STEPP INPUTS FOR THE SRIA FOR HORIZON EUROPE SPACE TECHNOLOGIES

HIGH LEVEL SUMMARY AND RECOMMENDATIONS

STEPP summary of proposals and development recommendations for the full scale SRIA for Horizon Europe (Space Technologies)

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PREAMBLE

The following document is a high-level summary of the STEPP inputs for the full-scale Strategic Research and Innovation Agenda (SRIA) for Horizon Europe Space Technologies developed in the frame of the STEPP Project.

- The objective of the STEPP project is to provide sector consolidated inputs to the Commission-led consultation platform for Horizon Europe space technologies. The Platform will elaborate a SRIA including High Level inputs and implementation recommendations in the context of Horizon Europe. The SRIA is produced on the basis of an inclusive and structured process designed with a view of supporting the implementation of the Space Strategy for Europe.

- The 'Research and manufacturing sector' has been consulted by STEPP to produce its inputs for the full scale SRIA for Horizon Europe Space Technologies. The 'Research and manufacturing sector', consulted via the respective representative organisations, includes the following stakeholders:

  - **Space manufacturing industry**[1], **including SMEs**[2]: This is (mostly) the private industrial sector that designs, develops, and builds space systems (launchers, spacecraft, Ground segment). The European space manufacturing industry has consolidated sales of 8,49B€ in 2018 and is strong of 43454 employees across Europe. The majority (2/3) are working within 6 large industrial conglomerates such as Airbus, Thales, ArianeGroup, Leonardo..., the remaining (1/3) are distributed amongst a large population of smaller players, including more than 600 SMEs (worth 6% of space employment in industry). These stakeholders are organised within two main professional associations: **ASD-Eurospace**[3] (representing at least 85-90% of sector workforce), and **SME4Space**[4] (representing 5-10% of sector workforce).

  - **Aerospace research establishments**: the complex technology environment of space systems takes advantage of an established base of specialised space and aerospace research establishments (such as the DLR[5] institutes in Germany, CIRA[6] in Italy, NLR[7] in the Netherland, INTA[8] and Tecnalia[9] in Spain, ONERA[10] in France etc.). These research establishments support industry in the context of RDT[11] activities with specific competences in research. They are also equipped with highly technical modelling, simulation, research and test facilities (space propulsion vacuum test chambers, vibration benches, aerothermodynamics tools, space environment models and simulation tools, radiation test facilities etc.). While there is no unified information source on the importance of this sector, current knowledge suggests that this group of entities represent between 5000 and 10000 researchers and technicians involved in space programmes in Europe. There are two main professional associations

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[1] *All space industry data is sourced:* Eurospace Facts & Figures 2019 edition.
[2] *Small and Medium-sized Enterprises*
[3] *Eurospace.org*
[4] sme4space.org
[5] *German Aerospace Centre*
[6] *Italian Aerospace Research Centre*
[7] *Netherlands Aerospace Centre*
[8] *National Institute for Aerospace Technology - Spain*
[9] *Private Technology Center - Spain*
[10] *The French National Aerospace Research Centre*
[11] *Research, Development and Technology*

representing these stakeholders, with a special focus on space research: **ESRE**[12] and **EARTO**[13].

- **Research units in universities** and other higher education establishments: referred as 'Labs', these are usually small (2-15 people) highly specialised research teams providing support in advanced areas relevant to space systems design, development and sometimes production. These labs support the space-manufacturing sector for scientific research (such as wave propagation, materials characterisation, high particle physics, astrophysics, planetary physics, exobiology, etc...) often in RDT phases, but also for the production of complex scientific payloads. These labs will also often be end-users of the research produced in space, and thus support space agencies in Europe for their scientific programmes. There are no unified statistics on the workforce involved in these activities, but the ESA[14] capabilities database[15] (updated annually by Eurospace) identifies 151 of such labs across Europe. The **EASN**[16] brings together the main European universities involved with space and aerospace research.

- **The STEPP inputs for the full scale SRIA for Horizon Europe Space Technologies comprise the following information and recommendations (for each topical chapter):**
  - **European context and justification (WHY)**
  - **Key development areas (KDAs) associated to the objectives to achieve (WHAT is the development target)**
  - **Governance Toolbox (Means to achieve the objective, the HOW), with, for each Key development area:**
    - **Preferred forms of funding**
      - **For all proposed KDAs, the preferred form of funding is the grant**
    - **Preferred implementation mechanisms**
      - **Roadmap based approach (proposal for implementation through a potential European Co-programmed Partnership or a potential Strategic Research Cluster)**
      - **Traditional (not roadmap based e.g. SRC Roadmaps) collaborative research**
    - **Budget per periods (2021-2022; 2023-2024; 2025-2028) in M€**

[12] esre-space.org – Association of European Space Research Establishments
[13] earto.eu – European Association of Research and Technology Organisations
[14] *European Space Agency*
[15] *tec-polaris.esa.int*
[16] *easn.net – European Aeronautics Science Network*

INTRODUCTION

BACKGROUND

In July 2018, the European Commission established a consultation platform for Horizon Europe Space Technologies. The Platform main purpose was to elaborate a SRIA including high level inputs and implementation recommendations in the context of Horizon Europe.

The SRIA was produced on the basis of an inclusive and structured process designed with a view of supporting the implementation of the Space Strategy for Europe. This process notably involved the expression and coordination of views expressed by the European space sector. In order to ensure the plurality of all views, the Platform has provided for the consultation of two communities, whose results were eventually integrated at Platform level. The two communities that have formed the basis of the consultations were:

- On the one hand, the 'Institutional sector' comprised of EU[17] member states representatives, main space agencies in Europe (e.g. ESA, ASI[18], CDTI[19], CNES[20], DLR/Agency) and relevant EU bodies (Council, Parliament, DGs etc.). This community was directly consulted by the European Commission.

- On the other, the 'Research and manufacturing sector', comprised of the manufacturing industry (large and small), the RTOs[21] (public and private), the Labs (Universities and Research establishments). This community was directly consulted by STEPP.

More precisely, STEPP supported the Commission-led consultation platform by providing specific inputs to the European Commission in the context of the Platform.

To do so, STEPP set-up and coordinated a team of experts from the Research and manufacturing sector to elaborate all STEPP inputs to the Platform. Those inputs were elaborated to support the elaboration of the SRIA, with a phased approach that provided for extensive review and feedback loops with stakeholders within the STEPP project and with stakeholders in the European Commission-led Platform. This approach enabled to gather initial inputs from a few selected experts, and expand their vision towards a sector wide consensus by collecting feedback from a much wider community.

After months of work, those consolidated inputs were presented to Commission and institutional stakeholders, as well as the experts from the Research and manufacturing sector, during the STEPP Consolidation and Review Workshop in September 2019 which aimed at reviewing in full the key development proposals emerging from the STEPP process.

Through a full review of the developments proposals prepared and presented by the STEPP experts' teams, the workshop allowed the participating stakeholders to discuss and converge on the budget pointers (mechanisms and level of resources) and the programmatic orientations needed for the SRIA, along with preliminary discussions on the identification of synergy areas and crosslinks. It important to keep in mind that STEPP developments approach is conceived with due respect to existing roadmaps,

The following document is therefore a high-level summary of the STEPP inputs for the full scale SRIA for Horizon Europe Space Technologies developed in the frame of the STEPP Project and presented in the STEPP Workshop.

[17] *European Union*
[18] *Italian Space Agency*
[19] *Centre for the Development of Industrial Technology*
[20] *French Space Agency*
[21] *Research and Technology Organisations*

DOCUMENT ORGANISATION

The STEPP proposal is organised to match the organisation structure of the Consultation Platform established by the Commission to bring together all stakeholders in the SRIA. In order to contribute effectively to the Platform activities, the STEPP input was organised along the 4 working group lines established by Commission:

- **WG Foster Competitiveness of space systems:** addressing RD&I[22] recommendations for topical activities in the areas of spacecraft, satellite, generic spacecraft technologies, supporting ground segments including test and manufacturing.
- **WG Reinforce Access to Space:** addressing RD&I recommendations for topical activities in the areas of launch systems and services improvement, including supporting ground segments, for operations, integration, test and manufacturing.
- **WG Promote Synergies:** STEPP experts have assessed the potential emergence of synergies, aspects of relevance to defence and security concerns and dual-use technologies, and organisational aspects pertaining to the much needed development of a common approach to technology planning across the variety of processes and RD&I promoter entities (national programmes, EU programmes, ESA programmes). These aspects are highlighted as transversal issues whenever relevant, and presented as a dedicated section herein.
- **WG Strengthen opportunities:** within each activity and area falling in the remit of the three topical WGs above, the STEPP experts have elaborated a governance toolbox, assessing the implementation opportunities available with suitable funding schemes and related governance recommendations. The STEPP contribution to the Strengthen opportunities WG was thus elaborated as a transversal input of the WG Foster, the WG Reinforce and the WG Synergies.

The document is thus organised mainly along the system development proposals relevant to the two first WGs, plus additional activities identified specifically for the Synergies domains. Each WG is allocated one section, and within each section the contents are organised in a variety of Chapters, with each Chapter presenting specific Key Development Areas that would be relevant to the elaboration of the future Workprogramme for Space in Horizon Europe. Within each Chapter, the STEPP experts have defined the scope covered by the activities, identified Key Development Areas, and have made the relevant proposals for governance, implementation, budgets, and synergies to feed the discussions in the two other WGs.

The result is comprehensive proposal for a Strategic Research and Innovation Agenda for European space sector competitiveness[23].

[22] *Research, Development and Innovation*

[23] *It is important to note that the Horizon Europe programme for Space has two components. A component addressing competitiveness concerns as well as generic technologies and building blocks, whose SRIA is developed by joining forces between stakeholders in the Research and Manufacturing sector and in the institutional sector, to enable the collection of concerns driven by competitiveness, and commercial market needs. A component addressing RD&I needs of the EU space infrastructures and programmes (Galileo, Copernicus, SSA/SST and Govsatcom), whose Workprogramme is driven solely by the inter-institutional dialogue and comitology, without the direct involvement of the Research and Manufacturing sector.*

FOSTER COMPETITIVENESS OF SPACE SYSTEMS

This section covers 5 main chapters:

- **Foster Competitiveness of space systems,** embracing the core competitiveness needs to enable the strengthening of European space stakeholders' presence and competitiveness on two important commercial market segments, with the promotion of system level end-to-end solutions for **commercial telecommunication**s missions, **Earth observation** missions and their related **ground segments.**
- **Future space ecosystems**: on-orbit operation, new system concepts - this new development area has the potential to modify the space economic environment, with a potential array of commercial applications ensuing. It addresses two main topics: **space sustainability** and de-orbiting technologies and solutions, and the development of system enablers for **on-orbit operations** (such as refuelling and in-orbit maintenance operations, orbital assemblies and robotic manipulation).
- **New industrial processes and production tools**: commonly dubbed *Industry 4.0* this is an area where the introduction and development of new processes and digital tools will impact the sector competitiveness at its core, enabling **faster time to market**, the **optimisation of test and integration processes**, and enabling **larger scale production** to satisfy emerging high volume demands for new applications and markets (e.g. the New Space).
- **Enabling technologies** (cross-mission, space and ground): the space sector is a high-level technology integrator, it requires the prudent integration of the latest available technologies in a few selected areas, for **avionics**, **materials and mechanisms**, **EEE**[24] components, **power**, **propulsion** and **system security**. This chapter, in synergy with the mission driven requirements of the previous chapters, proposes a development path focusing on technologies and building blocks, with a focus to maturing and de-risking the most appropriate solutions for space systems.
- **Contribution to space science:** this chapter makes proposals aiming at keeping the European space sector at the forefront of space science and mission, and at taking full advantage of the richness and variety of space science data available from European missions.

FOSTER COMPETITIVENESS OF END-TO-END SYSTEMS AND ASSOCIATED SERVICES

COMMERCIAL TELECOMMUNICATIONS

European context

The satellite commercial telecommunication (SatCom) market is the first, and largest, commercial market segment in space. It now offers new opportunities. This well-established and historic market is now changing. The digital transformation, the paradigm shifts in mobility and security but also the potential deployment of IoT[25] and 5G networks is bringing new expectations in that market with tremendous data volumes. We now witness a growing interest and the emergence of new players in the space sector willing to take advantage of space-based networks for data. A main driver today is the reduction of the cost of capacity in orbit and the acceleration of SatCom integration into terrestrial networks.

[24] *Electric, Electronic and Electromechanical*
[25] *Internet of Things*

In this market segment, European SatCom manufacturers have adapted on all fronts to maintain a 40% market share over the 2015-2017 period, although the market has suffered from a slowdown affecting the more conventional market demand (with 11 geostationary satellite orders, down from an average 20/year, the year 2018 is emblematic of a market shift), it is expected to come back in the range of 18 to 22 orders over the 2019-2023 period, but with renewed and growing international competition pressure.

The demand in term of competitiveness is to provide growing capacity per system, as well as flexibility and agility to face uncertainties and market evolutions, and improving system availability and latency for some applications to deliver high-quality experience to end-users.

The European research agenda needs to be a competitiveness enabler, promoting a coordinated RD&I plan where the complete system supply chain coordinates its efforts towards achieving core competitiveness goals, enabling the roll-out of innovative solutions and their adoption by end customers.

Key Development Areas

KDA 1: Performing antennas

Europe is facing a US[26] technological dependency for large affordable reflectors and a strong competition on active antennas. Europe require much larger antennas that offer a compact fill factor during launch, at an affordable cost, in particular to match the constellation market challenges.

Ultra-High Throughput Satellites (UHTS) and flexible digital satellite require design breakthrough, new technologies and processes to improve space antenna efficiency, flexibility and affordability, such as new materials with more performance accuracy and thermal stability and additive manufacturing. There is also a need to design very integrated and compact active antennas with advanced deployment and release mechanisms for reflectors and arrays (efficient storage and in-orbit flexibility). Finally, there is a clear need for fully flexible antenna solutions for software defined end-to-end satellite systems and affordable on-ground active antenna for consumer terminals.

The two main target concepts are to develop large and performing reflector antennas for high-gain and low-storage footprint, and large performing Direct Radiating Arrays (DRA) for a flexible and dynamic management of service areas.

The clear objective for the European SatCom supply chain is to develop secure active antennas, fully flexible antennas and new generation compact active antennas (e.g. 5G-compatible).

KDA 2: Satellite data management and processing

Technology evolution and improvements in the field of ground telecommunication are deeply accelerating, driven in particular by the dynamics brought by the cellular transformation wave initiated by the 5G evolution. Keeping satellites communication at the right level of performance will require more performing and compact electronic devices, which still represent a high risk of technology dependence from North America or Asia**.**

Traffic processing capabilities are required by almost all mission types and from any kind of orbit, ranging from broadband connectivity to (narrow band) IoT. Smart and cost-effective solutions are needed for spacecraft adaptation to evolving missions and to accompany the growth in complexity of space infrastructure, such as large, very large and mega-constellation, particularly when using inter-satellite

[26] *United States of America*

links. New generation of data processing systems, based on full software defined and regenerative payload, is required.

This new generation of data processing systems must include dynamic routine and processing of the traffic, simplifying the payload and regenerative payload designs to strongly improve the usage of the scarce frequency resource and optimising ground segment cost of ownership.

KDA 3: End-users terminals

In satellite-based communication systems, devices and means to be installed or put in the hand of the end-users are key to ensure the expected quality of experience, and should not jeopardise the cost-effectiveness solution. End-user mobility is a key challenge to provide connectivity anywhere, at any time and for anybody. It must cover connectivity of systems, for ground and maritime vehicles (aboard ships, trains and automotive) and for pedestrians (mainly through 5G). Non-terrestrial networks must also contribute to extend service coverage and reliability of the global telecommunication network.

The increase of end-user mobility can be mainly reached by the development of multiple beams user terminals such as Flat Panel Antenna (FPA) solutions, both for non-ground and ground segment operation systems. Analysis and bread-boarding must be realised while the user equipment must be integrated for different market requirements.

These developments will be proposed in close coordination with the Ground Segment chapter proposal for development.

KDA 4: Infrastructure and networks

With the emergence of new telecommunication markets, ground infrastructure must be redefined and redesigned. The key development drivers are the new challenges such as higher capacity, flexibility, dynamicity, digital transformation and integration of 5G networks.

These new markets must be assessed in order to demonstrate the technical feasibility and the economical soundness of satellite solutions. New generations of satellite infrastructures, and standardised cellular system networks must be integrated in advanced 5G space-based design networks and ground-software designed networks with secure resource allocation management.

These developments will be proposed in close coordination with the Ground Segment chapter proposal for development.

KDA 5: Powerful broadband systems UHTS/VHTS

Consumer behaviour moved from a linear TV/multimedia consumption model (supported by broadcast solutions) to an IP[27]-connected world where non-linear multimedia consumption is dominating. Broadband satellite service markets, providing connectivity to fixed and mobile users, are still secondary to the large satellite broadcast service markets, but they are growing strong. This trend is expected to be confirmed in the coming years, as long as satellite-based technologies will be offering cost-effective solutions to complement terrestrial networks. The challenge is to increase mission capacity, digital payload flexibility on satellites and last, to develop compact satellites designs to seek further cost efficiencies with rideshare solutions, multiple launch capability, and cost-effective access-to-space.

Highly customised capacitive satellites in geostationary orbit are needed to compete with terrestrial solutions, providing services such as residential broadband and 5G networks, by maximizing system

[27] *Internet Protocol*

efficiency and enabling high data rate concentration on dedicated hot spots within the service area. Platform systems require very high dissipative payloads with more powerful and dissipative broadband missions. More generic and fully flexible geostationary satellites must be developed through a cost-effective approach and sufficiently compact for enabling launch rideshare. Medium capacity range over a large coverage and a large span of various missions (broadband and broadcast) need to be addressed through software defined customisation.

KDA 6: Optical and photonics systems

Next generations of High Throughput Satellites (HTS) systems are expected to achieve higher data rates for Internet and telecommunications services (up to 1Tbps[28]). Implementation of high capacity optical communication links between space and ground is required due to expected bottlenecks of RF[29] systems, also due to the growing competition for the RF spectrum. RF communications mainly use a bandwidth spectrum in saturation, limiting the capacity utilisation. Optical solutions, both in free or guided space, are becoming more integrated and better mastered for an efficient and cost-effective implementation for commercial use.

