PLATAFORMA TECNOLÓGICA
AEROESPACIAL
ESPAÑOLA

Space Taxonomy

Annex

PAE-ATX-ANX-01/03

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PAE-STX-ANX-01/01	01 Rev 01	Initial issue (July 2017 - 161 pages)
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PAE-STX-ANX-01/03	01 Rev 03	List of contributors added (July 2017 – 163 pages)

This report summarizes the PAE's proposed taxonomy for Space with the following main objectives:

1. Having a common understanding and language to define our Strategic Research Agenda (commonly accepted definitions of technologies).
2. Classifying the entries in our Catalogue of Capabilities and Infrastructures.
3. Obtaining, by analysis of the classified information, a better knowledge of our needs and capabilities to do research and taking better decisions.

The report is divided in two parts: the overview of the different levels of the taxonomy (taxonomy trees) contained in the basic document and the detailed description of all the branches contained in the present Annex.

There is a similar document defining the PAE-AEROTAXONOMY.

The following references have been used to prepare this document:

R1. "NASA Technology Roadmaps" May 2015 Draft

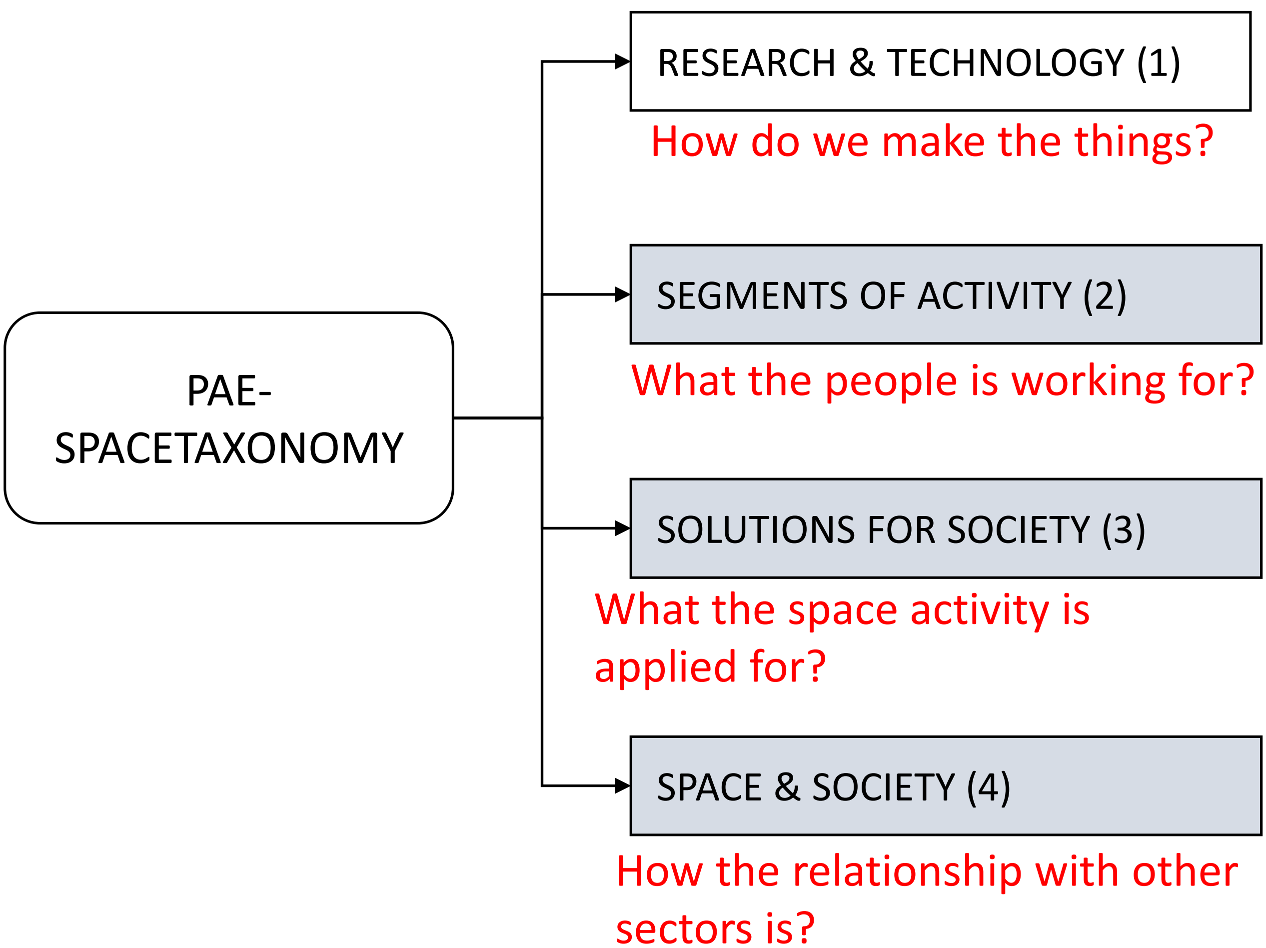
R2. "ESA Technology Tree" STM-277 Version 3.0 October 2013

R3. "Technology Roadmap of SMART", the Eureka Advanced Manufacturing Program, draft 2, published in January 13th, 2017 and used in part as a guide for the "New Industry paradigms for space manufacturing" part of the SPACETAXONOMY

R4 "North American Industry Classification System", United States 2017

R5 "REGULATION (EC) No 1893/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 December 2006 establishing the statistical classification of economic activities"

R6 "Space Economy at a glance 2014", OECD


PAE-
SPACETAXONOMY
RESEARCH & TECHNOLOGY (1)
How do we make the things?
SEGMENTS OF ACTIVITY (2)
What the people is working for?
SOLUTIONS FOR SOCIETY (3)
What the space activity is applied for?
SPACE & SOCIETY (4)
How the relationship with other sectors is?

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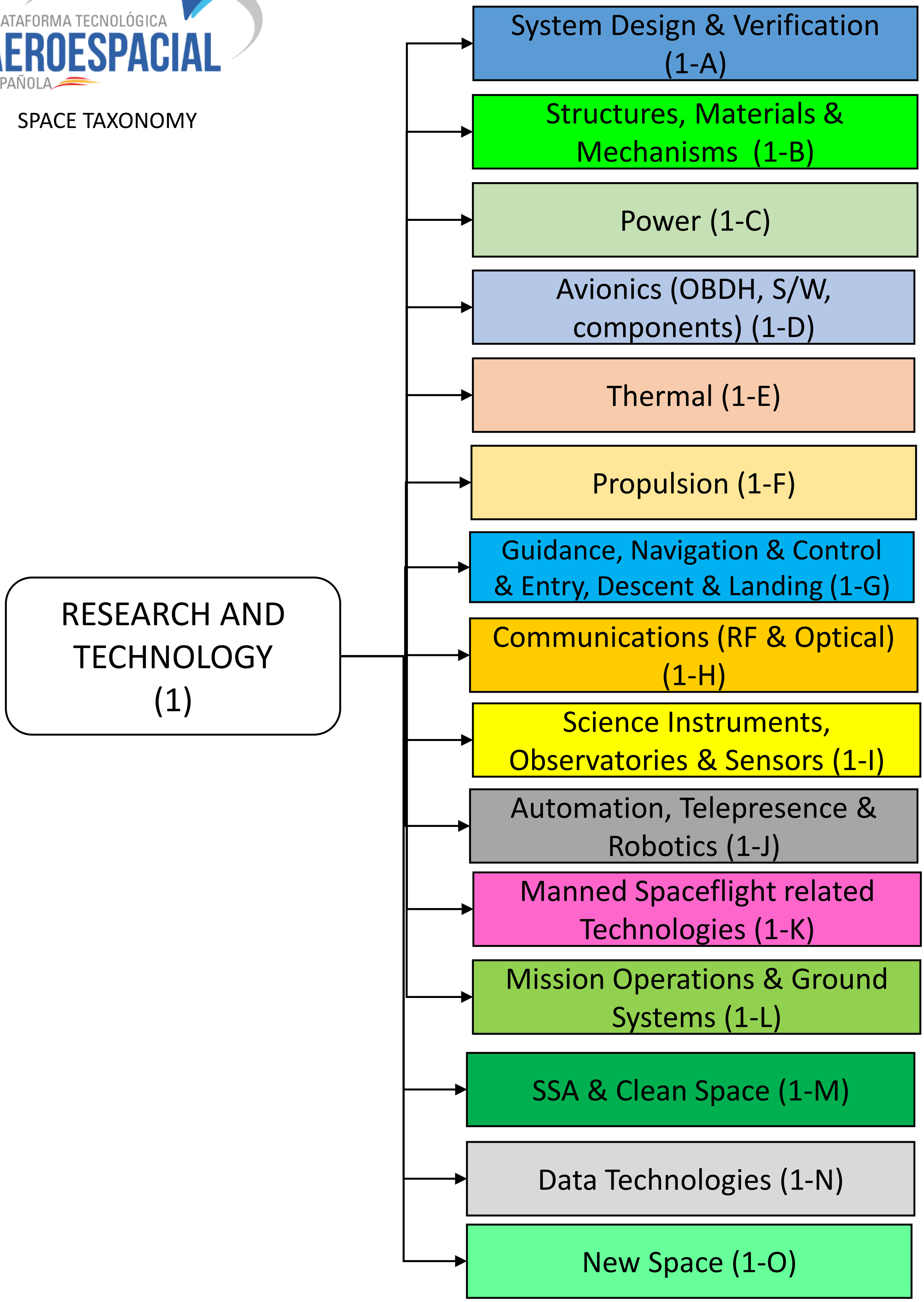
RESEARCH & TECHNOLOGY (1)

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

SPACE TAXONOMY



SYSTEM DESIGN & VERICATION (1-A)

DEFINITION:

Covers technology, methods and tools to support system engineering processes (specification, design, and verification) of space systems during the complete mission lifecycle (phases 0 to F). Focuses on reducing the schedule and/or cost of development of the space system (i.e. space and ground segment) whilst controlling quality and risk (mission success) to the required level. It covers new paradigms (e.g. model-based systems engineering), approaches and techniques for the development of space systems, which are mostly common to several service domains.
It also covers system aspects and AOCS/GNC functional chain engineering.
It also includes product safety and dependability, software quality assurance and product and quality assurance.

(Source: ESA TD8, TD5A, TD25A, B and C and PAE insertion for Cybersecurity)

SUBDOMAINS:

1-A-1. Mission & System Specification / Space System Engineering
1-A-2. Collaborative & Concurrent Engineering
1-A-3. System Analysis & Design
1-A-4. System Verification & AIT
1-A-5. System Dependability & Software
1-A-6. Software Quality Assurance
1-A-7. Product and Quality Assurance
1-A-8. Cybersecurity

RESEARCH & TECHNOLOGY (1)
SYSTEM DESIGN & VERIFICATION (1-A)

Mission & System Specification / Space Systems Engineering (1-A-1)

DEFINITION:

Covering the early phases of a project development life cycle, focusing on requirement engineering, specification and architecture formulation
It also covers system aspects and AOCS/GNC functional chain engineering.

(Source: ESA TD8A (Subdomains 1 and 2) and TD5A (Subdomains 3 to 6))

SUBDOMAINS:

1. Specification Methods and Tools
Methods and tools to support the capture, modelling and validation of requirements, including definition and formalisation of system architectures.2. Collaborative & Concurrent Engineering (CCE)
2. Requirement Engineering
Methods and tools to support the system requirement engineering process, including requirement management and related database issues.
3. AOCS/GNC Architecture
Includes concept and mode definition, and selection and accommodation of sensors and actuators.
4. Autonomy and FDIR
Covers control-related aspects and implementation (with 1-E-5 and 1-K-2).
5. Pointing Error Engineering
Covers budget methodology and tools.
6. Control Requirements Engineering
Includes software algorithm specification (with 1-E-5) and sensor and actuator specification.

Collaborative & Concurrent Engineering (1-A-2)

DEFINITION:

Covering aspects related to the process of concurrent engineering as well as the data underlying multidisciplinary collaboration.

(Source: ESA TD8B)

SUBDOMAINS:

1. Concurrent Design
Includes methods and tools to provide an integrated environment for the concurrent design of a mission/system.
2. Data Exchange
Covering methods and standards to support the exchange of multidisciplinary data, focusing on the data aspects of collaborative engineering.
3. Collaborative Engineering
Covers methods and tools to support collaboration of remotely located engineering teams and access to remote models/data. Includes aspects of interoperability and deployment of corresponding tools.

System Analysis & Design (1-A-3)

DEFINITION:

Including system-to-subsystem interaction and interfaces, relationships between domain-level analyses and system-level analyses.

(Source: ESA TD8C)

SUBDOMAINS:

1. Design and Simulation
Includes methods and tools to support the modelling and simulation based design and verification at system level.
2. Multidisciplinary Analysis
Includes methods and tools to support coordinated analyses for different technical disciplines.

System Verification & AIT (1-A-4)

DEFINITION:

Covering methods, tools and infrastructure necessary to integrate and verify space systems.

(Source: ESA TD8D)

SUBDOMAINS:

1. Advanced AIT Methods
Covering advanced methods, tools and standards to support the assembly, integration and testing plus verification of space systems across the life cycle.

2. Ground Support Equipment
Covering advanced tools and standards for supporting ground activities in all domains across the life cycle.
(GSE for propulsion systems is included in PRO-SUT)

System Dependability & Software (1-A-5)

DEFINITION:

Addresses the reliability, availability, maintainability and safety of the entire space system.

(Source: ESA TD 25A)

SUBDOMAINS:

1. Dependability and Safety Methods & Tools
Covers methods and tools to achieve mission success and hazard control.
2. Technical Risk Management Techniques
Covers the identification, evaluation, mitigation and acceptance of risks.

Software Quality Assurance (1-A-6)

DEFINITION:

Addresses the quality of the software development process and the resulting software products.

(Source: ESA TD 25B)

SUBDOMAINS:

1. SW Process Quality Techniques
Covers the techniques to assure the quality of the software development process.
2. SW Product Quality Techniques
Covers the evaluation and certification of the quality of the software products.

Product and Quality Assurance (1-A-7)

DEFINITION:

Covers the quality of space systems, their hardware and the human element. It also addresses methods and tools for the assessment and management of technical risks associated with space systems and their operations.

(Source: ESA TD 25C with PAE adaptation)

SUBDOMAINS:

1. Product Assurance Processes for Flight and Ground Systems
Covers the coordination and integration of PA disciplines (QA, safety, dependability, EEE parts, materials, mechanical parts, processes, software PA), auditing, critical items, configuration management, alerts, document and data control, nonconformance control and quality records.
2. Quality Assurance Processes for Flight and Ground Systems
Covers assurance of design, manufacture, assembly, integration, testing, procurement, recurring production, training, inspections, traceability and standards.

Cybersecurity (1-A-8)

DEFINITION:

Measures taken to protect the platform/spacecraft interfaces and the ground system infrastructure against unauthorized access or attack.
Spacecraft systems (ground and flying infrastructures) includes intensive use of computer or computer system. The access to this information systems require a vulnerability analysis to protect its integrity and ensure its operation and also to avoid the possibility of being mislead by false information. It can include critical systems protection, platform interfaces and network surveillance, data analytics, information security, mission assurance, and information operations capabilities. The risk analysis includes any possible information interface, physical, radio, …

(Source: PAE own elaboration)

SUBDOMAINS:

1. **Cyber-defence**
2. **Information protection**

STRUCTURES, MATERIALS & MECHANISMS (1-B)

RESEARCH & TECHNOLOGY (1)

STRUCTURES, MATERIALS & MECHANISMS (1-B)

DEFINITION:

Technologies and methodologies related to design, analysis, manufacture and test of structures and mechanical systems for S/C, planetary infrastructures, habitats, launchers and reentry vehicles.
Includes metallic and non-metallic structures such as advanced deployable structures (solar array, radiator, shield and antenna structures), highly-loaded structures, highly-stable structures and hot structures.
It also covers the materials mechanics and processes, their physical and chemical behaviour and the interaction with the operational environment through the S/C and ground infrastructure lifecycle. Furthermore, all manufacturing processes are covered.
All devices with moving parts (e.g. actuators, hold-down & release devices, pointing mechanisms, deployable booms, thrust vector control mechanisms); associated specific disciplines (such as tribology and pyrotechnics) and tools (such as mechanism and magnetic simulations) are also included.

(Source: ESA TD 20 (except 20H included into 1-K-2 and 1-K-9), TD 24 (24F is included into 1-B-3) and TD 15)

SUBDOMAINS:

1-B-1. Structural Design and Verification, Methods and Tools
1-B-2. Special and Advanced Types of Structures
1-B-3. Damage Tolerance & Health Monitoring
1-A-4. Launcher, reentry and planetary vehicle structures
1-A-5. Meteoroid & Debris protection (shield design and analysis)
1-A-6. Novel Materials & Materials Technology
1-A-7. Materials Processes (including obsolescence)
1-B-8. Cleanliness & Sterilization
1-B-9. Space environments effects on Materials & Processes
1-B-10. Materials for Electronics Assemblies
1-B-11. Mechanisms engineering and core technologies
1-B-12. Release mechanisms
1-B-13- Mechanisms control electronics
1-B-14. MEMS & special types of mechanisms

DEFINITION:

This includes all technologies related to the development and implementation of mechanical design tools, analysis tools and methodologies, testing tools and methodologies, load measurements and evaluation techniques etc.

(Source: ESA TD 20A)

Structural Design and Verification, Methods and Tools (1-B-1)

SUBDOMAINS:

1. S/C Design and Design Tools
Including CAD tools and methodologies.
2. Analysis Tools and Methodologies
Including structural verification tools and methodologies (acoustics, damage tolerance, thermo-elastic, deployment simulations, composite structures …).
3. Testing Tools and Methodologies
Including test data storage tools, test data evaluation tools, test prediction tools.
4. Inflight/In-orbit Loads and Vibration Measurement Techniques
Including sensors, integration, data recording/downloading, data evaluation.

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RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

DEFINITION:

It includes:

- High Stability and High Precision Structures.
- Inflatable and Deployable Structures.
- Hot Structures.
- Active / Adaptive Structures.
- Advanced Structural Concepts and Materials.

(Source: ESA TD 20 B, C, D, E and J)

Special & Advanced types of Structures (1-B-2)

SUBDOMAINS:

1. High Stability and High precision Structures, covering:

- material technologies for stable structures (manufacturing, verification, failure analysis and definition of allowables)
- joining and mounting (interfacing to other structures, verification of interfaces for high-stability and high-precision)
- thermo-elastic stability verification (design, analysis and test aspects)

Note: see also 1-J-2

2. Inflatable and Deployable Structures, covering:

- design and verification (design tools, deployment simulation, test methodologies, combined verification methodologies)
- structural material concepts (material testing, laminate / membrane design, in-orbit curing aspects)
- joining technologies (design and verification of joints: flexible-to-flexible and flexible-to-rigid)

3. Hot Structures, covering:

- design and verification for ceramic and metallic hot structures (manufacturing, detailed design, analysis and tests aspects: static, dynamic and thermo-elastic)
- new advanced hot structures materials (such as UHT ones)
- joining technologies (fasteners, brazing and other methods, including verification)
- health monitoring (sensors, data recording and evaluation)

4. Active / Adaptive Structures, covering:

- sensors / actuators technologies (e.g. electroactive polymers (EAP), piezo patches, fibres). *Mechanisms aspects covered by 1B11, 13 & 14*
- technologies for Structural Integration (including application of various sensor/actuator combinations)
- data acquisition and control logic technologies related to structural dynamics (covering multi-body dynamics analysis tools and methodologies)
- design and verification tools and methodologies (including detailed analysis and test tools)

5. Advanced Structural Concepts and Materials, covering:

- design and verification technologies for structures manufactured from novel materials (nanotube reinforced, foams, self-healing materials etc.).

