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AOCS AND GNC SYSTEMS

Harmonisation 2024 Cycle 1

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Technologies Covered

The AOCS & GNC Systems harmonisation covers a very large amount of technologies.

Until 2020 this harmonisation was solely focussed on Hardware (**AOCS & GNC Sensors & Actuators**).

New part in the Dossier: **Technology related to GNC/AOCS and Control systems,** incl. following:

- Control
- Estimation and Navigation
- Guidance and Optimisation
- On-board decision and Autonomy (shared with other systems)
- AOCS/GNC validation and verification
- AOCS/GNC systems architecture

Some of the Hardware technologies are common core sensors and actuators, re-used on many different missions (gyroscopes, star trackers, sun sensors, reaction wheels).

Some others are more bespoke technologies dedicated to some missions or market segments (hybrid navigators, navigation cameras, CMGs…)

Key Issues

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It is not straightforward to summarize considering the amount of technologies to be harmonized, please refer to chapter 4.5 of the THD.

- No current detector development for AOCS (Star Tracker & Cameras), post Faint Star.
- Maintain the leadership of Europe in some domains (Star Trackers) and acquire it in others (Gyroscopes).
- High Performance (enabling technologies) sensors still to be qualified (Very High Accuracy Star Tracker).
- No European Reaction Wheel ever selected for a large Constellation.
- Development required in the field of large, modern reaction wheels, including digitalisation.
- Ensure developments in the field of lightweight Lidar for landing applications and Inertial Measurement Units.
- Bring on time products for the reliable New Space market and identify their possible re-use in “traditional” space missions.
- Obsolescence and long-term supply issues to be anticipated.

Key Issues (cont'd)

It is not straightforward to summarize considering the amount of technologies to be harmonized, please refer to **chapter 4.5 of the THD**.

- **Control**: **performance** enhancement, non-linearities, uncertainties **robustness**, **fault-tolerant**, contribution to autonomy
- **Estimation and Navigation**: **performance/range enhancement**, data fusion, **robustness** to sensor error and degradation as well as environment perturbation, **calibration and identification**
- **Guidance and Optimisation**: **convergence** and **performance** guarantee, **robustness** to uncertainties and disturbances
- **On-Board decision and autonomy**: robustness and performance in decision-making, convergence, **failure tolerance, criticality management**
- **Verification and Validation**: **modelling**, facilities adapted to **new types of mission**, **non-deterministic algorithms**, **digitalisation** (DT)

State of Art in Europe

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Extract of THD for the common core sensors and actuators :

- **Star Trackers** and their detectors : several entities in Europe (Sodern F, Jena Optronik DE, Leonardo IT, Terma DK) guaranteeing continuous improvements and price containment. On the detector side, HAS2 (On Semi, BE) and Faint Star (Caeleste, B) are still available with strategic stock available. Large amount of players for the cubesat-microsat environment.
- **Gyroscopes** : FOG currently providing highest performing space gyroscopes (Astrix products from ADS and Exail F). First CVG (Innalabs, IE) qualified with medium-to-high performance for noise. Efforts continuing with both technologies to improve performance and competitiveness.
- **Reaction Wheels** : European reaction wheel suppliers offer compatible solutions for a wide range of missions ranging from Cubesats to large high-end satellites. Significant efforts being accomplished at Astrofein (DE) to develop large reaction wheels (up to 100 Nms) both for New Space and traditional High Reliabilty. Modernisation of Collins Aeroespace product line engaged with 100 Nms wheel, but still uses analog electronics.

State of Art in Europe (cont'd)

There are many European players in AOCS and GNC systems for spacecraft and launchers within ESA Member States.

An overview of the state of the art of AOCS and GNC systems technologies is given in chapter 4.2.2.

