CD03 presentation of TDE-GSTP outcomes*

*Proposition subject to change**

CD03 Avionics teams

ESA ESTEC

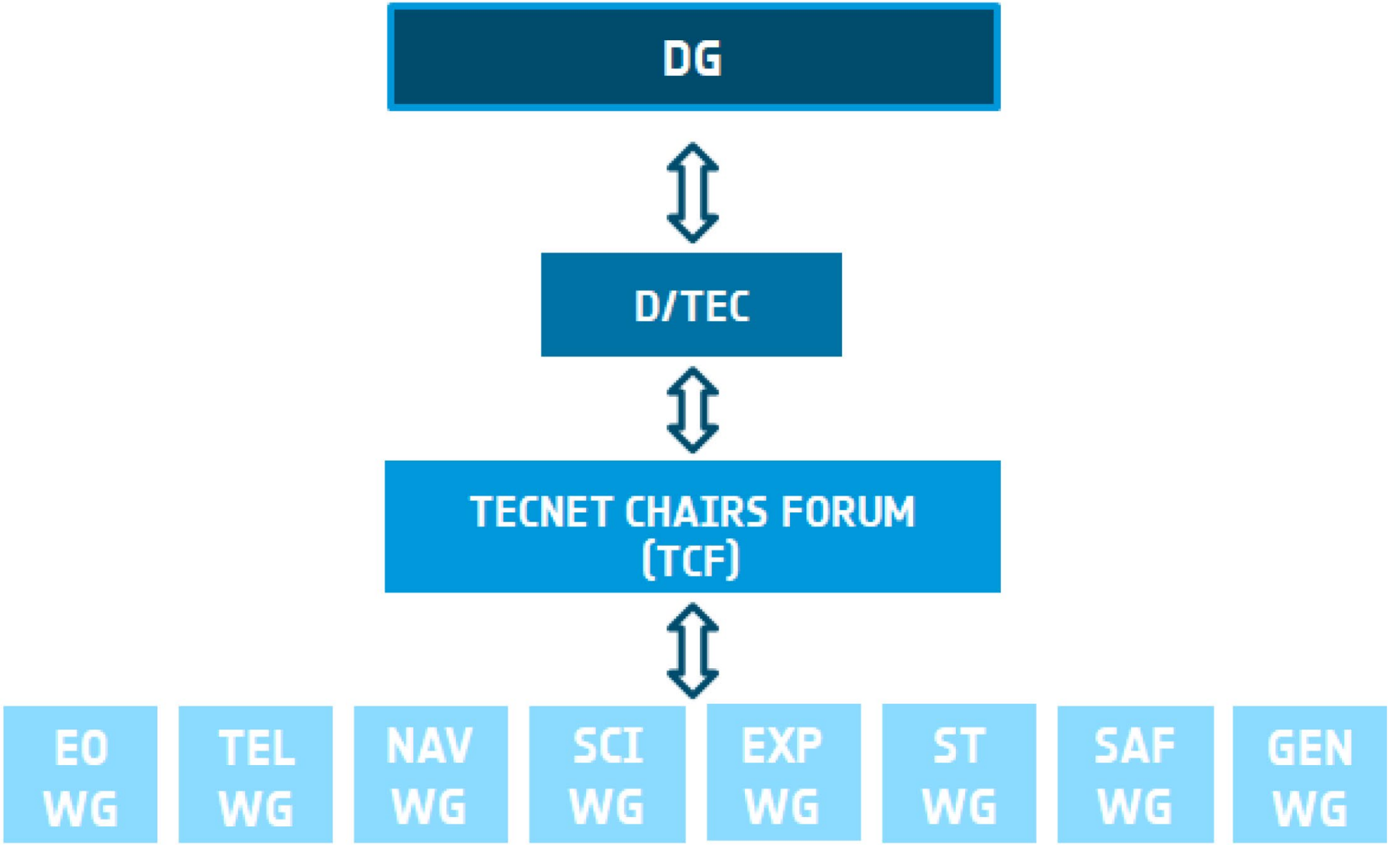
25/10/2022

Technical Domains of the CD3

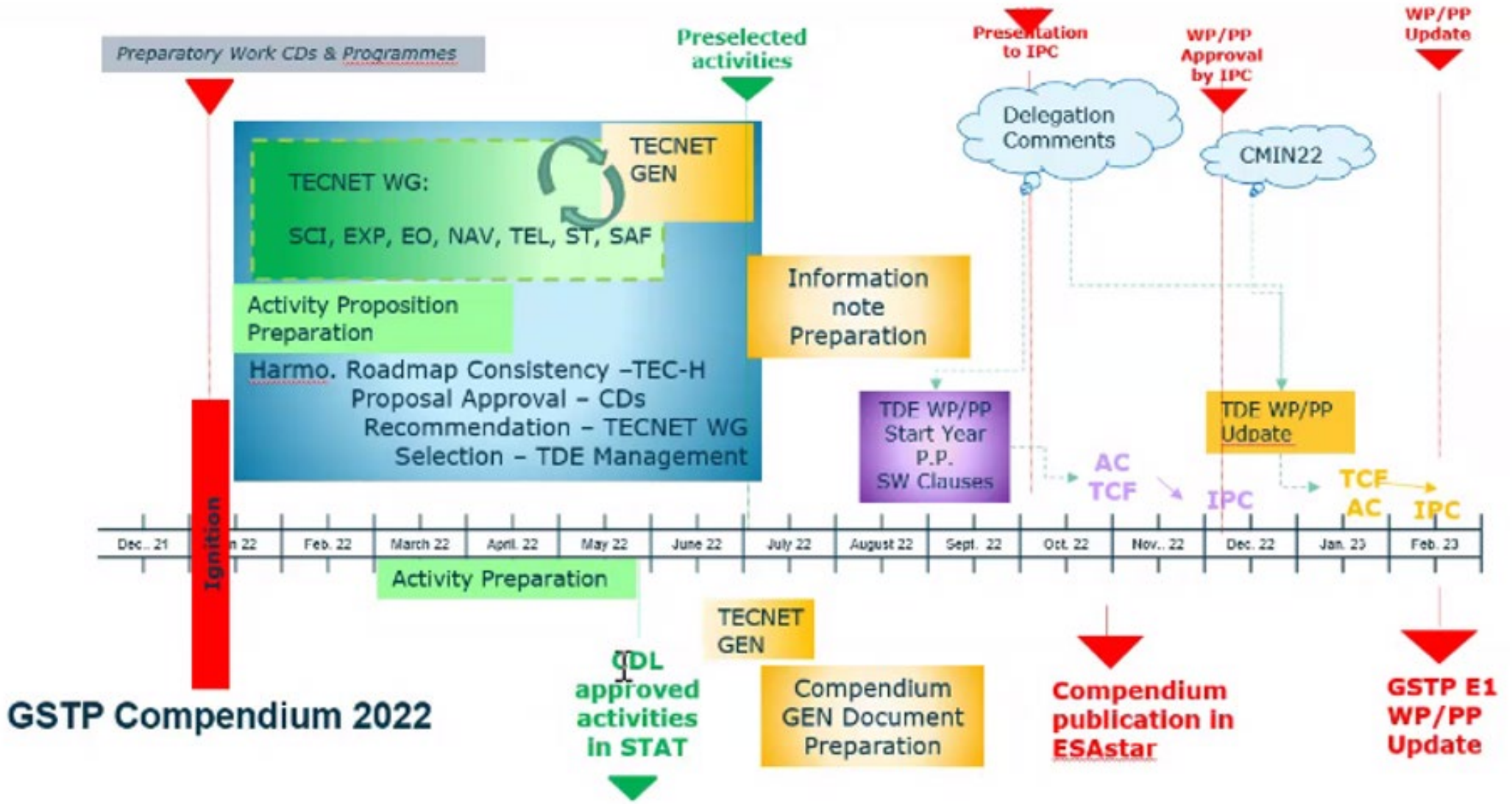
On Board Computer, Data Handling Systems and Microelectronics

Relevant ESA Competence Domain(s) (CD)	Roadmaps	Previous Roadmap(s)	Active Roadmaps	Next Roadmaps Update	Page Number
3 2 1 5	AOCS Sensors and Actuators	2001 2005.1 2009.1 2013.1 (AOCS I) 2015.2 (AOCS II)	2020.1		page 114
3	Avionics Embedded Systems	2006.2 2010.1	2016.1	2021.1	page 123
3	Data Systems and On-Board Computers	2003.1 2006.2 2011.2	2016.1	2021.1	page 128
3 1	Microelectronics: ASIC & FPGA	2002.2 2007.1 2011.2	2016.1	2021.1	page 133
3	On-Board Payload Data Processing	2003.1 2006.2 2011.2	2016.1	2021.1	page 140
3 5	On-Board Radio Navigation Receivers	2002.1 2007.2 2013.2	2019.2		page 145
3 9	On-Board Software	2003.1 2006.2 2010.1 2014.2	2020.1		page 150
3 5	RF & Optical Metrology	2008.1	2018.1		page 157
3 5 8	TT&C Transponders and Payload Data Transmitters	2003.1 2007.2	2012.2	2020.2	page 161
5 1 3 8	Optical Communication for Space	2004.1 2008.2 2012.2	2017.2		page 215
8 5 3	Ground Station Technology		2015.1 (MP) 2015.2 (RM)	2021.2	page 278
9 3 8	Big Data from Space	2017.1	2019.2		page 286

TECNET organisation



TDE 2023-2024 + GSTP Compendium timeline



Disclaimer

- This presentation presents the result of the pre-selection by TECNET and GSTP of activities proposed by CD03.

- The list of activities has to be approved by IPC and is subject to modifications:
  - An activity can be
    - removed (e.g. in case of duplication, not found adequate for the programme, etc.
    - An activity can be updated (e.g. clarification of its description).
    - An activity can be replaced by a backup activity (not provided in the list presented)
  - The procurement policy can be changed (usually from C to C(1) or C(2))
  - The reference in each individual description is an internal reference that will be update for presentation at IPC
  - …

CD03 rationale for activity selection

- The selection for the TDE 2023-2024 generic theme is based on these underlying objectives:
  - Provide and enhance End-to-End On-Board data processing solutions (Algorithms, HW, SW and IP Cores) and their engineering tools for supporting avionics and payload applications. This includes the On-board Data Management and disruptive data analysis technologies (AI/ML).
  - Promote the simplification, reuse, spin-in of development, operations and development tools in order to favour product lines, improve consistency, ensure independent evolution of sub-systems, and reduce system level testing. This includes MBSE and digitalization.
  - Develop new TT&C systems for all applications in order to increase the uplink and downlink data capacity and improve communications availability, efficiency and performances.
  - Improve, define and develop on-board solutions like autonomy, FDIR and security to enable future missions.
  - Factor disruptive innovation in the AOCS/GNC systems to prepare future missions and products.

- Activities are supposed to be selected from an Harmonisation Dossier.

CD03 - TDE plan 2023-2024 – TECNET-GEN

Reference	Title	Budget (k€)
T701-801QQ	AI-based Failure Prediction to Improve Operational Payload Availability	350
T701-802ED	Evaluation of neuromorphic computing technologies for very low power AI/ML applications	350
T701-804ED	Next-generation protocol for optical high-speed links	350
T701-805EF	IP Cores for High-Speed ADC & DAC Interface	400
T701-806ED	Model-Based Systems Engineering (MBSE) applied to Advanced Data Handling Architecture (ADHA) products	300
T702-801SW	LLVM for space applications	350
T702-802SW	Software validation using Artificial Intelligence techniques to automatically generate tests	400
T702-803SW	Verification and Validation Methods for Machine Learning Algorithms	400
T705-801SA	Multi-objective optimisation of thruster layout under constraint	350
T705-802SA	Advanced Control Techniques for increased on board autonomy	350
T705-803SA	End to end digitalisation of GNC/AOCS development	400
T705-805SA	Real Time System Identification for Complex System Modelling and Autonomy Operations	300
T706-803ES	TT&C Time Transfer in Deep Space	400
T709-805SW	Automating the transition from System to Model Based Software Engineering	400
Total		5,100

AI-based Failure Prediction to Improve Operational Payload Availability

Title: AI-based Failure Prediction to Improve Operational Payload Availability				**Budget (K€):**	350
				Duration (m):	18
Reference: 6063		**Harmonisation:** Avionics Embedded Systems B06	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 1 **Target:** 3	**Need/Push:** TRL 3, by 2025, increase availability of Sats		**Procurement:**	C

Objective(s):

To investigate and develop methodologies using AI, for prediction of core units and payloads failures before their occurrence and assess how this information can contribute to system unavailability.

Description:

Failure detection plays an important role in monitoring the integrity of electrical components but also units, payloads and overall system. Failure detection is performed as part the Fault Detection Isolation and Recovery (FDIR) system, however, at the moment, little is done in terms of failure prediction and assessment of changes in units behaviour. Most of the work performed in this scope targeting on ground data analysis and not on-board real-time assessment. Artificial Intelligence (AI) has the potential to contribute to a better failure prediction process by looking and analysing information coming from components/units/subsystems and assessing if their performance is decreasing with time. Failure and anomaly prediction capabilities based on data trend prognostics could lead towards an increase in the overall availability of the system through either applying recovery actions before occurrence of failure, or allowing to perform a smoother and faster switch to the redundant branch which would result in less or no interruption of payload or system operation. Finally, such approach could have the potential to better understand the degradation effects of units and system and may lead to a better overall mission operational availability.
The goal of the activity is to research mission payloads and understand how, through the use of AI, the outage can be minimised more than through the use of common and current approaches.

Tasks:
1) Identification and gathering of potential data of payloads that could be used for AI development (e.g. Sentinel, MSG, Telecom, Constellations, etc.) and for overall Neural Network training.
2) Identify the best types of machine learning algorithms that allow to evaluate behaviours based on training data. Analyse the statistical techniques, data distribution and probability theory. Provide methods to train and cross-validate and select as approach one of the two broad categories: supervised or unsupervised learning.
3) Develop AI methodology to predict failures in payloads or core units with the scope of minimising outage.
4) Apply the developed AI methodology to a small case study or proof-of-concept (e.g. at payload unit level) for which there is sufficient telemetry data available.
5) Perform comparison between conventional availability results and the resulted availability when the new developed AI approach is being used.
6) Provide input and lessons learned to the existing (i.e. SAVOIR) body of knowledge.

Deliverables:

Report - Approaches/Methods trade-off for AI/ML failure prediction
Report - AI methodology and algorithm user manual
Report - Payload availability/outage assessment and results (study case)
Software - AI/ML developed algorithm

Automating the transition from System to Model Based Software Engineering

Title: Automating the transition from System to Model Based Software Engineering				**Budget (K€):**	400
				Duration (m):	18
Reference: 6419		**Harmonisation:** On-Board Software B06a	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 3	**Target:** 4	**Need/Push:** TRL 4 by end 2026	**Procurement:**	C

Objective(s):

Develop and demonstrate tools, methods and processes for the consistent and efficient generation of software artifacts from system models for on-board and ground systems.

