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DOCUMENT

GSTP-6 Element 1 Compendium of Potential Activities Advanced Manufacturing

APPROVAL

Title GSTP-6 Element 1 Compendium of Potential Activities – Advanced Manufacturing	
Issue 1	**Revision** 2
Author TEC-TI	**Date** 5-11-2015
Approved by TEC-T / TEC-Q	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue 1	**Revision** 2		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

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1 INTRODUCTION

This document provides an additional list of candidate activities to the Work Plan of the GSTP-6 Element 1, following the process outlined in the September 2012 IPC: ESA/IPC(2012)98 - Preparing the work plans for the GSTP-6 Element 1.
As indicated in this referenced document, Technology development activities in ESA are organised in 9 service domains (SD) and 25 technology domains (TD).

This pre-selection complements the GSTP-6 Element 1 – Compendium of Generic Technology Activities issued in February 2013 and the GSTP-6 Element 1 – Compendium of Potential Activities Application-Specific Service Domains SD1, SD3, SD4, SD6, SD8, SD9 issued in December 2013. The present selection corresponds to activities belonging to the Generic Domain (SD7) in the specific area: Advanced Manufacturing

According to the ESA-wide process described in ESA/IPC(2008)61 rev 1, the activities which are part of this compendium have been pre-selected following an intensive internal exercise which included programmatic screening, technical evaluation and consistency checking with technology strategy and THAG Roadmaps.

This document is a revision of the Compendium of Advanced Manufacturing activities published on 18th of June 2015 (Reference TEC-T/2015-013/NP), and therefore replaces this previous document.

This compendium is issued to Delegations of GSTP-6 Participating States and their industries for comments. Such comments will be considered in the following updates of the work plan for this GSTP 6 Element 1.

The objective is to have a good indication of the developments the Participants intend to support, in order to present updates of the GSTP-6 E1 Work Plan with a consolidated set of activities to the IPC for approval.

2 ADVANCED MANUFACTURING

Background and Main Considerations for Technology Development

Advanced Manufacturing as a cross-cutting activity captures the opportunity of new manufacturing, materials, processes and creates sustainable competitive advantage for the European Space Industry in the global market. This is achieved by restructuring the supply chain to facilitate faster and more agile entry to the market place and by creating performance enablers thanks to new materials, added degrees of freedom in the design phase and novel manufacturing capabilities.

Advanced Manufacturing processes are readily available in the current European industrial landscape. They need to be matured to a space qualification level within the scope of the proposed initiatives, focussing on the verification/qualification of the manufacturers capabilities.

This compendium "*Advanced Manufacturing for Space Applications*" identifies new manufacturing technologies which can be implemented immediately and which show high potential for space applications in terms of design freedom, performances or costs and lead time (from concept to manufacturing) reduction.

The key advantage of these Advanced Manufacturing initiatives will be to enable the European Space Industry to create new high performance space products by actively reducing the limitations induced by the traditional manufacturing processes/concepts. The activities are aimed at revitalising and consolidating the European leadership in advanced manufacturing for space applications, by enabling new designs with less manufacturing constraints, establishing novel qualified designs and manufacturing processes in Europe, serving the European Space Industry's competitiveness.

Verification/qualification against space requirements is not only important for the final product but also for the space hardware manufacturing capabilities. Within the proposed initiative, the focus shall be devoted to the verification of compliance and industrial capabilities of high quality manufacturing platforms and networks openly available for the European Space Industry. This guarantees a sustainable industrial basis for new products and advanced processes, taking maximum benefit of their disruptive potential.

The current European R&D landscape offers some ideal opportunities to link with other Programmes supported by the EU. It will profit from the cross-fertilisation opportunities with the other currently running or intended European Programmes on Advanced Manufacturing, including:

- AMAZE (Additive Manufacturing Aiming towards Zero Waste and Efficient Production of High-Tech Metal Products) is a €20 Million Program aiming at developing a complete EU-autonomous supply chain for Additive Manufacturing by 2016.