Photonic solutions are already enablers for very high speed and capacitive data transportation capability within the spacecraft, with a reduced footprint, mass budget, power consumption and accommodation constraints. A higher level of integration at equipment level is now required for photonics. Developments will provide for new photonic RF functions and building blocks filtering and beam-forming), mixed RF and photonic hybrid improved simulation, leading to the development of Photonic Integrated Circuits (PIC) and compact components. The best payload function using photonic components must be identify, by making a trade-off between full RF solutions and photonic based solutions. The capacity of simulating mixed RF and photonic hybrid must be improved at equipment and payload level.

Optical links offer large optical bandwidth compare to conventional RF band, which allow high speed broadband connections. They also enable very capacitive inter-satellite links and ground-satellite links as far as systems are mastered. Seamless interconnection between satellites systems and ground networks must be designed and developed through high throughput optical feeder links (> 1 Tbps), high speed Inter Satellite Links (> 100 Gbps[30]) and Quantum Key Distribution (QKD).

KDA 7: Cyber-secured systems

Space infrastructures are the target of increasingly sophisticated cyber-attacks from a growing number of cyber-capable entities. This creates an unprecedented level of risk considering the growing dependence of the global economy and society on space-based services (and communications networks). The main European weakness is the lack of risk awareness of satellite operators and space industry although if it is usually understood that satellite end-to-end systems need to be protected.

Having a European framework helping industries and operators to be aware, understand, capitalize and share where and how to implement relevant protection measures in a consistent and coherent way is of peculiar importance. An independent European body collecting key information from attacks on space assets and proactively investigating the activity of potential attackers is key but would need public sponsorship to be set up.

Main future challenges that need to be addressed for cyber-secure space systems are the development of new low-cost techniques in order to improve encryption/authentication algorithms, in particular quantic computers capabilities, the development of new low-cost capabilities for RF protection at command

[28] Terabits Per Second
[29] Radio Frequency
[30] Gigabits Per Second

control or user level, and there is the need to customise and improve the cyber security techniques implementation within both on-ground and on-board assets of space systems as they are also fast evolving on standard IT[31] segments.

These developments will be proposed in close coordination with the System Security Solutions chapter proposal for development.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Performing Antennas	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	27	16	10
Satellite data management and processing	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	22	38	25
End-users terminals	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	4	8	4
Infrastructure and networks	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	5	5	4
Powerful broadband systems UHTS/VHTS	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	15	15	15

[31] *Information Technology*

Optical and photonics systems	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	15	30	15
Cyber-secured systems	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	40	40	25

COMMERCIAL EARTH OBSERVATION

European context

Earth observation is the second commercial and export market for the European industry. The current share of European observation satellite manufacturers on the commercial market is around 50%, while the European downstream sector captures around 30% of the imagery products/service market.

The world-wide market demand for imagery (and the related infrastructure) is expected to grow quickly in the next 10 years on the segments for very high resolution (larger satellites) and for mid/high resolution with high revisit (constellations of smaller satellites, and/or high resolution observation from Geostationary orbit, and/or HAPS[32]), with an estimated $33 billion in manufacturing market revenue [ref. Euroconsult]. The commercial resolution standard is today 0.5 m, which is expected to further grow in the next decade, together with an increased appetite for freshness of the information, up to persistent observation capabilities.

The last years have seen the emergence of new aggressive competitors in the High and Very High-Resolution imagery market. On the higher end, the established US and Israel competition is being enlarged by Korean, Japanese and Chinese players. Besides, new private actors are appearing on the mid-high market and their announcements raise high expectations for major price drop, even before any actual service implementation. This context has installed a tremendous pressure on prices for the manufacturing sector. High-resolution systems prices have already been divided by two over the last 10 years and the trend continues, with the perspective to deliver affordable constellations.

To support European competitiveness, innovation is needed on all fronts; from end-to-end system architecture, to platform, payload and ground solutions. Up to now, public support Europe-wide has naturally focused on the institutional programmes (mainly Copernicus and Meteosat at European scale). The time is right to promote a sustainable support to the innovation needed on the commercial and export market.

[32] *HAPS: High Altitude Pseudo Satellites - a variety of HAPS designs are currently being developed for operations in the higher atmosphere/stratosphere, based on inflatables or gliders. They have a largely synergetic technology base with satellites (power systems, payload systems etc.)*

Key Development Areas

KDA 1: End-to-end systems

The demand trends trigger the need to revisit the end-to-end architectures of Earth observation systems, in particular in order to address the expectations for enhanced timeliness and persistence.

A first reflexion axis deals with multi-layers concepts (satellites and possibly HAPS spread on a variety of orbits) and multi-sensors (radar and optical sensors).

Besides, those multi-layers concepts, and also simple constellations, require increased connectivity performance, with High Data Rate (HDR) links between satellites (in plane and out-of-plane), across orbits (LEO/MEO/GEO) and from LEO to ground (e.g. laser feeder links). Also, systems responsiveness will benefit from the optimisation of on-board and on-ground data processing partition with enhanced processing capacities, and enhanced autonomy on-ground and on-board thanks to novel AI [33] techniques.

In parallel, resilience of such complex systems will have to be ensured to face the growing cyber-threats.

Finally, accelerated integration, test and production processes are necessary to manufacture small to medium series of observation satellites.

The objective is to divide the satellite production time by at least 4, which raises particular challenges at optical and radar instrument integration level.

KDA 2: Satellite and platform for Earth observation (including constellation)

The demand for enhanced freshness of the information, up to persistence, has direct impacts at platform and satellite level.

Indeed, further technology progresses are required to develop highly agile small platforms, generate drastic platform cost reduction (design-to-value approach, e.g. thanks to commercial off-the-shelf (COTS) but also novel integration and test methods) and allow on-board management of huge amount of data.

On-board autonomy will also contribute to the overall performance enhancement, allowing optimising the imaging acquisition plans, automatically adapting to events detected within the captured images, and simplify on-ground operations.

KDA 3: Observation payload

To address the usages trends of the next decade at payload level, innovation is necessary along 4 axes.

Industry shall develop affordable optical payloads allowing High to Very High-Resolution in the range 0.2 m to 1 m. Technology break-through is expected in areas such as active optics, novel detectors and focal planes.

Besides, demand for new optical imagery products (e.g. low light and night optical vision, video, better qualification of the observation) requires the development of new observation schemes which have an impact on the platform (e.g. attitude control), novel focal planes (in particular matrixes), new image processing algorithms, the use of new detectors, new spectrally resolving imagers, hyperspectral

[33] *Artificial Intelligence*

sensors and thermal IR[34] sensors adapted to a commercial market. The need for persistence could also be fulfilled through high resolution imagers in geostationary orbit, these solutions are still at too low maturity levels.

On the other hand, the commercial and export appetite for Very High-Resolution radar imagery is growing and can be satisfied only if industry develops lower cost, lower mass and more performing front-end RF technologies, back-end RF technologies and antennas.

At last, implementation of design-to-value approaches is necessary to achieve the necessary drastic cost reduction to address the commercial and export markets (e.g. through mass reduction, enhanced power efficiency, use of COTS and new materials).

KDA 4: Ground segment

The ground segment is a core enabler to satisfy the evolving demand and keep the European sector in the commercial race. Future ground segment shall enable and support Big Data management and processing, satellite fleets management and enhanced autonomy.

Novel AI techniques and IT solutions will be necessary to develop solutions for massive data management on the cloud, multi-sources data fusion ground-segments interoperability, automated fleet control to limit operations.

Cyber-technologies and techniques will also be necessary to enhance resilience to growing external threats.

These developments will be proposed in close coordination with the <u>Ground Segment</u> chapter proposal for development.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
End-to-end systems	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	35	30	10
Satellite and platform for Earth Observation (including constellation)	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	40	35	15

[34] *Infrared*

Observation payload	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	40	30	20
Ground Segment	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	30	10	5

GROUND SEGMENT

European context

Ground operations have been a significant cost driver during the last decade, but now the ground segment is facing a disruptive period. New demand for small satellites with shorter mission lifetimes and drastically cost oriented approaches is increasing. Similarly, the mega-constellations systems are also putting new emphasis on cost management, with the added difficulty of controlling very large satellite fleets. This means a huge increase of data download and data delivery, with the use of higher frequencies but also requirements for data fusion, image intelligence with infrastructure security and an increasing demand on the SatCom market (with applications like autonomous vehicles, offshore communications, 5G networks).

This segment is confronted to a new cost model with strong competition. The competitors are coping with the data rates and scaling from the so-called Newspace approach. They implemented new approaches such as ground automation, standardisation of interfaces or scalable and reliable multi-mission data processing, and also image intelligence processing supported by AI/ML[35]. In order to cope with the international competition, the European Ground Segment supply chain needs to get up to speed.

Technology innovation and maturation can allow the ground operations sector to handle high data rate with stronger security requirements and develop *Software as a Service* (SaaS) with an open and flexible architecture available on cloud.

In this new market situation, Europe may have less visibility on space. China and the US public and private investment are creating technological and cost gaps to provide mission services on ground. Europe shall foster the technology innovation and maturation to keep and improve the current capabilities and competitiveness of the European sector.

Key Development Areas

KDA 1: Ground data handling and processing

Current space observation systems are mostly based on radar and optical payload. They provide static images that need to be analysed with human intervention. This implies a complex organization where

[35] *Artificial Intelligence/Machine Learning*

the human presence is still the key factor to successfully provide a fast response to a potential emergency situation, based on image/data analysis and assessment.

The main development driver today is to increase on-ground processing for Geographic-Information (GEO-I) products, by developing image analytics algorithm with real time capacity, in support of information dissemination to mass market, image intelligence processing for automatic object detection with image fusion for radar and optic systems, and to improve image intelligence. But also, processing for real-time video from satellite, zero-manning automation and automatic data quality analysis for re-calibration needed from detection and in support to correct data delivery.

Satellite missions, especially multi-mission satellites, and the adoption of more sophisticated payloads has increased and led to the need for an efficient handling of massive amount of data, despite the intrinsic scalability offered by the cloud. Basic services must evolve to provide fastest response to queries with instant retrieval of required/relevant data, keeping the focus on what the user is really looking for.

The main requirements are to increase data integration and data interoperability, and ease data delivery by developing semantic data integration, enhance video data management (sequence indexing, semantic search on video), multi-sensors data organisation and indexing and using AI for improving anomaly detection and prediction. That has to be complemented with developments to enhance catalogue, data interoperability and natural language support, standardisation of Analysis Ready Data and Data sub-setting for immediate and simplify delivery.

Current infrastructures have not been designed for todays' applications and are limited by a lack of scalability depending mainly on the lack of information. Satellite constellation missions will increase dramatically the amount of data available for download. Radar and optical missions require to process a massive amount of data for certain types of application. Therefore, the infrastructure has to be re-thought in terms of both hardware and software. Hybrid cloud approaches might become a way federate different infrastructure to support for specific periods a drastic boost of performance, and provide an even more reliable service. Therefore, ground deployment technologies are required such as the use of block chain technologies to track Earth observation data ownership into end-user applications and resilience of (multi) cloud-based ground systems, to mitigate failures and attacks. But also, dockerisation (microservices architecture) and implementation of DevOps[36] concepts for software development, especially secure coding (secDevOps). An AI and ML engine has to be prototyped to find a solution for efficient learning and execution on massive data and a standardisation of Earth observation training data for ML techniques. Finally, cloud computing development is becoming a clear driver for competitiveness with the deployment of models such as public cloud (organisation that sells services), mixed cloud (data sharing with various organisations) and hybrid cloud (composed of two or more clouds). This is a requirement for fast, cheap and flexible services model types such as Software as a Service (SaaS - application type for social contribution), Infrastructure as a Service (IaaS - infrastructure type for technology contribution), Ground segment as a Service (GaaS - application and platform type for environment contribution) and others.

KDA 2: Ground station and terminals

Current ground stations equipment is oriented to a single application, operating in a single frequency band with classic satellites that provide limited bandwidths. The recent arrival of high capacity High Throughput Satellites (HTS) has significantly modified the ground segment. It allows new possibility such as using several frequency rejections bands in the same satellite 'dual frequency systems' and require to switch between beams by frequency rejection and roaming.

[36] *DevOps is a set of practices that combines software development (Dev) and information-technology operations (Ops) which aims to shorten the systems development life cycle and provide continuous delivery with high software quality*

The new constellations (LEO/MEO - satellites) require ground segment tracking capabilities in different orbits and planes to be properly deployed. Reconfiguration to work interchangeably on LEO/MEO/GEO satellites will involve enhancing the technology of flat antennas with electronic beam steering. Finally, Geostationary missions are progressively being moved to lower orbits (LEO/MEO) which growing requirements on the ground stations to operate at higher frequencies and to use more accurate and precise tracking techniques.

The main requirements regarding antenna systems and user terminals are the development of multi-beam and multi-satellite antennas with a change of concept from the geostationary focus to a focus on LEO/MEO systems with multi-beam antennas (e.g. flat panel, phased-array, beam-forming/scanning) now replacing the traditional parabolic antennas aimed one single satellite location in geostationary orbit. This trend has to be complemented with the emerging needs for optical beams compatible antennas and technologies and new terminals for IoT applications.

Concerning the microwave active/passive systems, the ground station European actors need full flexibility/reconfigurability. This can be achieved by new software defined radio technologies, the extension via software of ground station capabilities without changing the hardware, to allow a great level of flexibility by reconfiguring the transmission/reception characteristics depending on the user/service needs. Developing fully digital transmitters/receivers with all-digital RF front ends will provide flexibility improvement of signal central frequency and bandwidth. Moreover, there is clear need to develop a cryo-cooled receiver to improve the sensitivity of the ground stations for interplanetary mission and improve the mitigation techniques such as interference, jamming and spoofing, to secure data and availability of service.

Upcoming space missions will require Telemetry tracking and control (TT&C) modems with new feature and improved performances to satisfy increasingly demanding requirements. In order to answer that challenge, the sector must adapt to new antenna technologies but also develop new digital modulation and coding schemes to make operations possible under a very limited link budget by increasing the telemetry (TM) throughput using variable coding and modulation (VCM) or adaptive coding and modulation (ACM) techniques. Obviously, there is a requirement for a miniaturisation for use in smaller terminals and the development of flexible modems that are multi-mission oriented in order to be adapted to higher data rates for LEO constellations. Spacecraft simulators will also require an upgrade related to TT&C improvements.

These improvements will have to be complementary with new techniques relevant to the station monitor and control (M&C) such as the use of cloud and virtualisation technologies to avoid single point of failure and the standardisation of an interface between M&C products to reduce the dependency from vendor specific solutions and favour competition. Higher automation will reduce human errors and mitigate the impact of any anomaly. Big data, ML and integrated task planning is needed with the development of M&C software for mega-constellations and cybersecurity to protect the ground station from any attack.

Finally, in order to compete on the highly competitive SatCom market, there is a clear need to improve gateways and networks management systems with the development of the GaaS, a standardisation at European level but also a higher flexibility to reuse excess of satellite capacity with inter-operability and new bands (Ka, Q/V, E/W, optical). Ground stations maintenance is also a concern in the future, and new techniques such as augmented reality, use of IoT technologies (added sensors in stations) and predictive maintenance (optimisation of spares, availability) will be necessary.

KDA 3: Control centres and operations

Human intervention for ground task execution needs to be reduced through software enablers, which should decrease the costs of a potential services to be provided to end-users and increase overall skills.

In order to answer this challenge, we need to develop Ground Fault Detection, Isolation and Recovery (FDIR) that identify problems roots cause, isolate and recover them, and also predict similar issues in the future as well as an Automated Decision Support (ADS) that gathers and provides relevant information for the users to take the correct decision, based on AI and ML. A situational awareness system is needed which prevents the information overload and therefore the analysis paralysis effect, it works towards increasing the efficiency of operations by working upon the meaningfulness of the alerts shown to the users, their optimisation and prioritisation. Vehicles preventive maintenance could predict in advance any possible satellite replacement to avoid gaps in service provision and to reduce mission operational costs. An integrated mission planning with a live feedback of operations and an automatic re-planning will enable efficient response to anomalous situations.

Flexible payload management (FLXPL) will allow flexible configuration, real time payload reconfiguration based on inputs and an orchestration of mission re-design as well as payload and ground reconfiguration process automation. Interference control is becoming necessary with intra-system interference estimation, emission and compartmentalisation limits. ML will improve and predict payload needs and efficient mission planning system will be in support of satellite constellation payload management. The evolution towards a GaaS with modular and flexible COTS technologies is aiming at becoming more reliable and scalable with a pay per use model, a growing necessity to tackle the challenge of the multi-mission operations. As well as the fleet management and mega-constellations CONOPS[37] and the space traffic management (FDS[38], collision avoidance, object catalogue). Enabling technologies developments such as human machine interfaces (e.g. voice control, virtual/augmented reality, 3D, holographic, natural language processing) and ground deployment technologies (cloud computing, dockerisation, AI/ML engine prototyping) will support these objectives.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Ground data handling and processing	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	16	16	16
Ground station and terminals	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	16	16	16
Control centres and operations	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	18	18	18

[37] *Concept of Operations*
[38] *Flight Dynamics System*

FUTURE SPACE ECOSYSTEMS: ON-ORBIT OPERATION, NEW SYSTEM CONCEPTS

SPACE SUSTAINABILITY AND DE-ORBITING TECHNOLOGIES AND SOLUTIONS

European context

Space sustainability is becoming a core topic of discussion in the space sector, Europe must be present at the leading edge of this initiative. At the core of the sustainability of the space environment lies the debris situation with its two main dimensions: the prevention/mitigation of debris generation (based on design and de-orbiting solutions at end-of-life) and the remediation (based on eliminating existing debris in orbit).

Europe must promote the maturation of technologies for space sustainability (prevention/mitigation and remediation) in general and de-orbiting aspects in particular to contribute to a sustainable and accessible orbital environment. This technological readiness will place the European industry in a prominent position with respect to future commercialisation of these technologies, anticipating the probable trend for a more stringent regulation environment. An example can be the birth of a business case behind EOL[39] and ADR[40].

