Concept and Performance Simulation with ASTOS

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Outline

- Overview Simulators in Phase 0 to Phase C
- Overview ASTOS Software
- Analysis tasks with ASTOS
- Application cases
  - Launch vehicle scenario
  - Orbital servicing scenario
- Outlook
- Conclusion

Simulator Overview for Phases 0/A/B/(C)

ECSS Technical Memorandum: System modelling and simulation

System Concept Simulator

- Rapid evaluation of system design concepts
- High-level mission requirements
- Execution of design trade-offs
- Low-fidelity models
- High reusability

Mission Performance Simulator

- Establishment and verification of the overall performance of the baseline mission from the user point of view
- Adequate payload models, i.e. instrument, GNC payload, …
- Operational reuseability

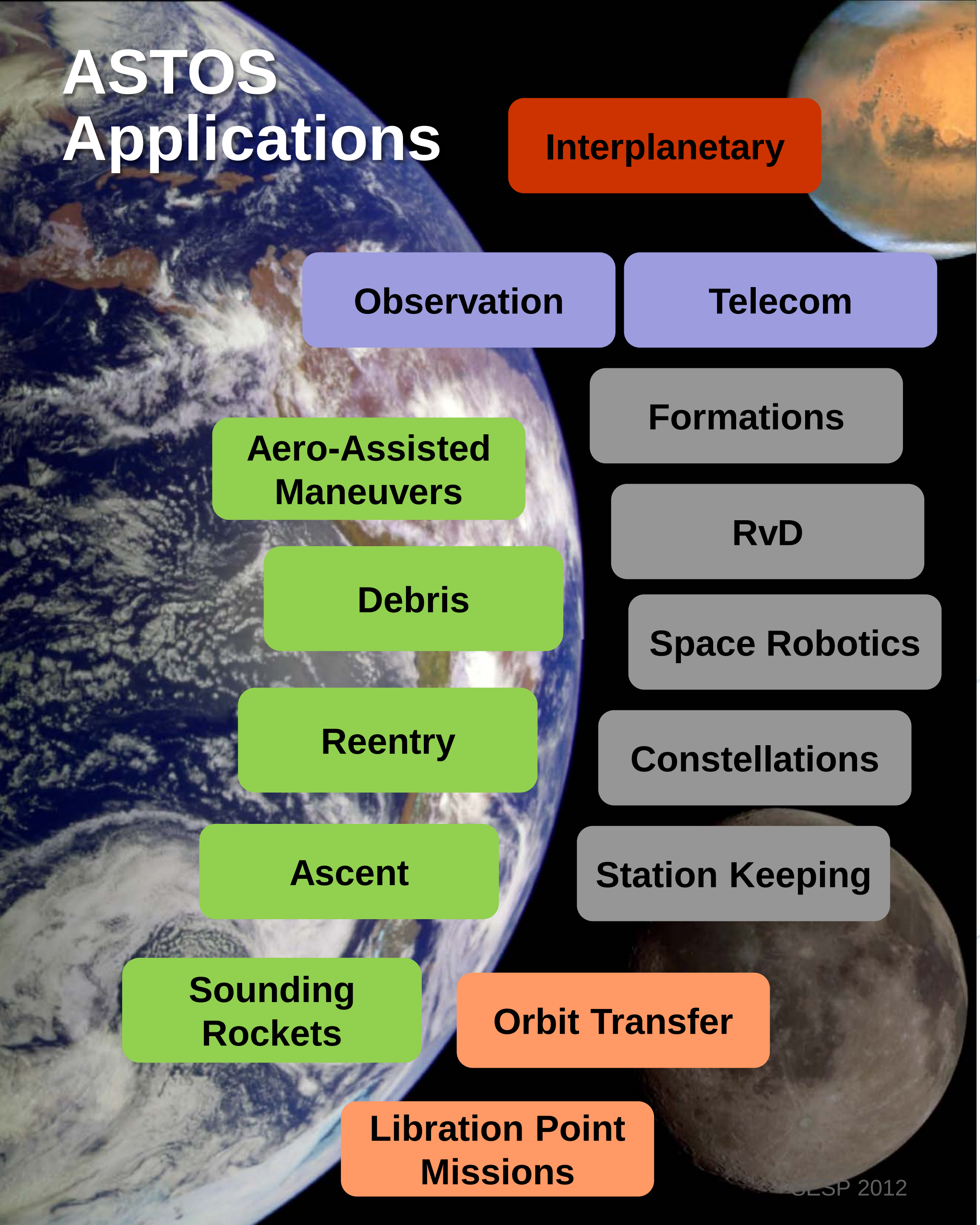
Functional Engineering Simulator

- Verification of critical elements of a baseline system design
- Functional model which is representative of the behaviour of the real modelled elements
- Used as basis for building real-time simulators that are exploited in the subsequent phases
- Verification that the preliminary and detailed design meets the system requirements

Different focus with high potential for reusability but also high dependency on the space application.

