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estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
T +31 (0)71 565 6565
F +31 (0)71 565 6040
www.esa.int

DOCUMENT

GSTP Element 1 “Develop” Compendium 2019: Advanced Manufacturing

Prepared by	**TEC-T**
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1. INTRODUCTION

The GSTP E1 "Develop" Compendium 2019: Advanced Manufacturing, is a list of candidate activities for the GSTP E1 "Develop" Work Plan. The aim of the GSTP E1 "Develop" Compendium 2019: Advanced Manufacturing, is to provide to industry and Delegations a consolidated overview by Competence Domain of the priorities in the development of Advance Manufacturing technologies within the GSTP Programme.

This document follows the previous GSTP Element 1 Compendia of Potential Activities (2013-2017) and complements the GSTP E1 Compendium 2019 for Generic Technologies (ESA-TECT-PL-015884).

This compendium is issued to Delegations of GSTP Participating States and their industries for comments. Such comments will be considered in the following updates of the work plan for this GSTP Element 1 "Develop".

The objective is to have a good indication of the developments the participants intend to support in order to present updates of the GSTP E1 "Develop" Work Plan with consolidated set of activities to the IPC for approval.

The first compendium for Advanced Manufacturing was issued in 2015, with the main objective of the initiative to:

- identify and implement new technologies which show high potential for space applications in terms of design freedom, performance, cost and lead time reduction, from concept to manufacturing;
- spin them in and mature them for space applications;
- favour their spin-out opportunities in larger and profitable markets.

Since its introduction the initiative has brought together industrial and institutional partners from all sectors of the manufacturing and design domain of space. This has assisted in the development and industrialisation of manufacturing processes in Europe, thus serving the European Space industry competitiveness.

The initiative continues to foster multi-sectorial cross-fertilization, facilitating spinning-in and spinning-off opportunities across different high-end technology and industrial domains and infrastructure opening new fields of innovation. It will continue to promote the creation and dissemination of design as well as verification, qualification, and standardisation methodologies, as well as maturing and creating the market and its uptake.

The recent introduction of Industry 4.0 has identified new opportunities, which are largely derived from the automotive and aeronautical industrial sectors. This includes the possibility for the European Space industry to adopt manufacturing digitalization and automation (robot-assisted production), Smart Factory production-line simulation and machine learning, hazard monitoring and predictive maintenance, Big Data-driven production, verification and quality control. At the same time new challenges such as increased and more stringent cyber-security will need to be addressed.

The current compendium for Advanced Manufacturing identifies new manufacturing technologies which can be implemented immediately while maintaining the original objectives of improving design freedom, performances, costs and lead time (from concept to manufacturing). The compendium is structured in three themes:

- Additive manufacturing
  Among the various advanced manufacturing technologies, additive manufacturing proved to enable disruptive capabilities and is addressed as separate theme. Additive Manufacturing has

the potential to change how future space products are designed, integrated and operated. The technology encompasses a wide range of materials and processes, will enable design for performance, mass customisation, and allow a full digital workflow facilitating integrated design adaptations.

- Advanced materials and processes
  This theme covers all advanced manufacturing technologies that do not directly fall in the category of additive manufacturing, such as materials development, composite technologies, joining processes, surface engineering, and PCB technologies.

- Smart manufacturing
  With the general objectives of advanced manufacturing, digitalisation enables an additional paradigm shift not only enhancing the original goals, but also to enable unprecedented agility and adaptability. The term smart manufacturing refers to the use in industrial production of interconnected, digital technologies that enable new and more efficient processes, and which in some cases yield new goods and services. It enables all information about the manufacturing process to be available when it is needed, where it is needed, and in the form that allows systematic analysis and feedback across entire manufacturing supply chain.

For more comprehensive background reading, see the white paper "Advanced Manufacturing for Space Applications" (ref ESA-TECMS-TN-015895).

2. LIST OF ACTIVITIES

GEN - Generic Technologies

CD1 - EEE / Components / Photonics / MEMS

Programme Reference	Activity Title	Budget (k€)
	Additive Manufacturing	
GT1A-301ED	Advanced manufacturing of 3D printed pseudocapacitive electrodes for supercapacitors.	500
GT1A-302ED	3D printed and custom-design multilayer ceramic capacitors	500
	Total	**1,000**

CD2 - Structures, Mechanisms, Materials, Thermal

Programme Reference	Activity Title	Budget (k€)
	Additive Manufacturing	
GT17-303MS	Additive manufacturing of metal matrix composites	1,500
GT17-304MS	Enhancement of design tools for additive manufacturing	600
GT1A-305MS	Repair solutions for additively manufactured parts	750
GT17-306MS	Metal powder recycling in additive manufacturing	1,200
GT1A-307MS	Copper alloys for additive manufacturing	750
GT1A-308MT	Development of a cryostat using additive manufacturing	600
	Advanced Materials and Processes	
GT1A-309MS	Development of new metallic alloys for additive manufacturing	900
GT1A-310MS	Development of Functionally Graded Materials (FGMs) for space components	1,200
GT1A-311MS	Development of a new polymeric composite magnetic materials	700
GT1A-312MS	Joining solutions for additive manufacturing	750
GT1A-313MS	Materials development for high speed data transfer in advanced electronics	600
GT1A-314MS	Finishing technologies for additively manufactured complex parts	600
GT1A-315QE	Multi-functional AM compatible polymers with enhanced resistance	500

Smart Manufacturing		
GT1A-316MS	Modelling, simulation and automated inspection of electronic assemblies	600
GT1A-317SW	Application of machine learning and artificial intelligence technologies for process data analysis	500
GT1A-318MS	Development of a digital twin for advanced manufacturing processes	600
GT1A-319MS	Development and integration of embedded sensors for advanced manufacturing processes	700
GT1A-320MS	Modelling and simulation of advanced manufacturing processes	800
GT1A-321MS	Development of in line non-destructive inspection techniques for advanced manufacturing	800
GT1A-322MS	Development of an end to end virtual testing concept	900
GT1A-323MS	Reliable modelling of composite structures manufactured with fibre steering	1,200
GT17-324QE	Multifunctional self-monitoring coating development for space environmental monitoring	600
	Total	**17,350**

CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing

Programme Reference	Activity Title	Budget (k€)
Advanced Materials and Processes		
GT1A-325EF	Enhanced RF/microwave parts by using advanced manufacturing techniques	1,200
	Total	**1,200**

CD7 - Propulsion, Space Transportation and Re-entry Vehicles

Programme Reference	Activity Title	Budget (k€)
Additive Manufacturing		
GT1A-326MP	Additive manufacturing enabled thruster	1,200
	Total	**1,200**

Note: In the GSTP Element 1 “Develop” Compendium 2019: Cybersecurity the activity: GT1Y-301SW *Applicability of cybersecurity to protect and allow exchange of manufacturing data*, deals with cybersecurity in the context of Advance Manufacturing cybersecurity.

