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EUROPEAN SPACE TECHNOLOGY HARMONISATION

PROPOSED WORKPLAN FOR 2018

AND LIST OF TECHNOLOGIES EARMARKED FOR 2019 AND 2020

1 INTRODUCTION

This document aims to present the proposed technologies which will be covered by the European Space Technology Harmonisation in 2018 and to provide a preliminary list of technologies which are to be considered for harmonisation for the period 2019 – 2020.

The process of defining the list of subjects for 2018 involved THAG, ESA Technical and Quality Management Directorate, ESA Programme Directorates and Industry and consists of the following steps:

a. Feedback from Industry, through Eurospace and SME4Space, on 2018 Harmonisation topic selection (based upon topics earmarked for 2018 in the 2017 Workplan)

b. Determination of the list of Harmonisation subjects for the year 2018, discussed with THAG at the Mapping Meetings held in February and April 2017

c. Finalisation of 2018 Workplan with THAG via e-mail during May 2017

d. Submission of the Harmonisation Workplan 2018 to the June 2017 IPC for approval.

2 CRITERIA FOR IDENTIFICATION AND SELECTION OF TECHNOLOGIES

The technologies for this Workplan are identified from the following input:

a. Actions from previous Harmonisation Meetings,

b. Review of the previous Harmonisation subjects and coverage of the ESA Technology Tree,

c. Proposals received from THAG Delegations, Industry via Eurospace and SME4Space, ESA Technical and Programme/User Directorates,

d. Results of the analysis of the implementation of past harmonised Roadmaps (tracking) and the need to revisit some Technologies.

In order to define the level of priority and identify the subjects to be proposed for next year, the following criteria are taken into account.

1. Technology maturity level

Harmonisation Roadmaps aim at bringing the addressed technologies and products to the necessary maturity, performance and competitiveness levels for the benefit of European institutional and commercial programmes. Harmonisation should not and is not compromising advanced basic research or innovation.

2. Strategic relevance for Europe

Leading edge technologies enabling new missions and technology areas strategic for ensuring European non-dependence have high priority.

3. Mission needs and market potential

Technologies answering to mission requirements or to a market demand.

4. Technology gap or unnecessary duplication

Thorough analysis of ESTMP and experts' inputs to assess gaps and overlaps

5. Need to revisit a technology roadmap

As a general rule, it is intended to revisit previously harmonised subjects every 3-5 years, to check technology or industrial landscape evolution. If not possible within this time frame, the objective is to at least revisit the subject before most of the activities in the previously approved Roadmap are planned to end, in order to ensure Roadmap continuity and avoid gaps. The revisit however depends on the specific subject and a decision on this must be supported by the results of an analysis of past roadmap implementation using the harmonisation tracking system.

3 LIST OF TECHNOLOGIES FOR 2018

Table 3-1 lists the ten technologies proposed for 2018.

1st cycle 2018			
Competence Domain	**Title**	**Revisit**	**New**
10	De-orbiting Technologies		X
5	Frequency and Time Generation and Distribution (Space & Ground)	2011 (G) 2013 (S)	
1	Photonics		X
2	Position Sensors	2009	
3	RF & Optical metrology[1]	2009	
2nd cycle 2018			
Competence Domain	**Title**	**Revisit**	**New**
7	Chemical Propulsion – Components	2012	
2	Coatings		X
2	Deployable Booms & Inflatable Structures	2010	
6	Life Support Technologies		X
9	System Modelling and Simulation tools	2012	

Table 3-1 List of Technologies for 2018

The 2018 IPC-THAG Meeting dates are as follows:

6-8	February	2018	1st	cycle	Mapping Meeting
10-12	April	2018	2nd	cycle	Mapping Meeting
11-13	September	2018	1st	cycle	Roadmap Meeting
4-6	December	2018	2nd	cycle	Roadmap Meeting

Note that these dates may be subject to change to avoid conflict with other ESA events and calendars.

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[1] Formerly named *Critical Enabling Technologies for Formation Flying – Metrology*

4 DESCRIPTION OF TECHNOLOGIES FOR 2018

The following descriptions of the technologies proposed for the Harmonisation Workplan for 2018 may be refined at the start of the cycles.

4.1 DE-ORBITING TECHNOLOGIES

4.1.1 Technology Overview

Today’s space debris environment poses a safety hazard to operational spacecraft, as well as a hazard to the safety of persons and property on Earth in cases of uncontrolled re-entry events. As of November 2015, more than 5100 launches had placed some 7200 satellites into orbit, of which about 4100 remained in space; only a small fraction - about 1100 - are still operational today. These are accompanied by almost 2000 spent orbital rocket-bodies and a large number of fragmentation debris and mission related objects. This large amount of space hardware has a total mass of more than 8000 tonnes. More than 200 objects have meanwhile fragmented.

International guidelines applicable to future missions as well as domestic regulations in more than 20 countries worldwide state that at the end of their operational lifetime satellites and upper stages have to be passivated (i.e. internal energy sources have to be made safe) and need to be removed from protected zones (the LEO protected region, i.e. up to 2000 km, and the GEO protected region). The LEO protected region is of particular importance for almost every Earth observation mission and for an increasing number of telecom ventures.

These requirements will have significant impacts on future missions design and call for an evolution of the standard platforms, in particular in LEO.

Spacecraft operating in the LEO protected region are required to leave this region not later than 25 years after the end-of-mission. Moreover, if the design does not comply with the on-ground casualty risk limit of 10^{-4}, a controlled re-entry shall be envisaged.

The requirement to maintain the casualty risk on ground smaller than 10^{-4} imposes stringent constraints at spacecraft system level. If compliance cannot be achieved via uncontrolled re-entry the spacecraft has to perform a controlled re-entry manoeuvre, with this imposing substantial modification of, at least, the propulsion subsystem, the AOCS, and of the platform structure. In addition, the increased propellant mass may impose the use of a larger launch vehicle, which can increase costs in the order of tens of millions. In order to avoid the large programmatic and cost implications of such modifications, driven by the propellant and thrust level required for the controlled re-entry, medium size satellites (from 500 kg to 2000 kg) would benefit also from the application of design for demise techniques. These techniques shall be applied through technologies to be implemented at system and equipment level.

Advancement in technologies is essential to allow full and efficient implementations of these requirements. Studies both at system level as well as technology level in design for demise, de-orbiting system and passivation are being run since 2013.

4.1.2 Areas Covered by this Technology Topic

In this Technology topic will be covered only technologies related with the End-of-Life (EoL) Operations of spacecraft linked to the compliance with Space Debris Mitigation requirements. Technologies related to Active Debris Removal or Servicing are not part of the scope of this topic.

The topic De-Orbiting Technologies is part of the Competence Domain 10 (see section 6).

4.1.2.1 Uncontrolled re-entry systems

Passive deorbit devices

Several studies in the past years have been dedicated to passive systems to facilitate timely re-entry. The concepts investigated are mainly based on two phenomena, one exploiting the atmospheric drag, specifically, with drag augmentation devices, and the another using Earth's magnetic and plasma fields, for instance, with electro-dynamic or plasma brake Tethers to reduce orbital velocity and lower the orbit.

Tether systems are mass effective, but require complex deployment mechanisms. Drag augmentation devices rely on simpler mechanisms and are mass efficient. However their effectiveness decreases exponentially with increasing altitude and the required cross-section augmentation closely correlates to the satellite mass.

Any of these passive systems increases the effective surface of the satellite. Hence, their design needs to be such that they do not increase the overall collision risk and, in particular, reduce risk of debris generation.

Passive deorbit systems are especially attractive for small satellites compliant with the casualty risk requirement that, in this way, can avoid including a dedicated propulsion system.

Design for Demise

An attractive solution to the casualty risk requirement is offered by Design for Demise. This is the intentional design of space system hardware so that it will burn up – or 'ablate' – during uncontrolled atmospheric reentry in order to reduce the number of surviving parts that reach the ground and the associated casualty risk.

Design for Demise is a recent concept, therefore some knowledge gaps still exist. The understanding of how spacecraft breakup during reentry is extremely complex due to the complex thermo-mechanical environment that the satellite faces during reentry. Furthermore, there is a lack of observations and measurements available, and it is difficult and costly to reproduce reentry conditions on Earth.

Particular focus is given to recurrent units used in several missions. The critical items identified are: Propellant and pressurant tanks, Reaction Wheels, SADM, Magnetorquers and Optical Payloads.

