AstroBus NEO - A Flexible Satellite Platform Product for Earth Observation Missions

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ABSTRACT

Modern satellite missions require a flexible platform covering a wide range of missions from small to large satellites, optical to radar instruments with precise pointing performance or agility needs, for institutional and commercial customers. In the context of Europe's Copernicus missions, a common platform has been established based on the AstroBus standard developed by Airbus Defence and Space. The newest evolution, called the AstroBus NEO platform, complies with latest operational standards and state-of-the art AOCS architectures and algorithms, which makes use of modular building blocks and well established processes for avionics development. This paper presents the AstroBus product and mission perimeter with focus on the AstroBus NEO avionics platform, its capabilities, applications, and future evolution.

1 Introduction

In this paper we start with an overview of the Airbus Defence & Space products for Earth observation and then zoom in on the AstroBus Avionics platform and its most recent evolution, AstroBus NEO, its principles and the AOCS development framework. Two recent applications of AstroBus NEO, ESA's CRISTAL and LSTM missions, are presented as an example of the product's versatility. Finally we explore the ongoing extension to control moment gyro based agile missions.

2 Airbus Defence & Space Products for Earth Observation

Airbus Defence and Space has established a family of products for earth observation comprising platform, instrument and satellite products.

2.1 S950 and S250 Satellite Products

The satellite product S950 is based on the AstroBus NG avionics platform and the Naomi-X instrument and provides a high agility Control Momentum Gyroscope (CMG) actuated optical satellite for very high resolution in the 1000 kg range. S950 is used for Airbus' own Pleiades NEO four satellite constellation.
The satellite product S250 is a smaller, cost efficient, software defined satellite, for optical and radar missions based on the AstroBus SE platform and the Naomi-C or AstroSAR instrument targeting constellations and new space applications.

2.2 AstroBus Avionics Platform Products

AstroBus is Airbus' Low Earth Orbit avionics product. It comprises a suite of flight hardware, software, documentation, test benches and tools, implemented and managed as an avionics product. It is maintained to adopt improvements and issues from individual projects, shared and addressed for

the benefit of current and future projects. Projects based on an avionics product benefit from proven elements already developed, validated and flown together. This limits non-recurring development costs, and offers attractive recurring costs enabled by savings in verification activities, software development and validation, procedures, and testing platforms.
Within the AstroBus family of products Airbus Defence and Space established three product lines to serve institutional, national and commercial Earth Observation applications ensuring flexibility, cost efficiency and sustainability.

AstroBus SE Platform Product
AstroBus SE has been set up to address the Earth Observation market with the a very cost attractive solution based on "New Space design", either with an optical payload, or a SAR Antenna payload. To achieve this it uses a defined platform with a fixed set of equipment.

AstroBus NG Avionics Product
AstroBus NG offers a very cost efficient delivery of an end-to-end avionics product. In combination with the OSCAR MK III On Board Computer (OBC) and the PUS-A Packet Utilisation Standard it delivers processes, methods, and tools based on a strong product re-use with certain variations out of the box.

AstroBus NEO Avionics Product
AstroBus NEO offers efficiency by delivering a modular and adaptable product relying on a product catalogue of hardware and verified software building blocks embedded in an efficient Eco System of tools and processes. The focus is on communality and re-use of architecture, tools and methods with a flexible configuration according to mission and programmatic needs.

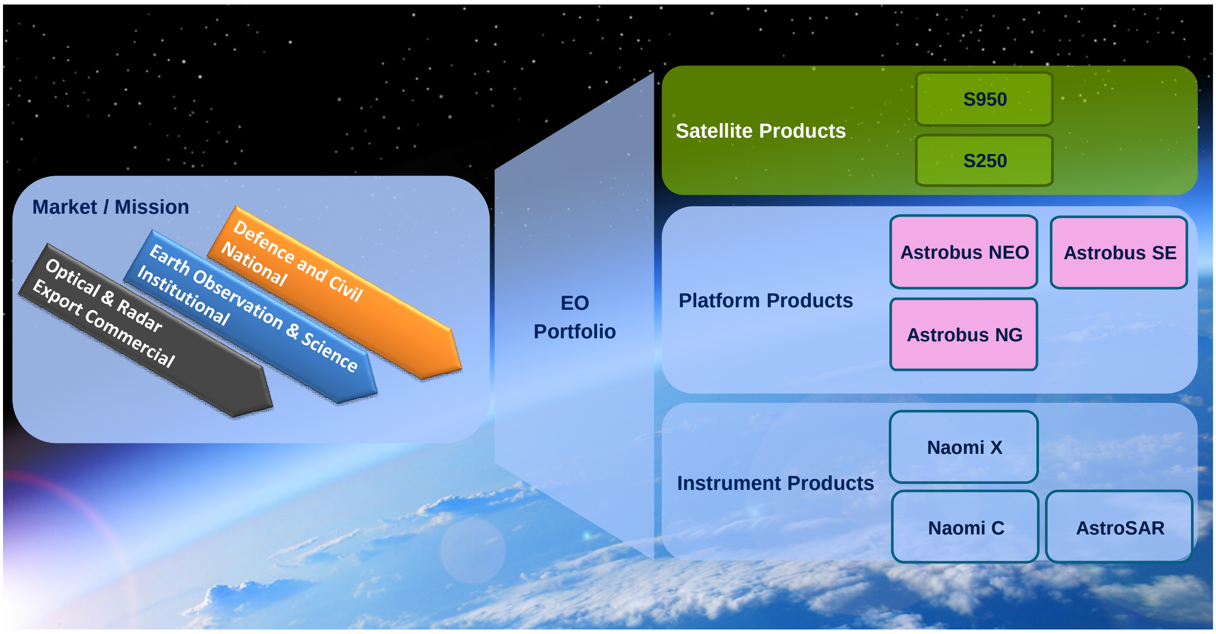

Figure 1. Airbus product family for Earth Observation (EO)