3. DESCRIPTION

3.1. GEN - Generic Technologies

3.1.1. CD1 - EEE / Components / Photonics / MEMS

Domain	*Advanced Manufacturing CD1 - EEE / Components / Photonics / MEMS*		
Ref. Number:	**GT1A-301ED**	**Budget (k€):**	**500**
Title:	**Advanced manufacturing of 3D printed pseudocapacitive electrodes for supercapacitors.**		
Objectives:	The objective of this activity is to develop a supercapacitor with a 3D printed electrode in order to improve the capacitance and the energy density by increasing the area, gravimetry, and volume.		
Description:	Supercapacitors (SC) are identified as potential interesting high power sources as they can bridge the gap between capacitors and batteries. They have an unusually high energy density when compared to common capacitors and high power density when compared to batteries. Supercapacitors are an important class of energy storage devices that could balance the need of high energy density and fast charging/discharging. For high power technologies, the use of SC should lead to a drastic reduction in mass. Compared to batteries, supercapacitors can provide higher power pulse but lower energy density. When the applications require a high energy density, batteries or hybrid solutions (batteries connected to supercapacitors) are preferred, the supercapacitors cannot be used due to their low energy density. Therefore, the low energy density of supercapacitors is considered as a major drawback for space applications that require high-energy storage devices. 3D printing of the electrodes with the use of pseudocapacitive materials would allow achieve outstanding gravimetric capacitances, thus increasing the energy density. The activity consists of the following steps: • Identify the appropriate additive manufacturing technique to print the SC electrode; • Develop and manufacture the printed electrode; • Test the performance of the 3D printed electrode; • Develop and manufacture the SC cell; • Test the performance of the SC cell with the 3D printed electrode and perform process optimizations; Provide a way forward for the improvements needed on the process and impacts at system level for space applications.		
Deliverables:	Breadboard, 3D printed SC cell		

Current TRL:	3	**Target TRL:**	4	**Duration (months):**	24

Target Application/ Timeframe:	Power storage for all missions

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD1 - EEE / Components / Photonics / MEMS*

Ref. Number: **GT1A-302ED** **Budget (k€):** **500**

Title: **3D Printed and custom-design multilayer ceramic capacitors**

Objectives: The objective of this activity is to develop and manufacture multilayer ceramic capacitors through an additive manufacturing method with custom-design and miniaturized models to be able to build various shapes with higher integration.

Description: The additive manufacturing of ceramic capacitors will lead to an increase in accuracy of custom-made designs and to increase the circuits' integration and miniaturization: rectangular filtering connectors.

Currently, classical multilayer ceramic capacitors' (MLCC) manufacturing technologies allow to build only parallelipidedic or circular capacitors. Custom design-shapes are useful for a higher integration on circuits or moreover for filtering purposes in the feed-through connectors applications. These custom shapes are needed in particular (but not only) for filtering (feed-through) applications and especially for a better integration on PCB due to their miniaturized custom-design shapes

These special designs are only accessible by machining of the MLCC's. This mechanical process is critical as it can generate electrical defects or lead to a reduced reliability of the capacitors. In addition, it cannot allow a miniaturization of the parts due to the mechanical limitations of the tools (trimming, drilling, drills, etc.). Moreover, these technologies and equipment are time consuming and expensive.

The main applications for which a custom design capacitor manufactured with an additive manufacturing method would be used is filtering as in rectangular filtering connectors. Flexibility of this innovative process would allow realizing capacitors with shapes that perfectly fit units to be filtered or circuits with custom footprints. This implies space and cost saving, miniaturization and higher integration.

The activity consists of the following steps:

- Develop the appropriate additive manufacturing technique to print the MLCC;
- Develop and manufacture the printed MLCC parts with miniaturized custom-design shapes;
- Test the performance of the 3D printed parts, and perform process optimizations;
- Provide a way forward for the the improvements needed on the process and impact at system level for space applications.

Deliverables: MLCC parts, Breadboard

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

3.1.2. CD2 - Structures, Mechanisms, Materials, Thermal

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT17-303MS**	**Budget (k€):**	**1,500**

Title: **Additive manufacturing of metal matrix composites**

Objectives: The objective of this activity is to develop the additive manufacturing processing of one high-end metal matrix composite reinforced by particles in order to assess the geometrical limitations of the technology and the post processing.

Description: Adding reinforcement represent the most efficient means to increase specific properties of metals – through making metal matrix composites. These materials despite their very attractive properties suffer from few draw backs, including the difficulty to machine them and the difficulties to weld them. To overcome these issues, an attractive solution would be to be able to process near net shape – topologically optimized parts to maximize structural or thermal performances.

In this activity, it is proposed to develop the additive manufacturing processing of one aluminium alloy reinforced with particles and to populate a material database.

To do so, the following steps will have to be followed:

- Review of the particulate aluminium MMCs that are today compliant to the ECSS-Q-ST-70-36 and determine a trend in terms of acceptable systems for the activity – as the application will very likely be structural. Down select 2 different developed approaches in terms of matrix, reinforcement volume fraction and processing strategies.
- Procure / generate raw material to be used for the development based on the output of previous task and address the means to ensure that the final material can be homogeneous. Perform a final selection of the particulate MMC system to be further developed. Establish a list of potential applications / demonstrators that would benefit from being made of this material.
- Design and optimize the end-to-end manufacturing of the particulate MMC. Elaborate a test plan to: generate a material database and ensure that the specific features that are inherent to the type of application selected.
- Design a prototype, run the test plan for generating the material database and run the test plan to evaluate the feasibility / properties of the specific features. This task shall be closed by a CDR including a test plan for the demonstrator.
- Manufacture and test the demonstrator according to test plan.

Deliverables: Prototype, report.

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT17-304MS** **Budget (k€):** **600**

Title: **Enhancement of design tools for additive manufacturing**

Objectives: The objective of this activity is to develop functionalities of current CAD/CAE and FEM tools and to establish guidelines for designing structural flexures to be produced by Additive Manufacturing.

Description: Flexures are recurrent elements in space hardware, being employed e.g. for the mounting of optical elements, in suspensions, as elastic joints and in compliant mechanisms.

Typically, the design of a flexure is highly dependent on the envisaged application and results of a compromise between conflicting requirements originating from different disciplines, such structural stability, thermal control, vibration and strength. Often an adequate design is the product of many iterations.

While the geometric freedom provided by AM has the potential to disrupt the performance of flexures, the streamlining of their design process needs to be ensured and can greatly benefit from enhancements of current design tools for Additive Manufacturing.

