ESA TECHNOLOGY TREE

Version 4.1

STM-277 4th ed.

COMPILED BY

TECHNOLOGY COORDINATION & PLANNING OFFICE

ESA/ESTEC TEC-H

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Technology Tree Change Log

Reason for change	Issue	Revision	Date
Initial issue	1	0	March 2003
Renumbering of TD15	1	1	June 2003
Second issue: Full document update	2	0	November 2006
Further update of TDs 9-10-11-12 and reduction to two levels	2	1	April 2007
Review of 2.1 vs 1.1 correspondence matrix	2	1.1	March 2008
No change to content; layout changed to bring the document into the ESA STM series	2	1.2	September 2008
Third issue: Full document update Updated to 2nd edition of STM-277	3	0	October 2013
Fourth issue: Full document update Updated to 3rd edition of STM-277 Appendices reorganised: – List of TDR in appendix removed – Detailed Change Log and list of items with editorial changes added (Appendices B and C respectively)	4	0	April 2020
Amendment to fourth issue Updated to 4th edition of STM-277 Changes and corrections, including – Updates to TD 18 and TD 25 – Update of the change log – Correction: removal of subdomain 3-D from the structure, consistent with change log – Update of the change log	4	1	November 2023

1 Introduction

1.1 Objective of this Document

The objective of this document is to present the ESA Technology Tree, which provides a classification system for all technical knowhow that is available in ESA.

The Tree was initially defined in the frame of the ESTER (European Space Technology Requirements Database) consolidation activities performed in April/May 2002. The present revision 4.1, performed in 2023 by the Technology Coordination and Planning Office (TEC-H), is an amendment to the version 4.0, which was also done by TEC-H in 2022 with the help of TECNET and the approval of the TECNET Chairs Forum, and Competence Domains Leads and members.

The Technology Tree presented in this document is a living tool and therefore will be subject to evolution as necessary.

1.2 Structure of the Technology Tree

The Technology Tree has a three-level structure. The first level of decomposition introduces 26 Technology Domains (TDs). The TDs are then further subdivided into Technology Subdomains (TSs) and Technology Groups (TGs), as appropriate.

For many ESA processes, only the first two levels of the Tree are used, namely the TDs and the TSs. An abbreviated version of the table is therefore also provided.

1.3 Document Overview

The document is divided into three sections and four Appendices:

Section 1 (this section) describes the objectives of the document, an outline of the changes between issues 3.0 and 4.1, a number of useful definitions and a brief historical background.

Section 2 contains an abbreviated version of the Tree (only TDs and TSs included).

Section 3 contains the full tabular format version, with descriptions (all levels included).

Appendix A provides a detailed description of the changes between issues 3.0 and 4.1 of the Technology Tree, including a connectivity matrix between version 3.0 and 4.1.

Appendix B provides the detailed change log between version 3.0 and 4.1.

Appendix C reports the list of items where editorial changes have been made, addressing mostly terminology and language review.

Appendix D provides the list of acronyms used throughout the document.

1.4 Historical Background

Before 2002, the technologies in ESA were structured as 56 separate groups (originally referred to as Product Groups), which were used mostly as references for databases. When in 2002 the list was revised and included 207 separate items, the need for a more organised and functional representation of technologies became clear. In order to improve the situation and provide a more structured classification, the concept of the ESA Technology Tree was established.

Issue 1.1 of the ESA Technology Tree was released in 2003 as the result of a collaboration amongst relevant ESA Directorates, and following that there were several updates. The document was first published as part of the STM series in 2008; a second edition was issued in 2013.

Since the first issue in 2003, the ESA Technology Tree has been used by ESA (e.g. for Harmonisation, ESA Technology Strategy, technology programme workplans, various databases) and by European industry.

1.5 2020 Update and 2023 Amendment

Since the last issue of the Technology Tree, things have changed both technologically and organisationally, plus a number of comments were made by users on both the content and the navigability of the Tree.

In response to the above comments, the 2020 Technology Tree update has been carried out according to the following guidelines:

- Consult and iterate with all ESA CDLs for suggestions on changes and improvements to the Technology Tree
- Analyse all received input and identify areas where there might be overlaps or where there is potential for misunderstanding
- Analyse areas where no changes have been made, in order to catch issues that might have been missed in previous reviews
- Provide a description of every item on the Tree with the help of relevant ESA experts
- Update the language used, to make it consistent throughout the document and to align with common definitions established elsewhere
- Request position of Industry and Delegations
- Consult, iterate and discuss the outcome with TCF for comments and approval

Issue 4.1 of the Technology Tree (TT) now contains:

- 26 TDs (26 in issue 3.0, 26 in issue 2.1)
- 107 TSs (107 in issue 4.0.101 in issue 3.0, 92 in issue 2.1)
- 346 TGs (343 in issue 4.0, 320 in issue 3.0, 274 in issue 2.1)

In 2023 the Technology Tree has been amended with some text improvements, corrections and additional Subdomains and Groups not previously covered. More details about the changes, and a connectivity matrix between versions 3.0 and 4.1, are provided in Appendix A.

1.6 Technology Tree Objectives

The objective of the Technology Tree is to provide a classification of all technological expertise currently available in ESA for space activities.

1.7 Definitions

In the context of this document, the following definitions are applicable:

Technology	A technology is defined as the technical knowhow that is required for the design, manufacture and test of a space product, including all related processes.
Product	Space products are all items needed for space activities that can be procured in the market, including services.

1.8 Granularity Guidelines

Consistent with the definition of technology given above, the granularity of the description of TD, TS and TG goes from more general (TD) to more specific (TG), as follows:

- TD: A technology domain includes knowhow relevant to a technical area that can be identified as being standalone and can therefore be considered independently of other TDs.
- TS: A decomposition of a TD to provide a more accurate description of its content in terms of different but related technical areas.
- TG: A further decomposition of each TS to identify a technology that is relevant to a family of products but that is not the description of a product in itself.

An example of a technology category is 3-B-II. The structure and levels are illustrated in Fig. 1.

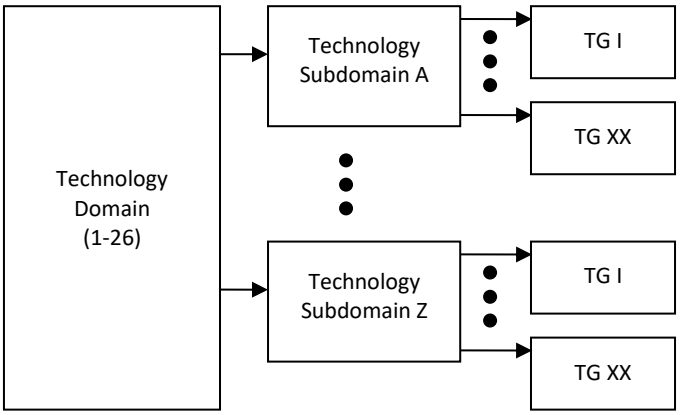

Figure 1: Structure of the Technology Tree

2 Technology Tree Issue 4.1 – Abbreviated Version

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
1	On-board Data Subsystems	A	Payload Data Processing
		B	On-board Data Management
		C	Microelectronics for Digital and Analogue Applications
		D	Machine Learning and Artificial Intelligence for On-board Data Subsystems
2	Space System Software	A	Software Technologies
		B	Space Segment Software
		C	Ground Segment Software
		D	Ground Data Processing
		E	Remote Sensing Payload Data Exploitation
3	Space Systems Electrical Power	A	Power Electronics
		B	Power Generation Technologies
		C	Energy Storage Technologies
4	Space Systems Environments and Effects	A	Space Environments
		B	Environments Effects
		C	Space Weather
5	Space System Control	A	Control (Sub-) Systems Engineering
		B	Control (Sub-) Systems Innovative Technologies
		C	Control Techniques and Tools
		D	AOCS/GNC Sensors and Actuators
6	RF Subsystems, Payloads and Technologies	A	Telecommunication Subsystems
		B	Radio Navigation Subsystems
		C	TT&C and Payload Data Transmitter (PDT) Subsystems
		D	RF Payloads
		E	RF Technologies and Equipment
7	Electromagnetic Technologies and Techniques	A	Antennas
		B	Wave Interaction and Propagation
		C	Electromagnetic and Radio Frequency Compatibility (EMC/RFC) and Electrostatic Discharge (ESD)
8	System Design & Verification	A	Mission and System Specification
		B	Collaborative and Concurrent Engineering
		C	System Analysis and Design
		D	System Verification and Assembly, Integration and Test (AIT)
9	Mission Operation and Ground Data Systems	A	Advanced System and Mission Operation Concepts
		B	Mission Operations
		C	Ground Data Systems
10	Flight Dynamics and GNSS	A	Flight Dynamics (FD)
		B	GNSS High-Precision Data Processing

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
11	Space Debris	A	Ground- and Space-based Debris and Meteoroid Measurements
		B	Modelling and Risk Analysis
		C	Debris Mitigation
		D	Debris Remediation and Protection
12	Ground Station Systems and Networks	A	Ground Station System
		B	Ground Communications Networks
13	Automation, Telepresence & Robotics	A	Robotic Applications and Concepts
		B	Automation & Robotics Systems and Subsystems
		C	Automation & Robotics Components and Technologies
14	Life & Physical Sciences	A	Instrumentation in Support of Life Sciences
		B	Instrumentation in Support of Physical Sciences
		C	Applied Life Science Technology
15	Mechanisms	A	Mechanism Core Technologies
		B	Non-Explosive Release Technologies
		C	Exploration Tool Technologies
		D	Control Electronics Technologies
		E	MEMS Technologies
		F	Tribology Technologies
		G	Mechanism Engineering
		H	Pyrotechnic Technologies
		I	Flexible Capture Mechanisms
16	Optics	A	Optical Subsystem Engineering
		B	Optical Components Technology and Materials
		C	Optical Equipment and Instrument Technology
17	Optoelectronics	A	Laser Technologies
		B	Detector Technologies
		C	Photonics
		D	Optical Communication Technologies
		E	Quantum Technologies
18	Fluid Mechanics	A	Fluid Mechanics Tools and Techniques
		B	Ground-Based Facilities
		C	Sensors and Measurement Techniques for Fluid Mechanics
		D	Flight Demonstrators and Flight Data Tools
		E	Fluid Mechanics Hardware
19	Propulsion	A	Chemical Propulsion Technologies
		B	Electric Propulsion Technologies
		C	Other Propulsion Subsystems
		D	Supporting Propulsion Technologies and Tools

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN
20	Structures	A	Structural Design and Verification Methods and Tools
		B	High Stability and High-Precision Spacecraft Structures
		C	Inflatable and Deployable Structures
		D	Hot Structures
		E	Active/Adaptive Structures
		F	Damage Tolerance and Health Monitoring
		G	Launchers, Reentry Vehicles, Planetary Vehicles
		H	Crew Habitation, Safe Haven and EVA suits
		I	Meteoroid and Debris Shield Design and Analysis
		J	Advanced Structural Concepts and Materials
21	Thermal	A	Heat Transport Technology
		B	Cryogenics and Refrigeration
		C	Thermal Protection
		D	Heat Storage and Rejection
		E	Thermal Analysis Tools
22	Environmental Control & Life Support (ECLS) and In Situ Resource Utilisation (ISRU)	A	Environmental Control & Life Support (ECLS)
		B	In Situ Resource Utilisation (ISRU)
23	Electrical, Electronic and Electro-mechanical (EEE) Components and Quality	A	Methods and Processes for Product Assurance of EEE Components
		B	EEE Component Technologies
24	Materials and Manufacturing Processes	A	Novel Materials and Materials Technology
		B	Materials Processes
		C	Cleanliness and Sterilisation
		D	Ground and Space Environmental Effects on Materials and Processes
		E	Modelling of Materials Behaviour and Properties
		F	Non-Destructive Inspection
		G	Material and Process Obsolescence
		H	Materials for Electronic Assembly
		I	Advanced Manufacturing Technologies
		J	Reliability and Reusability Aspects of Materials
25	Quality, Dependability and Safety	A	System Dependability and Safety
		B	Software Quality
		C	Product and Quality Assurance
		D	Commercial Off-The-Shelf Components and Subsystems
26	Others		

3 Technology Tree Issue 4.1 – Full Version

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
1	**On-board Data Subsystems** Spacecraft data management; payload data processing; 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.	A	**Payload Data Processing** Specific digital signal and data processing technologies and techniques; specific (high-speed, high-capacity-oriented) hardware (e.g. DSP, storage), software (signal/image processing, data compression/fusion, data security…) and networking technologies (including protocols and standards).	I	**System Technologies for Payload Data Processing** System aspects such as payload processing and storage architectures, algorithms, communication, etc., for Earth observation, science and manned-space applications. Technologies for big data processing and compressing sensing at system level.
				II	**Hardware Technologies for Payload Data Processing** Hardware technologies related to high-speed/high-performance equipment (e.g. DSP, mass memories, switches and communication links, digital video, data compression, data security).
				III	**Software Technologies for Payload Data Processing** Software technologies related to high-speed/high-performance payload data processing subsystems. Software technologies big data processing and compressing sensing.
		B	**On-board Data Management** Avionics and command and control subsystem specific aspects; such as data handling, subsystem management and autonomy, security; as well as specific hardware (e.g. computers, storage, micro-controllers), software (e.g. basic support packages) and networking technologies and techniques, etc.	I	**On-board Data Management Subsystem** Highly integrated subsystems, architecture, fault tolerance, on-board operation management and autonomy.
				II	**On-board Computers** On-board fault-tolerant dependable computers, their main components (microprocessors, I/O) and basic software.
				III	**On-board Data Storage** Development of data storage equipment (mass memories) and modules for spacecraft platforms.
				IV	**On-board Networks and Control/Monitoring** Development of the on-board data communication subsystems, including on-board command and control data networks, and their security, for performing monitoring and control across the platform, and wireless systems.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
1	**On-board Data Subsystems (cont.)**	C	**Microelectronics for Digital and Analogue Applications** Design methodologies and technology for space application specific integrated circuits (ASICs) and field programmable gate arrays (FPGAs). Digital and analogue designs, including IP cores. *(Note 1-C-1: design aspects of COTS subsystems are covered in TD 25-D)*	I	**Methodologies for Microelectronics** Rad-hardening by design allowing usage of commercial technologies. System-on-chip design methodologies; Hardware-Software co-design; **s**pace use of reprogrammable FPGAs. Low power high-performance processing algorithms and processors; analogue IC design. ASIC and FPGA design (design kit and libraries) and test tools. *(Note 1-C-I-1: Issues related to basic mechanisms of radiation effects are covered in TD 23)* *(Note 1-C-I-2: The software side of software–hardware co-engineering is covered in 2-B-II)*
				II	**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.
		D	**Machine Learning and Artificial Intelligence for On-board Data Subsystems** Developments, characterisation and evaluation techniques for On-board Data Subsystems.	I	**Machine Learning for On-board Data Subsystems** Development of Machine Learning techniques for payload and platform Data Systems applications including hardware and associated algorithms, anomaly detection, image compression, etc.
				II	**Characterisation and Evaluation of Machine Learning Techniques** Development of characterisation and evaluation techniques to identify suitability of Machine Learning for space applications. *(Note 1-D-II-1:SW implementation is covered under 2-A-I)*
2	**Space System Software** All basic techniques and technologies in the fields of software and Information Technology with respect to their application to space missions, both for space and ground segment.	A	**Software Technologies** 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.	I	**Software Autonomy and Artificial Intelligence** Autonomy aspects of software and implementation of artificial intelligence. It covers also system-level avionics aspects of on-board autonomy. *(Note 2-A-I-1: specific machine learning techniques are covered under 1-D-II)*

