Real-time verification and testing facilities – RTFIP

Final Presentation

Original contract and CCN2

2023-09-05

Agenda

- Overview, what is RTFIP?
- Technical achievements
  - RTFIP-GRALS (main contract)
  - RTFIP-Launcher (CCN2)

OVERVIEW

What is RTFIP?

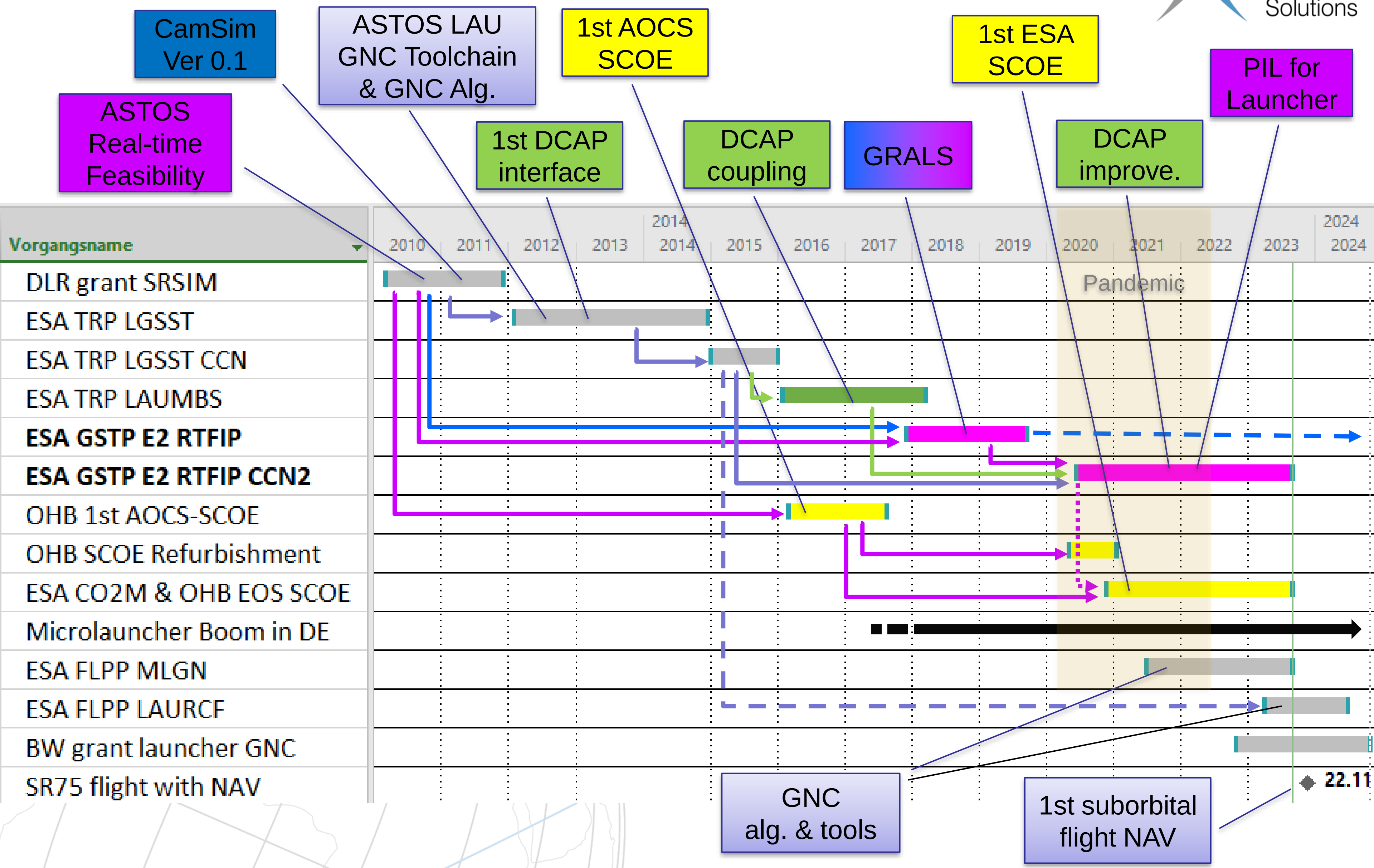
Real-Time verification and testing Facilities

- for image processing for navigation (original contract)
- for launcher GNC (CCN2)

Origin

- In 2017, there was a need to extend the existing toolchain of using ASTOS as a SCOE simulator to make adaptations to new use cases more efficient.