Engineering Activities

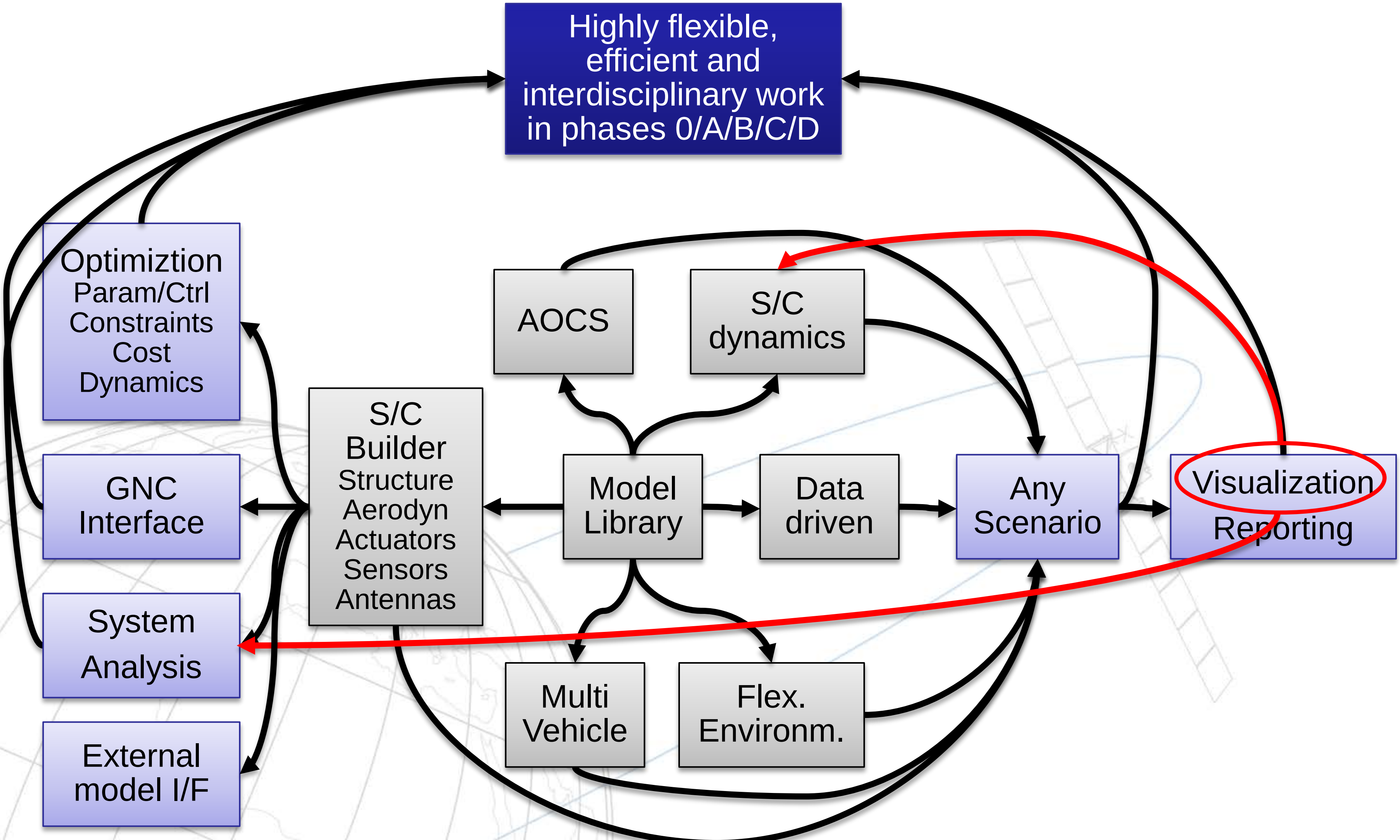
Engineering Activities	Phase 0	Phase A	Phase B	Phase C
Feasibility and Performance Analysis/Trade-Offs	Concurrent Design Activities			
Requirements Specification	Concurrent Design Activities	System & Mission Analysis		
Design Verification		System Interfaces and End-to-End Design Trade-off		
System and Mission performance verification		System Interfaces and End-to-End Design Trade-off		
Functional Subsystem V&V			Interfaces and End-to-End	