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	**Space System Software (cont.)**	A	**Software Technologies (cont.)**	II	**Software Functions** Functions that are implemented in software such as: application functions (data handling, thermal management, power management, AOCS, security etc.); supporting functions (operating systems, separations kernels, middleware, etc.). Includes, other advanced software functions such as parallel computing. *(Note 2-A-II-1: This includes also predevelopment for applications indicated in TD1-A-III)* *(Note 2-A-II-2: Coverage of Autonomy is under to 2-A-I)*
		B	**Space Segment Software** On-board 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.	I	**Methods and Tools for On-board Software Engineering Processes** All aspects of on-board software engineering, requirement engineering, automation of the life cycle, testing, model-based development, etc. In particular, it includes software emulators of on-board processors.
				II	**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 2-B-II-1: The system side of system–software co-engineering, and the hardware side of software–hardware co-engineering, are covered in 8-A-I and 1-C-I respectively.)*
				III	**Software Architectures** Software architectures for space segment software.
		C	**Ground Segment Software** Mission control system software design, verification, validation and maintenance methods/tools. Application of modern IT technologies to spacecraft operations, including Object-Oriented Technologies.		
		D	**Ground Data Processing** Archiving subsystems and analytical processing of space data.	I	**Ground Data Archiving Subsystems** Long-term data storage, preservation and accessibility of big data, volume technology, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
2	**Space System Software (cont.)**	D	**Ground Data Processing (cont.)**	II	**Ground Data Analytical Processing** (Intelligent) data mining, feature extraction, deep learning aspects, data retrieval, data analytics, visualisation tools, etc.
				III	**Technologies for Data Security, Openness and Privacy** Technologies and methods to ensure the Availability, Integrity and Confidentiality of data, including aspects related to the protection of information and data from breaches, hacks or unauthorised access. Technologies guaranteeing the desired level of information openness. Multi-level security architectures.
		E	**Remote Sensing Payload Data Exploitation** Technologies associated with development and operation of ground segment infrastructure and facilities (including user interfaces, mission analysis/planning, payload data acquisition, archiving, processing, dissemination, quality control), provision of related 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.	I	**Remote Sensing Data and Information Processing and Exploitation** Aspects related to data and information acquisition, integrity, archiving, processing, dissemination, and quality control, and to mission planning. Exploitation of federated and collaborative payload data ground segment services and data dissemination.
				II	**Remote Sensing Applications and Services** Aspects related to applications (e.g. algorithms, models, related environments, etc.), higher-level processing, information mining, information-based services, service support, outreach.
				III	**Remote Sensing Information Subsystems and User Interfaces** Aspects related to subsystems for accessing data and information and user interface tools and methods.
				IV	**Remote Sensing Core Infrastructure and Architectures** Aspects at ground segment level, like architectures, common infrastructure, support to management and operations, automation, etc.
3	**Space Systems Electrical Power** Techniques and technologies related to power subsystem architecture, to power generation, distribution and conditioning and to energy storage.	A	**Power Electronics** Power subsystem architecture, topologies, sizing, modelling and simulation tools and techniques. Power conversion, regulation, control and distribution.	I	**Power Conditioning** PCDUs, SAR, BDRs, BCRs, DC/DC converters, control circuits, control techniques, digital control techniques.
				II	**Specific Power Supplies** PPUs, high-voltage EPCs, wheel electronics, etc.
				III	**Power Distribution** Solid-state switches, PDUs.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
3	**Space Systems Electrical Power (cont.)**	A	**Power Electronics (cont.)**	IV	**Power Subsystem Architecture** Power subsystem topologies, power subsystem sizing, modelling and simulation tools and techniques.
		B	**Power Generation Technologies** Methods for generating power from different sources (e.g. solar, chemical, and nuclear sources) as well as energy harvesting.	I	**Photovoltaic Generator Technology** Solar cells (crystalline and thin films), photovoltaic assembly and solar array technologies.
				II	**Fuel Cell Technologies** Electrochemical power generation subsystems using a fuel and an oxidant.
				III	**Nuclear Fission Reactor Technologies** Power generation subsystems using fission reactors adapted for space use.
				IV	**Radioisotope Power Technologies** Power generation subsystems using the natural decay heat of radioisotopes, either for thermal control (Radioisotopes Thermal Units) or converted into electricity (radioisotopes thermo-electric generators).
				V	**Energy Harvesting Technologies** Low power subsystems powered by modules making use of vibrations, thermal energy, RF energy or other energy resources available on the vehicle.
		C	**Energy Storage Technologies** Technologies and methods of energy storage after generation from solar, chemical, or nuclear sources.	I	**Electro-Chemical Technologies for Energy Storage** Technologies converting chemical energy to electricity for storage purposes (e.g. batteries, fuel cells).
				II	**Mechanical Technologies for Energy Storage** *(Note 3-C-II-1: Detailed mechanisms aspects are covered in TD15)* Technologies storing energy by using kinetic or gravitational forces (e.g. flywheels).
		D	**Power Conditioning and Distribution** Including regulation, control and distribution.		