RTFIP Relationships



What is RTFIP?

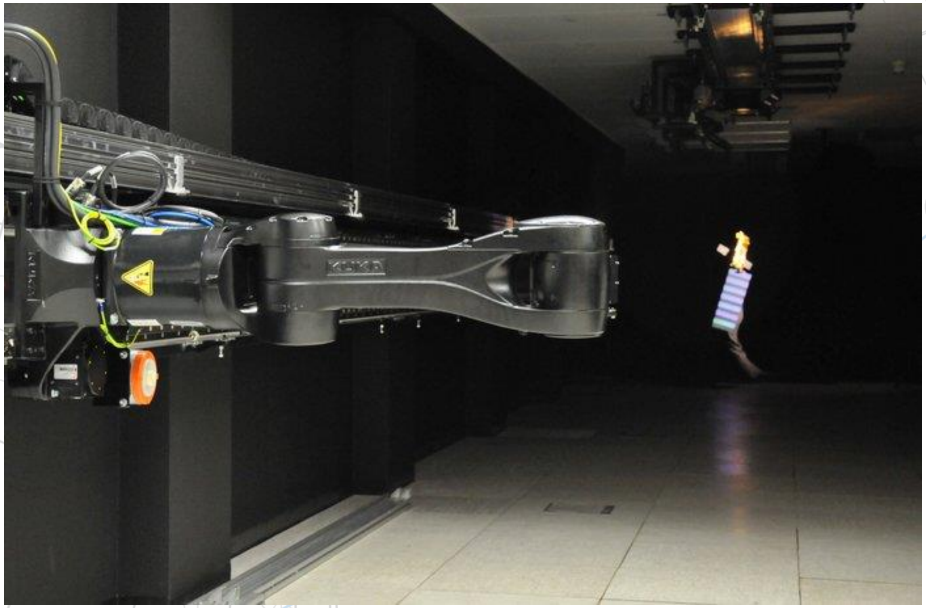
- RTFIP was
  - a co-funded project under GSTP Element 2
  - an important support for Astos Solutions to perform the required technology developments to prepare ASTOS as testbench for real-time verification and validation of GNC algorithms as COTS software
- RTFIP ran in parallel
  - to other similar activities but focused on core technologies which had to be improved to create a COTS product.
  - to AOCS-SCOE development activities, unintendedly (RTFIP CCN2).
- ASTOS development requires after RTFIP
  - a product phase to achieve TRL 8 of the COTS product. Until then the functionalities are available with engineering service.
- All activities enabled Astos Solutions
  - to be successful in the microlauncher market with more than 40 customers
  - to build up a GNC section.

Achievements

CORE CONTRACT

Objective

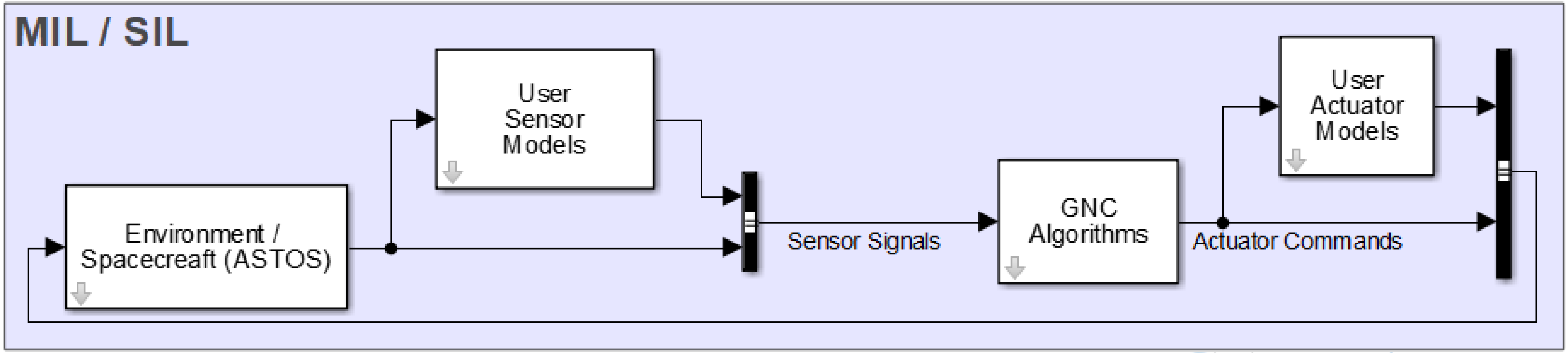
- Design and development of a reconfigurable and high-fidelity testing facility for GNC verification
- Demonstrate its capabilities in the GRALS/COMAU facility of the ESTEC Orbital Robotics and GNC Laboratory.