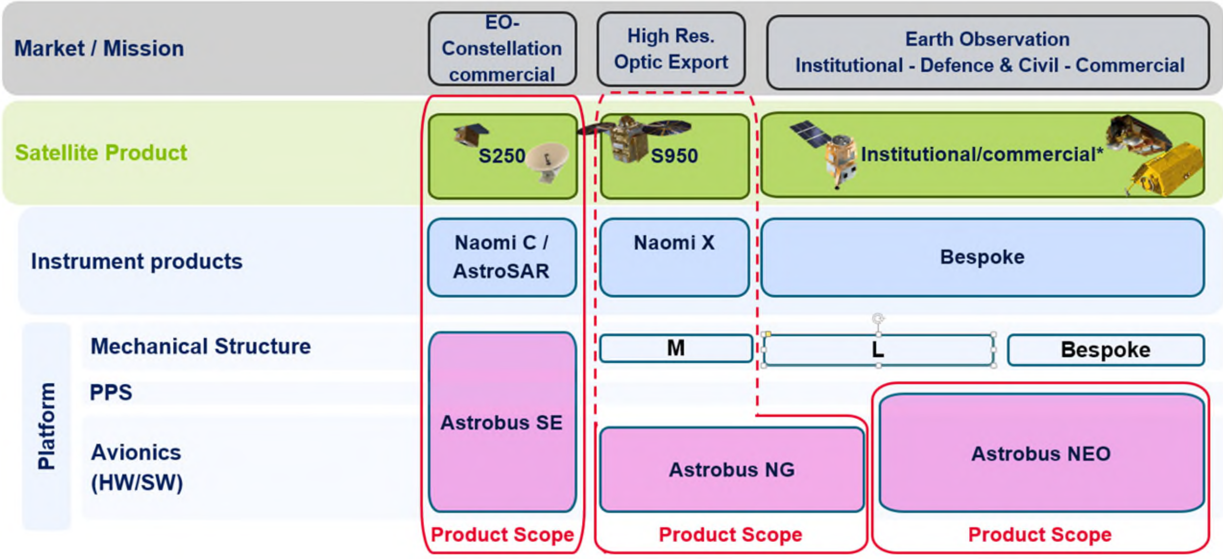

Figure 2. AstroBus avionics products and their application

3 The AstroBus NEO Avionics Product

AstroBus has been used on many Airbus export missions and several ESA missions since around 2007. The most recent evolution of AstroBus, AstroBus NEO, has been established and implemented with Copernicus missions LSTM and CRISTAL, based on a standard platform study with ESA, taking into account most recent evolutions from ECSS standards and operational interface requirements. This is meant to answer directly to the new class of institutional missions, and serve as the benchmark for many ESA missions to come. This includes the new PUS-C standard, file based operations, and compatibility to the new checkout system EGS-CC.

New equipment is frequently added to the portfolio, integrated and qualified at avionics product level, with the aim to increase the flexibility to the demands of different missions, technically or industrially, for example double sourcing of equipment units and involvement of Small and Medium Enterprises (SME).

3.1 What is the AstroBus NEO Avionics Product?

The AstroBus NEO avionics product is a Building Block based product platform enabled by a converged Eco System comprising processes, hardware and software components, standards and tools to build an extended avionics system comprising

- Platform Data Handling System: On Board Computer, Remote Interface Unit, Deciphering and Ciphering Unit, S-Band Transmission System
- Electrical Power System: Power Control and Distribution Unit, Battery, Solar Array Drive
- Attitude and Orbit Control System (AOCS) sensors and actuators
- Payload Data Handling System: Mass Memory and Formatting Unit, X-Band and K-Band Transmission System
- Central Software
- AOCS algorithms, simulation models and analysis
- Functional Verification test benches and test specifications, procedures and reports
- Satellite Database
- Operational Procedures, Telemetry Packets definitions, Failure Detection Isolation and Reconfiguration, user manuals

Its main features are:

- Catalogue based approach with majority of equipment with dual source
- Modular avionics architecture (Building Blocks) with a strong common core and selectable options to tailor mission needs
- Allowing efficient adaptations and appendages to tailor the performance of the mission
- Re-use of existing configurations of the same mission type
- Continuous improvement and evolution through feedback of lessons learnt and extensions for new mission needs

