ADCSS 2017 - Avionics Verification and Validation on the NEOShield-2 Project

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- On-board Software
- Atmospheric Flight Engineering

GROUND SEGMENT SYSTEMS

- Mission Control, Planning and Scheduling
- Data Handling
- Performance Simulation & Monitoring
- Calibration & Validation

The NEOShield-2 Project: Science and Technology for Near-Earth Object Impact Prevention

- Near-Earth objects (NEOs) will hit the Earth at irregular intervals in the future, with the potential for catastrophic damage to life and property.
- The objective of the **H2020 Neoshield-2 project**, led by AIRBUS DS GmbH, is the design and maturation of critical techniques required in NEO missions, including those aimed to analyse in detail potentially dangerous NEOs and to deflect them from their established orbit.
- The Guidance, Navigation and Control techniques with embedded Image Processing (GNC/IP) in close vicinity of asteroids and comets have been identified as one of the critical areas.

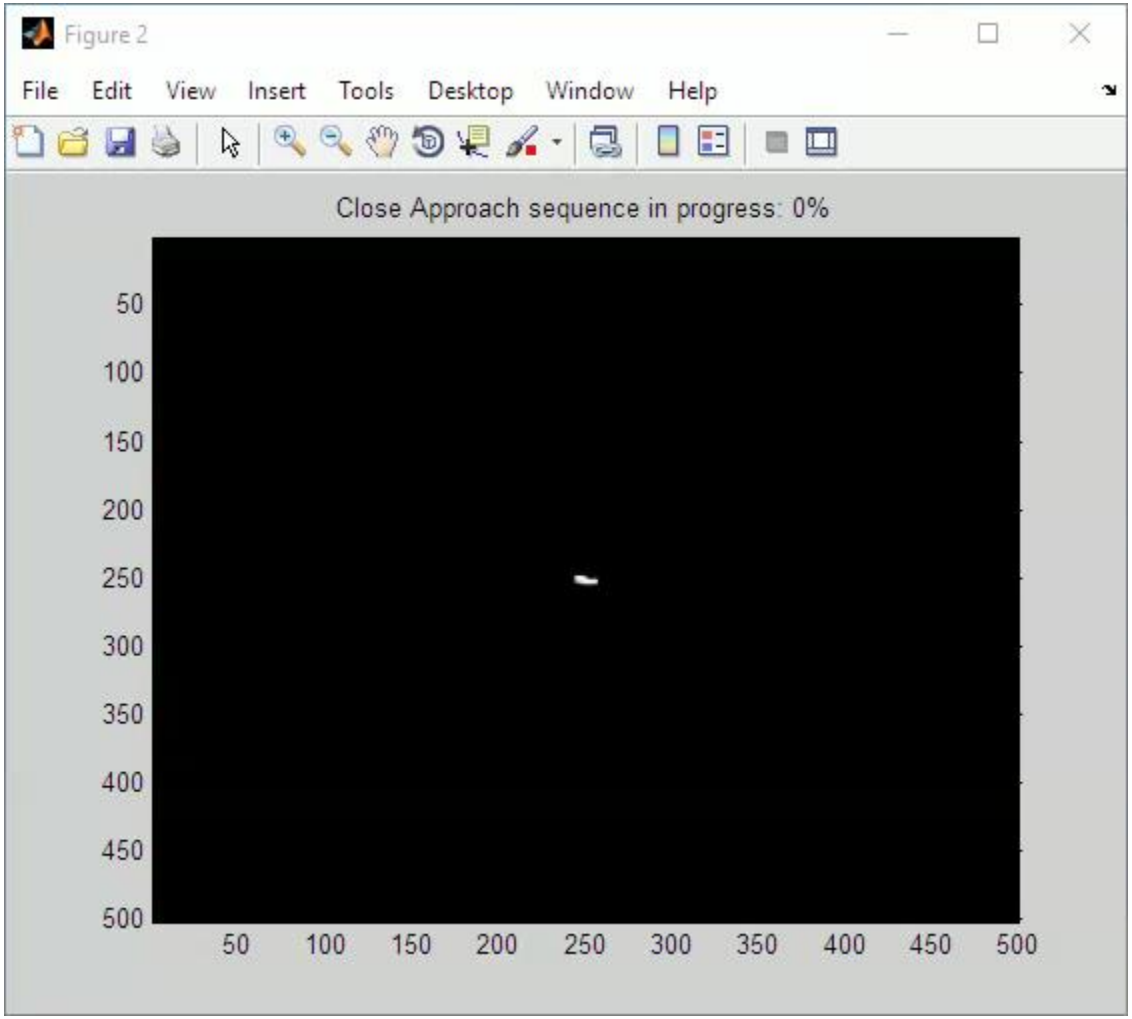
AIRBUS, deimos elecnor group, gmv INNOVATING SOLUTIONS, DLR, INAF ISTITUTO NAZIONALE DI ASTROFISICA NATIONAL INSTITUTE FOR ASTROPHYSICS, CNRS, l'Observatoire de Paris, Fraunhofer EMI