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
4	**Space Systems Environments and Effects** Space environmental effects 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.	A	**Space Environments** Methods and models, and inflight monitoring of space environments (including radiation, plasmas, micrometeoroids and micro-debris, atmosphere, contamination and potential threats).	I	**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 subsystems delivering model output for efficient use in development and operations.
				II	**In-flight Environments Monitoring** Technologies to gather data on space environments. Includes radiation detection (fluxes and derived quantities for all radiation components), plasmas, direct microparticle detection, situational awareness sensors.
		B	**Environments Effects** Effects due to space environments (radiation damage and interference, spacecraft charging, microparticle impact risk, …) development of computational tools and related experimental investigations.	I	**Environments 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.
				II	**Ground and Space Effects Investigations** Data for the development and validation of the analysis tools, including establishment and/or exploitation of on-ground and in-space investigations of the environments and the effects on technologies. Radiation effects, charging and ESD monitoring, direct and indirect impact detection, analysis of returned material, etc.
		C	**Space Weather** Technology developments contributing to the establishment of capabilities for predicting or evaluating hazardous environmental conditions in space, in the ionosphere or on-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.	I	**Space Weather Modelling Development and IT Infrastructure** Development of numerical models in the various space weather domains (solar, heliospheric, magnetospheric, ionospheric). IT infrastructure: development of an integrated but distributed subsystem that includes real-time and archived data, coupled modelling and user-oriented informatics tools.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
4	**Space Systems Environments and Effects (cont.)**	C	**Space Weather (cont.)**	II	**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.
5	**Space System Control** Design and implementation of control subsystems 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.	A	**Control (Sub-) Systems Engineering** System aspects and AOCS/GNC functional chain engineering.	I	**AOCS/GNC Architecture** Concept and mode definition. Selection and accommodation of sensors and actuators.
				II	**Autonomy and FDIR** Control-related aspects and implementation (with TD2 and TD9-B), including AI applications to space systems autonomy and enhanced FDIR.
				III	**Pointing Error Engineering** Budget methodology and tools.
				IV	**Control Requirements Engineering** Software algorithm specification (with TD2) and sensor and actuator specification.
				V	**Control Design and Verification** Detailed analysis and performance verification on functional engineering simulators and avionic test benches.
		B	**Control (Sub-) Systems Innovative Technologies** Enabling technology developments dedicated to specific missions and generic applications.	I	**GNC Technologies for Entry, Descent and Landing** GNC technology developments for aerobraking, precision landing, hazard avoidance, real-time guidance and navigation, specialised simulation tools and test beds.
				II	**GNC Technologies for Cruise, Rendezvous and Docking or Capture** GNC technology developments for exploration as well as active debris removal.
				III	**High Accuracy Pointing Technologies** Technology developments in AOCS, pointing acquisition and tracking subsystems.
				IV	**Competitive AOCS Technologies** For commercial and generic applications, tackling cost reduction at all levels (design and verification effort, building-block approach, hybridisation of sensors, …).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
5	**Space System Control (cont.)**	B	**Control (Sub-) Systems Innovative Technologies (cont.)**	V	**GNC Technologies for Launch Vehicles** Guidance, Navigation and Control Technologies for specific Launch vehicles applications, including reusability. (*Note 5-B-V-1: generic technologies for precise landing applications are covered in 5-B-I)*
		C	**Control Techniques and Tools** Generic and advanced techniques dedicated to design analysis and verification.	I	**Control Modelling Techniques** Mathematical modelling and software model development for: satellite dynamics and environment, sensors and actuators, and software components.
				II	**Advanced Control, Estimation & Optimisation** Development of efficient techniques and tools for design analysis and verification. Includes also adaptive and collaborative controls.
				III	**Multidisciplinary GNC Optimisation** Development of mathematical solvers and tools for concurrent optimisation of GNC-related aspects of the space vehicle and trajectory.
		D	**AOCS/GNC Sensors and Actuators** Specification and development of generic and custom products based on mission and market needs.	I	**AOCS/GNC Optical Sensors** Star trackers, Sun and Earth sensors, optical navigation sensors. Includes detectors (with TD17-B), optics (with TD16), microelectronics (with TD1-C), electronics, image processing, software algorithms.
				II	**AOCS/GNC Inertial and Magnetic Sensors** Gyros, accelerometers, IMUs, magnetometers. Includes MEMS, HRG, FOG technologies, control loops and hybridisation, microelectronics (with TD1-C), electronics.
				III	**AOCS/GNC Inertial and Magnetic Actuators** Reaction wheels, CMGs, magnetic torquers. Control loops, mechanisms & tribology (with TD15-F/G), power electronics (with TD3-D), microelectronics (with TD1-C).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	**RF Subsystems, Payloads and Technologies** All technologies and techniques operating in the RF domain related to satellite systems and networks, spacecraft payloads, instruments and specific ground equipment (see note below), for telecommunication, TT&C, navigation, Earth observation and space science, including security aspects. *(Note 6-1: Technologies for control centres, TT&C and Earth Observation Payload Data Transmission Ground Stations and Ground Station Networks are covered in TD12)*	A	**Telecommunication Subsystems** Telecommunication techniques and algorithms (coding, modulation, access, synchronisation, networking, security etc.), subsystem tools and telecommunication equipment.	I	**Telecommunication Subsystem and Engineering Tools** All aspects related to satellite telecommunication subsystem analysis, design tools and methodologies.
				II	**Telecommunication Signal Processing** All signal processing techniques and algorithms related to coding/decoding, modulation/demodulation, access, synchronisation, medium access control.
				III	**Telecommunication Networking Techniques** Telecommunication satellite networking aspects related to radio resource management, network management and control aspects, traffic modelling, etc.
				IV	**Telecommunication Equipment** All baseband telecommunication equipment (e.g. modulators, demodulators, front-ends). Used for fixed, mobile and broadcast satellite or hybrid satellite/terrestrial telecommunication subsystems, also including user terminals.
				V	**Telecommunication Security Techniques and Technologies** The techniques and technologies to secure end-to-end telecommunication subsystems. Quantum Key Distribution (with TD17-E-II).
		B	**Radio Navigation Subsystems** Radio navigation techniques and technologies, subsystems capable of generating, receiving, exploiting and analysing the signals from current and upcoming radio navigation subsystems (GPS, Glonass, EGNOS, Galileo), including subsystem tools and navigation equipment. *(Note 6-B-1 : RF Technologies are covered in 6-E.)*	I	**Navigation Subsystems and Concepts and Engineering Tools** All aspects related to ground and space navigation subsystems, Signal in Space, simulators, analysis tools and methodologies. Techniques and technologies to secure end-to-end Navigation services. Antispoofing and Antijamming techniques.
				II	**Navigation Ground and User Equipment** All technologies related to RF and baseband aspects, positioning and integrity algorithms, integration with other sensors, local augmentation, and integration with telecommunication subsystems and services.
				III	**On-board Radio Navigation Receivers** All aspects related to navigation space (reference) receivers, and related algorithms and technologies, including security aspects (antijamming and antispoofing).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	**RF Subsystems, Payloads and Technologies (cont.)**	B	**Radio Navigation Subsystems (cont.)**	IV	**RF Metrology** All aspects related to high accuracy RF metrology including algorithms and tools.
		C	**TT&C and Payload Data Transmitter (PDT) Subsystems** Spacecraft TT&C/PDM techniques and technologies, space link communications (RF, hybrid RF/optical subsystems, signal coding/modulation, ranging techniques, radio science experiments) and proximity links, as well as launchers telemetry. *(Note 6-C-1: RF Technologies are covered in 6-E.)*	I	**TT&C Subsystem and Tools** All aspects related to TT&C subsystems (coding, modulation, multiplexing, link analysis, interference, security) and subsystem analysis tools and methodologies.
				II	**Deep-Space Transponders** All aspects related to the design and development of deep-space TT&C transponders.
				III	**Near-Earth Transponders** All aspects related to the design and development of near-Earth TT&C transponders.
				IV	**Proximity Link** All aspects related to the design and development of units for proximity link applications.
				V	**High-speed Downlink PDT** All aspects related to (coded) modems for high-speed payload downlink (e.g. for Remote Sensing, DRS applications).
		D	**RF Payloads** Telecommunication payloads (transparent and regenerative), remote sensing instruments, and navigation payloads exploiting analogue, digital and optical technologies.	I	**Payload Architecture and Engineering Tools** Advanced simulation tools and analysis paradigms for complex payloads for Telecommunication/Remote Sensing/Navigation.
				II	**Telecommunication Payloads** Telecommunication payloads and architectures encompassing RF, digital and optical technologies.
				III	**Remote Sensing Instruments** Remote Sensing instruments both passive (e.g. radiometers, GNSS-R) and active (e.g. SAR, altimeters, RF sounding).
				IV	**Navigation Payloads** Navigation payload systems and subsystems.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
6	**RF Subsystems, Payloads and Technologies (cont.)**	E	**RF Technologies and Equipment** RF equipment, subsystems and building blocks, active and passive components, and related design and characterisation tools in the whole RF domain. *(Note 6-E-1: All quasi-optic and free-space aspects are covered by TD7 and TD12)* *(Note 6-E-2: All quality aspects are covered by TD23 and TD25)* *(Note 6-E-3: All ground station RF technologies for TT&C and payload data are covered by TD12)*	I	**RF Modelling and Design Tools** Design and analysis tools for RF equipments, components and technologies including RF design and analysis and high power phenomena prediction (e.g. Multipaction, Corona, power handling and passive intermodulation).
				II	**RF Equipment** RF equipment and subsystems (e.g. SSPAs, TWTAs, LNAs, frequency converters, multipliers and distribution networks, local oscillators and synthesisers, multiplexers, front ends).
				III	**RF Active and Passive Devices** 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, RF switches, couplers, combiners/splitters, circulators, isolators, cables and connectors), including packaging and interconnection.
				IV	**Vacuum Electronics for RF Amplification** Technologies and techniques related to high-power RF amplification using vacuum electronic technologies (e.g. TWT, vacuum triodes and transistors).
				V	**Frequency & Time Generation and Distribution for Space Applications** 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 telecommunication, navigation and science applications. *(Note 6-E-V-1: Optical atomic clocks are covered in 17-C-IV)* *(Note 6-E-V-2: Reference signals required for ground applications are covered in 12-A-V)*
				VI	**RF Measurement, Characterisation and Calibration Techniques** RF equipment and components, including for high-power, passive intermodulation, corona and multipactor testing.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
7	**Electromagnetic Technologies and Techniques** Antennas and related technologies, wave interaction and propagation, and electromagnetic compatibility.	A	**Antennas** Antenna subsystems 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 7-A-1: Ground TT&C antennas are covered in 12-A-II)*	I	**Antennas Design Tools** 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.
				II	**Reflector and Lens Antennas** 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 and metamaterial antennas. Manufacturing techniques and technologies of reflector and lens antennas.
				III	**Array Antennas and Standalone Radiators** Planar and conformal arrays, multi-frequency arrays, dual-polarisation arrays, active, semi-active and passive arrays. Small arrays and standalone radiators for medium and low gain applications for spacecraft and for user terminals. Fully electronic or hybrid 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. Manufacturing techniques and technologies of array antennas and standalone radiators.
				IV	**Millimetre-Wave and Sub-Millimetre-Wave Antenna Front-Ends** 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, calibration (both active and passive), focal plane arrays and front-ends (including direct detectors, mixers, multipliers, LO chain) and back-ends.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
7	**Electromagnetic Technologies and Techniques (cont.)**	A	**Antennas (cont.)**	V	**Measurement, Characterisation and Calibration Techniques for Radiative Payloads and Antennas** New antenna and payload measurement techniques (e.g. for multi-beam payloads or security aspects), validation of modelling software, techniques for measurement of antennas in the spacecraft environment and at operational conditions, feed networks (active and passive), interactions between antennas, millimetre-wave and THz antennas and feed networks. RF characterisation of reflective and transparent materials.
		B	**Wave Interaction and Propagation** 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 telecommunication, navigation, remote sensing (both for Earth and planets), TT&C and payload data transfer.	I	**Wave Interaction** Modelling of wave interactions for passive and active microwave and optical remote sensing of atmosphere, surface and subsurface features of Earth and planets. Related retrieval and correction algorithms, performance models and data processing.
				II	**Wave Propagation** Propagation, interception 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.
		C	**Electromagnetic and Radio Frequency Compatibility (EMC/RFC) and Electrostatic Discharge (ESD)** Design, models, simulation, testing techniques and technologies in the fields of electromagnetic compatibility (EMC), radio frequency compatibility (RFC), electrostatic discharge (ESD), and magnetic cleanliness.	I	**EMC Modelling and Simulation** Development of specific EMC models and simulation tools for application to spacecraft.
				II	**EMC Test Techniques** Validation of new EMC designs and novel EMC and magnetostatic test methods for application to spacecraft.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
8	**System Design & Verification** 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, security and risk (mission success) to the required level. 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.	A	**Mission and System Specification** Early phases of a project development life cycle, focusing on requirement engineering, specification and architecture formulation.	I	**Specification Methods and Tools** Methods and tools to support the capture, modelling and validation of requirements, including definition and formalisation of system architectures.
				II	**Requirement Engineering** Methods and tools to support the system requirement engineering process, including requirement management and related database issues.
				III	**System-Level Aspects of Avionics Embedded Subsystems** All system aspects related to Avionics, including architecture, interfaces and development of processes and related methods and tools for the avionics embedded subsystems.
		B	**Collaborative and Concurrent Engineering** Aspects related to the process of concurrent engineering as well as the data underlying multidisciplinary collaboration.	I	**Concurrent Design** Methods and tools to provide an integrated environment for the concurrent design of a mission/system.
				II	**Multidisciplinary Data Exchange for Collaborative Engineering** Methods and standards to support the exchange of multidisciplinary data, focusing on the data aspects of collaborative engineering.
				III	**Collaborative Engineering** 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.
		C	**System Analysis and Design** System-to-subsystem interaction and interfaces, relationships between segment-level analyses and system-level analyses.	I	**System Design and Simulation** Methods and tools to support the modelling and simulation-based design and verification at system-level.
				II	**Multidisciplinary Analysis** Methods and tools to support coordinated analyses for different technical disciplines.
		D	**System Verification and Assembly, Integration and Test (AIT)** Methods, tools and infrastructure necessary to integrate and verify space systems.	I	**Advanced AIT Methods** Advanced methods, tools and standards to support the assembly, integration and testing plus verification of space systems across the life cycle.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
8	**System Design & Verification (cont.)**	D	**System Verification and Assembly, Integration and Test (AIT) (cont.)**	II	**Ground Support Equipment** Advanced tools and standards for supporting ground activities in all domains across the life cycle. *(Note 8-D-II-1: GSE for propulsion systems is included in 19-D-IV)*
9	**Mission Operation and Ground Data Systems** Aspects related to the control and operations of space system elements (satellites, transfer vehicles, orbiters, landers, probes, rovers, etc.) and related ground segment, addressing the technologies associated with supporting subsystems and tools.	A	**Advanced System and Mission Operation Concepts** Studies, technology investigations and prototyping related to the implementation and validation of advanced system and mission operation concepts.		
		B	**Mission Operations** 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 and security of operation systems and processes.	I	**Distributed and Decentralised Operations** Operations of single missions and families of missions, formation flying and constellations.
				II	**Automation, Autonomy and Mission Planning Concepts** Concepts for automation, autonomy and mission planning of ground data systems and spacecraft operations.
				III	**Operation Support Processes** Aspects such as operation preparation, knowledge transfer from manufacturer to operations, training, dependability of operation (sub-)systems and processes.
		C	**Ground Data Systems** 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).	I	**Mission Control System, Automation, Mission Planning, Simulators and Station M&C and Data Centre Architecture and Technologies** 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).
				II	**Preparation and Procedure Tools for Ground Data Systems** Taking into account commonalities with EGSE requirements.
				III	**Human–Computer Interfaces and Technologies** Frameworks, toolkits and other aiding tools that ease the definition of HCI, sharing a common look and feel and usability.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
10	**Flight Dynamics and GNSS** Activities related to the analysis and definition of trajectory aspects of space projects, known as mission analysis. All operational ground activities related to the measurement and control of spacecraft orbit and attitude. Provision of precise navigation services to both ground and space-based users and also the provision of the geodetic reference frame.	A	**Flight Dynamics (FD)** Trajectory and attitude aspects of space missions; pre-flight trajectory design (mission analysis); in-flight determination and control of trajectory and attitude of the spacecraft, monitoring of spacecraft AOCS and generation of orbit- and attitude-related command parameters. Comprises mathematics, dynamics, optimisation and environment modelling. Mission critical requirements such as correctness, robustness, reliability and flexibility.	I	**Mission Analysis and Trajectory Design** Covers pre-flight mission design, trajectory optimisation and launch window calculations.
				II	**Advanced Flight Dynamics Operations** High-precision navigation at minor bodies, interplanetary RVD and formation control, FD support to GNC subsystems including novel sensors and actuators; aerocapture and aerobraking; entry, descent and landing; high-precision formation-flying control; high-precision orbit control for Earth observation.
				III	**Advanced Flight Dynamics Processes and Tools** Automation of flight dynamics operations, advanced modules of FD application SW and advanced operational processes (including intelligence).
		B	**GNSS High-Precision Data Processing** Operation of GNSS sensor networks, GNSS-related data processing, techniques for precise orbit- and clock-determination concepts for MEOs and LEOs and satellite geodesy.	I	**Ground Tracking Networks** Deployment, operation and data collection for GNSS sensor stations, network management, data handling services.
				II	**GNSS and Geodetic Data Processing** Models, algorithms, data monitoring, data quality assessment and delivery of services and products.
				III	**MEO and LEO Precise Orbit Determination Algorithms** Orbit dynamics and related models, analytical and numerical algorithms, for real-time (ground) and non-real-time (on-board/ground) data processing, performance analysis.
				IV	**Geodetic Reference Frames** Satellite geodesy, standards, processing of different observations.
11	**Space Debris** All aspects related to knowledge of the meteoroid and debris environment: space surveillance, databases, debris risk levels for current and future missions, reentry of space objects, hyper velocity impacts and protection, and mitigation measures.	A	**Ground- and Space-based Debris and Meteoroid Measurements** Ground- and space-based measurements and related technology developments.	I	**Ground-based Radar Measurements of Debris and Meteoroids** Beampark 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.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
11	**Space Debris (cont.)**	A	**Ground- and Space-based Debris and Meteoroid Measurements (cont.)**	II	**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.
				III	**In situ Radar and Optical Measurements of Debris and Meteoroids** Space-based radar and optical detection techniques to characterise the small-particle environment. Development, flight and data evaluation.
		B	**Modelling and Risk Analysis** Population models for meteoroids and debris (current and future evolution), statistical and operational risk analysis in space and reentry survivability and safety analysis on the ground.	I	**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.
				II	**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.
				III	**Reentry Risks** Structural analysis to determine the survivability of spacecraft components under the influence of aerothermal and aerodynamic stress during controlled and uncontrolled reentries. Development of simulation models and models of the spacecraft geometry, materials. Computation of ground safety. Prediction of reentry windows (date and location) of risk objects from surveillance data.
		C	**Debris Mitigation** Identification, standardisation and verification of the implementation of mitigation measures and accompanying models, environment prediction modelling.	I	**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, reentry survivability and mission survivability with respect to debris impacts, as well as standardisation of these activities.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
11	**Space Debris (cont.)**	C	**Debris Mitigation (cont.)**	II	**Design for Demise** Design requirements, methodologies and technologies to reduce the associate casualty risk during uncontrolled atmospheric reentry.
				III	**Passive Reentry** Passive subsystems dedicated to facilitate space systems atmospheric reentry within 25 years after end-of-life. (*Note 11-C-III-1: Structural aspects and mechanisms for drag augmentation devices are covered in TS 20-C)* *(Note 11-C-III-2: Propulsion aspects of electrodynamic thethers are covered in 19-C-IV)*
				IV	**Passivation Technologies** Technologies to deplete stored energy particularly in the power and propulsion subsystems. Includes also system aspects of reliability and robustness requirements.
		D	**Debris Remediation and Protection** Active removal techniques as well as HVI test techniques, development and validation of numerical simulations, evaluation and modelling of materials for shielding.	I	**Space Debris Environment Remediation** Long-term environment projections using models for traffic and mitigation actions. Identification of removal targets and evaluation of removal options.
				II	**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 spacecraft configuration, shield optimisation.
				III	**Design for Removal** Design requirements, methodologies and technologies to ease (uncooperative) space systems removal.
				IV	**In-Orbit Contactless Debris Removal** Contactless momentum transfer techniques for debris removal leading to reentry (e.g. using debris-targeted ion beams or laser to modify its orbit).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
12	**Ground Station Systems and Networks** 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.	A	**Ground Station System** Technologies and techniques related to the design of a ground station system and its constituent subsystems such as ground TT&C and payload data reception antenna systems using RF and optical techniques; transmit and receive radar and optical subsystems for ground-based space surveillance; TT&C, radar and optical signal and data processing.	I	**Advanced Ground Station Design Concepts** Design concepts for RF and optical ground stations for space communication and space surveillance applications.
				II	**Ground TT&C and Payload Data Reception Antenna Systems** RF design, optical design, mechanical structures, servo-mechanisms, and tracking processes.
				III	**Microwave and Optical Active/Passive Subsystems** All active components such as LNAs, detectors, HPAs, lasers, frequency converters, microwave sources, all passive components such as filters, switches, isolators, waveguides.
				IV	**TT&C, Radar and Optical Signal & Data Processing** Telemetry receivers, decoders and demodulators, telecommand modulators and encoders, telemetry data preprocessors, ranging subsystems and precise navigation techniques.
				V	**Frequency & Time Generation and Distribution for Ground Applications** All means of frequency generation such as atomic clocks, masers and crystal oscillators. Time reference generation and synchronisation. *(Note 12-A-V-1: Reference signals required for navigation, telecom and science applications are covered in 6-E-V)*
		B	**Ground Communications Networks** 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.	I	**Advanced Ground Communication Networking Concepts** New design concepts for data/communication in the ground segment.
				II	**Communication Network Technologies and Protocols** Issues related to communication and data exchange, including routing and modem issues as well as network protocols.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
13	**Automation, Telepresence & Robotics** Specification, development, verification, operation and utilisation of space automation (sub-)systems. Such (sub-)systems include (1) space robot (sub-)systems (comprising both arm-based subsystems for inspection, servicing and assembly of space system infrastructure or payloads and mobile robots for surface exploration on celestial bodies) and (2) space laboratory automation and payload control subsystems in manned and unmanned missions. *(Note 13-1: Detailed mechanisms aspects are covered in TD15)*	A	**Robotic Applications and Concepts** System aspects of innovative robotic concepts for missions.	I	**Planetary Robotic Exploration** 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.
				II	**Orbital Robotic Systems** Automation of orbital infrastructure, or non-cooperative satellites, satellite design for robotic servicing (including refuelling), compound operation of arms on free-flying platforms, assembly and servicing of space structures in orbit, multi-robot cooperation.
		B	**Automation & Robotics Systems and Subsystems** Detailed definition of robotic systems and subsystems, including technology developments dedicated to specific applications.	I	**Manipulation Robotic Subsystems** Robot arms, end-effectors and tools. *(see Note 13-1)*
				II	**Mobility Robotic Systems** Rovers, aerobots, underground and underwater explorers.
				III	**Payload Automation Subsystems** All automation aspects of space laboratories.
		C	**Automation & Robotics Components and Technologies** General purpose and specific Automation & Robotics (A&R) components and methods.	I	**Perception for Robots** Sensors and sensing methods (e.g. computer vision) which allow robots to perceive their environment and the state of the process they are controlling.
				II	**Control, Autonomy and Intelligence** Methods that allow robot (sub-)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.
				III	**Motion and Actuation of Robots** Means that allow a robot to physically interact with its environment (e.g. limbs, joints, chassis, wheel units, balloon envelopes, propulsion units). *(see Note 13-1)*.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
13	**Automation, Telepresence & Robotics (cont.)**	C	**Automation & Robotics Components and Technologies (cont.)**	IV	**Robot-User Interfacing** Commanding and programming means (e.g. immersive subsystems, haptic devices) and methods that allow users to interact with an automation and robotics subsystem. Includes teleoperation, telepresence, telescience.
				V	**Robot Ground Testing** Tools, methods and facilities that allow on-ground characterisation and verification of A&R (sub-)systems.
14	**Life & Physical Sciences** All technological aspects related to instrumentation in support of life and physical sciences, and for ensuring delivery of a complete instrument technology. The objective is an optimised scientific return, the emphasis being rather on a consistent system philosophy than on the development of component technologies. All technologies and techniques relating to planetary protection, both sterilisation methods and technologies, and also technologies needed to monitor contaminants.	A	**Instrumentation in Support of Life Sciences** Aspects of human physiology, biology, biotechnology, exobiology/planetary exploration.	I	**Sensors and Analytical Instrumentation** Whole range of sensors and analytical instruments needed to monitor scientific experiments and to extract scientific data.
				II	**Imaging Diagnostics and Image Treatment Technologies** Whole range from macroscopic imaging down to sub-microscopic imaging with the related image treatment technologies (contrast enhancement, compression etc.).
				III	**Cultivation, Processing and Bioprocessing** Simple cultivation of cells and microorganisms; bioreactor type cultivation including processing/ bioprocessing of materials for in situ resources utilisation.
		B	**Instrumentation in Support of Physical Sciences** Aspects of fluid science, material science, crystal growth, applied physics, planetary exploration.	I	**Sensors and Analytical Instrumentation for Physical Sciences** (High-)Temperature sensors to complex analytical instruments such as Raman Spectroscopy and X-ray diagnostics tools.
				II	**Imaging Diagnostics and Image Treatment Technologies for Physical Sciences** Macroscopic and microscopic imaging and other (e.g. interferometric) imaging methods with the related problems of image acquisition storage, transfer and treatment. Image acquisition ranges from single shot to high-speed imaging (500 frames/s).
				III	**In-Situ Resources Processing and Production** Low-volume processing of new materials and extends into processing and production utilising in situ resources in planetary exploration.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
14	**Life & Physical Sciences (cont.)**	C	**Applied Life Science Technology** Application of advanced and new technologies of the life sciences to specific problems of planetary exploration, planetary protection and human long-term presence in space. *(Note 14-C-I-1: technologies related to sterilisation effects on materials are covered in 24-C-I)*	I	**Application of Human Physiology Technologies** Application of human physiology technologies to human health monitoring/care and countermeasures for long duration spaceflight and includes radiation monitoring.
				II	**Bioburden/Biodiversity Monitoring** All technologies required at spacecraft and facility level to comply with COSPAR planetary protection requirements.
				III	**Biobarriers** All technologies required to isolate spacecraft subsystems with different bioburden levels. To be tailored to organic and biological cleanliness required, and to the specific bioburden reduction process.
				IV	**Dry Heat Sterilisation** Standard and non-standard dry heat bioburden reduction processes for subsystem and system (terminal process).
				V	**Low-Temperature Sterilisation** Gas and liquid sterilisation processes at low temperatures. Complementary to standard dry heat sterilisation.
				VI	**Precision Cleaning and Sterility** Cleaning processes to achieve high level of organic cleanliness and sterility. Required for sample acquisition and distribution subsystems, as well as for certain classes of sample return missions.
15	**Mechanisms** 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).	A	**Mechanism Core Technologies** Building-block technologies used individually or in combination to provide a mechanism function.	I	**Actuator Technologies** Technologies to provide torque or force: e.g. electromagnetic motors, voice coils, piezo motors, smart material actuators (e.g. shape memory alloy actuators, electroactive polymer actuators, spring actuators, paraffin actuators).
				II	**Dampers & Speed Regulator Technologies** Technologies to regulate the speed of a movable element or to damp mechanical loads (e.g. low melting point alloy regulator, fluid damper, mechanical damper, eddy current damper).
				III	**Motion Transformer Technologies** Technologies used to transform a motion (e.g. gears, pulleys and cables, harmonic drives, ball and roller screws).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms (cont.)**	A	**Mechanism Core Technologies (cont.)**	IV	**Motion & Force Sensor Technologies** Position sensors (potentiometers, optical encoders, resolvers, capacitive sensors, Hall sensors, etc.) switches, strain gauge sensors, accelerometers.
				V	**Guiding Technologies** Technologies providing linear or rotational guiding functions (e.g. ball and roller bearings, journal bearings, magnetic bearings, magnetic gears, ball joints, flexible guides and compliant mechanisms).
				VI	**Sealing Technologies** Technologies providing a static or dynamic sealing function.
				VII	**Electrical Transfer Technologies** 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, cable wrap, twist capsules, contactless electrical transfer technologies).
				VIII	**Development of New Devices for Future Exploration and Exploitation Missions** Connection and disconnection of structures, electrical and fluid circuits, deployment of shields and shelters, seismic and exploration functions including locomotion anchoring, penetrating, sealing mechanisms; for manned, robotic and automatic operation.
		B	**Non-Explosive Release Technologies** Non-pyrotechnic technologies used to release a force or torque (e.g. mechanical fuse, shape memory alloy, electromagnetic, paraffin).		
		C	**Exploration Tool Technologies** Tool technologies to acquire samples in exploration missions (e.g. drill bits, ultrasonic tools).		
		D	**Control Electronics Technologies** Technologies providing mechanism control (open and closed loop control electronics).		

