AEROFAST: Functional and Real-Time Simulation for Aerocapture GNC Assessment

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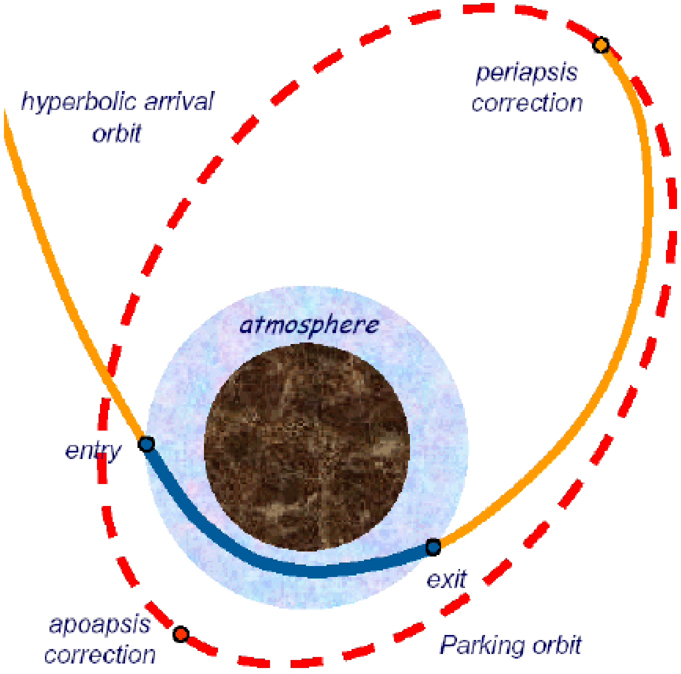
Introduction

The AEROFAST Project

- *AEROFAST: AEROcapture for Future SpAce Transportation*
- Collaborative project funded by the EC (FP7)
- Aimed at raising the maturity of aerocapture technology in Europe (from TRL 2-3 to TRL 3-4)
- Aerocapture allows for a large mass saving at launch (30 %)
- In preparation of future human exploration missions
- Industrial consortium: 12 partners coordinated by Astrium ST
- Ended successfully in September 2011

The AEROFAST Demonstration Mission

- Insertion from a hyperbolic fly-by into Martian orbit, through the atmosphere
- Three phases
  - Pre-aerocapture: hyperbolic path to the entry interface point (EIP)
  - Main aerocapture: from EIP to atmosphere exit
  - Post-aerocapture: transfer to a parking orbit (sun-synchronous low orbit)



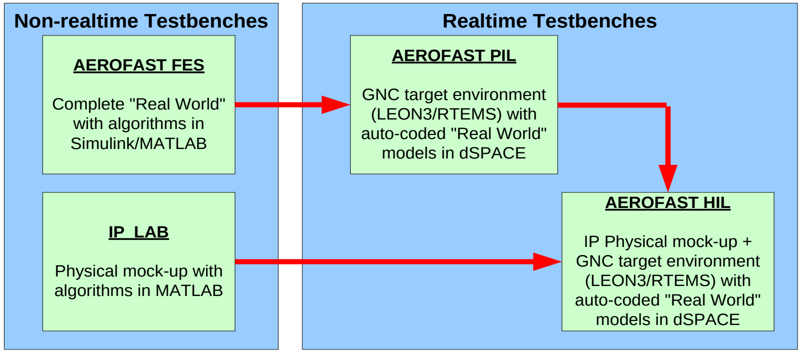
AEROFAST Objectives

- OBJ1: Preliminary definition of the aerocapture demonstration
- OBJ2: Make a significant progress by increasing the TRL of the planetary relative navigation and the aerocapture algorithm up to 5
- ***OBJ3**: Build a breadboard to test in real time the pre-aerocapture and aerocapture GNC algorithms*
- OBJ4: Demonstrate/prototype the thermal protection system for such a mission
- OBJ5: Define on-board instrumentation for aerocapture phase recovery