Extract of THD for some specific AOCS and GNC systems products and facilities :

- **Nanosat AOCS**: AOCS subsystems for nanosat mission are available in several European companies (AAC Clyde Space, BST, D-orbit, ISIS BV, Space Inventor, GomSpace,…), for different classes of performance and nanosat size range. Performance expansion and robustness enhancement as well as cost competitiveness.
- **Guidance optimisation**: Several optimisation solver and toolboxes are available in Europe to provide resource for control and guidance optimisation, some are already operational in non space applications (DLR, Embotech, GMV, SENER,…). The capacity to embark them on board spacecraft and space vehicles is to be demonstrated.
- **Vision Based Navigation**: A variety of synthetic image renderers (PANGU, SurRender, SISPO…) have been developed in vision based navigation testing, in combination in a number of facilities in Europe (GRALS, EPOS, LAMA, ROBY,…) for testing of scaled representative models. These means and facilities are key to verify GNC systems using Vision-Based techniques, such as ISAM, planetary missions.

Competitiveness and Benchmarking

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Star Trackers : Europe is still dominating the world market. The current development of the Very High Accuracy Star Tracker (Jena Optronik, DE) covers the last area for which Europe had no solution to offer versus US. HAS2 & FaintStar commercially available in the world (US competition not procurable)

Gyroscopes : Trend in the use of non-European gyroscope is decreasing thanks to the recent wider availability of solutions. Increased exports of Gyroscopes outside Europe. In the field of **IMUs**, still heavy US domination (despite ITAR), except for launchers. Efforts on going, both with ESA and H2020.

Reaction Wheels : European primes are coming back to Europe to source Reaction Wheels. Developments still required to keep this positive trend. Some of the European Products are old and need enlargement and new functionalities. Reminder : no large constellation built in Europe ever embarked European RW.

CMGs : At least 4 developments (F, IT, BE, DE) or product lines exist in Europe, no European need to procure overseas. In general, export controlled products within Europe (dual use or war material).

Lidars : Very good European Leadership in the field of Rendez-Vous Lidars (DE). European solutions also exported for Landing applications (UK).

Mission Needs and Market Perspectives

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	Application	Telecommunications				Earth Observation			Science & Exploration			Navigation	In-orbit Servicing Technology	Launchers
Area	Subcategory	NewSpace	LEO	MEO	GEO	NewSpace	LEO	GEO	Orbiter	Observatory	Lander	MEO	LEO/GEO	-
Gyroscopes	NewSpace	L	L	H	H	H	H							
	Coarse-Performance		L	L	H		L	L	L	H			L	
	Medium-Performance			L	H	H	H		L			H	H	
	High-Performance						H	H	L	H		L		
Star Trackers	NewSpace	H	H	L	L	H	L							L
	APS-based HiREL		H	H	H	L	H	H	H	H	H	H	H	
	High-accuracy						L	L		H				
Inertial Measurement Unit	New Space								L		H		L	H
	High Performance - Launchers													H
	High Performance - HiREL								H	L	H		L	
Magnetometers		H	H			H	H							
Magnetic Torquers	State of the Art	H	H	L		L	H					H	H	
	Demiseable Magnetic Torquer	L	L			L	H						H	
Sun Sensors		H	H	H	H	H	H	H	H	H	H	H	H	
Earth Sensors				L			L					L		
Reaction Wheels	New Space	H				H								
	State of the Art		H	H	L				H	L		H	H	
	Precise, Digital Speed Loop				H		H	H		H				
	High Torque						H							
	High Momentum				H								H	
CMGs							H			L				

Mission Needs and Market Perspectives (cont'd)

Mission / Mission Type	Control	Estimation	Guidance & Optimisation	On-Board Autonomy / FDIR	Validation & Verification	AOCS/GNC Architecture
Telecommunications	Higher pointing accuracy / stability for multi-beam Ka and optical missions		For GEO/MEO, **Optimised Angular momentum management** during Transfer	**Autonomy for Electric Orbit Raising and station-keeping** Enhanced FDIR for quasi-permanent availability	Multibody Modelling Sloshing model enhancement	Architecture simplification **Product line** Resources optimization
Constellations	**Multi-spacecraft control**	**Position knowledge needed** for autonomous manoeuvre	Guidance optimisation Swarm cases	**Autonomy for constellation management** FDIR at constellation level	Digital Twins for AOCS HW	**Architecture simplification**, Resources optimization **Verification automation**
Earth Observation	High **Pointing Accuracy & stability** High Agility	High **knowledge accuracy**	**Re-entry** controlled / assisted	**On-board autonomy for orbit maintenance and collision avoidance**, de-orbiting optimization	Digital Twins for AOCS HW	Architecture simplification, Resources optimization, **product line** Verification automation