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms (cont.)**	E	**MEMS Technologies** Micro-/nano-technologies providing a mechanism function (e.g. pointing, scanning). *(Note 15-E-1: Aspects related to quality are covered in TD23)*		
		F	**Tribology Technologies** Technologies related to the science of interacting surfaces.	I	**Lubrication Technologies** Technologies providing a lubrication function (e.g. solid lubricants, fluid lubricants, self-lubricating materials).
				II	**Material Surface Technologies** Technologies providing a specific material surface tribological performance (e.g. coatings, surface/heat treatment). *(Note 15-F-II-1: Issues related to material characterisation are covered in TD24)*
		G	**Mechanism Engineering** Specific mechanism engineering knowhow to develop space-related mechanisms.	I	**Mechanism 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, design to demise, operations in cryogenic environment).
				II	**Mechanism Engineering Tools** Specific tools used to support the design and development of space mechanisms (e.g. bearing sizing software, multi-body dynamic analysis software, close-loop control and micro-vibration analysis, tribology tools, gear analysis tools, electromagnetic analysis).
		H	**Pyrotechnic Technologies** Development and testing of new materials, ignition methods, actuation and miniaturisation.	I	**Explosive Composition Technologies** High-temperature survival and ageing characteristics; shock reduction technologies including testing.
				II	**Thermite and Gas Generation Technologies** Applications of thermite heating to provide connection, disconnection, release, joining, demising. Provision of oxygen for life and other gases for pressure functions.
				III	**Reliability Determination for Non-Repeating Functions** Analysis techniques for valid estimates of reliability at required levels of confidence, definition and demonstration of test and analysis techniques for small samples.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
15	**Mechanisms (cont.)**	H	**Pyrotechnic Technologies (cont.)**	IV	**Optical Ignition Technologies** Development of components and subsystems for alternative to electrical ignition, with potential to increase safety by reducing sensitivity to electrical disturbance.
				V	**Advanced Electropyrotechnics** Use of explosive foil initiators in order to reduce mass and cost and increase safety.
		I	**Flexible Capture Mechanisms** Specific mechanisms such as those needed in nets or harpoons concepts for in-orbit capture or for different applications including active debris removal.		
16	**Optics** Technologies and techniques for subsystems, instruments and components, as well as design, engineering and verification methods, in the field of optics.	A	**Optical Subsystem Engineering** Definition, design and engineering of optical subsystems and payload/instrument architectures; evaluation and verification (by analysis and testing) of the optical design performances (including straylight).	I	**Optical Subsystem Definition, Design and Engineering** Definition, design and engineering of optical subsystems and the conceptual definition of optical payload/instrument architectures.
				II	**Optical Design Performance Evaluation and Analysis** 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).
		B	**Optical Components Technology and Materials** All techniques and technologies for design and manufacture of optical components (from micro/nanostructures to lightweight telescope mirrors of several metres' aperture) as well as of stable optical benches; includes component mounting technologies and special optical materials; covers the whole 'optical' spectrum from X-ray to far-infrared.	I	**Optical Components** All technologies for refractive and reflective optical components such as (classical-bulk) filters, lenses, gratings, prisms, beam splitters, polarisers manufactured in conventional/ classical-bulk technology. Includes grinding/polishing techniques, special glass and substrates and coating technologies (radiation tolerant).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
16	**Optics (cont.)**	B	**Optical Components Technology and Materials (cont.)**	II	**Micro-Optics Components, MOEMS, Optical Fibres and Passive Integrated Optics** All passive optical components made in micro-/nanotechnology, such as diffractive elements, holographic elements, meta-material elements, micro-optic devices, micro-opto-electro-mechanical subsystems (MOEMS) like switches and dynamic gratings, optical fibres and integrated optics devices.
				III	**Mirror and Telescope Technologies** Design, materials and manufacturing technologies for lightweight mirrors and telescopes (including structures and baffles) with apertures ranging from 10 cm to several metres, operating at X-ray, UV, visible, IR and far-IR wavelengths; includes monolithic mirrors, segmented mirrors, deployable telescopes, super-polishing and coating, adaptive optics and wavefront control.
				IV	**Optical Mounting Technologies** Covers the design and development of stable optical mountings (component mounting and alignment technologies) (*Note 16-B-IV-1: optical benches are covered in 20-B-II)*
		C	**Optical Equipment and Instrument Technology** All techniques and technologies for the design, manufacture and test of optical equipments and instruments for imaging, spectroscopy, radiometry, sounding, remote sensing, metrology, ranging, illumination, free-space optical communications for applications in Earth observation, science and planetary research, telecommunication and navigation.	I	**Spectrometers, Imaging Spectrometers, Radiometers** Techniques and technologies for the design, manufacture and test of optical equipments and instruments for imaging, spectroscopy and radiometry, including Fourier-transform spectrometers.
				II	**Cameras, Illumination Devices, Displays** Techniques and technologies for the design, manufacture and testing of cameras and optical devices for illumination and display.
				III	**Laser Ranging and Imaging, Lidars and Altimeters** Techniques and technologies for the design, manufacture and testing of optical equipments and instruments for ranging, altimetry, 3D imaging (for GNC, planetary landers, RVD, rover navigation), atmospheric sounding, and remote sensing; includes tunable high-resolution filters.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
16	**Optics (cont.)**	C	**Optical Equipment and Instrument Technology (cont.)**	IV	**Interferometry, Aperture Synthesis and Optical Phased Arrays** Techniques and technologies for the design, manufacture and testing of optical equipments and instruments of very high-resolution based on interferometric methods, aperture synthesis and optical phased arrays, in particular for science missions and imaging/remote sensing from geostationary orbit.
				V	**High-Precision Optical Metrology** Techniques and technologies for the design, manufacture and testing of optical equipments and instruments for high-precision optical metrology in space (e.g. for formation-flying constellations), but also for on-ground verification of structures, mirror surfaces and telescopes.
				VI	**Optical Ground Support Equipments** Techniques and technologies for the design, manufacture and commissioning of optical equipment/subsystems for calibration and performance verification of optical subsystems.
17	**Optoelectronics** Development and application of technologies combining photonics (i.e. circuits handling photons) with electronics to achieve given functions.	A	**Laser Technologies** Technologies and techniques needed for the generation of coherent optical radiation.	I	**Laser Sources** 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.
				II	**Laser Pumping** 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.
				III	**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.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
17	**Optoelectronics (cont.)**	A	**Laser Technologies (cont.)**	IV	**Laser Frequency Control and Stabilisation** Laser cavity length control and tuning techniques, injection locking and seeding, for frequency control. Frequency stabilisation and locking techniques using optical stabilising 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.
				V	**Non-Linear Optics** 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.
		B	**Detector Technologies** All the technologies and techniques needed for the detection of optical radiation.	I	**Visible Detectors** Single-pixel (photodiodes), linear and 2D arrays, CCD and CMOS image sensors (APS), APDs, APD arrays, SiPM arrays.
				II	**Infrared detectors (NIR–FIR)** Photon and thermal technologies, including MCT, InGaAs, III-V, QWIP, QDIP, T2SL, microbolometers, pyroelectrics.
				III	**UV, X-ray & Gamma-Ray Detectors** Si, wide bandgap semiconductors, scintillators.
				IV	**Superconducting Detectors** HEB, SINIS-junctions, heterodyne mixers, etc.
				V	**Superconducting Devices** Low-temperature and high-temperature superconducting devices and sensors such as SQUIDs, Josephson-type junctions, gradiometers, etc.
				VI	**Focal Plane Technologies** Component technologies, integration, accommodation techniques, proximity electronics, interconnects (e.g. flex circuits), filters and windows.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
17	**Optoelectronics (cont.)**	C	**Photonics** Guided-wave optical technologies and techniques for handling optical signals, or to achieve specific functions for various applications.	I	**RF Photonics** 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 beam-forming and distribution networks, on-board optical links & interconnects, etc.
				II	**Micro- & Nano-Photonics** Photonic IC technologies, hybrid and monolithic integration of active and passive functions in various material subsystems including silica and semiconductor materials. Silicon photonics for on-chip optical functions.
				III	**Fibre-Optic Sensors** Pressure, temperature and strain sensors, including interrogation units for satellites, platforms and launchers.
				IV	**Optical Atomic Clocks** 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 subsystems, space qualification of subsystem elements.
		D	**Optical Communication Technologies** 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). *(Note 17-D-I- I: specific technologies like quantum communications for secure links, cryptography and global key distribution are addressed in TD17-E-II).*		

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
17	**Optoelectronics (cont.)**	E	**Quantum Technologies** Entangled photons for transmissions, enabling highly secure communication systems.	I	**Quantum Device, Metrology and Sensing** 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. Covers also Quantum Detectors Technologies.
				II	**Quantum Communication** QKD (together with 6-A-V); specific technologies like quantum communication or secure links, cryptography and global key distribution.
				III	**Quantum Information Processing and Simulations** Quantum computing, coherent computing and simulations.
18	**Fluid Mechanics** Technologies and techniques related to the flow of fluids: gases, liquids, and plasma. Composed of two sub-disciplines: Aerothermodynamics (gases and plasma) and Hydrodynamics (liquids). Aerothermodynamics is related with the dynamics of gases and plasma, its physical processes, pressure and thermal fields and deals with the atmospheric interactions with moving objects at low or high speeds. Hydrodynamics deals with the study of liquids in motion inside the propellant tanks of flight vehicles and involves the calculation of various properties of fluid propellant, such as flow velocity, pressure, density, and temperature, as functions of space and time.	A	**Fluid Mechanics Tools and Techniques** Engineering and computational fluid dynamics (CFD) techniques, both for internal and external flows, for the multidisciplinary design and analysis of space vehicles.	I	**Computational Fluid Dynamics (CFD)** Continuum and discrete particle models (including numerical algorithm and grid generation techniques) for multi-physics flow.
				II	**Engineering Techniques for Fluid Mechanics** Analytical, semi-empirical and parametric design tools.
				III	**Multidisciplinary Techniques for Fluid Mechanics** Coupling tools (including advanced optimisation algorithms) and/or databases of different technical disciplines.
		B	**Ground-Based Facilities** All types of wind tunnels and other test facilities for the design and analysis of space vehicles, both for internal and external flow.	I	**Cold Gas Facilities** Continuous and blow-down wind tunnels, ballistic ranges, etc.
				II	**Hot Gas Facilities** Arc-heated, piston driven, detonation driven, etc.
				III	**Dedicated Facilities for Fluid Mechanics** Contamination, hovering, base flow-jet interaction, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
18	**Fluid Mechanics (cont.)**	C	**Sensors and Measurement Techniques for Fluid Mechanics** 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.	I	**Intrusive Measurements for Fluid Mechanics Applications** Sensing technologies suitable for measurements in hostile environment – temperature, pressure, heat flux, etc.
				II	**Non-Intrusive Measurements for Fluid Mechanics Applications** Multi-spectral infrared, laser spectroscopy, electron-beam, etc.
				III	**Wireless Measurements for Fluid Mechanics Applications** Radio sensing, health monitoring, etc.
		D	**Flight Demonstrators and Flight Data Tools** 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.	I	**User Interface of Flight Demonstrators & Data Tools** Aspects related to tools and methods for data storage, handling and post-processing**.**
				II	**Informatics Environment of Flight Demonstrators & Data Tools** Aspects related to subsystems for data storage, handling and post-processing.
		E	**Fluid Mechanics Hardware**	I	**Filling and refilling** Flight vehicle engineering of the management of the passing of fuel between several tanks. With the consideration of reusable propulsion systems operating on ground and in flight, or the need of extension of life of space vehicles, these technologies are required for either storable or cryogenic propulsion systems with increased capabilities and storage volumes. With the development of Space Logistics, a diversification of technologies is now considered, including propellant management devices, sloshing and propellant management tools and techniques, and related fluid mechanics components.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
18	**Fluid Mechanics (cont.)**	E	**Fluid Mechanics Hardware (cont.)**	II	**Fluid Mechanics Hardware Equipment** Flight vehicle engineering of innovative aerodynamic surfaces, and the engineering of hardware equipment for the management of liquids and gases. This comprises primary surfaces are advanced ailerons, elevators, and rudders operative across all flight regimes. Complementary surfaces are innovative spoilers, flaps, slats, and airbrakes used to disrupt efficiently the airflow and efficiently reduce or increase the lift of the flying vehicle or to increase drag. Also included are parafoil, parachute, shape modulated heat shields, advanced technologies for the management of sound and acoustics in space vehicles, and innovative intake air collectors for air-breathing propulsion systems.
19	**Propulsion** Technologies and techniques to generate forces and torques to change the velocity and orientation of space vehicles (spacecraft, launchers, high speed atmospheric vehicles). The technologies (such as engines, tanks, chambers, nozzles, valves, etc.) are based on chemical, electrical, solar, nuclear, gravity, magnetic, and other techniques.	A	**Chemical Propulsion Technologies** Wide range of technologies for propulsion subsystems, based on the use of chemical energy, relevant to the following major applications: (1) spacecraft on-board propulsion (including micropropulsion); (2) reusable or expendable launch vehicles/upper stage/space tugs propulsion; (3) reentry manoeuvring propulsion subsystems.	I	**Liquid Propulsion Subsystems** Cold gas, mono- and bipropellant, on-board subsystems, cryogenic and LOX/hydrocarbon launch vehicle subsystems.
				II	**Solid Propulsion Subsystems** From microthrust subsystems up to launch vehicle boosters.
				III	**Air-Breathing and Hybrid Propulsion Subsystems** Ramjets, scramjets, rocket based cycles.
		B	**Electric Propulsion Technologies** Propulsion subsystems that use electrical energy (solar or nuclear), classified according to the following major applications: (1) spacecraft on-board propulsion (including micropropulsion); (2) orbital stages/tugs propulsion.	I	**Electrostatic Propulsion Subsystems** Subsystems based on Hall-effect thrusters, gridded ion engines, field emission thrusters.
				II	**Electrothermal Propulsion Subsystems** Subsystems based on resistojets, arcjets and power-augmented catalytic thrusters.
				III	**Electromagnetic Propulsion Subsystems** Subsystems based on magneto-plasma-dynamic thrusters and pulsed plasma thrusters.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
19	**Propulsion (cont.)**	C	**Other Propulsion Subsystems** Wide range of non-classical propulsion subsystems, for both spacecraft and launchers/upper-stages, and the technology field of breakthrough propulsion physics.	I	**Solar Thermal Propulsion Subsystems** Technologies and techniques related to the use of solar power to directly heat a part of the space vehicle and transform this heat into thrust by means of a dedicated engine.
				II	**Nuclear Propulsion Subsystems** Technologies and techniques related to the use of nuclear engines to produce thrust such as Nuclear Thermal Rocket (NTR), that uses a working fluid that is heated to a high temperature in a nuclear reactor, or Nuclear Electrical Rocket (NER), that uses the thermal energy from a nuclear reactor converted into electrical energy to drive an electrical thruster.
				III	**Solar Sailing Propulsion Subsystems** Technologies and techniques related to the use of the radiation pressure exerted by sunlight on large space vehicle surfaces.
				IV	**Tethered Propulsion Subsystems** Technologies and techniques related to the use of long cables to create a force at the end-masses of the system due to the centrifugal force (e.g. electrodynamic tethers, momentum exchange tethers). *(Note 19-C-IV-1: system level and design aspects of tether subsystems for reentry applications are covered in 11-C-III)*
				V	**Advanced Propulsion Concepts** Technologies and techniques related to advanced, new, and breakthrough concepts and ideas such as anti-gravity subsystems, air breathing propulsion , laser beamed propulsion, Lorentz force accelerators, cryosolids propulsion, etc.
		D	**Supporting Propulsion Technologies and Tools** Technologies and tools that are used in support of the development, qualification, integration and monitoring of propulsion subsystems. These tools and technologies, although similar in scope and classification, might differ substantially depending on their use for chemical, electrical or other propulsion.	I	**Propulsion Subsystems Modelling** Propulsion subsystem design tools, thruster and engine performance and life prediction tools, propulsion subsystem/space vehicle interaction tools and related orbit/trajectory definition tools.
				II	**Propulsion Subsystems Testing and Diagnostics** Facilities and diagnostic tools for ground performance, qualification and acceptance tests of propulsion subsystems; on-board propulsion diagnostics and health monitoring systems.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
19	**Propulsion (cont.)**	D	**Supporting Propulsion Technologies and Tools (cont.)**	III	**Propellants** Technologies for production, storage, transportation and characterisation of solid, liquid or gaseous propellants. Covers also all aspects related to green propellants.
				IV	**Ground Support Equipment (GSE)** All mechanical, fluid and electrical ground support subsystems dedicated to a propulsion subsystem integration, testing, loading and launch preparation.
20	**Structures** Technologies and methodologies related to design, analysis, manufacture and test of structures and mechanical subsystems for spacecrafts, 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.	A	**Structural Design and Verification Methods and Tools** 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.	I	**Space (sub-) systems Design and Design Tools** CAD tools and methodologies.
				II	**Structural Analysis Tools and Methodologies** Structural verification tools and methodologies (acoustics, damage tolerance, thermo-elastic, deployment simulations, composite structures …).
				III	**Structural Testing Tools and Methodologies** Test data storage tools, test data evaluation tools, test prediction tools.
				IV	**In-flight/In-orbit Loads and Vibration Measurement Techniques** Sensors, integration, data recording/downloading, data evaluation.
		B	**High Stability and High-Precision Spacecraft Structures** All technologies related to such structures, including advanced material applications, as well as manufacturing and verification aspects.	I	**Advanced Material Technologies for Stable Structures** Manufacture of stable structures, structural verification, failure analysis, definition of structural allowables etc.
				II	**Joining and Mounting Technologies** Interfacing to other structures, verification of interfaces for high-stability and high-precision structures. Includes design, materials and manufacturing technologies for stable, compact, lightweight optical benches operating at room temperature, but also down to cryogenic temperatures *(Note 20-B-II-1: optical mounting technologies are covered in 16-B-IV)*
				III	**Thermo-elastic Stability Verification Technologies** Design, analysis and test aspects.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures (cont.)**	C	**Inflatable and Deployable Structures** Shields, antennas, booms, solar arrays, airbags and inflatable landing subsystems, drag augmentation devices, etc. All technologies related to such structures, including materials, deployment simulations, damping, active control and verification methodologies. *(Note 20-C-1: system level and design aspects of drag augmentation devices for reentry applications are covered in 11-C-III*)	I	**Design and Verification Technologies** Design tools, deployment simulation, test methodologies, combined verification methodologies.
				II	**Structural Material Concepts** Material testing, laminate/membrane design, in-orbit curing aspects.
				III	**Joining Technologies For Inflatable and Deployable Structures** Design and verification of joints (both flexible-to-flexible and flexible-to-rigid) for inflatable and deployable structures.
		D	**Hot Structures** All technologies related to such structures, including related material developments, coatings and verification methodologies.	I	**Design and Verification Technologies for Ceramic Structures** Manufacturing aspects, detailed design aspects, analysis and test aspects, static, dynamic, thermo-elastic.
				II	**Design and Verification Technologies for Metallic Structures** Manufacturing aspects, detailed design aspects, analysis and test aspects, static, dynamic, thermo-elastic.
				III	**New Advanced Hot Structures Materials** Development and structural application of advanced materials such as UHT materials.
				IV	**Joining Technologies for Hot Structures** All aspects related to joining of hot structures, e.g. fasteners, brazing and other methods. Also includes verification methods.
				V	**Health Monitoring Technologies** Sensors, data recording, data evaluation etc.
		E	**Active/Adaptive Structures** All technologies related to the development and application of such structures, for dynamic control of flexible structures, noise reduction, load reduction, active and passive damping. Includes sensor and activator developments, structural and subsystem integration and control logics.	I	**Sensor/Actuator Technologies** Sensor/actuator developments e.g. electroactive polymers (EAP), piezo patches, fibres. *(Note 20-E-I-1: Detailed mechanisms aspects are covered in TD15)*
				II	**Technologies for Structural Integration** Various sensor/actuator combinations.
				III	**Data Acquisition and Control Logic Technologies Related to Structural Dynamics** Multi-body dynamics analysis tools and methodologies.
				IV	**Design and Verification Tools and Methodologies for Active/Adaptative Structures** Detailed analysis and test tools.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures (cont.)**	F	**Damage Tolerance and Health Monitoring** 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.	I	**Non Destructive Inspection Technologies** Development of new methodologies and related hardware, application in space programmes.
				II	**Structural-Health-Monitoring Sensor Technologies** Sensor development, structural integration etc.
				III	**Fracture Control Tools and Methodologies** Numerical tools, detailed analysis methodologies, e.g. for non-linear applications, damage tolerance for composites and ceramics.
		G	**Launchers, Reentry Vehicles, Planetary Vehicles** Includes all related technologies for the development of vehicle primary and secondary structures, control surfaces, shields, etc. (For ascent, entry, etc.).	I	**Technologies for Design and Verification of Advanced Primary Structures** Structural concepts for highly-loaded components, manufacturing methodologies e.g. fibre placement, RTM etc.
				II	**Advanced Tank Design and Verification Technologies** Metallic and composite tanks, interfaces to primary structure, common bulkheads, HMS, NDI, damage tolerance approaches, etc.
				III	**Landing Attenuation Technologies** Airbag technologies, landing legs, application of crushable materials, foams etc.
				IV	**Control Surfaces, Design and Verification Technologies** Design with ceramics as well as advanced metallic alloys, combined mechanical–thermal test methodologies etc.
				V	**Descent Subsystems** Descent subsystems like parachutes, parafoils, in-air capturing technologies.
		H	**Crew Habitation, Safe Haven and EVA suits** All technologies for the development of related primary and secondary structures, shields etc.	I	**Habitation Primary and Secondary Structure Technologies** Environmental shields, design and verification technologies.
				II	**EVA Suits and Mechanical Aspects** Design of load-/pressure-carrying elements, interface design between elements, structural material aspects, meteoroid/debris impact shielding aspects.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
20	**Structures (cont.)**	I	**Meteoroid and Debris Shield Design and Analysis** Development of related analysis and test tools and methods, shield developments, damage assessments etc.	I	**Tools and Methodologies for Design and Verification of Meteoroid & Debris Shields** Numerical tools, materials models, shield test methods, gas guns, shaped charges, data acquisition technologies.
		J	**Advanced Structural Concepts and Materials** Structures manufactured from novel materials (nanotube reinforced, foams, self-healing materials etc.).	I	**Design and Verification for Advanced Structures and Materials** Design and verification methods for structures manufactured from novel materials (nanotube reinforced, foams, self-healing materials etc.).
21	**Thermal** All technologies needed for the thermal control of space systems and subsystems.	A	**Heat Transport Technology** All technologies associated with heat transport, whether in the single phase or using the latent heat in two-phase subsystems.	I	**Heat Pipes** All technologies related to heat pipes, e.g. constant conductance, variable conductance and heat pipe diodes.
				II	**Capillary-Driven Loops** All technologies related to capillary-driven two-phase heat transport loops, including Capillary Pumped Loops (CPLs) and Loop Heat Pipes (LHPs).
				III	**Mechanically-Pumped Two-Phase Loops** All elements and associated technologies for mechanically-pumped two-phase heat transport loops.
				IV	**Mechanically-Pumped Single-Phase Loops** All elements and associated technologies for mechanically-pumped single-phase heat transport loops.
				V	**Heat Switches** All elements and technologies for heat switches, e.g. based on Loop Heat Pipes or mechanically driven.
		B	**Cryogenics and Refrigeration** All technologies associated with transferring heat from lower to higher temperature levels and cooling by evaporation of stored cryogens.	I	**Refrigeration and Heat Pumps** All refrigeration technologies required for temperature control of items in a near-room-temperature environment, including also heat pumps.
				II	**Cryo-Coolers** All active cryo-machinery and associated technologies for cooling to cryogenic temperatures (down to 1K).
				III	**Passive Coolers and Stored Cryogens** All technologies related to non-active cooling (e.g. radiators, cryostats).