Participation of Deimos in NEOShield-2

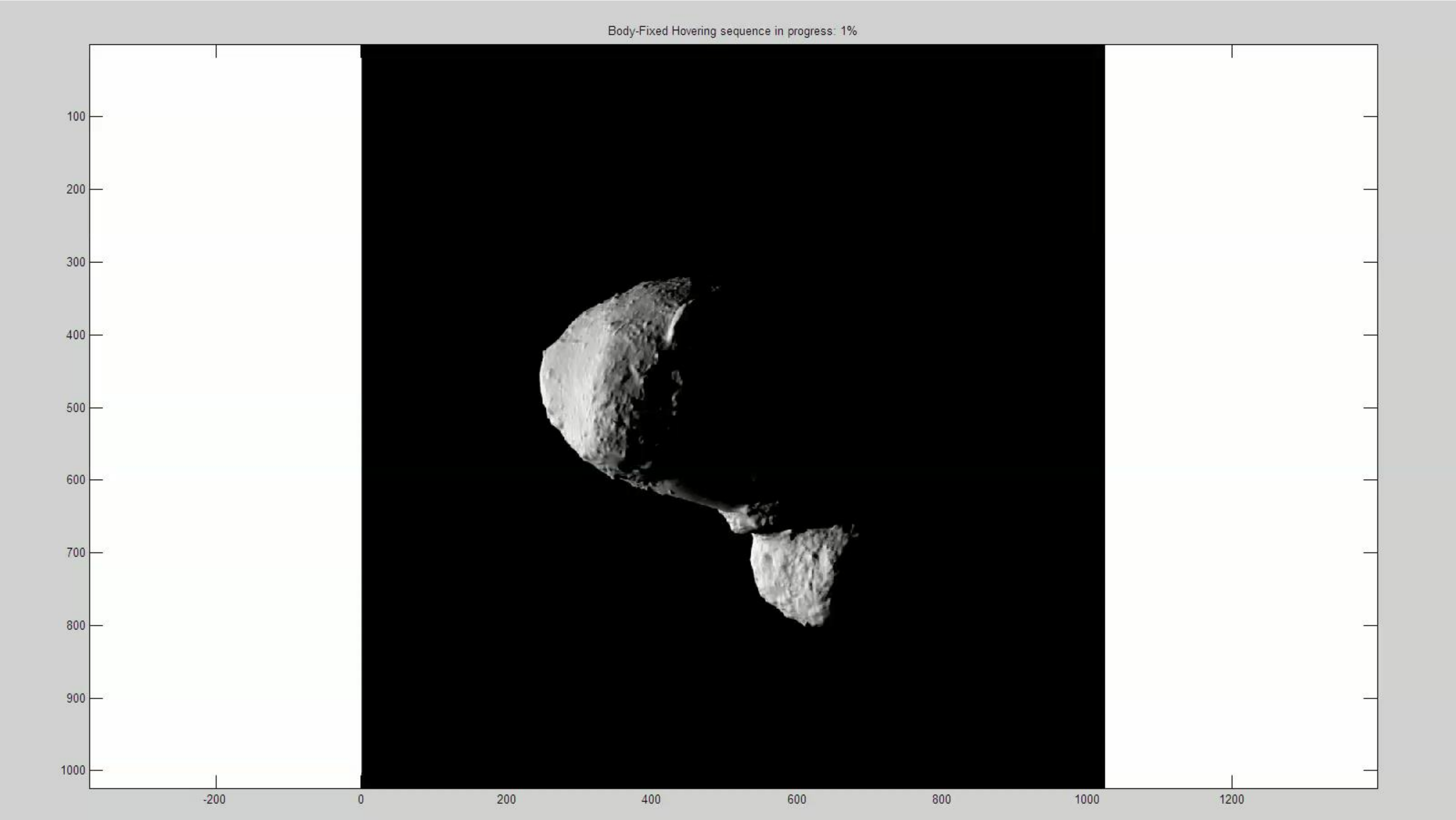
Deimos has led the analysis of the Reconnaissance S/C GNC in the project, performing the design, implementation and validation of the critical GNC/IP modes for the following phases of the mission:

Phase	Description	Duration	IP Technology	Periods/Deadlines
Close Approach	Safe reduction of velocity towards the NEO in 3 days, (from ~200km to ~5km).	**3 days!**	Centre of Brightness	G&C→60s/1s Nav→300s/60s IP→20min/5min
Arrival / Inertial Hovering	Maintain safe state after arrival during 6h before ground control.	6 hours	Features Detection and Tracking	G&C→1s/100ms Nav→60s/60s IP→60s/50s
Body-Fixed Hovering	Observe a sub-Nadir surface point and/or prepare for lander release or descent/landing.	2 hours	Features Detection and Tracking	G&C→1s/100ms Nav→60s/60s IP→60s/50s