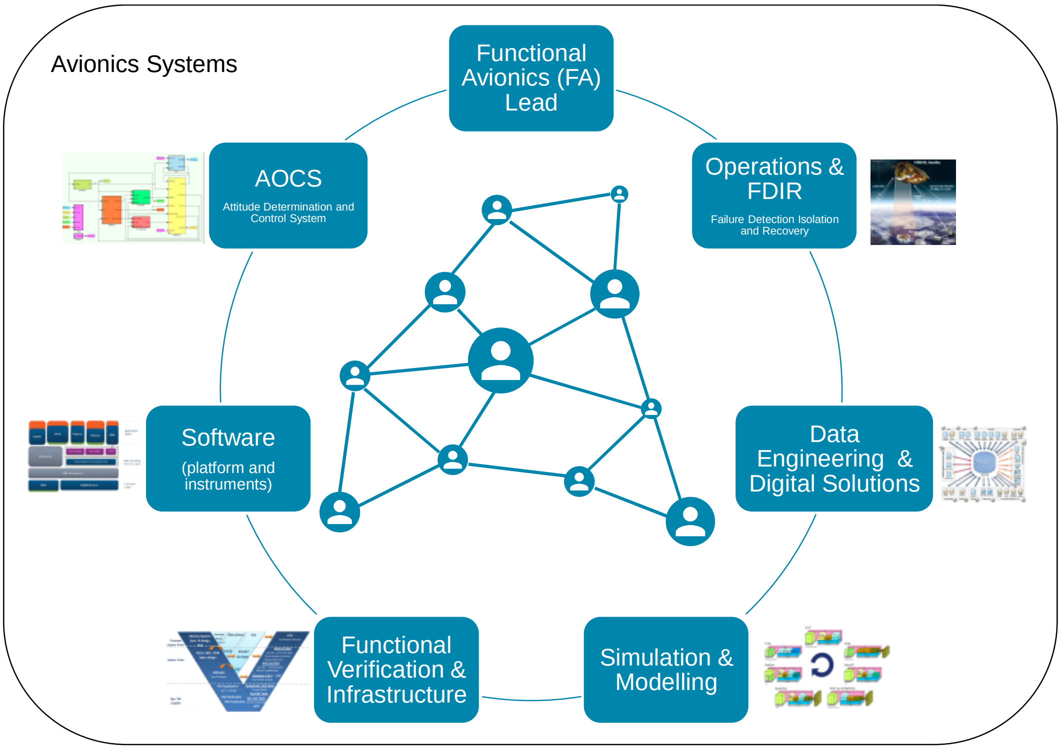

Figure 3. AstroBus NEO Functional Avionics (FA) system

The modular approach using pre-verified Building Blocks from the product catalogue allows an efficient re-use of elements on different assembly levels with low non-recurring cost and is open for extension with new elements including new space low cost options.

Important future extensions comprise the new OBC Ultra, which opens the door for a centralized GNSS Receiver and Star Tracker, and the extension to CMG based highly agile optical and radar missions.

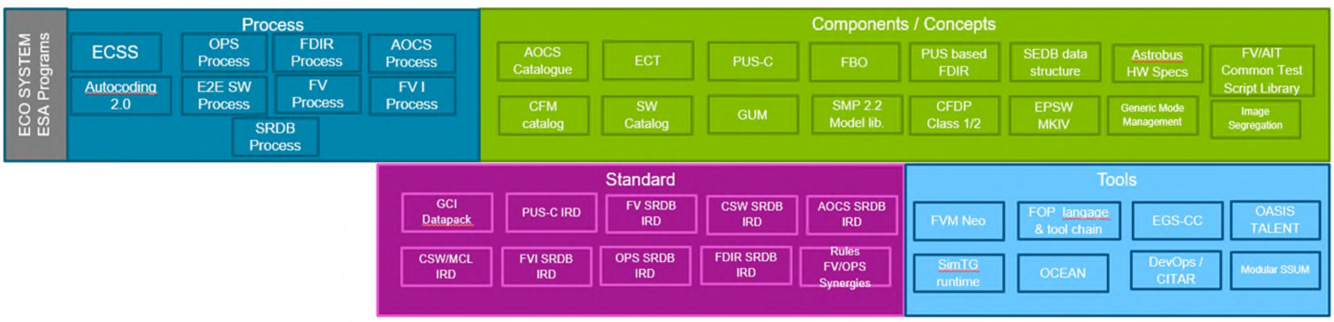

Figure 4. AstroBus NEO avionics product eco system

3.2 The AstroBus NEO AOCS Catalogue

The AstroBus NEO AOCS catalogue is structured around Generic Configuration Items (GCI) for all AOCS functions, e.g. sensor processing, actuator commanding, state determination and attitude controllers. A GCI comprises all elements necessary for the whole Functional Avionics perimeter.