This activity aims at further developing existing design tools for AM, and validating them via breadboard testing, in terms of:

- Simulation of the Additive Manufacturing process, for minimizing residual stresses and improving manufactural tolerances;
- Coupling the optimization process to thermal solvers;
- Maturing algorithms to massively and efficiently explore the optimization design space and allowing a straightforward conversion of the results of topology optimization into a useful geometry;
- Designing guidelines to be followed through the full design process including the definition of the design space and the setting of the optimization problem, taking into account the knowledge of the Additive Manufacturing process itself.

Deliverables: Breadboard, Report, Software

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 18

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-305MS** **Budget (k€):** **750**

Title: **Repair solutions for additively manufactured parts**

Objectives: The objective of this activity is to develop repair solutions using additive manufacturing for additive and non-additive parts.

Description: It is expected that in the coming years, more additively manufactured parts will be introduced. Therefore by developing robust repair solutions, all missions would benefit from this activity

Additive manufacturing (3D printing) continues to receive widespread attention by the European Space Industry. Space primes are already flying a number of additively manufactured parts on commercial satellites. In the next few years it is expected that more and more parts will be manufactured using various additive manufacturing techniques. This will pose a new set of challenges including how such parts are repaired, and how parts are integrated at a system level.

Through the development of current traditional manufactured parts (often made from aluminium or titanium) are being re-designed to take advantage of new materials. This includes the use of metallic glasses, polymers, and eventually metal matrix and ceramic composites.

During integration and service, it is likely that some parts may become damaged and so need to be repaired or replaced. Repair solutions will be developed which can be performed either in-situ or remotely. Such solutions could also be used to repair parts which have been made using conventional manufacturing techniques.

The activity shall consist of the following:

- Identification of a number of 3D printed components which could become damaged during integration or service;
- Develop an additive manufacturing methods for suitable repairing such components;
- Validate the solution by producing the components, introduce damage and then repair with the appropriate technique and then test the repaired part to ensure that it is fit for purpose.

Deliverables: Breadboard, reports, repair guidelines

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions designed using additive manufacturing production processes.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT17-306MS** **Budget (k€):** **1,200**

Title: **Metal powder recycling in Additive Manufacturing**

Objectives: The objective of this activity is to evaluate the aging of metal powders used in the process of additive manufacturing (AM) when subjected to increasing stages of recycling. The results of this activity may also be used as an input for the ECSS standard on Additive Manufacturing.

Description: For an economically viable powder-bed additive manufacturing (AM) process it is necessary to recycle and reuse the large amount of unfused powder. In powder-bed processes the actual volume of the built component is typically significantly less than the total volume of metal powder to be spread during the process. Therefore, many manufacturers apply procedures of sieving and reusing the remaining powder.

In order to make the Additive Manufacturing process more economically viable, i.e. further reduction of material wastage, the feasibility of using recycled feedstock powder needs to be determined.

However, it is common practice to restrict the number of cycles for powder reuse as studies have shown that the powder properties can evolve and eventually deteriorate after multiple uses in Laser Powder Bed Fusion systems. Hence, the reuse of powder for manufacturing of space components has widely been considered unacceptable, despite the large quantities of material wastage and the associated economic impact.

This activity seeks to remedy this situation by understanding the process boundary conditions that impact powder recycling on defect generation and final part properties, working towards developing some powder recycling guidelines for the space industry.

The activity shall follow a step-approach:

- Survey of standards, common practices and state-of-the art for powder recycling in AM for high end applications, considering industries such as medical, aerospace and space – for the material of interest.
- Strategy definition
    - Definition of strategy to quantify the evolution of metallic powders as a result of recycling in the AM process and the impact of re-using this powder on the final AM part properties. Establishing a relationship between the number of re-use cycles, the evolution of the powder properties and, most significantly, the degradation of the AM part properties for the selected material.
    - Definition of implementation/manufacturing strategy, including suitable test artefacts and test specimen geometries, AM machine type (considering for example the available powder reservoir), number of cycles, support structures, process monitoring, etc.,
- Develop manufacturing and post-processing procedures, including development of test plans for powders and AM test artefacts and specimens.
- Manufacturing and testing.
- Preparation of technical documentation describing the "kinetics of powder evolution" determined in this activity. Recommendations for manufacturing AM space components with recycled powders (e.g. limits of re-use cycles, implementation of decision matrix).

Deliverables:	Prototype, Report				
Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24
Target Application/ Timeframe:	All missions.				

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-307MS** **Budget (k€):** **750**

Title: **Copper alloys for additive manufacturing**

Objectives: The objective of this activity is to develop high density additively manufactured copper alloy parts using alternative power sources such as green lasers.

Description: Copper alloys are used for a variety of space applications, which include, but are not limited to chemical propulsion and heat exchangers. Often, these applications require a certain degree of geometrical complexity, which can make Additive Manufacturing a viable production technique.

One of the most widely applied AM method is metal powder bed fusion with a laser beam as an energy source. However, today's baseline lasers often have a wavelength of around 1080 nm, which is only poorly absorbed in many of the copper alloys relevant for space applications. This results in parts which have poor density and are therefore difficult to post-process.

The focus of this activity is to study alternative power sources, such as green lasers, which should result in a higher quality product when compared to conventional 1080nm lasers. However, the processing parameters for producing such high-density parts still need to be developed.

The following tasks will be carried out in this activity:

- Selection of at least 2 copper alloys and associated applications, where at least one is liquid propulsion
- Establishment of a test plan, to envelope key design properties of the selected applications
- Selection of the alternative power source, e.g. green laser
- Development of processing parameters, aiming at a relative density > 99.5%
- Testing on sample level, and manufacturing of a prototype part

Deliverables: Breadboard, Prototype, Reports

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 18

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-308MT** **Budget (k€):** **600**

Title: **Development of a cryostat using additive manufacturing**

Objectives: The objective of this activity is to develop, build and test a cryostat representative of an instrument application using additive manufacturing parts for the critical functions.

Description: Previous ESA activities showed the merit of using additive manufacturing to conceive complex Thermo-Mechanical parts to be used in Cryostat. Such manufacturing technique can not only open the field of possibilities to optimize support structures and shields for mechanical and thermal performances, but also permits to simplify the assembly and remove critical alignment steps.

The purpose of this activity is to manufacture but more critically environmentally test a representative optical instrument cryostat in order to reach a maturity on the concept that could permit projects to confidently envisage this type of solution.

The main tasks to be performed are the following:

- Identification of the benchmark instrument and consolidation of the requirements.
- Preliminary design of an alternative Cryostat using additive manufacturing parts for the critical functions. The following advantages of additive manufacturing can be investigated: using different materials (metallic or not), grading of material(s), topologically optimized structure etc.
- Tackle the specific product/quality assurance topics linked to this manufacturing technic, in crygo.
- De-risk some aspects of the design with low level breadboard tests.
- Detail Design of the Cryostat that leads to manufacturing files.
- Manufacture and test to TRL6 the Cryostat (environmental tests and performance tests before and after).
- Compare to Benchmark performance and lessons learnt.