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
21	**Thermal (cont.)**	B	**Cryogenics and Refrigeration (cont.)**	IV	**Sub-Kelvin Coolers** All technologies required to provide cooling below 1K.
		C	**Thermal Protection** All technologies associated with thermal protection and insulation subsystems for atmospheric entry.	I	**Ablative Subsystems** All technologies providing thermal protection based on chemical and/or physical reactions.
				II	**Reusable Subsystems** Thermal protection technologies for multiple applications on reentry vehicles.
		D	**Heat Storage and Rejection** All technologies associated with heat storage and rejection using coatings, insulation, thermal capacitors and radiators.	I	**Coatings and Insulation** All technologies for achieving thermal control surfaces and insulation.
				II	**Heat Storage** All types of thermal capacitors, e.g. phase-change materials.
				III	**Radiators** All technologies associated with radiative interfaces between the subsystem and its environment, including louvres.
		E	**Thermal Analysis Tools** All software tools and methods for the design and verification of space systems and subsystems.	I	**Thermal Software Tools** All software used for system- and subsystem-level analysis in the thermal area.
				II	**Thermal Data Exchange** All protocols, tools and methods for thermal data transfer from one software environment to another.
				III	**Thermal Analysis Methods** All analytical and numerical methods in relation with the development and application of software tools for design and verification.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
22	**Environmental Control & Life Support (ECLS) and In Situ Resource Utilisation (ISRU)** All technologies for controlling, maintaining and supporting human presence in space and the utilisation of local resources.	A	**Environmental Control & Life Support (ECLS)** 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.	I	**Environmental Control and Monitoring** All technologies related to air, water and food quality monitoring and control with respect to microbial and chemical contaminants.
				II	**Regenerative Life Support** All technologies related to air and air revitalisation, water and waste recycling and food preparation and production, using physico-chemical and biological processes.
				III	**Habitability Technologies** All technologies needed for design and implementation of a human habitat, aiming for crew wellbeing, crew motivation and optimum performance, including definition of key psychological factors.
				IV	**Integrated ECLS** All aspects and associated technologies for integrated human habitats and life support subsystems, including ground-based testbeds and overall simulation tools and methods.
		B	**In Situ Resource Utilisation (ISRU)** Technological aspects related to the use of indigenous materials at the site of an interplanetary mission for the production of resources such as propellants (e.g. methane, oxygen), reactants for fuel cells (e.g. carbon monoxide, oxygen) or fluids/gases for life support.	I	**ECLS Consumables** All technologies for collecting and processing fluids and gases to be used as consumables for ECLS in human habitats (e.g. oxygen, hydrogen, nitrogen, water).
				II	**ISRU Fuels** All technologies for collecting and processing fluids and gases to be used as consumables for propulsion and energy production.
				III	**ISRU Storage and Distribution** All technologies required for storing and distributing fluids and gases.
				IV	**ISRU Processing and Production** Low-volume processing of new materials and extends into processing and production utilising in situ resources in planetary exploration.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
23	**Electrical, Electronic and Electro-mechanical (EEE) Components and Quality** 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 subsystems.	A	**Methods and Processes for Product Assurance of EEE Components** 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 EEE components (including simulation of component parameter degradation), 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.	I	**EEE Components Evaluation and Testing** Development of laboratory techniques and test methods for characterisation, evaluation, qualification, derating, end-of-life, failure analysis and procurement of space components.
				II	**EEE Components Radiation Hardening** Process hardening, design hardening, mitigation techniques, verification and validation.
				III	**EEE Components Design and Development** Development and design of components adapted to the requirements for space applications.
				IV	**EEE Components Modelling** Simulation of EEE component responses to radiation at semiconductor level, including simulation and prediction of EEE component parameter degradation.
				V	**Radiation Hardness Assurance (RHA) Process** Definition of RHA requirements and development of irradiation test method/guidelines.
				VI	**Irradiation Test Facilities** Definition 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.
				VII	**Upscreening Commercial Off-The-Shelf (COTS) EEE Components** Spin-In of COTS components by characterisation and upscreening for specific space applications. This in conjunction with reference designs and mitigation techniques applied at component-, sub-system- and system-level. Development of characterisation and evaluation techniques.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
23	**Electrical, Electronic and Electro-mechanical (EEE) Components and Quality (cont.)**	B	**EEE Component Technologies** Component technologies most commonly evaluated using the processes in 23-A.	I	**Passive EEE 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.
				II	**Silicon-Based EEE Components** Discrete, analogue, digital and mixed signal technologies and device types across all integration levels and functional complexity ranges in bipolar and MOS technologies.
				III	**RF Microwave and Millimetre Wave EEE Components** Discrete and MMIC components including RF-CMOS, GaAs, SiGe, InP technologies, packaging and RF passive components.
				IV	**Optoelectronic Active and Passive Components** Optical and near-optical sensors, detectors, laser diodes, fibre optical connectors, optical assemblies and associated passive components.
				V	**Hybrids and Micropackaging** 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.
				VI	**Power EEE 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.
				VII	**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.
				VIII	**Micro Electro Mechanical Subsystems (MEMS)** Evolving range of technologies and applications including RF MEMS, pressure sensors, AOCS sensors, MOEMS, actuators, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
23	**Electrical, Electronic and Electro-mechanical (EEE) Components and Quality (cont.)**	B	**EEE Component Technologies (cont.)**	IX	**Nanotechnology in Microcircuits** Application of carbon nanotubes, nanofibers, innovative nanomaterials to microcircuit improvement.
				X	**Advanced Manufacturing of EEE Components** Application of advanced manufacturing techniques in the development of EEE Components for space applications. (*Note 23-B-X-1: manufacturing-process aspects are covered in 24-I)*.
24	**Materials and Manufacturing Processes** Materials mechanics and processes, their physical and chemical behaviour and the interaction with the operational environment through the spacecraft and ground infrastructure lifecycle. Furthermore, all manufacturing processes are covered.	A	**Novel Materials and Materials Technology** Materials not yet used in space but presenting potential interest.	I	**Material Assessment** Basic properties, possibility to scale-up, limitations. Material properties assessment for additive manufacturing processes.
				II	**Nanotechnology** Development, manufacture and test of nanotubes, nanofibres, nanocoatings.
		B	**Materials Processes** Materials manufacturing processes and fabrication techniques.	I	**Joining** Glueing, bonding, welding, brazing, soldering, fastening, repairing. *(Note 24-B-I-1: technologies related to the joining of high stability structures are covered in 20-B-II; technologies related to the joining of inflatable and deployable structures are covered in 20-C-III; technologies related to the joining of hot structures are covered in 20-D-IV.)*
				II	**Coating** Development, manufacture and test of all type of coatings such as paints, conformal coatings, organic/inorganic/metallic coatings, thermo-optical coatings, thermal control materials, optical materials, sol-gel coatings, ALD, oxidation protection, finishes.
				III	**Materials Characterisation and Feedback** All aspects related to thermo-physical/ mechanical/chemical properties, long-term ageing effects.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Manufacturing Processes (cont.)**	C	**Cleanliness and Sterilisation** 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.	I	**Sterilisation of Materials** Effect of sterilisation on materials and assemblies, compatibility of materials with sterilisation techniques. *(Note 24-C-I-1: Technologies related to verification of the bioburden reduction process are covered in 14-C-IV to 14-C-VI).*
				II	**Control of Molecular Contamination** Outgassing of materials, cleanliness monitoring techniques, contamination transfer processes, effects on performance, mitigation, surface contamination, … Laser-induced contamination, photofixation of contamination.
				III	**Control of Particulate Contamination** Contamination transfer processes, effects on performance, mitigation, protection, cleanroom monitoring.
				IV	**Control of Bio-Corrosion, Biocides, Plasma Corrosion etc.** Degradation of materials interacting with an atmosphere, including degradation resulting from an inhabited atmosphere.
				V	**Contamination Modelling and Lifetime Prediction of Material Behaviour** Modelling and lifetime prediction of the interaction of materials/environment with contamination (ground/space environment).
		D	**Ground and Space Environmental Effects on Materials and Processes** Analyses of interactions between materials and both ground and space environment to ensure safety and performance-related requirements.	I	**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, etc.
				II	**Interaction of Materials with the Ground Environment** (long term) Storage, logistics, corrosion, swelling, creep.
				III	**Interaction of Materials with the Inhabited Environment** Safety- and performance-related issues affecting the inhabited environment such as toxicity, flammability, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Manufacturing Processes (cont.)**	E	**Modelling of Materials Behaviour and Properties** Modelling, characterisation, analysis and testing of materials behaviour and properties.	I	**Microstructural and Nanostructural Characterisation of Materials** Qualitative and quantitative analyses of material micro- and nano-structure surface topography, porosity, defects and interfaces.
				II	**Modelling of Thermomechanical Processes of Materials including Lifetime Predictions** Methods developed to represent physical processes of materials at operative length and time scales.
				III	**Characterisation, Modelling and Testing of Fracture Mechanics** Development of models, methods and tests to identify a material fracture behaviour.
				IV	**Thermal Analysis of Materials** All characterisation activities of the functional properties of materials from cryogenic to reentry/launcher temperatures. This includes demisability aspects of materials.
				V	**Topological Optimisation** Methods to optimise material layout within a given design space, for a given set of loads, boundary conditions and constraints, in order to maximize the performance of the system.
		F	**Non-Destructive Inspection** Development of test and verification methods.		
		G	**Material and Process Obsolescence** Analyses of materials or manufacturing processes obsolescence due to regulation or availability.	I	**Regulation and Legislation-based Obsolescence** Materials and manufacturing process availability and limitations due to environmental regulations and export regulations (e.g. REACH, RoHS, etc.).
				II	**Scarce Materials** Production stop, bankruptcy, etc.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Manufacturing Processes (cont.)**	H	**Materials for Electronic Assembly** Materials and verification methods involved in electronic assemblies.	I	**Printed Circuit Board Technologies** Technologies and methods involved in the manufacture and evaluation of printed circuit boards.
				II	**Electronic Assemblies Technologies** Technologies and methods involved in the development and verification of components and interconnections mounted on printed circuit boards and harness.
				III	**Verification of Electronic Assemblies** Test and verification methods for electronic assemblies.
		I	**Advanced Manufacturing Technologies** Manufacturing technologies that bring added value compared to traditional manufacturing such as lead-time reduction, cost reduction, performance improvement, design freedom, or enable new capabilities.	I	**Composites Manufacturing** Manufacturing technologies of polymer, metal, and ceramic matrix composites, including nano-technologies such as CNT, graphene as well as other nano-engineered materials.
				II	**Additive Manufacturing** Additive manufacturing processes for metals, polymers, and ceramic materials. Technologies for manufacturing on-ground, in-orbit, and on moon or planetary bodies (including ISRU).
				III	**Materials Functionalisation** Establishment of functional gradients (e.g. 4D printing), adding function and performance through coatings (e.g. ALD, PVD, CVD) (together with 24-B-II), electrostructural composites, inclusion of response stimulus and sensing (e.g. embedded sensors).
				IV	**In-line Process Monitoring** Auxiliary processes targeting in-line and in-situ monitoring of process and performance parameters.
				V	**Intelligent Manufacturing Processes** Manufacturing subsystems with full capability for process monitoring, real-time communication and cooperation, and intelligent decision making. *(Note24-I-V-1: Complementary to 8-B-I, 8-B-II, and 8-B-III)*

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
24	**Materials and Manufacturing Processes (cont.)**	I	**Advanced Manufacturing Technologies (cont.)**	VI	**Advanced Materials Manufacture** Manufacturing aspects related foams, sol-gel processed materials, near-net-shape processing route, PVD & CVD processes, nanotechnology aspects of materials, bioinspired materials and structures, etc. *(Note24-I-VI-1: aspects related to use of functional gradients in materials processes are covered under 24-I-III)*
		J	**Reliability and Reusability Aspects of Materials** Development of test and methods for materials characterisation and verification, addressing reliability and reusability. *(Note 24-J-1: Technologies related to All types of NDI and NDE methods to assess reliability & quality aspects are covered in 20-F-I).*	I	**Advanced Physical & Chemical Characterisation and Analysis of Materials** Advanced technologies and methods to characterise and analyse materials: electron microscopy, X-ray diffraction, Raman spectroscopy etc.
				II	**Advanced Testing & Qualification and Validation Approaches of Materials** Test methods and approaches to qualify and validate materials against specific reliability requirements.
25	**Quality, Dependability and Safety** Quality, reliability, availability, maintainability and safety aspects of space and ground systems and their constituents (hardware, software and the human element), including design, manufacture, assembly, integration, testing. Methods and tools for the assessment and management of technical risks associated with space systems and their operations. Design, 58anufacture and qualification engineering processes to ensure the possibility of utilising partial or full COTS (sub-) systems.	A	**System Dependability and Safety** Reliability, availability, maintainability and safety of the entire space system.	I	**Dependability and Safety Methods & Tools** Methods and tools to achieve mission success and hazard control.
				II	**Technical Risk Management Techniques** Identification, evaluation, mitigation and acceptance of risks.
		B	**Software Quality** Quality of the software development process and the resulting software products.	I	**Software Process Quality Techniques** Techniques to assure the quality of the software development process.
				II	**Software Product Quality Techniques** Evaluation and certification of the quality of the software products.
				III	**Software Security Process Assurance** Techniques for software security process assurance.
		C	**Product and Quality Assurance** Methods and processes to ensure compliance of products delivered to customers with quality requirements.	I	**Product Assurance Processes for Space and Ground Subsystems** 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, non-conformance control and quality records.