Description:

The methods and tools used in system engineering and in software engineering expose some similarities in the objectives and means. However the transition from system models and requirements to software is still mostly done manually and is a source of major issues in projects. Software System Specifications are often mis-engineered, lack the vision of the overall system behaviour and induce delays and review failures.

This activity is aiming at improving this situation by ensuring a seamless flow between system models and software models through a better interconnection of the software modelling activities into the ones of system modelling. To achieve this objective, it is proposed to integrate software behavioural, architecture and data modelling at system modelling level to ensure a continuous and bi-directional flow between system and software activities. The integration is performed at the level of the models (e.g. by harmonization of the modelling languages and/or automatic model transformations) and data (e.g. through data-hub). This integration has to maintain the link between system and software requirements in order to ensure a proper traceability and the verification of the software validation against the requirement baseline. The approach is demonstrated through an application on a representative use case starting from system model(s) and ending with the generation of software artifacts (code, documentation, data, tests).

This activity encompasses the following tasks:
- Analysis of the System modelling process, languages and tools.
- Analysis of the Software development process, modelling languages and tools.
- Identification of a seamless development process and of required updates at system and software levels considering languages and tools.
- Identification of representative use cases to be used to validate the process.
- Implementation of the process, including potential update and development of tools.
- Validation of the process through its application on the use cases.

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.

Deliverables:

Software - All software updates and tools developed for ensuring the proper connection of system and software models.

Evaluation of neuromorphic computing technologies for very low power AI/ML applications

Title: Evaluation of neuromorphic computing technologies for very low power AI/ML applications				**Budget (K€):**	350
				Duration (m):	24
Reference: 6429		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics D11	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 1 **Target:** 3	**Need/Push:** Technology push for vision based applications and optical payloads.		**Procurement:**	C

Objective(s):

To demonstrate Machine Learning ultra low power inference.
To demonstrate training capability at the edge (where data are produced).

Description:

AI/ML is gaining more and more traction in satellites systems, however hardware plateforms based on GPUs or FPGAs do not offer efficient implementations with respect to power consumption. GPUs / FPGAs solutions usually consume few tens of watt when Neuromorphic solutions are rather in the watt range. Such a low consumption makes Neuromorphic very attractive for embedded applications where power is limited (satellites, probes, rovers, landers, ...). It also makes possible training at the edge (where data are produced) therefore eliminating or simplifying the ground segment. Unlike ARTES-AT activity (ARTES FPE 1A.114) looking as well at Neuromorphic technology for telecomunications (anti-jamming), the proposed activity will rather focuss on optical applications related to exploration (HRE), Earth Observation (EOP) or science (SCI).

The actvity encompasses the following tasks:

- To assess the benefits of Neuromorphic processing technology for Space applications (vision based navigation and optical payloads)
- To make a survey of commercially available hardware solutions
- To enhance hardware implementation of artificial neural network for space applications using neuromorphic ICs.
- To demonstrate the superiority of Neuromorpgic technology with respect to power consumption and benchmark algoritms on commercially available evaluation boards
- To assess the possibility of training/learning at the edge, where data are produced
- To analyse potential weaknesses with respect to radiation effects and propose mitigations techniques for future follow up activities
- To propose a way forward and derived roadmaps for either COTS or Rad Hard ASIC approach

Deliverables:

Breadboard - Neuromorphic demonstrator based on existing HW (commercially available boards).
Report - Evaluation report of Neuromorphic technologies and benchmark results.

Model-Based Systems Engineering (MBSE) applied to Advanced Data Handling Architecture (ADHA) products

Title: Model-Based Systems Engineering (MBSE) applied to Advanced Data Handling Architecture (ADHA) products				**Budget (K€):**	300
				Duration (m):	12
Reference: 6574		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** MBSE used a system level with the technology push of ADHA development. Such models and methodology to be ready for 2025 for targeting future ESA missions.	**Procurement:**	C

Objective(s):

Develop a methodology, a toolchain and modelling guidelines for introducing in a coherent way the MBSE techniques in ADHA units development cycle.

Description:

Nowadays all traditional satellites are based on electrical architecture interconnecting units containing electronics modules. Some companies understood the benefit of having flexible units that can welcome recurrent and generic modules to be then complemented by specific modules for targeting different applications. To meet the three ESA technology targets about spacecraft development time reduction, cost efficiency, and finally faster development and adoption of innovative technologies, ESA is currently developing in cooperation with the Data Handling European industry (primes and unit suppliers) an Advanced Data Handling Architecture (ADHA) based on standardised, interchangeable and inter-operable electronics modules with last generation of microelectronics components. In the frame of this activity, ADHA units and modules requirements are derived and the 2 first EM 6U-ADHA-U1 units are produced with their relevant test equipement.

It is proposed to apply Model Based System Engineering (MBSE) to ADHA and develop under this activity a methodology, a toolchain and modelling guidelines for introducing in a coherent way the MBSE techniques in ADHA units development cycle.

The tasks of this technology activity are:

- based on the ADHA requirements develop the MBSE 6U-ADHA-Ux unit logical architecture
- modelise the 6U-ADHA-U1 modules and backplane models based on their requirements, characteristics, properties and tested performances.
- modelise of the 6U-ADHA-U1 Physical Electrical architecture, Physical Mechanical & thermal architectures, and Data flow architecture (Telemetry, Tele-command and Payload Data).
- modelise the ADHA requirements architecture and validate the 6U-ADHA-U1 unit requirements validation.
- based on the lessons learnt of the previous tasks, propose a methodology, a toolchain and modelling guidelines for introducing MBSE techniques in the ADHA units development cycle to be used in the future by LSI, ADHA unit integrator and ADHA module suppliers.

Deliverables:

Engineering Model - MBSE models.
Report - - MBSE 6U-ADHA-Ux unit logical architecture
- MBSE 6U-ADHA-U1 modules and backplane models
- MBSE models of the 6U-ADHA-U1 Physical Electrical architecture, Physical Mechanical & thermal architectures, and Data flow architecture (Telemetry, Tele-command and Payload Data).
- MBSE model of the ADHA requirements architecture
- Validation of the 6U-ADHA-U1 unit requirements with the MBSE req. architecture
- Methodology, a toolchain and modelling guidelines for introducing MBSE techniques to ADHA community

Next-generation protocol for optical high-speed links

Title: Next-generation protocol for optical high-speed links				**Budget (K€):**	350
				Duration (m):	18
Reference: 6576		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics B23	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 1 **Target:** 3	**Need/Push:** Technology Push - TRL 6 by 2026		**Procurement:**	C

Objective(s):

To investigate suitable protocols and required components at physical layer for the (optical) communication at very high speed (up to 112 Gbps) to be implemented on space-qualified FPGAs/ASICs.

Description:

In 2019, the SpaceFibre ECSS standard was published. SpaceFibre is a high-speed protocol similar to commercial protocols such as PCI express and USB 3, which allows data rates of up to 10 Gbps per lane (via optical, can be further extended by multiple lanes).

Technically, for non-space applications, these capabilities were state-of-the-art in the mid 2000s. In the meanwhile, commercial protocols moved on to support much higher data rates (28, 56, 112 Gbps), which require different Serializer/Deserializer (SERDES) techniques (e.g. PAM4) and line codes (e.g. 64b/67b, 128b/130b, 242b/256b). There is no protocol option, targeting such performance figures, that has been evaluated on space qualified hardware. Commercial IP cores often come at high cost and with difficult license terms, therefore an alternative for the European space industry is required.

Several European manufacturers work on optical transceivers suitable for space applications that provide data rates beyond 10 Gbps per lane. However, required standardisation efforts for the components as well as interoperability status between different solutions needs to be clarified.

The tasks of the activity are the following:

- Survey of all components and aspects related to the network physical layer that require standardisation, including e.g., connectors, fibres, transceivers, repeaters, data rates, and number of lanes.

- Survey of space and terrestrial high-speed link protocols related to the datalink layer that are suitable for optical on-board communication. The survey includes the critical assessment of the capabilities of different protocols (scalability, adaptability to future transceiver implementations, increasing number of data rates, number of lanes, improved encoding schemes and error correction schemes), of the implementation complexity in space-qualified hardware, and cost/licensing aspects.

- A trade-off and selection of a preferred solution.

- Survey of validation aspects for optical high-speed communication links.

- Design and manufacturing of a basic COTS-based breadboard, demonstrating the capabilities of the chosen protocol.

Deliverables:

Breadboard - Demonstration of protocol
Report - Survey of validation aspects for optical high-speed communication links
Report - Survey of physical layer aspects
Report - Survey of space and terrestrial high-speed link protocols

Orbital Maneuvering Enabled by Gauging Aggregate properties (OMEGA)

Title: Orbital Maneuvering Enabled by Gauging Aggregate properties (OMEGA)				**Budget (K€):**	350
				Duration (m):	18
Reference: 6628		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** TRL 4 by 2025 for technology push	**Procurement:**	C

Objective(s):

To develop robust time-varying guidance and control strategies for in-orbit servicing & assembly using predictive dynamical models.

Description:

This activity is part of the mini project "Spacecraft Clustering Technologies". This mini-project aims at developing technologies to attach multiple defunct spacecraft to a controlled large orbital structure with the double goal of securing the spacecraft materials for future use, while at the same time removing the risk of collision.

The operational "Spacecraft Clustering" scenario foresees a tug that departing from a large orbital structure, approaches and captures a defunct spacecraft. The tug returns to the orbital structure, attaches the defunct spacecraft to the structure, and provides the structure with orbital maneuvering ability.

The tug GNC system will need to handle large changes in the mass distribution, structural flexibility and environmental perturbations introduced by contact, manipulator movement or propellant transfer. In these cases, the system dynamic variations are significant and static linear feedback strategies are insufficient to ensure good pointing performance and disturbance rejection.
Multivariable robust and linear-parameter varying control provides a strong framework to address these challenges.

Furthermore, for a large variety of manoeuvres expected during in-orbit servicing & assembly, the resulting disturbances can be anticipated using a sufficiently accurate predictive model of the dynamics (as input to feed-forward control). However, obtaining such accurate models is not a trivial task since the physical phenomena involved in robotic in-orbit servicing or assembly missions are highly nonlinear.

To overcome such challenges, modern methods (including machine learning) can be combined with online system identification and parameter estimation strategies to produce physically meaningful predictive models together with uncertainty bounds.

This activity aim to enable the stabilisation of spacecraft assemblies (either servicer + serviced spacecraft or elements of a structure under construction) for the benefit of a wide range of future in-orbit servicing and assembly missions.

The activity encompasses the following tasks:
- Literature survey
- Scenario & requirements definition
- Development of learning enhanced robust and adaptable control & guidance algorithms
- Implementation on representative space processor
- Worst case analysis of the methods
- Conclusions and recommendations

Deliverables:

Report - Technical documentation
Software - Autocoded GNC SOFTWARE

LLVM for space applications

Title: LLVM for space applications				**Budget (K€):**	350
				Duration (m):	18
Reference: 6678		**Harmonisation:** On-Board Software C04	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 3	**Target:** 4	**Need/Push:** TRL 4 by 2026, TRL5 by 2029	**Procurement:**	C

Objective(s):

To add to LLVM the support of new space qualified processing devices and their execution environments while assisting the development process of flight software.

Description:

GNU GCC and Clang LLVM are two established compilers in the sector. GCC is the official compiler produced by the GNU Project and supports a large number of traditional programming languages and multiple architectures (e.g. ARM, SPARC, RISC-V). Similarly, to many other open source communities, GCC is controlled by free software enthusiasts who are typically sponsored by commercial companies (such as RedHat, Intel, AMD).
LLVM is a collection of modular, extensible and reusable compiler tools. Clang is the LLVM compiler front-end for C, and C++ programming languages. The modular architecture of LLVM allows reducing the time/cost to support a new architecture or a new programming language and makes it easier to maintain. LLVM/Clang license allows deriving commercial products from LLVM without any restrictions. The official ARM Compiler is based on LLVM.
The activity is aiming at ensuring the correct support of space-qualified architectures by LLVM and develop and add specific LLVM modules supporting the process development of flight software. The prospective modules to develop shall improve the static analysis of code considering real-time embedded developments, increase the observability for easing the debugging of code, implement optimization of the binary code to specific processor architectures used in space applications, ease the integration into a Model-Based Software Engineering environment.
Tasks:

- Analysis and selection of the new architectures to support: new generation of processors (Leon multi-cores, RISC-V ARM multi-cores) and execution environments.
- Identification and selection of the new features to be implemented as LLVM modules covering at least the support of a better static analysis, an improved observability and debugging, a generation of optimized binaries for the selected target architectures.
- Identification of Use Cases exercising the new modules. Use Case based shall consider existing modules or complete flight software on which deviations (e.g. to coding standard) and bugs are added.
- Porting of LLVM on selected architectures and environments, development of the selected modules.
- Verification and validation based on the Use Cases. Demonstration of the new features, evaluation of performances.

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.

Deliverables:

Software - LLVM toolchain for the selected architecture(s) and execution environment(s) including the additional selected module(s)

Software validation using Artificial Intelligence techniques to automatically generate tests

Title: Software validation using Artificial Intelligence techniques to automatically generate tests				**Budget (K€):**	400
				Duration (m):	18
Reference: 6679		**Harmonisation:** On-Board Software E10	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 4	**Need/Push:** This activity will benefit all the software development by improving the quality level of the software.		**Procurement:**	C

Objective(s):

To automatically generate tests for software validation

Description:

"Validation" in ECSS-E-ST-40 is the "process to confirm that the requirements are correctly and completely implemented in the final product". Validation is meant to systematically acquire proof that the software product correctly and completely fulfills the relevant applicable requirements, both functional and non-functional. According to ECSS-E-ST-40, validation is to be carried out by test. Testing is an important activity that can be performed at different levels: unit (test of individual software unit), integration (testing in which software components, hardware components, or both are combined and tested to evaluate the interaction between them) and overall software product (for closing requirements). Testing requires significant efforts transcribed in planning and budget.

The activity is aiming at exploring Artificial Intelligence (AI) techniques to automatically generate the software tests. All the tests performed during the development of the Software will be considered including unit tests, integration tests and validation tests. Each type of test could potentially use a different technique, e.g. fuzzy logic for unit tests, Bayesian networks for integration tests and Machine Learning/Deep Learning for validation tests.
This activity encompasses the following tasks:
- Analyze existing testing approaches executed during the development of critical software including the identification of tools and Model-Based Software Engineering (MBSE) environments.
- Analyze the AI techniques in order to identify for each type of tests, which is the most appropriate technique to use.
- Selection of the testing and AI techniques, identification of corresponding Use Cases. The Use Cases shall cover both manual written and automatically generated code (from Model-Based Engineering tool and Matlab/Simulink).
- Develop the AI models corresponding to the selected techniques with possible integration in a MBSE environment.
- Evaluation of the performance through the application on the selected Use Cases.