Damage Tolerance & Health Monitoring (1-B-3)

DEFINITION:

Includes all technologies related to the development and implementation of damage tolerance and health monitoring tools, methodologies and hardware, including fatigue, fracture control, non-destructive inspection (NDI) and sensor developments.

(Source: ESA TD 20F and TD 24F: identical to subdomain 1 or TD 20F-I)

SUBDOMAINS:

1. Non-Destructive Inspection Technologies
Including the development of new methodologies and related
hardware, application in space programmes.
2. Structural-Health-Monitoring Sensor Technologies
Including sensor development, structural integration etc.
3. Fracture Control Tools and Methodologies
Including numerical tools, detailed analysis methodologies, e.g. for non-linear applications, damage tolerance for composites and ceramics.

RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

Launcher, re-entry and planetary vehicle structures (1-B-4)

DEFINITION:

(ascent, entry, …) Includes all related technologies for the development of vehicle primary and secondary structures, control surfaces, shields etc.

(source: ESA TD 20G)

SUBDOMAINS:

1. Technologies for Design and Verification of Advanced Primary Structures
Including structural concepts for highly-loaded components, manufacturing methodologies e.g. fibre placement, RTM etc.
2. Advanced Tank Design and Verification Technologies
Including metallic and composite tanks, interfaces to primary structure, HMS, NDI, damage tolerance approaches, etc.
3. Landing Attenuation Technologies
Including airbag technologies, landing legs, application of crushable materials, foams etc.
4. Control Surfaces, Design and Verification Technologies
Including design with ceramics as well as advanced metallic alloys, combined mechanical–thermal test methodologies etc.

Meteoroid & Debris protection (shield design and analysis) (1-B-5)

DEFINITION:

Includes the development of related analysis and test tools and methods, shield developments, damage assessments etc.

(source: ESA TD 20I)

SUBDOMAINS:

1. Tools and Methodologies for Design and Verification of Meteoroid & Debris Shields
Covers numerical tools, materials models, shield test methods, gas guns, shaped charges, data acquisition technologies.

Novel Materials & Materials Technology (1-B-6)

DEFINITION:

Includes materials not yet used in space but presenting potential interest.

(Source: ESA TD 24A)

SUBDOMAINS:

1.Material Assessment
Including basic properties, possibility to scale-up, limitations.
2. Nanotechnology
Covering development, manufacture and test of nanotubes, nano-fibres, nano-coatings.

RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

Material Processes (including modelling of behaviour and properties and obsolescence) (1-B-7)

DEFINITION:

It includes:

- Material Processes (manufacturing and fabrication techniques)
- Modelling of material behaviour and properties
- Material obsolescence

(Source: ESA TD 24B, E and G)

SUBDOMAINS:

1. Material Processes, covering:

- joining (Including gluing, bonding, welding, brazing, soldering, fastening, repairing). *Technologies of joining for Special and Advanced types of Structures are covered by 1-B-2*
- coating (development, manufacture and test of paints, conformal coatings, organic and inorganic coatings, thermo-optical coatings, thermal control materials, optical materials, sol-gel coatings, ALD, oxidation protection, finishes)
- characterization and feedback (all aspects related to thermo-physical/ mechanical/chemical properties, long-term ageing effects)
- advanced materials manufacturing (manufacturing aspects related to CFRP, ceramics, CMC, MMC, foams, functionally-gradient materials, sol-gel processed materials, near-net-shape processing route, PVD & CVD processes, ISRU processes for solid materials manufacture, nanotechnology aspects of materials…)

2. Modelling of material behaviour and properties, covering:

- microstructural and nano-structural characterization of materials
- modelling of thermomechanical Processes of Materials including lifetime predictions
- characterisation, modelling and testing of fracture mechanics
- thermal analysis of materials (characterisation of the functional properties of materials from cryogenic to re-entry/launcher temperatures)

3. Material Obsolescence, covering

- regulation and legislation-based obsolescence: addresses the materials and manufacturing process availability and limitations due to environmental regulations and export regulations (e.g. REACH, RoHS, ITAR, etc.).
- scarce materials: due to production stop, bankruptcy, etc.

RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

Cleanliness & Sterilization (1-B-8)

DEFINITION:

Includes the techniques, tests and technologies to ensure and verify that the hardware fulfils the requirements in terms of contamination, sterilisation and degradation in a broad sense.

(Source: ESA TD 24C)

SUBDOMAINS:

1. Sterilisation of Materials
Effect of sterilisation on materials and assemblies, compatibility of materials with sterilisation techniques.
(Note: Technologies related to verification of the bioburden reduction process are covered in 1-L).
2. Control of Molecular Contamination
Outgassing of materials, cleanliness monitoring techniques, contamination transfer processes, effects on performance, mitigation, surface contamination, … Laser-induced contamination, photo-fixation of contamination.
3. Control of Particulate Contamination
Includes contamination transfer processes, effects on performance, mitigation, protection, cleanroom monitoring.

DEFINITION:

It is concentrated only on the effects on materials of the ground or space environment and the effects that materials may produce affecting inhabited environments (on ground and in space ones). The study of space environment and clean space requirements on space systems (including materials) is included into 1-M

(Source: ESA TD 24D and PAE own elaboration)

Space environments effects on materials & processes (1-B-9)

SUBDOMAINS:

1. Interaction of Materials with the Space Environment
Electromagnetic radiation from EUV to FIR, X-rays, particle radiation, vacuum, atomic oxygen, charging, contamination, synergistic effects, dust & particles, planetary gases…
2. Interaction of Materials with the Ground Environment
Covering issues such as storage, logistics, corrosion, swelling.
3. Interaction of Materials with the Inhabited Environment
Addressing safety- and performance-related issues affecting the inhabited environment such as toxicity, flammability, ….

DEFINITION:

It is concentrated on the technologies associated with electronics assemblies: PCB technologies, surface mounting technologies and the development of verification techniques for electronic assemblies (the verification itself is part of the quality assurance included into 1-A-7).

(Source: ESA TD24 H and PAE own elaboration)

Materials for Electronics Assemblies (1-B-10)

SUBDOMAINS:

1. Printed Circuit Board Technologies
2. Surface Mount Technologies
3. Verification of Electronic Assemblies

RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

Mechanisms engineering and core technology (1-B-11)

DEFINITION:

It includes:

- **Mechanism core technologies**: Building-block technologies used individually or in combination to provide a mechanism function.
- **Mechanism Engineering**: Specific mechanism engineering knowhow to develop space-related mechanisms.
- **Tribology Technologies**: Technologies related to the science of interacting surfaces.

(Source: ESA TD 15A, F and G)

SUBDOMAINS:

1. Mechanism core technologies, covering:

- Actuators: 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).
- Dampers & Speed Regulator: 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).
- Motion Transformer: Technologies used to transform a motion (e.g. gears, pulleys and cables, harmonic drives, ball and roller screws).
- Motion & Force Sensor: e.g. switches, optical encoders, resolvers, strain gauge sensors, capacitive sensors, accelerometers.
- Guiding: Technologies providing linear or rotational guiding functions (e.g. ball and roller bearings, journal bearings, magnetic bearings, ball joints, flexible guides).
- Sealing: Technologies providing a static or dynamic sealing function.
- Electrical Transfer: Technologies whose function is to transfer an electrical signal between two parts in relative motion, with or without contact (e.g. slip rings, roll rings, contactless technologies).

2. Mechanism engineering, covering:

- Engineering Disciplines: Specific engineering disciplines involved in the design and development of space mechanisms (e.g. motorisation sizing, micro-vibration analysis, functional tolerance budgets, multi-body dynamic analysis, tribology).
- Engineering Tools: Specific tools used to support the design and development of space mechanisms (e.g. bearing sizing software, multi-body dynamic analysis software).

2. Tribology Technologies, covering:

- Lubrication: Technologies providing a lubrication function (e.g. solid lubricants, fluid lubricants, self-lubricating materials).
- Material Surface: Technologies providing a specific material surface performance (e.g. coatings, heat treatment). (Note: Issues related to material characterisation are covered in 1-B7)

RESEARCH & TECHNOLOGY (1)
STRUCTURES, MATERIALS & MECHANISMS (1-B)

Release mechanisms (1-B-12)

DEFINITION:

It includes:

- **Non-explosive Release Technologies**: Non-pyrotechnic technologies used to release a force or torque (e.g. mechanical fuse, shape memory alloy, electromagnetic, paraffin).
- **Pyrotechnic Technologies**: Including development and testing of new materials, ignition methods, actuation and miniaturisation.

(Source: ESA TD 15B and H)

SUBDOMAINS:

1. Non-explosive Release Technologies
2. Pyrotechnic Technologies, covering:

- Explosive Composition Technologies: Covers high-temperature survival and ageing characteristics; shock reduction technologies including testing.
- Thermite Technologies: Cover applications of thermite heating to provide connection, disconnection, release, joining. Covers also provision of oxygen for life and other gases for pressure functions.
- Reliability Determination for Non-Repeating Functions: Covers analysis techniques for valid estimates of reliability at required levels of confidence, definition and demonstration of test and analysis techniques for small samples.
- Optical Ignition Technologies: Covers the development of components and systems for alternative to electrical ignition, with potential to increase safety by reducing sensitivity to electrical disturbance.
- Advanced Electro-pyrotechnics: Covers the use of explosive foil initiators in order to reduce mass and cost and increase safety.
- Development of New Devices for Future Exploration and Exploitation Missions: Covers connection and disconnection of structures and fluid circuits, deployment of shields and shelters, seismic and exploration functions, anchoring, penetrating, sealing; for manned, robotic and automatic operation

Mechanisms control electronics (1-B-13)

DEFINITION:

Technologies providing mechanism control (open and closed loop control electronics).

(Source: ESA TD 15D)

SUBDOMAINS:

MEMS & special types of mechanisms (1-B-14)

DEFINITION:

It includes:

- **MEMS Technologies**: Micro-/nano-technologies providing a mechanism function (e.g. pointing, scanning).
- **Exploration Tool Technologies**: Tool technologies to acquire samples in exploration missions (e.g. drill bits, ultrasonic tools). It has a strong relationship with 1-J-1 and 1-J-3 in Automation, Telepresence and Robotics.

(Source: ESA TD 15C and E)

SUBDOMAINS:

1. MEMS Technologies
Quality aspects of MEMS are covered by 1-A-7
2. Exploration Tool Technologies

POWER
(1-C)

POWER
(1-C)

DEFINITION:

Addresses the techniques and technologies related to power system architecture, to power generation, distribution and conditioning and to energy storage.

(Source: ESA TD 3)

SUBDOMAINS:

1-C-1. Power System Architecture
1-C-2. Power Generation Technologies
1-C-3. Energy Storage Technologies
1-C-4. Power Conditioning and Distribution, Control and Regulation

Power System Architecture (1-C-1)

DEFINITION:

Including power system topologies, sizing, modelling and simulation tools and techniques.

(Source: ESA TD 3A)

SUBDOMAINS:

Power Generation Technologies (1-C-2)

DEFINITION:

It includes all the possible power generation technologies used in space: photovoltaic, fuel cells, nuclear and thermo-electrical ones.

(Source: ESA TD 3B)

SUBDOMAINS:

1. Photovoltaic Generator Technology
Including solar cells (crystalline and thin films), photovoltaic assembly and solar array technologies.
2. Fuel Cell Technologies
3. Nuclear and Thermo-Electric Power Generator Technologies

Energy Storage Technologies (1-C-3)

DEFINITION:

It includes all the possible energy storage technologies used in space: basically the electro-chemical and mechanical ones.

(Source: ESA TD 3C)

SUBDOMAINS:

1. Electro-Chemical Technologies for Energy Storage
2. Mechanical Technology for Energy Storage
(Note: Detailed mechanisms aspects are covered in 1-B-11)

Power Conditioning & Distribution, Control and Regulation (1-C-4)

DEFINITION:

Including regulation, control and distribution.

(Source: ESA TD 3D)

SUBDOMAINS:

1. Power Conditioning
PCUs, DC/DC converters, SAR, BDRs, BCRs etc.
2. Specific Power Supplies
PPUs, high-voltage EPCs, wheel electronics, etc.
3. Power Distribution
Solid-state switches, PDUs.

Avionics (OBDH, S/W, components) (1-D)

RESEARCH & TECHNOLOGY (1)

Avionics (OBDH, S/W, components) (1-D)

DEFINITION:

It includes:

- **On-board data systems**: Addresses both spacecraft data management and payload data processing and covers the hardware and software required for data acquisition, data processing, storage for both payload and spacecraft data, on-board networking and the space-link network layer and above.
- **On-board software**: Addresses only space segment (ground segment software is included in 1-K). All basic techniques and technologies in the fields of software and Information Technology with respect to their application to space missions.
- **EEE components**: Covers technologies related to the design, production and testing of EEE components which meet the performance and reliability requirements for use in on-board electric/electronic systems. (Note: This technology domain is concerned with quality issues).

(Source: ESA TD 1 (on-board data systems), TD 2A and 2B (on-board software) and TD 23A and 23B modified by PAE (components)

SUBDOMAINS:

1-E-1. Payload Data Processing
1-E-2. On-Board Data Management
1-E-3. Microelectronics for Digital and Analogue Applications
1-E-3. Advanced Software Technologies
1-E-4. Space Segment Software
1-E-5. Methods and Processes for Management of components including radiation hardness assurance (RHA)
1-E-6. Components Technology

Payload Data Processing (1-D-1)

DEFINITION:

Covering specific digital signal and data processing technologies and techniques, as well as specific (high-speed, high-capacity oriented) hardware (e.g. DSP, storage), software (signal/image processing, data compression/fusion…) and networking technologies (including protocols and standards).

(Source: ESA TD 1A)

SUBDOMAINS:

1. System Technologies for Payload Data Processing
Covers system aspects such as payload processing and storage architectures, algorithms, communication, etc., for Earth observation, science and manned-space applications.

2. Hardware Technologies for Payload Data Processing
Covers hardware technologies related to high-speed/high performance equipment (e.g. DSP, mass memories, switches and communication links, digital video, data compression).

3. Software Technologies for Payload Data Processing
Covers software technologies related to high-speed/high performance payload data processing systems.

RESEARCH & TECHNOLOGY (1)
Avionics (OBDH, S/W, components) (1-D)

DEFINITION:

Covers avionics and command & control system specific aspects, such as data handling, system management and autonomy, as well as specific hardware (e.g. computers, storage, micro-controllers), software (e.g. basic support packages) and networking technologies and techniques, etc.

(Source: ESA TD 1B)

On-board Data Management (1-D-2)

SUBDOMAINS:

1. System
Highly integrated systems, architecture, fault tolerance, onboard operation management and autonomy.

2. Onboard Computers
Covers onboard fault-tolerant dependable computers, their main components (microprocessors, I/O) and basic software.

3. Data Storage
Covers the development of data storage equipment (mass memories) and modules for spacecraft platforms.

4. Onboard Networks and Control/Monitoring
Covers the development of the onboard data communication systems, including onboard command and control data networks for performing monitoring and control across the platform, and wireless systems.

RESEARCH & TECHNOLOGY (1)
Avionics (OBDH, S/W, components) (1-D)

Microelectronics for Digital and Analogue Applications (1-D-3)

DEFINITION:

Covering design methodologies and technology for space application specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs). Digital and analogue designs, including IP cores.

(Source: ESA TD 1C)

SUBDOMAINS:

1. Methodologies
Rad-hardening by design allowing usage of commercial technologies; System-on-chip design methodologies; Hardware-Software co-design; usage of reprogrammable FPGAs for space applications; high-performance and low power signal processing algorithms and processors; analogue IC design. ASIC and FPGA design (design kit and libraries) and test tools.
(Notes: Issues related to basic mechanisms of radiation effects are covered in 1-D-6. The software side of software–hardware co-engineering is covered in 1-D-5)
2. Digital and Analogue Devices and Technologies
Reusable IP cores, (ASIC) processors, detector readouts and sensor electronics front-ends, standard ASICs and ASSPs (Application Specific Standard Products), FPGAs.

RESEARCH & TECHNOLOGY (1)
Avionics (OBDH, S/W, components) (1-D)

Advanced S/W Technologies (1-D-4)

DEFINITION:

Advanced software development (requirements, design, verification, validation, maintenance and qualification) methods/tools. Advanced functions to be implemented in software. Both ground and space application included. Development of related standards.

(Source: ESA TD 2A)

SUBDOMAINS:

1. Advanced Software Development Methods and Tools
Methods and tools for the software development that are innovative in the commercial world and require analysis prior to adoption in the space domain. This includes for example the OMG (Object Management Group) technologies, new languages, etc.
2. Advanced software functions
New functions of the software systems that are anticipated to be needed but that need predevelopment or prototyping before actual space development. Includes autonomy, parallel computing, etc.
(Note: This includes also predevelopment for applications indicated in 1-D-1 subdomain 3)

RESEARCH & TECHNOLOGY (1)
Avionics (OBDH, S/W, components) (1-D)

Space Segment Software (1-D-5)

DEFINITION:

Onboard software requirements, design, verification, validation, maintenance and qualification methods/tools. Specific aspects related to the application of modern IT technologies. Includes flight software and related simulator technologies.

(Source; ESA TD2 B)

SUBDOMAINS:

1. Methods and Tools for Onboard Software Engineering Processes
All aspects of onboard software engineering, requirement engineering, automation of the life cycle, testing, model-based development, etc. In particular, it includes software emulators of onboard processors.

2. Innovative Software Management Process
Adaptive engineering, new planning approaches, cost estimation methods, distributed development. The focus is on the system aspects of software, the system–software co-engineering. Includes also software–hardware co-engineering. (Note: The system side of system–software co-engineering, and the hardware side of software–hardware co-engineering, are covered in 1-A-1 and 1-E-3 respectively.)

3. Software Architectures
Software architectures for space segment software. Includes e.g. concepts such as Arinc653. In particular, it includes also Plug and Play technologies.