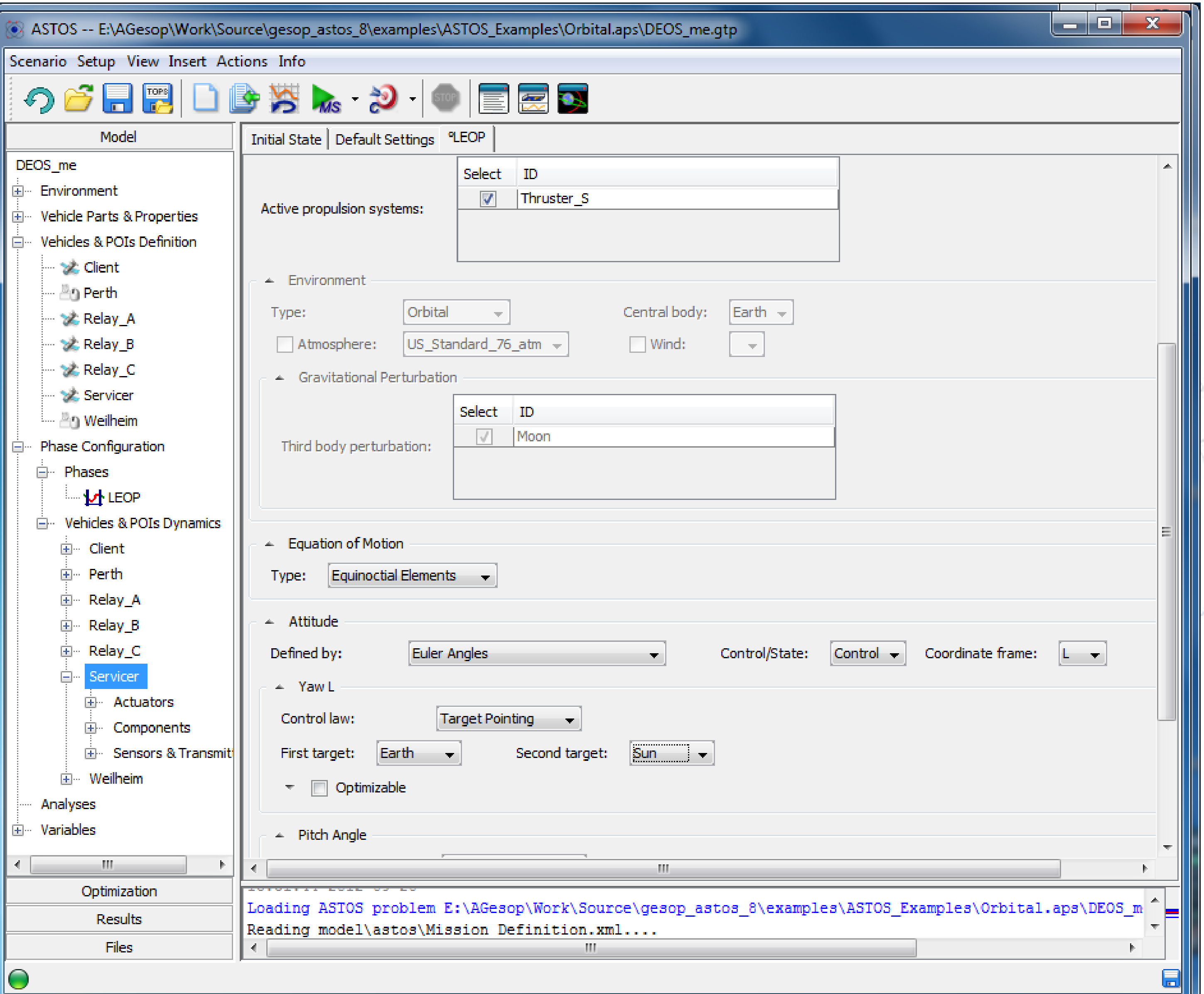
ASTOS Techniques

- Trajectory & vehicle optimisation
- Propagation & mission analysis
- Multi-Body simulation
- System analysis
- Safety analysis
- GNC analysis with flexible modes
- Monte Carlo simulations
- Visualization
- Reporting

What is behind ASTOS?



ASTOS Scenario Definition



1. Environment
2. Vehicle Parts
   - Servicer
   - Antenna
   - Camera
3. Vehicles & POI setup
4. Phases config.
5. Vehicles dynamics config.
6. Analysis

SUPPORTED ANALYSIS STEPS

1. Design Trade-offs with Support of Multi-Disciplinary Optimization

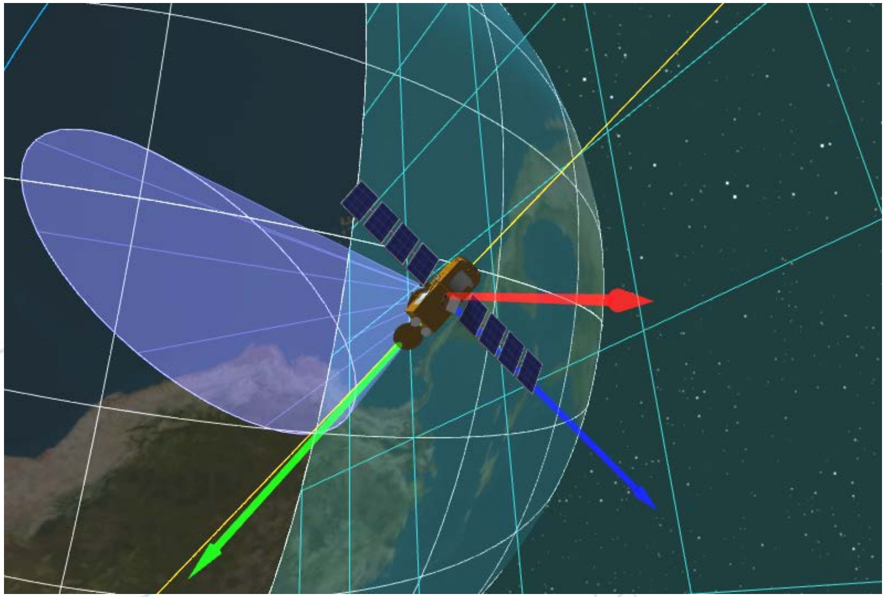
ASTOS-MDO uses

- All-At-Once (AAO) approach
  - Considering optimal control and mission and load constraints
  - Using simplified discipline models accurate enough for Phase 0/A/B1 and fast enough for AAO
- Output
  - Optimal vehicle design
  - Optimal trajectory design and manoeuvre plan
  - Reference trajectory for GNC