Participation of Deimos in NEOShield-2

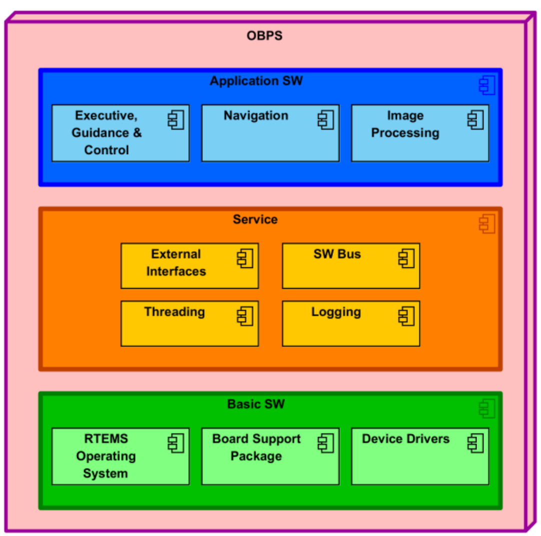


Participation of Deimos in NEOShield-2

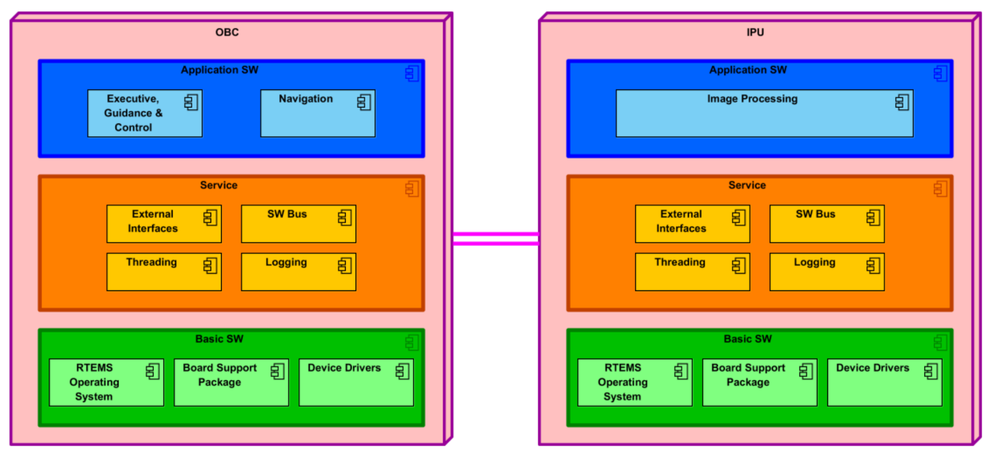


Avionics/GNC System architecture

- **Close Approach** GNC architecture:
  - Nav camera (NAC)
  - Radiometric measurements
  - Sun sensors
  - Star trackers
  - Gyroscopes
  - Reaction wheels
  - Monopropellant thrusters



- **Hovering Phases** - GNC architecture:
  - Nav camera (NAC or WAC)
  - Rangefinder
  - Sun sensors
  - Star trackers
  - Gyroscopes
  - Reaction wheels
  - Monopropellant thrusters



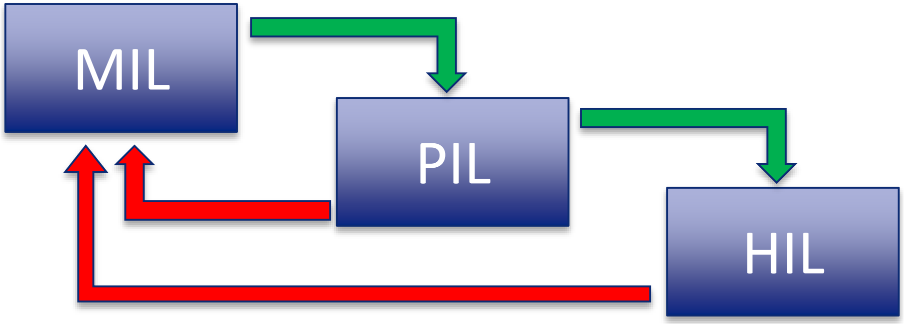
Test Benches and TRL

- The main objective of the development has been to achieve Technology Readiness Level **TRL5-6** for the three GNC/IP modes at the end of the NEOShield-2 project, by executing the GNC/IP algorithms on an **avionics PIL/HIL prototype**:
  - Processors representative of existing space-qualified versions: LEON3 for OBPS/OBC, PowerPC750 for IPU.
  - Representative Real-Time Operating System (RTEMS).
  - Representative space camera HW (proposed for ESA AIM mission).

5	Component and/or breadboard critical function verification in a relevant environment	Critical functions of the element are identified and the associated relevant environment is defined. Breadboards not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effects
6	Model demonstrating the critical functions of the element in a relevant environment	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) in form, fit and function

Test Benches and TRL

- The development process includes 3 test benches with progressive increment of realism:
  - The GNC/IP algorithms have been developed in a Matlab / Simulink environment, and firstly tested in a **Model-In-the-Loop** test bench, to demonstrate functional and performance requirements.
  - Then, ported to a **Processor-In-the-Loop** validation test bench in which the real-time performances have been also demonstrated while functional properties are conserved ("unit", open-loop tests are executed before GNC/IP SW full integration).
  - Finally, a **Hardware-In-the-Loop** test bench incorporating a space-representative camera has been used to increase the realism of this avionics test bench.
- Modifications deemed necessary (potentially due to scope change, algorithm tuning, etc.), are made at model-level and regression tests are executed.