Deliverables: Engineering Model

Current TRL:	4	**Target TRL:**	6	**Duration (months):**	36

Target Application/ Timeframe: Future Earth Observation and Science missions.

Applicable THAG Roadmap: Cryogenics and Focal Plane Cooling (2019)
Consistent with the activity F16 “Investigation on Additive Manufacturing for Cryostat Parts”

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-309MS** **Budget (k€):** **900**

Title: **Development of new metallic alloys for additive manufacturing**

Objectives: The objective of this activity is to develop new advanced titanium alloys which can take full advantage of the ALM process to deliver products with high end structural performance.

Description: Additive manufacturing is rapidly emerging as an advanced manufacturing technique which will be adopted by the European space industry. For metallic solutions, the choice of alloys are limited to a handful of aluminium alloys (e.g. Al10SiMg, SCAMALLOY) and alloys such as Ti-6Al-4V and Inconel 718.

There is no metallurgical reason why Ti-6Al-4V should be the best titanium alloy for additive manufacturing, it was simply chosen as high quality powder of this alloy composition was readily available.

There is therefore a need to develop a new generation of advanced metallic alloys which can take full advantage of the additive manufacturing process whilst delivering the required high end structural performance. This will be achieved through a combination of alloy design, microstructural modelling, manufacturing of samples and testing.

The activity will consist of the following tasks:

- Comprehensive literature review targeting high end structural applications;
- Microstructural modelling to develop relationships between the ALM process and the microstructure of advanced alloys (extended solid solubility, formation of metastable structures etc.);
- Grain size control using optimised ALM process parameters in combination with dopants;
- Strength and performance improvement through the use of alloying additions.

Deliverables: Optimised alloy compositions, Breadboards, Report

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: Fracture critical metallic parts

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-310MS** **Budget (k€):** **1,200**

Title: **Development of functionally graded materials (FGMs) for space components**

Objectives: The objective of this activity is to implement a functionally graded materials (FGM) end-to-end manufacturing process and prototype for a selected space application

Description: Functionally Graded Materials (FGM) have only recently become practically feasible thanks to the development of advanced manufacturing processes such as additive manufacturing (AM). The technology is still in its infancy with the need to identify applications that could benefit from such an approach. Nevertheless, there is high potential in the possible performance gain as well as lead time, cost, part and AIT effort reduction, in particular in the space industry. This activity is targeted at exploiting this technology in the early stages of its development by developing the necessary technological solutions and implementing a thoroughly devised end-to-end manufacturing process. A specific space application shall be targeted for the development. The requirements definition and achieved performances evaluation shall be performed in collaboration with a potential an end-user.

A step-based approach shall be followed:

- Review of the state-of-the-art of functionally graded materials and their manufacturing processes. Identification of space applications that could benefit from one or more of these technologies. Trade-off selection for the application to be developed;
- Develop a functional grading "strategy" (type of functional grading, material(s), manufacturing process(es), etc.) for the selected application to meet the requirements and identification of critical processes for the implementation of the functional grading strategy.
- Validation of the strategy based on both experimental approaches and modelling, including possible iterations. . Definition of the End-to-End manufacturing process based on elementary sample testing.
- Evaluation of the end-to-end manufacturing process on material sample level as well as on coupons and breadboards representative of the anticipated demonstrator features.
- Development of associated test plans. Updated end-to-End manufacturing process to be applied to the final demonstrator, including finalised design and test plan.
- Prototype manufacturing
- Testing of the prototype.

Deliverables: Prototype, process, report.

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: Space applications which require graded properties

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-311MS**	**Budget (k€):**	**700**

Title: **Development of a new polymeric composite magnetic materials**

Objectives: The objective of this activity is to develop 3D printed magnets for space applications.

Description: The net shape freedom provided by additive manufacturing technique could enable integration, miniaturization and efficiency increases of electronic and electrical devices.

Hard and soft magnets are at the core of almost every space mechanism and equipment, for example as actuators, motors, drive systems and their sensors, hold down, control and electronic components. They are normally processed as sintered or bonded magnet.

Sintered magnet are nowadays diffused because of their superior magnetic properties, but on the other hand, they are difficult to shape in complicated geometries due to their brittleness and not suitable for near net shape processing. At the same time, they exhibit poor corrosion resistance and need to be passivated or protected by coatings.

Bonded magnets, unlike sintered, enable the manufacturing of a wide variety of shapes and magnetization structures. However, the current production techniques have a number of drawbacks, including shape constraints, tooling requirements and material waste. In this regard the use of additive manufacturing opens up new design possibilities such as the fabrication of cooling channels within the magnet or the development of magnets with tailored magnetic properties, leading to the improvement of the overall electrical performance of the motors, or optimized mechanical and magnetic flux design in integrated sensors.

The proposed activity will be organized in the following steps:

- Selection of targeted space applications where the development of 3D printed magnet with tailored magnetic field will provide the largest benefit;
- Development of new magnetic materials characterized by complex magnetic field;
- Chemical/Thermal/Mechanical and magnetic characterization of new 3D printed magnets at sample level;
- Design and development of a breadboard representative of one selected targeted application (e.g. compliant mechanisms, sensors);
- Magnetic field modelling and testing sample and breadboard level.

Deliverables: Breadboard, Reports

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: Space electronic and electrical devices.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-312MS** **Budget (k€):** **750**

Title: **Joining solutions for additive manufacturing**

Objectives: The objective of this activity is to develop joining solutions which will allow additive parts to be joined to other additive parts and non-additive parts.

Description: It is expected that in the coming years, more complex part will be introduced. Therefore by developing robust joining solutions, all missions would benefit from this activity.

Additive manufacturing (3D printing) continues to receive widespread attention by the space industry, with a number of additively manufactured parts are already flying on commercial satellites. In the next few years it is expected that more and more parts will be manufactured using a variety additive manufacturing techniques. In addition, it is likely that traditional parts will be re-designed to take advantage of new materials. This includes the use of metallic glasses, polymers, and eventually metal matrix/ceramic composites and ceramics.

This will pose a new set of challenges including how such parts are integrated into spacecraft, satellites and launchers. Since many of the interfaces will consist of different metallic alloys (some with very different melting points) or metal/non metal or non-metal/non-metal joint combinations, this will require the use of novel joining techniques. Examples of such joining techniques include, but not limited to, solid state techniques such as Friction Stir, Rotary Friction and Linear Friction Welding, magnetic pulse joining, adhesive bonding, mechanical fastening and Co-Meld.

The following activities will be performed:

- A number of components will be selected which have undergone a re-design where the original material (e.g. aluminium) has been replaced with another material;
- Joining technologies will be developed or adapted to allow the newly designed part to be integrated at the spacecraft level;
- Sample testing and evaluation of the joined component at breadboard level.