2. Mission Analysis

Full support to the mission analysis work package

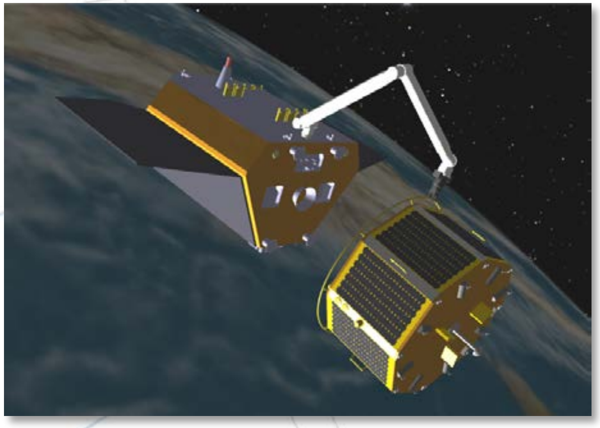
- Accurate trajectory propagation
- Multi-vehicle scenarios
- Attitude defined by pointing laws
- Analysis aspects cover
  - Departure & arrival window
  - Delta-V budget
  - Manoeuvre planning
  - Eclipses
  - Visibility & link budget
  - Payload environmental req.
  - Sensor field of view analysis incl. separate pointing laws for sensors

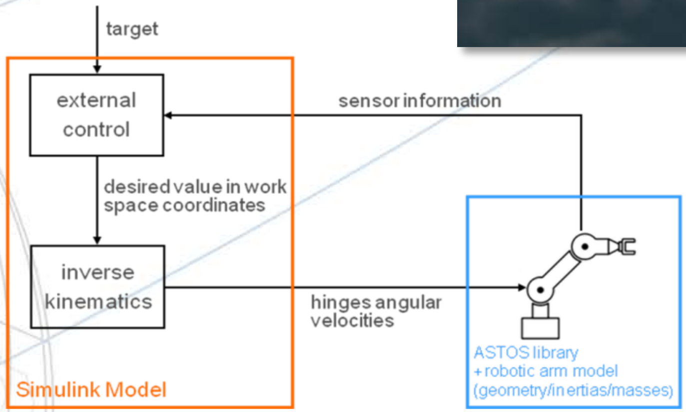


- Modelling of space environment according to ECSS

Multi-Body Dynamics

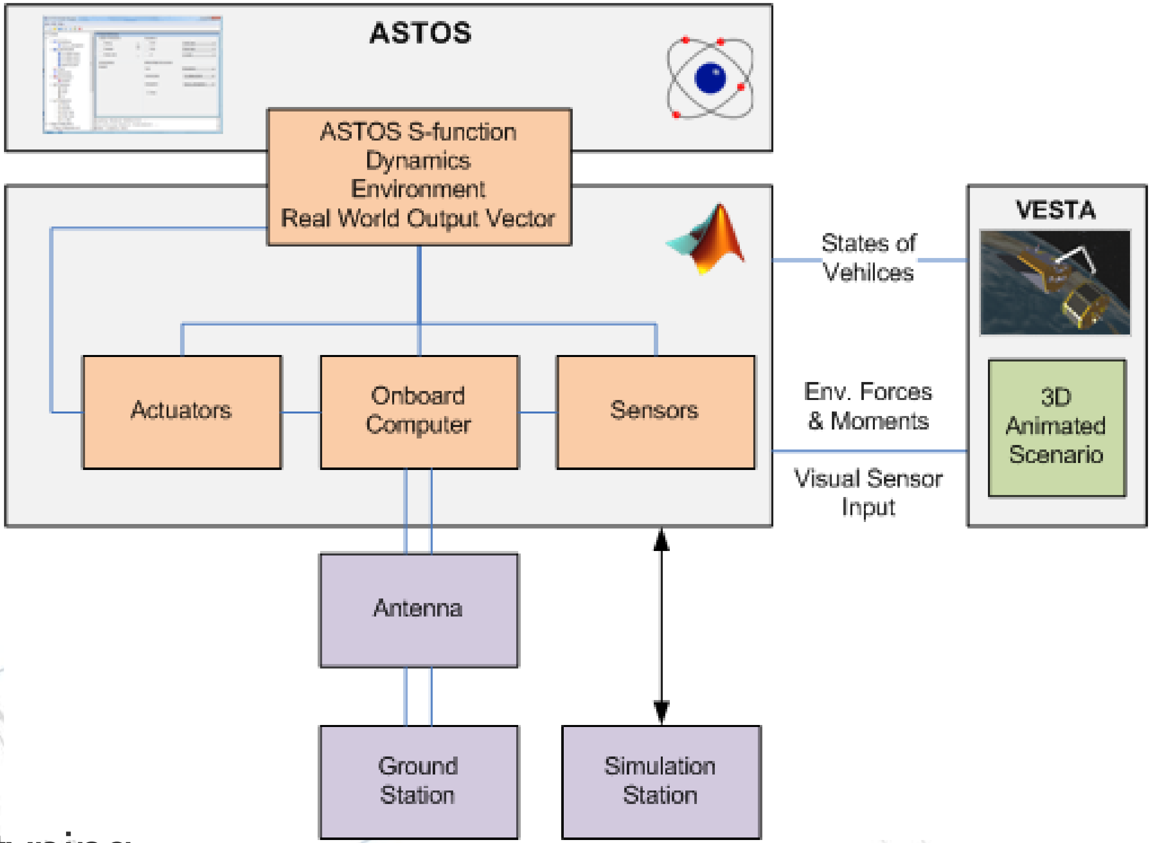
- Flexible body dynamics from DCAP
- Robotic arm interface with rigid multi-body dynamics
  - Definition of robotic arm elements by size, mass and inertia
  - Dynamics based on spin and momentum conservation
  - Simplification:
    - Angular velocities of hinges are commanded
    - No modelling of hinges itself
  - Robotic arm control by
    - Simulink model for angular control
    - Build-in Inverse Kinematics for 6dof targeting with constraints
  - Output
    - Cardan angles of hinges
    - Rigid multi-body dynamics, i.e. force and moment feedback on core satellite