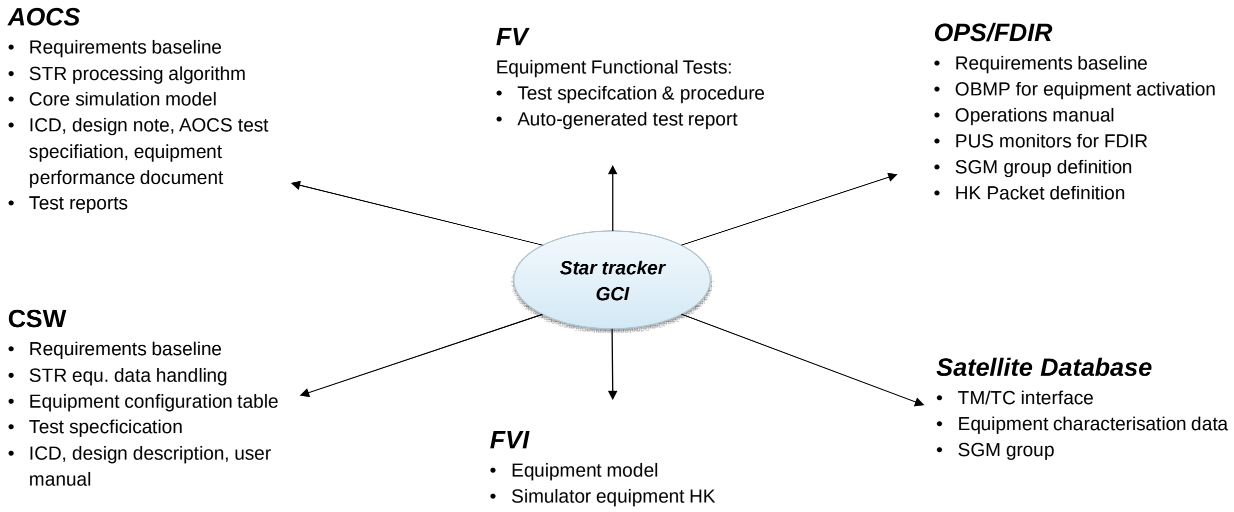

Figure 5. Elements of a Generic Configuration Item, star tracker example

The AOCS functions are arranged in a generic mode diagram offering different safe mode (ASM) normal mode (NOM) and orbit control mode (OCM) options depending on the mission, e.g. earth-pointing (EP) or sun-pointing (SP) safe mode.

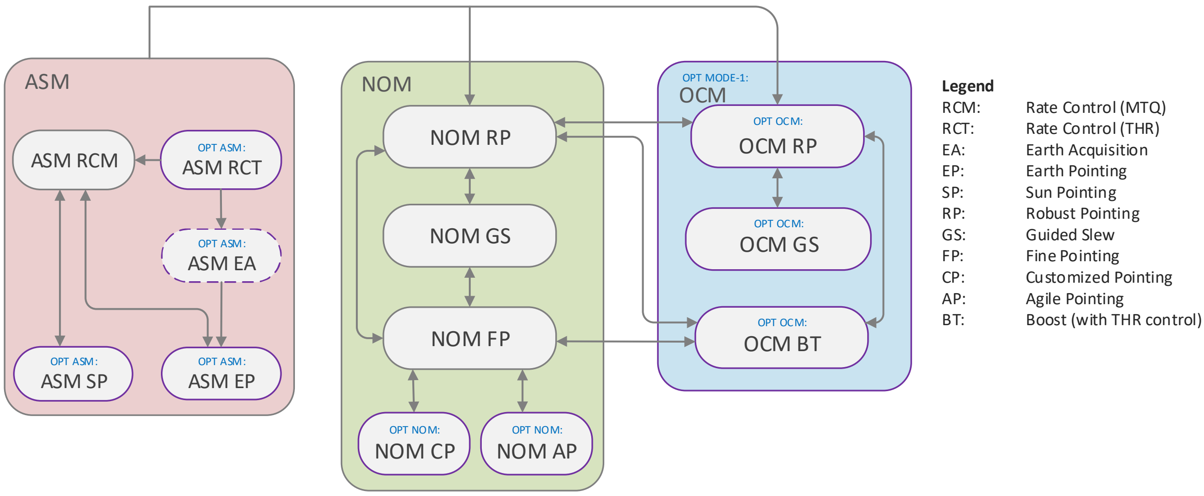

Figure 6. AstroBus NEO generic AOCS mode diagram

For sensors and actuators solutions from multiple suppliers are available, e.g. ZARM, SODERN, JOP, Beyond Gravity and others.

4 AstroBus NEO AOCS Development Framework

4.1 The FAME Development Environment

The key elements of the AstroBus product are its modularity and its sophisticated tool chain, the Functional AOCS Multi-purpose Environment (FAME) implemented in Matlab/Simulink. FAME allows to develop the AOCS design verification environment across the different project phases and supports specification, design, and operation activities related to AOCS. It is characterised by its genericity and modularity of major parts of the library. It uses and provides seamless integration of in-house libraries and respects Airbus standards (AOCS Naming Conventions, Coding Standards, AOCS Generic Architecture, Modelling Standards).

In frame of the AstroBus product context the FAME is used for:

- *Development* of AOCS control algorithms. It is easily and fast adaptable for the specific project objectives, which allows a smooth transition from early phases to detailed design. “Model-based development” is applied, which is a development that uses models to describe the functional behaviour of the elements which are to be developed. It is noted that, depending on the level or abstraction used for such a model, it can be used for simulation or code generation or both.
- *Analysis and Verification* of AOCS performance and AOCS functional behaviour, parameter variations (systematically or Monte Carlo) and contribution to system performance.
- *Auto-coding* of the AOCS flight code based on the Matlab/Simulink model, including re-injection of the flight code back in the FAME, automatic checks on AOCS models, generation of database inputs like on-board parameters, observables, TCs and Events definition and generation of software and quality related documents.
- Additionally it is also possible to simulate interactions of the AOCS with power and thermal behaviour and to design and verify the AOCS FDIR.