Building Blocks

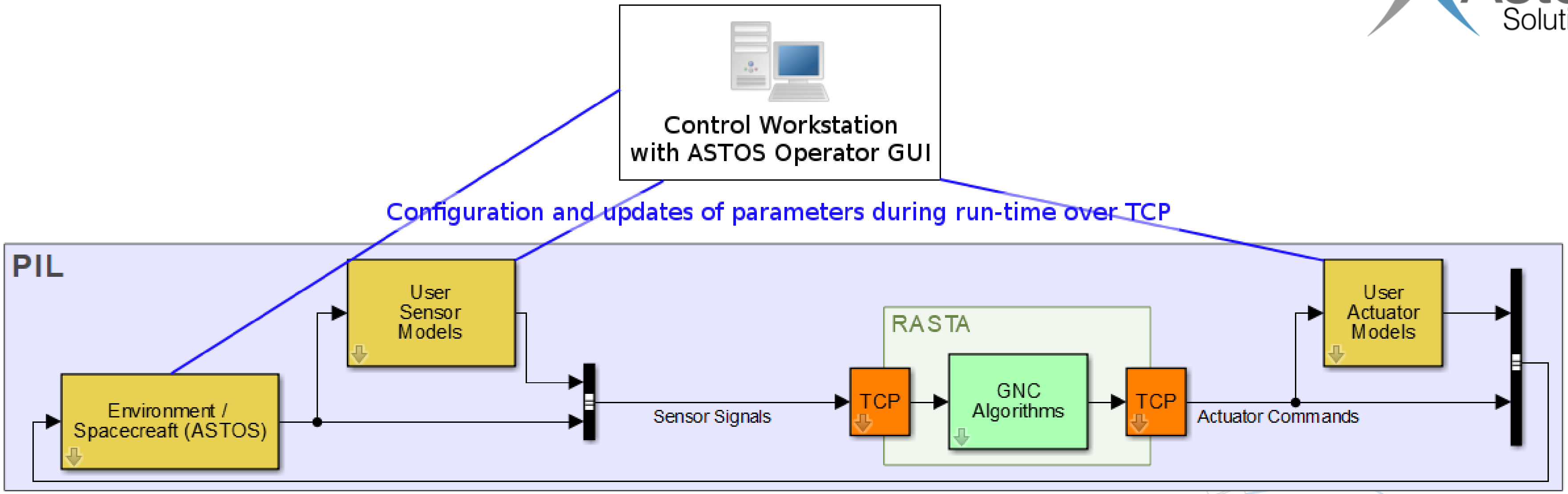
- ASTOS software as dynamics, kinematics and environment simulator
- dSPACE SCALEXIO as real-time processing platform
- Simulink as basic modelling environment for algorithms and as glue to integrate the system elements
- Kuka/COMAU robotic arm interface
- Astos Camera/Lidar simulator (scene generation, camera emulation)

Model In the Loop Simulator / Software in the Loop Simulator



- ASTOS extended by user sensor and actuator models
- GNC algorithms encapsulated
- For SIL the GNC algorithms are converted to code (manual conversion or using the Simulink coder)