3. AOCS/GNC Analysis

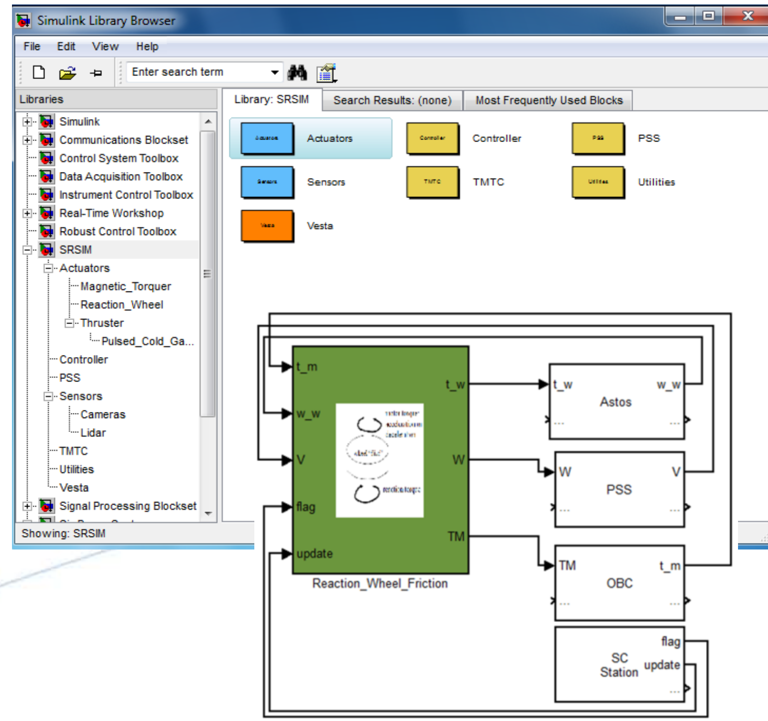
- ASTOS represents Real World and exports S-function to Simulink
- System and Onboard World in Simulink
- Realistic visualization in real-time
- Force and moment feed-back of environmental disturbances

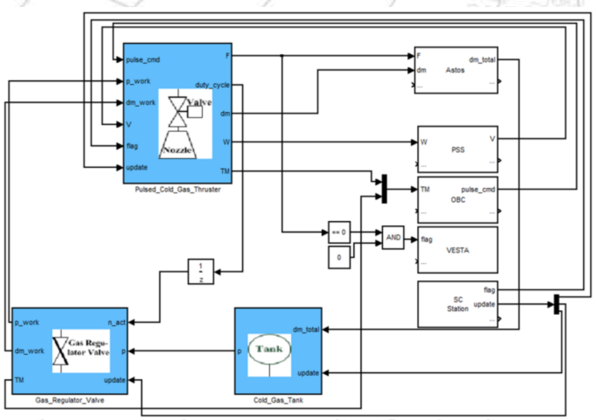


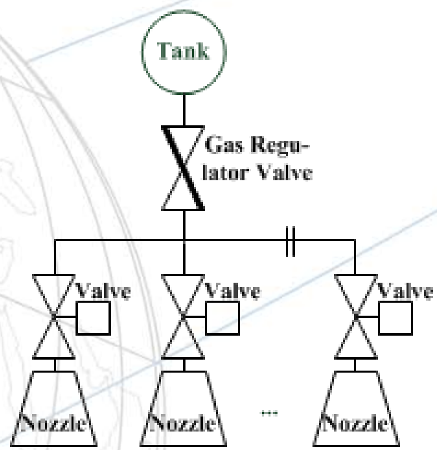
- ➢ Designed for rapid prototyping
- ➢ Coupled Mission and GNC analysis