- The goal of DEPLOYTECH is to advance the technology readiness level (TRL) of large space deployable structures starting with the development and qualification of three specific, useful, robust and innovative large space deployable technologies/concepts: an inflatable drag sail, a deployable solar array and CFRP solar sail booms. The EU FP 7 programme is funding the multimillion Euro DEPLOYECH activities with eight European partners and is assisted by NASA/MSFC.

- IRIDA (Industrialisation of Out-of-Autoclave Manufacturing for Integrated Aerostructures) has the main objective to reduce composite manufacturing costs, while maintaining high standards of safety and supporting the “greening” of the air transport section. This programme aims to develop a complete manufacturing technique able to produce aerospace quality composites with properties comparable to that of autoclave cured parts.

3 LIST OF ACTIVITIES

Specific Area: ADVANCED MANUFACTURING

The activities will be implemented in close coordination with all the responsible units in charge of process development/qualification and end application.

The activities in this Compendium and listed in the table below are covering areas of:

1. Materials processing
2. Surface engineering
3. Shaping
4. Joining
5. Assembly

GSTP-6 Reference	Title	Budget(K€)
	Materials Processing	
G61A-001QT	Low Cost Manufacturing of Engineering Ceramic Materials for Space Applications	400
G61A-002MS	3D Weaving processes for realisation of near net shaped hardware	500
G61A-003QT	Extended pot life resins for out of autoclave processing for large and complex part	600
G61A-004QT	Novel Low temperature curing resins for enhanced out of autoclave processing for large and complex space composites structure	1,200
G61A-005MS	Integrated Optical Fibres in Launcher and Spacecraft Composite Structures	500
G61A-006QT	Powder Metallurgy Based Materials for High Wear Resistance, High Hardness and High Temperature	600
G61A-007MS	Manufacturing of Interfaces for Thermo-Plastic Structures	400
	Surface Engineering	
G61A-008QT	Low cost/low temperature functional ceramic coating	500
	Shaping	
G61A-009MS	3D Honeycomb for curved structure manufacturing	600
G61A-010MS	Lattice Structures for Launchers and Spacecraft Produced with Automatic CFRP Processes	900
G61A-011QT	Advanced Forming Technologies for Complex Shapes	1,500
G61A-018QT	Additive Manufacturing Powder Material Supply Chain: Verification and Validation	1,000
G61A-019QT	Advanced aluminium alloys tailored for Additive Manufacturing space applications, targeting high end structural spacecraft parts	900
G61A-020QT	Development of large 3D printed structures: tank shells joined by FSW for ultimate cost reduction	2,500
G61A-021QT	Primary Structures made by Additive Manufacturing	1,200

G61A-022QT	Enhanced contamination control for Additive Manufacturing	500
G61A-023QT	Development of a manufacturing process for large polymer structures for spacecraft applications: high strength electrical and/or thermally conductive polymers for Additive Manufacturing	700
G61A-024QT	Integrated recycling and manufacturing process for on planet manufacturing using polymers materials	700
G61A-025MS	Development of Design Methods for AM including CAD Design / FEM analysis / Manufacturing features	900
G61A-026MP	Additive Manufacture of In-space Engine chambers	2,000
G61A-027MS	Development of embedded thermal functions in structural parts using 3D printing	900
G61A-028QT	Development of a gradient sized mesh for cryocooler by Additive Manufacturing	1,000
G61A- 029ET	Development of one single part integrating waveguide filter, bends, couplers, supporting structures made by Additive Manufacturing -	1,000
G61A-031MM	Development of thermally ultra-high stable compact grating spectrometer mirrors via Additive Manufacturing	500
G61A-032MM	Development of low areal density Aluminium alloy mirrors using Additive Manufacturing	400
G61A-033MS	Development of a Compliant Mechanism Based on Additive Manufacturing	500
G61A-034MS	Development of shock absorbing protection made of crushable materials (lattice / cellular structure) using Additive Manufacturing	600
G61A-035ET	Evaluation and consolidation of Additive Manufacturing processes and materials for the manufacturing of RF hardware	1,000
Joining		
G61A-012QT	Dissimilar transition joints for Aluminium demisable structures	400
G61A-013QT	Surface Nano-Texturing of Metals for Adhesive Bonding Improvement in Metal/CFRP and Metal/Metal Structural Joining.	600
Assembly		
G61A-014MS	Integral Manufacturing of Full CFRP Sandwich Structures for Optical Benches	700
G61A-015MS	Manufacturing of Large Friction Stir Welded Structures for Satellites and Launchers Applications	1,200
G61A-016QT	Rigid-flex PCB interconnections	900
G61A-017QT	High Density PCB assemblies	1,800
	Total	**29,600**