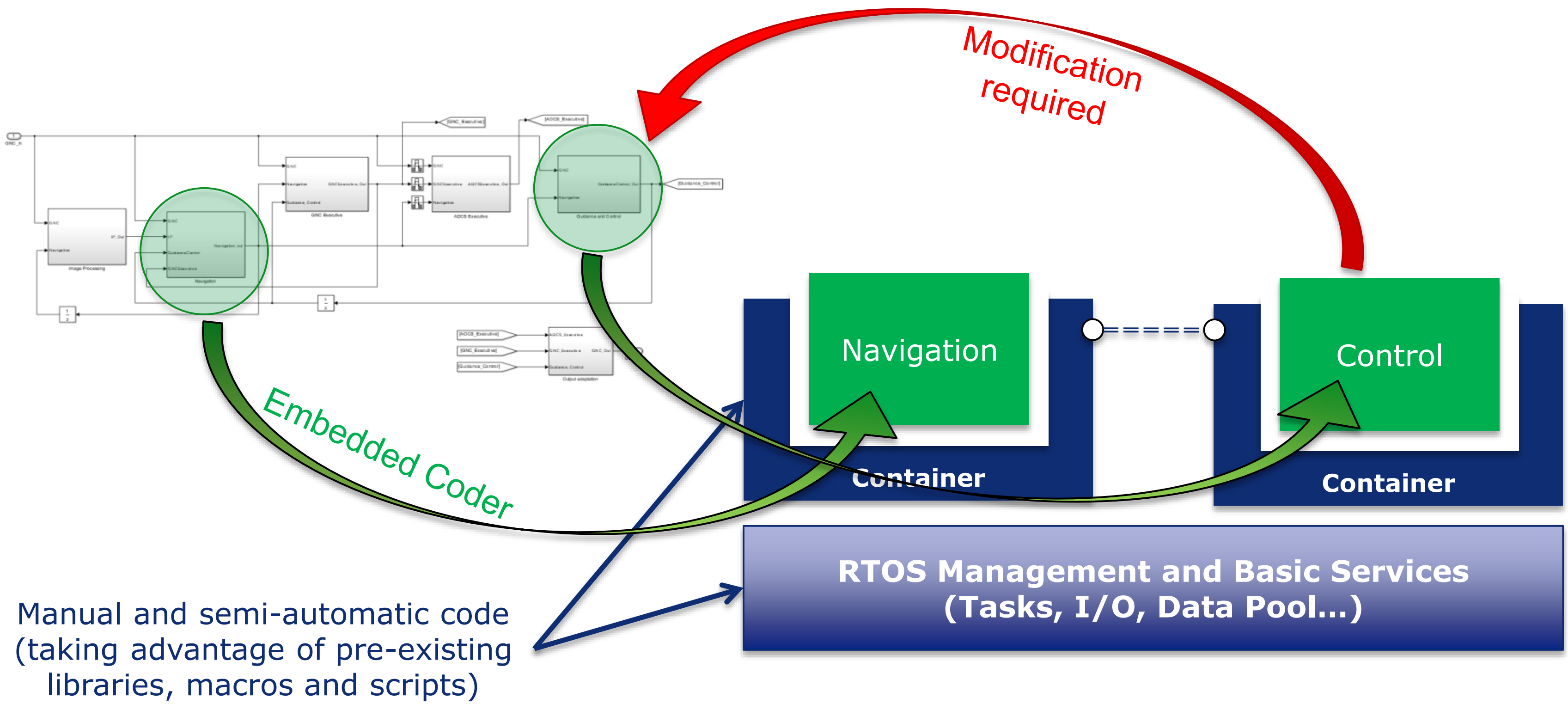


Optimized Development Process

- Given the variety of test benches and the potential regression tests necessity, the main objective of the development process is to guarantee fast transitions of the SW under test among test benches.
- There are significant differences between the behaviour of models and the SW running on space representative targets (latencies, execution-time variability, resources availability…).
- An inter-disciplinary team of engineers must be involved in the early phases of the project in order to identify potential sources of issues that may be hidden in the Simulink / non-realtime environment but would arise in subsequent stages.
- The development of the GNC/IP algorithms needs to be performed according to an internal modelling guideline designed to streamline the subsequent autocoding and validation procedures.
- Test Sequence:
    - Monte Carlo → Autocoding → Open-Loop UT → Closed-Loop System Tests