The following diagram demonstrates the flow of auto-generated items to test benches and the satellite (flight code):

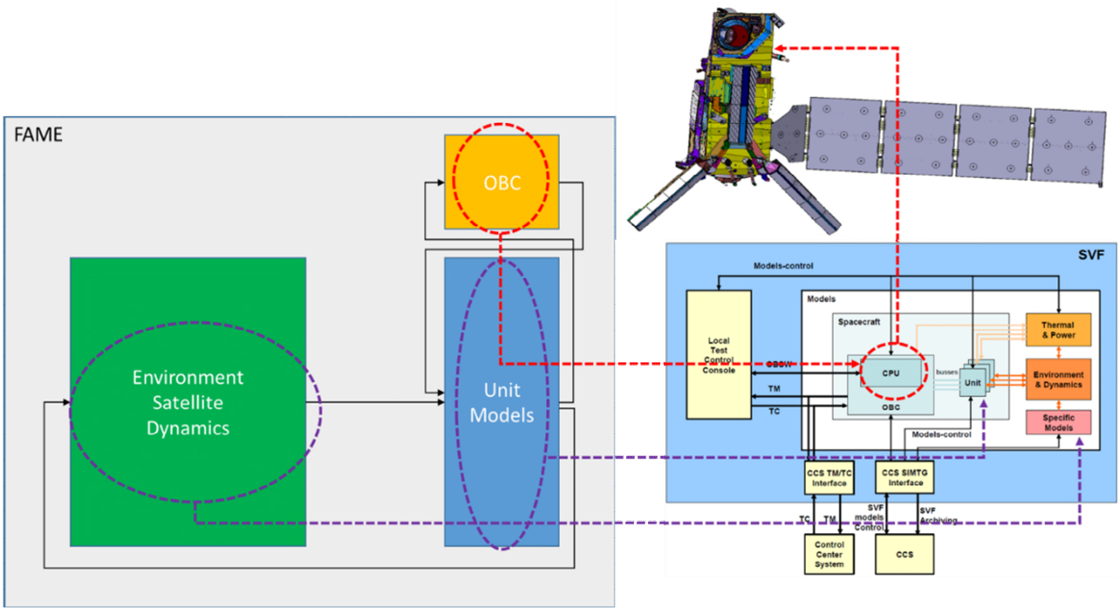

Figure 7. Flow of auto-generated items from FAME to satellite (flight code) and test benches (equipment and environment/dynamics models).

The AstroBus product itself provides a clear AOCS Library Management with Generic Configured Items (GCI) and Specific Configured Items (SCI). SCIs are project specific and systematically collected. Each GCI includes generic

- Detailed design description
- TM/TC and S/W ICD
- Functional requirements
- Test specification and functional testing

Each GCI is split in hierarchical levels (see figure below):

- *Functions*: options level representing AOCS Functions
- *Modules*: architectural level
- *Components*: detailed algorithmic parts
- *Support Function*: classical support functions, mainly mathematics

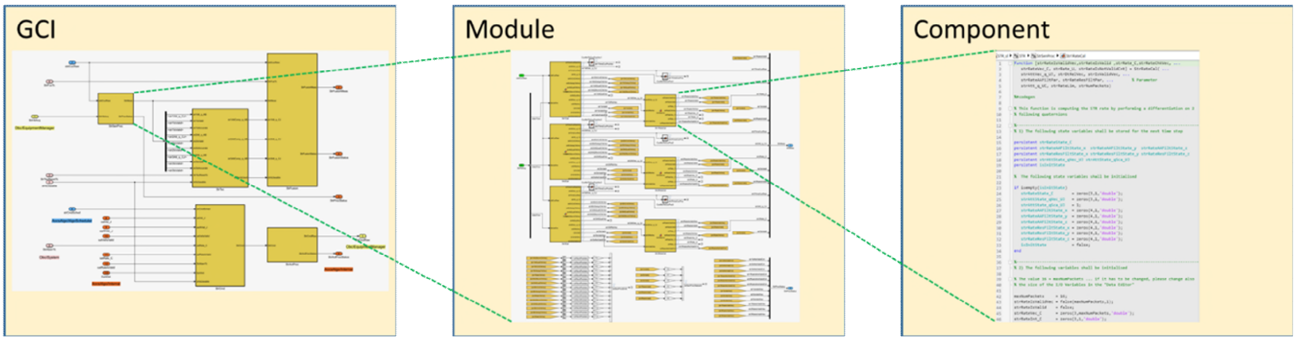

Figure 8. Example of GCI split in Modules and Components

Every level contributes not only with a piece algorithm, but also with associated documentation. Whenever an item of *any* level is reused, the piece of algorithm and its documentation are still valid and don't need adaptation. The same is valid whenever an item is replaced, only the piece of documentation attached to it needs to be adapted. All other parts don't need to be touched.