4 DESCRIPTION OF ACTIVITIES

Specific Area: ADVANCED MANUFACTURING

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-001QT** **Budget (k€):** **400**

Title: **Low Cost Manufacturing of Engineering Ceramic Materials for Space Applications**

Objectives: Demonstration of low cost manufacturing of engineering ceramic materials leading to reduced production costs for space applications including CMCs without reducing the quality and the properties.

Description: The demand in using ceramic materials in Space Applications is largely increasing, since they combine extremely interesting properties, including highest stiffness and highest compressive strengths, with low density and lowest expansion coefficients. Most times ceramics are only used when there are no other solutions satisfying the tight requirements e.g. high stability also during thermal cycles as in optical benches or electric insulation and thermal conductivity as for Traveling Wave Tubes (TWTs). Main limiting factors are the manufacturing costs, especially in the final machining.

Today new manufacturing routes (including polymeric precursors utilisation, filament winding ceramics manufacturing WIPOX®, or Ultra High Temperature Ceramics) are available which could allow significant costs reduction in ceramics materials productions potentially opening the products/applications portfolio to load bearing structures, mechanisms, structures with improved wear/clamping performances, thermal management systems ultra-stable structures (optical benches), mirrors and telescopes. Moreover, high and ultra-high temperature applications such as nozzles and re-entry vehicles can be targeted.

The following tasks will be performed:

1) Literature review of existing engineering ceramics production processes. For the state of the art manufacturing processes of different space applications the key cost drivers shall be identified within the manufacturing chain.
2) Trade-off study of the identified advanced manufacturing technologies. The Trade-off shall include at least an evaluation of the feasibility to use this technology for the manufacturing of Ceramics used in different space applications (as listed) as well as the main advantages, cost benefits and the associated risks.
3) Implementation in the production process of a typical space application in combination with currently widely available laser technologies for machining and post-processing. The chosen advanced manufacturing technologies shall be implemented in the production flow and the feasibility shall be shown in a Demonstrator production. Limits shall be evaluated and a cost comparison performed.
4) Demonstrator testing as manufacturing process verification. The

testing shall validate that with the new, low cost manufacturing process the requirements for the chosen space application have been met.

5) Advanced Manufacturing Technology evaluation and conclusion. All results shall be summarized in a report and the technology benefits & limitations assessed.

Deliverables:	Manufacturing Process Verification Advanced Manufacturing Technology Report

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

Target Application / Timeframe :	Load bearing structures, mechanisms, structures with improved wear/clamping performances, thermal management systems ultra-stable structures (optical benches), mirrors and telescopes. Moreover, high and ultra-high temperature applications such as nozzles and re-entry vehicles can be targeted.

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-002MS** **Budget (k€): 500**

Title: **3D Weaving processes for realisation of near net shaped hardware**

Objectives: The objective is to demonstrate the versatility of 3D weaving processes for the manufacturing of composite materials with the demonstration of multifunctional properties of composite structures. The performance of the manufactured hardware will be compared with conventionally produced ones and traded-off in terms of mechanical performance, shape accuracy, mass, lead-time, design freedom, and costs.

Description: 3D weaving processes enable the realisation of near net shaped hardware with complex geometry. The use of 3D weaving is of particular interest for space applications that are optimised for high stiffness. The weaving structure can be tailored to locally meet the stress level requirement. It offers enhanced design freedom through avoidance of any additional joining requirements and the possible combination of weaving different fibres, e.g. C-fibres for structural integrity, polymeric fibres for spacer elements, and metallic fibres for heating functionality. This results in truly multi-functional hardware with the added value of significantly reduced manufacturing time, as the manufacturing process is an integrated part of the design.