TD	TECHNOLOGY DOMAIN	TS	TECHNOLOGY SUBDOMAIN	TG	TECHNOLOGY GROUP
25	**Quality, Dependability and Safety (cont.)**	C	**Product and Quality Assurance (cont.)**	II	**Quality Assurance Processes for Space and Ground Subsystems** Assurance of design, manufacture, assembly, integration, testing, procurement, recurring production, training, inspections, traceability and standards.
				III	**Product and Quality Assurance Aspects of Commercial Off-The-Shelf (COTS) Subsystems** Assurance of design, manufacture, AIT, procurement, testing, traceability and standards specific for commercial off-the-shelf subsystems.
				IV	**Product and Quality Assurance Processes for Small Satellites** Assurance of design, manufacture, AIT, procurement and standards specific for small satellites and related applications.
		D	**Commercial Off-The-Shelf Components and Subsystems** Subsystems partly or fully based on COTS technologies for payload and platform data system applications. Development of reference design based on COTS technologies for space applications; development of mitigation techniques enabling utilisation of COTS technologies in Space and launch environment. It covers also characterisation and evaluation of COTS subsystems including development of associated technologies.	I	**COTS Technologies Reference Design** Development of reference designs based on COTS technologies for space applications.
				II	**COTS Technologies Mitigation Techniques** Development of mitigation techniques enabling utilisation of COTS technologies in the launch and space environment. Mitigation techniques at component, subsystem and system level.
				III	**COTS Components and Subsystems Characterisation and Evaluation** Characterisation and evaluation of COTS components and subsystems including the development of associated methodologies.
26	**OTHERS** Please contact the TEC-H office at ESTEC if you need to include additional technologies not covered in this document.				

Appendix A – Differences between Technology Tree 3.0 and 4.1

Issue 4.1 of the Technology Tree (TT) now contains:

- 26 TDs (26 in issue 3.0, 26 in issue 2.1)
- 107 TSs (107 in issue 4.0.101 in issue 3.0, 92 in issue 2.1)
- 346 TGs (343 in issue 4.0, 320 in issue 3.0, 274 in issue 2.1)

An outline of the changes introduced in this latest revisions is as follows:

TT 4.0:

- 48 items have been added
- 240 items have an updated title and/or description
- 10 items have been moved inside the TT
- 3 items have been deleted
- 2 entries have been split in two separate entries

TT 4.1

- 4 items have been added
- 10 updates of title and/or descriptions.

In more detail, the major changes that have been introduced in issues 4.0 and 4.1 are:

- Machine Learning Techniques and AI have been introduced in On-board Data Subsystems (TD1) within a dedicated TS.
- Artificial Intelligence and Data Security have been introduced in Space System Software (TD2).
- Space Debris (TD11) has been detailed, adding new TGs and a new TS on ‘Debris Remediation and Protection’.
- Processing and Production of in-situ resources has been moved from Life and Physical Sciences (TD14) to Environmental Control & Life Support (ECLS) and In Situ Resource Utilisation (ISRU) (TD23).
- ‘Optical Communications’ has been moved from Optics (TD16) to Optoelectronics (TD17), creating a dedicated TS.
- ‘Quantum Technologies’ has been detailed in Optoelectronics (TD17), creating new TGs in a specific new TS.
- TD18 has been changed from ‘Aerothermodynamics’ to ‘Fluid Mechanics’ in amendment 4.1 (after being already updated to ‘Fluid Dynamics’ in release 4.0) to enlarge the coverage of the Domain, and has undergone extensive restructuring and rewriting.
- Specific TSs on ‘Advance Manufacturing Technologies’ and ‘Reliability and ‘Reusability of Materials’ have been introduced in Materials and Manufacturing Processes (TD24) which has undergone major rewriting.
- Commercial Off-the-Shelf components have been introduced in Quality, Dependability and Safety (TD25), creating new TGs and a dedicated TS.
- Several new TGs have been created in Space Systems Electrical Power (TD3), Electromagnetic Technologies and Techniques (TD7), System Design and Verification (TD8), Mechanisms (TD15), Optics (TD16) and Electrical, Electronic and Electro-mechanical (EEE) Components and Quality (TD23).

The following table provides a mapping matrix from entries in issue 4.1 to entries in issue 3.0.

TT 3.0	Type of change	TT 4.0 / TT 4.1
2-A-I: Advanced Software Development Methods and Tools	Group deleted	Advanced software methods related to Machine Learning are moved under 1-D-II (new group) Advanced Software methods related to Artificial Intelligence are now covered under the NEW 2-A-I Other generic developments shall be considered directly under subdomain 2-A
3-B-III: Nuclear and Thermo-Electric Power Generator Technologies	Group split into 3-B-III: Nuclear Fission Reactor Technologies and 3-B-IV: Radioisotope Power Technologies	3-B-III now covers content limited to fission; 3-B-IV content is limited to natural decay of isotopes
3-D: Power Conditioning and Distribution	Removed	3-A now covers the content
3-D-I: Power Conditioning	Moved	3-A-I
3-D-II: Specific Power Supplies	Moved	3-A-II
3-D-III: Power Distribution	Moved	3-A-III
11-C: Debris Environment Remediation and Protection	Subdomain split into 11-C: Debris Mitigation and 11-D: Debris Remediation and Protection	11-C covers aspects related to debris mitigation while 11-D content is limited to remediation (including removal) and protection
14-D: Applied Physical Science Technology	Removed	22-B now covers the content
14-D-I: Processing and Production	Moved	22-B-IV
15-H-VI: Development of New Devices for Future Exploration and Exploitation Missions	Moved	15-A-VIII
16-C-VI: Optical Communications	Moved	17-D (now Subdomain)

TT 3.0	Type of change	TT 4.0 / TT 4.1
17-C-V: Quantum Devices	Moved	17-E-I
24-B-IV: Advanced Materials Manufacturing	Moved	24-I-VI

Appendix B – Detailed Change Log

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT01	1-C-I	Changed	Text modified with the addition of: "**Hardware-Software co-design, space use of reprogrammable FPGAs**"	
TT02	2-A-I	Removed	Group removed **and replaced by the group "Software Autonomy and Artificial Intelligence" (2-A-I) cf. TT39**	
TT03	2-A-II	Changed	Change of title to "**Software functions";**	
TT04	2-A-II	Changed	Change of text to: **Functions that are implemented in software such as: application functions (data handling, thermal management, power management, AOCS, security etc.); supporting functions (operating systems, separations kernels, middleware, etc.).** **Includes other advanced software functions such as parallel computing.** *(Note 2-A-II-1: This includes also predevelopment for applications indicated in TD1-A-III)* *(Note 2-A-II-2: Coverage of Autonomy is under to 2-A-I)*	
TT05	2-B-II	Changed	Change of title to: "**Software Management Process**"	
TT08	6-B-III	Changed	Change of description: **Covering all aspects related to navigation space (reference) receivers, and related algorithms and technologies**	
TT09	6-B-IV	Changed	Change of Title to "**RF Metrology**"	
TT10	6-B-IV	Changed	Change of description: **All aspects related to high accuracy RF metrology , including algorithm technology and tools.**	
TT11	3-A-	Changed	Description changed with the addition of: "**Including power subsystem architecture, topologies, sizing, modelling and simulation tools and techniques. Includes power conversion, regulation, control and distribution."**	
TT12	3-D-I	Moved	Content Moved to the new group **3-A-I/Power Conditioning** and description modified to "**PCDUs, SAR, BDRs, BCRs, DC/DC**	**3-A-I**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
			converters, control circuits, control techniques, digital control techniques"	
TT13	3-D-II	Moved	Content moved to the new group **3-A-II/Specific Power Supplies**	**3-A-II**
TT14	3-D-III	Moved	Content moved to the new group **3-A-III/Power Distribution**	**3-A-III**
TT15	3-B-III	Split	Split in **3-B-III/Nuclear fission reactor technologies** and new group **3-B-IV/Radioisotope power technologies**	**3-B-III & 3-B-IV**
TT16	5-B-	New	New group: "**GNC technologies for Launch Vehicles**"	**5-B-V**
TT17	14-D-I	Moved	Moved to **22-B-IV** and Title changed to "**ISRU Processing and Production"**	**22-B-IV**
TT18	19-D-III	Changed	Include "**green propellants"** in the description	
TT19	19-C-	Changed	Change in title to "**other propulsion subsystems"**	
TT20	19-A-	Changed	Description changed to include micropropulsion and space tugs	
TT21	19-B-	Changed	Description changed to include micropropulsion and orbital stages/tugs (in place of a more generic "upper stage")	
TT22	24--	Changed	Title of the domain changed to "**Materials and Manufacturing Processes**"	
TT25	24-E-	New	New group: **"Topological Optimisation"**	**24-E-V**
TT26	11-C-	Split	Split in **Debris Mitigation** and **Debris Remediation and Protection**	**11-C & 11-D**
TT27	11-C-II	Moved	Content moved to **11-D-I/Space Debris Environment Remediation**	**11-D-I**
TT28	11-C-III	Moved	Content moved to **11-D-II/Protection against Debris and Meteoroids**	**11-D-II**
TT29	11-C-	New	New group: "**Design for Demise"**	**11-C-II**
TT30	11-C-	New	New group: "**Passive Reentry**"	**11-C-III**
TT31	11-C-	New	New group: "**Passivation Technologies**"	**11-C-IV**
TT32	11-D-	New	New group: "**Design for Removal"**	**11-D-III**
TT33	11-D-	New	New group: "**In-Orbit Contactless Debris Removal"**	**11-D-IV**
TT35	15--	New	New subdomain: "F**lexible Capture Mechanisms**"	**15-I**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT36	13-A-II	Changed	Added in the description "[…] **and refuelling**"	
TT37	20-C-	Changed	Added in the description "**drag augmentation devices**" and addition of the "*Note 20-C-1: system level and design aspects of drag augmentation devices for reentry applications are covered in 11-C-III*"	
TT38	19-C-IV	Changed	Note 19-C-IV-1 added: "*Note 19-C-IV-1: system level and design aspects of tether subsystems for reentry applications are covered in 11-C-III"*	
TT39	2-A-	New	New group: "**Software Autonomy and Artificial Intelligence**"	**2-A-I**
TT40	1-A-I	Changed	Description updated mentioning explicitly "**big data**" and "**compressing sensing**"	
TT41	1-A-III	Changed	Description updated mentioning explicitly "**big data**" and "**compressing sensing**"	
TT42	2-D-I	Changed	Rephrased "large data" with "**big data";** mention of **preservation and retrieval**	
TT43	2-D-II	Changed	Mention of **intelligence, data retrieval, data analytics and visualisation tools**	
TT44	2-D-	New	New group: **Technologies for Data Security, Openness and Privacy**	**2-D-III**
TT46	17-C-V	Moved	Moved and title changed to "**Quantum Device, Metrology and Sensing"** Description improved to include **Quantum Detectors**	**17-E-I**
TT47	17--	New	New subdomain "**quantum technologies"**	**17-E**
TT48	17-E-	New	New group: **"Quantum Communication"**	**17-E-II**
TT50	17-E-	New	New group: **Quantum Information Processing and Simulations**	**17-E-III**
TT51	6-A-V	Changed	Text changed: **Quantum Key Distribution (with TD17-E-II)**	
TT52	8-A-III	New	New group: **System Level Aspects of Avionics Embedded Subsystems**	**8-A-III**
TT54	24-A-I	Changed	Description changed with the addition of: **Material properties assessment for Additive Manufacturing processes**	
TT55	7-A-II	Changed	Description changed with the addition of: **"…and metamaterial antennas. Manufacturing techniques and technologies of reflector and lens antennas"**	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT56	7-A-III	Changed	Description changed with the addition of: **"…Fully electronic or hybrid** array feed networks**."** and **"It also covers manufacturing techniques and technologies of array antennas and standalone radiators"**	
TT57	7-A-IV	Changed	Description changed with the addition of: **"calibration (both active and passive), focal plane arrays and front-ends (including direct detectors, mixers, multipliers, LO chain) and back-ends."**	
TT58	7-A-V	Changed	Description changed with the addition of: **"...**(e.g. for multi-beam payloads **or security aspects"** and **"...and at operational conditions, feed networks (active and passive),** interactions between antennas, millimetre-wave and THz antennas **and feed networks,"**	
TT59	16-B-IV	Changed	Title changed to: **"Optical Mounting Technology"**	
TT60	16-B-IV	Changed	Description changed to: **"Covers the design and development of stable optical mountings (component mounting and alignment technologies).**	
TT61	16-B-IV	Changed	Addition of the note: *(Note 16-B-IV-1: optical benches are covered in 20-B-II")*	
TT62	20-B-II	Changed	Description changed with the addition of: **"Includes design, materials and manufacturing technologies for stable, compact, lightweight optical benches operating at room temperature, but also down to cryogenic temperatures"**	
TT63	20-B-II	Changed	Addition of the note: *(Note 20-B-II-1: optical mounting technologies are covered in 16-B-IV")*	
TT64	16-C-VI	Moved	Content moved to new subdomain **17-D/Optical Communication Technologies** description modified: removed quantum communication part from description and reference added.	**17-D**
TT65	17--	New	New subdomain "**Optical Communications Technologies"**	**17-D**
TT66	16-C-	New	New group: "**Optical Ground Support Equipment**"	**16-C-VI**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT67	24-B-II	Changed	Description changed to: **"Including development, manufacture and testing of all type of coatings such as paints, conformal coatings, organic/inorganic/metallic coatings, thermo-optical coatings, thermal control materials, optical materials, sol-gel coatings, ALD, oxidation protection, finishes"**	
TT68	24-C-V	Changed	Description changed to: "**Modelling and lifetime prediction of the interaction of materials/environment with contamination (ground/space environment)."**	
TT69	24-D-	Changed	Title changed to: **"Ground and Space Environmental Effects on Material and Processes"**	
TT70	24-D-II	Changed	Description changed to: "**Covering issues such as (long term) storage, logistics, corrosion, swelling, creep."**	
TT71	24-E-IV	Changed	Description changed to: "**Covers all characterisation activities of the functional properties of materials from cryogenic to reentry/launcher temperatures. This includes demisability aspects of materials"**	
TT72	24--	New	New subdomain: **Reliability and Reusability Aspects**	**24-J**
TT73	24--	New	New group: **Advanced Physical and Chemical Characterisation & Analysis of Materials**	**24-J-I**
TT74	24--	New	New group: **Advanced Testing, Qualification and Validation approaches of Materials**	**24-J-II**
TT75	24--	New	New subdomain: **Advanced Manufacturing Technologies**	**24-I**
TT76	24--	New	New group: **Composites Manufacturing**	**24-I-I**
TT77	24--	New	New group: **Additive Manufacturing**	**24-I-II**
TT78	24--	New	New group: **Materials Functionalisation**	**24-I-III**
TT79	24--	New	New group: **In-Line Process Monitoring**	**24-I-IV**
TT80	24--	New	New group: **Intelligent Manufacturing Process**	**24-I-V**
TT81	24-B-IV	Moved	Group moved to **24-I-VI/Advanced Materials Manufacture** and description updated: removed the functional gradients (now covered under the new group 24-I-III, note	**24-I-VI**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
			added) and bioinspired materials added	
TT82	3-A-	Changed	TS name changed to "**Power Electronics**"	
TT83	6-A-I	Changed	Title changed to "**Telecommunication Subsystem and System Concepts and Engineering Tools**"	
TT84	6-B-I	Changed	TG name changed to "**Navigation Subsystems and Engineering Tools**"	
TT85	6-B-II	Changed	TG name changed to "**Navigation Ground and user Equipment**"	
TT87	6-C-I	Changed	TG name changed to "**TT&C Subsystem and Tools**"	
TT88	6-C-I	Changed	Description changed to: "**Covering all aspects related to TT&C subsystems (coding, modulation, multiplexing, link analysis, interference, security) and subsystem analysis tools and methodologies**"	
TT89	15-A-I	Changed	Description changed to: "**Technologies to provide torque or force: e.g. electromagnetic motors, voice coils, piezo motors, smart material actuators (e.g. shape memory alloy, electroactive polymer, spring actuators, paraffin actuators.**"	
TT90	15-A-IV	Changed	Description changed to: "**e.g. position sensors (potentiometers, optical encoders, resolvers, capacitive sensors, Hall sensors, etc.) switches, strain gauge sensors, accelerometers.**"	
TT91	15-A-V	Changed	Description changed to: "**Technologies providing linear or rotational guiding functions (e.g. ball and roller bearings, journal bearings, magnetic bearings, magnetic gears, ball joints, flexible guides and compliant mechanisms).**"	
TT92	15-A-VII	Changed	Description changed to: "**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, cable wrap, twist capsules, contactless electrical transfer technologies).**"	
TT93	15-F-II	Changed	Description changed to: "**Technologies providing a specific material surface tribological performance (e.g.**	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
			coatings, surface/heat treatment).”	
TT94	15-G-I	Changed	Description changed to: “**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, design to demise, operations in cryogenic environment).**”	
TT95	15-G-II	Changed	Description changed to: “**Specific tools used to support the design and development of space mechanisms (e.g. bearing sizing software, multi-body dynamic analysis software, close-loop control and micro-vibration analysis, tribology tools, Gear analysis tools, Electromagnetic analysis).**”	
TT96	15-H-II	Changed	Title changed to: “**Thermite and gas generation technologies**”	
TT97	15-H-II	Changed	Description changed to: “**Cover applications of thermite heating to provide connection, disconnection, release, joining, demising. Covers also provision of oxygen for life and other gases for pressure functions.**”	
TT98	15-H-VI	Moved	Group moved	**15-A-VIII**
TT99	5-C-II	Changed	Description changed to: “**Covers the development of efficient techniques and tools for design analysis and verification. Includes also adaptive and collaborative controls**.”	
TT100	3-D-	Removed	Subdomain removed; Technology Groups under it, moved to **3-A/Power Electronics** (see **TT12, TT13, TT14**)	
TT101	3--	Changed	Title changed to “**Space Systems Electrical Power**”	
TT102	3-B-	New	new group: “**Energy Harvesting Technologie**s”	**3-B-V**
TT103	4--	Changed	Title changed to “**Space Systems Environments and Effects**”	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT104	6-C-	Changed	Description changed to: **"Both spacecraft TT&C/PDM techniques and technologies, space link communications (RF, hybrid RF/optical subsystems, signal coding/modulation, ranging techniques, radio science experiments) and proximity links, as well as launcher TM"** Note 6-C-1 added :"*RF Technologies are covered in 6-E*"	
TT105	10-A-I	Changed	Description changed to: "**Covers pre-flight mission design, trajectory optimisation and launch window calculations**."	
TT106	19-D-I	Changed	Description changed to: "**Includes propulsion subsystem design tools, thruster and engine performance and life prediction tools, propulsion subsystem/space vehicle interaction tools and related orbit/trajectory definition tools.**"	
TT107	20-G-II	Changed	Description changed to: "**Including metallic and composite tanks, interfaces to primary structure, common bulkheads, HMS, NDI, damage tolerance approaches, etc.**"	
TT108	3-A-	New	New group: "**Power Subsystems Architecture**"	**3-A-IV**
TT109	6-C-	Changed	Title changed to: "**TT&C and Payload Data Transmitter (PDT) Subsystems** "	
TT110	6-C-V	Changed	Title changed to: "**High-Speed Downlink PDT**" and EO changed to "**Remote Sensing**" in the description	
TT111	6-D-I	Changed	Title changed to: "**Payload Architecture and Engineering Tools**"	
TT112	6-D-I	Changed	Description changed to: "**Advanced simulation tools and analysis paradigms for complex payloads for Telecom/Remote Sensing/Navigation.**"	
TT113	6-D-III	Changed	Title changed to: "**Remote Sensing Instruments**"	
TT114	6-D-III	Changed	Description changed to: "**Remote Sensing instruments both passive (e.g. radiometers, GNSS-R) and active (e.g. *SAR*, altimeters, RF sounding).**"	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT115	6-E-I	Changed	Description changed to: "**Design and analysis tools for RF equipments, components and technologies including RF design and analysis and high power phenomena prediction (e.g. Multipaction, Corona, power handling and passive intermodulation).**"	
TT116	6-E-III	Changed	Description changed to: "**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, RF switches, couplers, combiners/splitters, circulators, isolators, cables and connectors), including packaging and interconnection.**"	
TT117	6-E-VI	Changed	Description changed to: "**RF equipment and components, including for high-power, passive intermodulation, corona and multipactor testing.**"	
TT118	7-B-I	Changed	Description changed to: "**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. Related retrieval and correction algorithms, performance models and data processing.**"	
TT119	23-A-	New	New group: "**Upscreening Commercial Off The Shelf Components (COTS)"**	**23-A-VI**
TT120	23--	Changed	Note 23-1 removed	
TT121	23-B-	New	New group**: "Advanced Manufacturing of EEE Components**" and addition of the note *(Note 23-B-X-1:manufacturing-process aspects are covered in 24-I*).	**23-B-X**
TT122	1--	New	New subdomain: "**Machine Learning and Artificial Intelligence for On-board Data Subsystems**"	**1-D**
TT125	20-G-	New	New group**: "Descent subsystems**".	**20-G-V**
TT126	25-C-	New	New group**:** "**Product and Quality Assurance Aspects of Commercial Off-The-Shelf (COTS) Subsystems**"	**25-C-III**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT127	25-C-	New	New group**:** "**Product and Quality Assurance Processes for Small Satellites**"	**25-C-IV**
TT128	2-E-	Changed	Title changed to: "**Remote sensing payload data transmission**"	
TT129	20-A-I	Changed	Title changed to "**Space (sub-) systems Design and Design Tools**"	
TT130	6-E-V	Changed	Title changed to: "**Frequency & Time Generation and Distribution for Space Applications**"	
TT131	6-E-V	Changed	Note 6-E-V-2 added (*"Reference signals required for ground applications are covered in 12-A-V"*)	
TT132	12-A-V	Changed	Title changed to: "**Frequency & Time Generation and Distribution for Ground Applications**"	
TT133	5-A-II	Changed	Description changed to: "**Control-related aspects and implementation (with TD2 and TD9-B), including AI applications to space systems autonomy and enhanced FDIR."**	
TT134	9-B-II	Changed	Description changed to: "**Concepts for automation, autonomy and mission planning of ground data systems and spacecraft operations."**	
TT135	10-A-III	Changed	Description changed to: "**Automation of flight dynamics operations, advanced modules of FD application SW and advanced operational processes (including intelligence).** "	
TT136	25--	Changed	Description changed to: "**Quality, reliability, availability, maintainability and safety aspects of space and ground systems and their constituents (hardware, software and the human element), including design, manufacture, assembly, integration, testing . It also addresses Methods and tools for the assessment and management of technical risks associated with space systems and their operations.** **Design, manufacture and qualification engineering processes to ensure the possibility of utilising partial or full COTS (sub-) systems.** "	
TT137	25--	New	New subdomain: **"Commercial Off the Shelf Components and Subsystems**"	**25-D**
TT138	25--	New	New group**: "COTS Technologies Reference Design"**	**25-D-I**

