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RAPID DEPLOYMENT OF DESIGN ENVIRONMENT FOR EUCLID AOCS DESIGN

Aerospace

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Introduction

- **Euclid is a cosmology mission dedicated to study the geometry and the nature of the Dark Universe with unprecedented accuracy**
  - Observe a 15000 deg^2 wide area of the sky from L2
  - Scientific goals result in very demanding performances for the AOCS subsystem: RPE < 75 mas over 700 sec during observations
- **Euclid S/C: procured by ESA and supplied by TAS-I**
- **SENER is the prime contractor of the AOCS sub-system**
  - Work executed in partnership with ADS-NL
  - SENER responsibility is for the whole AOCS. Design, implementation and verification of GNC/AOCS modes and their SW, units subcontracts and overall verification.
- **Current AOCS status is fully in line with expectations**
  - AOCS SRR completed in 1 month and AOCS PDR in 7 additional months
  - PDR colocation was held at the end of November
  - Units' subcontractors activities are being launched with good progress

Euclid Design Simulator and AOCS Development

- **In the frame of EUCLID AOCS development two simulators are employed:**
  - ESE: Engineering Simulation Environment, responsibility of Elecnor-Deimos
    - *Functional Engineering Simulator, one of the formal test environments supporting overall Euclid AOCS verification and validation process*
  - EDS: Euclid Design Simulator
    - *The AOCS design environment*
- **Euclid Design Simulator**
  - Developed during Phase-B2 activities, will be evolved and maintained over the whole project life-cycle
  - Environment employed in design iterations: it's the framework in which AOCS modes, functions, interfaces and databases are being created
  - Units models: initial models in EDS → evolution through suppliers info → revert to EDS for update and test → specification

SENERIC

- **SENERIC is a suite for high-fidelity tools and models for the design, analysis, and validation of an AOCS**
  - Initially funded by Spanish Ministry of Technology, turned in internal R&D project for continuation
- **SENERIC is at the core of DKE, mathematical functions, sensors, and actuators of EDS. Models and libraries available for:**
  - AOCS Equipment: sensors and actuators
  - AOCS/GNC Functions: for rapid prototyping, analysis and design
  - Environment: force-torque perturbations, ephemerides, time references
  - Mathematical operations & transformations
  - S/C Dynamics and kinematics
- **Employed in the design of Planck and IXV AOCS, in PROBA-3, and for the design and auto-coding of OPTOS Attitude Control System**
- **Math library taken as basis of EUCLID AOCS math library**

Dynamics

- **Dynamics: joint integration of the S/C and reaction wheels, sloshing, and telescope Filter Wheel Assembly (FWA/GWA) dynamics equations**

$$\begin{bmatrix} I_{tot} & I_{RW}U_{RW} \\ I_{RW}U_{RW}^{T} & I_{RW}I_{n\times n} \end{bmatrix} \begin{pmatrix} \dot{\bar{\omega}}_{SC} \\ \dot{\bar{\omega}}_{RW} \end{pmatrix} = \begin{pmatrix} -\bar{\omega}_{SC} \times (I_{tot}\bar{\omega}_{SC} + I_{RW}U_{RW}\bar{\omega}_{RW} + \bar{u}_{FWA}I_{FWA}\omega_{FWA}) \\ -\bar{T}_{f}(\bar{\omega}_{RW}) \end{pmatrix} + \begin{pmatrix} \bar{T}_{ext} \\ \bar{T}_{RW} \end{pmatrix} + \begin{pmatrix} -\bar{u}_{FWA}I_{FWA}\dot{\omega}_{FWA} \\ \bar{0} \end{pmatrix}$$

- **The FWA/GWA is modelled by explicitly imposing a kinematic motion by directly injecting the angular rate and acceleration profiles**
  - Acceleration obtained respecting integral relation with rate
  - This ensures a correct torque profile and conservation of angular momentum