Key Development Areas

KDA 1: End-of-life strategies (EOL)

EOL strategies comprise the final steps of a mission to remove the spacecraft from its orbit after the operational lifetime is finished. Key developments must be identified in order to cover existing gaps in the skills and capabilities of the European sector. The efforts must be focused on investigating novel technologies and on improving the current TRL[41] of the existing technologies to fulfil those goals and technological developments. The main development driver is the respect of current regulation for end-of life de-orbiting, and the anticipation of future international standards.

Active re-entry systems with enhanced degree of autonomy and accuracy must be developed to avoid oversized missions and spacecraft. This involves mission/spacecraft design, high-reliability mechanisms, GNC/AOCS[42], propulsion and aerothermodynamics. Passive re-entry, not relying on active spacecraft subsystems, requires development on trajectory optimisation and prediction, high fidelity design, modelling capabilities and high reliability mechanisms. On-board tracking systems must be implemented to determine spacecraft state with the minimum latency and to trigger autonomous operations. Precise prediction of ground casualty risks, trajectory monitoring and ground operations facilities compatible with SSA[43] infrastructure are required as well as the use of passive systems such as conductive tethers.

[39] *End-of-life*
[40] *Active Debris Removal*
[41] *Technology Readiness Level*
[42] *Guidance Navigation Control/Attitude and Orbit Control System*
[43] *Space Situational Awareness*

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
End-of-life strategies	Grants	Traditional (not roadmap based) collaborative research	9	12	10

ON-ORBIT OPERATIONS

European context

On-orbit operation is a game changer for space systems. All the services proposed in orbit (e.g. life extension, refuelling, payload maintenance and repair, active debris removal, in-orbit assembly and manufacturing) would globally reduce the launch mass and life-cycle costs for a satellite mission, by extending its life time, and the extended use-reuse of its systems, promoting the development of new space infrastructures, more sophisticated and flexible, while cheaper. On-orbit operation will transform the concept of 'static space' into a 'dynamic and sustainable space'. It will enable the development of new and disruptive space competencies and technologies.

It is urgent for Europe to develop its own on-orbit operation technologies to take a major role in the market and to leveraging previous developments achieved in H2020 to propose an in-orbit demonstrator mission.

The presence of millions of debris in orbit (dead satellites, rocket bodies and fragments of collisions) constitutes a serious threat to safe operations in space.

Expected regulations and proposals from international institutions will aim at reducing the number of debris, while focusing on prevention schemes. The market anticipations for a debris removal service could be supported by the development of further regulation (international consensus which will likely result in funds allocated for debris removal missions), thus creating an array of opportunities for commercial operators able to supply a debris removal service.

Though it is still nascent, the market for active debris monitoring and removal alone is predicted to grow significantly in the next decade. Market drivers to consider are:

- Increasing number of launch vehicle providers and decreasing costs for satellite development lead to a growing number of operators, and spacecraft, in orbit.
- Deployment of an unprecedented number of satellites in the next 5-10 years, creating added tension on the already crowded (and dangerous) low earth orbits.
    - Several commercial constellations seek to provide affordable internet services globally at very high latency, whilst others focus on target markets such as IoT. Though some of these constellations might not see the day as many are not yet fully funded, the fundamental mega trends such as increased reliance on high-speed internet access or connected objects will likely lead to the successful deployment of some of these projects.
- Commercial operators increasingly developing independent systematic end-of-life management strategies.

- Governments implementing policies focused on active debris removal and allocating budget for the de-orbiting of defunct satellites and of used rocket upper stages.

Key Development Areas

KDA 1: Robotic manipulation

Robotic manipulation is a specific controlled physical interaction between two space objects. It involves such actions as inspection (camera positioning according to various viewpoints), capture (berthing), maintenance (equipment exchange) or refuelling. The end effector at the robotic arm's tip and its interface are an essential element that have to be adapted to the required action: capture of the target space asset, manipulation of units (equipment, payloads, coatings, large structural elements, etc), plugging and unplugging of equipment, exchange of power and data or fluids, cutting (MLI[44], safety wires), screwing/unscrewing bolts, valves).

In each case, the effector must be equipped with an adequate set of sensors (optical, RF, contact, torque and force sensors), and specialised tools to ensure those dexterous operations. Manipulation capability is determined by the arm joints (driving the number of degrees of freedom) and related actuators (joint motors involving advanced mechatronics), orchestrated by appropriate trajectory planning and control. Local intelligence with necessary autonomy has to be implemented on-board to ensure that the robotic operations are achieved with the required accuracy; nonetheless tele-operations may also be involved for remote control, on top of continuous monitoring tasks.

There is a clear need to enhance performances (upgrade and/or repair) of satellites by providing with renewed payloads and/or platform equipment, and pave the way to in-orbit assembly of large essential structures like big antennas.

The activities shall pursue the objective to reach an in-orbit service European standard and to develop space qualified robotic actuators supporting operations with ad hoc interfaces, as well as associated controllers and remote operations capabilities.

KDA 2: Refuelling interfaces for life extension

For refuelling, the efforts will have to be placed to develop a standardized tool box which provides the right mechanical and fluidic interfaces necessary for each application (this allows to provide more than one service on a given mission), be it for chemical (single or bi-propellant) or for electrical (Xenon) propulsion systems. The tools will be designed in order to be interfaced with a common tool drive, featuring the necessary power and data lines. In parallel, effort will also have to be placed towards the development and standardisation of interfaces to streamline the types of end-effectors and allow a better inter-operability between spacecrafts. The qualification of the refuelling interfaces and associated end-effectors and also the systems that demonstrate architectures and technologies for refuelling have to leverage up to maturation.

There will be synergies and coordination requirements with the end-effector developments. The end-effector of the robotic arm and its interface are an essential element that have to be adapted to the required action: capture of the target space asset, manipulation of units, payloads, and large structural elements, plugging and unplugging of equipment, exchange of power and data or fluids. In each case, the effector must be equipped with an adequate set of sensors (optical, RF, contact, torque and force sensors), tools and the necessary local intelligence, in order to implement the required operations with the required accuracy.

KDA 3: In-space robotic assembly/manufacturing

A properly equipped vehicle would act as the key enabler for in-space structures assembly. In-orbit assembly capability will enable satellite manufacturers to change shaped reflectors in orbit or assembling larger solid multi-beam for broadband communication missions, but also in-orbit mating of payloads and platforms, thus upgrading the performance of the mission, while decreasing deployment

[44] *Multi-Layer Insulation*

risk and overcoming launcher volume constraints. Telescopes, mega-antennas, solar concentrators, solar arrays, re-fuelling stations and solar system exploration spacecraft are examples of structures that could benefit from this service.

In-orbit assembly and manufacturing will be implemented in two main steps. The first consist in validating the capability of in-orbit assembly, using units delivered from Earth. It requires the development of ORU[45] interface and end-effector. The second one is the validation of units for in-orbit manufacturing, which requires manufacturing technology demonstrators. Additive and shaping manufacturing techniques are involved such as polymer and 3D printing, extrusion, forming, bending, welding, crimping, as well as the ability to test and accept the manufactured components. A further relevant application could be represented by the (partial) recycling of space debris.

The activities shall pursue three main goals. First, the consolidation of manufacturing and product quality control techniques of large structural elements in space, ensuring that the required characteristics are met. Then, a system study will have to assess the accommodation of adequate manufacturing facilities on board spacecraft. All the system and interface aspects will have to be taken into account: volume, mass, power, thermal control, micro debris generation. Finally, demonstrate systems architectures and technologies for in-orbit assembly and manufacturing, e.g. at ISS[46] (TRL 4).

KDA 4: Active debris removal (ADR)

ADR mission concept and operations cover a wide spectrum of technologies that will enable the development of efficient and reliable missions. Actually, any ADR mission gathers a number of critical technologies which do not show enough maturity to implement a real mission. Although e.Deorbit mission implemented by ESA, where there are still a number of building blocks that need further development, for instance, multi-body dynamics modelling, simulation and testing but also complex IP techniques and vision-based navigation based on AI to yield state of uncontrolled spacecraft. Close-proximity operations around a non-cooperative target, which calls for enhanced control techniques and improved FDIR architectures among others is needed as well as mechanisms to ensure the appropriate contact and attachment in a generic surface or alternatives to the development of a standard interface for attachment.

Stabilization techniques and technologies and flight dynamics techniques for visual inspection of target (different from vision-based navigation) need to be developed. Capture technologies are necessary such as the development of new and maturation of others (e.g. net and harpoon), technologies and flight dynamics techniques for detumbling a target (to allow for capture) and post capture dynamics prediction as well as autonomous on-board collision avoidance manoeuvres based on enhanced data processing and decision-making capabilities.

KDA 5: On-orbit operations demonstration

The On Orbit Operations demonstrations axes would allow to increase the TRL and validate a number of technologies critical for in-orbit operation, enabling to enter in operational area and as a continuation of current EU H2020 relevant projects.

After maturing the critical technologies (manipulators, refuelling interfaces, assembly/manufacturing process, actuators & sensors, GNC, …), the final objective of the next steps is to test in orbit the combination of such technologies and perform the capture of a satellite (large compared to the servicer) through a robotic/mechanism system and the overall controllability, to ensure a refuelling connection and demonstrate its sealing, to transfer fluid (propellant representative) between the servicer and the customer and to transfer and connect (electrical, data) a payload to the customer spacecraft. The demonstration relies on two spacecrafts, one representative of the service and the other of the client. It

[45] *Orbital Replacement Unit*
[46] *International Space Station*

must be equipped with the cooperative servicing interfacing, meaning capture interface, external replaceable units' interface and refuelling interface. This demonstration can be scaled up by adding additional objectives such as in-orbit test of active fuel transfer subsystems, new rendezvous sensors qualification and robotic manipulator for in-orbit servicing.

The demonstration would relies on a set-up featuring a representative of the servicer spacecraft on the one hand, and a representative of the serviced client satellite on the other hand. Both should be equipped with the cooperative servicing interfacing according to demonstration objectives (e.g. specialized interfaces for electrical connection (power, data), replaceable units, capture, fluidic connection and refuelling).

The primary objectives would be then to perform in-orbit demonstration of a set of capabilities among the following: equipment/payload exchange (incl. electrical and data transfer) on the dummy serviced client, mating and connection of large structures (antenna, e.g.) beforehand (manufactured and) assembled by the servicer, active capture, refuelling (incl. connection with sealing demonstration and active fuel transfer).

Further, this demonstration might be scaled up by adding additional objectives such as: new rendezvous sensors qualification, capture and handling of uncooperative satellite clients (incl. stabilization and control of the stack configuration subsequent to capture manoeuvre), possibly extended to tumbling clients, what might then foreshadow active debris removal, etc.

These developments will be proposed in close coordination with the New Injection Solutions Key Development Area proposal for development.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Robotic manipulation	Grants	Roadmap based approach - KDA proposed in potential SRIC	8	8	10
Refuelling interfaces for life extension	Grants	Roadmap based approach - KDA proposed in potential SRIC	3	3	4
In-space robotic assembly/ manufacturing	Grants	Roadmap based approach - KDA proposed in potential SRIC	4	4	6
Active Debris Removal	Grants	Roadmap based approach - KDA proposed in potential SRIC	10	15	15
On-orbit operations demonstration	Grants	Roadmap based approach - KDA proposed in potential SRIC	20	20	30

NEW INDUSTRIAL PROCESSES AND PRODUCTION TOOLS

DIGITALISATION AND NEW PROCESSES

European context

The increasing worldwide space competition requires manufacturing business to explore new ways to design, manufacture, assemble, test and deliver products. Future services will also require better data collection and management from design to delivery.

Time to market needs to be reduced. Digitalisation and design for manufacturing are key to produce products fit for the market on time whilst keeping the right level of product's quality.

Cheaper production costs need to be stimulated. End-to-end digitalisation is key to give access to the real-time data and insights at any production steps for all disciplines. It is the only way to make smarter and faster decisions in shop floors, which can ultimately boost the efficiency and profitability of the entire operations.

Smarter production sites need to be developed based on efficient processes to manage and optimise all aspects of the manufacturing processes and supply chain. The ergonomic of production activities has to be improved.

Finally, sector modernisation will increase the attractiveness of the space industry, as a key to ensure that new talents will join to prepare the future.

Key Development Areas

KDA 1: Digital twin

Digital twin must be used to build and test equipment in a virtual environment. Space system and equipment must have a digital description and simulation capabilities available through the complete lifecycle. It must also use Model Based Engineering and testing software.

Regarding the manufacturing, a digital description and simulation capabilities of production with AIT[47] facilities is needed. This has to be complemented with digital description and simulation capacities of analysis and data analytic tools. Digital twin must also be implemented in AIT Centres and at launch facilities.

KDA 2: Advanced testing

Space systems must use advanced testing techniques that will become accessible with the development of innovative solutions for automated inspection and control that reduce processes lead time and cost are targeting. Also, the use of Built-In test equipment (BITE) to support maintenance processes, the development of advanced test facilities and development of remote testing with the exploration of automatic test results validation and test reports is a key target. Providing automatic reaction to anomalies during tests will become more than useful with the checkout of common elements of the next generation and the use of ML and AI for optimisation.

[47] *Assembly, Integration and Test*

KDA 3: End-to-end connected factory

Connected factories have the objective to use a constant flow of data from connected operations and production systems to learn and adapt to new demand. With the implementation of processes and methods, the overall system can be more efficient and agile, enabling less production downtime and a greater ability to predict and adjust to changes. It can possibly lead to a better competitive position in the marketplace. In order to reach this objective, the sector must develop a digital continuity of supply chain data flow, design as a standard digital platform that will optimise, simplify and structure data exchange between supplier and provider. Secure data exchange to avoid intrusion has to be guaranteed.

An external remote expertise and digital track and trace will enhance visibility of the supply chain with an advanced Statistical Process Control (SPC), that collect and analyse data, to assess variation in process and product characteristics and make decision based on statistical output. Connected Advanced Product Quality Planning (APQP) will ensure customer satisfaction with new products or processes and predictive maintenance method will prevent asset failure by analysing production data to identify patterns and anticipate production stop. Finally, the sector must develop a connected feedback loop, where system's output is used as input for future operation and help in decision making with a digital knowledge management.

KDA 4: Workforce efficiency and advanced manufacturing

There are several solutions to help reducing lead time and increasing the way of working through data information that enable interaction between industrial means and people. Improving the decision-making process, the efficiency and the security of the workforce are key to achieve saving. These solutions require several developments such as augmented workstations to ensure an end-to-end solution based on a 'ready to use' point of use but also an augmented operator using IoT technology to connect people and machines and monitor health and safety of operators. Smart tools and machines such as Robots/Cobots, user friendly tools with continuous information flow will enable a larger adoption by operators and an accelerated training.

To ensure advanced manufacturing, innovative technologies and methodologies are required to improve competitiveness. This means having an efficient and intelligent production and effective organisation. Additive manufacturing design tools can lower manufacturing cost and modular platform for multi-programmes and multitasking can avoid new costly investment for each and every programme. Finally, clean manufacturing with a particular focus on energy, recycling, waste management will be mandatory in the frame of the REACH[48] compliance.

KDA 5: Production flow optimisation

The optimisation of the production flow is an important step in delivering products of high reliability and quality while also respecting the right production time. Developments should focus the digital track and trace to facilitate stock management with a real-time monitoring that show at any time the localisation and manufacturing progress, focusing on highly secured IoT systems to ensure secured connectivity of all required elements inside the factory and outside with suppliers. Process optimisation analytics will

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[48] *REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals - REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. For more information on how the regulation affects the space sector please visit: https://eurospace.org/working-groups/#reach*

[48] *International Traffic in Arms Regulations - a United States regulatory regime to restrict and control the export of defence and military related technologies to safeguard U.S. national security and further U.S. foreign policy objectives. The vast majority of US space qualified technologies and products exports are regulated by ITAR.*

decrease cycle times and increase reactivity in case of issues as well as the production means and remote maintenance.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Digital twin	Grants	Traditional (not roadmap based) collaborative research	2	4	0
Advanced testing	Grants	Traditional (not roadmap based) collaborative research	2	3	0
End-to-end connected factory	Grants	Traditional (not roadmap based) collaborative research	1	2.5	0
Workforce efficiency and advanced manufacturing	Grants	Traditional (not roadmap based) collaborative research	1	2.5	0
Production flow optimisation	Grants	Traditional (not roadmap based) collaborative research	1	1	0

ENABLING TECHNOLOGIES (CROSS-MISSION, SPACE AND GROUND)

AVIONICS

European context

Mission requirements ask for increased performance and autonomy, in order to enable European systems competitiveness. Avionics is a key element that provide the infrastructure upon which user functionalities are implemented. The increase of computer performance and flight reconfigurability have led to develop software and firmware with a higher number of functionalities, in order to simplify the hardware. Performance is a key driver to ensure competitiveness while reducing costs.

Furthermore, rapid evolution of the market will promote flexible solutions based on on-board software and reprogrammable functions to allow hardware reconfiguration.

End-users are changing their mind concerning the reliability of electronics. Further investigations and characterisation will increase the use of commercial technologies for space applications.

Modernisation of satellite operations is needed, in order to provide new services. Operators focus on operation costs reduction and concept simplification with increased on-board autonomy.

Key Development Areas

KDA 1: High capacity reconfigurable FPGAs

European FPGA[49] families need to be extended to larger families, providing high capacity of reconfiguration for complex digital functions. This technology shall be flexible and developed along with efficient HW/SW[50] co-design tools, being in a continuous evolution. FPGA programming environment tools need to be very large and provide efficient tools for simulation and validation.

These developments will be proposed in close coordination with the EEE Components chapter proposal for development.

KDA 2: Specific avionics components/modules

Specific avionics components or modules need to improve overall system performance and reduce costs by implementing high-speed mixed analogue/digital technology, digitally controlled secondary power converters and high-speed serial links with various levels of quality of service and point to point, bus or network technologies. Miniaturisation, functional integration and agile development cycles at satellite level are also key drivers for the New Space applications market.

KDA 3: Data processing platform(s) with reference evaluation

Standardised data processing platform(s) with reference evaluation boards need to be distributed to the European industry. The platform will increase the performance of CDMS[51] central processing function that has processing capability for both control functions and sensor functions.