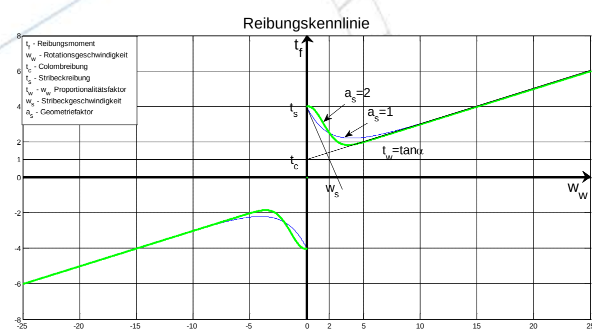
Equipment Database

- Actuators
  - Pulsed cold gas thrusters
  - Magnetorquer with characteristic curve
  - Momentum wheels
  - providing TM, power and fuel consumption
- Sensors
  - Currently simple sensor models (field of view)
  - Camera model for relative navigation
  - Error flags and power consumption



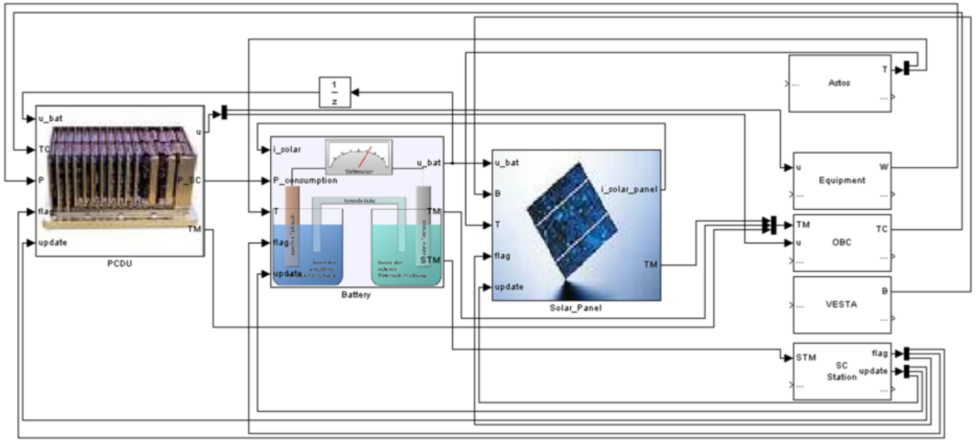






4. System Analysis

- System analysis is considered as far as it is related to the trajectory, affected subsystems and GNC design
  - Power system with models for battery and solar panels
  - Thermal model
  - TM/TC including link budget
- Use of geometrical representation in VESTA for computation of physical properties at interfaces to subsystem models, like irradiation on surfaces and solar cells for thermal and power modules



- Interfaces are provided to link
  - external subsystem models
  - payload models
- as part of
  - the simulation
  - a dedicated post-analysis

Example

LAUNCHER MDO AND GNC

Launch Vehicle MDO

- Architecture
  - Stage sizing with parameterized geometry
  - Structural mass estimation using regression tables depending on size and load cases, verification with structural optimization by ODIN (MT Aerospace)
  - Propulsion system design using RPA (chemical equilibrium)
    - extended system analysis like heat transfer rate and engine cycle
    - suitable for preliminary design phases
  - Estimation of controllability using modal analysis
- Output
  - Load cases
  - NASTRAN file exported by ODIN
  - Optimal vehicle design
  - Reference trajectory considering boundary and path constraints
  - High level mission requirements

Launch Vehicle GNC

- Architecture
  - ASTOS
    - Rigid body dynamics
    - Reference trajectory
    - Requirements and reporting
  - DCAP (TAS-I)
    - Flexible body dynamics
  - MATLAB
    - Controller design
  - Simulink
    - Sensor/actuator definition
    - Navigation algorithms
    - Open loop guidance simulation
    - Closed loop control simulation

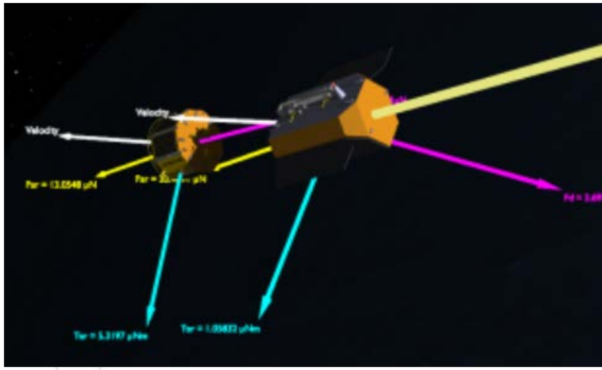
- Output
  - Sizing of attitude control system
  - Load cases like bending moment
  - GNC budgets
  - Minimum propellant reserve
  - Injection accuracy
  - Ground track drift