The AstroBus product is under configuration control with versioning and patch management. Each project is based on a dedicated version of the product. In case of bugs, solved issues (= patches) are systematically collected and are under configuration control. Relevant projects are informed about the patch and individual measures are taken. Finally, individual patches are integrated into the product for next official release. This means that all projects contribute to the continuous improvement of the product through the lessons learnt feedback loops.

Depending on the mission dependant needs, equipment and GCIs, which contain the AOCS related functionalities can be selected from the product catalogue. Based on the selection, a project specific instantiation of the AOCS algorithm, the initial parameterization and the associated simulation environment is automatically assembled and can be used for AOCS analyses, auto-coding and further deliveries.

Note that modularity is not only "Product Design" - it's a key element that makes the product efficient

- When new „options" are implemented
- Project specific adaptations are required
- With any kind of product evolution and product maintenance

4.2 Auto-Coding and Delivery Process

Based on the instantiation of the project specific items within the FAME, the C-code of the AOCS algorithm is automatically generated from the Matlab/Simulink implementation using the Autocode Toolbox and the MATLAB Embedded Coder. The generated C-code is an exact representation of the AOCS algorithm and is directly integrated in the Central Software (CSW) without any modification. Once integrated in the CSW, the AOCS algorithm is tested on Functional Verification test benches, while the verification on FAME level is done by re-injection of the generated C-code into the Simulink test environment. The flexibility of the FAME allows running of all tests either with Software or Model in the Loop (SIL or MIL).

In addition to the C-code software related documents like Interface Control Documents (ICD), Configured Item Data List (CIDL), on-board default parameters, observables, TCs and Events definitions and Data Base interface files are automatically generated. The tooling also retrieves the status of the ticket system to give an up-to-date and transparent status of the maturity of each delivery reported in the CIDL.

Items needed by Functional Verification, e.g. generic Core Functional Models (CF) and their parameter files used by the Real-Time Simulator, and software and operations related documents, are also included in the Auto-Coding process (see figure below).

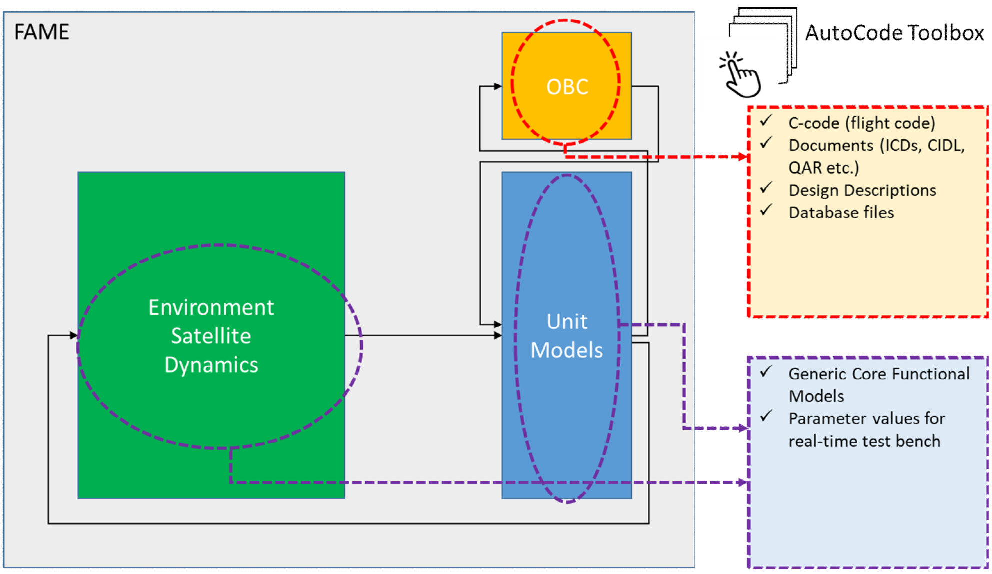

Figure 9. Generation of items for the OBC (e.g. flight code, database files) and the Real-Time test bench (e.g. models and related parameterization)

Quality is ensured by applying automatic check routines already during early implementation phase to verify the modelling rules. Results of the checks, software metrics (e.g. model and code coverage) and the maturity status of the algorithms can be automatically documented and reported to the quality assurance engineer. The FAME also includes a tool chain to generate test documentation for functional and performance verification. Due to the high level of automation, the effort to perform deliveries to other disciplines is very limited, which makes the process perfectly suitable for agile development. Furthermore, the environment and the process allows a high level of flexibility to react on special project specific needs. Improvements made in projects flow back to the product such that other project can profit. The process also allows incremental deliveries. Another advantage of the high level of automation is a stable quality and reliability of all deliverable items.

5 AstroBus NEO for Copernicus

AstroBus NEO is the backbone for the common platform development in the frame of ESA's and European Commission's Copernicus missions CRISTAL and LSTM.
Planned to be launched in 2027, the Copernicus Polar Ice and Snow Topography Altimeter Mission (CRISTAL) will carry a dual-frequency radar altimeter and a microwave radiometer that will measure sea-ice thickness, overlying snow depth and ice-sheet elevations, but also support applications related to coastal and inland waters, as well as ocean topography. These data will contribute to a better understanding of climate processes and support maritime operations in the polar oceans.
The Copernicus Land Surface Temperature Monitoring Mission (LSTM) will carry a high spatial-temporal resolution thermal infrared sensor and will measure the temperature of the land-surface. It will help improving sustainable agricultural productivity at field-scale in times of increasing water scarcity and variability as well as to understand and respond to climate variability, to manage water resources for agricultural production and to predict droughts.

