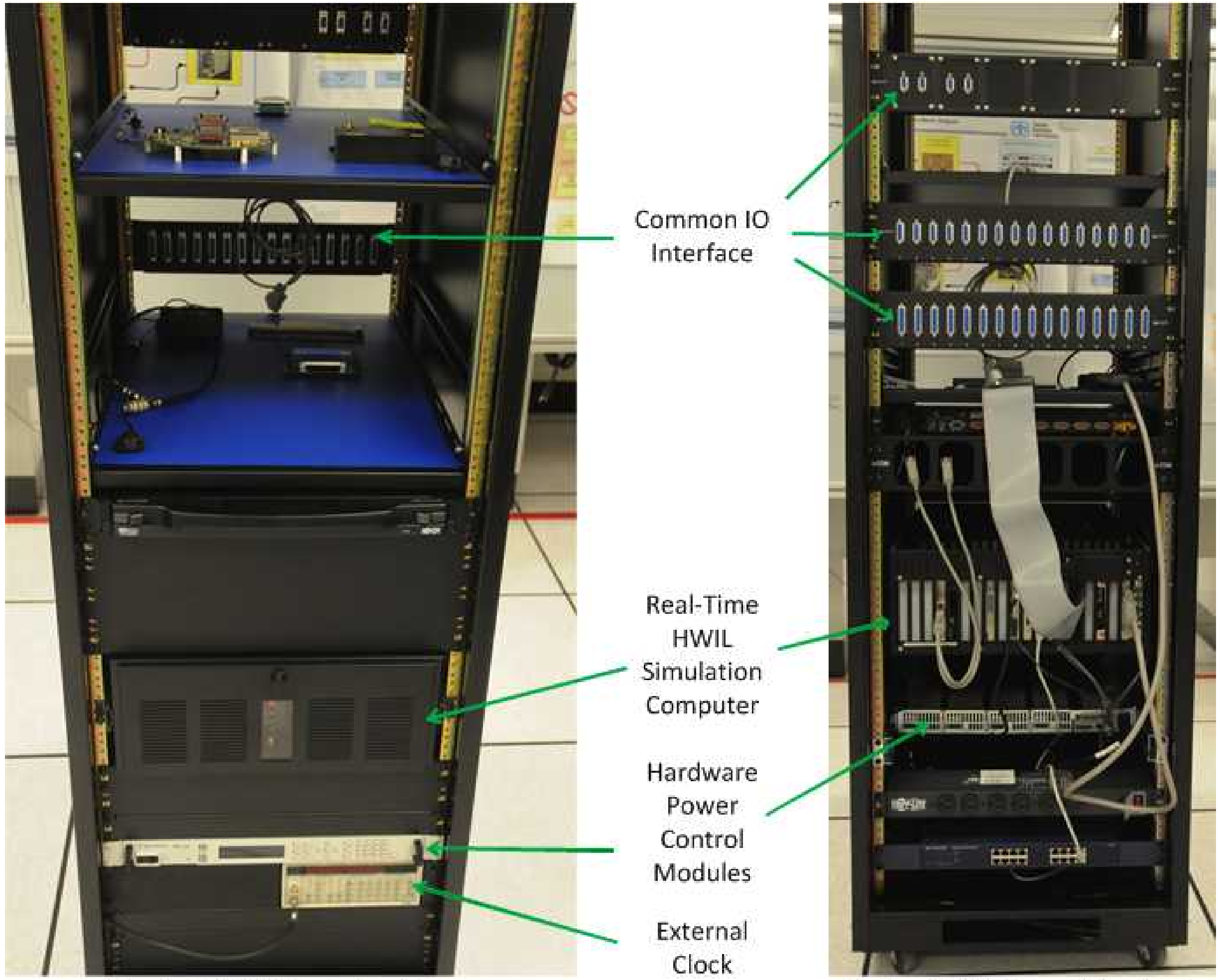


- High Fidelity Simulation with many Interconnected Dependencies between Blocks and Subsystems can Result in Complicated Flow Diagrams