Simulation Core - Actuators

- **MPS (Micro-Propulsion System). Cold gas thrusters for attitude control in scientific observations.**
  - Accurate model needed in line with strict pointing requirements
  - Modelling of thrust noise frequency profile by filtering a white noise source
- **RCS (Reaction Control System). Employed for attitude and orbit control**
  - Effects included: integration & sampling, thrust time profile (rise+tail), noise, plume impingement
  - RCS pulse forced scaled over the AOCS cycle to model correct linear impulse independently of the sample time
- **RWA (Reaction Wheels Assembly)**
  - "Distributed" model: separate integration of equation of motions and simulation of dynamic behaviour
  - The RWA will have to be stopped and restarted hundred of thousands of times during the mission
  - Wheels braking modelling must ensure conservation of angular momentum
  - Dead time included during torque reversals
  - RWA dynamics simulates static+viscous+Coulomb friction

Simulation Core - Sensors (I)

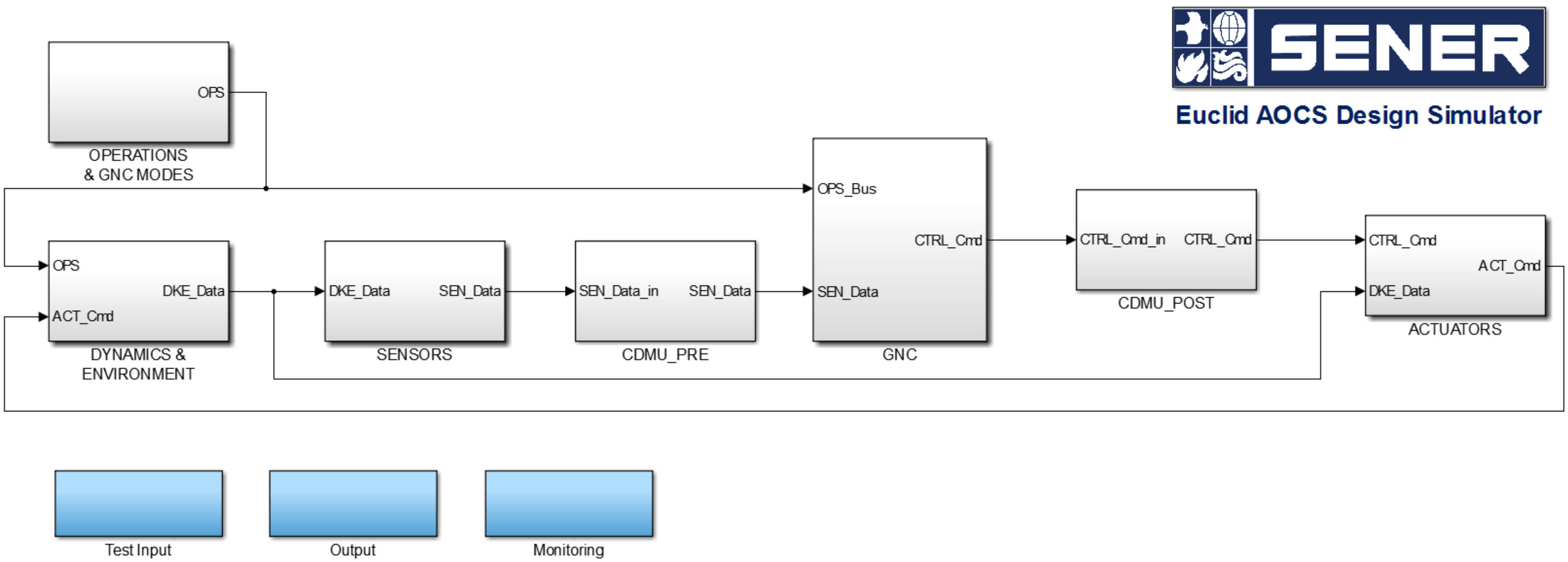
- **Gyroscope**
  - Rate integrating gyro model employed for 4 independent heads
  - Ad hoc filtering of White noise sources employed to reconstruct Allan variance profile
- **Accelerometers**
  - Approach similar to gyro.
  - Linear accelerations due to sensors accomodation + rotational dynamics included
- **Coarse Rate Sensors**
  - Analogous to gyros
- **Sun Sensors (SAS)**
  - Non-ideal cosine output simulated
  - Albedo included based on offline computation taking into account Earth illumination and sensor FOV

Simulation Core - Sensors (II)