Figure 10. Current AstroBus NEO applications include CRISTAL (left) and LSTM (right).

The satellites of CRISTAL and LSTM show distinctive differences in terms of shape, mass, orbit as well as equipment configuration (see Figure 11) and they are driven by completely different instrument types with associated performance needs. Nonetheless, like most satellites they also have a large overlap in functional requirements which allows to respond in the design with a common AOCS core architecture and underlying functions in order to be operated with the same look and feel from Ground.
The scope of the commonality spans over all AOCS modes and operational phases of the missions, i.e. from initial acquisition, nominal operation (normal mode for instrument operation, orbit control mode for orbit maintenance) up to the post-mission disposal phase. The same applies to the functional chains of the common AOCS equipment, which provide the same TM/TC interface, the same FDIR observables and associated monitors as well as the same strategy for functional verification.
The common core is enhanced by specific building blocks from the AstroBus NEO catalogue, e.g. to satisfy dedicated attitude performance needs by enhanced filtering algorithms or a guidance function for the accurate live pointing of the downlink antenna towards the ground stations.
New mission specific functions that have been implemented for CRISTAL or LSTM have been integrated back into the AstroBus NEO product catalogue using the integration process for Generic Configuration Items. This integration comprises the various elements belonging to a new function, such as its functional requirements, its implementation, the technical documentation and interface specification as well as the verification strategy with a set of tests.

One example for the product’s modularity on the one hand and the integration process on the other hand are the AOCS Safe Modes of the two missions: although the steady state pointing of the individual modes is fundamentally different – Earth Pointing vs. Sun Pointing - there is a significant overlap in the functionality used. Both modes are based on strong flight heritage from previous AIRBUS missions and have been introduced as GCIs with common elements into AstroBus NEO in the frame of CRISTAL and LSTM. The commonalities comprise e.g. a common sub-mode for Safe Mode entry (called RCT when using thrusters; RCM when using magnetorquers) and conceptually generic functions for the monitoring of the convergence progress and sub-mode success criteria. Based on such generic type of information the generic AOCS mode manager can be easily parameterized for the specific mode concept used in the individual missions.
The AOCS mode diagrams for CRISTAL and LSTM are shown in Figure 7 below. Both are tailored from the generic AstroBus NEO mode diagram presented in Figure 6. It can be seen that the tailoring does not only include the selection of the desired main and sub-modes, but also the corresponding manual, autonomous and FDIR related mode transitions.

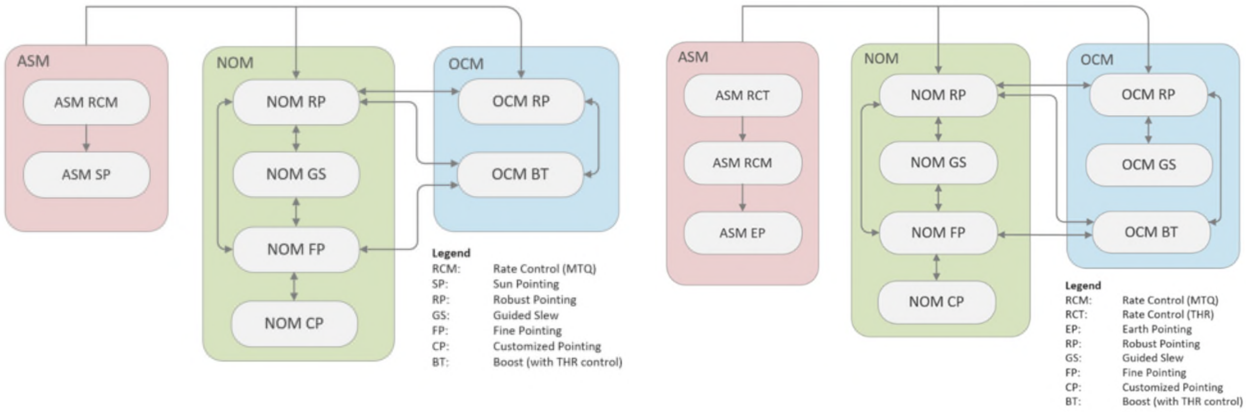

Figure 11. AstroBus NEO AOCS mode diagram tailored for LSTM (left) and CRISTAL (right).

The described examples for the two Copernicus missions give an idea of the flexibility of AstroBus NEO as Satellite Platform Product when used for different types of satellite missions. Its modularity allows to cover very different mission needs in an effective way while minimizing the non-recurring cost when re-using elements (GCIs) developed in the frame of previous missions. New missions supported by the product continuously enrich its catalogue of available variants and options and by that decrease the cost for subsequent missions.