Model-Based Simulation Work Flow



Real-Time HWIL Simulation Common Hardware Interface Platform



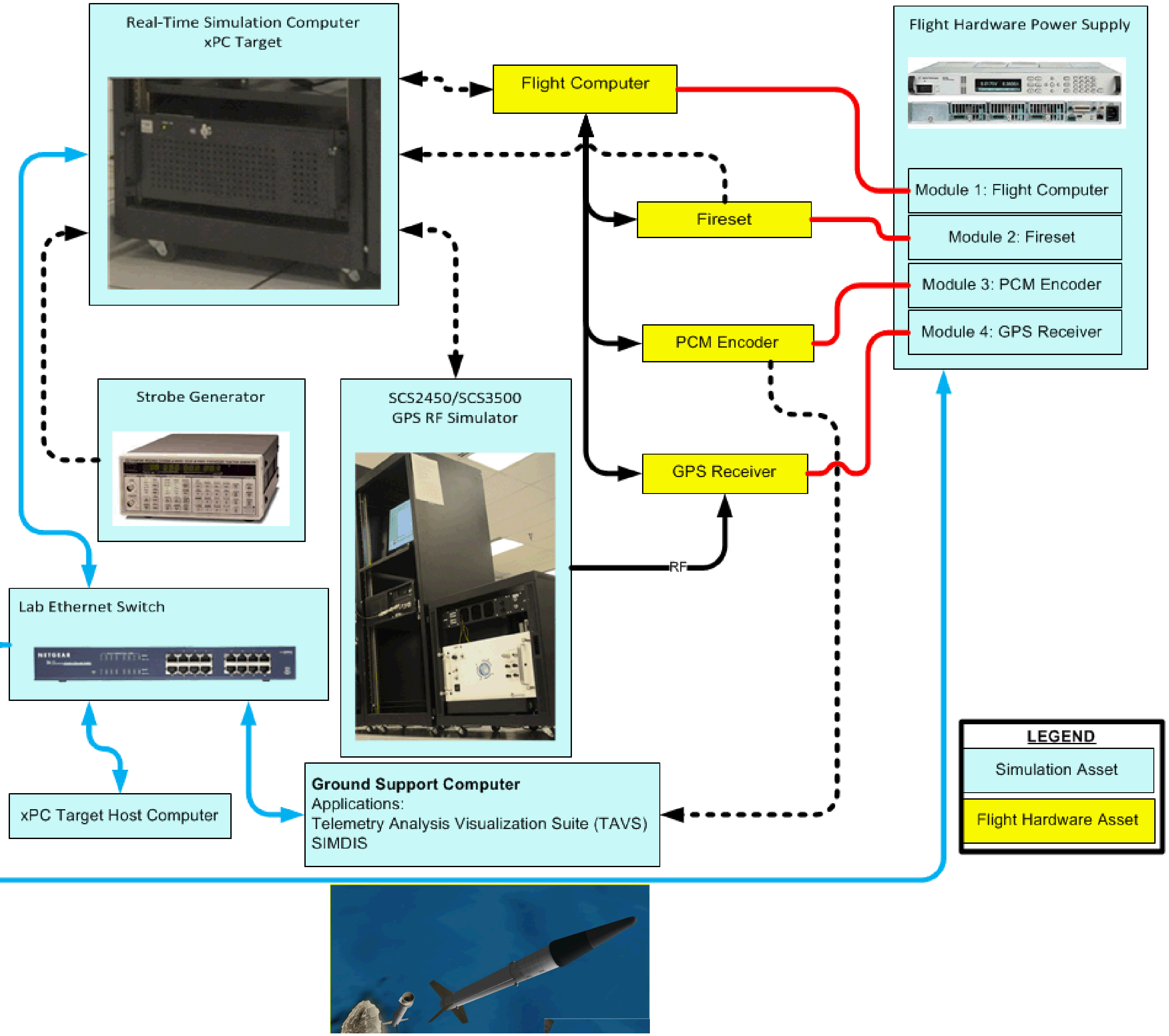
Front of HWIL Simulation Rack

Back of HWIL Simulation Rack

Signals as Shown:
16 DAC
96 ADC
192 DIO

Easily Re-configurable with Different ``Flight Like" Hardware

Real-Time HWIL Simulation



Conclusion

- NGC Department has Developed a Strategy for Responsive Simulation Prototyping
  - Model-Based Simulation using Mathworks Simulink
    - Model-Based Simulation Standards
    - Custom Simulink Libraries
    - Subversion Control
    - Common Simulink Model Development Environment
  - Real-Time HWIL Simulation using Mathworks xPC Target, National Instruments Veristand, Green Hills MULTI
    - Auto-Generated Real-Time Simulation Executable
    - Common Hardware Interface Platform
    - Run Autonomously
    - Visualization of the Simulation

Strategies have Significantly Reduced the Development Time to Successfully Implement Model-Based Simulations for Flight Test Programs