Mission Needs and Market Perspectives (cont'd)

Mission / Mission Type	Control	Estimation	Guidance & Optimisation	On-Board Autonomy / FDIR	Validation & Verification	AOCS/GNC Architecture
Meteorology	**High Pointing Accuracy & stability**		Orbit manoeuvres		Integrated modelling with Payload Sloshing model enhancement	**Microvibration isolation**
Science (non-Earth)	**High Pointing Accuracy & stability**	High **knowledge accuracy**	Robustness to environment uncertainty	**High autonomy in non visibility perio**ds (e.g. conjunctions for interplanetary) Advanced **FDIR for Payload protection** Robustness to Space Weather events	Demanding verification **Complexity when payload used in platform AOCS**	Integrated architectures with Payload (interface, timing, co-development, …)
Exploration	Robustness to uncertainty, variation Non linearity	**High accuracy navigation**	Guided entry scenario	**Improved Autonomy for critical phases in non-visibility periods** **Autonomous rendez-vous & docking** **Safe and precision EDL especially wrt navigation**	Multibody **Modelling** Plume soil interaction for EDL Robust modelling of uncertainties	Operability Multi-phase, sometimes multi-configuration (separations) Large sensors and actuators suites

Mission Needs and Market Perspectives (cont'd)

Mission / Mission Type	Control	Estimation	Guidance & Optimisation	On-Board Autonomy / FDIR	Validation & Verification	AOCS/GNC Architecture
Navigation	Pointing realisation	Attitude knowledge	**Optimised Angular momentum management** during Transfer	Autonomy for Electric Orbit Raising **FDIR for high availability & survivability**	Multibody Modelling	Operability MEO environment
Micro, nano and pico satellites	low performance / low reliability COTS HW (e.g **fault-tolerant, non-holonomic**)	cope with low performance / reliability COTS HW data fusion / Navigation for deep space missions		cope with low performance / reliability COTS HW Autonomy for deep space missions	**Improvement needed on V&V**: better fidelity, validation of facilities, hardware-in-the-loop, integration at avionics and system level verification Confidence on **HW emulators for HIL benches**	**increasing performance** with simple architecture

Mission Needs and Market Perspectives (cont'd)

Mission / Mission Type	Control	Estimation	Guidance & Optimisation	On-Board Autonomy / FDIR	Validation & Verification	AOCS/GNC Architecture
Launchers and upper stages	Mission preparation reduction Flight envelope **Robust descent and landing algorithms** Robust failure detection and recovery **Handling of multiphysics interactions** **Handling of nonlinear and unknown environments** **TVC**	IMU, **hybrid navigation**, data fusion	**Multi phase guidance** Different trajectory / configuration	Critical failure management Safety	**Multibody Modelling** Multi stage	
In-orbit servicing and debris removal	Non rigid dynamics control Moving parts Non linear	**Reliable & robust target pose estimation**	Close proximity operations **safety** **escape capacity**	FDIR Autonomy for Safety in close proximity operations	**Multibody modelling**	Sensor suite

European Strategic Interest (cont'd)

Need for **low cost use and integration of AOCS units via standardisation of interfaces and improvement of unit EGSE and on ground check out capabilities** (see outcomes of the **SAVOIR working groups**, in particular concerning Hardware and Software interfaces of sensors and actuators)

Need to contribute by **AOCS and GNC components, architecture and systems to develop European capacity for sustainable Space environment, typically enabling future ISAM, (autonomous) collision avoidance and active debris removal missions**

Need to contribute by **AOCS and GNC components, architecture and systems to develop European capacity for strategic missions related to security, resilience, independence**

Need to contribute by **AOCS and GNC components, architecture and systems to consolidate and complement the European launch systems portfolio**

Reference to Prioritisation

AOCS 2020 : According to the implementation of the previous roadmap mentioned in Sect. 6.1, 18 ESA activities of the 2020 Roadmap have been approved since then and are “Partially Funded” or “Fully Funded” for a budget of about **11.2 M€**.