- **FGS (Fine Guidance Sensor)**
  - CFI for the AOCS; physically mounted on telescope
  - Most relevant sensor for science observation phase
  - Complex functioning: sensor modes logic, attitude lock, acquisition delays, data outages, measurement delays, absolute/relative measurement, performances function of angular velocity
  - Custom in-house model built implementing specified behavious and characteristics
  - Wrapping built to allow EDS to swap in-house model for customer-provided model
  - Customer-provided model incrusted in EDS with mínimum modifications
- **Star trackers**
  - Integration+process delay taken into account
  - Velocity-dependent noise included
  - Spatial effects due to FOV and detector characteristics (pixel error) modelled by first and second order transfer functions with variable (velocity and rotation axis dependent) gains

Simulation Core

- **CDMU (Central Data Management Unit)**
  - AOCS is executed as part of the onboard software, running on the CDMU
  - CDMU pre-GNC and post-GNC functional subsystems included in model in order to represent correctly the timely data flow due to the finite AOCS execution time

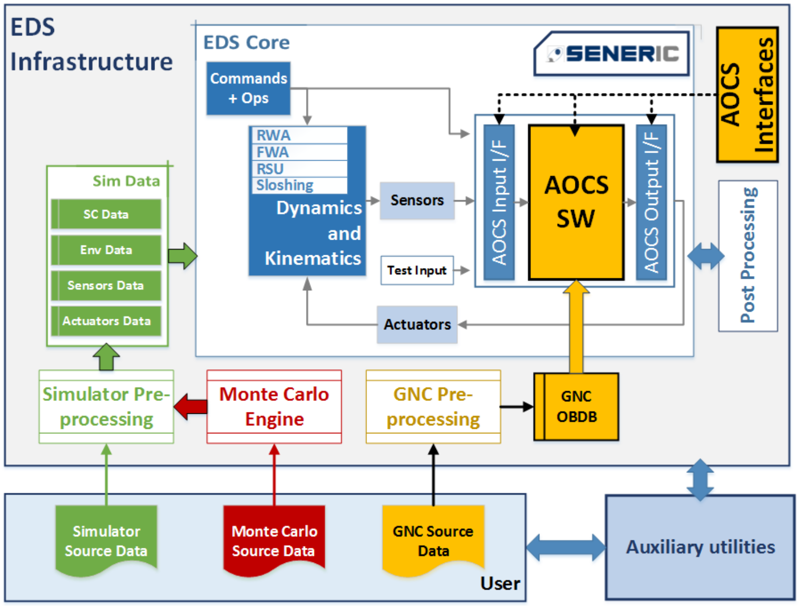


EDS Workflow and Infrastructure

- **The EDS was developed taking into account the following usage guidelines:**
  - fast input/parameters set-up
  - Allow quick algorithms design loops: modify AOCS algorithm or unit model, run test case, check output, modify again
  - Allow systematic execution: manage large data sets, run and store in an orderly fashion different sim cases, including Monte Carlos
- **EDS high level components:**
  - Simulink simulation core
  - MATLAB simulation and data management infrastructure
  - Utilities for workflow efficiency and ancillary operations