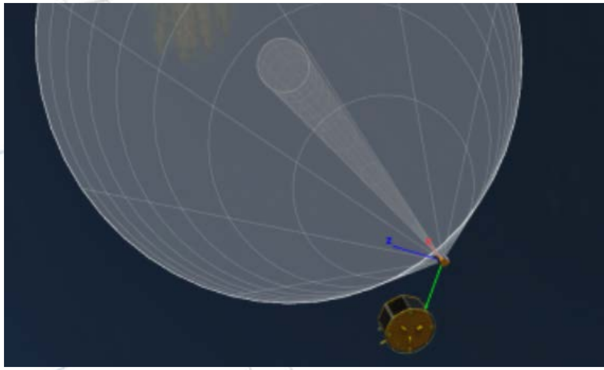
Example

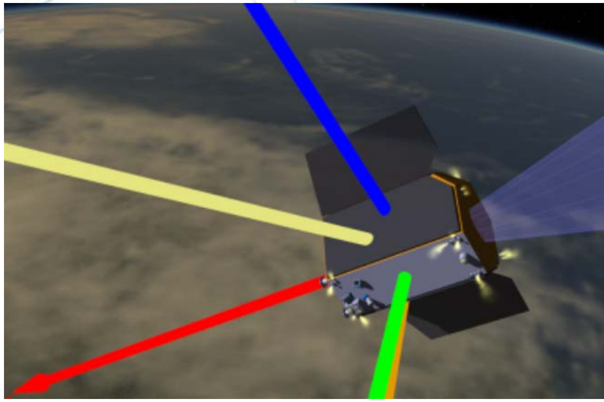
ORBITAL SERVICING - DEOS

Orbital Servicing Mission DEOS

- Coupled mission, system and GNC analysis
- Specific Algorithms
  - Optimal rendezvous maneuver
  - Manipulator arm interface
  - Computation of environment based on geometry, e.g. differential drag
  - Navigation based on visual sensors
  - Specific GNC algorithms like search and pointing algorithms based on visual navigation
  - Guidance algorithms for forced motion
  - Control algorithms with visualization of thrusters

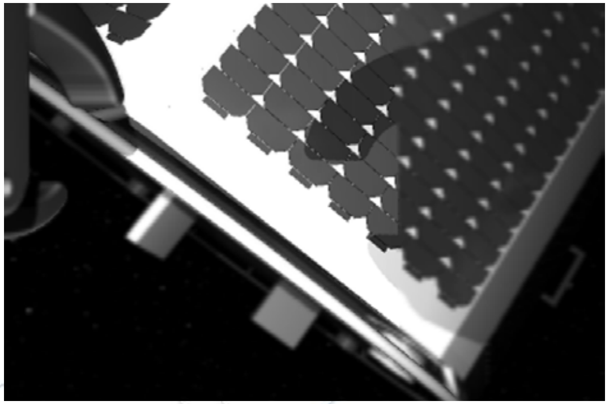


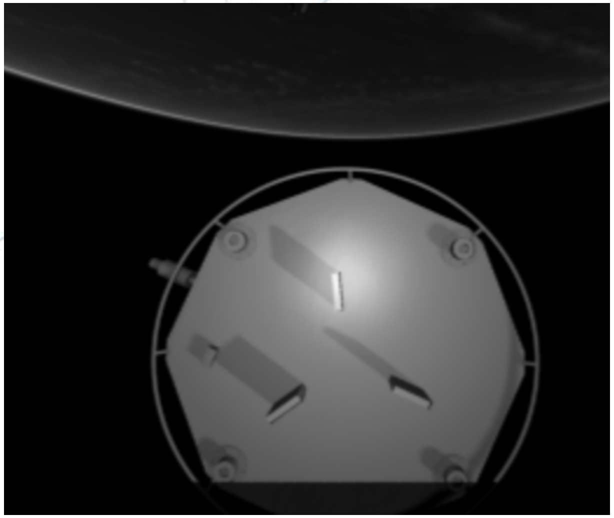




Camera Simulator applied to DEOS

- Real-time generation of imaging sensor output considering
  - frame rate
  - field of view
  - focal length
  - sensor resolution
  - sensor technology
  - sensor spectrum (requires 3D models with corresponding material definition)
- Allows navigation via an image processing algorithm
- Hardware solution with CameraLink interface is available
- Suitable for evaluation of sensors and sensor parameters





Summary of ASTOS Utilization

All three simulators (SCS, MPS, FES) are supported with following capabilities

- Requirement specification and validation, maintenance during life cycle, automatic reporting of verified requirements
- Design Trade-Offs at system level using GUI for rapid scenario configuration and system modelling according to the required fidelity of the specific analysis
- Evaluation of system concepts
- Assessment of engineering margins using sensitivity and worst case analysis
- System and mission performance verification and functional subsystem verification and validation of GNC related payload
- E2E mission performance budgets of GNC payload