Among the most important findings of these studies was the discovery that, in addition to the need to re-design the critical pieces of equipment, there is also a need to expose these elements to the heat flow early during the reentry using system level techniques, e.g. repositioning equipment, structural breakup, etc.

Passivation

Passivation operations are currently performed on a best effort basis by the satellite operators, making use of the currently available architectures and equipment to deplete the stored energy as far as possible, particularly in the power and propulsion subsystem. These systems may have to endure extreme environmental conditions for as long as the satellite stays in orbit without thermal control (forever in the case of GEO satellites). Therefore further assessment of the safety of electric and propulsion systems and development the reliable and robust passivation solutions requires further activities.

Optimisation of de-orbit manoeuvres and operations

Analysis and optimisation of the de-orbit manoeuvres for satellites in different orbits (MEO, HEO, L2) can minimize their system impact. This work shall be complemented by an optimisation of the ground operations that can reduce the risk of the end-of-life operations, trying to make the best use of their resources to complete the EoL operations. These technologies can be applied for both future missions but also missions already in orbit.

4.1.2.2 Controlled deorbit systems

Although medium and large satellites are typically equipped with dedicated propulsive systems for attitude and orbit control, the impact of end-of-life de-orbit manoeuvres at system level is significant, especially in case a controlled re-entry is required, since this pushes up the required thrust level and the propellant mass.

Furthermore, there is often a conflict of interest for a satellite operator when declaring the End-of-mission while the satellite is still functional consumables available. Practical experience shows that there is a tendency to extend the operations beyond the foreseen lifetime. Frequently the missions are terminated by a technical anomaly not allowing to perform the EoL operations. As a consequence several technology development activities are needed in order to ensure successful completion of the end-of-life manoeuvres by increasing the reliability of EoL process completion, optimising the de-orbiting strategies and developing de-orbiting systems which can, in some cases, operate autonomously from the satellite bus.

Controlled re-entry support systems

Even with the application of Design for Demise techniques in the future, it is likely that large satellites will need to perform a controlled re-entry to comply with the on-ground casualty risk requirement. Furthermore this is an option based on higher TRL technology that can also be more affordable if performing a controlled re-entry does not imply a change of launchers.

Controlled re-entry typically requires an extra Delta-V 2 to 3 times higher than the operational mission and a high thrust capability, in order to lower the perigee from about 250 km to 60 km or below in the last manoeuvre. This implies significant changes to the propulsion system architecture, particularly with respect to the traditional mono-propellant systems used in LEO.

In order to reduce the cost and mass impact different technologies are under assessment: Due to the large amount of propellant required, the system will also have to be re-pressurised, options for optimising the re-pressurisation function are being studied to improve propulsion system performance and reduce overall dry and wet mass. The current options for high thrust mono-propellant engines (hydrazine 400N engine) are expensive and are not optimised for this use. The development of low-cost options and options compatible with green propellants shall be considered.

Finally, in order to perform most of the de-orbit manoeuvres with high specific impulse systems and make use of the power available (as the payload is switched off), electric propulsion technologies (e.g. arcjets) could be considered as a way to avoid a very significant mass increase.

Autonomous De-orbit Systems

These systems aim to provide satellites with a separate de-orbit system that could allow for the autonomous de-orbit (controlled or uncontrolled) at EoL. The system could allow de-orbiting the S/C even in the event of a major anomaly that renders the S/C non-operational. The de-orbit system shall be based on a modular concept with different levels of autonomy, adaptable to the needs of different S/C designs. Solid Rocket Motors can be a suitable technology for the implementation of this functionality, due to the high thrust, low power required and short operation time. However other systems that are more flexible for other uses during the mission shall also be assessed.

Besides the development of these on-board systems the development of technologies to increase the autonomy of the de-orbit operations also for active Spacecraft. This may be key for the future implementation of EoL operations in constellations where a large number of spacecraft perform these operations in parallel.

Semi-controlled re-entry

As controlled re-entry over an unpopulated area requires a high thrust-to-mass ratio, a new concept could be considered in order to perform such manoeuvres using lower thrust (i.e. < 1N, allowing for example the use of EP to perform these comprehensive de-orbit manoeuvres). The aim of such concept is trying to limit the possible re-entry areas to a reduced number of orbits, avoiding the most populated regions. However several issues remain unclear and a detailed analysis of the uncertainties, controllability and operational constraints shall be performed.

4.2 FREQUENCY & TIME GENERATION AND DISTRIBUTION (GROUND&SPACE)

4.2.1 Technology Overview (Ground & Space)

Ultra-stable frequency and time sources play an important role in many modern applications, such as high speed data transmission, time keeping, space navigation, geodesy in addition to supporting key elements of basic research in space. This Harmonisation will focus on the requirements, techniques and technologies related to the generation, transfer and comparison of reference Time/Frequency signals as required for the implementation and operation in space and ground segments since they are seen as critical equipment for a number of key ESA missions and, once mastered, also enable many applications in the consumer market and therefore represent a strategic interest for Europe. It will also include new technical developments that are key enabling elements in the realisation of new sensor measurement strategies in geodesy and fundamental physics.

The frequency and timing community is led scientifically and technically by the National Metrology Laboratories NML's. In addition to its primary role in establishing the primary frequency and time scale, and for providing a means for the inter-comparison of these frequency standards, they also pursue the development of improved clocks in domains of core interest to ESA for various future applications. ESA's access to (technical and scientific expertise) and consultation with the NML's is of vital importance in the enabling of its future implementation plans.

The continuous improvement in the performance of frequency standards is leading to the development of additional equipment in order to distribute ultra-stable frequency signals and compare the performance of the various clocks. Efficient clock comparisons will also enable the evaluation of the reference signals in various proposed applications. The existence of such a clock dissemination network is vital for the comparison of the best clocks in Europe and eventually globally.

The inter-comparison of the newest ultra-stable frequency sources rely implicitly on the existence of a high performance frequency comparison network. Spacecraft positioning for example via ultrastable laser ranging, navigation techniques, radioscience research (e.g. gravitational wave experiments and their related core components including ultrastable lasers and low Brownian noise optics) will also directly benefit from these developments.

4.2.2 Areas Covered by this Technology Topic (Ground & Space)

The harmonisation of current developments in various metrology laboratories is desirable, in order to improve the performance of ground station clocks. Current developments in the area of frequency dissemination and comparison are of direct application to ESA, for applications such as the distribution of ultra-stable signals to distributed antenna front-ends, the synchronisation between ground stations, and the improvement of navigation techniques.

Other missions benefiting from the above improvements include all deep space missions, such as missions to Mars, as well as other solar system and exploration missions and formation flying missions (e.g. LISA).

The topic Frequency & Time Generation and Distribution (Ground & Space) is part of the Competence Domain 5 (see section 6).

4.3 PHOTONICS

4.3.1 Technology Overview

In the frame of this new Harmonisation topic, “Photonics” covers the applications of waveguided optics (fiber and planar waveguides) including the generation, detection and manipulation of the light for “low-power” applications. The only exemption is the Optical Wireless Links for intra-satellite communications. This Dossier does not cover Laser Communication Terminals, LIDARs and Free Space Optical Processing which are covered in other harmonisation dossiers.

Optical Fibers is a new technology in Spacecraft Engineering. The dual launch of SMOS (carrying over 700m optical communication links for its payload, the biggest in the world) and PROBA II (carrying the first Fiber Optic Sensor subsystem in the world) in November 2009 signify the starting point for Photonics Space Flight in European Space Missions.
Since then, and driven by the requirements of the Telecommunication satellites for High Throughput Payloads, photonic technologies have emerged as an enabling technology in COMSATs. In Microwave Payloads hybrid microwave/photonic designs have been proposed by the two main primes which plan to offer this solution to RFQ by Operators as soon as 2019/20. Similarly for the Digital Payloads, high-speed optical have been baselined for first time in 2017 by one of the big Primes (links at rates up to 20 Gbps) while the requirement for the next generation Digital Payloads calls for 56 Gbps data rates.

For the Satellite Platforms, fiber optics are currently under development and qualification for use as the thermal monitoring subsystem. Also, novel approaches for incorporating such a fiber optics-based thermal monitoring subsystem in pre-fabricated S/C panels lead to a new paradigm on how to build a S/C in a shorter Assembly Integration and Testing time. On the communication cabling linking the various instruments to the On Board Processor or Mass Memory the “Space-Fiber” has been established and it is now going through ECSS standardisation. This process will promote the fiber-based “Space-Fiber” as eventually the preferred standard and medium for the communications links with instrumentation.