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RESEARCH & TECHNOLOGY (1)
Avionics (OBDH, S/W, components) (1-D)

Methods & Processes for Management of components (RHA included) (1-D-6)

DEFINITION:

For determining and enhancing technology/component reliability and suitability for flight applications. Definition of radiation hardness assurance (RHA) requirements, modelling of particle interaction with matter and resulting radiation effects in components, including simulation of component parameter degradation – EEE and any other type of component like optoelectronic or magnetic ones -, characterisation of radiation effects in terms of technology and design-dependent basic mechanisms, radiation hardening/mitigation and radiation verification testing, including definition of irradiation test facility requirements and dosimetry.
(Source: ESA TD 23B and PAE own elaboration)

SUBDOMAINS:

1. Evaluation and Testing
Includes the development of laboratory techniques and test methods for characterisation, evaluation, qualification, de-rating, end-of-life, failure analysis and procurement of space components.
2. Radiation Hardening
Process hardening, design hardening, mitigation techniques, verification and validation.
3. Design and Development
Development and design of components adapted to the requirements for space applications and capable of meeting space component qualification requirements.
4. Modelling
Simulation of component responses to radiation at semiconductor level, including simulation and prediction of component parameter degradation.
5. RHA Process
Definition of RHA requirements and development of irradiation test method/guidelines.
6. Reliability Test Facilities
Definition of test facilities for space, and in particular of irradiation test facility requirements covering particle species, energy, flux, beam size, uniformity and accuracy. Definition of dosimetry and dosimetry accuracy. Definition of all interfaces (mechanical and electrical) to enable irradiation testing of EEE components.

Components technology (1-D-7)

DEFINITION:

Covers the component technologies most commonly evaluated using the processes included in 1-D-6.

(Source: ESA TD 23A)

SUBDOMAINS:

1. Passive Components
Capacitors, inductors, resistors, crystals, magnetics, switches, wires, cables, connectors, piezo actuators, heaters, harnesses, non integrated electro-mechanical components. RF passive components such as isolators, circulators, etc. are also addressed.

2. Silicon-Based Components
Discrete, analogue, digital and mixed signal technologies and device types across all integration levels and functional complexity ranges in bipolar and MOS technologies.

3. RF Microwave and Millimetre Wave Components
Discrete and MMIC components including RF-CMOS, GaAs, SiGe, InP technologies, packaging and RF passive components.

4. Optoelectronic Active and Passive Components
Optical and near-optical sensors, detectors, laser diodes, fibre optical connectors, optical assemblies and associated passive components.

5. Hybrids and Micro-packaging
Thick and thin film hybrid technologies, microwave hybrid circuits, DC–DC converter technologies, crystal oscillators, multichip modules, system-on-a-chip (SOC), 3D stacking and interconnect technologies, IC packaging technologies, RF and MMIC packaging and subassemblies.

6. Power Components
Very-high-voltage MOSFETS, IGBT, SiC, GaN power devices, power including for realisation of high-performance DC–DC power conversion transistors and thermal management components.

7. Wide Band Gap Technologies
SiC, GaN and Diamond for advanced MMIC applications and harsh environment sensor technologies and for realisation of high performance DC–DC power conversion transistors.

8. Micro Electro Mechanical Systems (MEMS)
Evolving range of technologies and applications including RF MEMS, pressure sensors, AOCS sensors, MOEMS, actuators, etc.

9. Nanotechnology in Microcircuits
Application of carbon nanotubes, nano-fibres, innovative nanomaterials to microcircuit improvement.

Thermal (1-E)

Thermal (1-E)

DEFINITION:

It includes:

- **Spacecraft Thermal Control**: all technologies needed for the thermal control of space systems.
- **Aero-thermodynamics**: Dynamics of gases (physical processes & modelling), especially of atmospheric interactions with moving objects at high speed. It encompasses the whole spectrum from take-off to landing, but also orbital ascent/descent, aero-heating and thermodynamics of propulsion.

(Source: ESA TD 21 and TD 18)

SUBDOMAINS:

1-F-1. Heat Transport Technology
1-F-2. Cryogenics and Refrigeration
1-F-3. Thermal protections
1-F-4. Heat Storage and Rejection
1-F-5. Thermal Analysis Tools
1-F-6. Aero-thermodynamics Numerical Methods
1-F-7. Aero-thermodynamics Ground Based Facilities
1-F-8. Aero-thermodynamics Sensors and Measurement Techniques
1-F-9. Aero-thermodynamics Flight Databases

Heat Transport Technology (1-E-1)

DEFINITION:

Covers all technologies associated with heat transport, whether in the single phase or using the latent heat in two-phase systems.

(Source: ESA TD 21A)

SUBDOMAINS:

1. Heat Pipes
Covers all technologies related to heat pipes, e.g. constant conductance, variable conductance and heat pipe diodes.

2. Capillary-Driven Loops
Covers all technologies related to capillary-driven two-phase heat transport loops, including Capillary Pumped Loops (CPLs) and Loop Heat Pipes (LHPs).

3. Mechanically-Pumped Two-Phase Loops
Covers all elements and associated technologies for mechanically pumped two-phase heat transport loops.

4. Mechanically-Pumped Single-Phase Loops
Covers all elements and associated technologies for mechanically pumped single-phase heat transport loops.

5 Heat Switches
Covers all elements and technologies for heat switches, e.g. based on LHPs or mechanically driven.

DEFINITION:

Covers all technologies associated with transferring heat from lower to higher temperature levels and cooling by evaporation of stored cryogens.

(Source: ESA TD 21B)

Cryogenics and Refrigeration (1-E-2)

SUBDOMAINS:

1. Refrigeration and Heat Pumps
Covers all refrigeration technologies required for temperature control of items in a near-room-temperature environment, including also heat pumps.
2. Cryo-Coolers
Covers all active cryo-machinery and associated technologies for cooling to cryogenic temperatures (down to 1K).
3. Passive Coolers and Stored Cryogens
Covers all technologies related to non-active cooling (e.g. radiators, cryostats).
4. Sub-Kelvin Coolers
Covers all technologies required to provide cooling below 1K.

Thermal protections (1-E-3)

DEFINITION:

Covers all technologies associated with thermal protection and insulation systems for atmospheric entry.

(Source ESA TD 21C)

SUBDOMAINS:

1. Ablative Systems
Covers all technologies providing thermal protection based on chemical and/or physical reactions.
2. Reusable Systems
Covers thermal protection technologies for multiple applications on reentry vehicles.

Heat Storage and Rejection (1-E-4)

DEFINITION:

Covers all technologies associated with heat storage and rejection using coatings, insulation, thermal capacitors and radiators.

(Source: ESA TD 21D)

SUBDOMAINS:

1. Coatings and Insulation
Covers all technologies for achieving thermal control surfaces and insulation.

2. Heat Storage
Covers all types of thermal capacitors, e.g. phase-change materials.

3. Radiators
Covers all technologies associated with radiative interfaces between the system and its environment, including louvres.

Thermal Analysis Tools (1-E-5)

DEFINITION:

Covers all software tools and methods for the design and verification of space systems.

(Source: ESA TD 21E)

SUBDOMAINS:

1. Thermal Software Tools
Covers all software used for system-level analysis in the thermal area.

2. Thermal Data Exchange
Covers all protocols, tools and methods for thermal data transfer from one software environment to another.

3. Thermal Analysis Methods
Covers all analytical and numerical methods in relation with the development and application of software tools for design and verification.

Aero-thermodynamics Numerical Methods (1-E-6)

DEFINITION:

Includes engineering and computational fluid dynamics (CFD) techniques, both for internal and external flows, for the multidisciplinary design and analysis of Space Vehicles.

(Source: ESA TD 18A)

SUBDOMAINS:

1. Computational Fluid Dynamics (CFD)
Continuum and discrete particle models (including numerical algorithm and grid generation techniques) for multi-physics flow.
2. Engineering Techniques
Analytical, semi-empirical and parametric design tools.
3. Multidisciplinary Techniques
Coupling tools (including advanced optimisation algorithms) and/or databases of different technical disciplines.

DEFINITION:

Includes all types of wind tunnels and other test facilities for the design and analysis of space vehicles, both for internal and external flow.

(Source: ESA TD 18B)

Aero-thermodynamics Ground Based Facilities (1-E-7)

SUBDOMAINS:

1. Cold Gas Facilities
Continuous and blow-down wind tunnels, ballistic ranges, etc.
2. Hot Gas Facilities
Arc-heated, piston driven, detonation driven, etc.
3. Dedicated Facilities
Contamination, hovering, base flow-jet interaction, etc.

Aero-thermodynamics Sensors and Measurement Techniques (1-E-8)

DEFINITION:

Includes all types of measurement techniques for ground facilities and flight platforms, for the design and analysis of space vehicles, both for internal and external flow.

(Source: ESA TD 18C)

SUBDOMAINS:

1. Intrusive Measurements
Sensing technologies suitable for measurements in hostile environment – temperature, pressure, heat flux, etc.
2. Non-Intrusive Measurements
Multi-spectral infrared, laser spectroscopy, electron-beam, etc.
3. Wireless Measurements
Radio sensing, health monitoring, etc.

Aero-thermodynamics Flight Databases (1-E-9)

DEFINITION:

Includes the informatics environment to conserve, retrieve and use flight data from experimental test beds and demonstrators, and their associated wind tunnel and CFD extrapolation to flight data.

(Source: ESA TD 18D)

SUBDOMAINS:

1. User Interface
Aspects related to tools and methods for data storage, handling and post-processing.
2. Informatics Environment
Aspects related to systems for data storage, handling and post-processing

PROPULSION
(1-F)

PROPULSION (1-F)

DEFINITION:

Following ESA's technology domains this area includes both launcher propulsion and in-space propulsion technologies (separated by NASA in two different technology areas). Under the Advanced Propulsion subdomain, any unconventional system could be included (the ones explicitly included in the description and any other one that could appear in the future). In any case, the description follows the one proposed by ESA.

(Source: PAE own description based on ESA TD 19)

SUBDOMAINS:

1-F-1. Chemical Propulsion
1-F-2. Electric Propulsion
1-F-3. Advanced Propulsion
1-F-4. Propulsion Supporting Technologies and Tools

Chemical Propulsion (1-F-1)

DEFINITION:

Includes a wide range of technologies for propulsion systems, based on the use of chemical energy, relevant to the following major applications: (1) spacecraft on-board propulsion; (2) reusable or expendable launch vehicles/upper stage propulsion; (3) re-entry manoeuvring propulsion systems.

(Source ESA TD 19A)

SUBDOMAINS:

1. Liquid Propulsion Systems
Includes cold gas, mono- and bipropellant, onboard systems, cryogenic and LOX/hydrocarbon launch vehicle systems.
2. Solid Propulsion Systems
Includes from micro-thrust systems up to launch vehicle boosters.
3. Air-Breathing and Hybrid Propulsion Systems
Includes ramjets, scramjets, rocket based cycles.

Electrical Propulsion (1-F-2)

DEFINITION:

Includes propulsion systems and components that use electrical energy (solar or nuclear), classified according to the following major applications: (1) spacecraft onboard propulsion; (2) upper stage propulsion.

(Source: ESA TD 19B)

SUBDOMAINS:

1. Electrostatic Systems
Includes systems based on Hall-effect thrusters, gridded ion engines, field emission thrusters.
2. Electro-thermal Systems
Includes systems based on resistojets, arcjets and power-augmented catalytic thrusters.
3. Electromagnetic Systems
Includes systems based on magneto-plasma-dynamic thrusters and pulsed plasma thrusters.

Advanced Propulsion (1-F-3)

DEFINITION:

Includes a wide range of non-classical propulsion systems, for both spacecraft and launchers/upper-stages, and the technology field of breakthrough propulsion physics.

(Source: ESA TD 19C)

SUBDOMAINS:

1. Solar Thermal Propulsion Systems
2. Nuclear Propulsion Systems
3. Solar Sailing Propulsion Systems
4. Tethered Propulsion Systems
5. New Concepts
Including laser-beamed propulsion, Lorentz force accelerators, cryo-solids, etc.

Supporting Technologies & Tools (1-F-4)

DEFINITION:

Includes several and tools that are used in support of the development, qualification, integration and monitoring of propulsion systems. These tools and technologies, although similar in scope and classification, might differ substantially depending on their use for chemical, electrical or advanced propulsion.

(Source: ESA TD 19D)

SUBDOMAINS:

1. Modelling
Includes propulsion system design tools, thruster and engine performance prediction tools, propulsion system/space vehicle interaction tools and related orbit/trajectory definition tools.
2. Testing and Diagnostics
Including facilities and diagnostic tools for ground performance, qualification and acceptance tests of propulsion systems; on-board propulsion diagnostics and health monitoring systems.
3. Propellants
Including technologies for production, storage, transportation and characterisation of solid, liquid or gaseous propellants.
4. Ground Support Equipment (GSE)
Including all mechanical, fluid and electrical ground support systems dedicated to a propulsion system integration, testing, loading and launch preparation.

Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

DEFINITION:

It includes:

- **Space System Control**: Covers the design and implementation of control systems for space applications. Includes AOCS for satellites; GNC for space vehicles and launchers; pointing acquisition and tracking systems for antennas, laser terminals, and line-of-sight stabilisation equipment.
- **Flight Dynamics and GNSS**: Comprises the activities related to the analysis and definition of trajectory aspects of space projects, known as mission analysis. It includes all operational ground activities related to the measurement and control of spacecraft orbit and attitude. Furthermore it deals with the provision of precise navigation services to both ground and space based users and also the provision of the geodetic reference frame.
- **Radio Navigation Systems / Subsystems:** Covers radio navigation techniques and technologies, elements and subsystems capable of generating, receiving, exploiting and analysing the signals from current and upcoming radio navigation systems (GPS, Glonass, EGNOS, Galileo), including system tools and navigation equipment.
- **Entry, Descent and Landing Systems:** Covers the technologies **e**nabling heavier payloads travelling at faster velocities to enter and descend through atmospheres and land safely with higher precision than currently possible.

(Source: ESA TD 5 (Space System Control), ESA TD 10 (Flight Dynamics and GNSS) and ESA TD 6B (Radio-navigation Systems and Subsystems) and NASA TA9 (Entry, Descent and Landing Systems))

SUBDOMAINS:

1. **AOCS/GNC Sensors and Actuators (1-H-1)**
2. **Control System Engineering including innovative techniques (1-H-2)**
3. **Control Techniques and Tools(1-H-3)**
4. **Flight Dynamics (1-H-4)**
5. **Global Navigation Satellite Systems (GNSS) (1-H-5)**
6. **Radio Navigation Systems / Subsystems (1-H-6)**
7. **Aero-assist and atmospheric entry (1-H-7)**
8. **Descent and Targeting (1-H-8)**
9. **Landing (1-H-9)**
10. **Vehicle for EDL (1-H-10)**

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

AOCS/GNC Sensors and Actuators (1-G-1)

DEFINITION:

Covers the specification and development of generic and custom products based on mission and market needs.

(Source: ESA TD 5D)

SUBDOMAINS:

1. **AOCS/GNC Optical Sensors**
Startrackers, Sun and Earth sensors, optical navigation sensors. Includes detectors (with 1-H-8), optics (with 1-I), microelectronics (with 1-D-3), electronics, image processing, software algorithms.
2. **AOCS/GNC Inertial and Magnetic Sensors**
Gyros, acceleros, IMUs, magnetometers. Includes MEMS, HRG, FOG technologies, control loops and hybridisation, microelectronics (with 1-D-3), electronics.
3. **AOCS/GNC Inertial and Magnetic Actuators**
Reaction wheels, CMGs, magnetic torques). Includes control loops, mechanisms & tribology (with 1-B-11), power electronics (with 1-C-4), microelectronics (with 1-D-3).

RESEARCH & TECHNOLOGY (1) Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Control System Engineering including innovative techniques (1-G-2)

DEFINITION:

It includes:
- **Control Systems Engineering:** Covers system aspects and AOCS/GNC functional chain engineering.
- **Control Systems Innovative Technologies**: Covers enabling technology developments dedicated to specific missions and generic applications.

(Source: ESA TD 5A and 5B)

SUBDOMAINS:

1.1 AOCS/GNC Architecture
Includes concept and mode definition, and selection and accommodation of sensors and actuators.

1.2 Autonomy and FDIR
Covers control-related aspects and implementation (with 1-D-4 , 1-D-5 and 1-L-2).

1.3 Pointing Error Engineering
Covers budget methodology and tools.

1.4 Control Requirements Engineering
Includes software algorithm specification (with 1-D-4 and 1-D-5) and sensor and actuator specification.

1.5 Control Design and Verification
Includes detailed analysis and performance verification on functional engineering simulators and avionic test benches.

2.1 GNC Technologies for Entry, Descent and Landing
Covers GNC technology developments for aero-braking, precision landing, hazard avoidance, real-time guidance and navigation, specialised simulation tools and test beds.

2.2 GNC Technologies for Cruise, Rendezvous and Docking or Capture
Covers GNC technology developments for exploration as well as active debris removal.

2.3 High Accuracy Pointing Technologies
Covers technology developments in AOCS and pointing acquisition and tracking systems.

2.4 Competitive AOCS Technologies
For commercial and generic applications, tackling cost reduction at all levels (design and verification effort, building-block approach, hybridisation of sensors, …).

Control Techniques and Tools (1-G-3)

DEFINITION:

Covers generic and advanced techniques dedicated to design analysis and verification.

(Source: ESA TD 5C)

SUBDOMAINS:

1. **Modelling Techniques**
Covers mathematical modelling and software model development for: satellite dynamics and environment, sensors and actuators, and software components.
2. **Advanced Control, Estimation & Optimisation**
Covers the development of efficient techniques and tools for design analysis and verification.
3. **Multidisciplinary Optimisation**
Includes the development of mathematical solvers and tools for concurrent optimisation of GNC-related aspects of the space vehicle and trajectory.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Flight Dynamics (1-G-4)

DEFINITION:

Flight dynamics support addresses the trajectory and attitude aspects of space missions. This includes the pre-flight trajectory design (mission analysis). In flight, it includes the determination and control of trajectory and attitude of the spacecraft, monitoring of spacecraft AOCS and generation of orbit- and attitude-related command parameters. The FD domain of expertise comprises mathematics, dynamics, optimisation and environment modelling. FD support is mission critical and thus must be correct, robust, reliable and flexible.

(Source: ESA TD 10A)

SUBDOMAINS:

1. **Mission Analysis and Trajectory Design**

Covers pre-flight spacecraft mission design, trajectory optimisation and launch window calculations.

2. **Advanced Flight Dynamics Operations**

Covers high-precision navigation at minor bodies, interplanetary RVD and formation control, FD support to GNC systems including novel sensors and actuators; aero-capture and aero-braking; entry, descent and landing; high-precision formation-flying control; high precision orbit control for Earth observation.

3. **Advanced Flight Dynamics Processes and Tools**

Covers automation of flight dynamics operations, advanced modules of FD application SW and advanced operational processes.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Global Navigation Satellite Systems (GNSS) (1-G-5)

DEFINITION:

Covers operation of GNSS sensor networks, GNSS-related data processing, techniques for precise orbit- and clock-determination concepts for MEOs and LEOs and satellite geodesy.
It does not include GNSS downstream applications but only the use of GNSS signals to position and track space systems.

(Source: ESA TD 10B and PAE clarification)

SUBDOMAINS:

1. **Ground Tracking Networks**
Covers the deployment, operation and data collection for GNSS sensor stations, network management, data handling services.
2. **GNSS and Geodetic Data Processing**
Models, algorithms, data monitoring, data quality assessment and delivery of services and products.
3. **MEO and LEO Precise Orbit Determination Algorithms**
Orbit dynamics and related models, analytical and numerical algorithms, for real-time (ground) and non-real-time (onboard/ground) data processing, performance analysis.
4. **Geodetic Reference Frames**
Satellite geodesy, standards, processing of different observations.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Radio Navigation Systems / Subsystems (1-G-6)

DEFINITION:

Covers radio navigation techniques and technologies, elements and subsystems capable of generating, receiving, exploiting and analysing the signals from current and upcoming radio navigation systems (GPS, GLONASS, EGNOS, Galileo), including system tools and navigation equipment. (Note: It has strong relationship with 1-G).