The following tasks will be performed:

1) Review of state of the art 2D and 3D weaving processes, selection of target applications and demonstrators.
2) Development, manufacturing and test plan.
3) Weaving and manufacturing process optimisation.
4) Performance evaluation comparing 2D/3D weaving process with conventional hardware.
5) Performance trade-off.
6) Critical revision for the application of 2D/3D weaving processes for spacecraft applications.

Deliverables: 3D weaving demonstrator.

Current TRL: 2 **Target TRL:** 4 **Duration (months)** 18

Target Application / Timeframe : Space applications that are optimised for high stiffness . TRL 4 by Q4 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-003QT** **Budget (k€): 600**

Title: **Extended pot life resins for out of autoclave processing for large and complex part**

Objectives: The objective is to develop resin systems exhibiting extended shelf/pot-life to enable wider utilisation of the out of autoclave process for large or complex parts. This shall be an optimisation between extended pot-life as well as minimisation of curing temperature for a variety of target applications.

Description: Composite and adhesive resin systems form a cornerstone for the manufacture of any modern spacecraft however both the manufacturing and procurement processes are often limited by the pot and/or shelf life of the prepreg/resin materials. A longer shelf life could mean a reduction of the amount of scrappage which occurs from any typical spacecraft composite system manufacturing line. Typically, it can be necessary to scrap and re-procure significant quantities of unused prepreg or resin materials simply because the shelf life is shorter than any recurrent manufacturing. Improved shelf life could significantly reduce both the cost of manufacture and the environmental footprint of composite processes. Secondly, the extension of pot life for resin systems could allow for extended manufacturing cycles for both larger and more complex smaller composite artefacts particularly seen as part of out of autoclave processing. A brief review of available literature indicates some interest in approaches to extend both the pot and shelf life of commonly used resin systems.

The use of CFRP out-of-autoclave technologies is utilised for increasing number of applications for improved automation, either for large structures or smaller complex geometries. The production of large structures require long layup times at room temperature that can reach the order of a week. But also smaller structures can require significant out-time of the prepreg, many of which are required to be stored in low temperature freezers to prevent curing. The limitation of prepreg resins is therefore more fundamental, depending on required layup time and ultimate curing temperature. Extended processing times at room temperature can limit the spectrum of possible applications or compromise the final mechanical performance of the CFRP.

Any study shall consider both the composite and adhesive resin system as a mated pair, which shall be tailored for compatibility towards each other.

Following the initial analysis a trade-off of the significance of both the pot life and shelf life shall be performed to assess the relative potential benefits of improving either property. Any activity shall preferentially identify chemical modifications to extend both properties.

Phase 1 (350K€/14 months)
The following tasks will be performed:

1) Review of current space applications for out of autoclave processes and available resin/prepreg systems, including a mid-term technology trend. Selection of applications processes that requires resin performance improvement in terms of extended pot-life.
2) Procurement, quantification and laboratory materials assessment of candidate

resin systems properties and capabilities.
3) Preliminary trade-off of candidate systems. Selection of candidate systems.
4) Development and test plan for two resin systems.
5) Small scale testing and resin optimisation, definition of breadboard demonstrator for phase 2.

Phase 2 (250K€/ 10 months)
The following tasks will be performed:

1) Up-scaling of optimised resin systems and prepreg production.
2) Manufacturing and testing of breadboard demonstrator.
3) Critical revision, ROM costs for full qualification, spin-off potential.

Deliverables: Demonstrator of the extended pot life resins, samples.

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

Target Application / Timeframe : TRL5 by Q4 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-004QT** **Budget (k€): 1,200**

Title: **Novel Low temperature curing resins for enhanced out of autoclave processing for large and complex space composites structure**

Objectives: The objectives of this activity is to develop a new formulation of low temperature curing resin with enhanced pot and/or shell life to allow out of autoclave processing of large and complex structure.

Description: The low temperature curing ability and the extended pot/shell life shall be tested on the manufacturing of large and/or complex part by out of autoclave processing (e.g. primary and secondary structure for spacecraft and radiators plus launcher structures).