In Launchers, opto-pyrotechnics have been specified for use in ARIANE-6 leading to the first application of this kind. Fiber Sensors are also considered for health monitoring. In such a case the optical fibers are embedded in the composite structure parts of the launcher. Lastly, communication links may be served by the space-fiber standard especially due to the long distances involved.

While the majority of these applications make use mainly of fiber optics and discrete photonic devices ESA has initiated a consistent program of activities to shift the technology towards microphotonic integration. It is expected that several of functions will be implemented by such microphotonic technologies that will of lower mass, volume, and power consumption.

4.3.2 Areas Covered by this Technology Topic

The topic Photonics is part of the Competence Domain 1 (see section 6).

This technology Topic will cover all aspects of waveguided optics including fiber and integrated optics. It will include also all the applications of photonics i.e Payloads, Platforms, More specifically it will cover:

Analog Payload

Microwave Photonics Equipment for:

- Frequency Generation Unit
- Frequency Conversion Unit
- Switch/Router
- Beam Forming Network
- RF Filtering

Digital Payload

- Multigigabit parallel interconnects (based on rad-hard drivers and in future on low-power 3D packaging of opto-electronics with silicon ICs)

Platforms

- Optical SpaceFiber Tranceivers
- Active Optical Cable for SpaceWire
- Attitude transfer and distance metrology on-board satellites in Scientific application.
- Optocouplers, Optical Encoder
- Photonic Power Remoting for TMTC functions
- Fibre optic sensors: thermal monitoring, monitoring strain, composite embedded sensors, shape sensing, 3 axis Photonically interrogated MEMS accelerometers for low frequency micro vibrations
- Contactless laser Doppler vibrometry
- Fiber optic gyroscopes
- Pre-Fabricated optically-wired Panels
- Opto-pyrotechnics
- Frequency comb technology (spectroscopy, metrology)

Ground Segment

- Optical SpaceFibre/SpaceWire for GSE
- Fibre optic sensing for test centre
- Optical Wireless in AIT

Launchers

- Opto-pyrotechnics
- FOG for launcher
- Optical SpaceFiber
- Fiber sensors for launcher applications

4.3.2.1 Photonic Technologies involved

Passive Components:

- Optical Harness for photonic applications: (High density harness, fibre optic connectors, cable assemblies, flexfoil assemblies, cryogenic communication harness)
- Fibre WDM components (AWG, filters, couplers)

- Frequency stabilisation components (gas cells, MZI, FP cavities-including compact low Brownian noise reference etalons)
- Low-loss optical coatings based on single-crystal multilayers
- Polarisation maintaining components
- Splitters, Circulators
- Faraday Rotators, Optical isolators
- Radhard doped optical fibres for amplifiers(Er, Er/Yb)
- Packaged FBG sensor
- Fusion splice
- Passive Photonic Integrated Cicuits-

Active Components:

- Laser Diodes: Transmitters for communication (radiation hard, low power, 10-56Gbps), 1550 DFB seed laser, 980nm High power CW pump laser (25W), VCSEL based optocoupler, frequency comb lasers,
- Optical phase modulator (broadband, low vπ),
- Optical switch (MOEMs),
- Optical amplifier technology (EDFA, SOA),
- Photo-receivers: for high speed communications (low power, radhard, 10-56Gbps), photodiode arrays for encoders, High power photo receiver for RF links, large bandwidth balanced photodetectors for coherent communication
- Hybrid and Heteregenous integrated Active Photonic Integrated Circutis

4.4 POSITION SENSORS (FOR MECHANISMS)

4.4.1 Technology Overview

Most of space missions include mechanisms. In order to check or to control the position of these mechanisms, position sensors are necessary. Most of the Space mechanisms are providing rotary movements and therefore require rotary position sensors. However, linear sensors are sometimes used on space programmes. Both types will be addressed.

This harmonisation covers the full range of position sensors in terms of:
- performances, from one position per turn until very high accuracy and resolution sensors (e.g. >24bits per turn)
- technologies
- linear and rotary types
- devices with mechanical contact or contactless
- absolute and relative position signal
- angular rate feedback
-

All these sensors are based upon one of the following technologies:
- Mechanical, electromechanical or contactless switches
- electrical variable resistance sensors
- magnetic sensors (hall effect, magnetoresistive..)
- inductive sensors (magnetic resolver, RVDT, LVDT, eddy current (Kaman), Inductosyn…)
- capacitive sensors
- optical sensors

The position sensors are split in 3 categories linked with their performances levels, which, in practise, result in the 3 following different domains of applications:

- **Switches**: / Reference Position sensor providing one position per movement or one position per turn. This category is usually named “Switches”, which are in most of the cases for providing a TM (telemetry) about the release and / or the achievement of a displacement / deployment. Switches are some time part of a “closed loop” to trigger safety mechanism power switch off (heaters for actuators based on thermal phenomena : wax actuator, etc)

- **Low and Medium Accuracy Position Sensors** (i.e. Potentiometers): Are sensors providing limited accuracy per linear movement or per turn – few 0,1 % linearity. Conversely, being purely analogical, some times are considered as “infinite resolution” (resolution driven by the acquisition electronics). The resolution / accuracy order of magnitude is degree or few tenth of degree. Have limited cost and low induced user constraints. In some cases they can accept noisy signals. Are usually based on variable resistance techniques. Are sensitive to the quality of the tribological contact between the wiper and the track (not recommended for controlling the mechanism function, but only to report the achieved position or the progress). In particular they are sensitive to insulating polymers and/or debris generated by wear & contact. Low and Medium

accuracy position sensor provides low or medium resolution positions per linear movement or per turn. This category is usually called “Low and Medium Accuracy Position Sensors” or “Potentiometer” or “Potentiometer equivalent”. Such designation results from the fact that people typically address resistive angular position sensors as “Potentiometers” because most of these sensors are based on variable resistance techniques provided by means of a linear or rotating brush contact on a resistive path. These sensors are sensitive to the quality of the tribological contact between the wiper and the track that can change with time and operation under vacuum environment. For this reason this technology is not recommended to be used for controlling the mechanism function, but only to report the achieved position or the progress of the mechanism displacement/deployment. That situation might change due to the recent emergence of new and more reliable techniques which will be addressed in this dossier. These new technologies, either magnetic, inductive, capacitive or optical ones, could be used to build sensors with medium to high accuracy, with a cost dependant on performances.
Apart from the low and medium accuracy criterion, this family of sensors is defined by its low cost and its low induced User constraints. This is specifically what the customers are usually looking for when they can accept noisy signal.
Concerning this category of position sensors, it might be interesting to study Spin-In activities for contactless technologies coming from other application fields than space.

- **High Accuracy Position Sensors** (i.e. Optical Encoders in Europe) High performance position sensors, called “Optical Encoder”: Such designation results from the fact that most of the used European techniques able to provide such level of performances is based on optical principles. For this category of sensors, the main requirements come from the extreme accuracy requested for scientific payloads, (i.e . when a closed loop control of the position is needed) but also for Telecom equipments, like ADPM for instance. Apart from optical techniques, several other technologies exist in Europe to reach these high performances.
  One can further discriminate between incremental encoders requiring a reference action upon each start-up, and absolute encoders which display the position at each Power ON. Furthermore, there are also single–turn absolute Encoders and multi-turn absolute Encoder available. The latter usually incorporates a mechanical gear to register position across several 360 deg turn.
  Note that usually resolution is further discriminated into “hard coded” bits which represent physical instances on e.g. the encoder glass disk, and electronically interpolated bits which are computed from the hard coded bits and usually do require extensive signal conditioning efforts within the control electronics loop

The switches and potentiometers are low cost position sensors, while the cost of the High Accuracy Position Sensors (Optical Encoder) is significantly higher and performance-dependant. For high accuracy sensors, special attention should be given to the variety of units which are used to designate an angle (bits, degree, part of degree, arc minute, arc second, micro-rad…).

Therefore the 3 following performance definitions are relevant:

- the **Resolution, which** covers two separate notions :

  - first is the size of the smallest increment which can be shown on the measurement display. On a digital display, it is the value of the least significant digit. On an analogue display it is the smallest display change detectable. This is hereafter called ***Algorithm Resolution, which*** is the size of the smallest increment which can be shown on the measurement display.