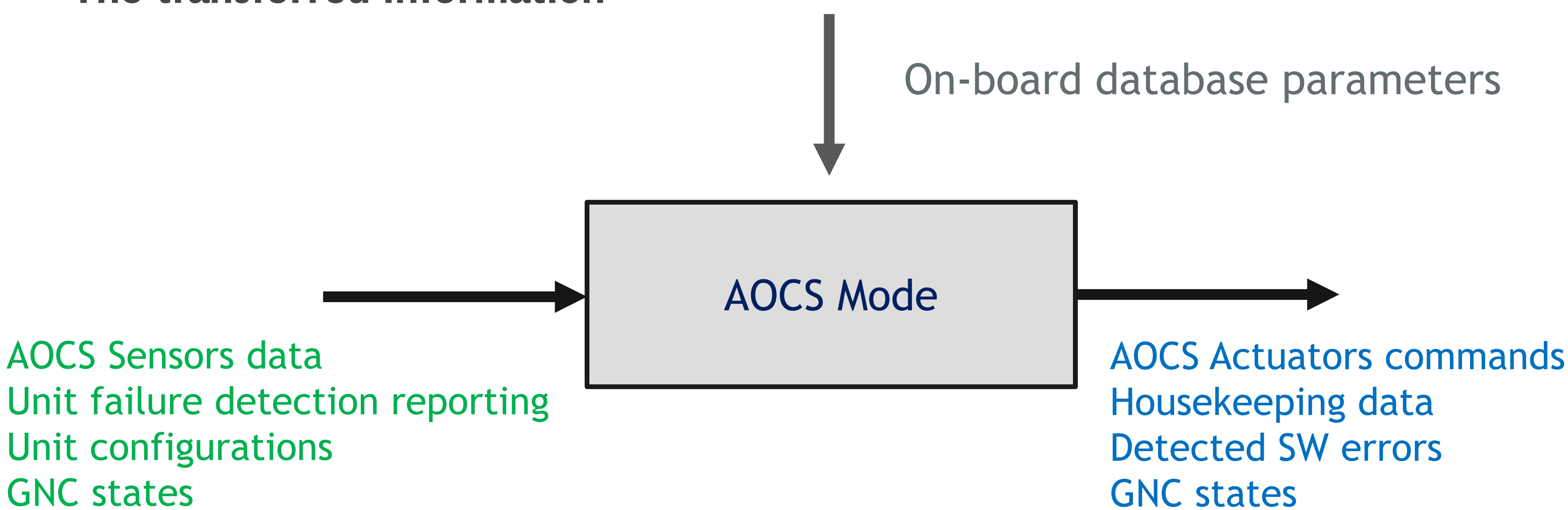
Simulations execution

- **Three execution modes allowed:**
  - Design Run
    - *allow rapid iteration on algorithms design and simulator parameters, minimizing the set-up effort.*
    - *aim: configure the simulation with a single MATLAB command*
  - Systematic Run
  - Monte Carlo
- **Data management**
  - Source databases: user-defined parameters
  - Pre-processing: transforming user-friendly parameters into data needed by simulation core
  - XML databases and m-files used: m-files for quick setup and debug, xml for more structured runs
  - XML files can be generated directly from m-files, to reduce data preparation effort



AOCS Interfaces (I)

- **Interfaces definition plays a relevant role in the design and development process**
- **All AOCS modes except Safe will be auto-coded**
- **The AOCS modes will have software I/F only with AASW-MAN (manually coded AOCS software). Logic interfaces are with**
  - Sensors and actuators through the AASW-MAN
  - Directly with AASW-MAN itself
- **The transferred information**



AOCS Interfaces (II)

- **Strong data typing approach is employed in the definition of the AOCS modes models**
- **Input/Output AOCS-AUTO data are organized into Simulink Buses, analogous to C data structures**
  - The Bus Objects are autocoded into C-code type definitions, which constitute part of the actual flight software
- **The AOCS interfaces are defined in terms of such data buses and their elements, with their data types and dimensions**
- **The interfaces must be iterated and documented, and will be needed by the AOCS-MAN SW and by the ESE to embed the AOCS-AUTO code**
- **EDS contains a utility that allows generating the interfaces minimizing the iteration effort**
  - Interface signals, data types and sizes are defined in a specific Simulink model
  - Resulting Bus Objects for all modes are automatically generated (single command)
  - The Bus definition libraries revert in the Simulator interface blocks, ensuring consistency with what expected by GNC

AOCS Software Development (I)

- **The AOCS is being developed according to the Model-Based Design (MBD) philosophy**
  - The model is an executable specification that is continually refined throughout the development process
- **MATLAB/Simulink allow to**
  - Link models with requirements
  - Generate C code with comments and tags that trace with the model and the requirements
- **AOCS algorithms:**
  - Part of the model to be included in the AOCS Application Software
  - Are being evolved in the EDS
  - Will eventually be developed as auto-generated code on the embedded processor
  - Will be verified in SIL, SVF and HIL facilities

AOCS Software Development (II)

- **Model-Based design development and validation plan follows the evolutionary model**
  - Iterative approach where progressive versions of the model/software are planned
  - For each version a model validation is foreseen
- **The AOCS model will evolve based on simulation loops performed in the EDS environment**
  - Simulations on the EDS will be the start point to develop the formal validation tests
- **Each AOCS mode is created as a referenced model**
  - Root class representing the overall mode
  - Decomposition in smaller elements according to functionalities (submodes, functions) and assignment to specific C code functions during autocoding
  - Simulink architecture defined and analysed taking into account Simulink to C mapping

The way to see the future

Thank you