Outlook

- Implementation of additional models to support SCS, MPS, FES, e.g. interface to ECOSIM based subsystem models
- Implementation of interfaces to link high fidelity instrument and payload models for extended MPS applications
- Provide ASTOS as dynamics and environment simulator in PIL/HIL testbed based on dSPACE hardware

Conclusion

- A rapid-prototyping approach for system concept and performance simulation has been presented.
- Analysis methods comprises optimization, mission, system and GNC analysis
- The resulting software framework is based on ASTOS with interfaces to DCAP, ODIN, RPA and Matlab/Simulink. Interfaces to other system tools can be added.
- Performance analysis is currently focusing on GNC aspects, but will be extended to scientific payloads
- It is dedicated to concurrent design facilities, like ESA/CDF, and has been successfully applied to orbital servicing, launcher ascent and low thrust orbital transfer.
- Further extensions supporting PIL/HIL are ongoing.

Leadership requires solutions

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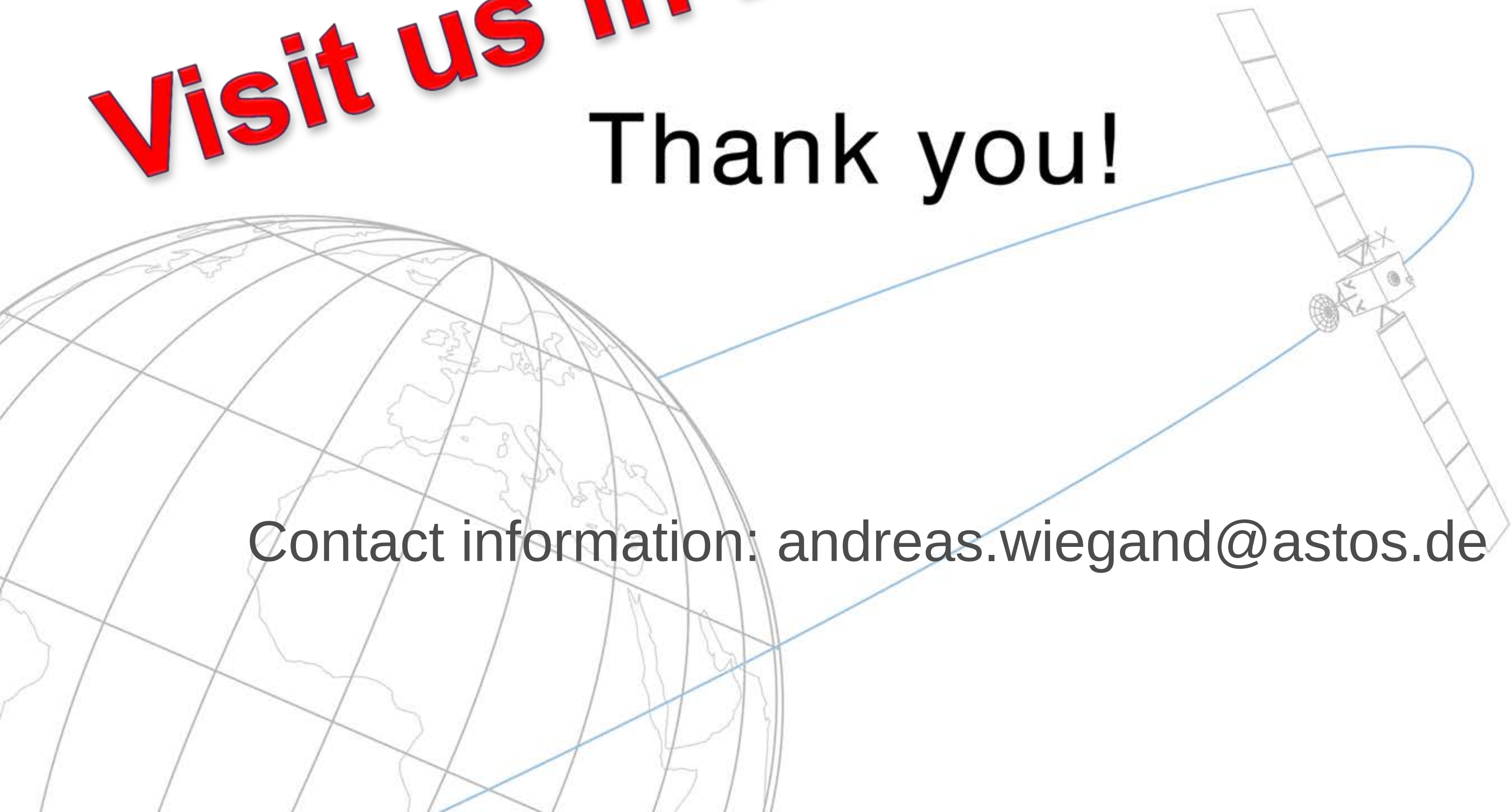
Thank you!



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