  - second is the smallest significant increment which can be detected by the system and which change on the display has physical meaning. This is hereafter called ***Effective Resolution, which*** is the smallest significant increment which can be detected by the system - featuring at least a monotonous behaviour. When Users commonly speak about resolution performances, in most of the case that means effective resolution. This is also the case in this document, unless Algorithm Resolution is specifically indicated.

- the **Accuracy**: defines how far the measured value is from the true position value.
  Errors due to the instrument itself, the acquisition electronic, environmental conditions, linearity and hysteresis have to be taken into account. Among accuracy errors that have to be considered by the Users, some might be due to the measuring instrument itself and others might be due to the acquisition electronics.
  Sensibility to environmental conditions like temperature, electromagnetic fields … have always to be considered.

- the **Repeatability**: is the ability of obtaining the same result when measuring the same input in similar motion with the same measuring instrument but at a different time and including or not a Power ON / OFF on the device.

“Optical encoder” or High Accuracy Position Sensors are most of the time used in closed control loop of a mechanism, especially for very accurate pointing or scanning mechanism.
In most of the cases, advanced filter and signal treatment are associated to this mechanism control loop in order to obtain extreme performances. This signal treatment is very often numerical, which requires a level of resolution significantly higher than the level of accuracy provided by the position sensor. Therefore, it is technically necessary to have the resolution of an optical encoder much higher than its stated accuracy, in order to get an insignificant impact of the computation error on the overall performance.

4.4.2 Areas Covered by this Technology Topic

The Technology Topic covers the Technological Domain 15-A-IV of the ESA Technology Tree (Motion and Force Sensor Technologies).

The topic is part of the Competence Domain 2 (see section 6).

The full range of position sensors is covered, in terms of:

- Performances (from one position per turn until very high accuracy and resolution)
- Sensors Technologies
- Linear and rotary sensors
- Devices with mechanical contact or contactless
- Absolute and relative position signal

- Angular rate feedback

Most position sensors are for TM (Telemetry) purpose. They report the successful achievement of the function of a mechanism, such as release or deployment. They can also be used to provide data on the mechanism behaviour during the operation. For some specific applications, sensors are used to provide angular rate feedback.

In most cases, the mechanisms are driven in open loop, and therefore the mechanism function is not dependent on the position sensor.
For high accuracy pointing mechanisms, the mechanism actuator is driven in close loop. In such cases, the final performance is directly linked to the accuracy and resolution of the position sensor.

The AOCS sensors, such as gyroscope, accelerometer, magnetometer, etc., will not be addressed in this dossier. Pressure sensors and Force sensors based on piezo technologies and stress gauges will not be addressed since they are not providing position information.

4.5 RF & OPTICAL METROLOGY

4.5.1 Technology Overview

Concerning the metrology sensors, different technologies may form part of the metrology chain, depending on the level of the required relative distance and attitude accuracy. These technologies can be classified in RF, optical and optical interferometry. According to the characteristics and limitations of these technologies, the level of accuracy that can be obtained varies from nm (optical interferometry) up to cm-m (RF metrology). The nm accuracy obtained by optical interferometry usually covers only a small range of unambiguity which has to be pinpointed to its absolute or long range distance by other metrology techniques.
Table 4-1 summaries the expected levels of accuracy from each metrology technology. (Values in μm/Hz or nm/Hz denote stability rather than accuracy.)

FF Metrology Technology		**Accuracy Level**
RF Metrology	TT&C ranging	Coarse m ; 1 cm/s Fine cm ; 1 mm/s
	RF ISL metrology	
	Radar	
	Wireless (IEEE standards)	
	GNSS space rxs	
Optical Metrology	Coarse lateral	0.005°
	Fine lateral	10 μm / √Hz
	Fine absolute longitudinal	10 μm / √Hz
	Fine relative longitudinal	10 nm / √Hz
	Fine pointing	nrad
Optical Interferometry	Fringe sensor unit	nm

Table 4-1: Metrology Technologies and level of accuracy

Due to their high accuracy, optical metrology systems can only operate within a relatively small angular field of view. They normally use a Radio Frequency (RF) metrology system to pre-align the satellite constellation to an accuracy, which enables the optical metrology system to take over.
The RF metrology technologies can be classified into two groups, those using GNSS signals, mainly missions Earth orbit (LEO orbit as well as HEO/GEO), where the key technology is the GNSS receiver and a second group, not using the GNSS signals, based on inter-spacecraft ranging signals. In this second case, two possible technologies exist, based on standard ranging transponders, or based on the RF GNSS-like signals. Wireless based (IEEE terrestrial standards) is a third technology suitable for multiple spacecraft mission (>2 spacecraft) with high data rate requirements. Some topics can be considered common between the several technologies, such as signal processing techniques, building blocks of RF transmitter/receiver and relative navigation algorithms.

4.5.2 Areas Covered by this Technology Topic

Different types of missions might benefit from RF and optical metrology, examples are Formation Flying (FF), Rendezvous (eg: ATV, Mars Sample Return), planetary landing missions, etc. Missions with cm control level would need only RF metrology and mN thrusters. Missions down to a control of µm level accuracy require in addition the use of optical metrology and µN thrusters. For mission requiring a control level accuracy at nm level it is beneficial if the optical metrology system is an integral part of the main mission and not an external sensor. Interferometric precision requires Optical Path Difference (OPD) control at an accuracy of fractions of a wavelength, i.e. nm. Typical applications requiring this precision us (parts of) the spacecrafts as optical elements while the constellation provides the function of an optical system.

In a general architecture (that might be revisited depending on the actual mission need), the coarse relative navigation is performed by RF metrology. It produces relative measurements (ranging and angular measurements among the spacecraft) and provides these measurements and the relative state vector (relative position, relative velocity, and if required relative attitude and attitude rate) as inputs to the GNC subsystem. The RF metrology technology ensures good relative navigation accuracy as start conditions for the subsequent optical metrology subsystems (coarse and fine lateral optical metrology, and longitudinal optical metrology). The optical metrology then takes over increasing the measurement accuracy up to the mission needs, or up to an accuracy that may be required for a payload internal metrology system to take over.

The border between RF metrology and optical metrology is normally set by the limits of the first technology and the required minimum accuracy to link the optical measurements to. Nevertheless, technology improvements allow refinement of the old boundaries, so that trade-off between costs, mass, power consumption, etc. can be refined for different missions, giving more or less weight to the RF and/or optical part of the end-to-end metrology chain.

RF and optical metrology instruments are normally meant to be used as part of the satellite platform in support of the GNC subsystem. As mentioned above, for certain applications the metrology system might also be considered as part of the payload providing supplementary information to the GNC/AOCS subsystem.

This topic is part of the Competence Domain 3 (see section 6).

4.6 CHEMICAL PROPULSION – COMPONENTS

4.6.1 Technology Overview

The Technology Topic covers all chemical propulsion components and systems from simple cold gas systems, with increasing complexity to monopropellant and bipropellant systems.
All these systems are used for spacecraft propulsion application, the selection being made by trading their main parameters off against the particular mission requirements.
The performance of such systems is primarily measured in terms of Thrust and Specific Impulse (it is a measure of the energy content of the propellants, and how efficiently it is converted into thrust).

A large portion of the chemical propellants currently used for space applications have toxicity levels that demand special measures to reduce risks to personnel handling these propellants or environments exposed to these propellants (e.g. Hydrazine, Nitrogen Tetroxide, Ammonium Perchlorate).
Green propellants have been investigated to overcome these issues and previously a separate harmonization dossier was created for Green propellants due to the lack of maturity of the technology at the time.
Currently small (monopropellant) green propulsion systems have been used on missions, and in selection of propulsion systems on new missions, green propulsion options are traded-off against more "classical" propellants with the best candidate for the mission being chosen.

Therefore green propulsion has thus reached a level of maturity that a separate dossier is no longer required and is now included in this dossier as any other propellant/system for spacecraft.

The development of component and system technologies for chemical propulsion in Europe started in the 1960's. Starting from the cold gas system, various other chemical propulsion concepts, and relevant components, have been developed with increasing complexity and performance based on monopropellant and bipropellant.
All these systems are still used for spacecraft propulsion application, the selection being made by trading their main parameters off against the particular mission requirements.
The performance of such systems is primarily measured in terms of Thrust and Specific Impulse.

- The performance of cold gas systems is low (low specific impulse and low thrust therefore high propellant mass is needed), but on the other hand they are very simple, cheap and light. Therefore they are used in case of small spacecraft's and/or small manoeuvres that can or should be performed at low thrust and high accuracy and stability (e.g. roll control, 3-axis attitude control, constellation deployment, etc.).