Deliverables: Breadboard, Reports

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions designed using additive manufacturing production processes.

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-313MS** **Budget (k€):** **600**

Title: **Materials development for high speed data transfer in advanced electronics**

Objectives: The objective of this activity is to develop a routing solutions for large pin-count chips and future high-speed applications using advanced RF materials and multiple layers of microvias (Advanced HDI PCBs).

Description: Increased clock speed of processors require advanced PCB technologies to maintain signal integrity. Short and dense routing is enabled by microvia technology for which GSTP activities are ongoing (High Density Interconnect PCB assemblies). While the current activity intends to cover signal speeds in the range of 5 to 15 Gbps, near-term applications are already planning up to 28 Gbps. Advanced RF materials with low loss and increased microvia routing will be required to handle such signals.

In this activity the following tasks are proposed.

- To define the design and reliability drivers leading to the selection of advanced RF materials;
- To implement lessons-learned for design, material and test definition from communities such as IPC, HDPUG and the referenced previous activities;
- To design advanced HDI PCBs with multiple layers of microvias;
- To manufacture advanced HDI PCBs;
- To perform reliability and performance testing of advanced RF HDI PCB assemblies.

Deliverables: Technology Samples, Report

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: RF materials and technologies for future high-speed applications.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-314MS**	**Budget (k€):**	**600**

Title: **Finishing technologies for additively manufactured complex parts**

Objectives: The objective of this activity is to establish finishing process capabilities for complex parts made by additive manufacturing.

Description: Additive Manufacturing of metal parts is revolutionising the space industry thanks to the new design freedom, cost reduction and performance optimization. One of the challenges of the AM process is the insufficient surface finish, internal stresses and the presence of surface defects.

It is therefore important to develop finishing technologies which are capable of producing parts in a final condition which are compliant to space relevant requirements. Previous activities have shown that finishing technologies can be developed successfully at sample level. An activity is now required to bring the technologies to the stage where the technologies can be adopted for complex part geometries. Materials relevant for space application shall be considered

The activities foreseen during this activity are the following:

- Review existing state-of-the-art for finishing technologies for AM parts manufactured using metallic materials such as Al, Ti, SS, Inconel alloys
- Select a number of prototype parts associated with the performance requirements (for example, fatigue, surface finish)
- Manufacturing of prototype parts and the surface and sub-surface characteristics identified.
- Apply the selected finishing technologies and compare the performance of the parts before and after the application of the finishing technology.

Deliverables: Process, Prototype, report

Current TRL:	4	**Target TRL:**	6	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Additive Manufacturing (2017)
Consistent with the activity E02 “Surface engineering of parts made by ALM applied to complex, internal geometries, also targeting RF and antenna applications”

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-315QE**	**Budget (k€):**	**500**

Title: **Multi-functional AM compatible polymers with enhanced resistance**

Objectives: The objective of this activity is to develop polymers that are intrinsically resistant to the LEO environment which can be processed using additive manufacturing.

Description: Nanosat flight missions allow access to space with a relatively low entry price point, short development time and reduced design complexity. There is currently a lack of commercially available space resistant AM compatible polymers which prevents the additive manufacturing technology from entering numerous low-earth orbit applications.

This new generation of polymeric materials can enable flexible and highly optimised design strategy, allowing engineers a design that is not constrained by machining limitations. The intrinsically resistant polymeric structures do not require protective coatings, hence the structure can be designed for function and assembly, reducing the MAIT resources and the overall development time.

The improved polymers could be realised by hybridization of current engineering thermoplastics (e.g PEEK, PEKK, PA, PEI or other high performance polymers) through the addition of extra components such as nanoparticles (examples include nanotubes, metal oxide clusters and particles, and silicone derivatives). This targets space environmental compatibility for exposure to atomic oxygen, UV radiation, and allows electrical charge dissipation and thermal management to be improved.

The foreseen tasks for this project include:
- The primary screening of formulations (ensuring good particles dispersion and thermo-mechanical properties),
- Optimisation of the most appropriate formulation for AM (e.g. printing temperatures and resolution),
- Testing in a relevant environment (LEO conditions) on sample and breadboard.

Deliverables: Breadboard, Report

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: LEO missions, where the material resistance is of paramount importance.

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-316MS** **Budget (k€):** **600**

Title: **Modelling, simulation and automated inspection of electronic assemblies**

Objectives: The objective of this activity is to develop a procedure for modelling and simulation techniques and tools that can provide new methods for reliability assessment beyond the traditional tests and inspection techniques.

Description: Each mission has environmental requirements for its electronics that depends on the nature of destination (deep space, orbital, surface), the thermal design of the spacecraft or instrument and the related compromises (survival or operational heaters). Even with small mismatches in the CTE between materials, stresses can arise due to the presence of temperature gradients within the electronics assembly. To improve the reliability of electronic products and at the same time to shorten the time needed for design and verification testing, efficient test methods as well as accurate numerical simulations have become ever more important. For example, finite element method (FEM) is a powerful numerical technique used in the design and development of products. Different FEM software and tools provides a wide range of simulation options for both modelling and analysis of a system. Modelling and simulation can therefore reduce reliance on experimentation and accelerate the implementation of new materials and processes.Efficient modelling and simulation techniques are needed to help predicting the effect of a system's design on its reliability performance. In addition, utilising computational simulations can help to reduce the cost of reliability evaluations especially for new generation packages and solder materials and joint geometries.

As today's board complexity is increasing with higher density, more components, more solder joints, and shrinking package technologies, AOI (Automatic Optical Inspection) enables manufacturers to accurately control and monitor the manufacturing processes such as the solder printing and component placement. Artificial Intelligence (AI) empowered tools can be utilised to analyse and optimize the production process by managing process data from the connected AOI systems. In this activity the following tasks are proposed.

- Develop and validate appropriate lifetime models for different mission conditions and mission profiles;
- Identify and evaluate appropriate modelling and simulation tools/software;
- Perform lifetime predictions and to correlate those with verification test results;
- Develop guidelines for the application of lifetime models for different types of packages and solder joint geometries;
- Optimise the automated inspection of PCBs and electronic assemblies using machine learning.

Deliverables: Lifetime model, Report, Software

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: All missions. Electronic assemblies.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-317SW**	**Budget (k€):**	**500**

Title: **Application of machine learning and artificial intelligence technologies for process data analysis**

Objectives: The objective of this activity is to develop an algorithm for manufacturing process robustness, anomaly detection and failure modes investigation in space applications.