Need of functional and real-time simulation for GNC evaluation

Approach

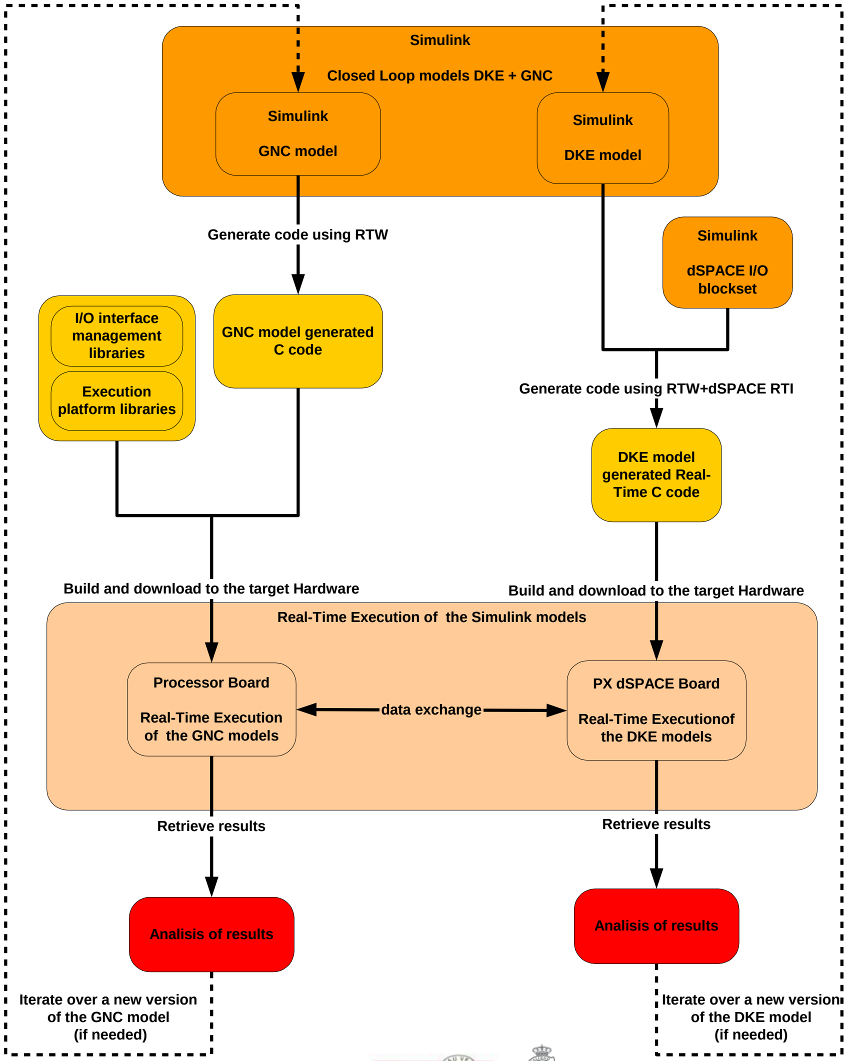
- First choice: to validate separately the pre-aerocapture and aerocapture GNC designs
  - Interest on setting aerocapture initial conditions independently from pre-aerocapture final conditions
- For each phase, two facilities are needed:
  - Non-Realtime: AEROFAST Functional Engineering Simulators
  - Real time: AEROFAST Real-Time Testbenches (PIL and HIL configurations)
- Our approach: **unified architecture**
  - Supports GNC Verification & Validation process
  - Intended for model reuse across facilities (FES → PIL → HIL)