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.

Deliverables:

Software - Artificial Intelligence models able to generate the different type of tests involved in the development process of critical flight software, possibly integrated in a MBSE environment.

Verification and Validation Methods for Machine Learning Algorithms

Title: Verification and Validation Methods for Machine Learning Algorithms				**Budget (K€):**	400
				Duration (m):	18
Reference: 6683		**Harmonisation:** On-Board Software E09	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 4	**Need/Push:** All missions including ML based applications will benefit from a correct validation of ML techniques.		**Procurement:**	C

Objective(s):

To define verification and validation methods for applications relying on Machine Learning techniques

Description:

Currently, Machine Learning (ML) is starting to be integrated in more and more areas of the space industry, some of them are safety- or mission-critical (e.g. vision-based navigation). One fundamental challenge for this adoption process is the limited ability of verifying the results of ML algorithms and establishing the required confidence in them. In particular, for supervised learning algorithms, at runtime there is no base truth available for the validation, so conventional validation methods prove to be ineffective.

An effort has to be made to assess the available formal and non-formal verification and validation methods in this context, and define a subset of guidelines and recommendations for specific use cases and types of machine learning.

This activity encompasses the following tasks:
- Analysis of the ML techniques intended to be used in the frame of critical applications.
- Analysis of verification and validation techniques that can be applied on the identified ML techniques
- Identification of representative Use Cases
- Selection or development of the ML models related to the Use Cases.
- Application of the verification and validation techniques
- Assessment and recommendations

Software shall be delivered under an ESA Software Community Licence, so that any individuals or entities within ESA Member States can access to it and can provide update to the community of users.

Deliverables:

Software - Software product supporting the verification and validation applications of Machine Learning applications
Software - Machine Learning applications (Artificial Intelligence models and data) on which validation techniques are applied

Multi-objective optimisation of thruster layout under constraint

Title: Multi-objective optimisation of thruster layout under constraint				**Budget (K€):**	350
				Duration (m):	15
Reference: 6687		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** Technology push applicable to any mission with complex topology of the spacecraft.	**Procurement:**	C

Objective(s):

To improve the current thruster accommodation approach towards an optimization process that accounts for command and control algorithm requirements, physical constraints, and failure tolerance.

Description:

The spacecraft propulsion layout for a given mission will determine the resulting available control authority as well as fuel consumption efficiency.
Current practices of thruster configuration design include a large amount of iterations to ensure that the thrusters layout can be accommodated considering multi-disciplinary issues such as plume impingement, structural and thermal issues, contamination of sensitive equipment, thruster performances, constraints from minimum impulse bit (MIB) effects, actuation period, modulation etc. Many of those artifacts are only dealt with late in a project, leading to cost and schedule overruns as well as an inefficiencies on the GNC system for the mission.
Thruster architecture optimization is a complete subject addressing theoretical aspects as well as system level considerations, which have to be considered to incorporate mission and subsystem constraints and requirements. This lead to a nonlinear multi dimensional and multi-disciplinary optimization problem.
A multi-objective optimization of the propulsion layout under all the relevant constraints would ensure to obtain maximum 6 degrees of freedom controllability, minimum possible fuel consumption for the mission, and the possibility of a fault tolerant actuation system.

The activity encompasses the following tasks:
- Review the current practice in location and orientation of thrusters under bounded constraints.
- Define (in cooperation with all involved disciplines) the key drivers and constraints applicable to the thruster layout definition problem (e.g. thermal and plume impingement constraints, control constraints) and formulate the optimization problem to be dealt with.
- Develop a solution in the form of an optimization procedure under constraints, to produce a general framework for any spacecraft that can capture all the multi disciplinary boundary constraints and solve the nonlinear constrained optimization problem using hybrid optimization techniques. The fault tolerant control problem shall be considered as a constraint in the optimization.
- Define and use a number of reference spacecraft configurations, that are sufficiently complex, as test cases for the optimization procedure. Test the procedure with these test cases and compare the results to available existing configurations resulting from the traditional design process.

Deliverables:

Report - Technical documentation
Software - Optimisation framework

Real Time System Identification for Complex System Modelling and Autonomy Operations

Title: Real Time System Identification for Complex System Modelling and Autonomy Operations				**Budget (K€):**	300
				Duration (m):	15
Reference: 6689		**Harmonisation:** Avionics Embedded Systems B31	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Need for missions requiring accurate on-board knowledge of plant dynamics to tackle dynamics complexity and to enable autonomous operations (on-line monitoring, decision-making and analysis)		**Procurement:**	C

Objective(s):

To develop on-board system-identification algorithms for on-line monitoring, decision-making and analysis.

Description:

Future spacecraft missions require high accuracy on-board models in order to enable active monitoring, health diagnosis as well as control adaptation and reconfiguration. Accurate pre-flight knowledge of the plant to be controlled is today necessary for designing accurate Guidance, Navigation & Controls (GNCs) for stabilisation and instrument pointing systems (including for instance precise structural modal analysis).

However, in autonomous operations the dynamical models may not always be available online. When operating in situ initial on-board models may not always have the desired accuracy when derived from analytical physical modelling principles or ground experiments. This motivates the need to use on-board system identification techniques for the generation of in situ-model dynamics. The on-board modelling techniques addressed in this study shall be categorized as model based estimation and identification techniques for the generation of dynamical models and model calibration and shall include machine-learning-based strategies.

System identification techniques shall be developed with the purpose to determine accurately in a computational efficient and reliable manner model dynamics and parameters for control purposes (control, adaptation, monitoring, estimation, perception and reconfiguration).
These techniques shall be suitable for on-line identification and therefore must be capable of providing meaningful output without a pre-defined excitation input.

Novel system identification techniques shall be developed and tested with the purpose to generate online high fidelity models which cannot be reliably predicted by low order computational models (uncertainties, non-linearities, un-modelled dynamics etc..), sub-scale experiments or non-representative ground experiments (slosh in micro-g). Model validation and verification issues associated with the development of the on-board modelling strategies including uncertainty characterisation shall be included in the study.

The activity encompasses the following tasks:
- Review and select on-board uncertainty modelling techniques
- Assess the dynamic and kinematic modelling requirements for a high performance mission
- Perform a trade-off study between the various on-line model identification techniques and perform a final selection of candidate techniques
- Develop a SW prototype and integrate it in a GNC functional simulator
- Evaluate impact on system performance

Deliverables:

Report - Technical documentation
Software - System-identification algorithms

Advanced Control Techniques for increased on board autonomy

Title: Advanced Control Techniques for increased on board autonomy				**Budget (K€):**	350
				Duration (m):	18
Reference: 6695		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 1	**Target:** 3	**Need/Push:** Technology push for implementation on LEO missions	**Procurement:**	C

Objective(s):

To increase and leverage on board autonomy and decision making by advanced control techniques leading to faster and more efficient orbit manoeuvres planning and execution.

Description:

Enhanced on board autonomy in performing orbit control and collision avoidance manoeuvres is key aspect to increase mission availability and operational efficiency. This becomes particularly relevant considering the increasing amount of space debris and active satellites from mega constellations which lead to significant operational effort.

On-board autonomy increase can be implemented by making use of advanced techniques, such as machine learning and embedded and real-time optimisation, for estimation as well as prediction of collision risks leading to autonomous and optimized orbit manoeuvre calculation. This would lead to faster and optimal decision making with the objective to either minimise the down time for scientific observations or to minimise fuel consumption based on configuration of the implemented optimizer. The ultimate aim of the activity is to support the European industry to cope with challenges arising from increase of space debris and constellations.

This activity encompasses the following tasks:
- Study case selection (different Low Earth Orbit (LEO) missions shall be selected for which the developed algorithms shall be implemented and verified)
- Definition of satellite system and Attitude and Orbit Control System (AOCS) requirements. Definition of interface requirements for the interaction with ground in terms of database and data exchange
- Development of algorithms using advanced techniques, such as machine learning and embedded and real-time optimisation, enabling the enhanced on board autonomy in the definition of the AOCS functions (guidance, orbit control, collision avoidance manoeuvre). Constraints such as for example payload sun illumination constraints and inter-satellite links shall be defined and taken into account for optimizing manoeuvre planning and execution. Furthermore, the system shall also consider the autonomous failure management by making use of all available on board resources.
- Development of a simulator which shall include all relevant parameters to fully demonstrate functionality, performance and robustness of the developed on-board algorithms. The simulator shall include the interface with ground.
- Definition of a test plan and verification of the algorithms on the simulator. Assessment of processing load with benchmark scenarios. Comparison and assessment of the advantages of the developed algorithms with respect to the classical approach.

Deliverables:

Report - Simulator for algorithm testing
Report - Implementation results on identified use case
Report - On board algorithm description for implementation

End to end digitalisation of GNC/AOCS development

Title: End to end digitalisation of GNC/AOCS development				**Budget (K€):**	400
				Duration (m):	12
Reference: 6700		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** Techno push	**Procurement:**	C

Objective(s):

To define the end to end digital development of AOCS/GNC subsystem, including definition of artefacts, tools, method and techniques, as well as needed development, based on a pilot use case application

Description:

Digitalisation is creating new processes and radically altering existing workflows. The activity is aiming to analyse the digital transformations to come for AOCS/GNC subsystem: what will the influence of digitalisation be on subsystem development process? which impact on standard AOCS/GNC artefacts produced in ESA projects? which consequences of digitalisation and Model Based engineering in the AOCS/GNC verification?
The activity will participate in defining tools, methods and techniques to used (and developped) for digital engineering in AOCS/GNC domain engineering, as well as with definition of needed developments. The study will be based on a pilot case, in order to experiment on a real case the digitalisation of the process.
This activity encompasses the following tasks:
- to assess impact of digitalisation of AOCS/GNC process on the production of artefacts used in the project cycles reviews as review inputs (in replacement of current standard documentation), e.g. based on current ESA reviews definition and objectives, define possible qualitative and quantitative artefacts to support these reviews, their relation with requirements engineering, modelling validation, engineering management plan and V&V cycle
- to revisit a typical AOCS development case in terms of tasks, inputs/outputs flow, products, process, skills, tools, facilities to define who/what, at which steps, on which facilities, and how could the AOCS subsystem be embedded in a Model Based System Engineering process.

The following tasks of the activity are:
1/ model-based flow-down of pointing requirements and associated V&V cycle ,
2/ data sharing: structure and phases (importance of data range for AOCS robustness, ie. nominal values and their range of variation/uncertainty ; AOCS tuning data evolution and configuration ; AOCS data tuning dependency to the use -e.g. variable with specific tuning for some testing, some part of the mission lifetime, etc...) .
3/ continuity of the models used for AOCS V&V and avionics/system V&V, together with continuity of the test reference scenarios/success criteria and relation with system requirements,
4/ model-based analysis of AOCS simulations and test results.

Deliverables:

Prototype - prototype algorithms/sw as developed in the digitalisation use cases
Report - Technical Notes + proposal for standards/handbooks evolution in AOCS/GNC development

IP Cores for High-Speed ADC & DAC Interface

Title: IP Cores for High-Speed ADC & DAC Interface				**Budget (K€):**	400
				Duration (m):	18
Reference: 6713		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics J17	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** Techno Push of EEE data conversion devices.	**Procurement:**	C

Objective(s):

Develop and verify reusable digital IP cores fully implementing the JESD204B/C high-speed interface standards, addressing current and future high-speed data acquisition and conversion EEE devices.

Description:

Next generation Earth Observation, Telecom and broadly Software-Defined Radio payloads exploit high-speed Analog-to-Digital (ADC) and Digital-to-Analog (DAC) devices, which require high-speed digital interfaces to cope with the throughput demand in the order of gigabit-per-second (Gbps). Furthermore, these devices are thoroughly used in Multiple-Input/Multiple-Output (MIMO) systems, and therefore require synchronisation for simultaneous operation. Two major protocols are JESD204 and ESISTREAM; while the former is an industry standard adopted by many EEE suppliers, the latter is supported by one supplier.

Commercial JESD204 IP cores exist, but they are either a) open, but prohibitively expensive, especially for smaller companies; b) locked to a development tool/device vendor; c) locked to a given ADC/DAC vendor. Furthermore, these IP cores have not been developed with the Space environment in mind, therefore require hardening against single-event effects (SEEs), which may not be possible due to their closed nature. ESISTREAM IP cores also exist, are open source and provided free by the supplier, however their verification status requires improvement and its adoption is unclear.

With many ESA missions and industry products relying on devices having JESD204 interfaces, it is imperative to have verified, SEE-hardened, configurable and device & technology independent IP cores. The provision of a JESD204 IP core covers two different needs simultaneously: a) interface of ASIC/FPGA with existing EEE components; b) building-block for future EEE ADC/DAC devices. The IP cores will be part of the ESA IP Core's portfolio, making it accessible for future ESA projects and missions, devices and also for smaller companies.

Tasks:
- Study the latest JESD204 standard, derivation of requirements and identification of configurable parameters
- Development of a verification environment based on Universal Verification Methodology (UVM)
- Development of JESD204 IP cores for Transmit and Receive in VHDL, and verification using UVM framework
- Development of user-friendly IP core configuration tool for tailoring based on specific device/mode requirements
- Synthesis on representative FPGA devices: space-qualified BRAVE, RTG4/PolarFire and COTS (Xilinx)
- Trial synthesis for selected ASIC targets
- Laboratory demonstrator with representative FPGA and data conversion devices
- Produce User Manuals, with integration guidelines

Deliverables:

Breadboard - Laboratory Demonstrator
Prototype - JESD204B Transmit IP Core Source Code
Prototype - JESD204B Receive IP Core Source Code
Report - User Manual and IP Core Documentation

TT&C Time Transfer in Deep Space

Title: TT&C Time Transfer in Deep Space				**Budget (K€):**	400
				Duration (m):	24
Reference: 6908		**Harmonisation:** TT&C Transponders and Payload Data Transmission B03	**Application Domain:** GEN - Generic Technologies	**Programme:**	TDE (TRP)
TRL	**Initial:** 3 **Target:** 4	**Need/Push:** Technology Push: TRL 6 by 2027 for SCI/EXP missions		**Procurement:**	C

Objective(s):

To implement additional function in Deep Space Transponder, providing accurate onboard time based on TT&C signals and time transfer.

Description:

Current Deep Space Transponders include, in addition to uplink TC and downlink TM data communications, the functionality of two-way code-based ranging and turnaround carrier phase coherency. The two-way ranging functionality is based on sequences that can be e.g. PN ranging (phase modulated together with the TC/TM data, and turned around either transparently (bent pipe) or regeneratively), or using Spread Quadrature Pseudo Noise (i.e. CDMA/spread-spectrum that is spreading the data via suppressed carrier modulation using PN code chip sequences).