Description: Over the past years, the tendency to capture huge volumes of historical data describing process operations together with complex experimental datasets has become a reality. In this regard, the use of artificial intelligence (AI) and in particular machine learning (ML) for data mining addresses the question of which is the best way to use this historical data to discover regularities and to facilitate future decisions. Following the significant progress and recent success in many science and engineering domains, the activity is aiming at exercising AI/ML technique to provide substantial benefits to the advanced manufacturing processes domain (e.g. additive manufacturing).

Advanced and new manufacturing processes and technique may benefit from the integration and operational usage of AI/ML techniques. The use of these technologies might be beneficial to extract relevant information from big data generated through the different steps of the new advanced manufacturing processes. Furthermore, the falling cost of large data storage devices and the increasing facility of collecting data over networks; the improvement of computational power, enabling the use of computationally intensive methods for data analysis in parallel to the development of robust and efficient machine learning algorithms further highlight the need and actuality of this activity.

In the frame of this activity, a software prototype shall be developed, able to extract data from existing sources and categorize them in useful information in order to the use the state of the art AI/ML algorithms for advanced manufacturing processes modelling, process anomalies detection and failure mode investigation.

The main steps that shall be completed in the frame of this activity are the following:

- Identification of case studies (e.g. additive manufacturing process modelling, in situ monitoring, NDI inspections, defect identifications etc.) and related data sources available;
- Review of the state-of-the art, preliminary use cases selection, definition of the preliminary requirements and identification of the validation process to be applied;
- Design and definition of the software preliminary architecture;
- Detailed design and definition of the software architecture;
- Software Implementation and integration;
- Software testing and performance assessment;
- Software validation and risk assessment based on the reliability of the software in the decisional process.

Deliverables: Prototype, Report, Software

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	18

Target Application/ Timeframe: All missinos.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-318MS** **Budget (k€):** **600**

Title: **Development of a digital twin for advanced manufacturing processes**

Objectives: The objective of this activity is to develop a digital twin for a selected manufacturing process such as composite or additive manufacturing technologies.

Description: The concept of digital twins in industry relates to the development of data models for physical systems to accurately reproduce physical and performance characteristics of processes and products. It is often referred to as a virtual replica of the physical asset which can be used to monitor and evaluate its performance. In the scope of Industry 4.0, the digitalization of manufacturing processes bring significant potential in the improvement, namely in lowering manufacturing costs, improving performances, increasing reliability, and in reducing the time to market. In this context the use of digital twins is seen as an essential tool to predict capacity, rate, yield, performance, and feeding in data to failure analysis models. Three categories of digital twins can be considered:

- Supervisory: Passive process monitoring and identification of key thresholds.
- Interactive: Limited control capabilities of process parameters.
- Predictive: Full process simulation through model and data collection allowing real-time process control.

With this activity, the advantages of using a digital twin for a selected manufacturing process will be demonstrated including the following tasks:

- Select a case study for a relevant manufacturing process such as composite or additive technologies;
- Analyse the application of digital twins to the selected process, identify the variables to be measured, monitored, controlled;
- Develop and tailor the digital twin model;
- Implement and integrate the digital twin in the selected manufacturing process;
- Establish performance assessment and validation of the developed digital twin. This is possibly complemented by failure analysis models and physical performance analysis of manufactured parts;
- Assess the applicability of the developed digital twin tool to other MAIT processes in the space sector.

Deliverables: Prototype, Report, Software

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: Advanced Manufacturing Processes, e.g. additive manufacturing, composite manufacturing

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-319MS**	**Budget (k€):**	**700**

Title: **Development and integration of embedded sensors for advanced manufacturing processes**

Objectives: The objective of this activity is to develop the technologies to embed COTS sensors (e.g. strain, temperature) during manufacturing.

Description: Within the domain of smart manufacturing, the acquisition of data is of fundamental importance. There is clearly a need to extract as much information from the manufacturing process as possible (big data) through the use of sensor technology and in line process monitoring. There are a wide range of sensors which are commercially available which are used in a number of manufacturing sectors (automotive, aerospace, etc). Types of sensors include temperature, pressure, strain, and acoustics.

Where possible, the embedded sensor technology shall provide data during the manufacturing process, during transportation and storage on earth, during the launch phase, operational lifetime of the satellite/spacecraft, and during the final demise stage.

A key pillar common to all embedded sensor applications is the ability to transfer the data produced, thus this activity should also include the embedding of the data transfer technology. There are several possibilities to achieve this including embedded conductors or wireless devices.

In this activity the following tasks will be performed:

- To identify a number of products which will benefit from the introduction of embedded sensors, and the associated manufacturing processes.
- To perform a review of current sensor technology which will identify the type of sensor which is needed and to see if the sensor technology is currently commercially available.
- To develop the manufacturing process so that the sensors can be successfully embedded during manufacturing, and to ensure that the information generated by the sensor can be read with minimal interference to MAIT and systems architecture.
- To manufacture and test a prototype part.

Deliverables: Breadboard, Prototype, Report

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-320MS**	**Budget (k€):**	**800**

Title: **Modelling and simulation of advanced manufacturing processes**

Objectives: The objective of this activity is to identify and adapt process modelling and simulation tools which are currently used in other industrial sectors (e.g. aerospace, automotive etc.), to space applications.

Description: Within the objectives of advanced manufacturing to improve design freedom, performance, cost, or lead-time of production, digitalisation will enable an additional paradigm shift not only enhancing the original goals, but also to enable unprecedented agility and adaptability. The associated technologies are many, from developments in machine learning and data science, which permit increasingly autonomous and intelligent systems, to low-cost sensors, which underpin the Internet of Things (IoT), to new control devices that make second-generation industrial robotics possible.

Within other industrial sectors such as aerospace and automotive, many process modelling and simulation tools have been developed, many of which are now fully commercialised and in the public domain. Technology areas which may benefit from the introduction of such tools include additive manufacturing, welding, casting, forming, forging, composite manufacturing and polymer processing.

In this activity the following is proposed.

- To identify a range of manufacturing processes which are currently used (or being developed) to manufacture space parts which would benefit from the introduction of process modelling and simulation tools.
- Identify the appropriate commercial tools which match the manufacturing process as close as possible. The selected process models will be used to accurately predict the performance of the part. This in turn will help and define process windows, thus increasing the confidence in the manufacturing process, which will reduce the formation of anomalies during manufacturing.
- Select at least two products and associated manufacturing processes, and introduce the process modelling simulation tool, and determine the possible benefits, which could include performance improvement, cost reduction or lead time reduction during manufacturing.
- The models will be adapted and tailored for the selected manufacturing process.
- The final model/process simulation tool shall be validated through the production and testing of samples in a representative production environment.

Deliverables: Simulation tool, reports.

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT1A-321MS**	**Budget (k€):**	**800**
Title:	**Development of in line non-destructive inspection techniques for advanced manufacturing**		
Objectives:	The objective of this activity is to develop, verify and validate Non Destructive Inspection (NDI) technologies able to identify and quantify defects during selected advanced manufacturing processes.		