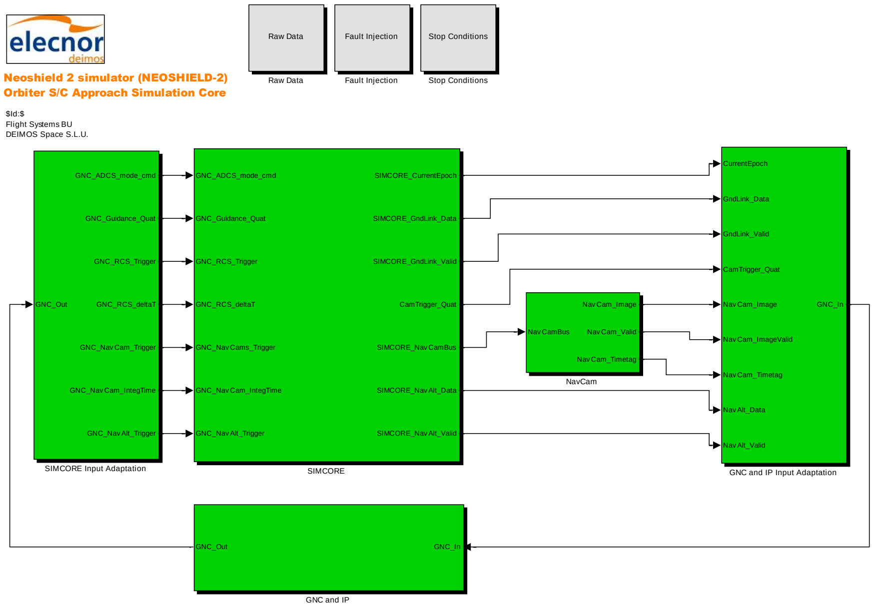
Optimized Development Process

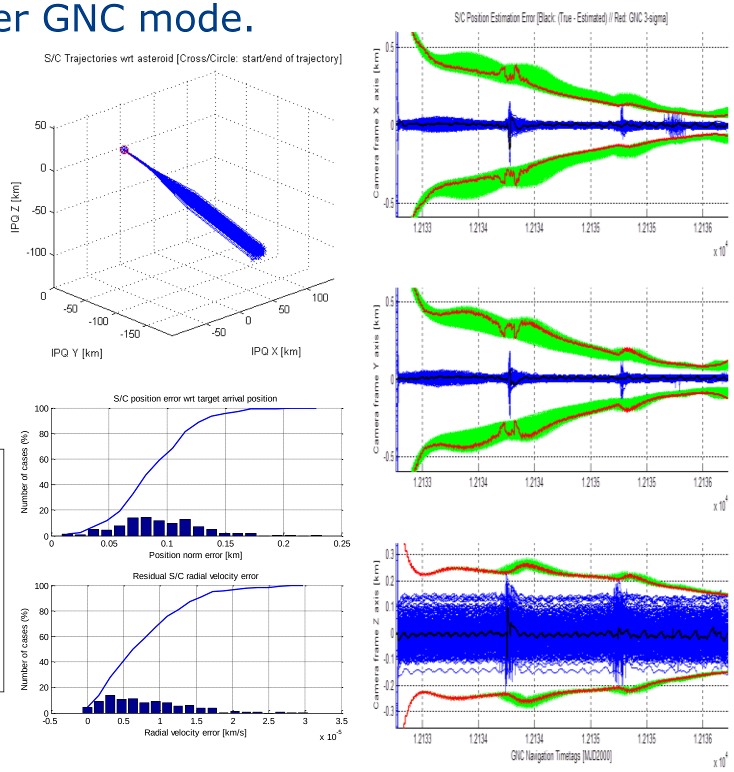
- The M / S models have been designed to ease the production of flexible, modular and maintainable code components.
- The potential modifications required in the GNC/IP models would be made in an isolated and simple way, including regression testing of the models in the MIL bench.



Model-In-the-Loop Architecture and Tests

- Architecture of the MIL simulator is based on SIMPLAT framework (DEIMOS' product).
- Includes models for Dynamics-Kinematics, environment, NEO model, sensors and actuators; considering also non-ideal situations and dispersions
- Capable of performing Monte Carlos shots per GNC mode.

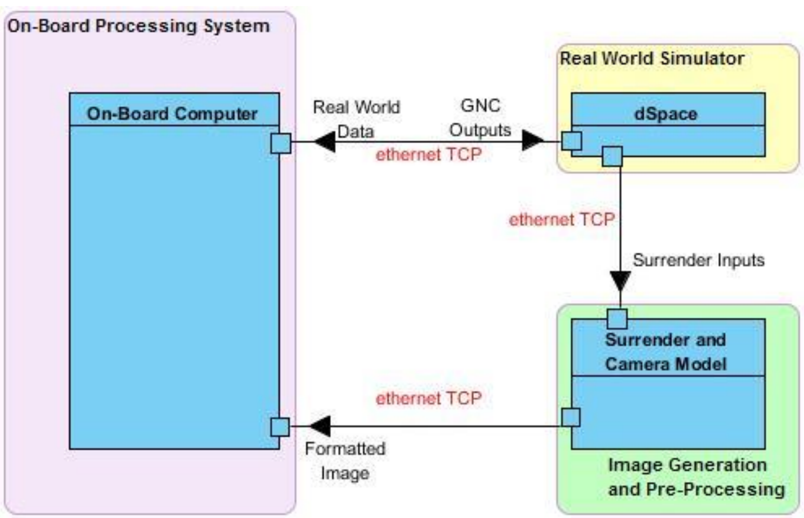




Processor-In-the-Loop Architecture

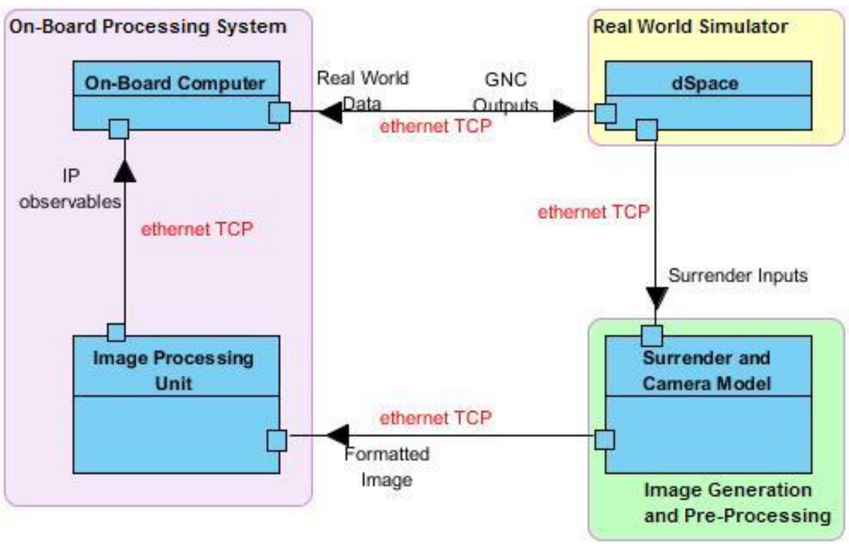
- Objective: test the algorithmic and real-time performance of GNC/IP routines.
- Conditions: representative processors and interfaces between them.
- Two architectures are proposed to evaluate different solutions.