Processor in the Loop Simulator



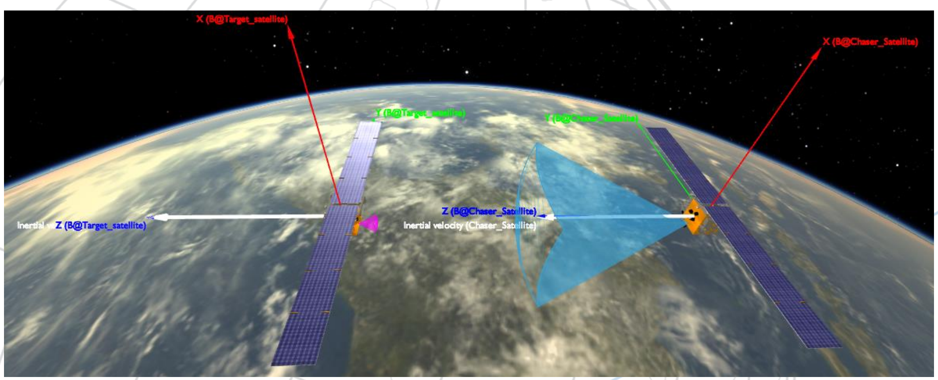
- ASTOS and user models executed by SCALEXIO
- GNC algorithms executed on LEON/RASTA
- Communication between SCALEXIO and RASTA over Ethernet. Communication protocol and GNC code automatically generated and deployed based on the SIL simulator.

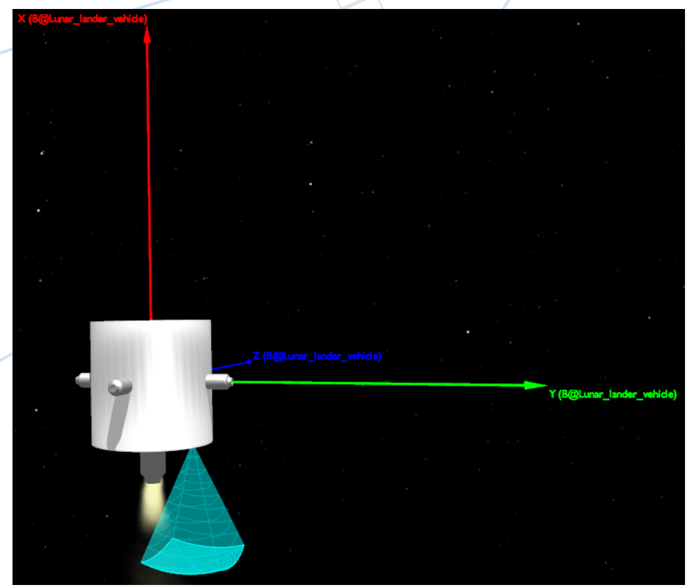
Key Features

- ASTOS software is used as DKE simulator for all simulator configurations from MIL to HIL
- Easy switching between the configurations
- ASTOS‘ real-world data and sensor data is available in Simulink through an s-function
- Sensors and actuators can be either used from ASTOS or added in Simulink
- ASTOS provides sensor/actuator error modelling capability
- Reconfiguration to PIL needs to be performed only once; afterwards easy switching between the configurations is possible.
- A target toolbox allows for target cross-compiling of the onboard code and integration in PIL/HIL testbench. Currently only for Gaisler RASTA and LEON4-N2X.
- An interface to the Astos Camera/Lidar real-time simulator is provided.
- An Operator GUI reduces the editable configuration parameters to those required for execution of the tests (GUI builder)