Pre-aerocapture development logic

Testbench Development Cycle

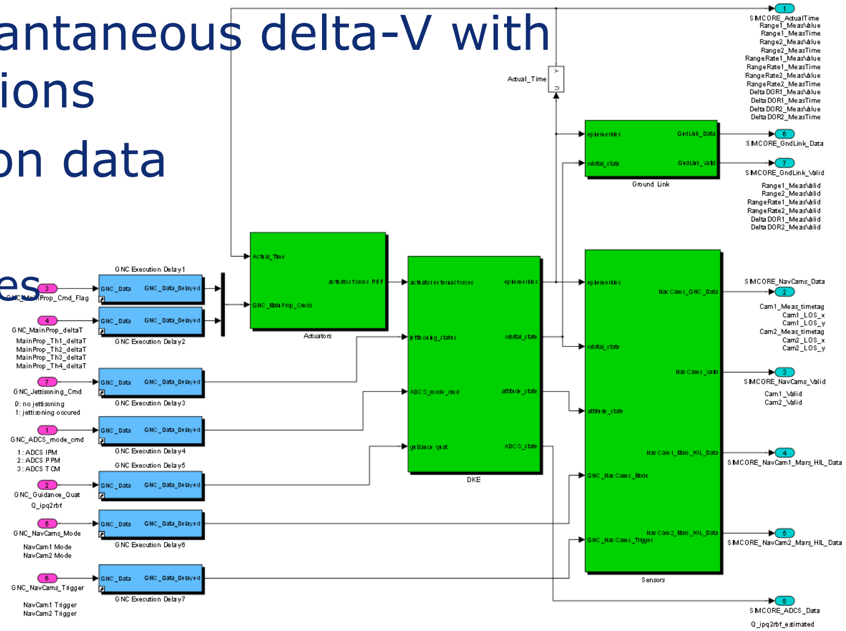
- Two-fold iterative process
  - GNC models
  - DKE, sensor and actuator models
- Two testing flows
  - Sequential
  - Regression



Non-realtime AEROFAST Simulators

Pre-aerocapture FES

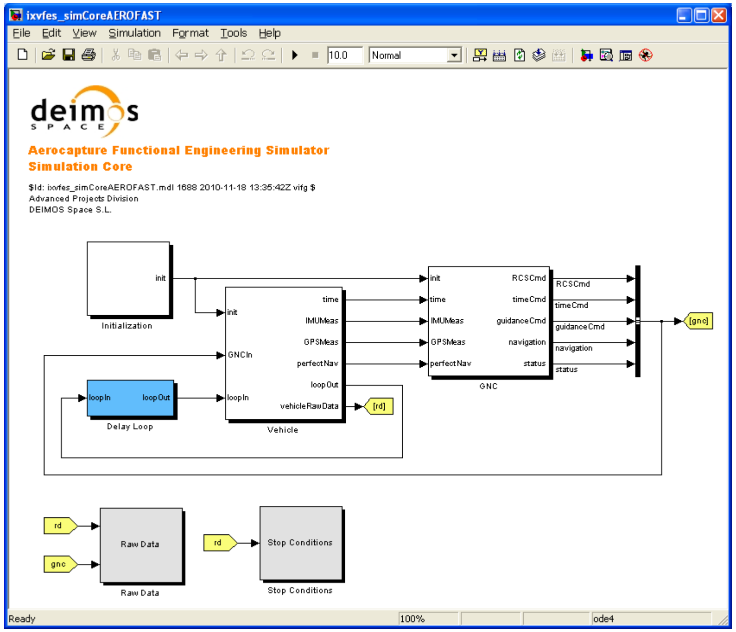
- 4-DOF simulator
- MATLAB/Simulink
- Based on SIMPLAT (in-house simulation infrastructure)
- Trajectory from Earth orbit to entry interface point near Mars
- Main propulsion model: instantaneous delta-V with magnitude/direction dispersions
- Includes models of navigation data
  - Radiometric measurements
  - Navigation camera observables
  - ADCS estimation data