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT139	25--	New	New group: **"COTS Technologies Mitigation Techniques"**	**25-D-II**
TT140	25--	New	New group**: "COTS Components and Subsystems Characterisation and Evaluation"**	**25-D-III**
TT141	1-C-	Changed	Note 1-C-1 added *("design aspects of COTS subsystems are covered in TD 25-D")*	
TT142	1--	Changed	Title changed to "**On-board Data Subsystems**"	
TT143	1-B-I	Changed	Title changed to "**On-board Data Management Subsystem**"	
TT144	1-B-III	Changed	Title changed to "**On-board Data Storage**"	
TT145	1-C-I	Changed	Title changed to "**Methodologies for Microelectronics**"	
TT147	1-D-	New	New group "**Machine Learning for On-board Data Subsystems**"	**1-D-I**
TT148	1-D-	New	New group "**Characterisation and Evaluation of Machine Learning Techniques**"	**1-D-II**
TT149	2-A-	Changed	Title changed to "**Software Technologies**"	
TT150	2-D-I	Changed	Title changed to "**Ground Data Archiving Subsystems**"	
TT151	2-D-II	Changed	Title changed to "**Ground Data Analytical Processing**"	
TT152	2-E-I	Changed	Title changed to "**Remote Sensing Data and Information Processing and Exploitation**"	
TT153	2-E-II	Changed	Title changed to "**Remote Sensing Applications and Services**"	
TT154	2-E-III	Changed	Title changed to "**Remote Sensing Information Subsystems and User Interfaces**"	
TT155	2-E-IV	Changed	Title changed to "**Remote Sensing Core Infrastructure and Architectures**"	
TT156	3-B-	Changed	Description added	
TT157	3-B-II	Changed	Description added	
TT158	3-B-III	Changed	Description added	
TT159	3-C-	Changed	Description added	
TT160	3-C-I	Changed	Description added	
TT161	3-C-II	Changed	Title changed to "**Mechanical Technologies for Energy Storage**"	
TT162	3-C-II	Changed	Description added	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT163	4-A-II	Changed	Title changed to "**In-flight Environments Monitoring**"	
TT164	4-B-I	Changed	Title changed to "**Environments Effects Analysis Tools**"	
TT165	4-C-I	Changed	Title changed to "**Space Weather Modelling Development and IT Infrastructure**"	
TT166	5-A-	Changed	Title changed to "**Control (Sub-) Systems Engineering**"	
TT167	5-B-	Changed	Title changed to "**Control (Sub-) Systems Innovative Technologies**"	
TT168	5-C-I	Changed	Title changed to "**Control Modelling Techniques**"	
TT169	5-C-III	Changed	Title changed to "**Multidisciplinary GNC Optimisation**"	
TT170	6--	Changed	Title changed to "**RF Subsystems, Payloads and Technologies**"	
TT171	6-A-	Changed	Title changed to "**Telecommunication Subsystems**"	
TT172	6-A-II	Changed	Title changed to "**Telecommunication Signal Processing**"	
TT173	6-A-III	Changed	Title changed to "**Telecommunication Networking Techniques**"	
TT174	6-A-IV	Changed	Title changed to "**Telecommunication Equipment**"	
TT175	6-A-V	Changed	Title changed to "**Telecommunication Security Techniques and Technologies**"	
TT176	6-B-	Changed	Title changed to "**Radio Navigation Subsystems**"	
TT177	6-B-III	Changed	Title changed to "**On-board Radio Navigation Receivers**"	
TT178	6-E-III	Changed	Title changed to "**RF Active and Passive Devices**"	
TT179	6-E-IV	Changed	Title changed to "**Vacuum Electronics for RF Amplification**"	
TT180	7-C-	Changed	Title changed to "**Electromagnetic and Radio Frequency Compatibility (EMC/RFC) and Electrostatic Discharge (ESD)**"	
TT181	8-B-II	Changed	Title changed to "**Multidisciplinary Data Exchange for Collaborative Engineering**"	
TT182	8-C-I	Changed	Title changed to "**System Design and Simulation**"	
TT183	8-D-	Changed	Title changed to "**System Verification and Assembly, Integration and Test (AIT)**" to be more explicit	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT184	9-A-	Changed	Title changed to "**Advanced System and Mission Operation Concepts**"	
TT185	9-C-II	Changed	Title changed to "**Preparation and Procedure Tools for Ground Data Systems** "	
TT186	12-A-III	Changed	Title changed to "**Microwave and Optical Active/Passive Subsystems**"	
TT187	13-A-	Changed	Title changed to "**Robotic Applications and Concepts**"	
TT188	13-A-I	Changed	Title changed to "**Planetary Robotic Exploration**"	
TT189	13-A-II	Changed	Title changed to "**Orbital Robotic Systems**"	
TT190	13-B-	Changed	Title changed to "**Automation & Robotics Systems and Subsystems**"	
TT191	13-B-I	Changed	Title changed to "**Manipulation Robotic Subsystems**"	
TT192	13-B-II	Changed	Title changed to "**Mobility Robotic Systems**"	
TT193	13-B-III	Changed	Title changed to "**Payload Automation Subsystems**"	
TT194	13-C-I	Changed	Title changed to "**Perception for Robots**"	
TT195	13-C-III	Changed	Title changed to "**Motion and Actuation of Robots**"	
TT196	14-B-I	Changed	Title changed to "**Sensors and Analytical Instrumentation for Physical Sciences** "	
TT197	14-B-II	Changed	Title changed to "**Imaging Diagnostics and Image Treatment Technologies for Physical Sciences** "	
TT198	14-B-III	Changed	Title changed to "**In-Situ Resources Processing and Production**"	
TT199	15-G-I	Changed	Title changed to "**Mechanism Engineering Disciplines**"	
TT200	15-G-II	Changed	Title changed to "**Mechanism Engineering Tools**"	
TT201	16-A-	Changed	Title changed to "**Optical Subsystem Engineering**"	
TT202	16-A-I	Changed	Title changed to "**Optical Subsystem Definition, Design and Engineering**"	
TT203	17--	Changed	Description changed by adding "Development and application...**to achieve given functions**"	
TT204	17-B-I	Changed	Removal of "Visible Detectors **(mostly Si-based)**" in the title	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT205 **(*superseded by TT 307 in TT 4.1)***	~~18--~~	~~Changed~~	~~Title changed to "**Fluid Dynamics**"~~	
TT206	18--	Changed	Description changed to "**Technologies and techniques related to the flow of fluids: gases, liquids, and plasma. Composed of two sub-disciplines: Aerothermodynamics (gases and plasma) and Hydrodynamics (liquids). Aerothermodynamics is related with the dynamics of gases and plasma, its physical processes, pressure and thermal fields and deals with the atmospheric interactions with moving objects at low or high speeds. Hydrodynamics deals with the study of liquids in motion inside the propellant tanks of flight vehicles and involves the calculation of various properties of fluid propellant, such as flow velocity, pressure, density, and temperature, as functions of space and time"**.	
TT207 ***(superseded by TT 308 in TT 4.1)***	~~18-A-~~	~~Changed~~	~~Title changed to "**Fluid Dynamics Tools and Techniques**"~~	
TT208 ***(superseded by TT 310 in TT 4.1)***	~~18-A-II~~	~~Changed~~	~~Title changed to "**Engineering Techniques for Fluid Dynamics**"~~	
TT209 ***(superseded by TT 311 in TT 4.1)***	~~18-A-III~~	~~Changed~~	~~Title changed to "**Multidisciplinary Techniques for Fluid Dynamics**"~~	
TT210 ***(superseded by TT 312 in TT 4.1)***	~~18-B-III~~	~~Changed~~	~~Title changed to "**Dedicated Facilities for Fluid Dynamics**"~~	
TT211 ***(superseded by TT 313 in TT 4.1)***	~~18-C-~~	~~Changed~~	~~Title changed to "**Sensors and Measurement Techniques for Fluid Dynamics**"~~	
TT212 ***(superseded by TT 314 in TT 4.1)***	~~18-C-I~~	~~Changed~~	~~Title changed to "**Intrusive Measurements for Fluid Dynamics Applications**"~~	
TT213 ***(superseded by TT 315 in TT 4.1)***	~~18-C-II~~	~~Changed~~	~~Title changed to "**Non-Intrusive Measurements for Fluid Dynamics Applications**"~~	
TT214 ***(superseded by TT 316 in TT 4.1)***	~~18-C-III~~	~~Changed~~	~~Title changed to "**Wireless Measurements for Fluid Dynamics Applications**"~~	
TT215	18-D-	Changed	Title changed to "**Flight Demonstrators and Flight Data Tools**"	
TT216	18-D-I	Changed	Title changed to "**User Interface of Flight Demonstrators & Data Tools**"	
TT217	18-D-II	Changed	Title changed to "**Informatics Environment of Flight Demonstrators & Data Tools**"	
TT218	19--	Changed	Description added	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT219	19-A-I	Changed	Title changed to “**Liquid Propulsion Subsystems**”	
TT220	19-A-II	Changed	Title changed to “**Solid Propulsion Subsystems**”	
TT221	19-A-III	Changed	Title changed to “**Air-Breathing and Hybrid Propulsion Subsystems**”	
TT222	19-B-I	Changed	Title changed to “**Electrostatic Propulsion Subsystems**”	
TT223	19-B-II	Changed	Title changed to “**Electrothermal Propulsion Subsystems**”	
TT224	19-B-III	Changed	Title changed to “**Electromagnetic Propulsion Subsystems**”	
TT225	19-C-I	Changed	Title changed to “**Solar Thermal Propulsion Subsystems**”	
TT226	19-C-I	Changed	Description added	
TT227	19-C-II	Changed	Title changed to “**Nuclear Propulsion Subsystems**”	
TT228	19-C-II	Changed	Description added	
TT229	19-C-III	Changed	Title changed to “**Solar Sailing Propulsion Subsystems**”	
TT230	19-C-III	Changed	Description added	
TT231	19-C-IV	Changed	Title changed to “**Tethered Propulsion Subsystems**”	
TT232	19-C-IV	Changed	Description added	
TT233	19-C-V	Changed	Title changed to “**Advanced Propulsion Concepts**”	
TT234	19-C-V	Changed	Description changed to “**Technologies and techniques related to advanced, new, and breakthrough concepts and ideas such as anti-gravity subsystems, air breathing propulsion , laser beamed propulsion, Lorentz force accelerators, cryosolids propulsion, etc.”**	
TT235	19-D-I	Changed	Title changed to “**Propulsion Subsystems Modelling**”	
TT236	19-D-II	Changed	Title changed to “**Propulsion Subsystems Testing and Diagnostics**”	
TT237	20-A-II	Changed	Title changed to “**Structural Analysis Tools and Methodologies**”	
TT238	20-B-	Changed	Title changed to “**High Stability and High-Precision Spacecraft Structures**”	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT239	20-C-III	Changed	Title changed to "**Joining Technologies For Inflatable and Deployable Structures**"	
TT240	20-D-IV	Changed	Title changed to "**Joining Technologies for Hot Structures**"	
TT241	20-E-IV	Changed	Title changed to "**Design and Verification Tools and Methodologies for Active/Adaptative Structures**"	
TT242	20-H-II	Changed	Title changed to "**EVA Suits and Mechanical Aspects**"	
TT243	20-J-	Changed	Added description since no description was provided	
TT244	20-J-I	Changed	Title changed to "**Design and Verification for Advanced Structures and Materials** "	
TT245	20-J-I	Changed	Description changed to be more explicit : "**Design and verification methods for** structures..."	
TT246	21--	Changed	Description added	
TT247	21-C-I	Changed	Title changed to "**Ablative Subsystems**"	
TT248	21-C-II	Changed	Title changed to "**Reusable Subsystems**"	
TT249	21-E-	Changed	Description changed to include space subsystems	
TT250	21-E-I	Changed	Description changed to include subsystem level of analysis	
TT251	22-A-	Changed	Title changed to "**Environmental Control & Life Support (ECLS)**" to be more explicit	
TT252	22-A-III	Changed	Title changed to "**Habitability Technologies**"	
TT253	22-B-	Changed	Title changed to "**In Situ Resource Utilisation (ISRU)**" to be more explicit	
TT254	22-B-II	Changed	Title changed to "**ISRU Fuels**"	
TT255	22-B-III	Changed	Title changed to "**ISRU Storage and Distribution** "	
TT256	6-E-II	Changed	Description changed to include TWTAs, distribution networks and front ends	
TT257	23--	Changed	Title changed to "**Electrical, Electronic and Electro-mechanical (EEE) Components and Quality**"	
TT258	23-A-	Changed	Title changed to: "**Methods and Processes for Product Assurance of EEE Components, ~~including Radiation Hardness Assurance~~"**	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT259	23-A-I	Changed	Title changed to "**EEE Components Evaluation and Testing**"	
TT260	23-A-II	Changed	Title changed to "**EEE Components Radiation Hardening**"	
TT261	23-A-III	Changed	Title changed to "**EEE Components Design and Development**"	
TT262	23-A-III	Changed	Removal of a useless/redundant part in the description "**and capable of meeting space component qualification requirements**"	
TT263	23-A-IV	Changed	Title changed to "**EEE Components Modelling**"	
TT264	23-A-V	Changed	Title changed to "**Radiation Hardness Assurance (RHA) Process**"	
TT265	23-B-I	Changed	Title changed to "**Passive EEE Components**"	
TT266	23-B-II	Changed	Title changed to "**Silicon-Based EEE Components**"	
TT267	23-B-III	Changed	Title changed to "**RF Microwave and Millimetre Wave EEE Components**"	
TT268	23-B-VI	Changed	Title changed to "**Power EEE Components**"	
TT269	23-B-VIII	Changed	Title changed to "**Micro Electro Mechanical Subsystems (MEMS)**"	
TT270	24-B-III	Changed	Title changed to "**Materials Characterisation and Feedback**"	
TT271	24-D-	Changed	Description added	
TT272	24-E-	Changed	Description added	
TT273	24-E-I	Changed	Description added	
TT274	24-E-II	Changed	Description added	
TT275	24-E-III	Changed	Description added	
TT276	24-G-	Changed	Description added	
TT277	24-H-	Changed	Description added	
TT278	24-H-I	Changed	Description added	
TT279	24-H-II	Changed	Title changed to "**Electronic Assemblies Technologies**"	
TT280	24-H-II	Changed	Description added	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT281	25-B-I	Changed	Title changed to "**Software Process Quality Techniques**"	
TT282	25-B-II	Changed	Title changed to "**Software Product Quality Techniques**"	
TT283	25-C-	Changed	Description added	
TT284	25-C-I	Changed	Title changed to "**Product Assurance Processes for Space and Ground Subsystems**"	
TT285	25-C-II	Changed	Title changed to "**Quality Assurance Processes for Space and Ground Subsystems**"	
TT286	1-A-	Changed	Description changed to take **data security** into account	
TT287	1-A-II	Changed	Description changed to take **data security** into account	
TT288	1-B-	Changed	Description changed to take **security** into account	
TT289	2-E-I	Changed	Description changed to take **data integrity** into account	
TT290	4-A-	Changed	Description changed to include potential threats	
TT291	4-A-II	Changed	Description changed to include situational awareness sensors	
TT292	7-B-II	Changed	Description changed to take **interception** models into account	
TT293	8--	Changed	**"Security"** added in the description to complete the whole system engineering process	
TT294	9-B-	Changed	**"Security"** added in the description since it can have an impact on mission operations	
TT295	4-A-	Changed	Title changed to "**Space Environments**" (-s added)	
TT296	4-B-	Changed	Title changed to "**Environments Effects**" (-s added)	
TT297	7-A-I	Changed	**s added to the title "Antenna<u>s</u> Design Tools"**	
TT298	16-B-	Changed	Title changed to "Optical Component**s** Technology and Materials" (-s added)	
TT299	20-A-III	Changed	Title changed to "**Structural Testing Tools and Methodologies**"	
TT300	24-H-III	Changed	Description added	
TT301	6-E-IV	Changed	Description changed to "**Technologies and techniques related to high-power RF amplification using vacuum electronic technologies (e.g. TWT, vacuum triodes and transistors).**"	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT302	6-B-	Changed	Note 6-B-1 added in the description: "*RF Technologies are covered in 6-E*"	
TT303	1-B-IV	Changed	Description changed to take **security** into account	
TT304	6-B-I	Changed	Description changed to: **"All aspects related to ground and space navigation subsystems, Signal in Space, simulators, analysis tools and methodologies. Techniques and technologies to secure end-to-end Navigation services. Antispoofing and Antijamming techniques"** to account for security aspects	
TT305	6-B-III	Changed	Description changed to: "**Covering all aspects related to navigation space (reference) receivers, and related algorithms and technologies including security aspects (antijamming and antispoofing)"** to account for security aspects	
TT306	14-D-	Removed	Subdomain removed; Technology Groups under it, moved to **22-B/In Situ Resource Utilisation (ISRU)** (see **TT17**)	
TT307 (supersedes TT 205 in issue 4.1)	18--	Changed	Title changed to "**Fluid Mechanics**"	
TT308 (supersedes TT 207 in issue 4.1)	18-A-	Changed	Title changed to "**Fluid Mechanics Tools and Techniques**"	
TT310 (supersedes TT 208 in issue 4.1)	18-A-II	Changed	Title changed to "**Engineering Techniques for Fluid Mechanics**"	
TT311 (supersedes TT 209 in issue 4.1)	18-A-III	Changed	Title changed to "**Multidisciplinary Techniques for Fluid Mechanics**"	
TT312 (supersedes TT 210 in issue 4.1)	18-B-III	Changed	Title changed to "**Dedicated Facilities for Fluid Mechanics**"	
TT313 (supersedes TT 211 in issue 4.1)	18-C-	Changed	Title changed to "**Sensors and Measurement Techniques for Fluid Mechanics**"	
TT314 (supersedes TT 212 in issue 4.1)	18-C-I	Changed	Title changed to "**Intrusive Measurements for Fluid Mechanics Applications**"	
TT315 (supersedes TT 213 in issue 4.1)	18-C-II	Changed	Title changed to "**Non-Intrusive Measurements for Fluid Mechanics Applications**"	
TT316 (supersedes TT 214 in issue 4.1)	18-C-III	Changed	Title changed to "**Wireless Measurements for Fluid Mechanics Applications**"	