(Source: ESA TD 6B)

SUBDOMAINS:

1. **Navigation System Tools**
Covering all aspects related to ground and space navigation systems, subsystems, Signal in Space, simulators, analysis tools and methodologies.
2. **Ground Receivers**
Covering all technologies related to RF and baseband aspects, positioning and integrity algorithms, integration with other sensors, local augmentation, and integration with telecommunication systems and services.
3. **On-board Receivers**
Covering all aspects related to navigation space receivers or reference receivers, algorithms and technologies.
4. **Formation-flying RF metrology**
Covering all aspects related to high accuracy RF metrology required for formation-flying applications, including algorithm technology and tools.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Aero-assist and atmospheric entry (1-G-7)

DEFINITION:

Aero-assist and atmospheric entry (AAE) systems are defined as the intra-atmospheric technologies that decelerate a spacecraft from hyperbolic arrival through the hypersonic phase of entry. The mission requirements range from high-speed entries of scientific probes at Venus and Saturn, to sample return capsules to Earth (Mars sample return being the most challenging), and human missions to Mars.

(Source: NASA TA9.1 except TA9.1.5 Instrument & Health Monitoring included into 1-B-3 and TA9.1.6 Entry Modelling and Simulation included into 1-G-2)

SUBDOMAINS:

1. **Thermal Protection Systems for Rigid Decelerators:**
Rigid decelerators are the tried and true way of entering planetary atmospheres to date. TPS, a component of the rigid decelerator, offers a mass efficient way of achieving mission success by protecting human or science cargo from the extreme entry environment encountered during rapid deceleration. Improved robustness along with mass efficiency will serve both robotic and human missions. (Strong relationship with 1-E)
2. **Thermal Protection Systems for Deployable Decelerators:**
The materials that provide thermal protection for deployed decelerators must be lightweight, robust, and able to be stowed and deployed prior to operation. (Strong relationship with 1-E)
3. **Rigid Hypersonic Decelerators:**
Mass-efficient rigid aeroshells are required for most robotic entry missions of the future. (Strong relationship with 1-B)
4. **Deployable Hypersonic Decelerators:**
Deployable entry systems provide a means by which the ballistic coefficient at entry is relatively unconstrained by launch shroud limitations. (Strong relationship with 1-B)

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RESEARCH & TECHNOLOGY (1) Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Descent and Targeting (1-G-8)

DEFINITION:

Descent and targeting subsystems and technologies are defined as those that bridge the hypersonic portion of the entry sequence with the terminal phase of landing. The presence of an atmosphere is inherently assumed. Descent is generally considered to include flight through supersonic and high subsonic conditions. Initiation is predicated on a staging event such as a parachute deployment that may not exist in every mission sequence. Descent ends with the initiation of terminal descent propulsion or a landing system. Targeting occurs during terminal descent; this is the phase of EDL in which terrain-relative decisions and final preparations for landing are made. The transition from descent to terminal descent could include the disposal of supersonic decelerators, vehicle reorientation to facilitate surface sensing, and using propulsion to divert away from sensed hazards.

(Source: NASA TA9.2 except TA9.2.4. GNC Sensors included into 1-G-1 and TA9.2.5 Descent Modelling and Simulation included into 1-G-2)

SUBDOMAINS:

1. **Attached Deployable Decelerators:**
Large increases in the drag area of an entry vehicle can be achieved through the use of deployable decelerators. These devices differ from the entry variant in that they are deployed endo-atmospherically after the peak heating and peak deceleration phases of flight.
2. **Trailing Deployable Decelerators:**
Trailing deployable decelerators are necessary for providing stabilization and deceleration of the entry vehicle through low supersonic and subsonic flight and into terminal descent, and often have secondary applications for events like stage separation.
3. **Supersonic Retro-propulsion:**
Utilizing a propulsive terminal descent stage higher in the atmosphere and at higher speed may provide velocity reduction at a lower cost and risk than developing a separate, new aerodynamic decelerator system.
4. **Large Divert Guidance**:
Numerical algorithms are used to guide the vehicle to a target that is relatively far away, given the vehicle's altitude from the surface.
5. **Terrain-Relative Sensing and Characterization:**
These are the sensors used to determine position and velocity relative to a surface or surface feature.
6. **Autonomous Targeting:**
The vehicle makes an onboard decision, based on sensor data, about its desired target point for that phase of the trajectory.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Landing (1-G-9)

DEFINITION:

The landing phase begins with the final preparations for touchdown (such as the deployment of surface interaction systems) and ends with the landing event itself, which is complete when the kinetic energy of impact has been dissipated and the vehicle is at zero velocity relative to the surface. The landing event may also include an egress or deployment phase to bring the system to operational state. The landing phase surface
sensing may begin before the descent phase ends, resulting in an overlap between the two phases. The key areas of technology development are the systems to sense the surface, descent propulsion motors and plume surface interaction mitigation, touchdown systems, high-g survivable systems, and small-body guidance.

(Source: NASA TA9.3)

SUBDOMAINS:

1. **Propulsion and Touchdown Systems:**
Systems that enable safe, robust contact with a solid surface. In some cases, the touchdown could be destructive for some objective (e.g., a penetrator).
2. **Egress and Deployment Systems:**
These are methods to allow a robotic element or a human to exit the landed vehicle and commence surface operations.
3. **Propulsion Systems:**
This area includes requirements specification and implementation of rocket engines that are used for maneuvering the vehicle in the direction of the target and (potentially) avoiding hazards either in the atmosphere or on the ground.

RESEARCH & TECHNOLOGY (1)
Guidance, Navigation & Control and Entry, Descent & Landing (1-G)

Vehicle for EDL (1-G-10)

DEFINITION:

A comprehensive understanding of component-, subsystem-, and system-level performance is inherent to all successful entry vehicle systems. Systems technology capabilities perform a key role for identifying, characterizing, and maturing system-level integration and design. Vehicle systems technologies will thus be segmented into six areas that have implications across the entire EDL architecture.

(Source: NASA TA9.4 except TA9.4.7 GNC Sensors and Systems included into 1-G-1)

SUBDOMAINS:

1. **Architecture Analyses:**
In this roadmap document, architecture analyses are not considered a technology unique to EDL. Computational advances from the whole 1-G area will be utilized as appropriate to enable architecture analyses for future missions.
2. **Separation Systems:**
For the purposes of this roadmap document, transition and separation systems are considered to be an engineering design problem, not thought at this time to require new technology.
3. **System Integration and Analysis**:
EDL vehicle implementation requires integration of multiple unique subsystems into a system-level capability. System integration and analysis picks up where architecture analysis ends by accomplishing subsystem-level design and performing subsystem-level design trades based on detailed engineering assessments. Moderate levels of engineering fidelity should be expected that rely on validated engineering approximations or engineering design capabilities.
4. **Atmosphere and Surface Characterization**:
Atmospheric modeling is important to all aerodynamic phases of flight, including aero-capture, aero-braking, entry, and descent. Precise landings require guided vehicles to navigate through variations in atmospheric density and winds. Controlled terminal descent and landing requires an accurate knowledge of the surface characteristics. Instrument-focused technologies needed to fill this strategic knowledge gap for sending humans to Mars can be found in 1-I.
5. **Modeling and Simulation:**
Improved multi-disciplinary simulations that can capture the complex flows of larger, heavier vehicles are needed to enable risk quantification and design decision-making. EDL systems are reliant on robust and efficient modeling and simulation capability because it is generally not possible to adequately test all aspects of an EDL system in a truly relevant environment prior to use. Simulation capability is thus on the critical path of defining system design, margins, and reliability.
6. **Instrumentation and Health Monitoring:**
EDL instrumentation for both engineering data and vehicle health monitoring provides a critical link between predicted and observed performance of the AAE system; it is crucial for improving the design of current systems and for ensuring sufficient system reliability prior to deployment or use. EDL instrumentation provides the final validation for modeling and simulation capabilities, which drives down uncertainties and improves overall prediction reliability for future missions.

Communications (RF & Optical) (1-H)

RESEARCH & TECHNOLOGY (1)

Communications (RF & Optical) (1-H)

DEFINITION:

It includes:

- **RF Systems, Payloads and Technologies**: Covers all technologies and techniques operating in the RF domain related to satellite systems and networks, spacecraft payloads, instruments and specific ground equipment (Technologies for control centres, TT&C and Earth Observation Payload Data Transmission Ground Stations and Ground Station Networks are covered in 1-K), for telecommunication, TT&C, Earth observation and space science, including security aspects. Radio-navigation systems and subsystems are included in 1-H)
- **Electromagnetic Technologies and Techniques**: Covers antennas and related technologies, wave interaction and propagation, and electromagnetic compatibility.
- **Optoelectronics:** Covers the development and application of technologies combining photonics (i.e. circuits handling photons) with electronics to achieve given functions
- **Optical Communications:** Covers techniques and technologies for the design, manufacture and testing of optical equipment/subsystems and terminals for optical communications between satellites and between spacecraft and ground stations (e.g. feeder links, deep-space communications); includes specific technologies like quantum communications for secure links, cryptography and global key distribution.

(Source: ESA TD 6A, 6C, 6D and 6E (6B is included into 1-G-6) , TD7, TD17 and TD16C-VI)

SUBDOMAINS:

1. **Telecommunication Systems / Subsystems (1-H-1)**
2. **TTC & Payload Data Modulator Systems / Subsystems (1-H-2)**
3. **RF Payloads (1-H-3)**
4. **RF Technologies & Equipments (1-H-4)**
5. **Antennas (1-H-5)**
6. **Wave Interaction & Propagation (1-H-6)**
7. **EMC / RFC / ESD (1-H-7)**
8. **Photonics Technologies (Emitters, Detectors and photonic devices) (1-H-8)**
9. **Optical Equipment for Communication(1-H-9)**

RESEARCH & TECHNOLOGY (1)
Communications (RF & Optical) (1-H)

Telecommunication Systems / Subsystems (1-H-1)

DEFINITION:

Covers telecommunication techniques and algorithms (coding, modulation, access, synchronisation, networking, security etc.), system tools and telecom equipment.

(Source: ESA TD 6A)

SUBDOMAINS:

1. **Telecom System Engineering Tools**
Covering all aspects related to satellite telecom system and subsystem analysis, design tools and methodologies.
2. **Telecom Signal Processing**
Covering all signal processing techniques and algorithms related to coding/decoding, modulation/demodulation, access, synchronisation, medium access control.
3. **Networking Techniques**
Covering telecom satellite networking aspects related to radio resource management, network management and control aspects, traffic modelling, etc.
4. **Telecom Equipment**
Covering all baseband telecom equipment (e.g. modulators, demodulators, front-ends). Used for fixed, mobile and broadcast satellite or hybrid satellite/terrestrial telecom systems, also including user terminals.
5. **Telecom Security Techniques and Technologies**
Covering the techniques and technologies to secure end-to-end telecom systems.

TTC & Payload Data Modulator Systems / Subsystems (1-H-2)

DEFINITION:

Covers both spacecraft TT&C/PDM techniques and technologies, space-link communications (RF, hybrid RF/optical systems, signal coding/modulation, ranging techniques, radio science experiments) and proximity links.

(Source: ESA TD 6C)

SUBDOMAINS:

1. **TT&C System Tools**
Covering all aspects related to TT&C systems (coding, modulation, multiplexing, link analysis, interference) and subsystem analysis tools and methodologies.
2. **Deep-Space Transponders**
Covering all aspects related to the design and development of deep-space TT&C transponders.
3. **Near-Earth Transponders**
Covering all aspects related to the design and development of near- Earth TT&C transponders.
4. **Proximity Link**
Covering all aspects related to the design and development of units for proximity link applications.
5. **High-speed Downlink PDM**
Covering all aspects related to (coded) modems for high-speed payload downlink (e.g. for EO, DRS applications).

RF Payloads (1-H-3)

DEFINITION:

Covers telecommunication payloads (transparent and regenerative), remote sensing instruments, and navigation payloads exploiting analogue, digital and optical technologies.

(Source: ESA TD 6D)

SUBDOMAINS:

1. **Payload Tools**
Advanced simulation tools and analysis paradigms for complex
payloads for Telecom/EO/Navigation.
2. **Telecommunication Payloads**
Covering telecommunication payloads and architectures encompassing RF, digital and optical technologies.
3. **EO Instruments**
Covering EO instruments both passive (e.g. radiometers, GNSS-R) and active (e.g. SAR, altimeters, RF sounding).
4. **Navigation Payloads**
Covering navigation payload systems and subsystems.

RESEARCH & TECHNOLOGY (1) Communications (RF & Optical) (1-H)

RF Technologies & Equipments (1-H-4)

DEFINITION:

Covers RF equipment, subsystems and building blocks, active and passive components, and related design and characterisation tools in the whole RF domain.

(Notes: All quasi-optic are covered by 1-H-9 and free-space aspects are covered by 1-L. All quality aspects are covered by 1-D-6 and 1-A-7. All ground station RF technologies for TT&C and payload data are covered by 1-L).

(Source: ESA TD 6E)

SUBDOMAINS:

1. **RF Modelling and Design Tools**
Covering design and analysis tools for RF equipment and components.
2. **RF Equipment**
Covering RF equipment and subsystems (e.g. SSPAs, LNAs, frequency converters and multipliers, local oscillators and synthesisers, multiplexers).
3. **RF Devices**
Covering the design, specification, development and characterisation of active devices (e.g. diodes, transistors, mixers, multipliers, integrated circuits) and passive devices (e.g. filters, resonators, MEMS devices, cables and connectors), including packaging and interconnection.
4. **Vacuum Electronics**
Covering technologies and techniques related to high-power RF amplification using vacuum electronic devices (e.g. TWT).
5. **Time and Frequency**
Covering the techniques and technologies for the generation of reference signals (oscillators and clocks of all types, e.g. quartz, VCOs/NCOs, Rb, Cs, H-maser) and their means for comparison and dissemination as required for telecom, navigation and science applications. (Note: Optical atomic clocks are covered in 1-G-8)
6. **RF Measurement, Characterisation and Calibration Techniques**
Covering RF equipment and components, including for high-power, corona and multipactor testing.

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

RESEARCH & TECHNOLOGY (1)
Communications (RF & Optical) (1-H)

DEFINITION:

Covering antenna systems and architectures, design tools, technologies and measurement techniques for various applications for space systems and ground users, up to THz frequencies, such as communications, navigation or sensing, spacecraft pointing, TT&C, etc. (Note: Ground TT&C antennas are covered in 1-L).

(Source: ESA TD 7A)

Antennas (1-H-5)

SUBDOMAINS:

1. **Antenna Design Tools**
Covering modelling, synthesis and optimisation techniques and tool development for new types of antennas and their feed networks, arrays, reflector and small antennas, both isolated and in the spacecraft environment.
2. **Reflector and Lens Antennas**
Covering single and multiple beam reflector antenna architectures, reflector design, multiple reflectors, reconfigurable reflector antennas, shaped, unfurlable and foldable reflectors, frequency- and polarisation-selective surfaces, active and passive lenses, feed elements and feed arrays with their feed networks, reflect-arrays.
3. **Array Antennas and Standalone Radiators**
Covering planar and conformal arrays, multi-frequency arrays, dual polarization arrays, active, semi-active and passive arrays. Small arrays and standalone radiators for medium and low gain applications for spacecraft and for user terminals. Array feed networks. Electronic scanning arrays. Fixed and steerable beam arrays for fixed and mobile user terminals. Satellite TT&C standalone and multi-element antennas.
4. **Millimetre-Wave and Sub-Millimetre-Wave Antenna Front-Ends**
Covering antennas, instruments, new architectures and technologies for THz passive and active remote sensing instruments such as radiometers, imagers, limb sounders. Also reflectors and quasi-optic assemblies, focal plane arrays and front-ends.
5. **Measurement, Characterisation and Calibration Techniques for Radiative Payloads and Antennas**
Covering new antenna and payload measurement techniques (e.g. for multi-beam payloads), validation of modelling software, techniques for measurement of antennas in the spacecraft environment, interactions between antennas, millimetre-wave and THz antennas. RF characterisation of reflective and transparent materials.

RESEARCH & TECHNOLOGY (1)
Communications (RF & Optical) (1-H)

Wave Interaction & Propagation (1-H-6)

DEFINITION:

Covering technologies and techniques related to propagation models and modelling techniques, interference modelling and experimentation, wave interaction modelling, and associated retrieval algorithms and models. Applications are telecommunications, navigation, remote sensing (both for Earth and planets), TT&C and payload data transfer.

(Source: ESA TD 7B)

SUBDOMAINS:

1. **Wave Interaction**
Covering modelling of wave interactions for passive and active microwave and optical remote sensing of atmosphere, surface and subsurface features of Earth and planets. Retrieval algorithms.
2. **Wave Propagation**
Covering propagation and interference models and their validation at microwave and optical frequencies through Earth and planetary atmosphere, stratosphere, ionosphere. Microwave propagation in urban and indoor environments. Link budgets in complex propagation environments.

EMC / RFC / ESD
(1-H-7)

DEFINITION:

Covering design, models, simulation, testing techniques and technologies in the fields of electromagnetic compatibility (EMC), radio frequency compatibility (RFC), electrostatic discharge (ESD), and magnetic cleanliness.

(Source: ESA TD 7C)

SUBDOMAINS:

1. **EMC Modelling and Simulation**
Covering development of specific EMC models and simulation tools for application to spacecraft.
2. **EMC Test Techniques**
Covering validation of new EMC designs and novel EMC and magnetostatic test methods for application to spacecraft.

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

RESEARCH & TECHNOLOGY (1) Communications (RF & Optical) (1-H)

DEFINITION:

Covers the development and application of technologies combining photonics (i.e. circuits handling photons) with electronics to achieve given functions.

It includes:

1. **Laser Technologies**: covering the technologies and techniques needed for the generation of coherent optical radiation.
2. **Detector Technologies**: covering all the technologies and techniques needed for the detection of optical radiation.
3. **Photonics**: Covers guided-wave optical technologies and techniques for handling optical signals, or to achieve specific functions for various applications.

(Source: ESA TD 17A, 17B, 17C) (Note: it also exists a strong relationship with area 1-I)

Photonics Technologies (Emitters, Detectors and photonic devices) (1-H-8)

SUBDOMAINS:

1.1 Laser Sources
Covers continuous wave (CW) lasers and pulsed diode-pumped bulk solid-state lasers (e.g. Nd:YAG, etc.), mode-augmented diode lasers for the near-infrared (NIR) spectral region (VCSEL, ECLD, etc.), mode- augmented quantum cascade lasers (QCL) and GaN for the mid-IR and visible spectral regions respectively, LEDs, diode-pumped rare Earth (RE) doped waveguide lasers, doped fibre lasers, etc.