Non-realtime AEROFAST Simulators

Aerocapture FES

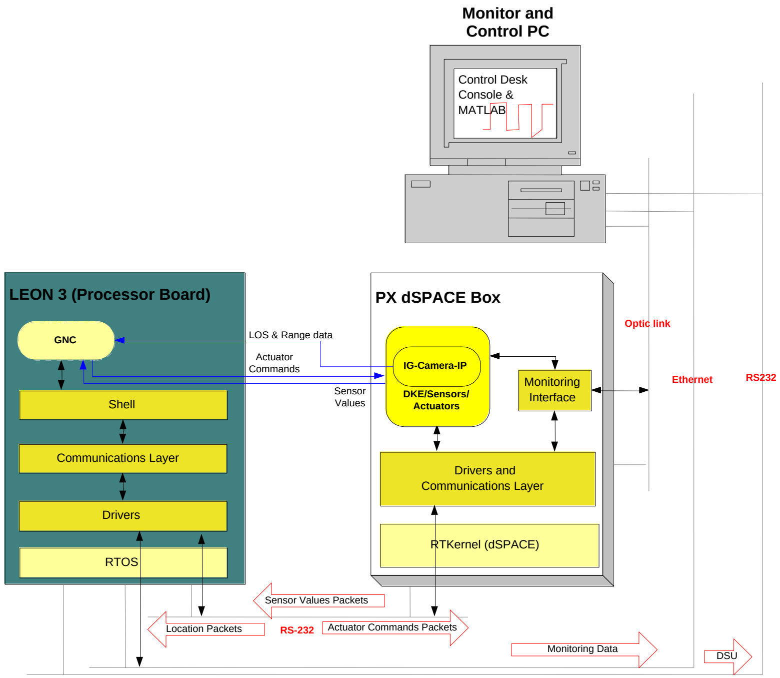
- 6-DOF re-entry simulator (IXV-FES reuse)
- MATLAB/Simulink
- Based on SIMPLAT (in-house simulation infrastructure)
- Customized with Mars environment and biconic shape capsule



Real-Time AEROFAST Simulators

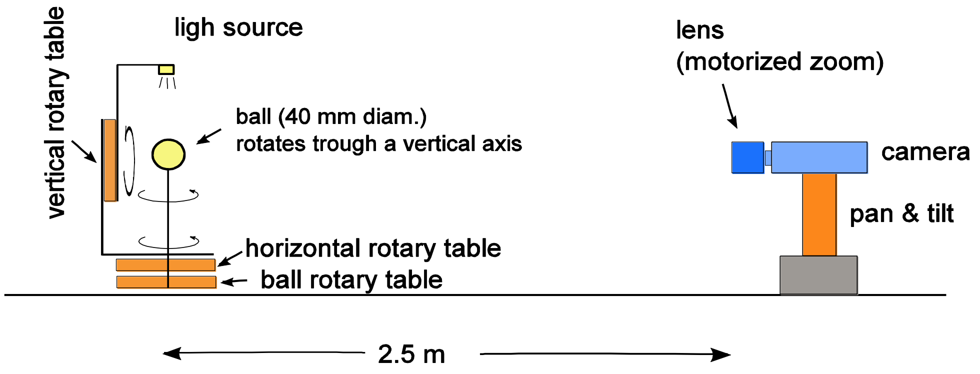
Real-time Testbench (Processor-In-the-Loop configuration)

- PX dSPACE Box runs DKE, sensor and actuator models
- LEON 3 processor runs the GNC model
- Control Desk computer controls the experiment