Close Approach



On-Board Computer: LEON3

Hovering



On-Board Computer: LEON3
Image Processing Unit: Power PC 750

Surrender Synthetic Image Simulator (software product by Airbus Defense & Space – Toulouse), used for the rendering of asteroid surface images, simulating the performance of the navigation cameras.

GNC/IP Unit, Open-Loop Unit Tests (in target)

Variable	Max Error
GNC Outputs:	
- Current Epoch	0
- GndLink_Data	1e-015
- GndLink_Valid	0
- CamTrigger_Quat	3e-016
- ImageValid:	0
- Cam_Timetag	2e-016
- Alt_Data	4e-006
- Alt_Valid	0
RAW Data:	
- RAW Ephemerides:	0
- RAW Dyn Kyn Orbit	1e-015
- RAW Dyn Kyn Attitude	0
- RAW Dyn Mass:	0
- RAW Dyn ADCS:	4e-016
- RAW Dyn PanelsRot:	0
- RAW Dyn Ext_Pert_SRP	1e-015
- RAW Dyn Ext_Pert_All	1e-015
- RAW Dyn Ext_Accum_Mom	2e-013
- RAW RCS_AccumDeltaV	2e-016

Simulink Model & Test Harness

produces

Input Vectors (.mat)
Reference Outputs (.mat)

uses

Matlab Support Scripts

produces

Input Vectors (.h)
Reference Outputs (.h)

uses

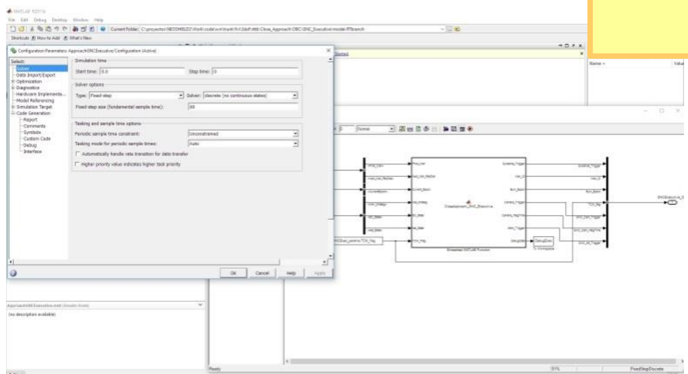
Unit Test Driver

calls

Functional Code

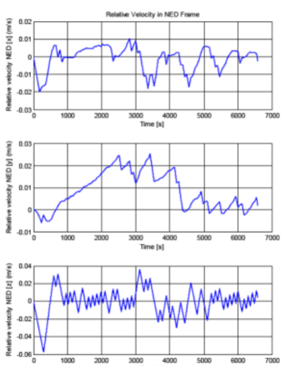
produces

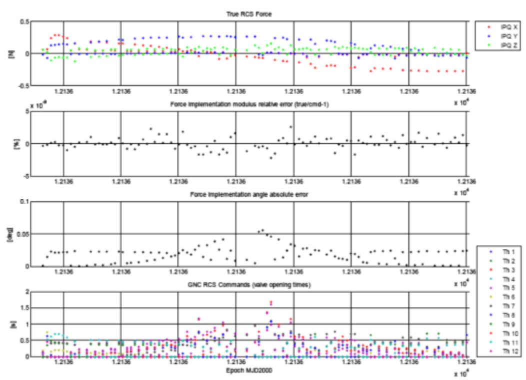
Unit-Test Execution Report



GNC/IP PIL Closed-Loop System Tests

- The GNC/IP algorithms are integrated with the on-board data handling SW so closed-loop tests are now possible to validate functional and real-time performance.
- Tests start-up procedure is complex. Up to 4 nodes plus the development & test manager workstation (used also to receive "OBSW Telemetry") must be synchronized.
- Test duration is up to 72 hours. The size of the logged information is an issue. Automatic scripts extract information from received TM and DKE recorded data, make it compatible with the tools used in the MIL test bench allowing a fast analysis of the test results.