- Monopropellant systems consist generally of: propellant tanks to store the propellant, containing also the pressurising gas (a diaphragm or a surface tension propellant device are needed to ensure gas free depletion of the propellant), thrusters (each including a flow control valve and a catalyst bed where the propellant is decomposed) latch valves, fill/vent/drain valves to have an interface with the ground support equipment for all the operations on ground (testing, loading, unloading), liquid filter to protect the components from particle contamination, pressure transducer to monitor the pressure in the system during flight. Monopropellant systems have an intermediate performance between cold gas and bipropellant. They commonly used for medium/big spacecraft having a moderate requirement on the delta velocity to be provided.

- Bipropellant systems have the best performance and therefore are utilised in the more demanding missions (big GEO telecommunication satellites, planetary missions). The structure and relevant sections can be described as follows:

  - The bi-propellant system exist in two main forms – NTO/MMH and N2H4/MMH (commonly referred to as a dual mode application).
  - The high pressure section, where the pressurising gas is stored in dedicated high pressure tanks
  - The pressure regulation section, where a pressure regulator lowers the downstream pressure of the gas down and therefore in the propellant tanks, to the design level.
  - Downstream of the pressure regulator two identical propellant storage sections are present for fuel and oxidiser respectively
  - Fuel and Oxidiser are kept separated in two propellant distribution lines, until they finally mix with each other in the thruster's combustion chambers.

4.6.2 Areas Covered by this Technology Topic

The sub-systems addressed in this Topic are typically cold gas (inert gas), mono-propellant (hydrazine, hydrogen peroxide) and bi-propellant (typically MMH and NTO propellants) systems and the development strategy to increase their performance parameters (Thrust, Specific Impulse, Mass, Complexity etc) for spacecraft and planetary landers. In terms of the Propellant tanks and High pressure vessels, this Harmonisation addresses all types of low and high pressure "thin-walled" tanks for spacecraft, including chemical propulsion propellant and pressurant tanks as well as tanks for electric propulsion systems (i.e. xenon tanks) Note: It does not address "thick-walled" tanks as these are not considered state of the art, nor in need of harmonisation in order to fund expensive development programmes.
Also this Topic does not address specific launch vehicle applications such as cryogenic applications unless otherwise indicated in the text, thus illustrating where activities in one technology domain may also benefit development in other domains.

Therefore, the following technologies related to *Chemical Propulsion Components* will be addressed:

- Chemical Thrusters
  - Cold Gas
  - Catalytic decomposition (Monopropellant)
  - Bipropellant (Unified and Dual-mode)
- Thin-walled tanks:
  - Chemical Propulsion Propellant Tanks
  - Chemical Propulsion Pressurant Tanks
  - Electrical Propulsion Xenon Tanks
  - Horizontal transportation issues
  - Design of expulsion devices (PMD design, diaphragm) for compatibility with multiple launchers and satellites.
  - Manufacturing Technologies and Processes:
    - Low cost manufacturing techniques for very thin walled metallic liners (domes and cylindrical parts)

        - Integration of propellant management devices within thin walled metallic liners
        - Joining techniques for thin walled liners (domes and cylindrical parts)
        - Over-wrapping of large but thin walled metallic liners
        - Implementation of thermal hardware (heaters and sensors) between very thin walled metallic liners and the over-wrap
        - NDI techniques for tanks (overwrapped and metal)
        - Damage detection methods for COPVs

    - In-flight use:
        - Operator requirements on propellant tank functional performance
        - Intrinsic tank level advances for improvements to propellant gauging accuracy
        - Minimisation of static residuals
- Valve Technology ,high pressure (gas) and low pressure(gas, liquid)
    - Isolation Valve: Non-ITAR and to replace Pyro-valves
    - Check Valve
    - Pressure Relief Valve
    - Pyro-Valves
    - Fill/Drain valves
- Throttable engine Technologies
- Pressure Regulators
    - ITAR-free Integrated Pressure Regulator
        - Mechanical, Electrical
- Filters
- Pressure Transducers
    - High pressure
    - Low pressure
    - Ultra high temperature
- Mass Flow Sensors
- Advanced Materials Applications
- Propellant Material Compatibility Studies (generic)
- Test Facilities
- Propellants
- GSE

Chemical Propulsion - Components form part of the domain 19 (Propulsion), sub-domain A (Chemical Propulsion Technologies) and sub-domain D (Supporting Propulsion technologies and Tools), of the ESA technology tree.
The topic Chemical Propulsion - Components is part of the Competence Domain 7 (see section 6).

4.7 COATINGS

4.7.1 Technology Overview

Space hardware is exposed to challenging environmental conditions all through their lifecycle, which may affect the integrity of the materials which constitute them or the functionality of their subsystems.

These demanding conditions include humid and saline environment at the launch site, temperature variations, vacuum, atomic oxygen, radiation and high re-entry temperatures.

The operation of a part in its subsystem can also impart severe constraints on the materials, such as frictional loads in mechanism parts or extreme high temperatures in propulsion systems.

The surface of materials used in space components can also be required to have specific properties, to ensure the functionality of the part. A mirror or reflector surface must be able to reflect electromagnetic signals are certain wavelengths, while a radiator needs to emit thermal radiation at various rates, depending on the surrounding temperature.

The selection of materials used for a given part of the spacecraft is guided by multiple, sometimes conflicting, requirements. These include mechanical properties, weight, manufacturability, service temperature, thermal stability and electrical properties, among others. Materials selected to fulfil a set of those requirements may therefore need to be associated to a coating, which will protect them from environmental conditions or operational constraints or allow them to fulfil other key requirements.

For instance, carbon-fibre-reinforced polymers, selected for their low density, must be protected against radiation or be covered with a reflective surface for antenna or mirror applications. Ceramic matrix composites, considered for use in combustion chambers for their high temperature resistance and low weight, need to be shielded from the erosive and oxidizing combustion gases. Structural metallic materials, selected for their superior mechanical properties and good machinability, require protection from corrosion. They can also require surface plating to allow polishing to the very low surface roughness required for optical applications.

Various forms of coating and associated processes are therefore being developed to address those needs.

Coatings development is a truly interdisciplinary field, as it addresses the wide range of applications – and associated requirements – of materials used in space systems, e.g. optics, RF, tribology, corrosion, radiation, thermal, propulsion.

Application methods for coatings are varied and depend on the nature of the substrate material. Coatings can be deposited chemically or physically from the vapour phase. They can also be sprayed or formed in a solution by a chemical or electrochemical process. Recent advances include coatings based on metamaterials or self-regulated coatings for active thermal control.

Surface modifications by mechanical treatments, such as peening or texturing, are considered out of scope of this dossier, as they do not induce an additional layer of material with distinct composition from the substrate.

4.7.2 Areas Covered by this Technology Topic

Coating technologies covered in the Technology Dossier can be classified into three categories, defined by the objective of the coating:

- Coatings for ground and space environment protection: these include coatings for corrosion, radiation or atomic oxygen protection.
- Coatings for operational environment protection: these include coatings intended to protect the materials from the constraints imposed by the application. Examples include coatings for tribological applications (e.g. to reduce friction), environmental barrier coatings for high temperature applications (e.g. propulsion, re-entry) and conformal coatings for electronic components.
- Functional coatings: these coatings impart a specific function to material on which they are deposited. This category includes coatings for reflectors, optical mirror coatings, variable emissivity coatings for thermal control.

The Technology Dossier is intended to address of the design, modelling, manufacturing and characterisation of coatings.

The development of coating materials and associated deposition processes will constitute the core of the Technology Dossier, which is therefore focussed on TD24, particularly B-II, but also A-II, D-I to III, E-I, II, IV. However, the ultimate objective of a coating is to allow the part or subsystem to fulfil the application for which it was designed. The coating development is therefore driven by the requirements of the end application. Such applications cover a wide range of disciplines, which will provide key contributions to the definition and implementation of the Technology Dossier. The relevant Technical Domains include TD3, TD6, TD7, TD15, TD16, TD17, TD18, TD19, TD20, TD21, TD23.

This topic is part of the Competence Domain 2 (see section 6).

4.8 DEPLOYABLE BOOMS & INFLATABLE STRUCTURES

4.8.1 Technology Overview

4.8.1.1 Deployable Booms

Deployable structures present great advantages, since savings in mass and volume can be made as a compact stowed configuration can better withstand the launch loads, while the structure in its deployed configuration has to survive only the in-orbit loads, which are considerably lower. In addition, in case of large structural elements, the number of launches to place them into orbit and the number of in-orbit assembly operations, either by means of astronauts in extra vehicular activities or service vehicles, can be minimised.