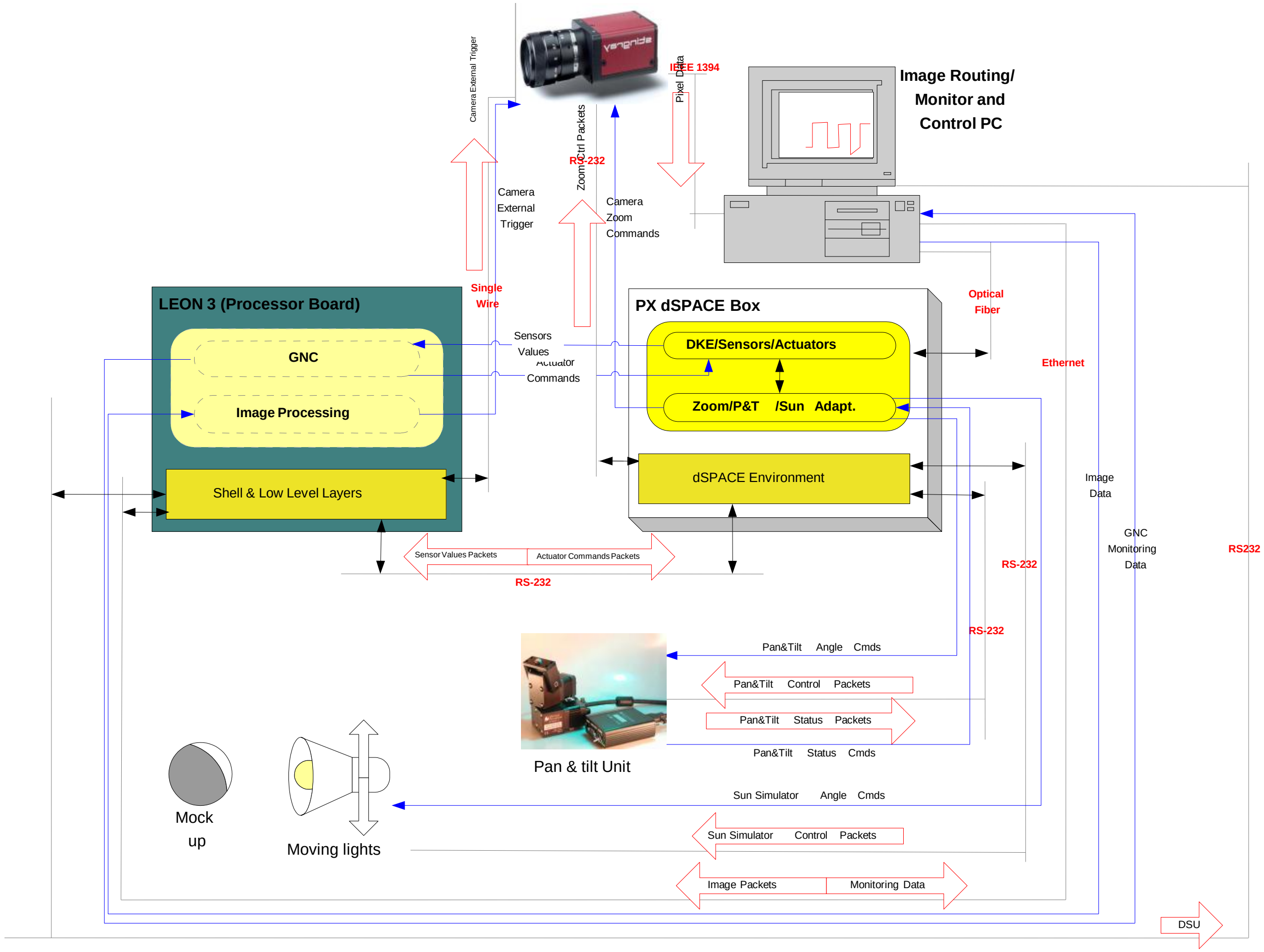
Real-time Testbench (Hardware-In-the-Loop configuration)

- Mock-up of the optical navigation system, with spherical targets, lights and camera with zoom on pan-and-tilt platform
- Image processing (IP) routines are executed in real-time on images grabbed from the camera
- PX dSPACE Box runs DKE, actuator and sensor models, now using image generation chain HW in the loop and controlling the pan/tilt platform
- LEON 3 processor runs the GNC model and the image processing SW
- Control Desk computer controls the experiment, records camera images and sends them to the LEON 3 processor