[49] *Field Programmable Gate Array*
[50] *Hardware/Software*
[51] *Command and Data Management System*

KDA 4: Introduce new CONOPS concepts

Satellite operation required simplification and tooling needs to be improved while reducing cost. Development of new concept of operation (CONOPS) can fill these needs, through the development of Satellite Data Base and associated tooled process to support the OBSW[52] missionisation, the modernisation of existing satellite operation concepts to keep manageable complexity level and the development of specific standards for information exchange between supplier and integrator.

KDA 5: Model Based System Engineering tools

The development of Model Based System Engineering tools will allow the sector to achieve an automated or tooled validation process. These tools shall be efficient for HW/SW co-design, for on-board software auto-code generation but also to support automation of integration, verification and validation (e.g. use of AI and Big Data). Specific standards shall be developed for information exchange between supplier and integrator.

KDA 6: AOCS units and subsystem evolution

AOCS units and subsystem require evolution in term of cost reduction of MEMS[53] gyroscope and medium performance gyroscope (HRG[54]). Optical Navigation sensor should be modular and multi-function and Europe shall develop mini and high capacity CMGs[55]. Reaction wheels should target higher capacity and lower vibration. Platform and payload design require optimisation through active line of sight.

KDA 7: Communications subsystem

New types of communication satellites are increasing such as mega-constellation missions in LEO. In support to the evolution of satellite communications, services and operations shall be extended to new bands and capabilities. On-board and on-ground protocols have to be improved and stacked with novel protocols for uplink, downlink and ranging. S-band and X-bands technologies have to be supported for platforms communications, but also laser communications using low-cost and compact terminals, particularly for inter-satellite links.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
High capacity reconfigurable FPGAs	Grants	Roadmap based approach - KDA proposed in potential SRIC	2	2	4

[52] *On-Board Software*
[53] *Microelectromechanical systems*
[54] *Hemispherical Resonator Gyroscope*
[55] *Control Momentum Gyroscope*

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Specific avionics components/modules	Grants	Roadmap based approach - KDA proposed in potential SRIC	1	1	1
Data processing platform(s) with reference evaluation	Grants	Roadmap based approach - KDA proposed in potential SRIC	2	2	8
Introduce new CONOPS concepts to simplify satellite operations & improve the tooling	Grants	Roadmap based approach - KDA proposed in potential SRIC	9	9	9
Model Based System Engineering tools	Grants	Roadmap based approach - KDA proposed in potential SRIC	2	2	6
AOCS units & subsystem evolution	Grants	Roadmap based approach - KDA proposed in potential SRIC	8	8	11
Evolution of satellite communications	Grants	Roadmap based approach - KDA proposed in potential SRIC	4	4	5

MATERIALS, THERMAL, MECHANICAL, STRUCTURES AND RELATED PROCESSES

European context

Europe has a globally competitive space sector concerning materials, structures and associated manufacturing processes, composed by a large industrial sector and a strong research and science community. Innovations in these fields have always been a catalyst for enabling disruptive space applications. Promotion of innovations in materials, structures and manufacturing processes should therefore be a top priority for Europe, to maintain and further enhance its leading position in space research and technologies.

Materials and associated manufacturing processes are the building blocks for spacecraft, in particular high-performance materials like composites and light alloys for structural functions, but also special adhesives, multi-layer insultation materials, lubricants and primers for other key functions.

The main challenges faced by space materials are driven by structural and mechanical constraints at launch, by the harsh space environment (vacuum, extreme temperatures), by miniaturization needs, and by function integration and demise requirements. Strong trends have been observed towards satellite growing compactness for optimisation of launcher fill-up and multi-satellite deployment. The rapid digitalisation and associated increased number of digital equipment escalates drastically the need for efficient thermal dissipation. The materials development roadmap is also driven by REACH obsolescence concerns.

Europe must strengthen its position as a Newspace actor, bringing disruptive and competitive solutions for thermo-mechanical, structures, materials, with European made technologies.

Key Development Areas

KDA 1: Materials and processes

REACH and export regulations (e.g. ITAR[56]) today affect significantly space material technologies. Cleaner materials and European sources for non-dependence are needed.

Multifunctional or engineering design materials, such as 3D-printed materials and structures or metamaterials, could satisfy the specific functional needs concerning mass/volume ratio, faster innovation cycles and the Newspace industries requirements.

Efficiency in the use of materials and production should be increased to obtain best results minimizing test phase.

Finally, research in disruptive material technologies should continue with a focus on ceramics, high temperature alloys and advanced composites.

KDA 2: Structures

Increasing European manufacturers competitiveness calls for reduction of cost and lead-time. Major challenges consist of moving from a computer-aided design to a fully digital one, composed of large size single block structures with embedded sensors, paving the way to 3D printing. Single functions products should become multi-functions ones with eco-friendly materials and technologies (e.g. mechanical-thermal coupling, thermal-RF coupling). Finally, manual manufacturing operations require digital-aided operations.

KDA 3: Thermal

Innovative thermal control solutions will enable the improvement of European global performances and give support to a wide thermal range, from very high-power telecommunication payload to very compact satellites (e.g. constellations).

Multi-physics engineering and simulation tools are required to reduce design lead time and non-recurring cost.

Solutions for thermal management systems should be investigated for variable emissivity radiators on standard and high temperature missions, especially for mini-satellites concepts, scalable solutions that can be assembled as arrays and particular applications.

[56] *International Traffic in Arms Regulations - a United States regulatory regime to restrict and control the export of defense and military related technologies to safeguard U.S. national security and further U.S. foreign policy objectives. The vast majority of US space qualified technologies and products exports are regulated by ITAR.*

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Materials and processes	Grants	Traditional (not roadmap based) collaborative research	4	2	1
Structures	Grants	Traditional (not roadmap based) collaborative research	6	6	5
Thermal	Grants	Traditional (not roadmap based) collaborative research	4	3	7

EEE COMPONENTS

European context

EEE components are at the source of most electronic and/or photonic systems and hardware that make the core of the satellites. They are key elements to the general trends that are strongly impacting the evolution of space-borne hardware. Two major trends can be considered, one with the need of more flexible and reconfigurable satellites, the other with the need of more affordable solutions for satellites and Newspace trend. Computing/processing, data handling, data links, and data storage are increasingly critical functions aboard satellites, in particular for data hungry applications (such as broadband and mobile communications and remote sensing). The level of performance to undertake these functions is a key driver for competitive advantage in commercial space systems markets.

Space-qualified (radiation hardened) EEE components are a major domain of technological dependence for the space sector. While dependence reduction has been well addressed in the past years through different programmes (mostly via the EU H2020 programme), there is still a lot to do as the geopolitical uncertainties are even more pronounced nowadays. Many critical suppliers in the field of EEE components have been taken over by non-European companies or investors, with unrestricted access to products being growingly jeopardised. The global situation is so complex (e.g. with IP aspects) that it is sometimes difficult to assess the part of dependence that may even affect a product line produced in Europe.

However, it should be recognised that Europe has remained a key player in terms of high-level research and technology centres, with manufacturer of several EEE components' families, knowledge and abilities for back-end, packaging and testing, and a strong end-user presence.

RD&I shall remain strong in this area, with a view to ensuring the level of performance required by critical and commercial space applications with full European availability of EEE parts and components.

Note that the EEE component domain reference has a larger than average number of acronyms. Readers are invited to refer to the acronym list for definitions.

Key Development Areas

KDA 1: Data handling and computing

First and foremost, Europe must develop Ultra Deep Sub Micron (UDSM) digital technologies with sub-22nm transistor-based. The sector should investigate radiation hardness of the thinnest nodes (FinFET or FDSOI[57]). This is essential to the European space industry to create the future ASIC/FPGA hardware. Moreover, companion chips for UDSM are a priority (memories and small passives) as well as the next generations of high capacity FPGA (embedded FPGA, on chip NVM). Europe must develop a commercial base for a sustainable mixed-signal ASIC process. Mixed-signal IP model/portfolio should be reusable, maintained and well supported as well as a cutting-edge high-speed DAC and ADC (up to 60 GHz). Finally, there is a clear need to develop HW architecture for Programmable Neuronal Network (for AI and Machine/Deep learning).

KDA 2: Power components

Regarding power components, Europe needs a flexible and adaptive power sections for better efficiency of power conditioning of units and efficient power components (e.g. power GaN[58] transistors and diodes). Active discrete power components for space are necessary, in particular, a power GaN supply chain in EU, would reduce the issue of European dependence. The development of new integrated circuits for power amplification (POL[59], PWM[60], drivers) and Monolithic integration on WBG[61] technology as well as passive components for power handling and storage such as connectors, relays, magnetics, high voltage resistors and capacitors, super-cap is a priority. Finally, Europe must ensure unrestricted access to materials for TWT[62] production.

KDA 3: Microwave components

There is a clear need regarding Microwave components in Europe and several technologies can answer that needs such as RF/mW on Silicon (e.g. RF CMOS[63], BiCMOS[64] SiGe[65], FDSOI) and the next generations of microwave power transistors (GaN for Ka, Q, V, W-bands, GaN on diamond). But also, a small, integrable, high-Q, RF passives and low consumption switches as well as technologies for Sub-mW and THz active and passive components.

KDA 4: Photonic and optical components

Europe needs photonic components suited for space, from first generation (to be space evaluated) to PICs (e.g. laser diodes, photo-detectors, modulators, amplifiers) and new generation of optical passive components, fibres and interconnects. Moreover, imagers, detectors for earth/planetary observation are also a priority, including high resolution and multi/hyperspectral sensitivity, new generation of image sensors, exploring what is coming from nanotechnologies (e.g. implementation of ALD[66]).

[57] *Fin Field-Effect Transistor or Fully Depleted Silicon on Insulator*
[58] *Gallium Nitride*
[59] *Point of Load*
[60] *Pulse Width Modulation*
[61] *Wide Band gap*
[62] *Travelling Wave Tube*
[63] *Complementary Metal Oxide Semiconductor*
[64] *Bipolar CMOS*
[65] *Silicon Germanium*
[66] *Atomic Layer Deposition*

KDA 5: Packaging issues

Packaging issues may be seen as one of the biggest technology challenge Europe is facing in the near future. In order to have higher level of integration, high frequency and high data rate capability but also, embedded components for higher integration, improved power dissipation and photonic connection, the sector must develop advanced PCBs[67]. High-pin count packages and package-less reliable assembly but also high-density connectors and interconnects for high data rate and high frequencies are needed. Advanced glues (high temperature, anisotropic) and system-in-package for high integration combining and associating digital, microwave and photonic chips are priorities. Advanced concepts such as Wafer Level Packaging (WLP, Fan-in or Fan-out), 2.5D or 3D integration, are necessary to follow the 'More Than Moore' trend. Development in 3D chips integration and advanced materials for ultimate thermal dissipation at the level of electronic circuits, boards or units (e.g. graphene-based, CNT[68]-based) as well as 3D additively manufactured parts, heterogeneous (metals, ceramics, organics) to improve or complement packages and boards are needed. Finally, Electrical Wiring System Integration (Electro-structural Composite for Space Launchers and Satellites) will also be a necessity.

KDA 6: Use of commercial components for lower and more affordable cost

Europe must use commercial components for lower and more affordable cost in the EEE components segment (as well as others). In order to successfully use these components, the sector needs to increase the concept to families of component less concerned so far (e.g. passives and others) and address assembling conform to REACH and RoHS[69] regulations as well as investigate innovative mitigation techniques to allow Pb-less assembling (ex: use of ALD). Radiation hardened die in commercial package and characterization of commercial technologies for radiation performance are necessary. Finally, qualification of Sub Micron digital technologies (COTS) for launcher applications such as radiation environment (SEE[70] triggered by protons or heavy ions), intrinsic reliability (technology) or electromagnetic compatibility will be a challenge.

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[67] Printed Circuit Board
[68] Carbon nano Tubes
[69] RoHS: Restriction of Hazardous Substances Directive 2002/95/EC, short for Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment, was adopted in February 2003 by the European Union. https://ec.europa.eu/environment/waste/rohs_eee/index_en.htm
[70] Single Event Effects

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Data handling and computing	Grants	Roadmap based approach - KDA proposed in potential SRIC	20	20	29
Power components	Grants	Roadmap based approach - KDA proposed in potential SRIC	5	5	9
Microwave components	Grants	Roadmap based approach - KDA proposed in potential SRIC	10	5	8
Photonic and optical components	Grants	Roadmap based approach - KDA proposed in potential SRIC	2	2	15
Packaging issues	Grants	Roadmap based approach - KDA proposed in potential SRIC	3	3	9
Use of commercial components for lower and more affordable cost	Grants	Roadmap based approach - KDA proposed in potential SRIC	5	3	7

This topic is proposed to be implemented through an Horizon Europe SRIC that could be support by the already existing and working Components Technology Board (CTB).

MECHANISMS AND DEPLOYABLE STRUCTURES (INCLUDING SOLAR ARRAYS)

European context

Designing and developing mechanisms for satellites is an important issue, faced with specific constraints starting with the mechanical and acoustic stress during launch phase and the thermal and vacuum conditions of the space environment.

New trends, aiming at increasing the compactness of satellites, led to the development of extremely efficient, low-cost, modular mechanisms and deployable structures.

Bigger space vehicles and instruments will require more complex mechanisms and their performance must be ensured.

Finally, providing reconfigurable missions will require flexible mechanisms and structures to perform adjustment of capabilities.

Mechanism products used for micro-vibration suppression and line of sight stability on satellites are available in the European market and additive manufacturing process for development of space mechanisms have rapidly increased in the recent years. Europe has the potential, through continuous innovation, to strengthen its recognized position on the worldwide market of mechanisms and structures for space.

The mechanisms and deployable structures chapter exhibits synergies with developments in other chapters of the SRIA, such as the on-orbit operations (e.g. telemanipulation, effectors), Earth observation (e.g. jitter and vibration control, stability, LoS[71]) and telecommunications (e.g. large deployable antennas, high power solar generators).

Key Development Areas

KDA 1: Micro-vibration and line of sight (LoS)

Market challenges improvements focus on high-precision systems and high-resolution imaging. The main areas of application have been identified where current technologies have demonstrated their limits and are thus hindering the performance of satellites. Manufacturers need to provide high-precision systems in active instruments for improvement in high-stability LoS visual and IR imaging (LoS between satellites).

Isolating payloads from vibration sources is a priority, the possibility to incorporate active Fast Steering Mirrors (FSM) to compensate injected noise could be a solution. Indeed, high resolution imaging for Earth observation is limited due to satellite jitter and the reduction and attenuation of noise in mechanisms increase the instrument performance.

Satellites using optical communications require improvement of high Line of Sight (LoS) stability for visible and IR imaging to provide high precision, particularly for systems with active instruments that need to reach higher and higher orbits, up to geostationary.

[71] *Line of Sight*

KDA 2: Mechanisms for high power systems and large deployable appendages

Management of high-power systems in space requires developments in mechanisms associated to solar generators with high voltage and to electric propulsion for power transmission and storage.

Hold and release mechanisms solutions require to sustain high loads and to limit the tension relaxation shocks that propagate when released due to space environment.

The development of technologies and products allowing to deploy large appendages from a stowed configuration to an operational configuration, such as thermal radiators, solar arrays, antenna reflectors, pointing mechanisms for electric propulsions and instruments, needs to be accelerated.

KDA 3: In-orbit servicing

As part of future in-orbit servicing missions and systems, mechanisms are expected to be major enablers for autonomous and robotic operations in space, especially for docking and berthing, utility connection, capture, handling and repairing.

KDA 4: Compact mechanisms

To replace current solutions, addressing the trend for more compact and smaller satellites, more compact mechanisms should be developed with enough power to replace current solutions. Innovative solutions need to be investigated, in particular for antenna deployment or thruster orientation mechanisms, large aperture systems or sunshield deployment.

KDA 5: Health monitoring and sensors

In order to ensure effective operation of space vehicles, degradation monitoring and research of different technologies for monitoring and detection of damages on structures and mechanisms are mandatory. Position sensors and sensing technologies applicable to different types of mechanisms, from low-cost high-recurrent applications to specific high-performing sensors, have to be identified.

KDA 6: Additive manufacturing for harsh environment

Additive manufacturing methods are becoming a valid contender for implementing solutions to reduce the mass of structural components and providing a new approach to implement solutions with mechanisms using unconventional configurations. The harsh environment of space requires specific developments and investigations into the robustness of these manufacturing methods.

KDA 7: Deployable structures

Alternative materials for rigid solar array panels need an investigation to develop optimised designs and manufacturing processes for ultra-performant substrates.

The development of flexible solar arrays is a key issue for Europe. Photovoltaic array (PVA) design development needs to be adapted to flexible solar arrays and the assembly of these building blocks requires validation.

General solar array performance and cost efficiency need to be improved to maintain European leadership. Solar concentration requires development based on optical concentration or other technologies adapted to space architecture and conditions. PVA protection needs to be validated for solar arrays operating in a harsh radiation environment.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Micro-vibration and line of sight	Grants	Traditional (not roadmap based) collaborative research	2	2	4
High power systems and large deployable appendages	Grants	Traditional (not roadmap based) collaborative research	2	2	4
In-orbit servicing	Grants	Traditional (not roadmap based) collaborative research	2	2	2
Compact mechanisms	Grants	Traditional (not roadmap based) collaborative research	2	2	2
Health monitoring and sensors	Grants	Traditional (not roadmap based) collaborative research	2	2	2
AM[72] for harsh environments	Grants	Traditional (not roadmap based) collaborative research	0	0	0
Deployable structures	Grants	Traditional (not roadmap based) collaborative research	5	5	6

POWER SOLUTIONS

European context

The power subsystem is a critical enabler for new and evolving space missions. The trends towards higher power needs (driven by telecommunication and observation missions, and also by the generalisation of electric propulsion systems) are driving the power system towards higher efficiency (energy generation, energy density), higher voltage, and compactness.

In order to improve power-system competitiveness, some elements require significant reduction in mass, volume, power dissipation, cost and lead-time. Performance and cost improvement shall be defined at unit level by enveloping new concepts and new technologies such as solar array, and energy storage with different conditioning and distribution units or power processing units. On another hand, other improvements shall be promoted at subsystems level by developing new architectures such as direct drive and harness. The use of space qualified parts as well as COTS parts are also recommended.