It is expected this yearly budget will increase with the rise of industry-driven (such as GSTP Element 2) activities, New Space and the expansion of the scope of the dossier to Systems.

Proposed Development Approach

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For **gyroscopes, accelerometers and inertial measurement units** :

- Maintain and improve the range of high accuracy gyroscopes enabling Science and Earth Observation missions.
- Support the development fully European IMUs (SEE Tolerant)
- Support competitiveness & performance improvements for coarse to medium gyroscopes.

For **APS Detectors and Star Trackers** :

- Develop (or adapt) & Qualify a high end & high resolution image sensor to enable future developments for very high accuracy Star Trackers. Also envisage evolutions of FaintStar. Ensure long term support of existing detectors.
- In relation with the thermal refrigeration roadmap, qualify a fully European Cooler for Star Trackers.
- Support the qualification a very High Accuracy Star Tracker (0.1 arcsec)
- Improve the SW qualification classification of Star Trackers to enable easier integration in safe & survival modes.

For **Magnetometers and Magnetorquers** :

- Maintain at least two distinct sources of supply and improve demiseability of MTQ for the larger ones.
- Qualify Magnetometers with digital interface

Proposed Development Approach

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Sun Sensors : Guarantee availability of sun sensors for all types of ESA missions

Optical Navigation Systems : Develop re-useable building blocks for image acquisition, storage and processing. Ensure responsiveness to bespoke missions needs.

Lidars and 3D Cameras : Support the current product line of LIDARs and expand the existing capabilities to enable new types of missions (i.e. landing). Support the development of smaller SWaP LIDARs for easier use on smaller satellites.

Reaction Wheels :

- Ensure the availability in Europe large Reaction Wheels (100 to 150 Nms)
- Qualify a high performance Reaction Wheel with digital wheel speed loop for Science and Observation Missions.
- Support the transition from analog to digital interface on reaction wheels.
- Engage and support developments in the field of New Space to reduce dependence to non-European suppliers for large constellations.

Proposed Development Approach (cont'd)

The main objectives to be reached by this Roadmap are preliminarily listed below

- AIM A : Develop Guidance, Control, Navigation and Estimation techniques, tools and methods for **enhancing performance and robustness**
- AIM B: Develop Guidance, Control, Navigation and Estimation techniques, tools and methods for enabling **new classes and types of missions (eg. ISAM, landing, re-usable launcher,…)**
- AIM C: Develop AOCS and GNC techniques, tools, methods and subsystem for **commercially-driven missions (incl. nanosats and smallsats)**
- AIM D: Develop and expand AOCS and GNC components for enabling **more autonomy** in future missions
  (eg. autonomous orbit manoeuvres, autonomous AOCS/GNC anomaly recovery, autonomous constellation control,…)
- AIM E: Contribute to the **zero-debris policy and initiatives for sustainability at AOCS and GNC systems**
- AIM F: Explore and expand **AI techniques use for the benefit of AOCS and GNC systems and engineering**
- AIM G: Contribute to Space development **digitalization evolution for AOCS and GNC systems**
- AIM H: Develop **AOCS and GNC systems simulation and Verification and Validation ecosystem, with efficiency, risk-reduction and interoperability goals**
- AIM I: Prepare and Develop AOCS/GNC benchmarks and **AOCS/GNC systems demonstration models**

Conclusions

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<u>We propose to articulate the preparation of the roadmap along these lines</u> :

Support and guide industry in the field of “reliable New Space”

Continue to guarantee double European sourcing for key units

<u>The main objectives to be reached by this Roadmap are</u> :

Analyse the developments engaged in the field of New Space and assess on a case by case their re-usability for higher end missions