1.2 Laser Pumping
Covers laser-diode arrays LDA (CW and QCW), high-power single emitter (CW) diode sources and related pump-packaging issues, flash-lamp, solar pump, electron-beam, etc. Implementation of efficient spectral control of LDA emission.

1.3 Laser Oscillators and Amplifiers
Geometrical mode control of both stable and unstable resonator designs. Mode matching techniques and device technologies, etc. Q-switched and mode-locking techniques. Laser amplifier stages, coherent power control and combination. Amplifier designs for CW and pulsed applications; bulk amplifiers, flared semiconductor amplifiers, doped fibre amplifiers.

1.4 Laser Frequency Control and Stabilisation
Covers laser cavity length control and tuning techniques, injection locking and seeding, for frequency control. Covers frequency stabilisation and locking techniques using optical stabilizing reference cavities (OSRC) for phase control and the achievement of sub-Hz line widths and absolute frequency locking to narrow spectral features. Implementation of electronic-optical feedback techniques for linewidth reduction. Development and implementation of methods to reduce the Thermal Noise Limit (TNL) on SRC optics. Development and verification of novel methods to achieve sub-mHz linewidth emission.

1.5 Non-Linear Optics
Covers harmonic generation, non-linear crystals and poled waveguide materials, parametric conversion, multi-photon processes, stimulated light scattering, spatial laser beam cleaning using phase conjugated mirrors, saturable absorbers, etc.

2.1 **Visible Detectors (mostly Si based)**
Covers single-pixel (photodiodes), linear and 2D arrays, CCD and CMOS image sensors (APS), APDs, APD arrays, SiPM arrays.

2.2 Infrared detectors. (NIR–FIR)
Covers both photon and thermal technologies, including MCT, InGaAs, III-V, QWIP, QDIP, T2SL, microbolometers, pyroelectrics.

2.3 UV, X-ray & Gamma-Ray Detectors
Covers Si, wide bandgap semiconductors, scintillators.

2.4 Superconducting Detectors
Covers HEB, SINIS-junctions, heterodyne mixers, …

2.5 Superconducting Devices
Including low-temperature and high-temperature superconducting devices and sensors such as SQUIDs, Josephson-type junctions, gradiometers, etc.

2.6 Focal Plane Technologies
Covers component technologies, integration, accommodation techniques, proximity electronics, interconnects (e.g. flex circuits), filters and windows

3.1 RF Photonics
Covers photonic devices for generation, handling and distribution of microwave signals on board satellites, frequency down-conversion, time delay, RF signal phase and amplitude control, optical beamforming and distribution networks, on board optical links & interconnects, etc.

3.2 Micro- & Nano-Photonics
Covers photonic IC technologies, hybrid and monolithic integration of active and passive functions in various material systems including silica and semiconductor materials. Silicon photonics for on-chip optical functions.

3.3 Fibre-Optic Sensors
Covers pressure, temperature and strain sensors, including interrogation units for satellites, platforms and launchers.

3.4 Optical Atomic Clocks
Covers laser cooling and trapping techniques for atoms, ions and molecules, optical frequency combs based on mode-locked lasers and ultra-high-Q microcavities. Includes also fibre-optic and free-space optical frequency dissemination over large distances, subsystem integration and verification into clock systems, space qualification of subsystem elements.

3.5 Quantum Devices
Covers laser-cooled atom sensors including atom interferometers, magnetometers, photon confinement and trapping techniques leading to BECs, atomic-scale sensing devices, etc. Implementation of laser-cooled and coherent population trapping (CPT) and the technology required for its implementation; chip gas cells, etc.

Optical Equipments for Communications (1-H-9)

DEFINITION:

Covers techniques and technologies for the design, manufacture and testing of optical equipment/subsystems and terminals for optical communications between satellites and between spacecraft and ground stations (e.g. feeder links, deep-space communications); includes specific technologies like quantum communications for secure links, cryptography and global key distribution.

(Source: ESA TD 16C-VI)

SUBDOMAINS:

Science Instruments, Observatories & Sensors (1-I)

Science Instruments, Observatories & Sensors (1-I)

DEFINITION:

The Science Instruments, Observatories, and Sensor Systems technology area encompasses technologies to collect disparate types of data from Earth and space. These technologies are either identified to satisfy a particular mission need ("pull technologies") or to develop new measurement techniques that may lead to new scientific discoveries ("push technologies"). This TA is broken into three sub-areas: remote sensing instruments and sensors; observatories; and in-situ instruments and sensors. These technologies are applicable to missions from very small to large.

(Source: NASA TA8 (for 1-I-1, 1-I-2 and 1-I-3 and ESA TD 16A, 16B and 16C (except 16C-VI included into 1-H-9))

SUBDOMAINS:

1. **Remote Sensing Instruments & Sensors (1-I-1)**
2. **Observatories (1-I-2)**
3. **In-situ Instruments and Sensors (1-I-3)**
4. **Cross-cutting support technologies and tools (1-I-4)**

Remote Sensing Instruments & Sensors (1-I-1)

DEFINITION:

Remote sensing instruments and sensors include components, sensors, and instruments sensitive to electromagnetic radiation, particles (charged, neutral, dust), electromagnetic fields, both direct current (DC) and alternating current (AC), acoustic energy, seismic energy, or whatever physical phenomenology the science requires.

Note: see also 1-H-8 and 1-I-4.

(Source: NASA TA8.1. See also ESA TD 16B and 16C)

SUBDOMAINS:

1. **Detectors and Focal Planes:**
Improve sensitivity and operating temperature of single-element and large-array devices.
2. **Electronics:**
Radiation-hardened, extreme environment capable, and data processing electronics with reduced volume, mass, and power.
3. **Optical Components:**
High-throughput optics with large fields of view, high stability, spectral resolution, and uniformity at many different temperatures.
4. **Microwave, Millimeter-, and Submillimeter Waves:**
Transmitters and receivers: low-noise amplifier technologies, with reliable low-power high-speed digital- and mixed-signal processing electronics, and algorithms.
5. **Lasers:**
Reliable, highly stable, efficient, radiation hardened, and long lifetime (> 5 years).
6. **Cryogenic/Thermal:**
Active technologies used to cool instruments and focal planes, sensors, and large optical systems.

Observatories (1-I-2)

DEFINITION:

Observatory technologies are necessary to design, manufacture, test, and operate space telescopes and antennas, which collect, concentrate, or transmit photons. Observatory technologies enable or enhance large aperture monolithic and segmented single apertures as well as structurally connected or free-flying sparse and interferometric apertures. Applications span the electromagnetic spectrum.

Note: see also 1-H-5

(Source: NASA TA8.2. See also ESA TD 16B and 16C)

SUBDOMAINS:

1. **Mirror Systems:**
The ability to manufacture and test monolithic and segmented large-mirror systems that can accommodate normal and grazing incidence in the visible/ultraviolet (UV)/infrared (IR) and X-ray portions of the spectrum.
2. **Structures and Antennas:**
Structures that can support large antennas and hold mirrors in a stable, strain-free state under the influence of anticipated dynamic and thermal stimuli. Note: see also 1-B-2
3. **Distributed Aperture:**
For extra-large apertures, a method to create the aperture via deployment, assembly, or formation flying — where formation-flying technology is an actively controlled virtual structure.

RESEARCH & TECHNOLOGY (1)
Science Instruments, Observatories & Sensors (1-I)

DEFINITION:

In-situ instruments and sensors include components, sensors, and instruments sensitive to fields and particles able to perform in-situ characterization of the space environment and planetary samples. In-situ instruments and sensors technologies enable or enhance a broad range of planned and potential missions in the next two decades. In-situ instruments and sensors support comet, Moon, and planetary missions.

Note: see also 1-M-3

(Source: NASA TA8.3)

In-situ Instruments and Sensors (1-I-3)

SUBDOMAINS:

1. **Field and Particle Detectors:**
A variety of instruments aiming to characterize a large, spatially rich, and temporally dynamic space environment spanning from Earth's and planetary ionospheres and magnetospheres to the solar corona, the heliosphere or heliopause, and the local interstellar medium.
2. **In-situ (other):**
In-situ sensor technologies (for chemical, mineralogical, organic, and in-situ biological samples) include sample handling, preparation, and containment; chemical and mineral analysis; organic analysis; biological detection and characterization; and planetary protection. These technologies need to be applied in extreme temperatures, pressures, and environments.

Cross-cutting support technologies and tools (1-I-4)

DEFINITION:

This area covers the basic technologies and tools needed to develop instruments and observatories and not included in another areas (as RF instruments or Optoelectronics already included in 1-H). Particularly, it includes optical system engineering.

(Source: PAE own definition based on ESA TD 16A)

SUBDOMAINS:

1. Overall Optical System Definition, Design and Engineering
Covers the definition, design and engineering of optical systems and subsystems and the conceptual definition of optical payload/instrument architectures.

2. Optical Design Performance Evaluation and Analysis
Covers evaluation and verification of optical design performances by analysis (e.g. optical models, Zemax, ASAP, CodeV) and/or testing (e.g. optics laboratory); includes evaluation of straylight and design of means for straylight suppression (e.g. baffles).

Automation, Telepresence & Robotics (1-J)

Automation, Telepresence & Robotics (1-J)

DEFINITION:

Covers the specification, development, verification, operation and utilisation of space automation systems. Such systems include:

- Space robot systems (comprising both arm-based systems for inspection, servicing and assembly of space system infrastructure or payloads and mobile robots for surface exploration on celestial bodies)
- Space laboratory automation and payload control systems in manned and unmanned missions.

Note: Detailed mechanisms aspects are covered in 1-B-11, 1-B-12 and 1-B-13.

(Source: ESA TD 13)

SUBDOMAINS:

1. **Applications & Concepts (1-I-1)**
2. **Automation & Robotics Systems (1-I-2)**
3. **Automation & Robotics components & technologies (1-I-3)**

Applications & Concepts (1-J-1)

DEFINITION:

Covers system aspects and innovative robotic concepts for missions.

(Source ESA TD 13A)

SUBDOMAINS:

1. **Planetary Exploration**
Includes novel concepts for handling/assembly of surface infrastructure elements, novel aerobot concepts, novel robot concepts for exploration (including of asteroids), micro- and nano-rover concepts and swarms.
2. **Orbital Systems**
Includes automation of orbital infrastructure, or non-cooperative satellites, satellite design for robotic servicing, compound operation of arms on free-flying platforms, assembly and servicing of space structures in orbit, multi-robot cooperation.

Automation & Robotics Systems (1-J-2)

DEFINITION:

Covers the detailed definition of robotic systems and subsystems, including technology developments dedicated to specific applications.

(Source ESA TD 13B)

SUBDOMAINS:

1. **Manipulation Systems**
Includes robot arms, end-effectors and tools. (Note: Detailed mechanisms aspects are covered in 1-B-11, 1-B-12 and 1-B-13)
2. **Mobility Systems**
Includes rovers, aerobots, underground and underwater explorers.
3. **Payload Automation Systems**
Covers all automation aspects of space laboratories.

Automation & Robotics components & technologies (1-J-3)

DEFINITION:

Includes general purpose and specific Automation & Robotics (A&R) components and methods.

(Source ESA TD 13C)

SUBDOMAINS:

1. **Perception**
Includes sensors and sensing methods (e.g. computer vision) which allow robots to perceive their environment and the state of the process they are controlling.
2. **Control, Autonomy and Intelligence**
Covers methods that allow robot systems to perform perception processing, understanding of the operating environment, motion planning and control, attention allocation, anticipation, activity planning, and reasoning about their own state and the state of other agents.
3. **Motion and Actuation**
Covers the means that allow a robot to physically interact with its environment (e.g. limbs, joints, chassis, wheel units, balloon envelopes, propulsion units). (Note: Detailed mechanisms aspects are covered in 1-B-11, 1-B-12 and 1-B-13)
4. **Robot-User Interfacing**
Includes commanding and programming means (e.g. immersive systems, haptic devices) and methods that allow users to interact with an automation and robotics system. Includes teleoperation, telepresence, tele-science.
5. **Robot Ground Testing**
Includes tools, methods and facilities that allow on-ground characterisation and verification of A&R systems.

Manned Spaceflight Technologies (1-K)

Manned Spaceflight Technologies (1-K)

DEFINITION:

It includes:

- **Instruments in support of Life and Physical Sciences:** covering:
    - Instruments and technologies to study aspects of human physiology, biology, biotechnology, exobiology/planetary exploration and solve specific problems of planetary exploration, planetary protection and human long-term presence in space.
    - Instruments and technologies to study aspects of fluid science, material science, crystal growth, applied physics, planetary exploration and solve problems of specific application of material science technology to use in situ resources for extra-terrestrial production of components (e.g. heat and radiation shields etc.)
- **Human Health, Life Support and Habitation**
- **Human Exploration Destination**

(Source: NASA TA6.1. See also ESA TD 13, 14, 22A and 22B)

SUBDOMAINS:

1. **Environmental Control Life Support Systems ECLS (1-K-1)**
2. **Extra-vehicular activity systems (1-K-2)**
3. **Human Health and Performance (1-K-3)**
4. **Environmental Monitoring, Safety and Emergency Response (1-K-4)**
5. **Radiation effects on humans (1-K-5)**
6. **In-Situ Resource Utilization (1-K-6)**
7. **Sustainability & Supportability (1-K-7)**
8. **Human Mobility Systems (1-K-8)**
9. **Habitat Systems (1-K-9)**
10. **Missions Operations and Safety (1-K-10)**
11. **Cross cutting systems (1-K-11)**

Environmental Control Life Support Systems ECLS (1-K-1)

DEFINITION:

It deals with providing an environment suitable for sustaining human life throughout the duration of a mission. Covers all technologies for controlling, maintaining and supporting human presence in non-terrestrial environments, such as regenerative (recycling) technologies for air, water and waste, food production and preparation, environmental monitoring and control, including habitability issues.

Note: It is related with ESA's TD 22-A

(Source: NASA TA6.1)

SUBDOMAINS:

1. **Air Revitalization:**
The overarching function of this area is to maintain a safe and habitable atmosphere within a spacecraft, surface vehicle, or habitat.
2. **Water Recovery and Management:**
This area provides a safe and reliable supply of potable water to meet crew consumption and operational needs.
3. **Waste Management:**
The objective of this area is to safeguard crew health, increase safety and performance, recover resources, and protect planetary surfaces, all while decreasing mission costs.
4. **Habitation:**
This area focuses on habitation functions that closely interface with life-support systems, including food preparation and production, hygiene, metabolic waste collection, clothing/laundry, and the conversion of logistics trash to resources.

Extra-vehicular activity systems (1-K-2)

DEFINITION:

EVA systems are critical to every foreseeable human exploration mission, from in-space microgravity missions in LEO to planetary surface exploration. In addition, a launch, entry, and abort (LEA) suit system is needed to protect the crew during launch, landing, and cabin contamination/depressurization events, as well as the ascent/decent transition for planetary excursions. An EVA system includes hardware and software that spans multiple assets in a given mission architecture and interfaces with many vehicle systems, such as life support, power, communications, avionics, robotics, materials, pressure systems, and thermal systems.

Note: It is related with ESA's TD 20-H

(Source: NASA TA6.2)

SUBDOMAINS:

1. **Pressure Garment:**
The suit, or pressure garment, is the set of components a crew member wears and uses. It includes the torso, arms, legs, gloves, joint bearings, helmet, and boots. The suit employs a complex system of soft-goods and mobility elements in the shoulders, arms, hips, legs, torso, boots, and gloves to optimize performance while pressurized without inhibiting unpressurized operations. The LEA suit also contains provisions to protect the crew member from both nominal and off-nominal environments (e.g., gravitational, sound, chemical) encountered during launch, entry, and landing, as well as potential descent/ascent to planetary surfaces.
2. **Portable Life Support System (PLSS):**
The PLSS performs functions required to keep a crew member alive during an EVA. These functions include maintaining thermal control of the astronaut, providing a pressurized oxygen (O2) environment, and removing products of metabolic output such as carbon dioxide (CO2) and water (H2O).
2. **Power, Avionics, and Software (PAS):**
The PAS system is responsible for the EVA system's power supply and distribution, collecting and transferring several types of data to and from other mission assets, providing avionics hardware to perform numerous data display and in-suit processing functions, and furnishing information systems to supply data that enables crew members to perform their tasks with more autonomy and efficiency.

RESEARCH & TECHNOLOGY (1)
Manned Spaceflight Technologies (1-K)

Human Health and Performance (1-K-3)

DEFINITION:

HHP technologies is to maintain the health of the crew and support optimal and sustained performance throughout the duration of a mission.

Note: It is related with ESA's TD 22-A

(Source: NASA TA6.3)

SUBDOMAINS:

1. **Medical Diagnosis and Prognosis:**
This functional area provides a suite of medical technologies, knowledge, and procedures that minimize the likelihood and consequence of off-nominal medical events during exploration missions. Efforts are also focused on developing novel screening, diagnosis, and treatment technologies for conditions that drive medical risk, as well as developing the appropriate infrastructure to match the level of care required for exploration Design Reference Missions (DRMs).
2. **Long-Duration Health:**
This area focuses on providing validated technologies for medical practice to address the effects of the space environment on human systems and countermeasures to maintain crew physical health, behavioral health, and sustained performance on extended-duration missions.
3. **Behavioral Health:**
The objective in this area is to provide countermeasures and conduct monitoring to reduce the psychosocial, neurobehavioral, and performance risk associated with extended space travel and return to Earth. Technology advancements are needed to identify, characterize, and prevent or reduce risks associated with space travel, exploration, and return to terrestrial life on astronauts' behavioral health and performance
4. **Human Factors:**
This area focuses on technologies that support the crew's ability to effectively, reliably, and safely interact within mission environments. Elements include physical accommodation, fit, ergonomics of crew hardware interfaces, physical and cognitive augmentation, training, and Human-Systems Integration (HSI) tools, metrics, methods, and standards.

Environmental Monitoring, Safety and Emergency Response (1-K-4)

DEFINITION:

EMSER is aimed to develop technologies that ensure crew health and safety by protecting against spacecraft hazards and to ensure effective response should an accident occur.

(Source: NASA TA6.4)

SUBDOMAINS:

1. **Sensors: Air, Water, Microbial, and Acoustic:**
The objective of this area is to provide future spacecraft with advanced, networks of integrated sensors to monitor environmental health and accurately determine and control the physical, chemical, and biological environments of crew living areas and their environmental control systems.
2. **Fire: Detection, Suppression, and Recovery:**
The objective of spacecraft fire safety is to develop technologies that ensure crew health and safety by reducing the likelihood of a fire, or, if one does occur, minimizing the risk to the crew, mission, and/or system.
3. **Protective Clothing and Breathing:**
The objective of this area is to provide the crew with sufficient capability to address off-nominal situations within the habitable compartments of the spacecraft. Off-nominal events include fire, chemical release, microbial contamination, and unexpected depressurization.
4. **Remediation:**
The focus of remediation is to provide the crew with the ability to clean the habitable environment of the spacecraft in the event of an off-nominal situation. Off-nominal events include fire, an inadvertent chemical release, or microbial contamination.