Space missions could benefit (increased accuracy, onboard autonomy) from a timestamping function, based on a 1 Pulse-Per-Second (1 PPS) signal and time information generated by the transponder based on the (PN) ranging epoch combined with known range information and other information from ground segment, thus implementing one-way time transfer from earth.

The implementation involves the TT&C receiver locking to the PN uplink sequence and generating regular epoch. The ground station is performing 2-way ranging using the PN-ranging signals, including removal of ambiguity and other processing on the orbit. This information including ranging/range-rate from the groundstation is then uplinked to the TT&C receiver via telecommand. The receiver then performs a Timing algorithm and dynamic model, to generate onboard time using the received epoch timing and the information uplinked from the ground station. This onboard time can then be used in a timestamping function that is useful in several missions. The onboard time can be synchronised to- or related to- UTC.

The activity includes breadboarding the additional time transfer functionality, as upgrade to existing Deep Space Transponder functionality, operating in X-Band (7/8GHz) or Ka-Band (26/32GHz).

The activity encompasses the following tasks:
- review on time transfer techniques and maturity of elements needed to generate onboard real time clock synchronised to UTC
- confirmation of parameters needed for the implementation including ranging code rates and sequences
- Architectural Design defining the elements needed
- Detailed design and simulation, including (Timing) algorithm, PN epoch generation, 1 PPS generation
- Implementation and verification of timing functions breadboard including software / FPGA / Hardware inline with detailed design
- Demonstration of timestamping function
- Plan for upgrade path of Deep Space Transponder

Deliverables:

Breadboard - Breadboard of TT&C one-way time transfer function using Deep Space Transponder, including additional onboard functions, as well as breadboarding and provision of ground test equipment elements necessary to perform end to end testing.

CD03 - TDE plan 2023-2024 – TECNET sectorial

Domain	Title	Budget (k€)
EO - Earth Observation	ADHA GNSS Receiver Module (AGNSSRxM)	600
EO - Earth Observation	Very high-speed mass memory unit breadboard	500
EO - Earth Observation	Transient and microvibrations control for Optical missions in combination with RF instrument	350
EO - Earth Observation	Increased integration time for LEO optical payloads with Fast Steering Mirror	250
EO - Earth Observation	On-board digital chain for High Resolution (1-2m) optical imagers	900
EO - Earth Observation	Adaptive control and metrology for large deployable appendages	250
EXP - Exploration	Moon landing with navigation constellation support	400
EXP - Exploration	Ultra low power electronics module for Exploration and Night Survival	300
NAV - Navigation	Pulsar navigation filter design under realistic conops scenarios	350
SAF - Space Safety	EoL Passive detumbling service for removal of not operative satellites in LEO/MEO/GEO orbits	400
SCI - Space Science	Ultra Low Power Consumption Unit and Instrument Interface	250
ST - Space Transportation	Smart launcher - Verification & validation of safe autonomous GNC systems for launchers	400
ST - Space Transportation	Smart launcher - Autonomous MVM and monitoring systems for safe and adaptable launcher GNC systems	500
TEL - Telecommunications	Advanced Techniques for Momentum Management with Thruster Orientation Mechanisms	400
Total		5,850

ADHA GNSS Receiver Module (AGNSSRxM)

Title: ADHA GNSS Receiver Module (AGNSSRxM)				**Budget (K€):**	600
				Duration (m):	18
Reference: 5419		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics C46	**Application Domain:** EO - Earth Observation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 4	**Need/Push:** EO missions with integrated GNSS.		**Procurement:**	C

Objective(s):

Development of a GNSS Receiver module compliant with the SAVOIR reference architecture and the ADHA specification.

Description:

The activity is aiming at developing a new generation of GNSS Receiver module compliant with ADHA functional and interface requirements able to be integrated in an ADHA Unit with its backplane based on cPCI Serial Space standard.

The GNSS receiver module shall support single and/or multiple antenna inputs. The antenna inputs shall support single frequency and/or multi-frequency (e.g. E1/E5) navigation signal reception. The hardware design shall allow high quality measurements, coherent between all inputs, to support applications such as precise orbit determination (POD) and GNSS radio occultation (GNSS-RO). The hardware shall comprise all elements needed for a navigation receiver, including RF frontends, an FPGA for the digital receiver frontend, and CPU, memory and timing subsystem. Operational flexibility and reconfigurability of the hardware platform is foreseen, i.e. FPGA and receiver s/w are foreseen to be operationally reprogrammable.

The GNSS function shall provide at least pseudo range, carrier phase and Doppler measurement for each satellite tracked and position, velocity and time. Tracking of at least 24 satellites in single-frequency mode and of 18 satellites in dual/triple-frequency mode shall be supported. At least dual constellation (GPS and Galileo) is required.

The ADHA GNSS Receiver module functions shall include all the capabilities of a standard spaceborne GNSS receiver excluding the antenna. The GNSS receiver module shall be designed and implemented to allow a fleixible approach, allowing to remove/add components without design changes to support the different configurations (e.g. single/multiple antenna, single/multi-frequency, etc).

The activity shall investigate the usage of COTS as well and assess the possibility to have a common reference design allowing to use either COTS or rad-hard components.

The main tasks to be undertaken are included below:

- AGNSSRxM Detailed Specification (compatible with other ADHA module and unit specifications).
- AGNSSRxM HW & SW preliminary design
- AGNSSRxM HW & SW detailed design
- AGNSSRxM Engineering Model Manufacturing & Test
- AGNSSRxM Validation Test within ADHA Unit and results

Deliverables:

Engineering/Qualification Model - HW: Engineering Model - Final deliverables: GNSSM Engineering Model that fits in and ADHA Unit based on cPCI Serial Space Backplane.
Report - Documentation:, AGNSSRXM Detailed Specification, AAGNSSRXM Detailed Design, ICD (electrical, TM/TC), Manufacturing & Tests report (performances), AAGNSSRXM Development plan, User Manual (HW & SW)
Software - Test Software

Ultra Low Power Consumption Unit and Instrument Interface

Title: Ultra Low Power Consumption Unit and Instrument Interface				**Budget (K€):**	250
				Duration (m):	24
Reference: 5958		**Harmonisation:** Power Management and Distribution C01	**Application Domain:** SCI - Space Science	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Ice Giants missions or missions in general going far away from the Sun will benefit from this developement enabling more power available for the instuments.		**Procurement:**	C

Objective(s):

To develop an interface for avionics and instruments that is able to keep the units in a very low power consumption mode. The objective is to reduce the overall platform consumption to the minimum and only consume power when needed.

Description:

The usual concept in units and instruments is to keep the unit on all the time. Even when the unit is in idle mode, or not doing anything in particular, the power consumption is quite high compared to the power consumed in full operation.
In missions going far away from the Sun, like the Ice Giants, power is one of the key enablers for the mission. There are two ways of taking action: improve the power generation when the Sun illumination is low or reduce the power consumtion of the units.
This activity is devoted to the second concept. Developing an interface with the power bus and the communication bus that is able to consume extremely low power (<1W) while it is not operating (idle mode).
To do this, the activity should be carried out having in mind both the avionics needs and the power needs.
The goal is to develop concepts that could work overall at platform level in all units and instruments. A breadboard will be developed as a proof of concept showing ultra low power consumption in stand by mode.

Deliverables:

Breadboard
Report

Ultra low power electronics module for Exploration and Night Survival

Title: Ultra low power electronics module for Exploration and Night Survival				**Budget (K€):**	**300**
				Duration (m):	**14**
Reference: 6232		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics D02	**Application Domain:** EXP - Exploration	**Programme:**	**TDE (TRP)**
TRL	**Initial:** 2	**Target:** 4	**Need/Push:** Lunar Night Survival, ESA-E3P-EXPE-RS-003: MM-13/15-001: Technology push for Avionics and Thermal Control Systems	**Procurement:**	**C**

Objective(s):

To implement, test and deliver the breadboard of an ultra-low power processing and housekeeping module for use in platform, payload and rovers to support planetary night survival

Description:

Future HRE missions target Moon exploration with the requirement to land anywhere on the Moon and support Lunar Night survival. At the same time, Lunar missions are asked to support science which may operate sporadically during lunar night, but also cargo missions defined, which deliver Oxygen, water etc., for the astronauts that will land on the Moon after the first Lunar night. In the case of science payloads, the payloads shall have the capability to wake up during lunar night, whereas in the case of astronauts periodic logging of pressure and temperature of the consumables is required to ensure that they can be used by the astronauts after landing. In addition, retaining on board equipment at survival temperatures, requires periodic temperature logging and control during the lunar night. Even designs that foresee passive night time survival will require a way of logging the temperature over time for health assessment. Similar requirements are also applicable for Lunar rovers which shall survive Lunar night in an autonomous way.

The proposed activity, aims in exploiting the ultra-low power capabilities offered by lately developed programmable components, to develop a flexible and ultra-low power electronics and low mass module with:
- a ultra-low power timer functionality to support hibernation of platform or payload units.
- data logging function for critical payloads and critical platform units during lunar night.
- thermal control functionality, complementing the RHU-based passive thermal control.
- a reliable warm-up/wake-up logic for minimization of consumed power.
- other possible functionalities, such as activation of TTC equipment following a programmable time line, wake up authentication/security functions upon the reception of authenticated TCs.
- the possible capability to survive and operate at very cold temperatures (down to -100 degrees).

The tasks of the activity are:
- Selection of use cases to analyse and derivation of requirements
- Survey for candidate ultra low power components/architecture
- Design, implementation, prototyping of the module and demo SW
- Execution of functional tests
- Demonstration of representative use cases

Deliverables:

Breadboard - Elegant Breadboard with demo applications implementing different functional and power/energy profiling scenarios
Report - Preliminary design data package, including: Design justification, EEE Parts Lists, preliminary Failure Mode and Effects Analysis, preliminary Radiation analysis, preliminary Parts stress analysis, preliminary Worst case analysis, preliminary Risk and Feasibility

Pulsar navigation filter design under realistic conops scenarios

Title: Pulsar navigation filter design under realistic conops scenarios				**Budget (K€):**	350
				Duration (m):	15
Reference: 6313		**Harmonisation:** - -	**Application Domain:** NAV - Navigation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 3	**Need/Push:** Technology provides increased autonomy, accuracy and cost savings to any interplanetary mission, particularly at large distances from the Earth.	**Procurement:**	C

Objective(s):

To develop a navigation filter fed by pulsar signals that provides a refined robust on-board determination of PVT under realistic conops scenarios.

Description:

Pulsar navigation has been extensively studied in the past 15 years and a demonstration by NASA (SEXTANT experiment on the ISS in 2017) has shown the potential to enable accurate and robust autonomous navigation capabilities, which are particularly attractive in scenarios characterised by scarce availability or low accuracy of ground-based radiometric navigation. This is typically the case in interplanetary missions at large distance from Earth (pulsar navigation accuracy is independent from the distance to Earth, while ground-based radiometric navigation's accuracy degrades with distance). In addition, the infrastructure and operations needed for ground-based orbit determination are expensive and time consuming.
The interest in this concept has sparked the conceptual study of an instrument that could be embarked on planetary missions to get PVT information based on pulsar measurements (which achieves one order of magnitude reduction in power and mass/size specs compared to the SEXTANT experiment). This instrument currently has TRL 3.

The development of an on-board navigation filter is needed in order to improve the PVT solution obtained from pulsar measurements alone and improve orbital parameter estimation in between pulsar measurements by means of time-varying pulse-frequency estimation due to change in relative velocity to the target pulsar, and time-varying photon time-folding to account for the change in pseudorange to the target pulsar.
Relevant trade-offs for the filter design include the estimation state selection versus considered states and the pulse-processing method selection.
Mission scenarios considered in this activity are planetary flybys, interplanetary cruise, and navigation at L2.

The main tasks of this technology activity are the following:
- Define and simulate mission scenarios and the corresponding operational scenarios/conops (e.g. frequency of pulsar measurements, execution of slews, need of periodic ground-based orbit determination fixes, etc.).
- Design of the navigation filter to be robust to uncertainties (e.g. missing measurement data, model parameter uncertainties).
- Auto-code into SW and functionally validate the navigation filter in SW in the loop (SIL) in order to perform a profiling of the SW performance.
- Perform a tuning campaign to allow assessment of the expected navigation performance.
- Perform an extensive simulation campaign for performance assessment.

Deliverables:

Report - Technical documentation of conops and navigation filter design description
Software - Autocoded navigation algorithms

EoL Passive detumbling service for removal of not operative satellites in LEO/MEO/GEO orbits

Title: EoL Passive detumbling service for removal of not operative satellites in LEO/MEO/GEO orbits				**Budget (K€):**	400
				Duration (m):	18
Reference: 6349		**Harmonisation:** De-orbiting Technologies J04	**Application Domain:** SAF - Space Safety	**Programme:**	TDE (TRP)
TRL	**Initial:** 1	**Target:** 4	**Need/Push:** Target mission: LEO to GEO orbits Application: preparing techno for making passive targets readier for capture and de-orbiting TRL 6 can be achieved in 2026	**Procurement:**	C

Objective(s):

Develop on-board system to passively dump angular rates of defunct satellites in LEO/MEO/GEO to contribute to reach the zero debris objective.

Description:

Removal services facilitating the rendezvous and capture of non operative satellites still orbiting around the Earth is key factor to implement the zero debris objective.
The capture of the target satellite can be performed at sufficiently low relative angular velocities between the target and the chaser. It is therefore mandatory to implement system capable to dump the residual angular rates in case of premature end (major unrecoverable failure) of the satellite when it is still in orbit.

Copernicus Expansion missions have implemented for the first time a passive detumbling functionality by short-circuiting the magnetorquers in case of failure. This technology is mostly applicable to LEO satellites in the Copernicus class (with limitations in terms of size), but it is less efficient for higher orbits and larger SC sizes.
The study shall therefore explore different passive dumping solutions to cope with different orbits where the magnetic field is weaker and with larger size classes.

This activity encompasses the following tasks:
- Identifying potential solutions among the class of the LEO, MEO and GEO satellites
- Perform trade off among potential candidates (analyses of dynamics and orbit evolution) considering both efficiency in passive rate dumping and impact or application for SC nominal lifetime, with the objective to minimize any disruption to SC design.
- Elaborate a preliminary design and expected performance of the system considering realistic environmental and operational constrains
- Develop and test prototype breadboard of the identified solution in order to demonstrate performance using breadboard in laboratory environment (e.g. HW In the Loop simulations, motion platform, rate dumping measurements) and raise the respective TRLs to 3/ up to 4

Deliverables:

Breadboard - Breadboard of Passive Detumbling Device
Report - Documentation:
- Survey of candidate technologies
- Trade off report to select the best technology
- Design report for the selected technology
- Test report

Very high-speed mass memory unit breadboard

Title: Very high-speed mass memory unit breadboard				**Budget (K€):**	500
				Duration (m):	24
Reference: 6368		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics B21	**Application Domain:** EO - Earth Observation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Data Relay in GEO and next-generation of future MMUs (in terms of data rates and volumes) for EO in general.		**Procurement:**	C

Objective(s):

Investigate potential next generation flash devices to be used in space applications Mass Memory Unit.