Generally, this will result in: lowering the manufacturing cost, decreasing the environmental impact and improving the manufacturing possibility in term of shape, size, accuracy and complexity. Besides a decrease in storage constrain, such resin will enable lower curing temperature and thus higher integration possibility, out of autoclave processing with extended manufacturing cycles and thus less time constrain.

Phase 1: Material development (700K€ / 18 months)

The following tasks will be performed:
1) The contractor shall investigate the need for optimisation in term of material properties regarding out of autoclave process to enable the manufacturing of very large and/or complex structures related to primary and secondary structure for spacecraft.
2) Properties of existing resin system allowing low temperature curing and out of autoclave process will be reviewed. New chemical formulation or modification of existing resin systems will be defined to meet the requirement resulting from the first task.
3) Development and test plan for new resin systems
4) Small scale testing and resin optimisation, definition of breadboard demonstrators for phase 2 that need to include a large and a complex structure.
5) Evaluation and quantification of the benefits (environmental, energy, functional capability, production optimisation) from replacement of conventional resin with the new system.

Phase 2: Breadboarding demonstration : (500K€/ 12 months)

The following tasks will be performed:
1) Up-scaling of optimised resin systems and prepreg production
2) Manufacturing and testing of breadboard demonstrator
3) Critical revision, ROM costs for full qualification, spin-off potential

Deliverables: Resins prepreg and breadboard demonstration of the technology

Current TRL: 3 **Target TRL:** 6 **Duration (months)** 30

Target TRL 6 by Q4 2017.
Application / Timeframe : Primary and secondary structure for spacecraft and radiators plus launcher structures.

Applicable THAG Roadmap: Composite Materials (2014).

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-005MS** **Budget (k€):** **500**

Title: **Integrated Optical Fibres in Launcher and Spacecraft Composite Structures**

Objectives: The objectives of this activity shall be the development of the manufacturing process for the integration of optical fibres into CFRP composite structures. The process and the structural behaviour of the structures shall be developed.
For launchers, health monitoring of composite structures shall be considered, with potential application to re-usability of the structures.

Description: Recent developments in TRP and ARTES have provided significant results in the instrumentation of CFRP structures with optical fibres including Bragg grating sensors, among others. This allows for strain measurement and thermal measurement with a small number of optical fibres, by multiplexing a large amount of sensors.

The open questions still present concern mainly the integration of the optical fibres into the composite material and the characterisation of the micromechanical behaviour, mainly for strength. This is due to the differing dimensions and stiffness of the structural fibres and the optical fibres. A full characterisation in terms of fracture mechanics in the resin system, thermo-elastic compatibility and the coupled stiffness is necessary both for the structure and the sensor system.

The activity proposed will profit from the lessons learned in prior lower TRL developments in ARTES 5 (Highly Stable Antenna Technologies, High Performance Tanks with In-Situ Health Monitoring) and TRP (Optical-Fibre Temperature Sensor for Structural Health Monitoring: Engineering Model Space Assessment).

Deliverables: Demonstration of the integration of optical fibres into CFRP composite structures, e.g. secondary structure of Spacecraft.

Current TRL: 3 **Target TRL:** 6 **Duration (months)** 18

Target Application / Timeframe : Main applications considered are earth-deck panels and lateral panels of Spaceraft, targeting shape and stress monitoring during ground testing and orbit operation.
TRL 6 by 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-006QT** **Budget (k€): 600**

Title: **Powder Metallurgy Based Materials for High Wear Resistance, High Hardness and High Temperature**

Objectives: The objective of the activity is to develop and test parts made from powder metallurgy based materials. The aim is to demonstrate and evaluate their suitability for space applications where high temperature resistance, high wear resistance and/or high hardness are required.

Description: This activity will consist of identifying and possibly modifying (composition, process parameters) powder metallurgy materials used in other industries with similar requirements (e.g. aeronautics, medical industry) or promising novel/ advanced materials.

Powder metallurgy is currently used in several industries to replace conventional manufacturing processes, for demanding high performance applications, such as aero-engines or medical instruments. Powder metallurgy processes are near-net-shape processes which allow parts with complex shapes to be produced without extensive machining and with reduced material waste. This is highly valuable for high hardness, high wear resistance materials which are very difficult to machine/process and where small imperfections left by the machining process may lead to sudden failure of the final product.