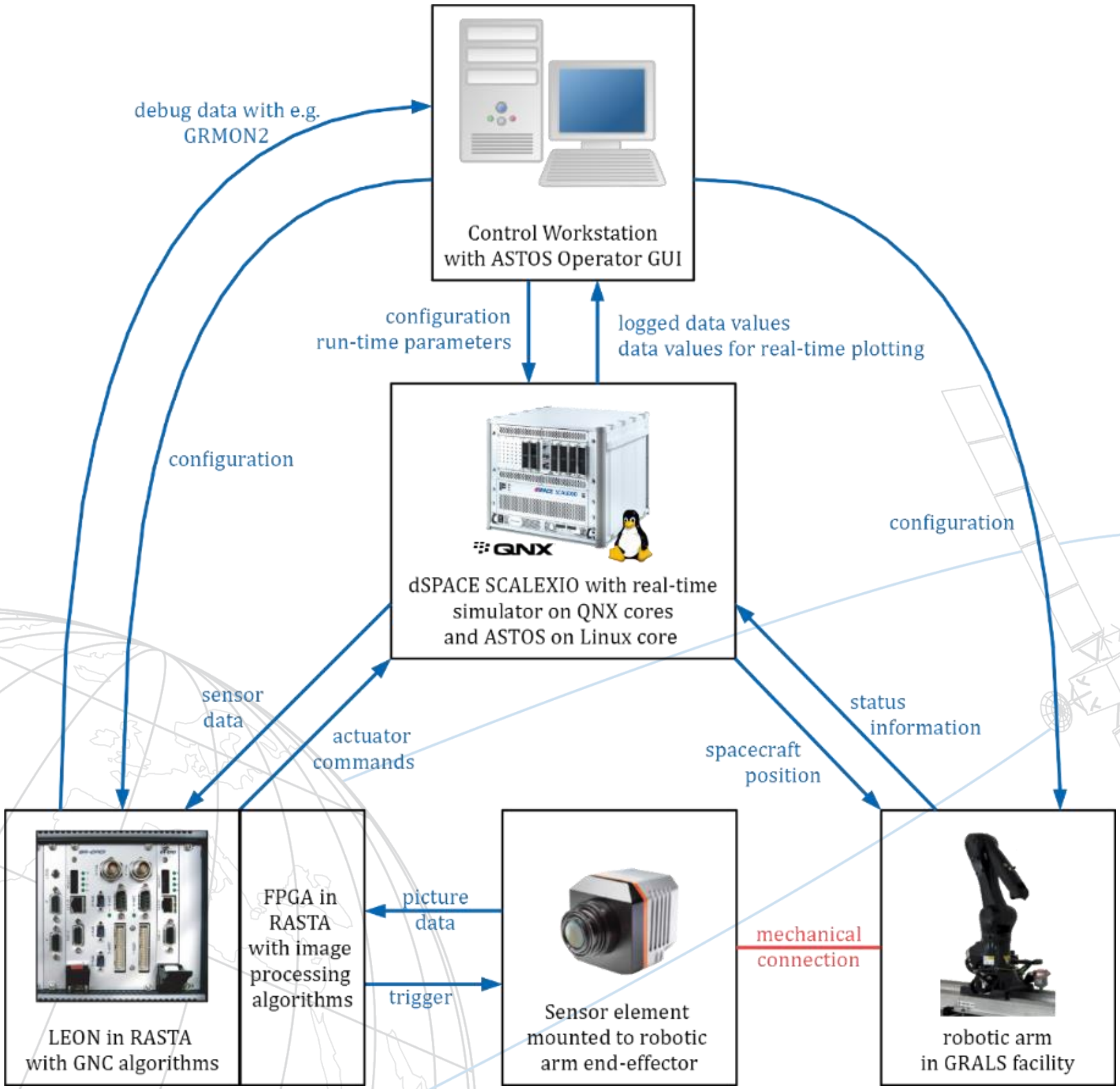
Demonstration Test Scenarios

- Two representative scenarios have been developed for the testing and performance evaluation of RTFIP.
- The scenario development comprised not only the ASTOS configuration but also the implementation of basic GNC algorithms in order to get feasible closed-loop simulations.
- Two domains have been selected:
  1. Rendezvous scenario
  2. Landing scenario on Moon