Booms were used already in the first European satellites, e.g. in ESRO-1B and 2 to carry solar X-rays, cosmic radiation and Earth’s radiation belts sensors, on HEOS-1 to carry a magnetometer. In order to be simple, robust and reliable the first booms used were not deployable. On the other hand, their functionality was limited by the envelope constraints of the launchers’ fairings.

The increasing demand in high performance antennae and large solar arrays triggered the development of deployable structures.

Beyond the advantages in increased capabilities for the large-sized payloads, the major drawback of the deployable (supporting) structures is their higher complexity (and lower reliability) due to the mechanisms required for their automatic deployment.

Because of the link between higher performances and increased complexity, it is a real challenge for the space mechanism designer to select and procure the most suitable technology or solution, optimal in terms of concept, performances, reliability/risk, and material that are suitable for a certain space application and compatible with the targeted schedule and overall costs.

The current tendency is to have longer deployable booms (in the range from 10 to 20 meters with a goal of 50 meters) carrying larger tip masses (for example up to 1000 Kg for instruments and up to 100 Kg for large deployable reflector antennas).

Typical applications/tasks for deployable booms/masts/structures onboard spacecrafts can be summarized as follows:

- Deployment of instruments
    - Magnetometers (e.g. on Cluster, on Oersted, on Double Star, CoilABLE boom on Galileo Interplanetary Explorer, on Cassini….)
    - Gamma ray spectrometers (AstroMast on Mars Odyssey)
    - Instrument booms (Lunar Prospector, WIND GGS = Global Geospace Science, UARS = Upper Atmosphere Research Satellite ….)
    - STACER coilable boom (from KALEVA-USA)
- Deployment booms for solar arrays
    - Strongback structures (solar arrays from Fokker)
    - Solar array deployment mast (FASTMast for the ISS)
    - Solar array rigid substrate (Aec-Able PUMA on GPS and Indostar…)
    - Support structure and drive mechanisms for flexible solar arrays (HST, SAFE : Solar Array Flight Experiment….)

    - Advanced design solar arrays (support structure for Thin Film Solar Cells)
- Deployment booms for antennae
    - Reflectors for Earth observation, Science and Telecommunications applications
    - Dipole antennae booms
    - Radioastronomy antennae (Ulysses)
    - High gain antennae (HGAS on Solar Max, EUVE…)
    - Phased array antennae(LADD = Lens Antenna Deployment Demonstration…)
    - Plasma wave antenna (on Galileo Interplanetary Explorer)
    - Spin axis antenna deployment boom (for RPI = Radio Plasma Imager)
    - Radar Interferometry Antenna Support Boom (ADAM masts for SRTM = Shuttle Radar Topography Mission)
- Deployment booms for ion thrusters (e.g. for SLES, Spacecraft Life Extension System..)
- Deployment booms for heat rejection systems (sun shield for NGST, large thermal radiators….)
- Connecting structures (between modules, satellites, support structures for large space telescopes,...)
- Supporting booms for cameras (IMP Mast = CoilABLE booms for Mars Pathfinder, SSI mast (Surface Stereo Imager) for Mars Polar Lander…..)
- Support booms for secondary mirrors
- Supporting booms for solar sails
    - Coiled solid booms (ESA/DLR deployment demonstrator)
    - Inflatable structures (COSMOS 1, Team Encounter…)
- Supporting truss for tethered satellite missions (FASTMast for TSS-1 and 1-R)
- Telescopic booms for tethered satellites (DRB=Deployable Retrievable Boom)
- Gravity gradient booms (CoilABLE mast on LACE = Low Power Atmospheric Compensation Experiment, SOOS = Stacked Oscar On Scout)
- Orbital Transfer Device Boom (telescope boom for crane used to build the ISS)

Types of deployable booms/masts technologies:

- Retractable
    - Tubular
    - Telescopic
    - Coilable
        - Masts
        - Tubes
    - Truss structures
- Non-retractable
    - Truss masts (e.g. for antennae, heat rejection systems, etc)
    - Hinged/articulated rigid booms
    - In-orbit assembled booms
    - In-orbit manufactured booms
    - Furlable antennae
    - Co-coiled booms (e.g. for solar sails)

The actuation of the various deployable boom types can be performed by:

- Electrical motors (e.g. in the hinges or at the root)
- Ropes/lanyard
- Springs (e.g. in the hinges)
- Strain energy stored in pre-stressed members

- Shape memory alloys
- Paraffin actuators
- Co-coiled (extracting) belts

Various materials are used for deployable structures:

- Metallic (e.g. spring elements made of steel or Copper-Beryllium, tubular elements from Aluminium or Titanium,….)
- Non-metallic (e.g. CFRP=Carbon Fibre Reinforced Plastics, GFRP=Glass Fibre
- Reinforced Plastics, Kapton,…)

Different applications require specific techniques, e.g. magnetometer booms require light, high precision non-metallic structures; deployable structures for tethered satellites need high stiffness and cable routing capability; radar topography missions need long, stiff and precise deployable structures such as not to conflict with the spacecrafts' AOCS; planned solar sails need long, thermally stable, coilable structures, etc.

4.8.1.2 Inflatable Structures

Concerning a particular case of deployable structures, i.e. "inflatable space structures", those have been under development and evaluation for 50 years. Indeed their potential for low cost flight hardware, high mechanical packaging efficiency and low weight made them very attractive. This was especially important in the context of the launch vehicles capabilities in the early 60's (very limited volume and mass).

Inflatable structures are deployable structures, whose deployment concept is based on inflation by gas.

An inflatable structure typically comprises several components:

- inflatable element (for example boom or torus);
- inflation system;
- rigidization system;
- deployment control system;
- payload membrane;
- launch container.

The verification of inflatable structures is a challenge. Indeed, inflatable structures have properties, which makes their testing particularly difficult: These are pressurised systems, sometimes of very large dimensions, low mass and with a change of state in case of rigidisation. The effect of earth gravity must be properly accounted for. Indeed, deployment is strongly influenced by gravity and these structures are in some cases not able to sustain their own weight (especially before rigidisation), requiring gravity compensation systems.

The atmospheric pressure also affects the test results. It might be of several orders of magnitude larger than the internal pressure required to inflate a thin membrane in vacuum (a few Pa). The modal properties of thin membranes (natural frequencies and damping) are different in air or vacuum. Tests under vacuum may be impracticable for large structures.

The test set-up itself is also a challenge for inflatable structures. Indeed, the instrumentation (strain gauges, accelerometers, …) cannot be used as this instrumentation influences the mass distribution (the accelerometer mass might be of the same order of magnitude as the membrane mass) and the stiffness (through the cabling). The solution is to use contact less measurement techniques.

Depending of the rigidisation technique, testing on ground may be difficult. Some techniques like UV or thermal curing, or metal-layer stretching are irreversible. Techniques relying on the space environment for rigidisation e.g. solar UV or thermal curing, dehydration require a simulation of this environment for on-ground testing.

In order to avoid the problems of verification by test, or to complement testing, verification by analysis may be chosen. Unfortunately, analysis methods for predicting the structural dynamic response, and to some extend even the static behaviour, of inflatable structures are mostly unproven. Therefore a combination of ground and flight tests (with the limitations explained above) is required to validate the accuracy and sufficiency of analytical methods.

The analysis requirements vary depending of the configuration:

- in stowed configuration, it can be considered as a standard spacecraft analysis, where static, dynamic and buckling analyses need to be run.
- the analysis of the deploying phase involves large deformations, material non-linearity, surface contact, maybe even material flow and coupled fluid-structure interactive.
- the verification of the deployed structure requires static, buckling and dynamic analyses. It involves non-linear analyses, membrane pre-loading and wrinkling.

4.8.2 Areas Covered by this Technology Topic

The “*deployable boom*” technology is limited to booms, supporting structures, truss structures, coilable extendable booms, i.e. all types of elongated structural elements stowed for launch and deployed in orbit by mechanical means.

The Technology Topic does not cover the payloads attached to the masts and booms (e.g. antenna dishes, cabling, sensors, etc.).

The Technology Topic does not cover simply articulated rigid booms and hinge type mechanisms, i.e. one degree of freedom mechanisms like SWARM or non-elongated elements like GAIA sunshield. In the same way simply articulated rigid booms elementary components (pivot joints, actuators, dampers…) are not covered.