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

RESEARCH & TECHNOLOGY (1)
Manned Spaceflight Technologies (1-K)

Radiation effects on humans (1-K-5)

DEFINITION:

The radiation area is focused on developing technologies to increase crew mission duration (100 to 1,000 days, depending on the mission) in the free-space radiation environment while remaining below the space radiation permissible exposure limits (PELs). It is generally accepted that to meet the sub-goal of extending crew mission duration, an integrated, optimized approach utilizing shielding options, biological countermeasures, improved understanding of the risks, and the ability to better predict and monitor the radiation environment will be required.

Note: It is related with ESA's TD 14-C and TD 14-D

(Source: NASA TA6.5)

SUBDOMAINS:

1. **Risk Assessment Modeling:**
The focus of this area is to develop tools that enable, quantify, and reduce uncertainty in assessing astronaut risk due to space radiation exposure, as well as to improve mission operations, mission planning, and system design for LEO, deep-space, lunar, and Mars missions.
2. **Radiation Mitigation and Biological Countermeasures (BCM):**
The focus of this area is to develop BCMs that can minimize or prevent physical, cognitive, and behavioral disorders due to space radiation without adverse side effects and loss of life.
3. **Protection Systems:**
The focus of this area is to advance the design of integrated radiation protection shielding technologies that extend the duration of missions beyond LEO by more than 60 days, within the scope of reasonable vehicle design and mass. The focus is to provide passive or active shielding through design advances, advanced materials, lightweight structures, and in-situ resources.
4. **Space Weather Prediction:**
The focus of this area is to advance improvements in solar particle event (SPE) forecasting and alert systems to minimize operational constraints for missions outside the protection of the Earth's geo-magnetic field. Note: it is related with 1-K-10.

2. **Monitoring Technology:**
The focus of this area is to prototype and mature advanced, miniaturized radiation measurement technologies, and to demonstrate these technologies as integrated vehicle systems using available platforms.

In-Situ Resource Utilization (1-K-6)

DEFINITION:

In-Situ Resource Utilization (ISRU) is the identification, acquisition, and utilization of local resources, both natural and discarded, for useful products and services. The purpose of ISRU is to significantly reduce the mass, cost, and risk of short-term and sustained human exploration by eliminating the need to launch large amounts of consumables, structures, and other items that are required for survival and for completing mission objectives successfully. ISRU also enables self-sufficiency at particular locations, especially destinations far from Earth.

Note: It is related with ESA's TD 22-B and TD 14-A,B and D

(Source: NASA TA7.1)

SUBDOMAINS:

1. **Destination Reconnaissance, Prospecting, and Mapping:**
This addresses investigating, sampling, and mapping regolith, the atmosphere, and the environment for future mining and utilization.
2. **Resource Acquisition:**
This addresses extracting, collecting, recycling, pre-processing, and storing targeted "raw" in-situ resources.
3. **Processing and Production:**
This addresses producing, transferring, and storing consumable products, such as water, air, and propellants that are needed by the crew, as well as scientific equipment, robots, rovers, etc.
4. **Manufacturing Products and Infrastructure Emplacement:**
This addresses creating infrastructure (landing pads, blast walls, thermal wadi), fabricating tools and parts, and constructing items needed for safety, redundancy, and comfort, as well as using resources (metals, plastics, regolith, etc.) available in-situ.

Sustainability & Supportability (1-K-7)

DEFINITION:

Sustainability and Supportability includes technology candidates required to establish a self-sufficient, sustainable, and affordable human space exploration program.

(Source: NASA TA7.2)

SUBDOMAINS:

1. **Autonomous Logistics Management:**
This addresses technologies needed to institute a centralized logistic depot to manage and optimize the use of consumables at the exploration destination and minimize human-specific logistics (i.e., food), as well as other logistics items that can be repurposed or recycled in order to reduce Earth dependency and logistics train.
2. **Maintenance Systems:**
This addresses technologies needed to perform routine system evaluation, preventive maintenance, and corrective actions on human exploration systems.
3. **Repair Systems:**
This addresses technologies that perform "wear-and-tear" repairs, as well as those that perform minimum or non-intrusive repair.
4. **Food Production, Processing, and Preservation:**
This addresses technologies that feed crew members and keep their food safe.

Human Mobility Systems (1-K-8)

DEFINITION:

Mobility systems include rovers, EVA tools, and translation aids that improve the safety and effectiveness of crews. They are essential for conducting surface operations and establishing architectural infrastructure. They enable the exploration of asteroids and missions to destinations like Mars.

Many of the mobility core technologies are covered in 1-J Automation, Telepresence and Robotics.

(Source: NASA TA7.3)

SUBDOMAINS:

1. **EVA Mobility:**
This addresses EVA tools, transition systems, and mobility aids to facilitate crew egress and ingress, and expedite the movement of crew on site.
2. **Surface Mobility:**
This addresses technologies for navigating rough surface terrain, allowing humans to work on the surface of terrestrial destinations.
3. **Off-Surface Mobility:**
This addresses technologies for navigating in the micro-gravity environment or at destinations with an atmosphere, including balloons and other airships.

PLATAFORMA TECNOLÓGICA AEROESPACIAL ESPAÑOLA

RESEARCH & TECHNOLOGY (1)
Manned Spaceflight Technologies (1-K)

Habitat Systems (1-K-9)

DEFINITION:

Habitat Systems enable safe, efficient, sustainable, and productive long-duration human exploration missions by using fully autonomous, resource-efficient habitats to significantly reduce the mass, cost, and human spaceflight risk associated with those missions.

Note: it is related with ESA's TD 13, TD 20-H and TD 22-A and B.

(Source: NASA TA7.4)

SUBDOMAINS:

1. **Integrated Habitat Systems:**
Addresses acoustical treatments and noise reduction; solar optic lighting and heating; low-toxicity, fire-retardant textiles; antimicrobial and surface coatings; and embedded sensors that monitor system performance. Also includes Structures for Habitats (corresponding to ESA's TD 20-H-I). Additional dependency technologies that support Integrated Habitat Systems capabilities are being included in 1-J (Robotics), 1-I (Science Instruments, Observatories, and Sensors), 1-A (Systems) as well as 1-K-1, 1-K-3, 1-K-4 and 1-K-5.
2. **Habitat Evolution:**
Addresses Exploration Habitat Systems Concurrent Engineering Modeling and Simulation. Maturing exploration habitat integrated concurrent model based engineering and model based systems engineering design environment and simulations capabilities are imperative to achieving overall design optimization, mass reduction, and crew performance optimization. Additional dependency technologies that support Habitat Evolution capabilities are being included in 1-J (Robotics), 1-I (Science Instruments, Observatories, and Sensors), 1-A (Systems) as well as 1-K-1, 1-K-3, 1-K-4 and 1-K-5.
3. **"Smart" Habitats:**
Focuses on evolutionary, intelligent, and autonomous habitat capabilities that enable long-duration, deep-space human missions that increase crew productivity, as well as crew and mission safety, while reducing mass, power, and volume needs. Additional dependency technologies that support "Smart" Habitat capabilities are being included in 1-J (Robotics), 1-I (Science Instruments, Observatories, and Sensors), 1-A (Systems) as well as 1-K-1, 1-K-3, 1-K-4 and 1-K-5.
4. **Artificial Gravity (AG):**
Includes spacecraft technologies that will reduce the detrimental effects of long-duration, zero-gravity on human physiology, including thrust vector navigation course correction of an AG (rotating) spacecraft in transit; technologies that manage the center of gravity (CG) balance of spacecraft while providing thrust to perform course correction; and momentum exchange for deployment of the AG spacecraft. These technologies will also benefit LEO and HEO commercial facilities development. Additional dependency technologies that support AG capabilities are being included in 1-J (Robotics), 1-I (Science Instruments, Observatories, and Sensors), 1-A (Systems) as well as 1-K-1, 1-K-3, 1-K-4 and 1-K-5.

Missions Operations and Safety (1-K-10)

DEFINITION:

Mission Operations and Safety technology candidates manage space missions, usually from the point of launch through the end of the mission (i.e., the 'start-to-finish' development and delivery of highly complex robotic and human spaceflight operations).

(Source: NASA TA7.5)

SUBDOMAINS:

1. **Crew Training:**
Crew training for deep space, long-duration missions will be improved with immersive virtual reality and "real-time," context-sensitive training. TA 11.3.4, Simulation-Based Training and Decision Support Systems, addresses crew-training needs for the purposes of Human Exploration Destination Systems.
2. **Planetary Protection:**
Planetary protection is a potentially significant challenge for human exploration. These technologies address threats to the Earth-Moon system from returning astronauts, hardware, and extraterrestrial samples.
3. **Integrated Flight Operations Systems:**
Integrated flight operations for long-duration, deep space missions will require striking complex balances between ground and space operations, with a shift toward increasing crew autonomy that will benefit from autonomous systems and comprehensive, highly integrated operational systems.
4. **Integrated Risk Assessment Tools:**
Integrated risk assessment tools for deep space, long-duration missions will help identify and analyze risks reducing threats to crew and missions.

Cross cutting systems (1-K-11)

DEFINITION:

This section includes dust mitigation and technology candidates for construction, assembly, and deployment of destination systems hardware.

(Source: NASA TA7.6)

SUBDOMAINS:

1. **Particulate Contamination Prevention and Mitigation:**
Includes a layered engineering defense that incorporates technologies for contamination prevention, exterior cleaning and protection, interior cleaning and protection, and preserving gas quality, as well as technologies associated with modeling plume and soil interactions.
2. **Construction and Assembly:**
Includes technologies for construction and assembly of in-space and surface structures and completing construction or assembly of deployable systems. Both traditional construction and assembly concepts and advanced deployable systems are included. Since most of the needed Construction and Assembly capability technologies are being developed under other areas (such as 1-J (Robotics), 1-I (Science Instruments, Observatories, and Sensors), 1-A (Systems), 1-B-2 (Special types of Structures), as well as 1-K-1, 1-K-3, 1-K-4, 1-K-5 and 1-K-9), these technologies are focused on shape charges for excavation and fabric blast debris protection.

Mission Operations & Ground Systems (1-L)

Mission Operations & Ground Systems (1-L)

DEFINITION:

It includes:

- **Mission Operations:** Addresses aspects related to the control and operations of space system elements (satellites, transfer vehicles, orbiters, landers, probes, rovers, etc.) and related ground segments, addressing the technologies associated with supporting systems and tools.
- **Ground Systems (including software):** Covers all elements and knowhow required for engineering of the facilities that connect the space segment with control centres. The application range covers high-performance deep-space stations to networks of small ground stations. It also includes mission control system software design, verification, validation and maintenance methods/tools and application of modern IT technologies to spacecraft operations, including Object-Oriented Technologies.

(Source: ESA TD 9, ESA TD 12 and ESA TD 2C)

SUBDOMAINS:

1. **Advanced System Concepts (1-L-1)**
2. **Mission Operations (1-L-2)**
3. **Ground Data Systems (Mission Control Systems) (1-L-3)**
4. **Ground Stations Systems (1-L-4)**
5. **Ground Communications Networks (1-L-5)**
6. **Ground Segment Software (1-L-6)**

Advanced System Concepts (1-L-1)

DEFINITION:

Covering studies, technology investigations and prototyping related to the implementation and validation of innovative or advanced system and mission operation concepts.

(Source: ESA TD 9A)

SUBDOMAINS:

Mission Operations (1-L-2)

DEFINITION:

Covering aspects related to operation processes and mission control concepts, including automation, autonomy at various levels and distribution/decentralisation, operations support processes (such as operation training) and associated tools, dependability of operation systems and processes.

(Source: ESA TD 9B)

SUBDOMAINS:

1. **Distributed and Decentralised Operations**
Includes operations of single missions and families of missions, formation flying and constellations.
2. **Automation, Autonomy and Mission Planning Concepts**
Includes concepts for automation and mission planning of ground data systems and spacecraft operations.
3. **Operation Support Processes**
Covering aspects such as operation preparation, knowledge transfer from manufacturer to operations, training, dependability of operation systems and processes.

DEFINITION:

Covering technologies and techniques related to mission control systems (MCS's), SIM and DC architectures, techniques and tools for operations planning and scheduling, commonalities of AIV and operations, decision support and process control, operations data archiving and access, human–computer interfaces (HCIs).

(Source: ESA TD 9C)

Ground Data Systems (MCS) (1-L-3)

SUBDOMAINS:

1 - Mission Control System, Automation, Mission Planning, Simulators and Station M&C and Data Centre Architecture and Technologies
Includes architectural concepts, definition of a general framework, a set of building blocks/libraries for any type of mission and state of the art technologies for Ground Segment CSOS (Complex System of Systems).
2 - **Preparation and Procedure Tools**
Taking into account commonalities with EGSE requirements.
3 - **Human–Computer Interfaces and Technologies**
Includes frameworks, toolkits and other aiding tools that ease the definition of HCI, sharing a common look and feel and usability.

RESEARCH & TECHNOLOGY (1)
Mission Operations & Ground Systems (1-L)

DEFINITION:

Covering technologies and techniques related to the design of a ground station system and its constituent elements such as ground TT&C and payload data reception antenna systems using RF and optical techniques; transmit and receive radar and optical systems for ground based space surveillance; TT&C, radar and optical signal and data processing.

(Source: ESA TD 12A)

Ground Stations Systems (1-L-4)

SUBDOMAINS:

1. **Advanced Ground Station Design Concepts**
Covers design concepts for RF and optical ground stations for space communication and space surveillance applications.
2. **Ground TT&C and Payload Data Reception Antenna Systems**
Includes RF design, optical design, mechanical structures, servomechanisms, and tracking processes.
3. **Microwave and Optical Active/Passive Systems**
Includes all active components such as LNAs, detectors, HPAs, lasers, frequency converters, microwave sources, all passive components such as filters, switches, isolators, waveguides.
4. **TT&C, Radar and Optical Signal & Data Processing**
Covers telemetry receivers, decoders and demodulators, tele-command modulators and encoders, telemetry data pre-processors, ranging subsystems and precise navigation techniques.
5. **Frequency & Time Generation and Distribution**
Covers all means of frequency generation such as atomic clocks, masers and crystal oscillators. Time reference generation and synchronisation.
Note: Reference signals required for navigation, telecom and science applications are covered in 1-H-4 (5)

Ground Communications Networks (1-L-5)

DEFINITION:

Covering all technological aspects for TT&C and payload data distribution, related to the use of modern commercial-off-the-shelf ground communication technology/services, for providing cost/performance effective solutions to the operations of space missions.

(Source: ESA TD 12B)

SUBDOMAINS:

1. Advanced Ground Communication Networking Concepts
Covers new design concepts for data/communication in the ground segment.

2. Communication Network Technologies and Protocols
Covers issues related to communication and data exchange, including routing and modem issues as well as network protocols.

Ground Segment Software (1-L-6)

DEFINITION:

Mission control system software design, verification, validation and maintenance methods/tools. Application of modern IT technologies to spacecraft operations, including Object-Oriented Technologies.

(Source: ESA TD 2C)

SUBDOMAINS:

SSA & Clean Space
(1-M)

SSA & Clean Space
(1-M)

DEFINITION:

It includes:

- **SSA (Space Situational Awareness):** Space environmental effects that are limiting on all space missions and need to be assessed during all mission phases. Assessment requires the creation of environment models and the knowledge of effects, which is obtained by inflight measurement and testing.
- **SST (Space Surveillance & Tracking):** All aspects related to knowledge of the meteoroid and debris environment including space surveillance, databases, assessing debris risk levels for current and future missions, reentry of space objects, hyper velocity impacts and protection, and mitigation measures.
- **Clean Space related technologies:** All the specific technologies (not included into other areas, although affecting to some of them) to develop an eco-friendly approach to space activities.

(Source: ESA TD 4A, 4B and 4C for SSA, TD 11A and 11B for SST and PAE own elaboration based on Clean Space Program from ESA for 1-M-4)

SUBDOMAINS:

1. **SST: Ground and space based debris and meteoroid measurements (1-M-1)**
2. **SST: Modelling, risk analysis, mitigation, remediation and protection (1-M-2)**
3. **Space Environments and Space Weather (1-M-3)**
4. **Clean Space related technologies (1-M-4)**

SST: Ground and space based debris and meteoroid measurements (1-M-1)

DEFINITION:

Includes ground- and space-based measurements and related technology developments.

(Source: ESA TD 11A)

SUBDOMAINS:

1. **Ground-based Radar Measurements of Debris and Meteoroids**

Beam-park experiments, observation and performance modelling for tracking and surveillance sensors, comparison of measurements and models. Processing of radar tracking data e.g. to reconstitute orbits of uncorrelated objects for operational collision avoidance and anomaly resolution.

2. **Ground-based Optical Measurements of Debris and Meteoroids**

High-altitude surveys for faint objects. Follow-up and catalogue maintenance of objects in high-altitude orbits. Development and operation of planning and processing software for optical measurements of artificial objects. Orbit determination and observations for anomaly resolution. Planning and performance analysis for optical space-based sensors.

2. **In situ Radar and Optical Measurements of Debris and Meteoroids**

Space-based radar and optical detection techniques to characterize the small-particle environment. Development, flight and data evaluation.

RESEARCH & TECHNOLOGY (1)
SSA & Clean Space (1-M)

SST: Modelling, risk analysis, mitigation, remediation and protection (1-M-2)

DEFINITION:

It includes:

- **Modelling and Risk Analysis:**
Includes population models for meteoroids and debris (current and future evolution), statistical and operational risk analysis in space and re-entry survivability and safety analysis on the ground.
- **Mitigation, Remediation and Protection:**
Includes identification, standardisation and verification of the implementation of mitigation measures and accompanying models, environment prediction modelling, active removal techniques as well as HVI test techniques, development and validation of numerical simulations, evaluation and modelling of materials for shielding.

(Source: ESA TD 11B and 11C)

SUBDOMAINS:

1.1 Debris and Meteoroid Environment Models
Development and application of models for the characterisation of impact flux on orbital surfaces. Development and operation of databases on space objects, launch and space event information.
1.2 In-orbit Risks
Operational collision avoidance, conjunction detection and analysis, orbit refinement, avoidance manoeuvre optimisation. Statistical risk assessment and analysis of requirements for collision avoidance (delta-V, remaining risk) for mission planning.
1.3 Re-entry Risks
Structural analysis to determine the survivability of spacecraft components under the influence of aerothermal and aerodynamic stress during controlled and uncontrolled re-entries. Development of simulation models and models of the spacecraft geometry, materials. Computation of ground safety. Prediction of re-entry windows (date and location) of risk objects from surveillance data.
2.1 Space Debris Mitigation
Development of models and tools for the analysis of mitigation requirements for a space mission, which includes the prediction of orbital lifetime, fuel assessments, re-entry survivability and mission survivability with respect to debris impacts, as well as standardisation of these activities.
2.2 Space Debris Environment Remediation
Long-term environment projections using models for traffic and mitigation actions. Identification of removal targets and evaluation of removal options.
2.3 Protection against Debris and Meteoroids
Testing, evaluation and development of HVI test techniques, development and validation of numerical simulations, evaluation and modelling of materials under HVI, impact damage data on S/C configuration, shield optimisation.