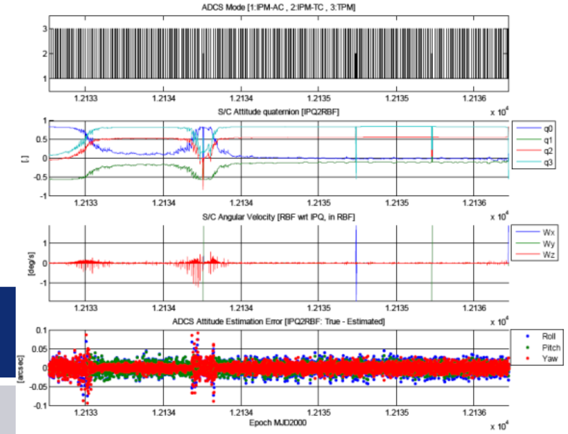


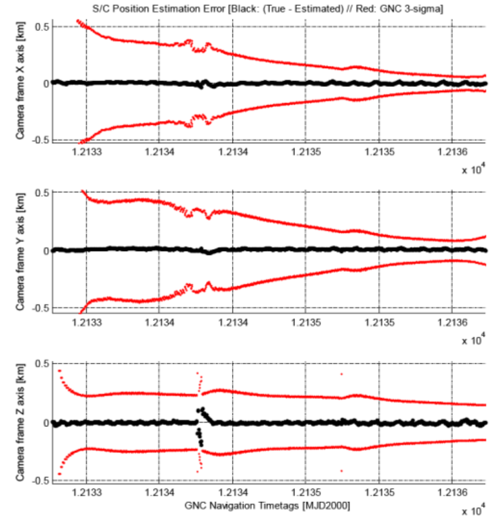


GNC/IP PIL Closed-Loop System Test Results

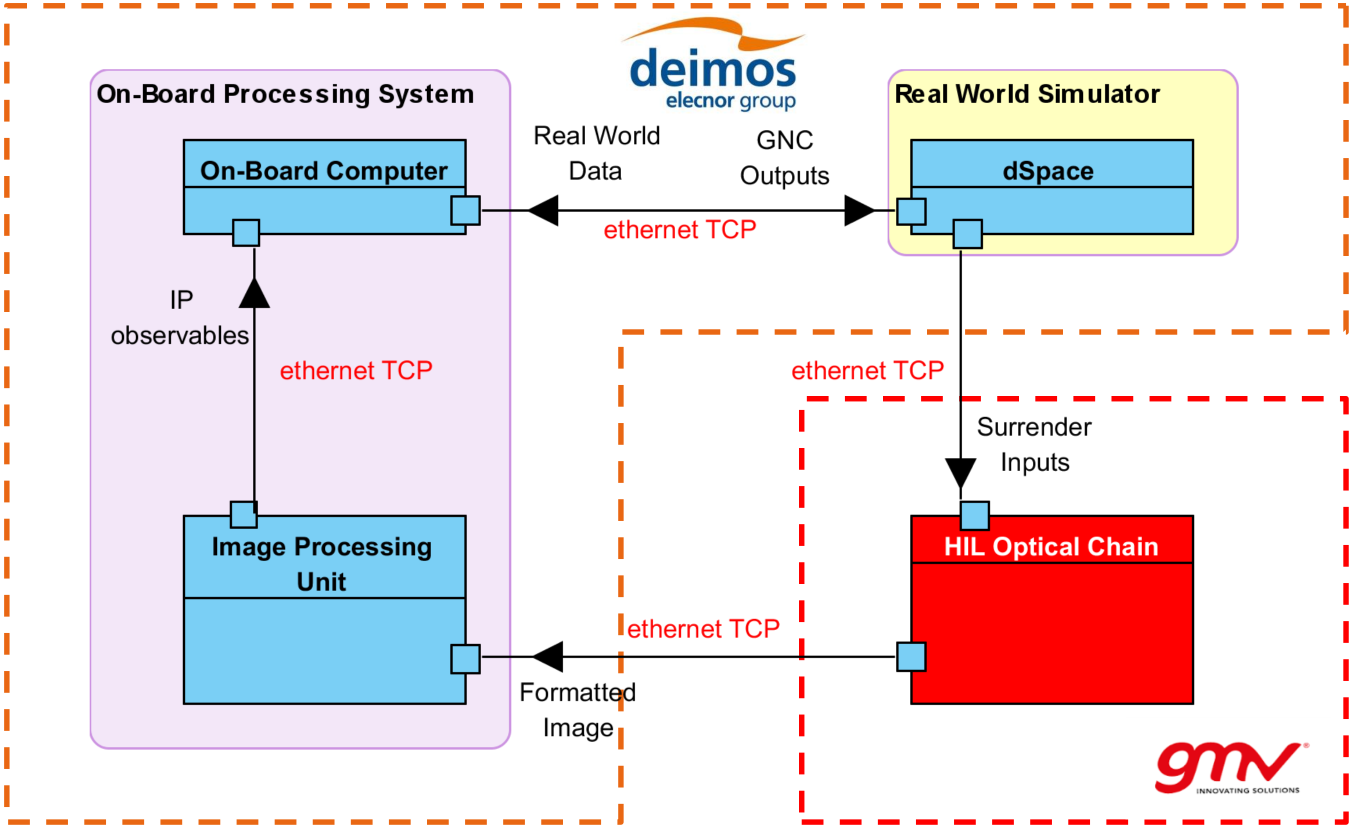
- Real-time performance meets the requirements.
- No significant numeric deviations wrt MIL => Functional performance is demonstrated

Phase	Function	Period/Deadline	Response Time	CPU Usage
Close Approach	G&C	60s/1s	<10ms	31%
	Nav	300s/60s	<300ms	
	IP (CoB)	20min/5min	<90s	
Arrival Inertial Hovering	G&C	1s/100ms	<10ms	42%
	Nav	60s/60s	<15s	
	IP (FDT)	60s/50s	<10s	16%
Body-Fixed Hovering	G&C	1s/100ms	<10ms	58%
	Nav	60s/60s	<25s	
	IP (FDT)	60s/50s	<10s	16%

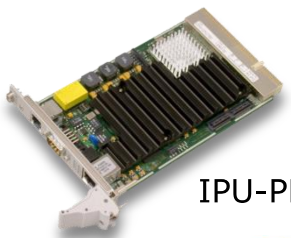




Transition from PIL to HIL (I)



Transition from PIL to HIL (II)



IPU-PPC

OBC-LEON3

dSPACE

Field	No. Elements	Type
Image Data	1 048 576	Uint16

TCP Message

Field	No. Elements	Type
Sun Attitude	4	double
Sun Position	3	double
Sun Velocity	3	double
Sun Angular Velocity	3	double
Cam Attitude	4	double
Cam Position	3	double
Cam Velocity	3	double
Cam Angular Velocity	3	double
Ast Attitude	4	double
Ast Position	3	double
Ast Velocity	3	double
Ast Angular Velocity	3	double
Integration Time	1	double