Multiple articulated long booms are also covered, since they are alternative technologies to all other types of deployable booms.

Concerning the specific domain of large deployable antenna reflector mechanism, deployable booms which might be applicable to that domain are covered (e.g. long booms to stretch a reflecting membrane, or a long boom with multiple articulations), but not specific or generic mechanisms which are related to the large reflector deployment as such.

With reference to the ESA Technology Tree, the “Deployable Boom” are in the Technology Sub-Domain 15-A, as shown in the below extract of the Technology tree (TEC-SHS/5289/MG/AP/ap issue 2 rev. 1), but also addresses 20-B (high-stability and high precision spacecraft structures) and 20-C (Inflatable and deployable structure).

This topic is part of the Competence Domain 7 (see section 6).

TD	Technology Domain	TSD	Technology Sub-Domain	TG	Technology Group
15	Mechanisms & Tribology: All devices which operation involves a moving function of one or several parts (e.g. actuator, hold-down&release device, pointing mechanism, deployable boom, thrust vector control mechanism), and associated specific disciplines and tools.	A	Mechanism core technologies: Building block technologies used individually or in combination to provide a mechanism function.	I	Actuator technologies: Technologies to provide torque or force (e.g. electromagnetic motors, voice coils, piezo motors, shape memory alloy actuators, electroactive polymer actuators, spring actuators, paraffin actuators).
				II	Dampers & speed regulator technologies: Technologies to regulate the speed of a movable element or to damp mechanical loads (e.g. low melting point alloy regulator, fluid damper, mechanical damper, eddy current damper).
				III	Motion transformer technologies: Technologies used to transform the motion (e.g. gears, pulleys and cables, harmonic drives, ball and roller screws).

The “*inflatable structures*” Technology Topic is limited to support/deployment structures for satellite appendages (beams, tori, reflectors, etc.) These structures are subjected to low thermo-mechanical loads and possess a long lifetime. Other inflatable structures, including inflatable re-entry bodies, habitats, airbags and balloons, are not part of the present evaluation.
However, it shall be noted that European industry has shown recent interest and expertise in these fields also. Furthermore, the synergy between the various types of inflatable structures needs to be assured.

4.9 LIFE SUPPORT TECHNOLOGIES

4.9.1 Technology Overview

Environmental control and life support systems are condition sine qua non of manned exploration missions. If for LEO missions such as for instance the International Space Station, an open loop approach (i.e. regular supply of consumables via cargo vehicle) is acceptable, missions of longer duration and beyond LEO will require a closed loop approach (i.e. regeneration of consumables and in-situ management of wastes). That is the management of wastes (e.g. organic, carbon dioxide, paper and packaging) and subsequent use of these to produce human consumables (i.e. oxygen, water and food). As soon as food is considered within a life support system, it implies the use of biological techniques. Therefore, closed regenerative life support systems normally include biological components, hereafter called biological processes.

The life support technologies needed for the implementation and execution of crewed missions are specific of crew size and mission duration. Nonetheless, the enabling building blocks, such as for instance water recycling system, air revitalisation systems and food production system, have two main characteristics:

- They are multi-phase flow (i.e. gas, liquid and solid) and include a transfer process between the phases
- They assure the controlled performance of a given biological reaction (e.g. photosynthesis for air revitalization, nitrification for urine treatment)

As a matter of fact, such biological processes rely on two generic technologies, namely the bioreactor technology and the membrane technology, which are the focus for the proposed technology topic.

Both technologies rely on fundamental and applied disciplines such as for instance materials, fluid physics and mechanics, thermodynamics, inorganic chemistry, biology, molecular biology, electronics, software, process engineering and automation, which have their own methodology, design tools and technologies. Research and development in these disciplines is on-going and dynamically evolving and so is the Life support topic.

Life support systems deals with the interaction, integration/customisation of these disciplines within the constraints of space applications.

4.9.2 Areas Covered by this Technology Topic

The Environmental Control and Life support dossier shall cover the technologies described above, which are needed for the implementation and execution of crewed exploration missions for:

- Cis-Lunar outpost/Mars transit missions : including carbon dioxid capture, perspiration capture, micro/nanofiltration, forward osmosis, photosynthesis, nitrification
- Planetary exploration (e.g. Moon village, Mars habitat): including novel concept for air revitalisation and water recycling, higher plant cultivation

The purpose of this harmonisation topic is also to address the complementary activities dealing with the required processes to demonstrate reliability performances of the technologies in the frame of space applications. This includes:

a) The development of system tools (i.e. mathematical models and software) to perform technology trade-off, architecture trade-off, integration within the space system and the space mission
b) The development of design tools (i.e. mathematical models and simulators), design guidelines and design rules to be used for designing bioreactor based on the biological process kinetics
c) The development of bioreactor characterization methodology to guarantee a systematic and reliable calibration and validation of the biological process
d) The development of design tools (i.e. mathematical models and simulators), design guidelines and design rules to be used for designing membrane process based on the transfer characteristics
e) The development of membrane characterization methodology to guarantee a systematic and reliable calibration and validation of the transfer process
f) The definition of guidelines and rules to be used for designing predictive control law for both biological process and transfer process
g) The verification methodology of the products obtained as a result of the biological transformation to guarantee a reliable integration within the space system
h) The establishment of PA requirements and of the verification tools required to reach the quality level required for space use.

The purpose of this topic is also to identify the need for new developments in the fields of:

- Small Instrumentation, including sampling systems and sample transfer system
- Diagnostics system, including sensors, analysers and lab-on-a-chip.

The topic Life Support Technologies is part of the Competence Domain 6 (see section 6).

4.10 SYSTEM MODELLING AND SIMULATIONS TOOLS

4.10.1 Technology Overview

In the context of European Harmonisation, “System Design and Verification Tools” includes tools used at system level for space system development and verification. This represents a significant investment for each individual project and it is therefore believed that harmonisation in this area will result in efficiency improvements. Tools used at discipline level itself will not be covered, and they might be harmonised in their own discipline, e.g. thermal analysis tools.

Examples of the type of facilities that are targeted are Software Validation Facilities (SVF) or Assembly, Integration and Testing support (AIT/EGSE) as well as system verification support. However this dossier covers many more types of these System Level Facilities.

The specific tools covered in this harmonization topic are System Modelling & Simulation (SM&S) tools.
There is a need to harmonise these tools (including their interfaces) with the related processes and methodologies in order to reduce the overall investment in Europe. This is particularly important for software validation and system test-bench simulator products for functional system verification. While COTS tools exist, European prime industry often uses their own internal tools. These tools (and their interfaces) are increasingly important today, since current design and verification approaches are based on reuse of simulator artefacts from design to verification or even operational phases, implying tools need to cope with additional configurability requirements.

Rationalisation of European Simulator tools is a specific topic to be covered in this 3rd revision of the technical dossier. This covers the components and tooling that build up European (System-level) Simulation Facilities to allow for a smooth model-based process supporting/ the mission/project lifecycle and to allow for a cross-mission and cross facilities reuse and exchange. The aim is to improve the efficiency in applying the System Simulation Facilities, improve their functionalities and quality, while trying to reduce cost, development time and risk to the project. In addition to prepare the facilities for future needs, for example new type of mission/systems. It is mandatory to also look at commercial solutions available, also outside the space sector.

Future systems addressed will be more and more autonomous and adaptive, and the corresponding simulation infrastructure will need to be able to handle this complexity by adequate methodologies. Discrete and analog/continuous systems are combined and will require hybrid environments to support the system design and verification process. The extension of purely functional system simulations towards more multi-disciplinary simulations is increasingly being used at system design and verification level.

4.10.2 Areas Covered by this Technology Topic

System Modelling & Simulation (SM&S) Tools constitutes a sub-domain of the System Design and Verification Technical Domain, TD8 (more specifically it falls into the Technology Group System Design and Simulation of the ESA Technology Tree - TD8-CI). In the new landscape of competence domains they are mainly considered part of Competence Domain 8 (Ground Systems and Operations, see section 6).

This dossier does not cover simulator instantiations for a specific purpose or project nor does it cover the development of a generic (grand) simulator to cover all needs. But the subject is the underlying requirements, architecture, the processes, methods and tools to constitute a wide variety of simulators and to build it in the most efficient way.