Description:

Future EO satellites could transfer a large amount of satellite payload data in a very short time frame (>100 Gbps) to a laser terminal for up-link to relay satellites in GEO.

However, current mass memory unit technology only allows read and write rates of a few Gigabits per second. This is mainly due to the currently used NAND flash components. While reading a page is much faster than writing it, the limiting factor is the comparably slow parallel interface to each flash component. To speed up transfers, the only solution is to parallelize as many components as possible. However, this solution is limited by the number of available FPGAs/ASICs pins and PCB routing resources.

In commercial mobile and automotive applications, the trend goes towards managed NAND devices, which combine complex 3D NAND with embedded memory management firmware for ECC, wear-leveling and bad block management as well as modern high-speed serial links. Not only do these devices allow impressive read and write speeds of several Gbps over only a few high-speed signal lines, they also could simplify the firmware of the MMU significantly since many management functions are already built in.

The downside is, however, that an up-screening of these components might be extremely complex due to the multilayered flash architecture and the advanced embedded management logic. In addition, interfacing the components is not trivial and requires dedicated protocol IP cores on modern FPGA/ASIC technology.

The tasks of the activity are the following:
- Investigate potential next generation flash devices that could be used in space applications
- Analyse if and how these devices could be up-screened
- Conduct a feasibility study and develop a preliminary design for a next-generation Mass Memory Unit
- Build a breadboard to demonstrate sustainable read/write speeds. The critical components of the breadboard include a modern FPGA that receives data via (optical) high speed links from an external test system and writes it to the flash memory devices using an appropriate memory interface protocol. The FPGA can also read data (simultaneously) from the memory devices and transmits it via (optical) high speed links back to the external test system.
- Initial radiation test campaign of the key components.

Deliverables:

Breadboard
Report - Architectural study
Report - Radiation campaign results

Transient and microvibrations control for Optical missions in combination with RF instrument

Title: Transient and microvibrations control for Optical missions in combination with RF instrument				**Budget (K€):**	350
				Duration (m):	12
Reference: 6466		**Harmonisation:** - -	**Application Domain:** EO - Earth Observation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 3	**Need/Push:** LEO Meteo missions, STREAM (Opt/RF rot.)	**Procurement:**	C

Objective(s):

To develop a control architecture to mitigate dynamic transients and pointing microvibrations for Optical missions combined with RF instrument or other mechanism, to enable high pointing stability at limited cost.

Description:

Earth Observation optical missions combined with RF instrument (eg. future LEO meteo missions, possibly with optical and microwave instruments, or embarking several instruments, or STREAM mission) or with other mechanism will face challenging pointing stability, from demanding optical requirements and critical mechanism microvibration, from large rotating antenna or steerable antenna.
Based on recent R&D activities outcomes, a new type of attitude control architecture will improve the pointing performance of such combined missions at limited cost since based on control techniques to be implemented in attitude control subsystem.
This solution will be able to mitigate together the rotating antenna static and dynamic imbalances or steerable antenna perturbation, with the flexible modes excitation and the Solar Array Drive Mechanism (SADM) disturbance, and with possibility to extend it to other platform mechanism microvibration at the same time.
This new system will benefit from:
A. The use of harmonic control with harmonics identification which enables very high rejection performance on several harmonics while having relaxed constraints on the processing for reduced electronic cost
B. The Proof-Mass Actuators (PMAs) directly accommodated on the Platform which enable to manage all disturbances together
The activity aims at the detailed design and analysis of this new type of microvibration control architecture, to be defined for Earth Observation Optical mission use cases (eg. missions with combined Optical and RF instruments - future LEO meteo missions & STREAM- and missions with important mechanism perturbation -eg using steerable antennas-).

The following tasks are considered:
- Definition of the mission (mission and system requirements, dynamic properties, disturbances, accommodation capacity)
- System architecture definition including: requirements flow-down, sensors accommodation and selection trade-offs, PMA actuators sizing and accommodation on the platform, preliminary design of the system state estimation and controller (based on use of harmonic control) with high tolerance to delays and knowledge error, and limited sampling frequency by design
- Detailed design with system modelling (full dynamics, disturbances with static & dynamic imbalances and coupling effects, sensors, actuators, controller, system delays), controller detailed design and robust tuning
- Detailed simulations and analysis of the control system performance, with sensitivity performance analysis for each of the disturbances
- Detailed conclusion, with quantitative synthesis on the performance and programmatic gain for using such architecture and techniques in future missions.

Deliverables:

Report - Documentation of the work: mission definition, architecture definition and trade-offs, detailed design and tuning, detailed modelling, and detailed performance analysis
Software - System controller including estimator algorithms and tuning parameters
Software - High fidelity simulator (dynamics with flexible modes and disturbances, sensors, actuators, and controller with estimator integrated)

Increased integration time for LEO optical payloads with Fast Steering Mirror

Title: Increased integration time for LEO optical payloads with Fast Steering Mirror				**Budget (K€):**	**250**
				Duration (m):	**12**
Reference: 6469		**Harmonisation:** - -	**Application Domain:** EO - Earth Observation	**Programme:**	**TDE (TRP)**
TRL	**Initial:** 2	**Target:** 3	**Need/Push:** TANGO or SCOUT mission with Optical P/L	**Procurement:**	**C**

Objective(s):

To develop Fast Steering Mirror control based acquisition mode or Optical-based solution (optical component moving) to enable a cost effective increase of the integration time for LEO optical payloads

Description:

On Low Earth Orbit (LEO) missions, small optical payload with small aperture may require specific attitude guidance and control for an image scrolling 'slow down' motion, in order to achieve sufficient integration time and Signal over Noise Ratio (SNR). This is also the case for TANGO mission. However such a solution has a strong and costly impact on the platform design (eg actuators sizing for rotating the whole satellite) and on the mission availability (time spent to accelerate, and decelerate the satellite rotation, and to repoint the instrument towards the different targets).
The proposed study aims at overcoming the above drawbacks for optical payloads integrating a Fast Steering Mirror (FSM), by controlling its pointing to achieve the 'slow down' motion and the increase of the integration time. Indeed the FSM is faster to rotate and re-point than the whole satellite, it has less constraints on its guidance (slow down motion less or not dependent from the target direction in Local Orbital Frame) and it prevents a complete resizing of the attitude control actuators (and possibly also sensors for following accurately the guidance).
Another option to be investigated and traded-off (pending the use case specificities) is to move a optical component within the instrument (e.g. a lens or a powered mirror), instead of the FSM, to achieve the same objectives.

The following tasks are considered:
- Selection of 1 or 2 missions (1 LEO, second one may be GEO) with a need for increased integration time (a preliminary overall optical design is to be available in the consortium as a prerequisite) and definition (mission and system requirements, dynamic properties, optical design and optical performance requirements including Wave Front Error & distortion)
- Trade-off on the solution retained for improving the integration time: FSM-based or Optical-Component-based solution
- System architecture definition: requirements flow-down, compensation system (FSM and/or another optical element), FSM accommodation, and compensation design trade-offs including guidance profiles, optical element size, actuators sizing and sensors selection
- Detailed system design and tuning , including guidance generation, controller with estimator, and detailed modelling (dynamics, GNC system and Optical system)
- Detailed simulations and performance analysis (LOS pointing, optical performances, instrument performances with SNR and Modulation Transfer Function)
- Conclusion

Deliverables:

Report - Documentation of the work: mission definition, architecture definition and trade-offs, detailed design and tuning, detailed modelling, detailed performance analysis
Software - High fidelity simulator (dynamics with flexible modes, sensors, actuators, controller with estimator integrated, and optical performance models)
Software - System controller including estimator algorithms and tuning parameters

Moon landing with navigation constellation support

Title: Moon landing with navigation constellation support				**Budget (K€):**	400
				Duration (m):	18
Reference: 6472		**Harmonisation:** - -	**Application Domain:** EXP - Exploration	**Programme:**	TDE (TRP)
TRL	**Initial:** 3	**Target:** 4	**Need/Push:** Future Moon (and possibly Mars) landers	**Procurement:**	C

Objective(s):

To assess the implications of the availability of a navigation constellation (e.g. LCNS) on the on-board GNC system for descent and landing on the Moon.

Description:

The availability of a navigation constellation around the Moon (the Lunar Communication and Navigation Services - LCNS) has the potential to integrate the GNC system capabilities as currently foreseen on Moon landers (e.g. EL3) to generate increased navigation performance, or increased robustness, or a relaxation of the requirements on the GNC sensors (thereby providing cost savings) or a combination of the above.
The activity will assess the fusion of the output of a navigation receiver that uses the navigation signals provided by the lunar navigation constellation with the lander equipped within a typical GNC sensor suite, including VBN (taking as reference the EL3 GNC architecture) together with realistic descent trajectories including divert manoeuvres. The baseline LCNS constellation architecture and different levels of reliability/availability will be considered.
The activity will include the following tasks:
- Development of a data fusion algorithm capable of fusing the output/measurements of a receiver using the navigation constellation signal with the on-board GNC sensors. This task will address known challenges of current GNC solutions such as the divergence of a navigation filter that only relies on absolute navigation (based on vision).
- Develop or adjust the on board integrity and FDIR mechanisms considering the addition of the lunar navigation receiver in the GNC suite. The filter design shall account for the possible different constellation configurations as well as provide a monitoring of signal mismodeling to address different levels of reliability/availability of the navigation signal. At the same time, the lunar navigation receiver output might allow monitor the reliability of currently used GNC sensors thus relaxing reliability figures and potentially overall cost and complexity.
- Evaluation of scalability of GNC design aiming at reduction and/or less performing on-board sensor suite to reduce cost and SWaP.
- Evaluating mission performance (landing accuracy, etc) or mission robustness versus different levels of navigation knowledge during approach and landing.
- Development of a simulation environment to support the V&V of the navigation filter as well as the trade-off studies for scaling of the GNC system.

This activity could serve as the baseline for preliminary design of a similar concept for Mars applications as well as possibly provide inputs for the definition of requirements for a Martian navigation constellation.

Deliverables:

Report - Technical documentation
Software - Prototype of navigation algorithms

Smart launcher - Autonomous MVM and monitoring systems for safe and adaptable launcher GNC systems

Title: Smart launcher - Autonomous MVM and monitoring systems for safe and adaptable launcher GNC systems				**Budget (K€):**	500
				Duration (m):	18
Reference: 6474		**Harmonisation:** - -	**Application Domain:** ST - Space Transportation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Technology push for all future space transportation systems		**Procurement:**	C

Objective(s):

To develop on-board functions within the GNC system that enable a progressive evolution from pre-computed robustness to embedded autonomy in the execution of a launcher mission

Description:

Modern launch systems are faced with a number of technical challenges, such as the following:
- stage fall-down management (e.g. minimisation of splash-down area)
- autonomous handling of no-fly-zones
- adaptive (e.g. payload-independent) flight programme
- autonomous structural loads management
- safe engine operation via lifetime preservation and active adaptation
- health management of subsystem component degradation

While means exist to handle some of these challenges at the expense of time-consuming and costly design, V&V, and mission preparation (missionisation) processes performed on ground, a paradigm shift can be envisaged whereby embedding autonomous funcitonalities on-board would allow to address the above challenges in a more efficient, and ultimately safe manner. The approach consist in transferring monitoring, control, optimisation, and decision-making capabilities on-board such that the currently achieved pre-computed robustness of a launch mission is replaced by enhancing the operational autonomy of a launcher while monitoring its safety on-board.

The following on-board functions are considered enablers for such operational autonomy:
- real-time optimised guidance and integrated low level adaptable control
- adaptive sensor fusion, including model-based and data-driven monitoring and detection (e.g. online stage fall down propagator via GNSS/INS fusion)
- on-board wind estimation system (leading to angle of attack and heat flux estimates)
- on-board system identification (e.g. local structural loads, flexible mode identification)
- on-line mission performance monitoring
- on-line safety margin assessment (via real-time reachability, robust performance analysis, etc.)
- MVM with enhanced decision-making capabilities (e.g. by on-board adaptation of optimisation criteria, either model-based or data-driven)

In this activity, a GNC system prototype, including all relevant algorithms, will be designed, tuned and autocoded into a GNC SW prototype that will be verified on a suitable simulation environment.

The envisaged tasks are the following:
- Review the state-of-the-art and the proposed concepts for safe operational autonomy
- Design the on-board functions identified as enablers for such safe operational autonomy
- Tune these on-board functions for a reference launch vehicle and multiple launch scenarios
- Autocode the GNC SW prototype
- Define and implement a V&V plan
- Define a plan for TRL maturation

Deliverables:

Report - Technical documentation for design, tuning, and V&V
Software - SW prototype of safe autonomous functions for a "smart launcher"

Smart launcher - Verification & validation of safe autonomous GNC systems for launchers

Title: Smart launcher - Verification & validation of safe autonomous GNC systems for launchers				**Budget (K€):**	400
				Duration (m):	18
Reference: 6484		**Harmonisation:** - -	**Application Domain:** ST - Space Transportation	**Programme:**	TDE (TRP)
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Technology push for all future space transportation systems		**Procurement:**	C

Objective(s):

To define a comprehensive launcher V&V framework, including the required toolset, in order to improve the current practice and to enable appropriate verification of future safe autonomous GNC systems.

Description:

Current launcher V&V processes are a major driver in cost and schedule and they are not adequate to cope with the evolving GNC architectures and topologies driven by autonomy.
Identified shortcomings of the state-of-the-art in launcher V&V are the following:
- Coverage using Monte Carlo approach is limited due to numerical inefficiencies in modelling and simulation time
- Current analysis tools are limited in addressing model uncertainties, nonlinearities and dynamical interactions
- A gap exists between analytic and simulation-based V&V techniques
- Because of the above, safety margins need to be embedded into the design, which affect performance
- All the above ultimately results in large cost and development times

This activity addresses the shortcomings listed above by developing an integrated framework that will bridge the gap between analytic and simulation-based tools. Essential elements of this framework are:
- Advanced uncertainty modelling tools to permit reliable robustness analyses such Stochastic Mu analysis and IQC analysis (to analyse systems with linear time-varying (LTV) parameters, neglected dynamics, delays, specific non-linearities such as friction or hysteresis)
- Deterministic and stochastic uncertainty modelling and quantification techniques (surrogate models, LFTs) together with their validation (physical modelling and experiment)
- Advanced stochastic worst case simulation based analysis tools (e.g. cross-entropy-based)
- Reachability analysis (to determine the maximum operational freedom for the system states while ensuring system safety)
- Simulation-based techniques (including data-driven V&V techniques such as machine learning-based methods, empirical risk minimisation via neural networks, etc).