[72] *Additive Manufacturing*

Developments in the power field are also necessary with regards to actions already undertaken in H2020 that need to scale up in TRL. Power subsystem needs to have consistency with other subsystem roadmaps of a spacecraft (e.g. telecom, thermal, propulsion). In particular, there is a direct link between the power requirements of the mission and the optimisation of the power subsystem, and there is a strong interaction between the power subsystem and the thermal management requirements.

The key drivers for power subsystems are modularity and flexibility to limit development and recurring efforts, power requirements growth, particularly to support the widespread use of electric propulsion, and finally to improve flexibility and efficiency transfer with digital control and low resistance switching transistors.

Key Development Areas

KDA 1: Power generation efficiency and flexibility

The solar generator is the baseline power generation solution for satellites. Europe must develop solar-generator solutions through innovation addressing next generation multi-junction high-efficiency solar cells, and high-efficiency and easily-scalable solar arrays (e.g. flexible solar arrays).

Other power generation solutions have to be considered for the future with associated innovation and research on regenerative fuel cell system and Radioisotope thermoelectric generator (RTG) and other non-solar power generating sources.

KDA 2: Power regulation and architecture (high voltage and harness optimisation)

After power generation comes power regulation and distribution with the introduction of innovative/digital architectures. Developments shall focus mostly on functions relying on EEE components:

- Digital power control, based on FPGA/ASIC analog/digital with power drivers,
- Wide-bandgap semi-conductors (especially GaN), for which a European source would be welcome as soon as possible,
- Direct Drive capabilities for high electrical thrusts (solar arrays supply directly electric thrusters),
- Distributed architecture for harness optimisation,
- Flat and flexible harness to optimise harness layout and accommodation,
- Satellite passivation, a way to manage debris.

These developments will be proposed in close coordination with the EEE Components chapter proposal for development.

KDA 3: Energy storage (high density/capacity)

Energy storage has been and will always be an issue for in-orbit operations, supplying the energy source with the continuity required by the mission. In order to perform missions and increase the capacity of the satellite, Europe must find solutions to enhance density and capacity storage of energy. This means that Europe shall improve battery costs, chemistry, packaging and also develop super capacitors for bus voltage stabilisation in case of short and high-power demands.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Power generation	Grants	Traditional (not roadmap based) collaborative research	9	5	4
Power regulation and architecture	Grants	Traditional (not roadmap based) collaborative research	7	4	3
Energy storage	Grants	Traditional (not roadmap based) collaborative research	9	5	4

SPACECRAFT PROPULSION

European context

Today the spacecraft propulsion market is organised along two segments: chemical propulsion systems (using traditional rocket propulsion technology), and electric propulsion systems (based on magnetic fields and plasma technology). The two technologies are not fully interchangeable, and some applications will still have to rely on chemical propulsion (particularly when high thrust is required). But it is now commonplace to trade-off the two technologies, based on mission parameters, cost and mass budget.

Electric and chemical propulsion systems are critical spacecraft subsystems and will both still be needed for future European space missions. Improving the available (or developing the feasible) propulsion systems will even enable more challenging missions. The European space propulsion supply range has to become independent from non-EU technologies and the competitiveness of their products has to be fostered in the context of the currently changing requirements and applications for:

- Large satellite constellations, their lifetime extension and de-orbitation,
- In-space services using space tugs for capturing satellites for refuelling, repair or de-orbitation,
- Robotic and man-rated exploration missions to moon and mars,
- Scientific missions to asteroids to explore the possibilities to influence their orbit,
- New generation of cost-efficient telecommunication and earth observation satellites,
- Very small (micro and nano) satellites (e.g. Cubesats).

The main innovation drivers are the costs. Even if the physical principle and the technology heritage of propulsion systems will not be changed in every case, these available products will have to be redesigned in order to achieve cost targets. New manufacturing technologies and materials have to be implemented, the design has to be suited for production in large batches and in automated production lines.

Alternative propellants have to be introduced with the target to reduce the full life cycle cost of the respective mission, and, for chemical systems, to comply with REACH and environmental regulations. Another criterion for alternative propellants research, with a long-term view, is the in-situ availability of the propellant as water on the moon or residual atmosphere on a low-altitude orbit for air-breathing electric propulsion.

Key Development Areas

Key developments proposed in this chapter have strong synergies and complementarity with the proposals identified for In-space Propulsion in the Reinforce access to space section.

KDA 1: Electric propulsion systems

Future electric propulsion systems require innovative and competitive components. The design drivers will be cost, availability, performance and reliability. The different propulsion components shall consist of several modules that reflect the expected functions of the component. This design methodology will allow to produce a maximum of common parts even for different propulsion systems and hence to increase the batch size and optimise the production costs.

The components have to be adapted to standard interfaces (mechanical, fluidic and electrical), the design has to be optimised for a better manufacturability using new processes as 3D printing and the components should be designed for automated series production lines.

The most urgently needed innovative and cost-efficient components are:

- Power Processing Units (PPU) and Radio Frequency Generators (RFG),
- Thrusters, neutralisers/cathodes,
- Pressure and mass flow regulators, isolation valves,
- Flexible harness and connectors,
- Propellant tanks for Xenon and Krypton,
- Thrust Vectoring Mechanisms (TVM).

These components are needed for the different power classes (10 W to 20 kW), thrust ranges (1 µN to 1 N), specific impulse ranges (800 s to 7000 s), lifetime (3 years to 15 years), propellant mass (1 kg to 900 kg).

Alternative propellant solutions to Xenon are a main research area, since Xenon costs are a considerable factor in the overall propulsion system (and they are very unstable, furthermore Xenon worldwide production capabilities are limited). The reasons are that for telecom satellites, Xenon is not only used for station keeping but also for orbit raising, thus consumption is higher. For constellations, the Xenon mass aboard a single satellite is small but for thousand satellites the total Xenon demand becomes quite significant and impactful on total costs. A few alternative gases are known as Krypton and Argon but they will require adaptation of the propulsion system design. When it comes to oxygen or solids propellants like Iodine, the compatibility to all affected materials has to be ensured. In case of solid propellants, a substantial redesign of the whole feeding system is necessary.

Propulsion solutions for Cubesats and Nanosats have to be matured considering the design objectives: miniaturised size, low-cost, high efficiency and low system complexity.

IOD/IOV[73] missions will not only allow to analyse ground/flight performance discrepancies but also provide the in-orbit verification for new propulsion systems or components to increase the reliability prior to commercial use.

[73] *In-Orbit Demonstration/Validation*

Standard references and consolidated diagnostics are required for testing electric propulsion systems on-ground to be able to compare the results from different facilities. Advanced diagnostics also have to be developed in order to support the most recent developments in the field.

For exploration missions to far distances or where heavy loads have to be carried, high-power electric propulsion systems beyond the 20-kW class have to be made available in order to enable such missions.

Some key electric propulsion developments are already pursued in the framework of the H2020 EPIC programme, which will initiate its second phase at the end of next year (2021-2024). EPIC unfolds in two main operating lines; disruptive Technologies (e.g. promoting electric propulsion thrusters, currently with a lower TRL) and incremental technologies (e.g. Hall Thrusters, Gridded Ion Engines, HEMP[74] thrusters). The precise roadmap of EPIC2 programme has not yet been disclosed, thus a harmonisation will be necessary to make sure that EU support is properly allocated to cover all the issues without duplications.

KDA 2: Chemical propulsion systems

Chemical propulsion systems will still be needed complementary to the electric propulsion systems when high-thrust manoeuvres are required or when electric power is not available during the whole mission. The different propulsion components shall consist of several modules that reflect the required functions of the component. This design methodology will allow to produce a maximum of common parts even for different propulsion systems and hence will increase the batch size and optimise the production costs.

The components have to be adapted to standard interfaces (mechanical and fluidic), the design has to be optimised for a better manufacturability using new processes as 3D printing and the components should be designed for automated series production lines.

The most urgently needed innovative and cost-efficient components are

- Thrusters for orbit raising, roll control and de-orbiting,
- Pressure regulators (could be from the same building blocks as those for electric propulsion),
- Valves for isolation, flow control, passivation, proportional regulation,
- Demisable propellant tanks for the different propellants,
- Pressurisation tanks,
- Electrical pumps.

These components are needed for the different thrust ranges (1 N to 1 kN), specific impulse ranges (200 s to 330 s), life time (3 years to 15 years), propellant tank volume range (15 L to 1500 L).

Alternative propellant solutions to hydrazine, hydrazine derivatives and MON[75] for oxidizer are required because of cost. The total life cycle cost for a mission can be remarkably reduced if the alternative propellant is less toxic and if its handling during the test campaigns and the operations during launch preparation can be simplified. Another reason to use alternative propellants is the regulatory obsolescence, due to REACH ban for example. Chemical liquid propellants can only be used in connection with compatible materials. If a propulsion system has to be qualified for an alternative propellant, this might imply to change the materials in all propulsion system components.

The most promising candidate as an alternative propellant is water and it can be used along the mission to produce via electrolysis the propellants (gaseous oxygen and hydrogen) for chemical thrusters. This propellant can probably be collected in-situ on the moon. Such propulsion systems are currently under

[74] *Highly Efficient Multistage Plasma*
[75] *Mixed Oxides of Nitrogen*

development but need urgently IOD/IOV missions to provide the in-orbit verification prior to commercial use.

Chemical propulsion solutions for Cubesats and Nanosats have to be matured considering the design objectives miniaturised size, low-cost, high efficiency and low system complexity.

For exploration missions, chemical propulsion systems with main engines in the thrust range from 6 to 10 kN for ascent vehicles and 30 kN for landers will be needed. The development of these engines was excluded for the Horizon Europe calls.

The new requirements for clean space and the emergence of new in-space services incite the European propulsion systems suppliers to propose new solutions and new technologies such as thrusters for de-orbiting with re-pressurisation system and demisable tanks, throttleable thrusters and valves with electric pumps and electric pressure regulators. In addition, the EOL passivation solution needs non-pyrotechnic isolation valves such as SMA[76] valves.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Electric propulsion systems	Grants	Traditional (not roadmap based) collaborative research	15	7	3
Chemical propulsion systems	Grants	Traditional (not roadmap based) collaborative research	15	7	3
NOTE: EPIC2 budget for electric propulsion development is to be considered on top of the present budget; as mentioned in the text, an harmonization action will be needed to avoid unnecessary duplication of activities.					

SYSTEM SECURITY SOLUTIONS

European context

Space systems, ranging from satellites and ground control centres, are the target of cyberattacks, due to their importance to support many applications in space and on Earth, such as navigation for transportation, telecommunication and disasters management or space surveillance and tracking. Several cyber-attacks have already been witnessed in Europe and there is an increase of potential threats in terms of number and complexity of attacks.

New upcoming applications will increase security needs. Growing systems interconnections are a risk factor, this concerns IoT, space servicing or even constellations. The growing number of satellites planned increase also the collision risks. Space assets will use a larger number of software at spacecraft and ground level, also creating more targets for attacks. Systems potentially under attack are subject to a higher sensibility. Indeed, for example, GNSS[77] is used for a lot for critical applications (autonomous

[76] *Shape Memory Alloy*
[77] *Global Navigation Satellite System*

vehicle). Finally, new system architectures will offer a larger attack surface (e.g. more interconnections, use of cloud), therefore, there is an increase of the risk of mission loss or spacecraft loss.

In Europe, the awareness of risks for the space segment and the importance of analysing space systems as a whole is quite low. The identification of attacks that require security support lacks of initiatives. The main development drivers for system security are:

- Low-cost techniques to improve encryption/authentication algorithms in particular to resist quantic computers capabilities,
- Low-cost capabilities for RF protection at command control or user level,
- Account at ground segment and space segment levels the cyber security techniques that are developed and which are fast evolving at IT level.

Key Development Areas

KDA 1: Identify

A framework for space activities must be established for both commercial and governmental level, involving collaborative work between all space actors and cybersecurity experts. To improve the level of awareness among all actors, actions must be implemented such as standard training, risk analysing performing and governmental expertise centre establishment. Threat intelligence bodies with public and industry expertise, are required, to anticipate threats, allow fast detection, collect all incidents and publish alert bulletins.

KDA 2: Protect

Satellite robustness should be increased against attacks through development of awareness and mitigation solutions. RF protection used against jamming needs to be available at lower cost. Security should be embedded in new software. Ground site, especially cloud-based ground systems, should also be protected from SW attack but also physical attacks.

Space data are increasing and require more secured exchanges with more reactive systems that develop faster authentication processing. Encryption is a key security tool for communications. Crypto solutions should anticipate quantum computing threats, increase the telecommunication link security with Transec solutions, enhance key management especially for IoT and constellations, and improve time performance.

Quantum communication should also be investigated and implemented. Quantum Key Distribution (QKD) will offer the possibility to secure communication links between equipped parties and resist future harder attacks supported by quantum computing techniques.

KDA 3: Detect

As the cyber threats increase, detection capabilities shall also be generalised to detect anormal signs on an infrastructure before attack and to increase security level. Detection capabilities are now well known on ground segment but are not available for all space systems because of the large number of specificities. A generalisation of detection capabilities adapted to space systems and a generalisation of Security Operation Centres (SOCs) for commercial and institutions are required. AI adapted to space system security will contribute to attack detection functions.

KDA 3: Respond and recover

It is essential to anticipate recovery and resilience capacity. The system resiliency, with its capacity to continue operation and recover quickly after a major attack, shall be implemented at mission level and ensure cloud-based ground system resilience. Architecture patterns shall be defined for system resilience. The role of AI in this context shall be assessed.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Identify	Grants	Traditional (not roadmap based) collaborative research	9	4	0
Protect	Grants	Traditional (not roadmap based) collaborative research	12	6	0
Detect	Grants	Traditional (not roadmap based) collaborative research	9	4	0
Respond & Recover	Grants	Traditional (not roadmap based) collaborative research	4	2	0

CONTRIBUTION TO SPACE SCIENCE

CONTRIBUTION TO SCIENTIFIC MISSIONS

European context

Space science encompasses all activities and technological developments that provide explanations about the workings of the universe through astrophysics (astronomy), and how the universe can be perceived physically through space exploration missions.

Europe must take a leading role in the contribution of scientific missions by creating concepts and proposals for new space science missions, maintaining close cooperation with ESA's missions and exploiting the scientific data delivered by European scientific and exploration missions, and by promoting the development of innovative instruments in an international and interdisciplinary environment.

Using widely and sustainably new scientific findings and industrial developments will help the EU to grow further technologies. Sustainable dissemination of space data via integration in education, training and qualification will enable to extend general education and knowledge of EU citizens. Knowledge and technology transfer from space to Earth need to be boosted and high-level scientific publications and data products need to be fostered, especially with the involvement of academic researchers and scientists in the analysis, interpretation and presentation of space data.

Key Development Areas

KDA 1: Science instruments and concepts

System performance and payload capabilities must be improved to promote European readiness for state-of-the-art instrument technologies.

New concepts for large optical telescopes, radio telescopes, using adapted radio interferometry and aperture synthesis, and telescope constellations are required. Development of precise, miniaturised sensors and measuring chains (MEMS technology) are needed to carry out acquisition, registration, evaluation and results analysis of space environmental conditions as well as physical and chemical condition of captured samples and their environment, as well as instruments for life monitoring. Interplanetary transportation systems and orbital space stations must be also implemented. Synergies between space and ground-based observations must be ensure.

New space materials, structures and mechanisms (e.g. multifunctional structures), requirements for high thermo-mechanical stability, pointing accuracy and specific space environmental condition but also miniaturisation, modularisation and low power consumption of building blocks as well as landing probes techniques and on-orbit operations aspects (e.g. production, assembly) are design and technology drivers for new science instruments.

These developments will be proposed in close coordination with the On-Orbit Operations chapter, the New Commercial Space Transportation Services chapter and all the Enabling Technologies chapters proposal for development.

KDA 2: Exploitation of scientific data

Long distance communications are an important parameter for space science, demanding high data rate/high throughput but also Ka, Ku bands and optical solutions. Tools for space data administration of all existing and planned scientific and exploration mission must be developed. Regimentation and code-of-conduct issues must be clearly defined to enable straightforward and manageable access to space data.

Data analysis algorithms and processing must be improved using ML, machine to machine interaction and big data technologies as well as, data storage, management and distribution that must be provided by interoperability, classification and efficient indexing data structures, distribution platforms and tools. It must enhance architecture for the exploitation of space data with respect to volume, timeliness and continuity.

Massive cloud processing required resilience of cloud-based ground systems, solutions for efficient machine learning algorithms and block chain technologies.

These developments will be proposed in close coordination with the Commercial Telecommunication chapter, the Commercial Earth Observation chapter and the Ground Segment chapter proposal for development.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Science instruments and concepts	Grants	Traditional (not roadmap based) collaborative research	5	6	6
Exploitation of scientific data	Grants	Traditional (not roadmap based) collaborative research	1	1	1

REINFORCE ACCESS TO SPACE

This section is organised with 3 chapters:

- **Innovation for competitiveness**, targeting initial operational capability by 2030, addressing mainly launcher **reutilisation** aspects.
- **Fostering and enabling new commercial space transportation solutions**, looking at the future of space transportation, including **new space routes** (e.g. cislunar and orbit to orbit), and **new system concepts, including micro-launchers**.
- **Modern, flexible and efficient European test, production and launch facilities**, means and tools, where new manufacturing and digital environments are applied to launch systems design, modelling, development, test, production and operations.

The synergies between the single chapters and at key development area (KDA) level are high. The development and best use of existing technology bricks and the cross-linking of activities and developments will enable the optimisation and cross-fertilisation of research and innovation areas in this section.

INNOVATION FOR COMPETITIVENESS, TARGETING INITIAL OPERATIONAL CAPABILITY BY 2030

LAUNCHER REUTILISATION

European context

Worldwide technology for launcher reusability has now proved its maturity. Current European reusable technologies are still in development stage. In order to address the reusability challenges and to keep pace with already competing operational systems, it is mandatory for Europe to promptly start and test fundamental building blocks and technologies as well as to validate integrated flight demonstrators at a relevant scale.