Moreover, in powder metallurgy processes (due to their fine grain structure) the material strength is often enhanced compared to parts produced from conventional processes. Defects generated in conventional manufacturing routes such as casting and forging are also reduced (e.g. porosity, microsegregation). Such advantages are of high importance in high temperature structural applications where high strength, good fatigue properties and high creep resistance are required.
Powder metallurgy parts are currently used in high temperature aeronautics applications (e.g. turbine discs in Ni-base superalloys) and high wear-resistance tools.

The benefits of powder metallurgy materials are of high interest for space applications, in high temperature parts such as rocket nozzles or where good wear resistance is needed, such as mechanism parts (e.g. gears). Powder metallurgy offers the unique opportunity to produce functionally graded materials with variation of properties (e.g. softer core and harder surface) Main targeted applications could include: mechanisms, ultra-stable structures, mirrors, gears and bearings, telescopes, detectors, optical elements, nozzles and valves as well as damping structures.

The following tasks will be performed:

1) Space applications (among the listed ones) where powder metallurgy will lead to a significant improvement in material structure (including functional grading of properties), part performance, part accuracy and manufacturing efficiency (cost and lead time) will be identified.
2) Suitable materials will be selected for the identified applications. This will include powder metallurgy materials used in other industries (including Aeronautics and Medical) as well as promising new/advanced materials

(including intermetallics, e. g. TiAl, Metal Matrix Composites, quasicrystal reinforced metals and mixtures only feasible by powder metallurgy, e. g. Cu-W).

3) Various consolidation processes will be investigated including Spark Plasma Sintering (SPS), Self-Propagating High Temperature Synthesis (SHS), Hot Isostatic Pressing (HIP) and the most suitable one selected for the intended applications.
4) The powder metallurgy manufacturing route and associated process parameters will be optimized for the identified applications (powder selection, compaction, heat treatment, post-processing) via a dedicated optimization test campaign.
5) Demonstrator parts will be manufactured and tested/verified (via a dedicated verification test campaign) to demonstrate success in meeting the applications requirements.

Deliverables: Study report, breadboard, prototype, process evaluation/qualification in a relevant environment.

Current TRL:	3	**Target TRL:**	6	**Duration (months)**	24

Target Application / Timeframe : Mechanisms, ultra-stable structures, mirrors, gears and bearings, telescopes, detectors, optical elements, nozzles and valves as well as damping structures
TRL 6 by 2017

Applicable THAG Roadmap: Not related to a Harmonisation subject .

Specific Areas	*ADVANCED MANUFACTURING – MATERIALS PROCESSING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-007MS** **Budget (k€): 400**

Title: **Manufacturing of Interfaces for Thermo-Plastic Structures**

Objectives: Demonstration of attachment technologies for load introduction/equipment interface brackets to panels of thermo-plastic CFRP structures.

Description: CFRP structures are in general not flexible to allow for adding attachments after manufacturing. The attachment locations are prepared for instance with inserts or co-cured brackets.

Thermo-plastic CFRP structures offer the potential to weld to other thermo-plastic elements. In addition, there is also the possibility to realise joints to dissimilar material parts (metal, thermoset CFRP) with the same methods.

Special attention is to be paid to surface preparation and alignment. This would allow for flexibility for handling late changes.

In particular, the following tasks will be done within this activity:

1) Demonstration of the (welding) attachment technology on a typical spacecraft or launcher structural element made out of thermo-plastic CFRP material.
2) Verification by analysis and test of the attachment strength and stiffness

Deliverables:

1) Demonstration and verification of attachement technology on a typical spacecraft or launcher structural element made out of thermo-plastic CFRP material.

Current TRL: 2 **Target TRL:** 4 **Duration (months)** 18

Target Application / Timeframe : Launcher structures and Spacecraft structures (panels and cylinders) with low thermoelastic stability demand.
TRL 5 by 2016

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING – SURFACE ENGINEERING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-008QT** **Budget (k€):** **500**

Title: **Low cost/low temperature functional ceramic coating**

Objectives: The aim of this activity is the development of low cost/ low temperature (below 100C) functional ceramic coating processes or a possible adaption of the processing window to enable a much wider use of the currently available ceramic based coating.