The tasks envisaged in this activity are the following:
- Review the state-of-the-art techniques for V&V of autonomous systems addressing the techniques mentioned above
- Define a framework based on these techniques that would support the V&V of a modern autonomous launcher (e.g. to guarantee that the interactions among control loop, real-time optimised guidance, high-level MVM decision layer, and perception layer are synchronized and not conflicting)
- Develop a SW tool that implements the framework (including approaches to define models that are adequate for the application of these techniques)
- Validate this toolset using a launcher benchmark (including a comparison with traditional V&V process)

Deliverables:

Report - Analytical framework design
Report - Toolset user manual
Software - Toolset for V&V of safe autonomous GNC systems for launchers

On-board digital chain for High Resolution (1-2m) optical imagers

Title: On-board digital chain for High Resolution (1-2m) optical imagers				**Budget (K€):**	**900**
				Duration (m):	**24**
Reference: 6507		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics D30	**Application Domain:** EO - Earth Observation	**Programme:**	**TDE (TRP)**
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** Mission Need: >TRL6 needed in 2022		**Procurement:**	**C**

Objective(s):

Define a generic functional architecture with:
- Sensorless WFE sensing
- Digitally stabilized superresolution/TDI
- Onboard Analysis Ready Data

Design, dev. & validate functions HW/SW feasibility

Description:

Background/justification
Digital processing solutions are a major contributor to the performance delivered by optical instruments. They allow for more cost-efficient missions and less complex instrument designs as image-based solutions may remove the need for specific HW (e.g. WFE sensors) and relax major requirements such as line of sight stability
Moreover, there is also an increasing need for data analysis on board to enable more autonomy and/or a faster and more cost-efficient delivery to end users. However, the results achieved so far are still suffering from a general lack of pre-processing solutions (co-registration, reflectance conversion, orthorectification, etc) whose implementation on board would significantly improve the data quality and usability
Availability of “standard” pre-processing engines will allow the re-use of HW and SW building blocks across diverse missions

Tasks
Define an updated generic reference on-board digital processing functional architecture by identifying:
- o EO usecases to address all common and application-specific functions. Mission requirements to be flowed down into preliminary functional performance requirements
- o All relevant interfaces and dependencies (e.g., optical sensors, active optics, avionics, data handling units, ground processing/operations, instrument design, radio/geo-metric calibration parameters, etc.)
- o Preliminary breakdown by potential components (FPGAs, processors, SoCs, COTS)

For each main novel functional element (WFE sensing, digital stabilization, Analysis Ready Data), the following will be done:
- Select specific use-case(s). Consolidate performance requirements
- Identify and review candidate algorithmic approaches. Define a justified baseline selection based on functional performance vs. complexity assessment (trade-off)
- Dataset generation, addressing target mission (representative instrument simulation) and target processing function
- Detailed design, implementation and performance validation of reference functions (golden models) in a high level language (+ respective ATBDs & test vectors)
- Feasibility assessment for critical functions (TBD within the activity) through validation on simulated (HW) environment and/or SW deployment
  oPlus, breadboard prototyping for digitally stabilized TDI with super-resolution
- Recommend future work

The Agency shall have the right to include the ATBDs & reference SW in future ITTs (e.g. dev. of IP-cores or flight SW libraries)

Deliverables:

Breadboard - HW implementation for digitally stabilized TDI with super-resolution
Other - Algorithm Theoretical Basis Documents describing all the algorithms developed.
Report - Report the work done (trade-offs, description of the digital chain architecture, targeted performance requirements, feasibility assessment, etc.)
Software - Reference models of the digital chain, including datasets, test vectors, as well as preliminary HW/SW prototypes (where available).

Adaptive control and metrology for large deployable appendages

Title: Adaptive control and metrology for large deployable appendages				**Budget (K€):**	**250**
				Duration (m):	**10**
Reference: 6526		**Harmonisation:** - -	**Application Domain:** EO - Earth Observation	**Programme:**	**TDE (TRP)**
TRL	**Initial:** 2 **Target:** 3	**Need/Push:** EO missions with large deployable appendages		**Procurement:**	**C**

Objective(s):

Develop adaptive control & metrology for large deployable appendages enabling cost effective mission and improved deployment time for collision avoidance

Description:

More and more Earth Observation missions require the deployment of large appendages (e.g. antenna, mirrors) like on Biomass, CIMR or Cryorad. Enabling these deployment capabilities has a strong impact on the complexity and cost of the Attitude and Orbital Control System (AOCS) with complex design & tuning, and related operations. In addition, these deployment activities take a lot of time (several steps with for each pointing & battery state of charge convergence) which may be critical with regards to the collision avoidance, as no orbit control manoeuvre may be allowed during the deployment.

In order to mitigate these drawbacks, several developments are considered.
- The adaptive AOCS control with robust Linear Parameter Varying (LPV) techniques could enable to perform in single step the tunings of the AOCS controllers for the different dynamic configurations/deployment steps. This would also reduce the number of operations
- The deployment state metrology, and related control could enable the on-board confirmation of the deployment step success and the autonomous transition to Normal Mode. In case of failed deployment, this system would still be beneficial to optimise the attitude/rate control bandwidth.

The activity encompasses the following tasks:
- Mission selection (based on EO use cases) and definition (requirements, modes architecture, dynamic properties over the deployment, including unlatched/deployment failure cases, disturbances)
- Literature review (LPV techniques, metrology with control)
- Normal and Safe Modes controllers detailed design and tuning with robust LPV techniques, considering 2 satellite configurations / deployment steps for the Normal Mode and the Safe Mode: with 2 scheduling parameter values for the Normal Mode and one for the Safe mode (covering previous and current steps two times).
In addition this task also has to consider the deployment ratio (between 2 configurations) and the dynamic state (adaptive rate bias always used in Normal Mode and based on available momentum and pointing and rate errors, safe mode with adaptive target momentum based on pointing and rate errors).
- Deployment state metrology conceptual design (focused on control aspects, with no hardware development) with related control and sub-modes: The stimulation has to be designed to determine the system state without damaging the possibly unlatched mechanism.
- Detailed system modelling, simulations and analysis of the control performance

Deliverables:

Report - Documentation of the work: mission definition, and literature review, detailed design and tuning, detailed modelling, detailed performance analysis
Software - Modes & submodes manager, Controllers including estimator algorithms and tuning parameters
Software - High fidelity simulator (dynamics with flexible modes in both latched and unlatched states, sensors, actuators, controller with estimator, disturbances)

Advanced Techniques for Momentum Management with Thruster Orientation Mechanisms

Title: Advanced Techniques for Momentum Management with Thruster Orientation Mechanisms				**Budget (K€):**	400
				Duration (m):	18
Reference: 6722		**Harmonisation:** - -	**Application Domain:** TEL - Telecommunications	**Programme:**	TDE (TRP)
TRL	**Initial:** 2	**Target:** 3	**Need/Push:** Technology push	**Procurement:**	C

Objective(s):

To improve the spacecraft momentum management with autonomous and optimal control of thrust orientation, enabling Reaction Wheel capacity reduction.

Description:

Modern Telecom/GEO Satellites employ electric propulsion thrusters for both Orbit Raising phase and Station Keeping. Gimbaled electric Thrusters via thruster orientation mechanisms (2 or 3 degree of freedom) are typically used both for orbital maneuvers (e.g. North-South Position in Station Keeping) and concurrently management of the on-board momentum by unloading the reaction wheels.
Conventional unloading strategies are often executed via controlled operations (e.g. sequence of programmed TOM angles along the orbit to ensure proper Thrust vector orientation). AOCS estimates the on board S/C momentum and controls the TOM angles in closed-loop to limit the angular momentum storage due to both the thrust misalignment with respect to the S/C centre of gravity and the environmental disturbance torques, while satisfying multiple constraints such as TOM allowed angular range, TOM activation cycles, consumption, wheel capacity and collocation (if any). Large wheels are typically employed for this reason, thus increasing S/C overall mass.

The proposed activity consists of investigating advanced on-board optimization methods to control the TOM angles in optimal way and efficiently manage the on-board momentum, such to increase the on-board autonomy (less dependency on ground, autonomous generation of TOM angle profiles), minimize the maximum required wheel capacity while satisfying mechanisms constraints such as maximum number of activation cycles and minimising consumption.

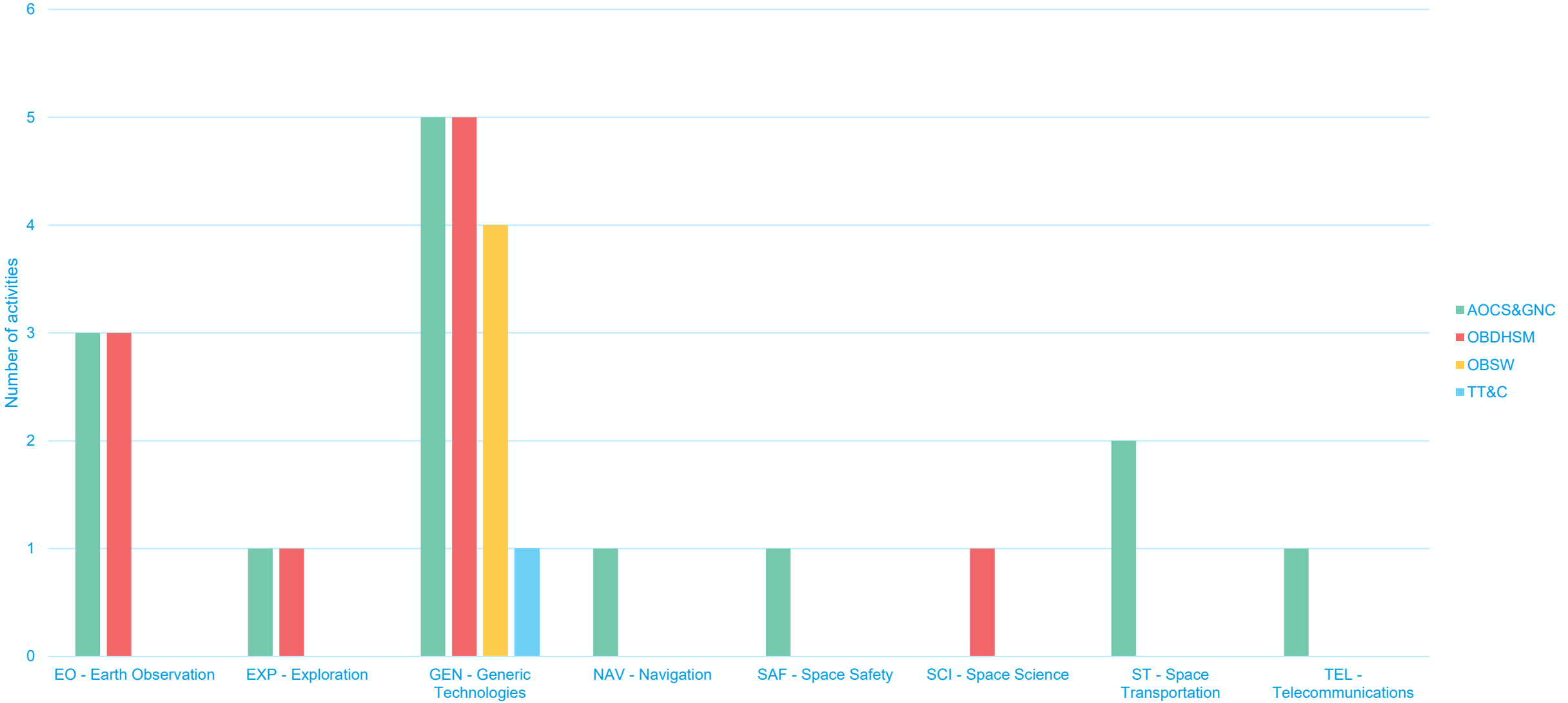
The activity is dedicated to GEO Telecom missions, taking into account their specifics in terms of sensor and actuator architecture, as well as AOCS design drivers and mission/operations constraints. Gain on Reaction Wheel offloading need is expected to be in the range of 30%, on top on operational cost decrease thanks to autonomous TOM guidance during EOR.

The activity is organised in the following tasks:
- Task 1: Existing application cases selection including performance requirements, sensors and actuators selection, AOCS subsystem /modes design, mission and system constraints for thrust control optimisation
- Task 2: Optimisation methods survey & selection of the most promising one
- Task 3: Design & analysis applied to the selected use cases
- Task 4: Implementation in simulator, including multi-body dynamics modelling
- Task 5: Validation test campaign
- Task 6: Assessment of autonomy, performance and mass gain vs heritage design and implementation way forward

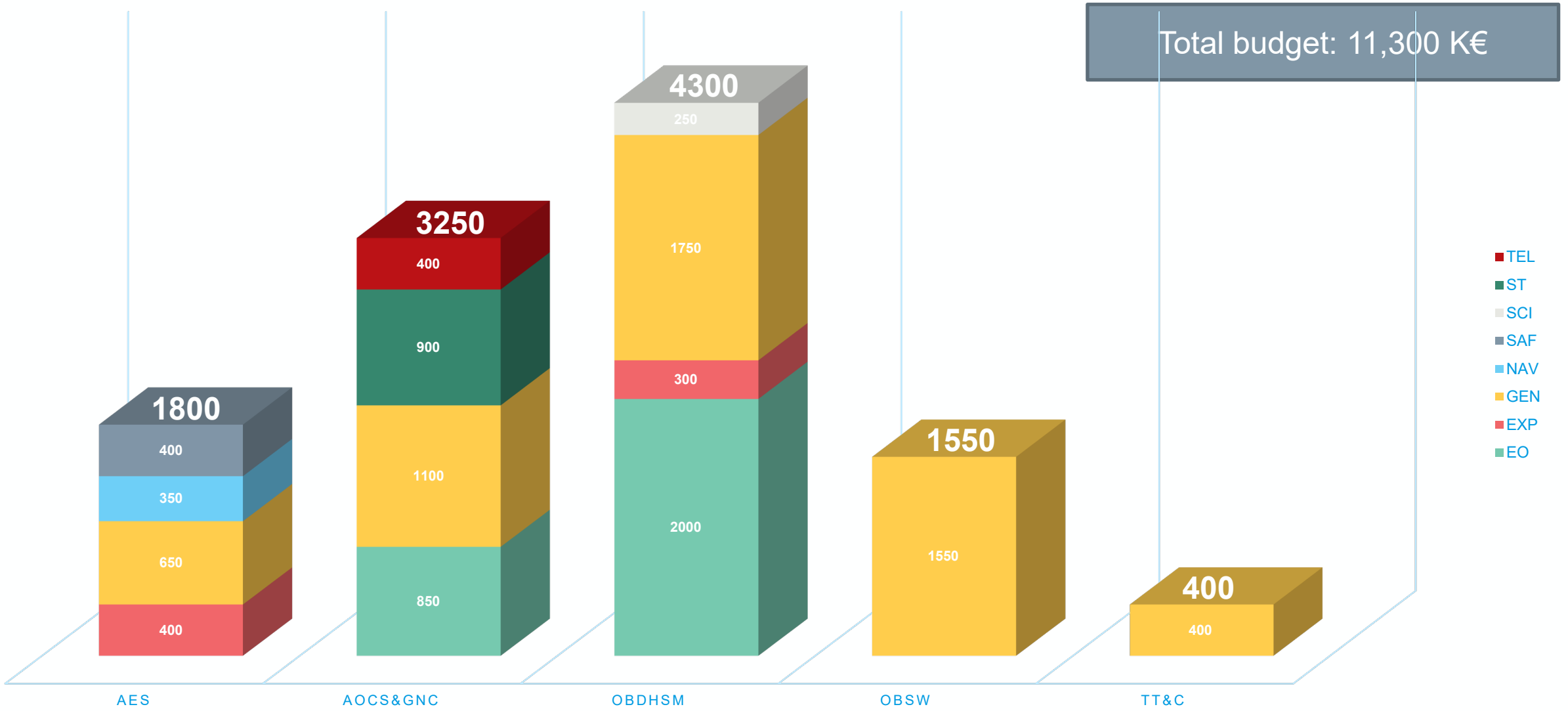
Deliverables:

Report - Analysis of multi objective constraints and survey of optimization techniques
Report - Validation of algorithms and application to reference use case
Report - Multibody simulator for generic use case
Report - Definition of on board algorithms for TOM control optimization

Summary per Application Domain (all TDE)



Summary per Technological Domain (all TDE)



CD03 - GSTP compendium

Reference	Title	Budget (k€)
	RISC-V Instruction Set Architecture simulation model and emulation in Virtual Platform for hardware-software codesign	500
	RTEMS SMP Extensions qualification	700
	Support for satellite mode definition, RAMS, FDIR and autonomy concept	800
	Attitude Determination and Control System (ADCS) Kit development for Nanosats	1000
	OBPMark benchmarks for on-board data processing	800
	End-to-end on-board data handling architecture based on optical high-speed links	1200
	Image Processing and Navigation architecture evolutions	750
	Model-based execution platform for space applications	1000
	Low-SWaP hybrid deep-space transponder for outer planets missions	1200
	Moon/Mars Relay Constellation RF simulator system	900
	GNSS antenna for lunar applications	1000
Total		9,850

Model-based execution platform for space applications

Title: Model-based execution platform for space applications				**Budget (K€):**	1000
				Duration (m):	30
Reference: 6801		**Harmonisation:** Avionics Embedded Systems A02	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 4 **Target:** 5	**Need/Push:** All missions will benefit from the results of the activity.		**Procurement:**	C

Objective(s):

To develop a model-based environment for configurable execution platform

Description:

The activity is aiming at developing a modelling environment targeting the automatic generation of the execution platform of payloads and platforms. It builds on top of the results of the previous activities in the domain (CoRA, PEPS). The modelling environment shall support the development and generation of execution platforms following a model-based approach considering already existing building blocks (PUS library, OBCP, MLFS, etc.). This includes the modelling of the overall software architecture and building blocks, the support of configuration of the models covering both the functions to be supported and their deployment on specific hardware (e.g. micro-controller for Cubesats and MPSoCs for large spacecraft).
The demonstration of the approach shall rely on representative uses cases covering different configurations, e.g. small and large payload and platforms, different executive kernels (e.g. RTOS and TSP), etc.

The activity encompasses the following tasks:
- Identification of representative use cases covering different size of spacecraft, platform and payloads and executive kernels with example applications (e.g. data processing for payload and spacecraft mode management)
- Selection of the modelling environment, selection of the architecture and functions to model (OBCP, PUS, MLFS, etc.), selection of the target (preferably multi-core or MPSoC - representative hardware or simulated environment) for the deployment.
- Update of the modelling environment to support the objectives of the activity including the development of the automatic generator(s) able to generate the code (software and possibly HDL if SoC device is selected) of an execution platform for a particular target environment corresponding to a configuration identified at model level.
- Validation of the model-based execution platform tool(s) through:
  - the modelling of an execution platform architecture considering the needs and the support of configurations identified by use cases,
  - the generation of the execution platforms and the execution of applications identified in the use cases.

Deliverables:

Software; Software

Support for satellite mode definition, RAMS, FDIR and autonomy concept

Title: Support for satellite mode definition, RAMS, FDIR and autonomy concept				**Budget (K€):**	800
				Duration (m):	24
Reference: 6819		**Harmonisation:** Avionics Embedded Systems B06	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 4 **Target:** 5	**Need/Push:** Modelling RAMS, FDIR and autonomy concepts earlier in the development process		**Procurement:**	C

Objective(s):

To develop support for the engineering of the operations and FDIR concept in a model-based approach

Description:

The operations and FDIR concept are currently engineered in a highly paper-based manner. With increasingly complex systems analysing dependencies between subsystems configurations as well as failure propagation and verification of failure and recovery actions becomes very challenging, typically leaving significant development risk in the C/D stage as assessment is currently solely based on inspection and review.
The AAML study defined several analyses that are relevant to the engineering of an avionic system and that are useful for performing trade-offs. Further, it implemented proof-of-concept modelling concepts and associated tooling for 3 types of analysis, i.e., commandability/observability, bus load and data latency, on-board functions, and performance. These analyses are performed based on a single system model that carries the information relevant for each analysis. As such, consistency is ensured between the views that the various disciplines have of the system.
The activity shall follow the recommendations, design, and processes from the SAVOIR FDIR handbook, SAVOIR-HB-003.

Tasks include:
- the definition of RAMS requirements and assessment of all RAMS analysis that shall come in support to FDIR definition at system and subsystem level.
- capture FTA and FMEA analysis (or any other relevant RAMS analysis identified in the first task), at system level, unit level and equipment level thereby consolidating the inputs for the global operations concept and FDIR design as early as possible in the life cycle. The model will enforce consistency of information across these hierarchies and enable failure propagation analysis with (existing) model-based analysis techniques such as COMPASS, thereby assisting verification activities at PDR and CDR by targeting critical areas and assessing system level impacts from all failure scenarios, their interdependence with modes shall be considered.
- capture the functional flow of the system modes, this functional flow will be used in the identification of where FDIR is acting in relation to modes.
- capture system modes definition with link to subsystem modes and hardware configurations.
- build the FDIR strategy by linking failure modes to observables and reconfiguration actions and by checking the overall consistency and compatibility with the RAMS requirements.
- capture all lessons learned and recommendation. This will also identify any lessons learned with respect to the SAVOIR FDIR handbook.

Deliverables:

Software

RISC-V Instruction Set Architecture simulation model and emulation in Virtual Platform for hardware-software codesign

Title: RISC-V Instruction Set Architecture simulation model and emulation in Virtual Platform for hardware-software codesign				**Budget (K€):**	500
				Duration (m):	18
Reference: 6851		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics J20	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 3	**Target:** 5	**Need/Push:** Technology Push. TRL5 by 2024.	**Procurement:**	C

Objective(s):

Develop a simulation model of a RISC-V Instruction Set Architecture (ISA) processor and peripherals, in a suitable hardware-software co-design environment, and perform design space exploration of a System-on-Chip.

Description:

RISC-V is an open-source and royalty-free hardware instruction set architecture (ISA) based on RISC principles. An open ISA is remarkably interesting for space, for several reasons: it reduces potential difficulties in license negotiation or export restrictions, it allows to perform modifications for radiation mitigation, or add or modify instructions to execute functions that are frequently required by space applications, such as bit manipulation, sub-word arithmetic, vector or SIMD computations…
RISC-V has been gaining popularity in the past years, and its use in space is now close to a reality thanks to several on-going System-on-Chip (SoC) developments that will embed RISC-V multi core processor, along with several other interfaces to enable their use in satellite payloads and platforms, such as SpaceFibre, TM/TC or cryptographic functions.
The successful adoption of this architecture and embarking of the future SoC depends in a great extent on the features of the hardware, and also on the availability of software development tool chains that enable the programming of the cores with suitable on-board software.
Hardware and software developments around RISC-V can benefit greatly from the hardware-software co-design development flow, which simultaneously considers hardware and software within the design process. This enables the co-development and co-verification of hardware and software through the use of simulation and/or emulation with the help of tools such as Virtual Platforms where simulation models of the processor ISA, and models of other components of the SoC can be executed at different levels of abstraction, and with the required simulation speed. In particular a fast ISA simulator of RISC-V facilitates early software development and the development software tool chains. All this before the first hardware prototypes are available.
ESA has promoted the development of the SoCRocket Virtual Platform, which has been made available to missions and projects. This platform is comprised by several functional blocks, and can be used to simulate a System-on-Chip, but at the moment, only LEON based systems are currently supported (AT697, SCOC3, GR712, and NGMP).

The main tasks to be accomplished are:
- Assess the suitability of a Virtual Platform to simulate a RISC-V based SoC taking into account trade-offs related to accuracy of the models and simulation speed, considering SoCRocket and possible alternatives.
- Create a simulation model of the RISC-V Instruction Set, that can be integrated in a Virtual Platform, directly or through an emulator, and aid the development of software.
- Develop and integrate new functional blocks in a Virtual Platform, such as: SpaceFibre, TM/TC functions, cryptography, Ethernet.
- Perform design space exploration in a RISC-V based multicore model of a System-on-Chip.

Deliverables:

Prototype; Prototype; Prototype; Report

Moon/Mars Relay Constellation RF simulator system

Title: Moon/Mars Relay Constellation RF simulator system				**Budget (K€):**	900
				Duration (m):	24
Reference: 6763		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 3 **Target:** 5	**Need/Push:** Relay constellation missions for moon/mars		**Procurement:**	C

Objective(s):

Develop a RF relay communications constellation simulator system including modeling full (set of) satellite transmitters and receivers

Description:

There is a strong interest in the development of data relay constellations for planetary exploration and navigation. All the Space Agencies are studying or developing data relay and navigation constellations for Moon and ultimately for Mars.
A RF relay constellation simulator system for Moon (and then upgradable to Mars) is considered an asset to support the development of the constellations and, more importantly, to support the development and test of the user terminals in a “real world”.
The objective of the activity is hence to develop a RF simulator of a data relay constellation.
The simulator shall be able to interface via RF with a user terminal unit and to:

- Model full satellite constellation transmitters and receivers;
- Emulate the user terminal spacecraft dynamic motion on planet surface, orbit, or during descent and ascent from the surface: Doppler, Doppler rate and delay;
- Emulate the relay satellite dynamic motion in orbit: Doppler, Doppler rate and delay;
- Emulate Tx and Rx antenna gain and phase patterns of the relay satellite and of the user spacecraft host;
- Emulate the interference generated by the multiple transmitters of the constellation;
- Emulate multipath effects;
- Emulate any atmospheric attenuation or delay effects (for Mars case)
- Emulate the (two way) range measurement function of the relay link to characterize the performance and functionality

The RF relay simulator shall emulate the constellation signals in S-band and K-band in a modular fashion (i.e. S-band module independent from K-band module). The RF constellation system shall employ software in the loop and hardware in the loop techniques to allow the user to design the test scenarios and to control external hardware blocks. The main goal is to have full control of all aspects of the user operating environment, to enable exact repeatability of the test and to allow the application of systematic errors or incidents that are normally impossible to verify or not tested during the RF compatibility tests. The emulation of the relay satellites shall be configurable to emulate different relay systems such as different (type of) moon or mars constellations. The application of the proposed development covers both TT&C and Communication needs.
Tasks:
1. Requirements Consolidation
2. Architectural and Detailed Design
3. Implementation
4. Test and Demonstration

Deliverables:

Prototype

GNSS antenna for lunar applications

Title: GNSS antenna for lunar applications				**Budget (K€):**	1000
				Duration (m):	15
Reference: 6804		**Harmonisation:** On-Board Radio Navigation Receivers E09	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 5 **Target:** 7	**Need/Push:** Arianne Group Astris kick stage (instrument in support of autonomous orbit determination) Lunar Gateway (potential collaboration with NASA as part of the Gateway Utilization Experiments)		**Procurement:**	C

Objective(s):

to design, develop and validate an engineering model of a GNSS steerable antenna for lunar GNSS applications

Description:

The use of GNSS signals in lunar orbit has been demonstrated on ground via high fidelity simulations in ESA and NASA and NASA demonstrated the reception of GNSS signals in the MMS mission in 2019, flying at about half the distance to the moon. The use of GNSS in lunar missions can significantly reduce the operational costs and complexity, allowing to achieve below 100m orbit determination on board in real time without the need of expensive ground stations. This technology can support lunar exploration missions (e.g. Lunar Gateway, Cis Lunar Transfer Vehicle, etc), launchers for lunar missions (e.g. Arianne6 ASTRIS kick stage) and the Moonlight navigation service (being the GNSS receiver one of the technologies proposed to be used for orbit determination and time synchronisation of the Moonlight navigation satellites).

The development of GNSS lunar receivers has been started in the agency in the past years and the first demonstration is planned to fly in lunar orbit as part of the lunar pathfinder mission in 2025. This demonstration mission is using a fixed antenna, requiring the satellite to change attitude to perform the experiment. Even if sufficient for a demonstration mission, this approach is not adequate to cover the needs of operational missions.

The objective of this activity is to design manufacture and test an antenna that can guarantee the minimum signal over noise ratio for the functionality of the navigation system, guaranteeing the necessary accuracy in positioning navigation. The activity shall cover, at least, the following points:
- critical review of the requirements based on the mission needs;
- critical review of the antenna technologies and configurations. A trade off shall be performed based at least on: performance, mass, volume, power consumption, stowed volume, cost;
- design manufacture and test the final selected configuration .

The activity is expected to deliver documentation and Hardware prototype (EQM – Engineering Qualification Model including antenna and mechanisms in case of mechanical steering).

Deliverables:

Engineering/Qualification Model; Report

RTEMS SMP Extensions qualification

Title: RTEMS SMP Extensions qualification				**Budget (K€):**	700
				Duration (m):	24
Reference: 6820		**Harmonisation:** On-Board Software C03b	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 3	**Target:** 5	**Need/Push:** 2023-2024	**Procurement:**	C

Objective(s):

Qualification perimeter extension of RTEMS-SMP (multi-core Real Time Operating System) for a much broader set of missions (including safety critical ones).

Description:

A particular version of the RTEMS SMP on-board operating system has been pre-qualified in the frame of another activity (G617-254SW) . The qualification perimeter of that version was constrained to a limited number of aspects.