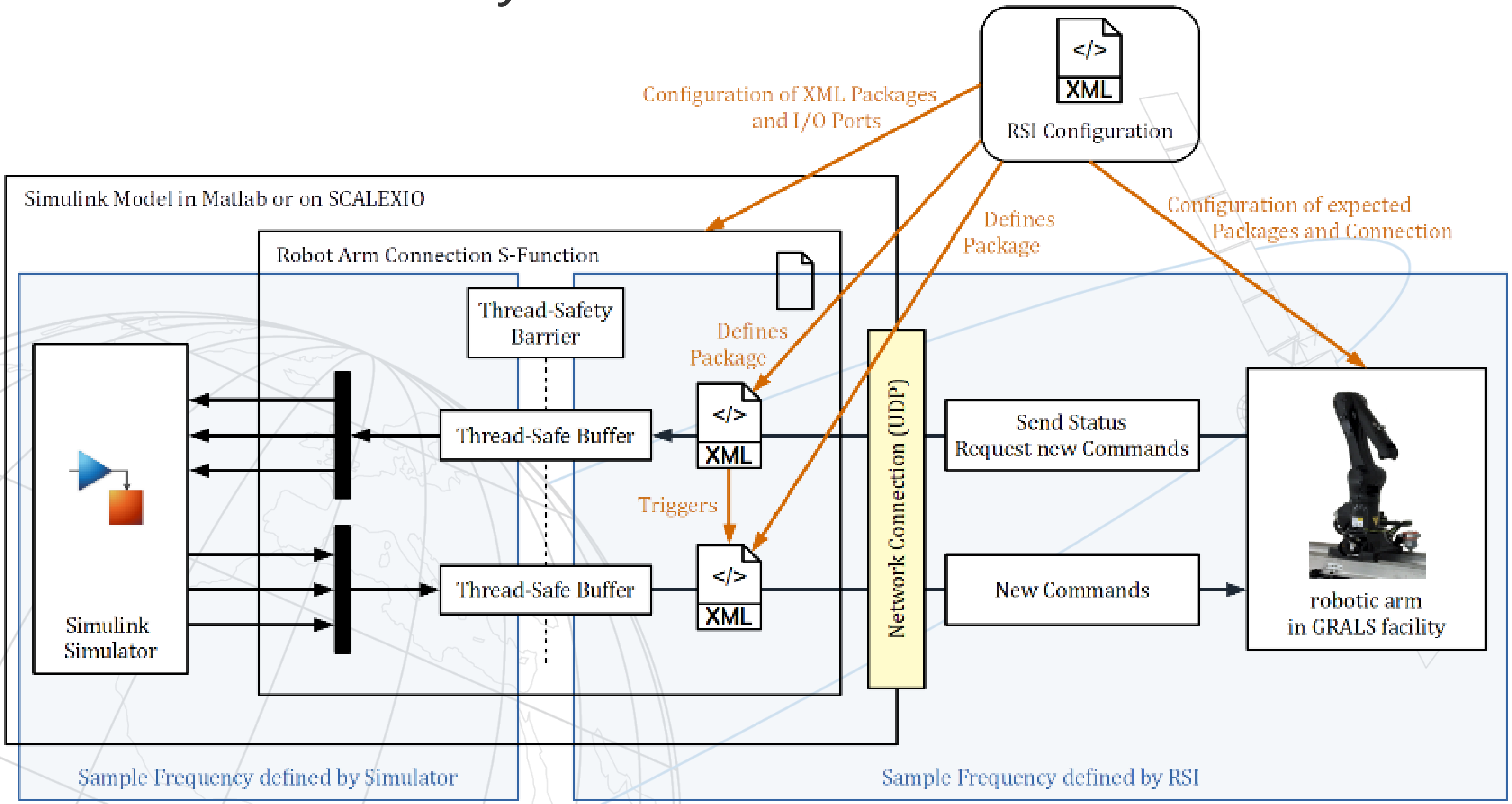


Architecture



Control of KUKA robot arm

- KUKA robot arm with a camera mounted to the end-effector
- Interfaces defined by KUKA