Real-Time AEROFAST Simulators

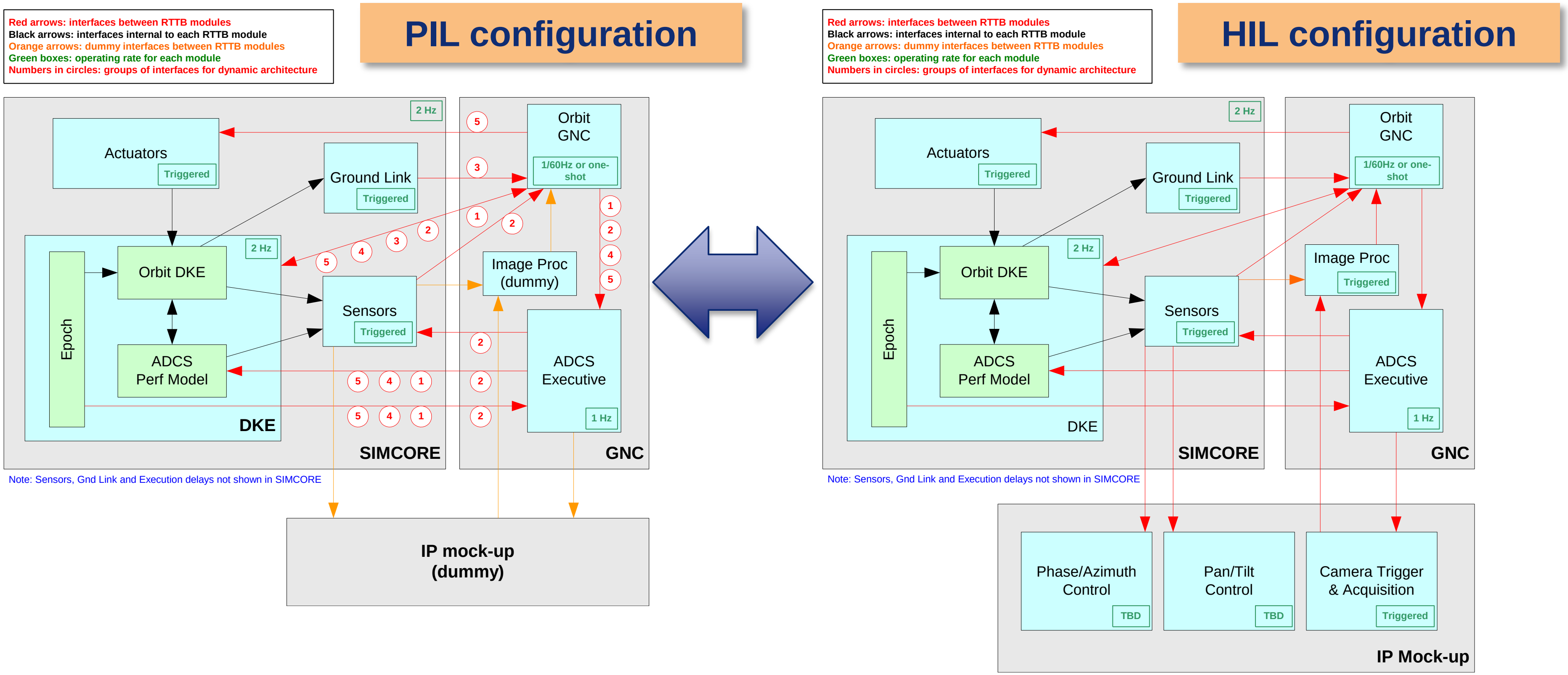
Real-time Testbench (Hardware-In-the-Loop configuration)



Unified Architecture

Features (1/3)