RESEARCH & TECHNOLOGY (1)
SSA & Clean Space (1-M)

Space Environments & Space Weather (1-M-3)

DEFINITION:

It includes:

- **Space Environment:** Methods and models, and inflight monitoring of space environments (including radiation, plasmas, micrometeoroids and micro-debris, atmosphere and contamination).
- **Environment Effects:** Covers effects due to space environment (radiation damage and interference, spacecraft charging, micro-particle impact risk, …) development of computational tools and related experimental investigations.
- **Space Weather** Covers technology developments that contribute to the establishment of capabilities for predicting or evaluating hazardous environmental conditions in space, in the ionosphere or on the ground due to space weather, through use of observation technologies coupled with modelling and IT technologies. The observations and modelling relate to phenomena on the Sun, in interplanetary space and coupling with the near-Earth environment.

(Source: ESA TD 4)

SUBDOMAINS:

1.1. Numerical modelling of environments: Establishment of numerical models that represent space environments and their variables, as required by mission development and operation. Associated data analysis, and systems delivering model output for efficient use in development and operations.
1.2. Inflight Monitoring: Technologies to gather data on the space environment. Includes radiation detection (fluxes and derived quantities for all radiation components), plasmas, direct micro-particle detection.
2.1. Effects Analysis Tools: Development of tools for each environmental domain and resources for coordinated assessment. Tools for use in development and operations for quantifying environmental effects in terms of engineering parameters, and for use in product assurance and testing.
2.2. Ground and Space Effects Investigations: Providing data for the development and validation of the analysis tools and including establishment and/or exploitation of on-ground and in-space investigations of the environments and the effects on technologies. Includes radiation effects, charging and ESD monitoring, direct and indirect impact detection, analysis of returned material, etc.
3.1. Modelling Development and IT Infrastructure: Development of numerical models in the various space weather domains (solar, heliospheric, magnetospheric, ionospheric). Also covers IT infrastructure: development of an integrated but distributed system that includes real-time and archived data, coupled modelling and user-oriented informatics tools.
3.2. Space Weather Monitoring Technology: In situ and remote measurement of space weather features for use in forecasting and nowcasting, including solar, heliospheric, magnetospheric and ionospheric domains.

Clean Space related technologies (1-M-4)

DEFINITION:

Covers all the specific technologies (not included into other areas, although affecting to some of them) to develop an eco-friendly approach to space activities as defined in the ESA Clean Space Program.

(Source: PAE own elaboration based on ESA approach for Clean Space program)

SUBDOMAINS:

1. **Eco-design:** technologies oriented to address environmental impacts and foster green technologies in space development.
2. **CleanSat:** technologies implemented from the design to reduce the production of space debris.
3. **eDeOrbit:** technologies developed specifically to de-orbit space debris and, particularly large pieces of it.

Data Technologies (1-N)

Data Technologies (1-N)

DEFINITION:

It includes all the technologies related with data generated by the different types of space missions (downstream applications). In particular:

- Data engineering and processing: integrate, visualise, archive, search, mining…
- Exploitation of data coming from Earth observation missions.
- Exploitation of Space Science and Exploration data.
- Application of Big Data technologies to space data.

(Source: PAE own elaboration taking into account ESA TD 2D and 2E)

SUBDOMAINS:

1. **Data engineering: integrate, visualize, archive, search, mining… (1-M-1)**
2. **Earth Observation Data Exploitation (1-M-2)**
3. **Exploitation of Space Science and Exploration data (1-M-3)**
4. **Big Data Application in Space Technologies (1-M-4)**

Data engineering: integrate, visualize, archive, search, mining… (1-N-1)

DEFINITION:

It includes all the technologies related with the management of space generated data oriented to their applications (from the final user point of view). Covers archiving systems and analytical processing of space data (integration/fusion, visualization, searching, mining...) for any kind of space mission. Particularities of Earth Observation Missions and Space Science ones are included into 1-N-2 and 1-N-3.

(Source: ESA TD 2D and PAE own elaboration)

SUBDOMAINS:

1. **Data Archiving Systems**

Long-term data storage, large data volume technology…

2. **Analytical Processing**

Data integration and fusion, data visualization, data searching, data mining, etc…) Big data technologies applied to space mission generated data are included into 1-M-4

Earth Observation Data Exploitation (1-N-2)

DEFINITION:

Technologies associated with provision of Earth Observation based data and information to user communities, support to data utilisation, applications and services, creation of higher level information products and the creation and provision of information-based services.

(Source: ESA TD 2E and PAE own elaboration)

SUBDOMAINS:

1. **EO Data and Information Processing and Exploitation**
Covers specific aspects of EO missions related to data and information acquisition, archiving, processing, dissemination, and quality control, and to mission planning. Also covers exploitation of federated and collaborative payload data ground segment services and data dissemination.
2. **Applications and Services**
Covers aspects related to EO based applications (e.g. algorithms, models, related environments, etc.), higher-level processing, information mining, information-based services, service support, outreach.
3. **Information Systems and User Interfaces**
Covers aspects related to systems for accessing data and information and user interface tools and methods.

Exploitation of Space Science and Exploration data (1-N-3)

DEFINITION:

Technologies associated with provision of Science and Exploration missions based data and information to user communities, support to data utilisation, applications and services, creation of higher level information products and the creation and provision of information-based services.

(Source: PAE own elaboration)

SUBDOMAINS:

1. **Science Data and Information Processing and Exploitation**
Covers specific aspects of Science missions related to data and information acquisition, archiving, processing, dissemination, and quality control, and to mission planning. Also covers exploitation of federated and collaborative data with special emphasis on fusion with ground based data (i.e.: coming from on-ground telescopes) and data dissemination.
2. **Exploration Data and Information Processing and Exploitation**
Covers specific aspects of Exploration missions related to data and information acquisition, archiving, processing, dissemination, and quality control, and to mission planning. Also covers exploitation of federated and collaborative data.

Big Data Application in Space Technologies (1-N-4)

DEFINITION:

It includes the application of big data technologies to any kind of data generated from space related missions including: data from the development of the ground and space infrastructure (phases A to D), data from the mission operations including disposal (phases E and F) to obtain valuable results not trivially extractable directly from the data.

(Source: PAE own elaboration)

SUBDOMAINS:

1. **Big Data Technologies applied to on ground infrastructure development**
2. **Big Data Technologies applied to in space infrastructure development**
3. **Big Data Technologies applied to EO space mission data**
4. **Big Data Technologies applied to Science and Exploration mission data**
5. **Big Data Technologies applied to telecom missions**
6. **Big Data Technologies applied to Navigation missions**
7. **Big Data Technologies applied to manned space flights**

New Space Paradigms (1-O)

RESEARCH & TECHNOLOGY (1)

DEFINITION:

It includes all the technologies related with new methodologies for space development improvement. In particular:

- Use of COTS (commercial of the shelf) components and technologies for space systems.
- Adaptation of mass production techniques to space systems (for launch systems, constellations and standardized products) including the automated manufacturing techniques applied to space systems.
- Additive Manufacturing including in space conditioning.
- Sustainable space manufacturing supply chain.
- Customer based manufacturing technologies.

(Source: PAE own elaboration and SMART Technology Roadmap for 1-P-5 and 1-P-6)

New Space Paradigms (1-O)

SUBDOMAINS:

1. **Use of COTS "Commercial Of The Shelf" components / technologies in space (1-P-1)**
2. **Mass production techniques for space (1-P-2)**
3. **Additive Manufacturing (including in space conditions) (1-P-3)**
4. **Sustainable Space Manufacturing Supply Chain (1-P-4)**
5. **Customer-based Manufacturing (1-P-5)**

Use of COTS "Commercial Of The Shelf" components & technologies in space (1-O-1)

DEFINITION:

It includes all the new approaches using commercial of the shelf components for spacecrafts and the necessary quality approaches to be implemented to assure the overall mission performances.
It also includes the spin-in of technologies used by other sectors into space vehicles and space missions in general.

(Source: PAE own elaboration)

SUBDOMAINS:

1. **Technologies for using COTS electronic components into space vehicles**
2. **Technologies for using COTS software components into space vehicles**
3. **Technologies for implementing in space vehicles technological solutions coming from another sectors**

Mass production techniques for space (1-O-2)

DEFINITION:

It includes all the technologies developed to adapt the mass production techniques coming from another industries – specially from aeronautic one – to space.
It also includes the technologies implemented to massively produce satellites for big constellations

(Source: PAE own elaboration)

SUBDOMAINS:

1. **Launch vehicles mass production technologies**
2. **Satellite constellations mass production technologies**
3. **Standardization applied to space launchers**
4. **Standardization applied to satellites**

DEFINITION:

It includes additive manufacturing, otherwise known as 3D printing, which builds up hardware layer by layer, enabling the construction of hardware that simply could not be built in any other manner.

(ESA'web page and PAE elaboration)

Additive Manufacturing (including in space conditions) (1-O-3)

SUBDOMAINS:

1. **Design and development technologies and guidelines for AM applied to space systems**
2. **Verification technologies and guidelines for AM applied to space systems**
3. **Qualification methodologies for AM space parts and systems**
4. **In-space manufacturing using AM technologies**

Sustainable Space Manufacturing Supply Chain (1-O-4)

DEFINITION:

Includes innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment.

OBJECTIVE:

Deploy production processes compatible with the REACH regulation. Reduction of raw materials´ use with respect to current reference by means of reduction of non- conformities, net-shape production and reuse of materials.

Note: It has a strong relationship with 1-M-4 (Clean Space in particular with Eco-design subdomain)

(Source: SMART report, paragraph 4.1.7 and ESA Clean Space program)

TECHNOLOGIES:

1. Process and product monitoring with Instant automatic feedback to design and manufacturing with self- learning systems to assure optimum design for manufacturing and zero defects
2. Cleaner processes, with less resource consumption: materials, energy, lubricants, etc. and reduction of generated waste
3. Improving the “Buy to Fly ratio” using additive manufacturing and other net-shape manufacturing techniques
4. Environmental compliant auxiliary materials
5. Reuse of ancillary materials
6. Less energy consumption processes such as titanium cold forming
7. Reducing consumption of tools by component, optimising their use with intelligent tool life control
8. Advanced supply on demand management tools

RESEARCH & TECHNOLOGY (1)
New Space Paradigms (1-O)

Customer-based Manufacturing (1-O-5)

DEFINITION:

Includes involving customers in manufacturing value chain, from product process design to manufacturing associated innovative services

OBJECTIVE:

Development of management processes that permit standard production in environments with highly changing rates or model changes.

(Source: SMART report, paragraph 4.1.8)

TECHNOLOGIES:

1. Simulation, concurrent engineering methods and prototyping technologies for shortening development and certification cycles
2. Development of SHM (Structural Health Monitoring) as a qualification element for spacecraft
3. Modular systems, structures and manufacturing for efficient adaptation to customer demands
4. Flexible tool-less manufacturing and assembly
5. Rapid prototyping techniques

SEGMENTS OF ACTIVITY
(2)

What the people
is working for?

SPACE TAXONOMY

SEGMENTS OF ACTIVITY (2)

What the people is working for?

People can work in one or several of the following fields:

- Doing science from space (2A)
- Doing RTD for space (2B)
- Managing programs (2C)
- Selling or studying the market (2C)
- Designing space systems or subsystems (2D)
- Manufacturing space elements (2E)
- Assuring the quality (2F)
- Assembling, integrating and validating (including testing) space elements or systems (2G)
- Providing the services linked with access to space (2H)
- Operating space missions (2I)
- Developing space based services (2J)
- Providing transportation and servicing in space (2K)
- Detecting hazards (coming from natural or artificial sources) to space infrastructure (2L)
- Allowing human flight to space (2-M)
- Doing general management & administration (2-N)

- Space Science (2-A)
- Research & Technology Development (2-B)
- Commercial & Programmes (2-C)
- Design (2-D)
- Manufacturing (2-E)
- Quality (2-F)
- Assembly, Integration, Verification & Tests (2-G)
- Access to Space (2-H)
- Mission Operations (2-I)
- Services & Applications (2-J)
- In Space Transportation & On-orbit Servicing (2-K)
- Space Situational Awareness (2-L)
- Human Factor (2-M)
- General Management & Administration (2-N)

SEGMENTS OF ACTIVITY (2)

Space Science (2-A)

DEFINITION:

Space science encompasses all of the scientific disciplines involved in space exploration and studying phenomena occurring in outer space, such as space medicine and astrobiology. It includes:

1. Astronomy including astrophysics, stellar astronomy, planetary science, galactic astronomy, extra-galactic astronomy and physical cosmology
2. Space Exploration including manned and unmanned spaceflight
3. Astronautics including space medicine
4. Astrobiology

(Source: https://en.wikipedia.org/wiki/Outline_of_space_science)

Research &Technology Development (2-B)

DEFINITION:

It includes all the activities dedicated to research (scientific studies) and technology development oriented to space infrastructure development including ground infrastructure dedicated to space related activities

(Source: PAE own elaboration)

Commercial & Programmes (2-C)

DEFINITION:

It comprises all the activities dedicated to manage the space programs starting from the commercial activities (looking for new businesses) and including all the program management disciplines applied to space programs. It includes:

1. Commercial
2. Project planning and implementation
3. Configuration and information management
4. Cost and schedule management
5. Integrated logistic support
6. Risk management

(Source: PAE own definition based on ECSS standards about management: http://ecss.nl/standards/ecss-standards-on-line/active-standards/management/)

Design (2-D)

DEFINITION:

It comprises all the activities dedicated to design any kind of spacecraft and associated ground systems starting from the applicable set of requirements and finalizing with the definition files to be used for manufacturing, AIV and quality assurance.

(Source: PAE own elaboration)

SEGMENTS OF ACTIVITY (2)

Manufacturing (2-E)

DEFINITION:

It comprises all the activities dedicated to manufacture the different parts of any kind of spacecraft or ground station, starting from the files defining the design.

(Source: PAE own elaboration)

Quality (2-F)

DEFINITION:

It comprises all the activities related with the assurance of the quality of any kind of spacecraft or ground station including product assurance and quality measurement, as well as quality system maintenance.

(Source: PAE own elaboration)

Assembly, Integration, Verification & Tests (2-G)

DEFINITION:

It comprises all the activities related with the assembly and integration of subsystems and parts to construct the space systems (spacecraft or ground stations), as well as all the verification activities including testing at different levels.

(Source: PAE own elaboration)

SEGMENTS OF ACTIVITY (2)

Access to space (2-H)

DEFINITION:

It comprises all the activities (commercial and technical ones) related with the provision of the service to launch any kind of satellite and position it into its orbit. Launcher development is not included here.

(Source: PAE own elaboration)

Mission Operations (2-I)

DEFINITION:

It comprises all the activities related with the operations of the space systems excluding the development of the ground stations. It includes mission design and preparation and mission operation itself from launching to final disposal. The development of services based on data coming from space missions is included into 2-J

(Source: PAE own elaboration)

Services & Applications (2-J)

DEFINITION:

It comprises all the activities related with the development and commercialization of any kind of service or application based on the use of data coming from space.

(Source: PAE own elaboration)

In-space transportation & on orbit servicing (2-K)

DEFINITION:

It comprises all the activities related with the provision of the service of transporting satellites from the injection point provided by the launcher to their final orbital position as well as on orbit servicing, including ISS or any other future serviceable space vehicle. The development of the necessary infrastructure (vehicles and ground systems) is not included.

(Source: PAE own elaboration)

Space Situational Awareness (SSA) (2-L)

DEFINITION:

SSA aims to detect, predict and assess the risk to life and property due to man-made space debris objects, reentries, in-orbit explosions, in-orbit collisions, disruption of missions and satellite-based service capabilities, potential impacts of Near-Earth Objects (NEOs), and the effects of space weather phenomena on space- and ground-based infrastructure.

SSA means to know what goes on in space by acquiring the independent capability to watch for objects and natural phenomena that could harm our infrastructure.It comprises all the activities related with the application of SSA measurements to watch and try to prevent the possible effects of space related environment into the Earth, including natural environmental effects, meteoroid and debris impact.

(Source: ESA SSA programme)

SEGMENTS OF ACTIVITY (2)

Human Factor (2-M)

DEFINITION:

It comprises the activities linked with the human factor in the space flight such as: selection and training of astronauts, flight as an astronaut, nutrition and care of astronauts, space medicine, space psychology, etc…

(Source: PAE own elaboration)

General Management & Administration (2-N)

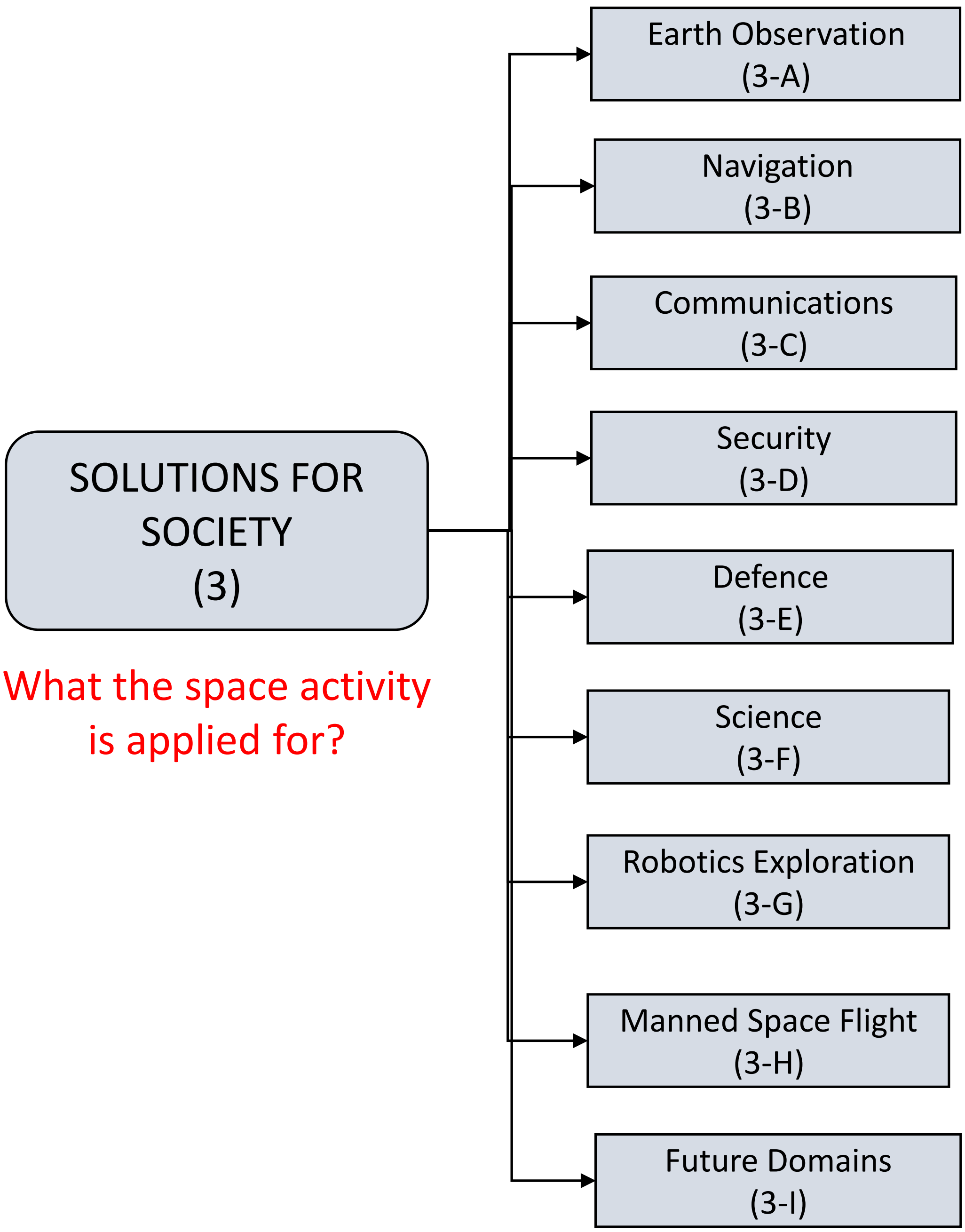
DEFINITION:

It comprises all the activities related with the general management of the entities and all the administrative services (human resources, legal, finance, etc…)

(Source: PAE own elaboration)

SOLUTIONS FOR SOCIETY
(3)

What the space activity is applied for?