TCP Message

HIL Optical Chain

Image Calibration and Formatting

Camera HW

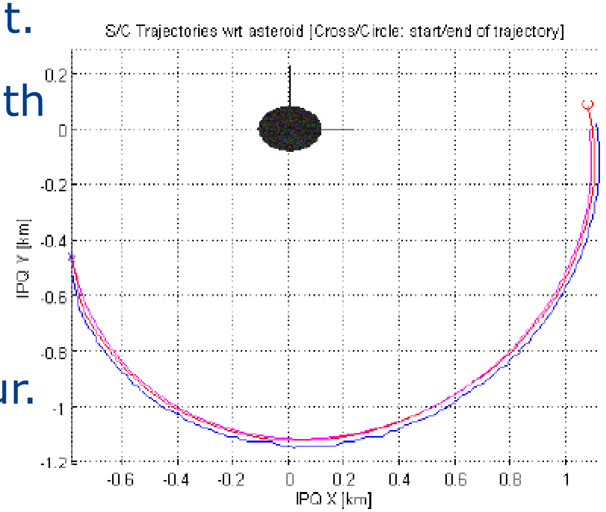
Scene Display

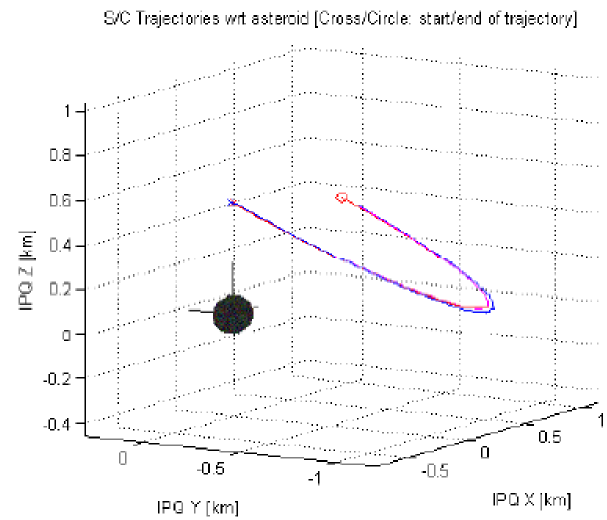
Image Generation

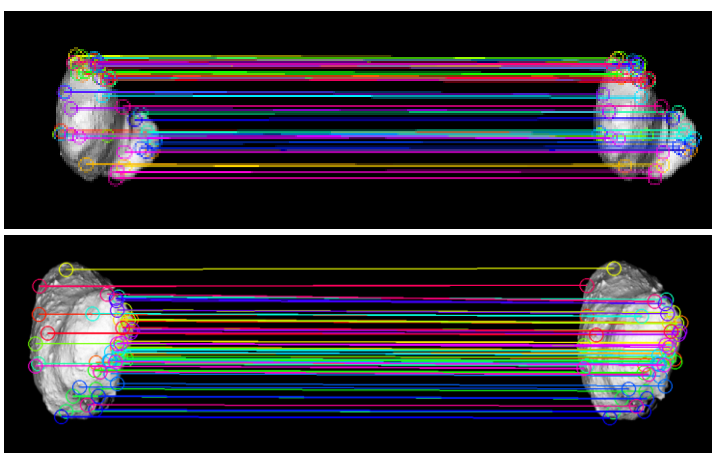
HIL Deployment at GMV's OPT-LAB

HIL Test Campaigns Results

- Smooth integration with HIL-LAB equipment.
- Executed a set of nominal test scenarios with real camera optical effects plus additional robustness test configurations including unfavourable conditions such as emulated radiation induced effects on the camera.
- No significant impact on real-time behaviour.
- GNC/IP SW showed robustness to the real camera optical effects and hardware in the loop configuration.







Conclusions

- Based on the achieved verification status, the **Technology Readiness Level of the critical GNC modes** (Close Approach Phase, Arrival-Inertial Hovering for 6h Phase and Body-Fixed Hovering Phase) for the Reconnaissance S/C GNC developments are between **TRL5-6**, as per formal independent certification by AIRBUS DS GmbH.
- The project results validate the **avionics design** for interplanetary missions with **Image Processing based Navigation**, as well as the development plan based on model based and **autocoding** techniques.
- The **Development Plan** needs to take into account since the beginning of the project the characteristics and requirements of the different modes and validation platforms, to include the necessary constraints in the models, to **ease the transitions** along the project life-cycle.
- The **heterogeneity of the PIL/HIL nodes architectures** (LEON3/RTEMS, PowerPC/RTEMS, IFs, dSpace, Windows®, Simulink®) is a challenge (different development environments, supported services…).

Acknowledgements

- We would like to express our gratitude to Airbus Defence and Space DE for their project coordination activities and valuable contributions and comments to improve the quality of the work as well as the final TRL certification.
- We thank also our partner GMV for their contribution to this work, making available their Optical Laboratory and supporting the HIL validation campaigns.
- Finally, we acknowledge and thank Airbus Defense & Space–Toulouse for licensing the use the Surrender Synthetic Image Simulator for the rendering of asteroid surface images, simulating the performance of the navigation cameras.

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Questions?

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