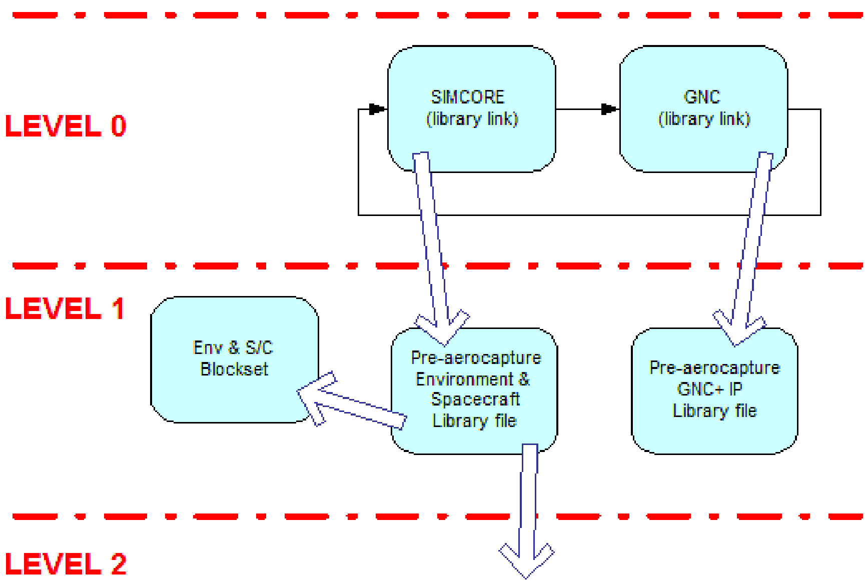
- Model variants with well-defined interfaces



Features (2/3)

- Modular and layered model architecture
  - DKE models and GNC models placed in separate Simulink libraries
  - Allows set-up of model variants at level-2

Pre-aerocapture model architecture



Features (3/3)

- Modular model setup scripts
  - Real-time testbenches reuse as much as possible the FES functionalities
  - Model variant setup scripts are shared by FES and real-time testbenches
  - The Real-Time Testbenches use additional scripts for building the GNC code
- Simulation models, GNC C code and precompiled RTEMS binaries are stored in a shared SW repository

Real-Time Validation Issues

Problem

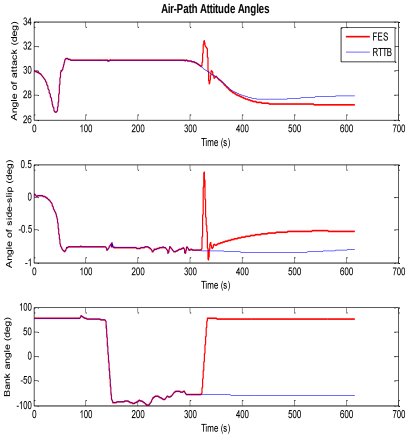
- GNC validation must take into account model uncertainties and random perturbations
- Functional validation (non-realtime) makes use of Monte Carlo simulations to account for off-nominal conditions
- What about real-time validation? How can we cope with random dispersions, since real-time Monte Carlo is unfeasible?

Approach

- Real-time worst cases were selected from Monte Carlo (non-realtime) simulations by identifying the longest execution cases
- Worst case delays for GNC code were found by profiling the GNC software during non-realtime execution

Need of Regression Testing

- The comparison of non-realtime and real-time aerocapture simulations revealed different GNC behaviour
- The origin of such differences was identified to be the GNC computational delays
- The differences disappeared when computational delays were modelled in the Aerocapture FES simulator
- The new iteration of the validation process (regression testing) was eased by the unified architecture



Conclusions and Lessons Learned

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Benefits of a unified architecture

- Efficient reuse of simulation models and features
- Easy execution of regression tests, to achieve functional revalidation when changes were required to simulator and/or GNC models

Lessons learned

- It is essential that the unified architecture is designed at development kick-off, to allow proper sharing of model library and database files
- Start real-time simulations as soon as possible for early identification of constraints imposed by the RT S/W implementation on functional design

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Thank you

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