In order to support a broader number of missions, it is proposed to extend the qualification perimeter in different ways (additional services and APIs, new target platforms, level of qualification of the software, additional drivers, toolchain improvement...).

These activities could include for example performing the delta activities needed to fulfill software criticality A requirements typical for safety critical applications.

Starting from the RTEMS-SMP version resulting from the RTEMS SMP qualification activity (G617-254SW) , the tasks requested are the following:

1) Consolidation of qualification extension options. This can be based on the qualification profile survey identified during the RTEMS SMP qualification.
2) Extension of the RTEMS SMP qualification test suite and qualification datapack to cover for the new extensions.
3) Analysis of the code and documentation of the new qualification perimeter, and adoption of changes as needed.
4) Generation of the documentation, artefacts and code needed to achieve the pre-qualification objective.

Deliverables:

Report; Software

Attitude Determination and Control System (ADCS) Kit development for Nanosats

Title: Attitude Determination and Control System (ADCS) Kit development for Nanosats				**Budget (K€):**	1000
				Duration (m):	18
Reference: 6815		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 3	**Target:** 6	**Need/Push:** Mission Need (nanosat market, pot. scalable to smallsat)	**Procurement:**	C(1)

Objective(s):

To develop an Attitude Determination and Control System (ADCS) Modular and Reliable Kit for nanosat platforms, making use of European state-of-the-art ADCS units, automation of code generation (for on-board SW & ground models) and Avionics hardware for nanosat form factor

Description:

The European nanosat market is expanding, together with the variety of mission applications. Nanosats are being adopted for operational missions in several domains, a performant and reliable configurable AOCS module is required to be cost and schedule competitive

One trend is to aim to ambitious missions in terms of ADCS performance, robustness and reliability. The ADCS development process, tailored to nanosat economy, and in particular solid & efficient Validation and Verification (V&V) are key success factor for producing ADCS system at the quality level expected for the coming nanosat missions. Improvement of the European Nanosat AOCS system is needed at definition and process level, together with taking benefit of automation of code generation or other cost-efficient production techniques.

The activity aims to develop an ADCS modular/reliable system providing a European top quality subsystem, making the use of the most adequate state-of-the-art ADCS hardware units, as well as avionics hardware, and benefiting from the automation of code generation and test generation for the ADCS SW production and the development of ground support models for AOCS V&V.

The activity will proceed to the ADCS development up to the Verification on an engineering model. The first part of the activity will be dedicated to establish the ADCS specification, based on ESA & Users survey, up to the flow down at ADCS unit and verification means level. MBSE for this step should be considered. Then ADCS hardware selection will be managed, taking into consideration performance, robustness, flight heritage and leading to complementary verification as needed, to ensure quality level for the overall system. The ADCS functional design will be based on a modular functional architecture, with options on the mode/submode functionalities to allow easy customisation of the subsystem for each user mission (Earth orbits). The ADCS SW architecture together with processing solution will implement the modular functional architecture of the ADCS. ADCS V&V will be ensured in an agile continuum of testing on simulator, numerical facility and engineering model including the ADCS hardware models. Specific care will be ensured in the development/(re-)use of the ground testing simulators and facilities (environment and dynamic models, interfaces, harness, synchronisation, etc...)

Task list:

- ADCS system (and verification means) specification
- ADCS architecture design and preliminary justification incl. HW selection and procurement (start.)
- ADCS detailed design and validation
- ADCS engineering model integration and testing
- ADCS design and compliance consolidation
- datasheet release, with supporting documentation
- continuation activities definition and roadmap planning (for complementary activities, extension of the product (line), process improvement, re-use plan, etc…

Deliverables:

ADCS datapack (specifications, design and justification technical notes, ADCS tuning and validation technical notes, ADCS SW documents, ADCS verification plan and results, VCD, PA documents -tailored to nanosat-)

ADCS engineering model

ADCS verification models and ground environment

ADCS SW

OBPMark benchmarks for on-board data processing

Title: OBPMark benchmarks for on-board data processing				**Budget (K€):**	800
				Duration (m):	18
Reference: 6814		**Harmonisation:** On-Board Computers, Data Handling Systems and Microelectronics D21	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 3 / **Target:** 4	**Need/Push:** Technology push		**Procurement:**	C

Objective(s):

This activity aims to finalize the implementation of OBPMark (On-Board Processing Benchmarks) and to promote a standard set of application-level computational performance benchmarks, as to enable a method of comparing end-user performance, availability and reliability of different devices and systems – such as both RHBD and COTS processors, FPGAs and ASICs.

Both classical on-board processing and machine learning applications are covered.

Description:

OBPMark has been initiated due to the lack of standard computational performance benchmarks for space applications. Traditionally, processing in space has been dominated by single core CPUs, FPGAs and dedicated ASICs. But as of late, several new device classes have been introduced for on-board applications, driven by influx of COTS components and need for flexible processing: Multicore processors, MPSoCs, array processors, many core DSPs, GPUs, VPUs (Myriad). Different device classes increase the difficulty for easily and accurately comparing computational performance, as well as availability and reliability under key on-board processing applications conditions.

As there are no standardized performance benchmarks, it increases the difficulty to accurately understanding the end-to-end achievable performance, availability and reliability of a system or device without performing costly case-by-case tests. This can drive the selection time for a component to late in the project, and increase risks for late changes or the need for several prototyping activities.

OBPMark has the following goals:

- To promote a standard set of application-level benchmarks, as to enable a method of comparing end-user performance, availability and reliability of different devices and systems – such as both RHBD and COTS processors, FPGAs and ASICs.
- To better understand limitations of different types of devices and systems and to quickly decide on division task in hardware and software for implementations in heterogeneous systems.
- To allow ESA to quickly provide recommendations for processing systems in future missions, through identifying key parameters together with the project teams
- Benchmark standard on-board processing functions, so that implementers will have the possibility for reusing the invested work in real-world use cases

Tasks:

1. Finalise the definition and implementations of the existing draft OBPMark benchmarks
2. Perform benchmarks, and power + performance measurements on a number of select RT, RHBD and COTS targets in radiation environment and during life test (possibly accelerated test) under key on-board processing applications conditions.
3. Publish the results

Deliverables:

Report; Report; Software

Image Processing and Navigation architecture evolutions

Title: Image Processing and Navigation architecture evolutions				**Budget (K€):**	750
				Duration (m):	24
Reference: 6807		**Harmonisation:** Avionics Embedded Systems A16	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 5 / **Target:** 6	**Need/Push:** Technology push addressing all missions relying on vision-based navigation		**Procurement:**	C

Objective(s):

To identify and develop the architectural evolutions that are needed in order to support the image processing and navigation functions on board future ESA missions.

Description:

Vision-based navigation is a key mission-enabling technique on a number of applications addressed in ESA missions, ranging from rendezvous and docking (e.g. MSR-ERO, ADRIOS), to missions to small solar system bodies (e.g. Hera, Comet-Interceptor), to precision landing (e.g. EL3, reusable launcher stages), to science (e.g. JUICE).
Advances in the processing technologies and SW architectures have the potential to increase the resources available on-board for image-processing and navigation algorithms, which could be enhanced and optimised to serve the next generation of missions relying on vision-based navigation.
The activity entails a multi-disciplinary approach whereby the architectural studies consider not only the physical architectures for execution of image and navigation processing (CPUs, FPGAs, ASICs, and possibly recent developments in the area of GPUs), but also the algorithmic and numerical implications intrinsic in the image processing and navigation functional design that affect the architectural design. A notable example is the performance optimisation attainable on repetitive processes through FPGA parallelization and pipelining. This HW/SW co-design approach will also take into account the specifics of several mission applications (and hence specificities of different image processing and navigation techniques) as well as practical implementation limitations or constraints applicable throughout the system life-cycle.
The activity entails the following tasks:
- Review the state-of-the-art on HW processors suitable for image and navigation processing (CPUs, FPGAs, ASICs, GPUs, etc.)
- Preliminarily define and trade-off suitable image processing and navigation architectures for a number of application scenarios, including at least: rendezvous and docking, precision landing, missions to small solar-system bodies, navigation in Jupiter orbit relative to Jupiter's moons
- Identify HW/SW solutions for each application scenario that can be easily inserted in a classical avionics architecture
- Develop a flexible and generic HW module or unit that can support image and navigation processing for the targeted application scenario
- Define and code the corresponding image-processing and navigation algorithms
- Autocode the algorithms into prototype flight SW
- Verify & validate the prototype flight SW in SW-in-the-loop, processor-in-the-loop, and hardware-in-the-loop test setups

Deliverables:

Engineering Model; Report; Software

End-to-end on-board data handling architecture based on optical high-speed links

Title: End-to-end on-board data handling architecture based on optical high-speed links				**Budget (K€):**	1200
				Duration (m):	24
Reference: 6811		**Harmonisation:** - -	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 2	**Target:** 6	**Need/Push:** Strong need for future missions with High Data Volume.	**Procurement:**	C

Objective(s):

Develop next-generation of products for end-to-end payload data handling architecture based on optical high-speed links.

Description:

In recent years, optical transceivers, Serializer/Deserializer (SERDES), and associated data transfer protocols reached a maturity level that makes a wider use on board spacecrafts feasible. Aside from reaching very high data rates of tens to hundreds of Gigabits per second, optical links are superior in terms of signal integrity, harness length, mass reduction, and fault isolation. However, there is a lack of standardization on both physical and protocol level at present and the advantages of optical communication for typical end-to-end payload data handling systems (including e.g., instrument control units, mass memory units, and payload transmitters) has not been demonstrated yet.

Therefore, this activity aims at gathering European key players (large system integrators, relevant unit manufacturers, providers of optical transceivers and fibers, and providers of protocol IPs) to develop a common standardization approach to develop the next-generation of products for end-to-end payload data handling architecture based on optical high-speed links. A prototype of a flight-representative end-to-end system will demonstrate the advantages of optical communication in general and the applicability of the standardization approach in particular.

The tasks of the activity are the following:

1 -Survey of all components and aspects related to the network physical layer that require standardization to enable a future-proof European roadmap for optical on-board communication, including e.g., connectors, fibers, transceivers, repeaters, data rates, and number of lanes. This survey shall lead to a set of draft documents, outlining a coordinated standardization approach.

2- Survey of space and terrestrial high-speed link protocols related to the datalink layer that are suitable for optical on-board communication. The survey shall critically assess the capabilities of different protocols, particularly considering their scalability, their adaptability to future transceiver implementations (ever increasing number of data rates, number of lanes, improved encoding schemes and error correction schemes), their implementation complexity in space-qualified hardware, and their cost/licensing aspects. The survey shall lead to a trade-off and finally to a selected preferred solution that can be deployed by the European industry in a standardized manner throughout the whole payload data processing chain.

3- Survey of validation aspects for optical high-speed communication links. The survey shall lead to a generic compliance (conformance) test specification that can be made applicable in European space programs.

4- Prototyping of an end-to-end payload data processing chain based on currently available optical communication technology, with a clear path to flight. The chain shall include breadboards representative of typical units (mass memory unit, front end electronics, instrument processing boards etc.), produced by corresponding different unit manufacturers in collaboration with optical components/fibers suppliers, and then integrated and tested for compatibility by a large system integrator with a dedicated EGSE. This will ensure a fast route to the integration of this technology into actual flight units and will demonstrate the applicability of the developed standards and conformance tests.

Deliverables:

Breadboard; Report; Report; Report; Report; Report

Low-SWaP hybrid deep-space transponder for outer planets missions

Title: Low-SWaP hybrid deep-space transponder for outer planets missions				**Budget (K€):**	1200
				Duration (m):	36
Reference: 6780		**Harmonisation:** TT&C Transponders and Payload Data Transmission -	**Application Domain:** GEN - Generic Technologies	**Programme:**	GSTP Compendium
TRL	**Initial:** 2 **Target:** 6	**Need/Push:** Proposed as an option in the communication architecture for HPSS-2 CDF, and applicable also to HPSS-1.		**Procurement:**	C

Objective(s):

New development of a low size, weight and power (low-SWaP) radio unit combining deep-space TT&C and proximity link functionalities in a scalable and flexible design.

Description:

For outer planets missions, consisting in an orbiter plus a lander (e.g. CDFs EPIG, Ice Giants, HPSS-1 and HPSS-2), without nuclear power sources and where generally the driving requirements are mass and power, the use of the TT&C subsystem of the orbiter allowing also communication with the lander with a proximity link, would provide an added value in terms of mass and power saving. With this approach there would not be need of an extra communication subsystem for such a purpose and only the TT&C subsystem would be in charge of both communications, with the ground station and with the lander on the surface of the outer planet or its moons.

The heart of this communication architecture would consist in a radio unit supporting classical TT&C functionalities, maybe also radio science, and implementing as well a Proximity-1 protocol layer and corresponding modulation/demodulation schemes. The unit would have at the physical layer baseband interfaces only CADUs and CLTUs for compatibility with current data handling subsystem and two independent modes of operation selectable by command, TTC or Proximity mode.

The frequency scheme would be the applicable one to the TT&C subsystem on the orbiter, i.e. deep-space X-band, and in such a way that both, uplink from the ground station and return link from the lander, would share the same frequency and both, downlink to the ground station and forward link to the lander from the orbiter would share the same frequency. In any case, the unit would have to be designed in a modular and flexible approach to its maximum extent, i.e. in order to optionally be able to be upgraded with an additional front-end for selecting a different frequency band for Proximity-1 link, in case of need for other similar missions, like for instance UHF band for current Martian missions or S-band for future Lunar missions.

Given that both, TT&C link with the ground station and proximity link with the lander, would share the same X-band frequencies, will not be possible simultaneous communication between orbiter and both, ground station and lander, and hence a store-and-forward relay communication approach would have to be followed at data handling subsystem level.

The use of X-band for proximity links would allow the use of relatively small steerable antennas on landers and hence reducing the RF output power needs. On the side of the orbiter, any of the available antennae of the subsystem (low, medium or even high gain) could be selected according to the link needs.

The design of the unit would have to take advantage of the state-of-the-art current technology for achieving the low-SWaP approach, while maximizing the use of software-defined radio (SDR) and providing flexibility to the maximum extent for allowing upgrades of future proximity link protocols or even ad-hoc proximity-like protocols with minimum impact on the hardware.

The activity encompasses the following tasks:

1. Analysis and solution trade-offs considering compatibility with current TT&C and proximity link data handling subsystems.
2. Justification of state-of-the-art technology and techniques intended for achieving the low-SWaP approach.
3. Requirement specification and design drivers.
4. Baseline design description, development and verification plan, including de-risking validation plans for identified critical functions, if any.
5. Analysis and justification files.
6. Manufacturing and testing of an engineering model, including the corresponding documentation.

Deliverables:

Engineering Model

Summary GSTP