Maintain the availability of a double source for each type of products

Maintain the European leadership in some areas (Star Trackers, Lidars), and develop / accelerate non-dependence in others (Gyroscopes, IMUs, Reaction Wheels)

Enhance the capability to characterise low-cost Sensors – in particular for cubesat/smallsat before a first flight opportunity

Expand Guidance, Control, Navigation and Estimation techniques, tools and methods for current classes of mission, for higher performance, robustness and capacities

Prepare and implement new Guidance, Control, Navigation and Estimation techniques, tools and methods for new classes of mission and phases (ISAM, landing, re-usable launcher, space vehicle, de-orbiting,…)

Take benefit of new techniques (AI, optimisation) and new process (digitalisation and V&V advanced techniques)

THD and Roadmap Now Available

Following the endorsement of the Conclusions document by IPC, we would like to inform you that final version of AOCS and GNC Systems Technology Harmonisation Dossiers (THDs) and Harmonisation Roadmaps (RMs) is available

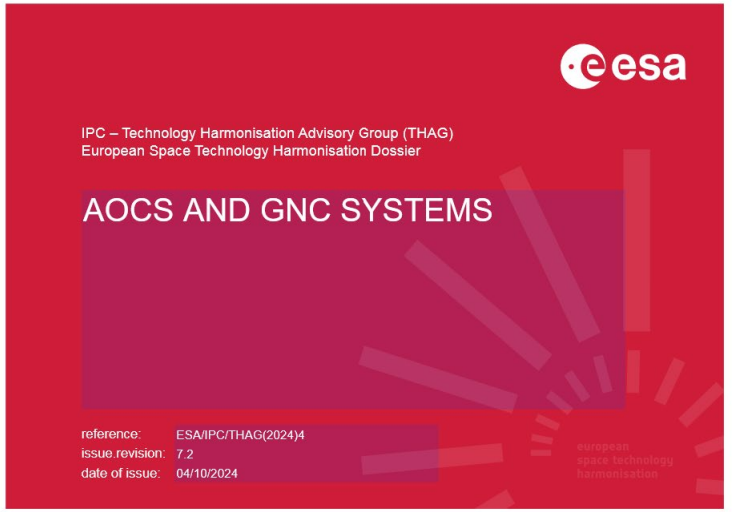
These documents should serve also as important references for the preparation of Technology related Workplans of ESA and other national and European organisations.

For your information: the final documentation is available to external, registered stakeholders via the Harmonisation Data Management System (HDMS) under the links given below.

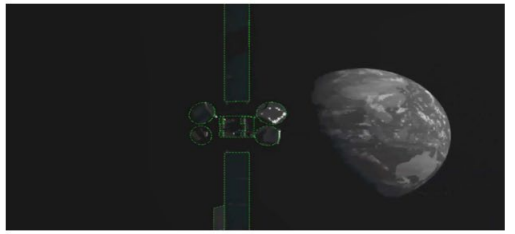
Non-registered entities shall send an email to harmo@esa.int in order to obtain login credentials.

ESA External links:

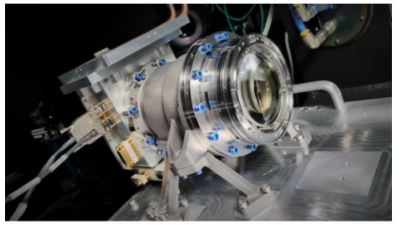
- AOCS and GNC Systems
  - THD link
  - RM slides



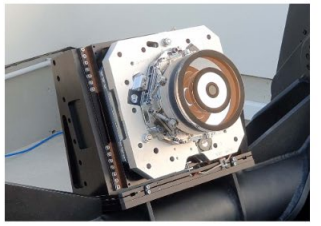
ADAMP - Ascent and Descent Autonomous Maneuverable Platform (courtesy of INCAS)



Genevis - Generic Vision-Based Technology Building Blocks (courtesy of Airbus Defence and Space)



MSR-ERO NAC – Narrow Angle Camera (courtesy of Sodern)



Astro XP – Very High Accuracy Star Tracker (courtesy of Jena-Optronik)

Thank you for your attention