SOLUTIONS FOR SOCIETY (3)
What the space activity is applied for?
Earth Observation (3-A)
Navigation (3-B)
Communications (3-C)
Security (3-D)
Defence (3-E)
Science (3-F)
Robotics Exploration (3-G)
Manned Space Flight (3-H)
Future Domains (3-I)

Earth Observation (3-A)

DEFINITION:

The single location where we can learn the most about our planet is found nowhere on Earth but high up above it. Today, images of our planet from orbiting satellites are acquired continuously; they have become powerful scientific tools to enable better understanding and improved management of the Earth and its environment.

Earth observation provides objective coverage across both space and time. In the long term, this monitoring of the Earth’s environment will enable a reliable assessment of the global impact of human activity and the likely future extent of climate change.

One major class of Earth observation instruments are termed optical because they obtain data by recording the Earth reflected energy across various wavelengths, including visible light and invisible infrared bands.

Other sensors known as radar instruments actively shine microwaves pulses down to Earth in order to record how these pulses get reflected back up to space. These instruments measure surface roughness instead of light or heat energy, and have the advantage of being able to see through cloud and darkness. A different type of instrument named a altimeter records very precisely the time it takes for a microwave or laser pulse to be bounced back to the satellite, measuring both land and sea height to an accuracy of a few centimetres.

The make-up of the Earth’s atmosphere is also the subject of Earth Observation monitoring. Atmospheric instruments work by detecting how the envelope of air surrounding our planet affects light, heat or radio energy passing through it. Certain 'signature' spectral wavelengths either absorbed or emitted by the atmosphere indicate the presence of associated chemicals and gases.

Earth observation techniques are also applied by satellites orbiting another objects in the universe to study them and their environments.

(Source: PAE own elaboration from ESA’s web page: http://www.esa.int/Our_Activities/Observing_the_Earth/View_from_above)

Navigation
(3-B)

DEFINITION:

Using the fixed stars, you can determine your position anywhere on the Earth's surface to within a few hundred metres, provided the weather is fine. But navigation satellites can tell you where you are to the nearest few metres or better, whatever the weather.

Distance measurements from two satellites tell you that you are situated somewhere on the circle where two spheres intersect. The spheres each have one of the two satellites at their center and their radii are the satellite-receiver distances. Knowing your distance from a third satellite fixes your position at one of the two points where the circle intersects the third sphere. One of the intersection points can usually be discounted – for instance, it may be thousands of kilometers above the Earth's surface. In practice, a fourth satellite is needed to synchronize your receiver's clock with a common time standard which is strictly adhered to by the clocks on board all the satellites. The use of a fourth satellite also resolves the position ambiguity that occurs with only three satellites. In general, the more satellites used, the greater the positioning accuracy. Many receivers have channels for receiving signals from up to 15 satellites.

It is only possible to determine a location on Earth if you know the location of the navigational satellites very precisely. This is achieved by placing the satellites in highly stable Medium Earth Orbits (MEOs) at an altitude of about 22 000 kilometers. MEOs are the orbits of choice for a number of reasons: their stability enables exact orbit predictions; the satellites travel relatively slowly and so can be observed over several hours, and the satellites can be arranged in a constellation so that at least four are visible from any point on the Earth's surface at any time.

Benefits from satellite navigation data are well known by everybody since every smart phone incorporates a navigation sensor and associated applications.

(Source: PAE own elaboration from ESA's web page:
http://www.esa.int/Our_Activities/Navigation/About_satellite_navigation2)

Communications (3-C)

DEFINITION:

Satellite telecommunication is the most mature of space applications. Starting 50 years ago with the launch of Telstar in 1962 and Syncom in 1963, satcom has continued to grow ever since.

At first, satellite performance was very limited. To compensate for this, very large ground stations with dish antennas more than 20 metres in diameter were required to establish links with them. The use of satellites was limited to long distance telephony and to the transport of television signals between studios.

New technology and different kinds of demand have changed the way communications satellites are used. More powerful satellites and the use of higher frequencies have made it possible for many people to receive direct signals from the sky. At the beginning of the 21st century, more than 100 million European homes were able to watch television programmes transmitted by satellites, either by direct reception or through cable distribution systems.

- When you listen to the radio, it is very likely that the signal you are receiving has been distributed from the central studios by satellite.
- Many newspapers and magazines are produced locally but printed centrally: the content of the paper is sent to the printing plants using satellite links.
- Even when a news or sports event shown on television is taking place just a few kilometers away from the studios, it has probably been transmitted via satellite.
- Most news agencies use satellites to distribute text, audio and video to their affiliates.
- In many countries, access to the Internet is by satellite communication and with the emergence of very powerful broadband satellites, users – equipped with their own broadband interactive satellite terminals – will get access to the Internet regardless of their distance from the nearest terrestrial node.
- Big satellite constellations al MEO orbits are currently under development to provide universal Internet and communication service all around the world.

(Source: PAE own elaboration from ESA's web page: http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Telecommunications_satellites)

Security (3-D)

DEFINITION:

Space-based systems are making an increasingly important contribution to security and to the Security and Defence Policy (CSDP). The world faces constantly evolving security threats that are more diverse, less visible, and less predictable than before.

Space assets provide a significant contribution to confronting these threats through their global monitoring, communication, and positioning capabilities.

(Source: PAE own elaboration and EU's web page: https://ec.europa.eu/growth/sectors/space/security_es)

Defence (3-E)

DEFINITION:

Besides the security applications (most of the time considered as part of defence policy), there are another military uses of the space including the weapon and anti-weapon systems based on space.

But there are civilian applications of space (particularly, observation, navigation and communications) that also have military uses and, most of the times, dedicated space infrastructures due to security reasons.

(Source: PAE own elaboration and NATO Space Operation Assessment: https://www.japcc.org/wp-content/uploads/NATO-Space-Ops-Assessment-Jan-09.pdf)

Science
(3-F)

DEFINITION:

Space science encompasses all of the scientific disciplines involved in space exploration and studying phenomena occurring in outer space, such as space medicine and astrobiology.

It includes:

- Astronomy including astrophysics, stellar astronomy, planetary science, galactic astronomy, extra-galactic astronomy and physical cosmology
- Scientific studies coming from Space Exploration (manned and unmanned ones)
- Astronautics including space medicine
- Astrobiology

(Source: https://en.wikipedia.org/wiki/Outline_of_space_science)

Robotics Exploration
(3-G)

DEFINITION:

Although in a wide sense any unmanned satellite could be considered as a robot space robotics, as a particular application of general robotics, considers two main scenarios: robotics under microgravity conditions for uses inside space stations and some tasks as orbital servicing and planetary robotics where the application field is the development of autonomous vehicles to move close to the surface of another planets or celestial bodies in general.

(Source: PAE own elaboration and IEEE Robotics and Automation Society’s web page: http://www.ieee-ras.org/space-robotics)

Manned Space Flight (3-H)

DEFINITION:

Any time where a vehicle flying up to space (internationally considered as flying at an altitude higher than 100 km) has any human being inside, we are doing a manned space flight.

Space development has always included manned space systems and, although the robotic exploration has made a lot of advances, the interest to fly to the space has been renewed in the last decade with the concept of space tourism and the more recent objective of going to Mars, probably coming back to Moon first.

Development of manned systems and long duration space travelling are currently acting as research and technology tractors for many other space and non-space technologies.

(Source: PAE own elaboration)

Future Domains (3-I)

DEFINITION:

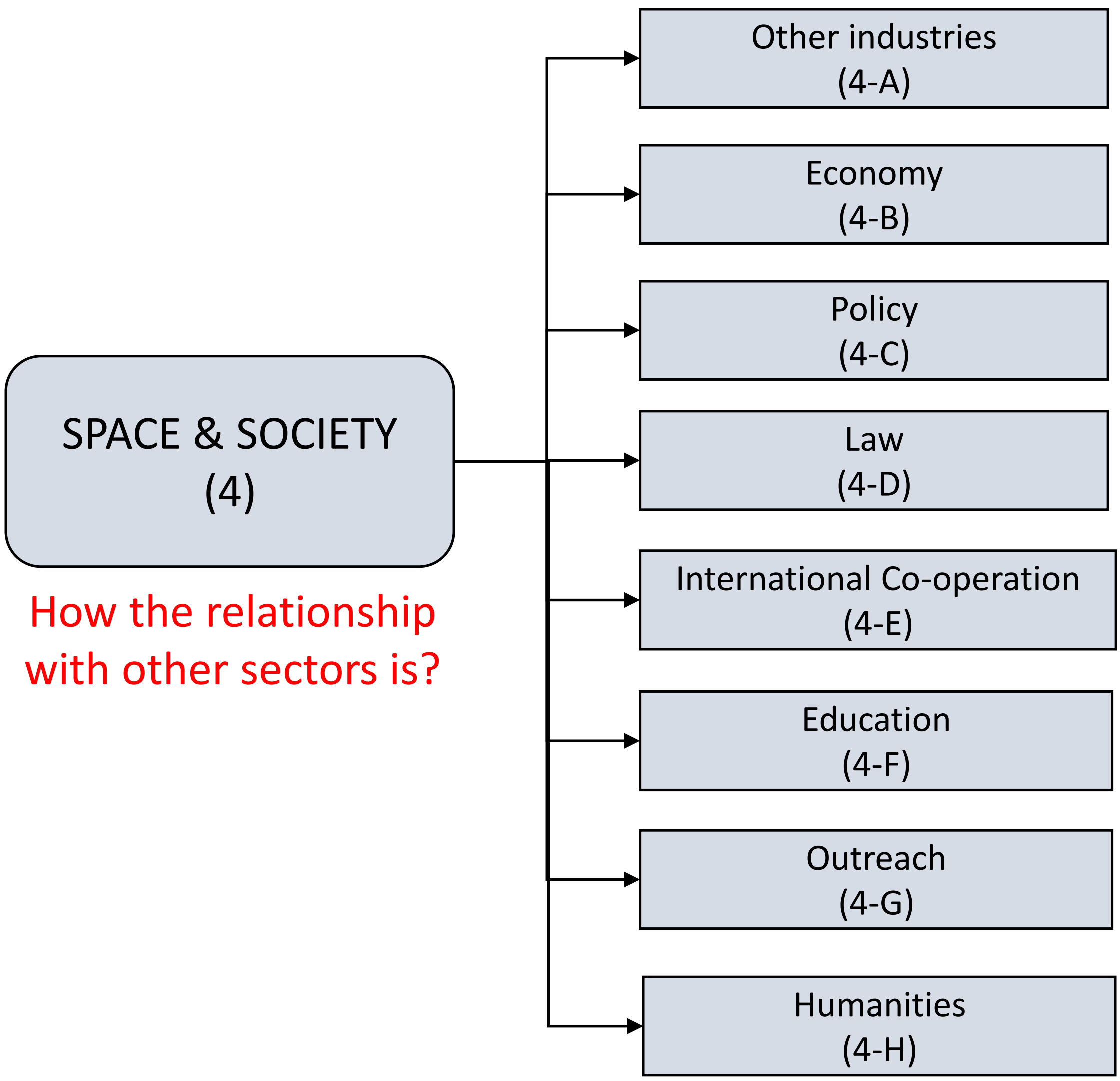
If the travel to the Moon or Mars become a reality in the next decades, some new applications of space could appear.

Mining from asteroids, energy harvesting from space and some another future applications not yet implemented or demonstrated can appear.

(Source: PAE own elaboration)

SPACE & SOCIETY
(4)

How the relationship with other sectors is?


SPACE & SOCIETY
(4)
How the relationship
with other sectors is?
Other industries
(4-A)
Economy
(4-B)
Policy
(4-C)
Law
(4-D)
International Co-operation
(4-E)
Education
(4-F)
Outreach
(4-G)
Humanities
(4-H)

Other industries (4-A)

DEFINITION:

The definition of the economic sectors to establish the possible relations between Space Industry and the rest of the sectors in society is made based into the reference document R4.
Although not all the included economic sectors are considered industries, we include here most of of them because they are defined as "Industry Classification" in the reference document.
Each subdomain has a correspondence with a sector in R4. There are some special sectors included in the other classes of this domain

(Source: NAICS and PAE synthesis)

SUBDOMAINS:

- **AGRICULTURE, FORESTRY, FISHING AND HUNTING (4-A-1):** Sector 11
- **MINING, QUARRYING, OIL & GAS EXTRACTION (4-A-2):** Sector 21
- **UTILITIES (ENERGY, WATER AND OTHER SYSTEMS) (4-A-3):** Sector 22
- **CONSTRUCTION (4-A-4):** Sector 23
- **PETROLEUM, CHEMICAL & PLASTIC PRODUCTS MANUFACTURING (4-A-5):** Sectors 324, 325 and 326
- **METALLIC & NON-METALLIC PRODUCT MANUFACTURING (4-A-6):** Sectors 327, 331 and 332.
- **MACHINERY MANUFACTURING (4-A-7):** Sector 333
- **COMPUTER, ELECTRICAL & ELECTRONIC PRODUCT MANUFACTURING (4-A-8):** Sector 334 and 335
- **MOTOR VEHICLE MANUFACTURING (4-A-9):** Sectors 3361, 3362, 3363
- **AIRCRAFT & MISSILES PRODUCTS AND PARTS MANUFACTURING (4-A-10):** Sector 3364 except Spacecraft related products and parts.
- **RAILROAD PRODUCTS MANUFACTURING (4-A-11):** Sector 3365
- **SHIP & BOATS MANUFACTURING (4-A-12):** Sector 3366
- **OTHER TRANSPORT EQUIPMENT MANUFACTURING (4-A-13):** Sector 3369
- **OTHER MANUFACTURING (4-A-14):** Sectors 311 to 316 (food, beverage, tobacco, textiles, apparel, leather and allied), 321 to 323 (wood, paper and printing), 337 (furniture) and 339 (miscellaneous)
- **AIR TRANSPORTATION (4-A-15):** Sector 481
- **OTHER TRANSPORTATIONS (4-A-16):** Sectors 482 to 493
- **ENGINEERING SERVICES (4-A-17):** related with sector 54 (professional &technical) and 55 (management of companies)
- **HEALTH CARE & SOCIAL ASSISTANCE (4-A-18):** Sector 62
- **OTHER SERVICES AND OTHER SECTORS (4-A-19):** Sectors 42 (wholesale trade), 44/45 (retail trade), 53 (real state, rental and leasing), 56 (administrative and waste services), 72 (accommodation and food services) and 81 (other services except public administration)

Economy (4-B)

DEFINITION:

Here we include the economy in general (sector 52 of NAICS classification) and, in particular:

- The different funding schemes applicable to space related activities (public or private funding)
- The studies from economical point of view of space related activities.
- The insurance applied to space related activities.

(Source: NAICS and PAE own elaboration)

Policy (4-C)

DEFINITION:

Space policy is the political decision-making process for, and application of, public policy of a state (or association of states) regarding spaceflight and uses of outer space, both for civilian (scientific and commercial) and military purposes. International treaties, such as the 1967 Outer Space Treaty, attempt to maximize the peaceful uses of space and restrict the militarization of space.

We include here all the public administration bodies related with space.

(Source: Wikipedia https://en.wikipedia.org/wiki/Space_policy and sector 92 of NAICS)

Law (4-D)

DEFINITION:

Space law can be described as the body of law governing space-related activities. Space law, much like general international law, comprises a variety of international agreements, treaties, conventions, and United Nations General Assembly resolutions as well as rules and regulations of international organizations.

We include here all the legal aspects of space including patents.

(Source: UNOOSA http://www.unoosa.org/oosa/en/ourwork/spacelaw/index.html)

International co-operation (4-E)

DEFINITION:

One of the benefits of space exploration is international cooperation. Although the Age of Space began in a fiercely competitive mode, political and funding realities have now shifted the balance toward cooperation. This is particularly true in the case of the International Space Station, with its 16 partner nations. And it promises to be increasingly true with the Vision for Space Exploration.

(Source: NASA https://www.nasa.gov/exploration/whyweexplore/Why_We_10.html)

Education (4-F)

DEFINITION:

Education includes all the activities dedicated to learning. Particularly:

- All the official education system levels from primary to university degrees.
- All the un-official learning systems from MOOCs (Massive open online courses) and any other distance learning to internal training courses provided inside industry, research centers and any other entity.

The inspirational activities, many times included under "education", are not included here but into "Outreach" (4-G)

(Source: PAE own elaboration and sector 61 of NAICS)

Outreach (4-G)

DEFINITION:

Under this generic title we include all the activities related with the public information, including:
- Press and news.
- Publicity at any level.
- Any communication activity: from general public ones to specialized congresses and events.
- Any inspirational program launched to attract young people to pursue scientific and technology careers.

(Source: PAE own elaboration and sector 51 of NAICS)

Humanities (4-H)

DEFINITION:

Under this generic definition we include all the activities related with humanities as, for instance:

- History (humans have dreamed about spaceflight since antiquity. The Chinese used rockets for ceremonial and military purposes centuries ago, but only in the latter half of the 20th century were rockets developed that were powerful enough to overcome the force of gravity to reach orbital velocities that could open space to human exploration: that adventure continues today).
- Arts, entertainment and recreation, including museums and planetariums, as well as filming or any other artistic expression.
- Social studies related with space.
- Libraries and any database containing relevant data for space.

(Source: PAE own elaboration, sector 71 of NAICS and http://www.aerospace.org/education/stem-outreach/space-primer/a-brief-history-of-space-exploration/)

In the elaboration of the present issue of the PAE’s taxonomies have participated the following entities and persons:

Miguel Ángel Castillo and Ángela Targhetta

Javier Borrás and Silvia Lazcano

Carlos Montesano and Pedro Rubio

Ángel Barrio

Demetrio López

José Luis Leal

Ignacio Tourné

Fernando Lasagni and Joaquín Rodríguez

Almudena del Teso

César Fernández and José Miguel Pascual

Héctor Guerrero, Marta March and Susana Martín

Plácido Márquez and Miguel Reynés

Bernardo Delicado

Vicente Gómez

Mario Insunza and Ana Santiago

Javier Coleto

Pablo Zúmel

Eusebio Valero

End of the document