Change ID	Ref. TT 3.0	Type of Change	Change Description	Ref. in TT 4.1
TT317	18--	New	New Subdomain “**Fluid Mechanics Hardware**”	**18-E**
TT318	18--	New	New Group “**Filling and refilling**”	**18-E-I**
TT319	18--	New	New group “**Fluid Mechanics Hardware Equipment**”	**18-E-II**
TT320	25-B-	New	New group “**Software Security Process Assurance**”	**25-B-III**

Appendix C – Editorial Changes

List of Items with editorial changes (new reference in parenthesis, when available) - improved descriptions, use of terminology in line with ECSS, typos, rephrasing, etc.

1-A
1-A-I, II, III
1-B
1-B-I, II, III, IV
1-C
2
2-A-II
2-D
2-E-I, II, III, IV
3
3-A
3-B-I
4-A
4-A-II
4-B
4-B-II
4-C
4-C-I
5
5-A
5-A-I, II, III, IV, V
5-B
5-B-I, II, III
5-C
5-C-I, II
5-D
5-D-III
6
6-A-I, II, III, IV, V
6-B
6-B-I, II, III, IV
6-C
6-C-I, II, III, IV, V
6-D
6-D-I, II, III, IV
6-E
6-E-I, II, III, IV, V, VI
7
7-A
7-A-I, II, III, IV, V
7-B
7-B-I, II
7-C-I, II
8
8-A
8-B-I, II, III
8-C
8-C-I, II
8-D-I, II
9
9-A
9-B
9-B-I, II, III
9-C
9-C-I, III
10
10-A
10-A-I, II, III
10-B
10-B-1
11
11-A
11-B
11-C
12
12-A
12-A-I, II, II, IV, V
12-B
12-B, I, II
13
13-A
13-A-I, II
13-B
13-B-I, II, III
13-C
13-C-I, II, III, IV, V
14
14-A
14-A-I, II, III
14-B
14-B-I, II, III
14-C
14-C-I, II, III, IV, V, VI
15-A-IV
15-H-VI (15-A-VIII)
15-H
15-H-I, II, III, IV, V
16
16-A
16-A-I, II
16-B-I, II, III, IV
16-C-I, II, III, IV, V
17
17-A
17-A-I, II, IV, V
17-B
17-B-I, II, III, IV
16-C-VI (17-D)
17-C-V (17-E-I)
18-A
18-B
18-C
18-D
18-D-II
19-A
19-A-I, II, III
19-B
19-B-I, II, III
19-C
19-D
19-D-I, II, III, IV
20
20-A
20-A-I, II, III, IV
20-B
20-B-I, II, III
20-C-I, II, III
20-D
20-D-I, II, III
20-D
20-D-I, II, III, IV, V
20-E
20-E-I, II, II, IV
20-F
20-F-I, II, III
20-G
20-G-I, II, III, IV
20-H
20-H-I, II
20-I
20-I-I
20-J-I
21
21-A
21-A-I, II, III, IV, V
21-B
21-B-I, II, III, IV
21-C
21-C-I, II
21-D
21-D-I, II, III
21-E-I, II, III
22
22-A
22-A-I, II, III, IV
21-B
21-B-I, II, III
14-D-I (21-B-IV)
23
23-A-I, III
23-B
23-B-I
24
24-A
24-A-I
24-B-I, II, III
24-C
24-C-III, IV
24-D-I, II, III
24-E-IV
24-F
24-G-I, II
24-B-IV (24-I-VI)
25
25-A
25-A-I, II
25-B
25-B-I, II
25-C-I, II

Appendix D – Acronyms

A&R	Automation & robotics
AI	Artificial intelligence
AIT	Assembly, integration and test
AIV	Assembly, integration and verification
ALD	Atomic layer deposition
AOCS	Attitude & orbit control system
APD	Avalanche photodiode
APS	Active pixel sensor
ASIC	Application specific integrated circuits
ASSP	Application specific standard products
BCR	Battery charge regulator
BDR	Battery discharge regulator
BEC	Bose-Einstein condensate
CAD	Computer-aided design
CCD	Charge-coupled device
CDL	Competence domain leader
CFD	Computational fluid dynamics
CMG	Control moment gyroscope
CMOS	Complementary metal oxide semiconductor
CNT	Carbon nanotube
COSPAR	Committee on SPAce Research
COTS	Commercial off-the-shelf
CPL	Capillary pumped loop
CPT	Coherent population trapping
CSOS	Complex system of systems
CVD	Chemical vapour deposition
CW	Continuous wave
DC	Direct current
DRS	Data relay satellite
DSP	Digital signal processor
EAP	Electroactive polymer
ECLD	External cavity laser diode
ECLS	Environmental control & life support
EEE	Electric, electromechanical & electronic
EGNOS	European geostationary navigation overlay service
EGSE	Electrical ground support equipment
EMC	Electromagnetic compatibility
EPC	Electronic power converter
ESD	Electrostatic discharge
ESTEC	ESA’s European Space Research and Technology Centre
ESTER	European space technology requirements database
EUV	Extreme ultraviolet
EVA	Extra-vehicular activity
FD	Flight dynamics
FDIR	Fault detection, isolation and recovery

FIR	Far-infrared
FOG	Fibre-optic gyro
FPGA	Field programmable gate array
GNC	Guidance, navigation & control
GNSS	Global navigation satellite system
GPS	Global positioning system
GSE	Ground support equipment
HCI	Human computer interface
HEB	Hot-electron bolometer
HMS	Health monitoring system
HPA	High-power amplifier
HRG	Hemispherical resonator gyro
HVI	High-velocity impact
I/O	Input/output
IC	Integrated circuit
IGBT	Insulated gate bipolar transistor
IMU	Inertial measurement unit
IP	Intellectual property
IR	Infrared
ISRU	*In situ* resource utilisation
IT	Information technology
LDA	Laser-diode array
LED	Light-emitting diode
LEO	Low Earth orbit
LHP	Loop heat pipe
LNA	Low noise amplifier
LO	Local oscillator
LOX	Liquid oxygen
MCS	Mission control systems
MCT	Mercury cadmium telluride
MEMS	Micro electro mechanical systems
MEO	Medium Earth orbit
MMIC	Monolithic microwave integrated circuit
MOEMS	Micro-opto-electro-mechanical systems
MOS	Metal oxide semiconductor
MOSFET	Metal oxide semiconductor field effect transistor
NCO	Numerically-controlled oscillator
Nd:YAG	Neodymium-doped yttrium aluminium garnet
NDI	Non-destructive inspection
NER	Nuclear electrical rocket
NIR	Near-infrared
NTR	Nuclear thermal rocket
OSRC	Optical stabilising reference cavities
PA	Product assurance
PCDU	Power control and distribution unit
PDM	Payload data modulator
PDT	Payload data transmitter
PDU	Power distribution unit

PPU	Power processing unit
PVD	Physical vapour deposition
QA	Quality assurance
QCL	Quantum cascade lasers
QCW	Quasi-continuous wave
QDIP	Quantum dot infrared photodetector
QKD	Quantum key distribution
QWIP	Quantum well infrared photodetector
RE	Rare Earth
REACH	Registration, evaluation, authorisation and restriction of chemical substances
RF	Radio frequency
RFC	Radio frequency compatibility
RF-CMOS	Radio frequency complementary metal oxide semiconductor
RHA	Radiation hardness assurance
RoHS	Restriction of hazardous substances
RTM	Resin transfer moulding
RVD	Rendezvous and docking
SAR	Solar array regulator
SAR	Synthetic aperture radar
SIM	Security information management system
SINIS	Superconductor/insulator/normal conductor/insulator/superconductor
SiPM	Silicon photomultiplier
SOC	System on a chip
SQUID	Superconducting quantum interference device
SRC	Stabilising reference cavity
SSPA	Solid state power amplifier
SW	Software
T2SL	Type 2 superlattice
TCF	TECNET Chairs Forum
TD	Technology domain
TECNET	Technology network
TG	Technology group
TNL	Thermal noise limit
TS	Technology subdomain
TT	Technology tree
TT&C	Telemetry, tracking and command
TWT	Travelling wave tube
TWTA	Traveling-wave tube amplifier
UHT	Ultra-high temperature
UV	Ultraviolet
VCO	Voltage-controlled oscillator
VCSEL	Vertical cavity surface-emitting lasers

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