Launcher reusability appears as one of the promising development orientations for future launchers. The expected benefits brought by full or partial reusability are on one hand flexibility and reactivity with regards to market variations and on the other hand they offer high potential for launch cost reduction. It is mandatory to develop those technologies and to gain experimental knowledge to achieve future sustainable space access, exploration and exploitation.

Key Development Areas

KDA 1: Stage reusability demonstrators

Flying a reusable demonstrator is a powerful image shaping and communication tool as it provides a large public visibility of a project even through the technology at full TRL and IRL[78] may not be available yet.

The objective of this proposal is to complement the current ESA reusability demonstration initiatives to improve the representativeness of flight environmental and operational situations at a relevant scale.

[78] *Integration Readiness Level*

Research and development should focus on the utilisation of available and affordable flight opportunity to expand the European reusability flight domain database (e.g. micro-launchers, sounding rockets, flight on top of Ariane solid rocket boosters) but also to enhance re-entry and recovery solutions, testing various techniques (e.g. propulsive retro boost and non-propulsive re-entry energy dissipation) as well as landing and recovery solutions (from conventional landing to vertical landing and in-flight capture). New ground operations facilities should be designed in support for early flight tests provided.

KDA 2: Engine technologies

Engine technologies should be designed for extended duration (and multiple operations). Innovative technologies and processes will be investigated. Multi-material 3D printing is an enabler of thermal stresses optimisation and increase life potential. Hydrostatic bearings design could offer a longer engine life and higher speed and additional maturation developments are required.

Regarding launcher equipment, the general innovation trend is driven by the electrification of functions and the related components, especially new generation liquid rocket engine regulation equipment (e.g. electric power valves, reusable ignitors) and embedded engine control system (FADEC[79] with integrated HMS[80]).

KDA 3: Thermal protection

The Thermal Protection System (TPS) is a critical subsystem for launcher in general, and reusability in particular (with specific constraints associated to the atmospheric re-entry phase at high speed). Key developments will address materials, material virtualisation, multi-functional materials, and will be driven by an effort of standardisation.

The TPS must enable launcher reusability at a lower global cost, meaning that production cost and refurbishing cost must not overcompensate the benefits of reusability.

A significant key development consists in virtual material and high-fidelity model for accurate material state simulation as a framework for predictive (manufacturing) quality and health in operation. The virtual material will allow the generation of a digital twin of the thermal protection material and system to better anticipate the need for replacement of parts replacing parts of the TPS.

Multifunctional materials will be obtained embedding electrically conductive nanoparticles inside the thermal protection material to create an electric network. Adding this electromechanical functionality will allow, in conjunction with ML and AI algorithm, to have an in situ, real time health monitoring system. The closed loop and interaction between the virtual material framework and the AI for health sensing will be at the base of the predictive analysis enabling to reduce the burden (and uncertainties) of human visual inspection.

Standardisation of elementary thermal protection systems is an enabler for large production of parts (large batches and series) and therefore cost reduction via economies of scale. Three technologies are required depending on the launcher structural area and recovery concept; non-refurbishable or partially refurbishable replaceable TPS, self-healing long duration, multi cycle resistant thermal protection material and lastly, mixed rigid-inflatable-deployable concept for aero-braking, and structure protection.

[79] *Full Authority Digital Engine Control*
[80] *Health Monitoring System*

KDA 4: Function channel, avionics, GNC, autonomy and flight software

A reusable launcher requires a more complex mission management approach with an increase of flight phases. Consequently, mission management synthesis from high level of flexibility has to be defined in order to provide a quick adaptation to new scenarios and to achieve the correct level of reliability.

To ensure the safety of the landing site, the reusable launcher will have to autonomously decide whether to abort flight or to attempt a landing. This will require a high level of software reliability and an advanced monitoring concept. This will also allow a decrease of costs with a larger perimeter of code generation.

Modular distribution and architecture are required to ensure the two main phases in the sequential management of the separate landing of the stages, which consist in controlling all the stages thanks to a centralised flight control and automating the flight software.

KDA 5: Health monitoring system (HMS)

HMS of a reusable launcher avoids the complete review of the health of the reused subsystem before its next flight. Specific to structures, the Structural Health Monitoring (SHM) system aims to reduce maintenance costs with increased levels of safety. It allows to optimise the use of the structure, minimising downtime and avoiding catastrophic failure. It also improves the product and changes the work organisation. To ensure effective monitoring, the SHM system must be reliable and durable. The development of methods that provide information on structural damages, allowing sensors adaptation to specific needs, must continue.

The reusable launcher qualification needs to integrate SHM system data which will be helpful in choosing pertinent data sets and using them in the global reliability assessment.

SHM system also requires a miniaturisation of its components, especially for the implementation of sensors network and acquisition systems, for power consumption and data transmission and post processing.

Post flight inspection by non-intrusive health check and multifunctional hybrid structures are required to pursue this objective.

KDA 6: Launcher control / Handling qualities

Mission satisfaction relies on the intrinsic performance of the vehicle, its GNC system in charge of this performance management, the sensors consistent to the mission and the actuators that fulfil specific recovery requirements.

The comeback phases of a reusable part of the vehicle are still at low maturity level in Europe, they are open to non-predictable flight domains. Research and development are needed for these phases, especially for the navigation chain and multi engine bay through data fusion methods, for safeguard and re-planification with decision making method, for failure coverage and mission definition through learning methods. Fault detection, isolation and recovery (FDIR) technology must be developed to cover previous requirements.

KDA 7: Tools and simulation for flight physics

Modelling and Simulation (M&S) must implement a common methodology to share and coherently manage operational scenarios, capabilities, functional chains, non-functional characteristics and interfaces in an effective and unambiguous manner. New space systems and new reusable launchers rely on more and more components being coupled together, which leads to even more complexity and require long-term collaboration between expert in various domains.

To meet the objectives and challenges, the sector identified a set of enablers affecting the system engineering methods and tools, such as system engineering tools and Human Machine Interface (HMI) that shall become as natural in the work environment as the office tool suite, to perform everyday engineering activities through tools with a user interface. Collaborative engineering shall be enhanced integrating diverse and transverse disciplines to reduce the time required to bring a new system/innovation to the market. Digital continuity shall be achieved across different disciplines through the adoption of architecture models to produce, share and iterate the specialist's contributions.

M&S for early validation shall be always improved to increase the usage of simulation to anticipate system validation. Data analytics methods shall be developed through AI for several functions to create added values. And lastly, automated knowledge management shall be defined in term of processes, methods and tools for the construction and management of systems engineering ontologies and as a support of complex problems.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Stage reusability demonstrators	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	65	50	50
Engine technologies	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	30	23	21
Thermal protection	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	7	4	4
Function channel, avionics, GNC, autonomy and flight SW	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	7	4	4
Health monitoring system	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	7	4	4

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Launcher control / Handling qualities	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	4	2	2
Tools and simulation for flight physics	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	4	2	2

FOSTERING AND ENABLING NEW COMMERCIAL SPACE TRANSPORTATION SOLUTIONS

NEW COMMERCIAL SPACE TRANSPORTATION SERVICES

European context

The Access to Space industry is undergoing a transformation, not only to reduce the cost of access to space, but also innovating to propose new space transportation services, with a supply push and demand-pull approach. These services include the transportation to new nodes, from orbit to orbit, cislunar missions (including landers and payload return as needed), dedicated launches for very small payloads (with micro-launchers or the development of rideshares). A whole new approach to the launch service market is developing. Following this trend and expanding the European supply array, with appropriate solutions, systems and services can give the opportunity to increase the European commercial space transportation business.

Nowadays, payloads can travel onwards to its final orbit or actively keep its orbit using a European portfolio of critical elements for orbital transportation systems. An extension to this capability is the ability to return payloads to Earth, with a reusable vehicle, and to land on other celestial bodies.

To lower the entry barrier from using space assets, it is important to move towards an end-to-end service capability, where the customer no longer needs specialised knowledge on space transportation services to book a ride. A minimum portfolio of transportation products and technologies should be defined and used as building blocks of this end-to-end service covering all relevant institutional and commercial market needs. As the market is rapidly evolving, proper adaptation of transportation elements is necessary and should cover the whole European transport chain, from development to production and operations.

As other space faring nations are also aggressively positioning themselves to secure strategic access to the lunar surface, Europe needs to ensure an independent as well as commercially viable capability, especially for non-human rated, robotic or experiment payloads. International cooperation has always been key for exploration and Europe needs to ensure a level playing field for that cooperation to be done on an equal partnership level, and to ensure that a lunar orbital economy can be developed with the involvement and contribution of the European sector.

Key Development Areas

KDA 1: Micro-launchers

Dedicated launch solutions for nano and micro satellites are expected to provide flexible, responsive and cost reduction service, to be competitive against rideshare service.

The key for success in European context is to rely to the greatest extent on past, running and coming investments and to leverage on funding or procurement opportunities from various institutions (EU/EC, ESA, National Agencies) for maturing major subsystems technologies (propulsion, structure, separation systems, avionics, operational approaches). The proposed micro-launchers shall take advantage of the maximum technology heritage as far as possible (e.g. with existing or in-plan rocket engines, stages and ground infrastructure). Opportunities shall be assessed based on recurring costs, looking for rationalisation (e.g. propellant type, materials, stage's diameter).

After an exhaustive review of technologies/hardware existing or under-maturation in EU and applicable to a micro-launcher system, it is proposed to list the missing bricks, assess non-space COTS solutions from EU and hardware or technology external to EU with a consolidation of international cooperation opportunities.

The key technology areas for a micro-launcher shall be mastered in the EU and could be part of the specific/complementary developments. Developments will address lighter and cheaper avionics systems, low shock separation systems, green auxiliary propulsion and attitude control subsystems (REACH compliant), space-based telemetry, dispensers for multi-satellites launch solutions, flight software, autonomous safety application, simplified ground segment and AIT operation for higher launch rates. Developments requirement for alternative launch solution like air-launch vehicle could be investigated.

KDA 2: New injection solutions

A flexible space transportation service, operating on an expanded number of market segments, will need to be established, in order to enable the further evolutions of the orbital economy.

The identification of a logistics network of space transportation building blocks that can be used for several missions constitutes a key element for future launch services development. The transportation solutions will cover flexible and modular deployment systems for multiple satellites, motorised dispensers and/or kick-stage transport vehicles to widen the application field with respect to launcher upper stage, low-cost (green and/or electric) propulsion systems, orbital GNC systems, low shock separation systems, payload comfort device improvement for a better service, a transport concept for raw material and fuel for in-orbit vehicles and a vehicle for in-orbit transportation of payloads.

These transportation building blocks will have to be cost effective to ensure a competitive European portfolio of space transportation services.

These developments will be proposed in close coordination with the On-Orbit Operations chapter proposal for development.

KDA 3: Transportation concepts to new space nodes

The entry barrier for the private sector to use space assets as part of their business model has to be lowered by offering an end-to-end space transportation service. This service should provide more transparency to customer by the establishment of optimal connecting nodes and will provide the end-to-end transport service rather than specific knowledge for each element. Transportation operations should change from ‘per mission’ basis to a point-to-point service (e.g. akin to buying an airline ticket) and should include feasibility, accessibility and reasonable pricing.

The evolution of the space market, from LEO, MEO, GEO orbits to cislunar trajectories and Moon landing, will require approaching new space nodes concepts to answer all future market segments. The trend also calls for very large payload capabilities.

The key challenge is to support a European space transportation logistics service by optimally connecting and adapting existing and new bricks. The EU should procure such end-to-end space transportation service, acting as an anchor customer and enabling space transportation industry to sustain and expand their service.

KDA 4: Landing solutions

Several technology building blocks have to be developed in order to propose competitive landing solutions in Europe.

The overall landing functional chain shall be addressed. Precision lander guidance, navigation and control, including reliable sensing capabilities, power and thermal management during the transport phase, entry, descent and landing technologies such TPS[81] materials and solutions, descent systems (e.g. parafoil, retro-rockets and other landing solutions such as inflatable systems) but also structural and mechanical elements need to be developed.

The evolution towards green propulsion system integration is important, able to supply a wide range of thrust.

Landing missions will also require the development of specific communication systems, for direct and through relay systems.

This challenge has synergies, and resonate with the reusability challenge in the previous chapter, considering in particular Earth re-entry, and ground logistics for return to Earth missions.

KDA 5: Autonomy, data fusion, navigation, mission planning

In the recent years, data processing, data transmission and computing power technologies have undergone fast evolutions and have reached a level of maturity in the mass market high enough to allow breakthrough in the launcher industry. Using available technology and adapting it to space transportation would help to tackle the major challenges ahead for cost reduction, availability and reliability.

Through the implementation of an integrated Health Monitoring System (HMS) connected to the enhanced avionics and navigation system, the whole data generated on the launcher could be processed through a powerful computer allowing to monitor subsystem state at every step and support autonomy and reusability, including with the support of AI.

One of the key parameters is data rate speed, which aims at increasing the volume data handled and processed, reliability and power consumption. To ensure these parameters, a high-speed reliable sensor network need to be implemented to allow transmission of any data on the launcher. In order to downlink a large volume of data, ground-board communication require enhanced data links. To process this high-volume data, a multicore on-board computer and AI algorithms are needed.

The maturation of these technologies will also benefit micro-launchers, new injections solutions and landing solutions.

KDA 6: Power distribution, energy storage, thermal management

Two key trends will foster development of new technology for energy/power management in space.

The first objective is to improve data generation and processing through increasing numbers of enhanced sensors as well as high electrification of subsystems while addressing the issue of limited voltage in space.

The second objective is to increase the variety of mission, including long orbital transfer between commercially strategic nodes. It will require long duration energy storage system and improvement of long duration thermal management, especially for cryogenic propellants.

A part of this proposal will take benefit from, and exhibit synergies with, the developments in the relevant generic technologies' chapters, such as the <u>Power Solution</u> chapter.

[81] *Thermal Protection System*

KDA 7: In-space propulsion

Space industry is evolving fast towards a wider commercial use of space assets, including a variety of orbits and extra-terrestrial resources. As a consequence, payloads of multiple sizes and masses will have to be delivered to a growing variety of destinations, possibly sharing transportation means through in-space highways with a mix of energy sources and transfer durations. The key enabler to reach any point using those routes will be the in-space propulsion.

To meet expectations, in-space propulsion will have to use new types of propellants that are green. In addition, propulsion system will have to be efficient, reliable, cost-effective, and the propellant used should be storable in space.

Storable propulsion system should allow multiple ignition and breakthrough throttleable capacities without performance loss. These parameters will also enable propulsion systems to take advantage of In-Situ Resources from celestial bodies.

Management of cryogenic propellant requires a secured storage, including a long-term storage to reduce boil-off but also an identification of mission specific propellant combination and propulsion system.

Concerning electric propulsion, direct dive options and solar-electric driven pump system need to be supported for applications where sufficient solar energy is available.

In-space propulsion technologies and building blocks are also addressed in the Spacecraft Propulsion chapter of the Foster Competitiveness section. Complementarities between the two chapters are high.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Micro-launchers	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	30	22	22
New injection solutions	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	56	42	42
Transportation concepts to new space nodes	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	12	9	9

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Landing solutions	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	12	9	9
Autonomy, data fusion, navigation, mission planning	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	9	7	7
Power distribution, energy storage, thermal management	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	9	7	7
In-space propulsion	Grants	Roadmap based approach - KDA proposed in potential Co-programmed Partnership	12	9	9

MODERN, FLEXIBLE AND EFFICIENT EUROPEAN TEST, PRODUCTION AND LAUNCH FACILITIES, MEANS AND TOOLS

MODERN, FLEXIBILE AND EFFICIENT EUROPEAN LAUNCH AND TEST INFRASTRUCTURES

European context

The main driver of this chapter is to seek cost reduction for more competitive launcher operation and the enabling of new services and new launch services concepts.

New markets and new launch concepts, such as reusability, deployment/replenishment of mega-constellation or even suborbital flights, as well as autonomous and remote operations, will require a modernisation of European ground facilities.

The innovation roadmap will address the new paradigms of launch services, including the emerging new market requirements in terms of time to launch, shorter schedules, new orbital destinations, and payload mass (from very small to very large payloads). It will support new disruptive concepts, such as reusable systems and autonomous/remote operations. Key drivers for the developments are: flexibility, deployability and standardisation.

Key Development Areas

KDA 1: Digitalisation

Launcher manufacturing, integration and operation have the objective of dynamic integration as a frame for flexible and fast reaction to a continuously changing market. A digital process enables the management of real-time data exchange which can generate Key Performance Indicators (KPI) used to solve problems and support in real-time operational decisions. Considering the need to increase launch base productivity, the full availability of the base and the minimisation of the asset's breakdown and downtime are the main objectives to be achieved in the next future. To achieve these different objectives and future needs, a factory 4.0 model is proposed.

The development towards Industry 4.0 has introduced the concept of predictive based maintenance. This concept should be introduced at ground segment level to enable continuous availability of devices, with maintenance planning and also corrective and preventive maintenance.

To enable the continuity of information supporting fast decision making, the connection of all devices is a requirement. The different manufacturing processes should be automated and implemented by monitor to detect and repair in real-time, using ML and connected tools.

Multi-functional/integrated structures are an answer for improving performance and reducing manufacturing and AIT cost. The product multidisciplinary optimisation needs to be balanced between modularity and "integrability". Industrial process simulation tools based on virtual reality needs to be developed in order to check the interest of the function integration.

Digitalisation is also a key driver for human centred production. For operation and training, the production system should be sized respecting the human centric performance and comfort objectives. Virtual environments should be created for operators' activity simulation, training and qualification.

Human factors and ergonomic analysis of digital procedures for production and maintenance, adding Human Machine Interfaces (HMI), will enable informational assistance to workers without task interruption.

These developments will be proposed in close coordination with the Digitalisation and New Processes chapter proposal for development.

KDA 2: Advanced data management

Design, manufacturing and operating space launchers generates very large volumes of data from many sources disseminated over many sites and information systems and with an extensive timeline of several years (decades). Consequently, properly collecting, indexing and linking the various pieces of data is a core challenge for the supply chain. The exploitation of all data will reinforce the efficiency and the capacity to do “right at first time”, and support clever decisions.