Description:

In the recent years, Advanced Manufacturing processes have started to mature towards a space qualification level, creating new high performance space products with increased design freedom and reduced costs and lead-time. Advanced Manufacturing processes such as Additive Manufacturing (AM), Automated Tape Placement (ATP), Automated Fiber placement (AFP) and/or Filament Winding (FW) are further used in space applications, expanding the utilization of more automated processes in this industry.

Nevertheless, the verification against space requirements is still crucial for the space hardware manufacturing. Currently NDI plays a critical role in the verification chain for space hardware, but its use is mostly limited to the end of the manufacturing process. At this point, the component is already manufactured and there is no possibility to act on the process, correcting the errors. It is envisioned that the introduction of NDI during the manufacturing process could improve the performance of space products and later reduce costs with inspection of the components, by allowing an early detection of defects.

In this context, the proposed activity focuses on the development of Non Destructive Inspection (NDI) technologies applied in-line with advanced manufacturing processes. It is intended that the defects coming from the manufacturing process are detected and quantified by the NDI technologies while the part, component or structure is manufactured. A verification and validation of the in-line NDI technology is foreseen.

As such the main tasks are:

- Identify manufacturing processes and selected products where internal defects are known to play a role in the performance of the product. These processes/products must have been already verified for the space sector.
- Trade-off the identified applications and processes, considering the potential benefits and feasibility of applying in-line NDI.
- Identify the manufacturing defects, define the maximum allowed defects sizes and select the suitable NDI techniques to be employed during the manufacturing process(es) for detecting defects of the allowable sizes or smaller.
- Develop the in-line NDI technique(s) (this could be performed off-line).
- Validate the selected in-line NDI method(s) through the manufacturing and testing of samples.
- Final verification testing of the selected NDI technology performed in-line in a representative production environment. The technology is validated and verified by in-line detection of defects. For this purpose, if necessary, the process can be altered to obtain representative defects during manufacturing.

The technology can be employed during the MAIT of primary and secondary space structures (e.g. satellites central tubes, shear panels, launchers interstages, launchers stage structures, etc.) with the following major benefits: 1) Faster and cheaper development plans. Manufacturing defects can be reduced; repairs and non-conformities due to the manufacturing processes eliminated; 2) Safer products. Identification of manufacturing defects that may be undetected at later integration stages can result in superior quality and higher safety. Finally, the technology consists in the first step towards the development of an interactive digital twin of the aforementioned manufacturing techniques: the information collected by the in-line NDI technologies could be used, in a further development, to automatically adjust process parameters and correct the detected errors

Deliverables: Breadboard

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-322MS** **Budget (k€):** **900**

Title: **Development of an end to end virtual testing concept**

Objectives: The objective of this activity is to develop an end-to-end virtual testing methodology that, including high fidelity manufacturing modelling, virtual assembly and virtual testing, will result in a reduction of the efforts required for qualifying a space structural system

Description: The qualification process for a space structure is currently very demanding in terms of time and budget. In order to qualify a space structure, both the manufacturing processes employed to produce the structure and the structural design need to go through a very demanding qualification campaign.

The general approach followed for substantiating a structural design goes from simpler coupon tests to more complicated elemental and detailed tests and finally to sub-component and component level tests while including the influence of manufacturing defects and the external environment.

Such lengthy and expensive path, followed in the qualification of space structures, can be simplified by ‘virtual testing.
In order to develop and validate this novel paradigm for space structures, the following main tasks are proposed:

- Identification of a space structural system where to implement end-to-end virtual testing techniques. The core manufacturing and assembly processes, together with max-allowed defects and NDI techniques, any integration activity and testing shall be outlined in a preliminary MAIT plan. Different processes can be considered for the same application; a trade-off will be performed during task 2 via virtual manufacturing.
- Develop numerical models of the manufacturing and assembly processes (e.g. composite prep egging, RTM, additive manufacturing, sheet metal forming, bonding, welding, etc.
- Manufacture and assemble the structural system identified in task 1 using the processes optimized in task 2. Perform coordinate measuring machine (CMM) metrology, non destructive inspection (NDI) of the product and, if available, destructive testing of cut-outs and/or over-cuts in order to validate the virtual manufacturing and assembly models.
- Develop numerical models to simulate the performance of the structure in the operational environment. Influence of process parameters, established in task 2, shall be accounted for and quantified during virtual testing.
- Test the breadboard manufactured and validate the test results in terms of failure strength, stiffness and mode of failure.

Deliverables: Breadboard

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 24

Target Application/ Timeframe: Structural system employed in space applications.

Applicable THAG Roadmap: Relevant to Roadmap Additive Manufacturing.

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*

Ref. Number: **GT1A-323MS** **Budget (k€):** **1,200**

Title: **Reliable modelling of composite structures manufactured with fibre steering**

Objectives: The objective of this activity is to develop reliable models of composite structures designed and manufactured with fibre steering technologies. The models should be able to predict the failure mode(s) and strength of the structure.

Description: Composite materials allow tailoring the reinforcing fibres direction in function of the performance to be optimized (strength, stiffness, mass, buckling, natural frequencies etc.). Within the same layer of the composite laminate it is possible to steer the fibres in order to achieve highly optimized solutions when compared to conventional manufacturing techniques such as prepregging, conventional tape placement, pultrusion, etc. In particular, for stiffness driven applications characterized by strength driven details (e.g. cut-outs, bolted joints, stringers), fibres can be placed following the paths of the stress field and reducing stress concentrations.

However fibre steered composites are characterized by different failure modes compared to conventional composite constructions due to the variability of material properties throughout the structure. These effects are not reliably covered by conventional analysis methods, that do not account for the effects of fibre steering, resulting in low margin of safety when considering data from conventional coupon test specimens. This is especially evident when the radius of curvature of the steered fibres is small.

The activity is divided in two stages: a first stage, A, focused on the development of the technology at material and sub-component level that shall have a duration of 24 months and budget of 800 k€; and a second stage, B, focused of further maturation of the technology up to full-component level, that shall have a duration of 12 months and budget of 400 k€.

The major tasks foreseen during the first phase of the activity are the following:

- Identify a benchmark structure where employing fibre steering technologies to improve structural performance. Perform a preliminary study to show the advantage of using fibre steering in the selected application. Define representative sub-components of the structure where fibre steering is intended and that can be independently tested and modelled.
  The baseline structure must have been already verified for the space sector and the tender must be already familiar with fibre steering processes.
- Review the state-of-the-art modelling methodologies for fibre steered composite materials. Identify and adapt the most suitable models for the benchmark structure and validate them via material-level test campaign of composite coupons with steered fibres. The models shall be able to predict both strength and failure modes experienced during material testing.
- Design the structural sub-components. Model them using the necessary details to account for the mechanical properties variations and failure modes. Test the structural sub-components under static and dynamic conditions in order to validate the modelling approach.