Achievements

SVF FOR LAUNCHER GNC CCN2

Task 1: ASTOS Improvements

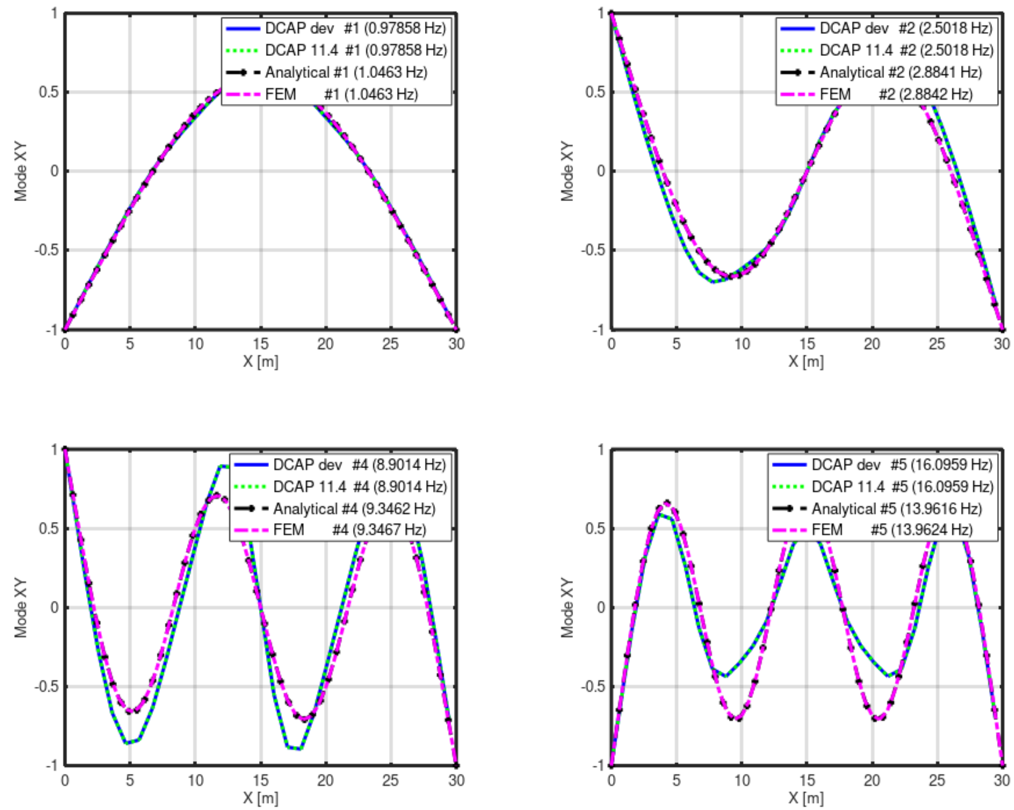
- Objectives
  - Improvements of various identified shortcoming of ASTOS
- List of performed activities
  - Investigation how to speed up ASTOS computational time to increase real-time update rate and implementation of most promising modifications
    - Result in increase between 32% and 43%
  - Other ASTOS improvements
    - Vehicle COM computation and node definitions related to DCAP
    - Improved sloshing model by adding special conditions for axial acceleration which allows for launch pad and coast arc phases
    - New simulation mode in ASTOS without grids for closed loop simulation and interfacing with DCAP correctly
    - Improved distributed aerodynamics computations
    - Input of user defined mode shapes and frequencies
    - Some minor changes …

Task 2: DCAP/MBS improvements

- Objective: make it work!
- Background
  - LGSST & LAUMBS development
    - coupling of ASTOS and DCAP (called MBS)
    - additional linearized flexible dynamics (called LFD) integrated in ASTOS using modeshape export from DCAP
  - Instabilities after stage separation
  - Minor other topics