This dossier relates to and partially overlap with other technical domains.
Specifically TD2-C Ground Segment Software has an overlap in the area of simulators and is partially covered in this dossier. Similar TD8-D II Ground Support Equipment has an overlap in the area of simulators with corresponding database, procedure execution and other tools.
For TD8-B I Collaborative and Concurrent Engineering, Concurrent Design technology group there is an area partially covered by this dossier concerning the simulator tools to support the concurrent design of missions/systems. System Concept Simulators fall into this category and are covered by this Dossier.
Emulators for modeling (on-board) processors are covered in the On-board Software Technical Dossier TD2-B. However, the Basic Software Simulator and SAVOIR Execution Platform, simulating the functional aspects of the HW platform at Device Driver or OS level, will be covered in this dossier as well.

This dossier has a link to the Functional Verification and Mission Operations technical dossier. The latter covers the bigger context of required infrastructure while this dossier focus on the System Modelling and Simulation aspects at technology level.

5 LIST OF EARMARKED TECHNOLOGIES FOR 2019 – 2020

Table 5-**5-1** and Table 5-**5-2** list the technologies earmarked for Harmonisation in 2019 and 2020, based upon end of current Roadmap and requests received. The actual topics for the relevant years will be selected taking into consideration previous commitments and the proposals received from ESA Technical and Programme Directorates, Industry (via Eurospace) and THAG Delegations during the preparation of the Harmonisation Workplan.

	2019	**Revisit**
1	Chemical Propulsion - Micropropulsion	2011
2	TT&C Transponder and Payload Data Transmission	2013
3	On-Board Radio navigation Receivers	2013
4	Fluid mechanics and Aerothermodynamic Tools	2012
5	Multibody Dynamic Simulation	2014[2]
6	Power Management and Distribution	2013
7	Technologies for Optical Passive Instruments – Mirrors	2013
8	Technologies for Optical Passive Instruments – Stable and Lightweight Structures	2012
9	Cryogenics and Focal Plane Cooling	2013
10	Pyrotechnic Devices	2013

Table 5-5-1 List of Potential Technologies for the 2019 Harmonisation Workplan

	2020	**Revisit**
1	Micro-Nano Technologies - MEMS	2014
2	Solar Array Drive Mechanism	2014
3	Composite Materials	2014
4	On-Board Software	2014
5	AOCS Sensors and Actuators - part I	2013
6	Electrochemical Energy Storage	2014
7	Critical Active RF Technologies	2014
8	Functional Verification and Missions Operations Systems	2014
9	System Data Repository	2014
+	Any and all subjects proposed for 2019 and not selected for that year	See Table 6-1

Table 5-5-2 List of Potential Technologies for the 2020 Harmonisation Workplan

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[2] Mapping

6 OVERVIEW OF TECHNOLOGIES 2000-2020

The table reported in the following pages provides an overview of the technologies that have been harmonised since 2000, organised per Competence Domains

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmo
1	EEE / Components / Photonics / MEMs	Optical Detectors, Visible Range	2006.1	
			2011.1	
			2015.1	
		Optical Detectors, IR Range	2006.1	2017.2
			2011.1	
		Micro-Nano Technologies - MEMS	2008 (MP)	2020
			2014.2	
		Photonics		2018
2	Structural / Mechanisms / Materials / Thermal	Electrical Motors	2002.2	
			2007.2	
			2015.2	
		Deployable Booms & Inflatable Structures	2003.2	2018
			2010.2	
		Solar Array Drive Mechanisms	2003.2	2020
			2008.2	
			2014.1	
		Electric Propulsion Pointing Mechanisms (EPPMs)	2004.2	
			2009.2	
			2016.2	
		Position Sensors	2009.1	2018
		Technologies for Hold Down, Release, Separation and Deployment Systems	2004.1	
			2008.2	
			2015.2	
		Pyrotechnic Devices	2003.1	2019
			2006.1	
			2013.1	
		Two-Phase Heat Transport Systems	2003.1	2017.1
			2009.1	
		Cryogenics and Focal Plane Cooling	2001	2019
			2007.1	
			2013.2	
		Composite Materials	2005	2020
			2010.2 (MP)	
			2014.2	
		Additive Layer Manufacturing	2015.1	2017.1
		Coatings		2018

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmo
3	Avionic Architecture / DHS / OnBoard S/W / FDIR / GNC / AOCS / TT&C (E2E)	Avionics Embedded Systems	2006.2	
			2010.1	
			2016.1	
		On-Board Payload Data Processing	2003.1	
			2006.2	
			2011.2	
			2016.1	
		Data Systems and On Board Computers	2003.1	
			2006.2	
			2011.2	
			2016.1	
		Microelectronics - ASIC & FPGA	2002.2	
			2007.1	
			2011.2	
			2016.1	
		On-Board Software	2003.1	2020
			2006.2	
			2010.1	
			2014.2	
		AOCS Sensors and Actuators (Part I & Part II)	2001	2020
			2005.1	
			2009.1	
			2013.1 & 2015.2	
		On-Board Radio Navigation Receivers	2002.1	2019
			2007.2	
			2013.2	
		RF & Optical Metrology	2008.1	2018
		TT&C Transponders and Payload Data Transmitters	2003.1	2019
			2007.2	
			2012.2	
4	Electric Architecture / Power & Energy / EMC	Solar Generators and Solar Cells	2004.2	
			2009.1	
			2015.1	
		Electrochemical Energy Storage	2002.1	2020
			2006.1	
			2010.2	
			2014.1	
		Power Management and Distribution	2003.2	2019
			2008.2	
			2013.2	
5	E2E RF & Optical Systems and	Power RF Measurements & Modelling	2004.1	
			2007.2	

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmo
	Products for Nav, Comms & Remote Sensing		2015.1	
		Critical Active RF Technologies	2004.2	2020
			2014.1	
		Frequency and Time Generation and Distribution (Space & Ground)	2005.2	2018
			2011.1 (Ground)	
			2013 (Space)	
		Technologies for Passive Millimetre & Submillimetre Wave Instruments	2006.2	
			2010.2	
			2016.2	
		Array Antennas	2005.2	2017.1
			2011.2	
		Reflector Antennas	2004.2	
			2009.2	
			2016.2	
		RF Metamaterials and Metasurfaces	2016.2	
		Microwave Passive Hardware		2017.2
		Technologies for Optical Passive Instruments (Stable & Lightweight Structures)	2008.2	2018
			2013.1	
		Technologies for Optical Passive Instruments (Mirrors)	2008.2	2018
			2013.1	
		Optical Communication for Space	2004.1	2017.2
			2008.2	
			2012.2	
		Lidar Critical Subsystems	2005.2	2017.2
			2010.1	
		Ground Station Technology	2015.1	
6	Life / Physical Science Payloads / Life Support / Robotics and Automation	Automation and Robotics	2001	2017.2
			2007.1	
			2012.1	
		Life Support Technologies		2018
7	Propulsion, Space Transportation and Re-entry Vehicles	Fluid Mechanic and Aerothermodynamics Tools	2002.1	2019
			2007.1	
			2012.2	
		Chemical Propulsion - Micropropulsion and Related Technologies	2002.2	2019
			2007.2	
			2011.2	
		Chemical Propulsion - Components (including Tanks)	2002.2	2018
			2008.1	
			2012.2	
		Chemical Propulsion – (Green Propulsion)	2002.2	
			2008.1	

CD ID	Competence Domain	Related Harmo Roadmap	Past Revisit	Planned/Ongoing Harmo
			2012.1	
		Electric Propulsion Technologies	2004.2	
			2005.1	
			2009.2	
			2013-2017*	
8	Ground Data Systems / Mission Operations	Functional Verification and Missions Operations Systems	2002.2	2020
			2008.1	
			2014.2	
		System Modelling and Simulation Tools	2006.2	2018
			2012.1	
9	Information Technology and data fusion and analytics	System Data Repository	2014.1	2020
		Multibody Dynamic Simulation	2014.1(MP)	2019
		Thermal & Space Environment S/W Tools and Interfaces	2002.1	
		Big Data from Space		2017.1
10	Astrodynamics / Space Debris / Space Environment	Radiation Environments & Effects	2005.2	
			2009.2	
			2015.2	
		De-orbiting Technologies		2018

Table 6-1: Harmonised Technologies organised per Competence Domain

** The last revisit of the EP Harmonisation Roadmap started in 2013 and continued to 2015 when was put on-hold. It is now being finalised and updated for release in 2017.*

Legend:
MP: Mapping Only
RM: Roadmap Only