Upon successful validation of the sub-components, the project can proceed to the second phase, consisting in the following major tasks:

- The sub-component models, shall be employed to develop a full-scale model of the benchmark structure and used to predict its behaviour, failure modes and margin of safety
- The structure shall be manufactured using fibre steering technology with appropriate quality control and non-destructive inspection
- The structure shall be mechanically tested. Data shall be correlated against predictions to validate the models.

Deliverables: Breadboard, Reports

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: All missions.

Applicable THAG Roadmap: Composite Materials (2019)
Consistent with activity A50 “Optimisation of composite primary structures via fiber steering”

Domain	*Advanced Manufacturing CD2 - Structures, Mechanisms, Materials, Thermal*		
Ref. Number:	**GT17-324QE**	**Budget (k€):**	**600**

Title: **Multifunctional self-monitoring coating development for space environmental monitoring**

Objectives: The objective of this activity is to develop new protective coatings with multi-functional sensor capabilities to operate in space environments.

Description: Sensors for monitoring equipment and materials are now smaller and more robust, especially for some harsh environments, such as the space environment. Nano materials and technological advancements have greatly improved sensor design, including portability and fast signal response times. The high surface area to volume ratios and surface functionalization make nanomaterials highly sensitive to changes in surface chemistry, enabling extremely low detection limits. Optical, electro-chemical and magnetic are the three major signal transduction methods used in nano-enabled sensors. Optical transduction is based on the interaction of a sensing element with electromagnetic radiation, using analytical techniques to monitor emission or absorption of a sample under irradiation by UV, visible or infrared light. The integrated sensors could provide online information on residual stress distribution and changes upon interaction with space environment. This could indirectly assist prediction of cracking and delamination's in the coating layer.

One challenging future direction for sensors is the integration of several functionalities into protective coatings, with the aim of developing several self-monitoring nano-sensors that are remote continuous monitoring devices that accurately detail the environmental conditions the surface is exposed to.

In this activity the following tasks are foreseen:

- Investigate the most promising protective coatings and their nano-sensor compatibility;
- Identify the specific environment to be monitored (for UV, contamination etc.);
- Development of the multi-functionality capabilities of the sensor;
- Test the sensors capability to operate in extreme environments;
- Develop prototype and perform verification for lifetime of a coating in relevant space environments (e.g. geostationary, low-Earth orbit).

Deliverables: Prototype, Report.

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	24

Target Application/ Timeframe: Space applications. Enables capability of performing in-orbit environmental monitoring.

Applicable THAG Roadmap: Relevant to Roadmap Coatings.

3.1.3. CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing

Domain	*Advanced Manufacturing CD5 - End-to-End RF & Optical Systems and Products for Navigation, Communication and Remote Sensing*

Ref. Number: GT1A-325EF **Budget (k€):** 1,200

Title: **Enhanced RF/microwave parts by using advanced manufacturing techniques**

Objectives: The objective of this activity is to investigate and consolidate end-to-end advanced manufacturing processes for RF/Microwave parts, capable to provide performance enhancement.

Description: RF/Microwave parts are complex structures with, in most of the cases, severe requirements in terms of RF, thermal, mechanical, accommodation and quality. The final design is a trade-off among the demands from the different aspects but also considering the limitations related to conventional manufacturing techniques such as Computer Numerical Control.

The challenge is stressed when frequency and/or complexity increase, which is a current trend in RF payloads.

This activity aims to assess end-to-end advanced manufacturing techniques capable to provide enhance performance in RF/Microwave parts. Complex waveguide filters, high frequency distribution networks, TWT parts, antenna feeds, etc. commonly found in RF payload can be further improved by defining new manufacturing approaches. Aspects such as surface roughness, complex routing, compactness, thermal dissipation, etc. may be further improved with the consequent system enhancement.

Considering consolidated material and manufacturing processes, design rules taking into account any potential constrain shall be drawn. These design rules will also take into account any additional manufacturing step (e.g. cleaning, smoothing) to be sure all are compatible between each other. With the set of design rules, a final detail design will be performed, manufacturing and tested.

The activity shall cover, at least, the following tasks:

- Identification of systems and RF parts to be re-worked. Clear identification of aimed improvement (RF, Thermal, Mechanical, etc.).
- Review of available material and manufacturing processes. Assessment of suitability of each of them for the aimed RF parts.
- Identification of design rules considering the pre-selected end-to-end manufacturing approach.
- Detailed design and analysis
- Breadboard manufacturing and test
- Conclusions and way forward

Deliverables: Breadboard, Report

Current TRL: 3 **Target TRL:** 5 **Duration (months):** 30

Target Application/ Timeframe: RF/Microwave parts

Applicable THAG Roadmap: Not relevant to a Harmonisation topic.

3.1.4. CD7 - Propulsion, Space Transportation and Re-entry Vehicles

Domain	*Advanced Manufacturing - CD7 - Propulsion, Space Transportation and Re-entry Vehicles*

Ref. Number:	**GT1A-326MP**	**Budget (k€):**	**1,200**

Title: **Additive manufacturing enabled thruster**

Objectives: The objective of this activity is to demonstrate an advanced manufacturing design enabled thruster for in-space applications.

Description: The current state of the art for space thruster design is driven by the available pressure budgets and traditional manufacturing techniques. Additive manufacturing has been used but in a highly constrained and risk adverse fashion. For example replacing injector to valve structural elements, producing near net form parts from expensive alloys or fabricating hard to machine materials. The inherent design flexibility of additive manufacturing techniques has not been exploited. Aspects of the thruster design such as complex hydraulic manifold opportunities or direct thermal and structural detailed design have been relatively unexplored by industry.

The objective of this activity is to actively pursue design opportunities that can really only be realized by additive manufacturing. For example reverse flow engines have the potential to eliminate the need for ultra high temperature materials and achieve comparable effects to regenerative cooling but at a much lower pressure budget.
Similarly transpiration cooling is a well known technique that has proved hard to realize through manufacturability issues. The obvious end state of additive manufacturing is to print the entirety of the article by integrating all the sub assemblies into a single build. AM presents many options to more reliably implement such strategies. The current approach by industry attempts to incrementally incorporate additive manufacturing into current design approaches. This activity seeks to generate and test a design enabled by using these manufacturing techniques. To do so the following approach will be adopted.

The activity foresees the following tasks:

- Establish requirements
- Trade of preliminary design approaches
- Preliminary Design Review
- Manufacture and test Development Model.

Deliverables: Engineering Model, Report

Current TRL:	3	**Target TRL:**	5	**Duration (months):**	36

Target Application/ Timeframe: Nanosatellite missions.

Applicable THAG Roadmap: Not relevant to any Harmonisation topic.