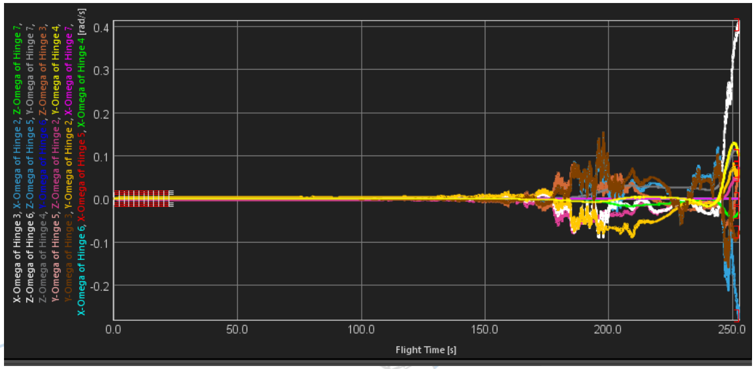
Task 2.1: Mode Shape Accuracy

- Analysis of mode shape accuracy considering different boundary conditions of the beam approximation (fix-free, free-free) against a newly implemented FEM algorithm and an analytic solution resulted in two bug-fixes.
- Outcome
  - DCAP: Risk of wrong boundary conditions
  - The mode shapes computed by DCAP are not very accurate in case of multiple flexible beams stacked together (3-stage rocket). A new program based on FEM drastically improve the simulation accuracy.
  - ➢ Future switch to new FEM tool



Task 2.2: Numerical Instability

- Extensive analysis considering 3 main drivers for instability
  - phase length
  - external forces (such as the engine thrust)
  - free hinge degree of freedom
    (up to 10 stages)
- Results are summarized in TN-010



- Outcome
  - MBS simulations get unstable in case of several free DoFs and complex dynamics. That situation happens already after the first stage is jettisoned for VEGA.
  - The origin of this behavior is located in the core DCAP files, but not identified yet
  - A work-around could be to lock all rotational degree of freedom of jettisoned stages, but a final solution to allow such long simulations is not available yet

Task 2: Summary MBS vs LFD

Application	ASTOS-MBS (DCAP)	ASTOS-LFD	ASTOS-FEM
Simulation of a single flexible body	X	X	
Long time simulation with stages separation, e.g. end-to-end multi-stage launcher ascent simulation		X	
Non-linear time simulations, e.g. non-linear spring stiffness, prescribed motion of components, …	X		
Detailed simulations over short time, e.g. stage/payload separation, landing, docking, …	X		
Long time simulation, e.g. towing of returning flyback booster with flexible rope	X		
Relative movement of vehicle equipment, e.g. solar panel/antenna deployment, component separation with spring elements, …	X		
Export of vehicle mode shapes and linearized dynamics for control design required by ASTOS-LFD	Only single stage/satellite	Input to LFD	X

- **MBS** is the "(Flexible) multibody dynamics" EoM where DCAP is computing the system dynamics
- **LFD**: is the "Linear flexible dynamics" where equations for the flexibility are added to the ASTOS EoM
- **FEM**: Finite element model developed for cross-validation, which will be used for mode shape export in the future

Task 3:
Tool-Chain for Real-Time Simulation

Topics

- Improvement of data handling
- Integration of RTFIP development into the commercial trunk of the ASTOS repository
- Demonstration that old RTFIP cases will work with the new commercial ASTOS trunk

ASTOS DMS
Data Management System

- Old ASTOS versions wrote all data into a file after simulation for post-processing
  - hundreds of output functions
  - High frequency output desired by control engineers
  - long-term simulations result in extremely huge simulation files tht cannot be loaded an more.
- Long-time, closed-loop and real-time simulations require to see the simulation data almost in real-time, during simulation.

Solution

- Client–server communication concept over TCP
- Various clients can create data, e.g. ASTOS simulation, GUI, SCALEXIO, …
- Special concepts for downsampling of data for improved visualization and speed-up of plotting.

Integration of RTFIP into Commercial ASTOS software

- Based on the experience gained in the core RTFIP activity, the DMS code has been rewritten.
- All parts of the ASTOS GUI that interact with the simulation files had to be adapted.
- Especially the migration from discrete update events towards a continuous change of the simulation data required significant changes in the ASTOS GUI code.
- Finally, all aspects of the RTFIP development made it into the trunk of the ASTOS software repository (solving conflicts with parallel developments).
- Further testing and bugfixing until release (ongoing).

Conclusion

- RTFIP has paved the way for a major redesign of the ASTOS architecture
- Reusability and rapid configuration have been identified as key aspects of future AOCS test systems, where the developments initiated by the RTFIP have been key for us.
- The RTFIP validation campaigns where very valuable in the domain of MBS simulations. They also revealed the limitations of the current solutions and initiated new developments.