6 AstroBus NEO for Agile Projects

Today, an increasing number of missions require target-based observations with high resolution sensors, small fields of views and relatively short data-take durations. Such mission profiles require on the one hand frequent and often large-angle attitude changes between and during data-takes and on the other hand a precise pointing of the spacecraft. The steering of the instruments (e.g. radar or optical) on specific attitude trajectories during data-takes and the fast slews in-between impose additional demands on the product to support different types of agile mission.
The modularity of the AstroBus Neo product enables the native extension of the existing AOCS mode architecture (see Figure 6) to agile missions with the introduction of the agile-pointing sub-mode (NOM-AP) for normal mode. This approach allows to maintain the existing capabilities of the product catalogue for non-agile operation (like functions e.g. for station keeping, safe-mode options) and limit the new developments to a clearly defined scope.
The NOM-AP sub-mode is capable of realizing agile attitude trajectories by commanding different kind of actuators, such as high-torque reaction wheels (RWs) or Control Momentum Gyroscopes (CMGs). Similar to other actuators, also high-performance actuators such as CMGs are added as GCIs to the product catalogue and can be used as replacement e.g. for the reaction wheel GCI. The main purpose of NOM-AP is the execution of efficiently ground-planned trajectories that are allowed to exploit both, the angular momentum as well as the torque envelope of the actuator array without entering undesired regimes, such as CMG array singularities. This approach complements the regular (non-agile) operations, which always stay in inherently safe regimes of the respective actuator arrays.

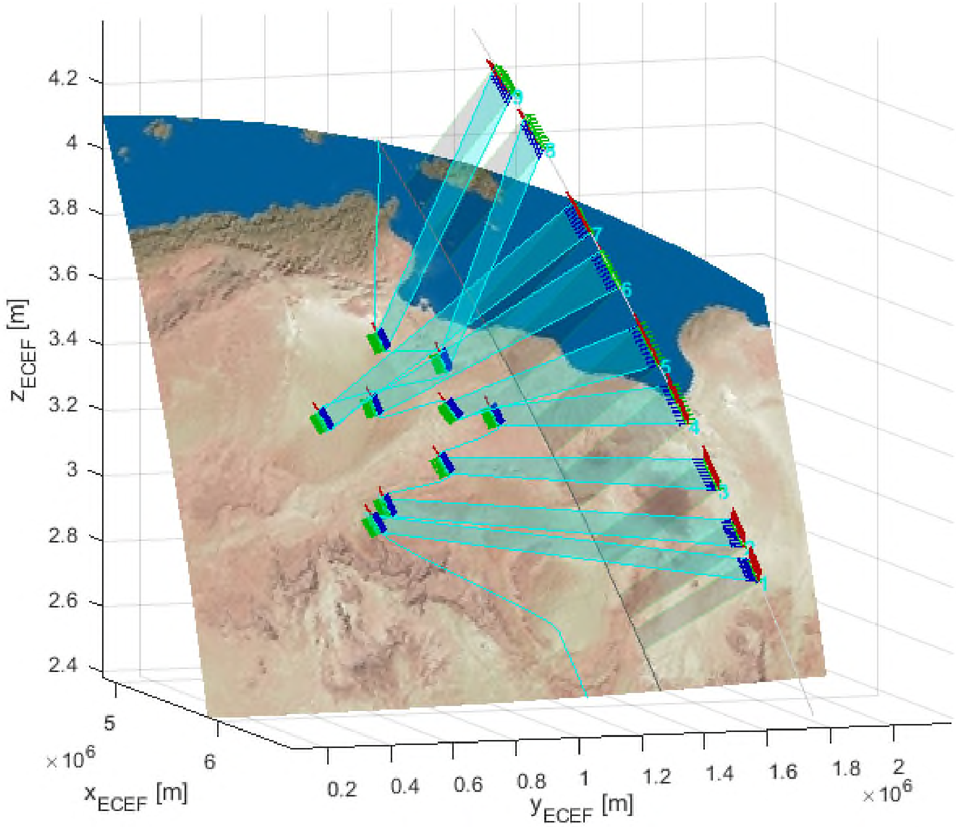

Figure 12. Exemplary agile observation scenario for future AstroBus Neo satellite.

As AstroBus NEO is designed to be usable for different types of future agile missions, the algorithmic design supports a generic type of agile attitude trajectory and is neither tailored nor limited to specific mission or instrument needs. This is possible as the guidance trajectories are generated by a separate

mission specific tool chain embedded in the mission planning system of the ground segment. Here the mission and instrument specific steering demands (during and in-between data-takes) are solved, the feasibility of the attitude trajectory execution in orbit is ensured, and the commands for the phase of agile motion are computed and compressed for upload to the space-segment.
In orbit, the execution of the attitude trajectories is not only time-based, but supported by a position dependent trigger based on the pre-planned orbit position. This approach inherently cancels out emerging along-track differences between expected orbit position during planning and true spacecraft position at the planned starting time of the data-take. The attitude determination in NOM-AP is optionally provided with information about the planned agile trajectories to not disturb the attitude knowledge during high fidelity data-takes.

7 Conclusion

AstroBus NEO is the backbone of the Airbus Defence & Space LEO product portfolio, implemented today in institutional missions and ready for extension for highly agile applications targeting institutional, commercial and defence markets.
With low non-recurring cost and high modularity AstroBus NEO can be adapted to specific mission needs and is open for further extensions.