Innovative data analysis systems are required to generate new relationship and exploitation paradigms between production, integration and operations phases. In addition, a unique engineering profiling, from design up to operation completion, will optimise the end-to-end supply chain, make the production processes faster and reduce lead time for the release of a new product. These enablers shall also increase the capability for Design for Manufacturing during the development phases, decreasing the need for new specific MAIT[82] means through new launcher developments. Reverse supply chain capability shall be addressed also enabling Maintenance/Revision Operations (MRO) for reusable launcher technologies.

These developments will be proposed in close coordination with the Digitalisation and New Processes chapter proposal for development.

KDA 3: Flexibility and configurability of ground services

The current configuration of ground stations does not allow them to adapt to different launcher systems, or client-oriented services, system reusability and integrated functionalities. Ground facilities and communication shall provide different services in order to respond to future needs. The key innovation drivers are flexibility and configurability.

Ground segment should support systems reusability for control and navigation. It has to be modular, multi-purpose and adaptable and to have remote functionalities. Different technologies can be involved in this development, increasing system efficiency and optimizing costs. New standards shall be defined introducing launcher design requirements enabling design-based ground service flexibility. To reach a greater flexibility both ground segment and the flight system shall evolve to a common standard enabling full flexibility between different missions.

The ground services shall include mission preparation systems based on simulation and Artificial Intelligence for the optimization of complex mission, to reconfigure mission if needed for space services purpose, or to analyse the structure behaviour in case of reusability.

Tracking and data relay ground services need to be improved. Ground facilities should be able to receive data from various sources and directly from space network, but also to process data and operate remotely. Moreover, planning constraints of space network required management from operation centres and inter-satellite optical communication for data transmission need to be implemented.

[82] *Manufacturing Assembly Integration Test*

KDA 4: Modernisation of existing facilities

In the last decade, the demand for launch services has considerably evolved both in terms of quantity and variety, supported by a greater openness to private organisations (triggered by the USA) and by a new wave of enthusiasm towards space exploitation.

The current European launch capability is only composed of two sites (Kourou and Esrange) and is limited in terms of services offered. In Kourou, only one launch platform per type of launcher is available. The Esrange Space Center is dedicated to sounding rockets and atmospheric probes. This situation, together with launcher production rates lower than market demand, represents a bottleneck in the current demand growth scenario.

Digitalisation will enable ‘dematerialisation’. The process of digitalisation aims to store, maintain, upgrade and exploit documentation in dedicated servers to simplify accessibility through personal exploitation environments, according to IoT approach.

Instantiable ground segment, composed by mission-dependent and mission-independent core may oversee the complexity of the current processes that slow down the performance. The ground shall integrate configurability through a transverse ground-board activity, taking into account the standardisation of electrical interfaces, modularity of the system and configurable components, addressing also standards which shall be taken into account by the launcher system and the satellites.

Currently, almost all the elements characterising the ground segment are designed and built to be permanent and there is no provision for relocation from one launch site to another. In order to address cost efficiency of the overall systems and answers to the requirements set by a wider range of missions, R&D[83] activities shall promote the mobility of the ground segment components, in order to relocate them for multiple purposes. Capability of continuous evolution for new features or missions, as already performed in software business, shall be developed. The ground segment shall be able to switch in a continuous evolution mode, as software versions, with constant paced releases in order to fulfil new needs.

The new generation of European launchers shall make use, at the maximum extent, of re-usability technologies. This aspect shall be taken into account in the lifecycle management of the re-usable components: the application of the state-of-the-art technologies like IoT and health monitoring will help in the implementation of agile re-verification/validation of the re-usable components with a consequent reduction in production costs.

KDA 5: Support new launch facilities

After decades of stagnation for space technologies, we are experiencing a large increase of space services and access to space demands. Launch facilities inherited from past investments must evolve to match the new market segments and the new services. Competitiveness will be linked to the capability to reduce cost and time to launch, allowing creation of flight opportunities for the private sector. Appropriate support to launch facilities will enable the changeover.

Ground segment remote operation need to adapt to new service and become modular, to guarantee low-cost and safe command and control system with modular components. Interfaces of ground segment need also to be standardised.

[83] *Research and Development*

KDA 6: Promote the use of existing space tests and launch facilities for new actors

New support policy and financing must be implemented for space users' newcomers exploiting European facilities.

Governance Toolbox

KDA	Preferred forms of funding	Preferred implementation mechanisms	Budget Period (M€)		
			2021-2022	2023-2024	2025-2028
Digitalisation	Grants	Traditional (not roadmap based) collaborative research	6	10	6
Advanced data management	Grants	Traditional (not roadmap based) collaborative research	6	7	10
Flexible and configurability of ground services	Grants	Traditional (not roadmap based) collaborative research	8	11	18
Modernisation of existing facilities	Grants	Traditional (not roadmap based) collaborative research	10	10	4
Support new launch facilities	Grants	Traditional (not roadmap based) collaborative research	13	13	7
Promote the use of existing space tests and launch facilities for new actors	Grants	Traditional (not roadmap based) collaborative research	3	3	5

PROMOTE SYNERGIES

There are several areas where European Space technologies could impact non-space sectors and at the same time non space R&I[84] funds and activities could complement space actions. RD&I efficiency will identify areas where to establish such synergies and to define and implement the most effective approach for cross-cutting activities and cross programme fertilisation.

Actions under the Promote Synergies chapter will:

- Support the development of critical space components, equipment, systems and technologies associated with technological non-dependence. Actions complementary to R&D activities will enhance the implementation of the priorities.
- Promote the use of common technology roadmaps to ensure greater complementarity of R&D projects.
- Support, if and as necessary, research on standardisation and certification for space systems.
- Reinforce synergies between space and non-space sectors and promote technology transfer/cross-fertilization with non-space sectors.
- Exploit synergies between civilian space activities and space and non-space security/defence activities.

TECHNOLOGY NON-DEPENDENCE

The dependence issue is widely recognised and shared among European space and defence stakeholders, constraints and risks being related to foreign countries export control regulations. In order to coordinate the European efforts, Commission, ESA and EDA[85] established the JTF[86], a well-structured and solid process for defining priority actions on critical space technologies on several technology domains. The aim is to carry on the funding of the selected priorities and enhance its implementation.

Coordinated long-term road mapping and end-to-end development plans will provide continuity and enhance effectiveness of the actions. Complementary tasks or actions may address the establishment of market and needs observatories. This should be organised through a dedicated support action. The action should perform an assessment of supply-chain sustainability, among others, innovation procurement and anchor tenancy should be investigated.

DUAL USE / SYNERGIES WITH DEFENCE

The aim is to exploit synergies between civilian and security/defence common needs with the aim to reduce cost, increase the market and improve the efficiency. A coordinated approach on R&D of common technologies serving civilian and security-defence purpose is needed. An approach could be to enlarge the critical space technologies for non-dependence priorities, by also including technologies of interest for defence and security. This will address the identification of common requirements and commonalities under dual use concept. As well, it will aim to aggregate the demand for Space and Defence markets.

As more commonalities can be found in the lower side of the TRL scale, the aim is to mature technology in the low up to medium TRL with a shared approach between Space and Defence. Investments in

[84] *Research and Innovation*
[85] *European Defence Agency*
[86] *Joint Task Force*

terms of technology feasibility studies, proof of concept and demonstration in a lab environment could be joint.

TECHNOLOGY TRANSFER

The aims are to enhance the coordination and reinforce the presence of space in other part of Horizon Europe with the objective of adding requirements of space technologies in non-space technological agendas. Transfer activities encompass different processes with difference objectives:

- Spin-in: to prospect, promote, demonstrate and qualify technologies developed for other use or markets for space uses. Additional funding should be mobilised for projects aiming at bringing COTS components into space applications.
- Spin-off: to match space technologies with non-space needs and support the transfer.
- Cross-fertilisation: between space and non-space by identifying common set of requirements and promoting co-developments in areas as recycling and saving of resources (technologies for the circular economy), micro/nano electronics, materials, additive manufacturing and processes, including in space, digitalisation, virtual reality and AI.

Incentives for joint projects between space and non-space companies and RTO may include proof of concept project based on demonstrators and from labs to industry approach.

BUILDING ON COMMON TECHNOLOGY ROADMAPS

High-level roadmaps will support the implementation of the SRIA priorities, aiming to ensure continuity of funding support to long-term objective. Complementary actions will be established to plug-in the SRIA-driven roadmaps into the technology specific Harmonisation roadmaps issued by ESA. As well, they will aim at enhancing the use of the Harmonisation Technical Dossiers for Horizon Europe call's topic description.

A permanent technology platform and a common roadmaps database will aim to reinforce sector co-operation. As well, they will enhance coordination and reinforce presences of space requirements on other agendas.

STANDARDISATION AND CERTIFICATION APPROACHES

Actions will support uptake and enhancement of space standards, building upon existing standards, extending to areas not covered and adapting to new scenarios such as EGNSS[87] downstream and Copernicus data.

Qualification and certification mechanisms, inspired by models for automotive and aeronautics, may support the establishment of space compatible supply chains and ensure the quality level of parts at reduced costs. Collaborative research in areas where standardisation in space is need could be the implementation mechanism in agreement with standardisation bodies such as CEN/CENELEC[88].

[87] *European Global Navigation Satellite System*
[88] *European Committee for Standardisation/European Committee for Electrotechnical Standardisation*

STRENGTHEN OPPORTUNITIES

In order to foster competitiveness of space systems and reinforce access to space whilst promoting dual use, synergies with defence and synergies between space and non-space sectors, different governance and funding schemes are available in the R&I landscape. The sector stakeholders have reviewed the array of possibilities and have proposed a suitable governance toolbox for all areas proposed for RD&I.

GOVERNANCE, IMPLEMENTATION AND FUNDING SCHEMES OPPORTUNITITES UNDER HORIZON EUROPE

THE IMPLEMENTATION MECHANISMS

The planning and implementation of RD&I programmes can be proposed with two different approaches, from a low level, bottom-up approach, without limited efforts of coordination between projects, to a high level top-down type of approach where research objectives and targets are predefined and RD&I activities are elaborated with a continuous technology planning, exhibiting strong monitoring and coordination efforts to achieve the initially planned overarching goal. Both approaches have pros and cons, and serve different purposes.

Collaborative research

Bottom-up RD&I is usually organised in the EU context through the vector of Collaborative Research. Topics of interest are identified in broad terms, maturity level targets of the research are often rather low, allowing for a wider potential for exploratory research, with a 'blue sky' approach.

The Collaborative Research scheme is usually implemented without the need to elaborate a complex development plan, and relies on the steering and orientations of a programme committee.

Roadmap-based research

Top-down RD&I is usually organised with a well targeted focus, and is supported by a technology plan and development roadmap. The development roadmap defines clear technical targets and research objective, it usually aims at higher maturity outcomes (although the starting point can be at a low readiness level) and promotes a stronger measure of coordination between projects and between calls.

Roadmap-based RD&I requires the setup of a specific entity or process capable of developing the technology plan, and to provide technical support to its implementation. A variety of options are available to support the roadmapping process.

Strategic Research Clusters (SRC)

For some themes, a multiannual programmatic approach is needed, implemented through a linked set of projects, to achieve a critical mass in the global context and to reach long term goals set for those themes. For each SRC, a challenging objective is defined. In many cases, these objectives are likely to be the demonstration of ground-breaking concepts and technologies on-ground, or in space. A roadmap shall be developed for each SRC, defining a set of projects, and also outlining the best suited programmatic or 'system' approach.

The SRC is a system of connected grants with common high-level objectives, to be reached when all the projects are developed and their results put under common frame. In SRCs, a roadmap is developed for the field of activity. The implementation is achieved through individual projects targeting different elements of the roadmap that is built on continuity.

Each SRC targets a specific topic or domain, and is supported by a Programme Support Activity (PSA). All beneficiaries within one SRC are 'complementary' beneficiaries, and as such their interactions are regulated through the SRC Collaboration Agreement.

Two 'pilot' SRCs were implemented in H2020, one on Electric Propulsion (EPIC) and one on Robotics (PERASPERA).

The SRC instrument has been recognised by STEPP stakeholders as a suitable tool to undertake well targeted research topics with the support of a commonly defined technology roadmaps, clearly stated technical targets and with a high level of coordination between projects and grants.

European Partnership Initiatives

Horizon Europe proposes three types of **European Partnership Initiatives.**

Co-funded Partnerships gather external entities managing and/or funding research and innovation programmes, other than Union funding bodies. In this case, the EU finances at least 30% of the eligible costs. While other sectors have made extensive use of this instrument in H2020 (e.g. ERA-Net Smart Energy Systems), up to now, this scheme has proved to be difficult to use in the space sector.

Co-Programmed Partnerships are based on memoranda of understanding or contractual arrangements among partners. These include the identification of complementary research and innovation activities to be implemented by the partners and by the Programme. Relevant examples under H2020 are the contractual Public and Private Partnerships (cPPPs) on robotics in Europe SPARC and Factories of the Future.

Institutionalised Partnerships are based on Articles 185 or 187 of the TFEU[89] for Joint Undertakings (JUs), and on the European Institute for Technology and Innovation (EIT) Regulation for the Knowledge and Innovation Communities (KICs).

The European Commission proposed that in Horizon Europe a co-Programmed Partnership ***<u>Globally Competitive European Space Systems</u>*** is established to address a subset of topics identified in the Space technologies SRIA. This proposal is welcome by the STEPP stakeholders.

The partnership will support global sector competitiveness via cost reduction strategies and by enabling the penetration of current and new and emerging markets.

The partnership will create added value, by ensures the Commitment/Involvement of all stakeholders, by generating additional activities, and leverage effects and by enabling multi-annual planning of activities that supports the emergence of demonstrators and large-scale projects.

The partnership key functions will include:

- Support the implementation, monitoring and updates of the SRIA,
- Support the elaboration of the annual Workprogrammes,
- Support the emergence and multi-annual planning/funding of demonstrators,
- Propose and assess KPIs, quantitative objectives,
- Promote coordination of activities (JTF, ESA Harmonisation).

[89] *Treaty on the Functioning of the European Union*

The scope of the partnership will be negotiated with all interested parties and potential participants. STEPP stakeholders have already pre-selected a few 'core partnership areas' in the proposals for the SRIA. They are the ones most driven by commercial market and competitiveness concerns. The core areas for the partnership are:

- Commercial Earth observation,
- Commercial telecommunications,
- Competitive ground segments,
- New space transportation (incl. micro-launchers),
- Reusable launch systems.

THE FINANCIAL/FUNDING INSTRUMENTS

Under the European Union Financial Regulation different **forms of EU funding** are possible.

Grants are direct financial contributions, which cover part or all direct and indirect costs.
Innovation Procurement can deliver solutions to challenges of public interest. *Public Procurement of Innovative solutions (PPI)* is used when challenges can be addressed by innovative solutions that are nearly or already in small quantity in the market and do not need new R&I. *Pre-Commercial Procurement (PCP)* can be used when near-to-the-market solutions do not exist yet and when new R&I is needed. PCP can then compare the pros and cons of alternative competing solutions. This will in turn enable to de-risk the most promising innovations step-by-step via solution design, prototyping, development and first product testing.

Prize is an award attributed to whoever best meets a given challenge. Currently, a prize on Low-cost Space Launch is open with a EUR 10 million award under the European Innovation Council pilot. This instrument is foreseen to continue under Pillar III of Horizon Europe on Open Innovation.

Financial instruments are included in the Union budget and are implemented, inter alia by the European Investment Bank (EIB) and European Investment Fund (EIF) via financial intermediaries and addressing different type of entities (start-ups, SMES, large companies) as beneficiaries as well as different phases of business development. These include products such as loans, venture capital, or guarantee schemes.

For space technologies and competitiveness support in Horizon Europe, **grants shall remain the main form of funding for space R&I activities**. They have been overwhelmingly supported as the most attractive and adapted funding mechanisms by all stakeholders in STEPP, for almost all programmatic areas identified.

KEY INPUTS FROM THE STEPP STAKEHOLDERS ON THE EUROPEAN COMMISSION'S PROPOSAL FOR A CPEP FOR GLOBAL COMPETITIVE SPACE SYSTEMS

The inputs presented below are the results of internal meetings and discussions at STEPP level on the European Commission's proposal for a Co-Programmed European Partnership for Global Competitive Space Systems.

STEPP PRELIMINARY INPUTS ON THE CPEP – DECEMBER 2019

STEPP Stakeholders are supporting the European Commission's proposal to define, with the institutions, the conditions for the emergence of a Co-Programmed European Partnership for Global Competitive Space Systems.

STEPP Stakeholders have set-up an internal process to bring up to Commission's knowledge the inputs of the research and manufacturing sector, comprised of the manufacturing industry (large and small), the RTOs (public and private), the Labs (Universities and Research establishments).

The inputs are composed of top-level general principles on the governance of the partnership, and second, on more specific issues related to the partnership's key features.

Top level General principles on the CPEP Governance

Balance of powers and role of the Member States:

On the balance of powers and responsibilities between STEPP stakeholders and the institutional sector in the partnership, an **equal split between institutions (under the MoU signed with COM) and the 'supply chain'** (under an ad hoc association, or MoU between Associations) should be a **minimum**.

The general decision-making principle in the Working Groups and in the Board should be, as far as possible, **based on consensus**. In case of no consensus, a decision making process should be defined with equal weights between institutions and the Associations

Additionally, STEPP Stakeholders believe that if the Member States (and Space Agencies) are already part of the institutional side of the partnership (based on the COM scheme)

- The SPEG terms of reference should be assessed of refined, because it would triplicate the presence of the Member States in the process at 3 levels (Partnership board, SPEG, and Programme Committee).
- If Member States are not part of the institutional side of the partnership, STEPP Stakeholders believe an advisory role could be well-suited to the SPEG in the partnership.

In each of the future Working Groups of the partnership, **experts coming from the Member States (and National Agencies) need to be involved** in the work/ co-drafting to make sure that they **guarantee the complementarity of actions** with the European and national programmes already put in place.

Openness of the partnership:

The Partnership should be **open to any new actor** that has expressed its interest to join, providing that it joins the partnership either via the various associations (on the private side) or via the Member States (on the institutional side).

Role of the Private side of the partnership:

As per other partnerships (H2020 partnership contractual arrangements), the European Commission should, in the future Contractual Arrangement, "**commit to duly consider inputs from the Private Side** etc.". It will guarantee that technical and programmatic inputs and budget recommendations by the Private side of the partnership to the Commission are **necessary inputs for the Work Programmes preparation**.

The Private side is ready to **commit to leverage** to the extent that its **inputs are correctly translated into the calls** dealing with competitiveness and in line with the current outlines of the SRIA that have been endorsed by all parties during the SRIA Platform Steering Committee meeting of November 7th.

The Private side commits to **ensure the monitoring of the KPIs**.

The various associations represented through STEPP (i.e. ESRE, EARTO, SME4SPACE, Eurospace) agree to **collaborate and work internally towards finding the most efficient solution**, in terms of internal organisation, to best implement their contribution to the private side's activities of the Partnership.

Specific principles related to the partnership's key features

Added values of the partnership:

Political visibility of the European space sector in Horizon Europe: The partnership is considered as the best platform to coordinate inputs and be visible to a non-space-specific Programme Committee, in a highly competitive cluster.

Consequently, the partnership will contribute to **secure a multi-annual budget** for Horizon Europe space technologies for competitiveness.

The partnership will **federate the different actors** (European Commission, Member States, agencies (incl. ESA), industry, SMEs, research technical organizations & research establishments) around common objectives and priorities. The variety of actors coupled to the openness will also **ensure for complementarity of actions** (with regards to ESA and national space programmes).

The partnership between European Commission, Member States (and Agencies) and the Associations will help **co-planning, roadmapping** and building on an ambitious SRIA dealing with prioritised content, associated to disruptive and innovative solutions that can answer the worldwide competitive market **on mid and long term** (i.e. roadmapping approach aiming at a common long-term objectives implemented with d**emonstrators**). Moreover this co-working mechanism will provide the leverage effect on the competitiveness and capabilities of the whole supply chain across Europe.

The partnership will allow for a **cross-functionality of activities** between within and outside the cluster.

Scope of the partnership:

The STEPP stakeholders are in the opinion that the budget dedicated to the partnership should be at the level of the ambitions developed in the whole SRIA.

The STEPP stakeholders fully support the European Commission's proposal to have a co-programmed partnership encompassing the entire scope of the SRIA. The STEPP stakeholders have nevertheless agreed on topic priorities inside the SRIA in the case that the partnership will not encompass the whole SRIA. (Find in annex 1).

Giving the low visibility on budget issues, more iteration with European Commission on how the other domains within our cluster are dealing with the issue of the division between partnership scope and the activities outside the partnership scope (i.e. in traditional collaborative research) would be useful.

Specific objectives:

The specific objectives of the partnership are directly linked to the scope of the partnership for which more information is needed for the STEPP stakeholders to converge, as described above.

In the frame of the topics priorities defined above (e.g. scope of the partnership), if the partnership is not encompassing the full SRIA, the STEPP stakeholders have defined specific objectives corresponding this potential scope. (Find in Annex 2).

Leverage:

As stated in the general principles regarding the governance, the Private side is ready to **commit to leverage** to the extent that its **inputs are correctly translated into the calls** dealing with competitiveness that would deliver the leverage effect on the European worldwide market positions.

ANNEX - ACRONYM LIST

Acronyms are usually explicated within the text when they are used the first time. This list is provided for all further reference.

5G: Fifth generation of cellular networks
ACM: Adaptive Coding and Modulation
ADC: Analog-to-Digital Converter
ADR: Active debris removal
ADS: Automated Decision Support
AI: Artificial Intelligence
AIT: Assembly, Integration and Test
ALD: Atomic Layer deposition
AM: Additive Manufacturing
AOCS: Attitude and Orbit Control System
APQP: Advanced Product Quality Planning
ASI: Italian Space Agency
ASIC: Application Specific Integrated Circuit
BICMOS: Bipolar CMOS
BITE: Built-in test equipment
CDMS: Command and Data Management System
CDTI: Centre for Development of Industrial Technology
CEN/CENELEC: European Committee for Standardisation/European Committee for Electrotechnical Standardisation
CIRA: Italian Aerospace Centre
CMG: Control Momentum Gyroscope
CMOS: Complementary Metal Oxide Semiconductor
CNES: French Space Agency
CNT: Carbon Nano-Tubes
CONOPS: Concept of operations
COTS: Commercial Off The Shelf
cPPP: Contractual Public and Private Partnerships
DAC: Digital-to-Analog Converter
DevOps: DevOps is a set of practices that combines software development (Dev) and information-technology operations (Ops) which aims to shorten the systems development life cycle and provide continuous delivery with high software quality
DG: Directorate General
DLR: German Aerospace Centre
DRA: Direct Radiating Antenna
DSM: Deep sub-micron
EARTO: www.EARTO.eu - *European Association of Research and Technology Organisations*
EASN: www.easn.net - European Aeronautics Science Network
EDA: European Defence Agency
EEE: Electric, Electronic and Electromechanical (components)
EGNSS: European Global Navigation Satellite System
EIB: European Investment Bank
EIF: European Investment Fund
EIT: European Institute for Technology and Innovation
EOL: End-of-Life
ESA: European Space Agency
ESRE: www.esre-space.org - *Association of European Space Research Establishments*
EU: European Union
FADEC: Full Autonomy Digital Engine Control
FDIR: Fault Detection, Isolation and Recovery
FDS: Flight Dynamics System
FDSOI: Fully Depleted Silicon On Insulator
FinFET: Fin Field Effect Transistor
FLPXL: Flexible Payload management
FPA: Flat Panel Antenna
FPGA: Field Programmable Gate Array
FSM: Fast Steering Mirrors
GaAs: Gallium Arsenide
GaaS: Ground segment as a Service
GaN: Gallium Nitride
Gbps: Gigabits per second
GEO: Geostationary Earth Orbit
GEO-I: Geographic-Information
GNC: Guidance Navigation Control
GNSS: Global Navigation Satellite System
H2020: Horizon 2020
HAPS: High Altitude Pseudo Satellite
HDR: High Data Rate
HEU: Horizon Europe
HMI: Human Machine Interface
HMS: Health Monitoring System
HRG: Hemispherical resonator gyroscope
HTS: High Throughput Satellite
HW: Hardware
IaaS: Infrastructure as a Service
INTA: National Institute for Aerospace Technology in Spain
IOD/IOV: In Orbit Demonstration/Validation
IoT: Internet of Things
IP: Internet Protocol
IR: InfraRed
IRL: Integration Readiness Level
ISS: International Space Station
IT: Information Technology
ITAR: International Traffic in Arms Regulations
JTF: Joint Task Force
KDA: Key Development Area
KPI: Key Performance Indicators
LEO: Low Earth Orbit
LoS: Line of Sight
M&C: Monitor & Control
M&S: Modelling and Simulation
MAIT: Manufacturing Assembly Integration Test
MEMS: Microelectromechanical systems

MEO: Medium Earth Orbit
ML: Machine Learning
MLI: Multi-Layer Insulation
MMH: Monomethylhydrazine
MON: Mixed Oxides of Nitrogen
MRO: Maintenance/Revision Operations
mW: Millimiter Wave
NLR: Netherlands Aerospace Centre
NTO: nitrogen tetroxide
NVM: Non-Volatile Memory
OBSW: On-Board SoftWare
ONERA: The French National Aerospace Research Centre
ORU: Orbital Replacement Unit
PCB: Printed Circuit Board
PCP: Pre-Commercial Procurement
PIC: Photonic Integrated Circuit
POL: Point-of-Load
PPI: Public Procurement of Innovative solutions
PPU: Power Processing Units
PSA: Programme Support Activity
PVA: Photovoltaic Array, Photovoltaic Assembly
PWM: Pulse Width Modulation
QKD: Quantum Key Distribution
R&D: Research and Development
R&I: Research and Innovation
RD&I: Research development and Innovation
RDT: Research Development Technology
REACH: Regulation, Evaluation, Authorisation and Restriction of Chemicals
RF: Radio Frequency
RFG: Radio Frequency Generator
RoHS: Restriction of Hazardous Substances Directive 2002/95/EC
RTG: Radioisotope Thermoelectric Generator
RTO: Research and Technology Organisation
SaaS: Software as a Service
SatCom: Satellite Communications or Communication Satellite
SEE : Single Event Effect
SHM: Structural Health Monitoring (system)
SiGe: Silicon Germanium
SMA: Shape Memory Alloys
SMEs: Small and Medium-sized Enterprises
SOC: Security Operation Centre
SPC: Statistical Process Control
SRC: Strategic Research Cluster (H2020 appellation)
SRIA: Strategic Research and Innovation Agenda
SRIC: Strategic Research and Innovation Cluster (Horizon Europe appellation)
SSA: Space situational Awareness
SST: Space Surveillance and Tracking
STEPP: Space Technologies for Europe Pilot Project
Sub-mW: sub-Millimiter Wave
SW: Software
Tbps: Terabits per second
Tecnalia: Private technology centre in Spain
TFEU: Treaty on the Functioning of the European Union
THz: TeraHertz
TM: Telemetry
TPS: Thermal Protection System
TRL: Technology Readiness Level (see relevant annex for details)
TT&C: Telemetry Tracking & Control
TVM: Thrust Efficient Multistage Plasma
TWT: Travelling Wave Tube
UDMH: Unsymmetrical dimethylhydrazine
UDSM: Ultra Deep Sub Micron
UHTS: Ultra-High Throughput Satellite
US: United-States
VCM: Variable Coding and Modulation
VHTS: Very-High Throughput Satellite
WBG: Wide Band gap
WG: Working Group
WLP: Wafer Level Packaging

ANNEX - THE TECHNOLOGY READINESS SCALE (TRL)

This section is based on excerpts from the official ECSS TRL Handbook: ECSS-E-HB-11 (2017).

BACKGROUND

The TRL methodology was originated at NASA in the 1970s in order to establish a method by which NASA selected new technology amongst numerous candidates for their complex spaceflight programmes. The scale progressed until 1995 with the definition of nine levels that became the Mankins 95 reference (M95r). From that moment, the principle of a maturity scale was adopted by many companies and government agencies around the world. However, although they were somewhat similar, different definitions or interpretation of the M95r were used. ECSS decided, in 2008, to first make a harmonization at European level and then to propose to ISO a global harmonization in 2009. This then resulted in an ISO New Work Item Proposal (NWIP) 'Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment'.

The ISO standard 16290 was published in 2013 and as a result, TRL are now globally harmonized. ECSS actively contributed to this ISO standard by providing members to the ISO WG. The ISO standard concerns the definition and the criteria of assessment, however the procedure for the TRL assessment or the way to use them within a project's framework was not the purpose of the standard. The standard is applicable primarily to space system hardware, although the definitions are used in a wider domain in many cases.

TRL AND ASSESSMENT BASIC PRINCIPLES

Technology readiness assessment (TRA) allows for the assignment of a measure of the maturity of a technology. It is important to make clear that undertaking a TRA is not a method to develop technologies. The way to develop, to test, to qualify or to verify the development cycle of products, or the model philosophy defined by projects, are not the object of TRL but the purpose of others discipline-specific ECSS standards and handbooks.

The measure provided by TRL assessment is valid for a given element, at a given point in time, and a given defined environment. It changes if the conditions (such as operational environment) that prevailed at the time of the assessment are no longer valid. Such a situation leads to TRL reassessment and re-grading, which can occur in particular when the re-build or re-use of an element is envisioned with variation in the design, development process, targeted environment or operations.

During Research and Development, or Research and Technology (R&T&D) activities, TRL can be used by the specialists developing the technologies to present their development plans (e.g. technology roadmaps) and to communicate with non-specialists or project managers, the costs or risks involved in taking particular technology choices with different TRLs.

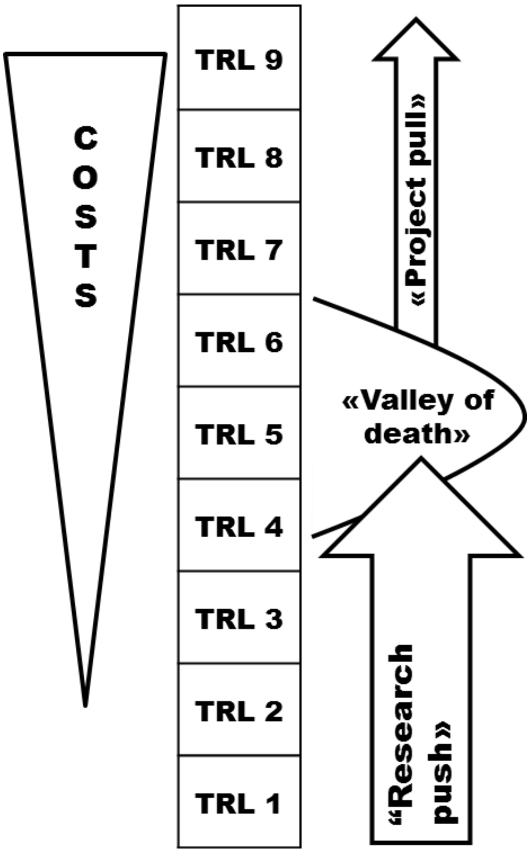
In the framework of projects, TRL is used during preliminary phases (0, A, B) as a tool supporting the decision whether or not to use or integrate specific technology in a space mission, and allowing such decision to be taken with sufficient knowledge of any risk relating to the degree of maturity.

Generally, R&T&D programs push ('research push') the technologies maturity as far as the intermediate TRLs. Projects then pull some technologies and develop these to the higher levels of maturity.

The intermediate levels of maturity (typically TRLs 4, 5 and 6) are sometimes called 'valley of death' since some technologies are developed until TRL 4 or below, however they are not developed beyond this achieved level (i.e. in the absence of a project "pull"), noting that projects are normally interested in TRL 6 or above (see **Figure**).

The costs associated with a specific technology achieving a higher level of TRL are generally increasing with each level attained.

Figure - Evolution technology maturity



It is important to highlight the following aspects in the application of TRL:

TRL assessment is not intrinsic to a technology: if a new target environment has different constraints or performance requirements, a TRL needs to be reduced (e.g. a TRL 9 in one application falls even as far as TRL 4 in another).

TRL 5 and higher are assessed to a specific mission environment. When an element at a TRL higher than 5 is intended to be used in a different environment, in this case there is a potential that the TRL is downgraded.

TRL does not take into account industrial capacities of production or technology access constraints (e.g. export control regulations).

TRL does not take into account technology obsolescence, however conversely obsolescence can drive the need for a TRL re-assessment.

If the production of anything inside an element is discontinued, the TRL of the element can be affected (see example ‘Heritage category C’.

TRL does not replace development cycle or quality rules.

TRL is not mandatorily incremental: it is not mandatory to achieve level 5 (sub-scale) before proceeding to level 6. More generally, it is not mandatory to go systematically through all levels.

A TRL can only be reached by an element if all of the sub-elements are at least at the same level.

An R&T&D action does not necessarily lead to an increment in TRL.

The time or effort to move from one TRL to another is technology dependent and cannot be linearly projected along the TRL scale.

The proof necessary for the assessment of TRL is as follows:

For TRL 7 and 8, when the derivation of the evidence for the assessment of TRL is based on testing, the test is performed using the requirements of ECSS-E-ST-10-03. It is important to note that testing alone is not sufficient when assessing a product for TRL 7 and TRL 8.

However, for TRL 1 to 6 where the derivation of the evidence for the assessment of TRL is selected to be based on testing, the test is performed using the state-of-the-art rules relevant to the TRL being assessed.

TRL SUMMARY - MILESTONES AND WORK ACHIEVEMENT (ADAPTED FROM ISO 16290)

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 1: Basic principles observed and reported	Potential applications are identified following basic observations but element concept not yet formulated.	Expression of the basic principles intended for use. Identification of potential applications.
TRL 2: Technology concept and/or application formulated	Formulation of potential applications and preliminary element concept. No proof of concept yet.	Formulation of potential applications. Preliminary conceptual design of the element, providing understanding of how the basic principles would be used.
TRL 3: Analytical and experimental critical function and/or characteristic proof-of-concept	Element concept is elaborated and expected performance is demonstrated through analytical models supported by experimental data and characteristics.	Preliminary performance requirements (can target several missions) including definition of functional performance requirements. Conceptual design of the element. Experimental data inputs, laboratory-based experiment definition and results. Element analytical models for the proof-of-concept.
TRL 4: Component and/or breadboard functional verification in laboratory environment	Element functional performance is demonstrated by breadboard testing in laboratory environment.	Preliminary performance requirements (can target several missions) with definition of functional performance requirements. Conceptual design of the element. Functional performance test plan. Breadboard definition for the functional performance verification. Breadboard test reports.

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 5: Component and/or breadboard critical function verification in a relevant environment	Critical functions of the element are identified and the associated relevant environment is defined. Breadboards not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effects.	Preliminary definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Preliminary design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Analysis of scaling effects. Breadboard definition for the critical function verification. Breadboard test reports.
TRL 6: Model demonstrating the critical functions of the element in a relevant environment	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) in form, fit and function.	Definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Design of the element, supported by appropriate models for the critical functions' verification. Critical function test plan. Model definition for the critical function verifications. Model test reports.
TRL 7: Model demonstrating the element performance for the operational environment	Performance is demonstrated for the operational environment, on the ground or, if necessary, in space. A representative model, fully reflecting all aspects of the flight model design, is build and tested with adequate margins for demonstrating the performance in the operational environment.	Definition of performance requirements, including definition of the operational environment. Model definition and realisation. Model test plan. Model test results.

Technology Readiness Level	Milestone achieved for the element	Work achievement (documented)
TRL 8: Actual system completed and accepted for flight ("flight qualified")	Flight model is qualified and integrated in the final system ready for flight.	Flight model is built and integrated into the final system. Flight acceptance of the final system.
TRL 9: Actual system "flight proven" through successful mission operations	Technology is mature. The element is successfully in service for the assigned mission in the actual operational environment.	Commissioning in early operation phase. In-orbit operation report.
NOTE: The present Table, taken from ISO 16290, is reproduced with the permission of the International Organization for Standardization, ISO. This standard can be obtained from any ISO member and from the Web site of the ISO Central Secretariat at the following address: www.iso.org. Copyright remains with ISO. The standard can be obtained from ISO or its members, see www.iso.org		