Description: The use of functional ceramic coatings has recently been required driven by the harsh mission environment like inner planetary missions. However the use of CFRP, Al alloys and thin film substrates is not compatible with the classical high temperature processing required during the implementation of ceramic coating. Another point that shall be taken into account is to increase the flexibility of the coating by further reducing the nominal thickness without impairing the functional properties such that the coating can be applied flexible substrates like thin foils.

The following tasks shall be carried out in the frame of this activity:

1) A reduction of processing window (deposition and curing temperature) by varying the binder matrix and the curing procedure (e.g. vacuum or room temperature curing). The target substrates under study shall be at least be compatible with Al alloys, CFRP surface and flexible (thin foil) surfaces.
2) A reduction of functional ceramic coating thickness with targeted layer thickness below 10m shall be addressed. The flexibility of improved coatings from task 1 shall be assessed on flexible substrates such as foils and thin metallic sheets.

Both tasks shall be accompanied by comprehensive materials and processing evaluation program and shall include ground as well as space environmental assessments. In addition an economic and environmental evaluation shall be performed.

Deliverables: Demonstration of low temperature functional ceramic coatings.

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

Target Application / Timeframe : Telecom, Navigation and Earth Observation missions in GEO, LEO and MEO orbits
TRL 5 by 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-009MS** **Budget (k€): 600**

Title: **3D Honeycomb for curved structure manufacturing**

Objectives: The primary objective of this activity is to demonstrate the added technological and manufacturing values using 3D type of honeycomb structure on the manufacturing process of all curved composite structures based on honeycomb core.

Description: 3D honeycomb is foreseen to drastically facilitate the manufacturing of all complex curved and bi-dimensional panels, fairing, mast and booms, antenna reflectors and sub-reflectors, telescope mirrors and re-entry vehicles.

The following tasks will be performed:

1) Review of all space (sub)systems that are using curve structure based on honeycomb including launchers, telecommunication and structure application in general.
2) Development of materials to answer all type of application (i.e. Space grade Aluminium, Fibre reinforced resin).
3) Trade-off and selection of 3 systems/structure that will show an increase in productivity, functionality and reliability when using 3D honeycomb (i.e antenna, fairy, boom) compare to system using classical honeycomb and splicing process.
4) Production of 3D honeycomb (metal and polymer).
5) Planning for detailed design, manufacturing, and testing for full space qualification.
6) Manufacturing and testing for space related performance and model optimisation.
7) Manufacturing of demonstrator/breadboard and full testing and model evaluation.
8) Critical revision of 3D honeycomb based structure and eventual manufacturing process modification.

Deliverables: Prototype demonstrator.

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

Target Application / Timeframe : All complex curved and bi-dimensional panels, fairing, mast and booms, antenna reflectors and sub-reflectors, telescope mirrors and re-entry vehicles

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-010MS** **Budget (k€): 900**

Title: **Lattice Structures for Launchers and Spacecraft Produced with Automatic CFRP Processes**

Objectives: The objectives of this activity shall be the design and development of stable CFRP lattice structures employing automatic fibre placement and similar machines. The structures to be targeted are plates and cylinders.

Description: The lattice structures can provide very significant mass saving in highly loaded structures for launchers (payload adapters, separation cylinders) and spacecraft (central tubes, shear and lateral panels, payload booms).

In some cases grid structures have been demonstrated to be superior to monolithic CFRP or sandwich structures for load capacity and stiffness. Thermoelastic stability is also one of the main performances offered to payload booms.

This activity is devoted to the identification of benchmark structures, the development of the lattice architecture with emphasis in the characterisation of cross-over routing, the development of the automated manufacturing process, and the design of different types of mechanical interfaces to other structures. Sample and component testing shall be included for joints, inserts et al.

A very important factor is the necessary manufacturing process automation offered by fibre placement, tape placement, filament winding and similar machines.
Depending on the particular application, a trade-off shall be performed between thermoset and thermoplastic resins.

Deliverables: Two demonstrators to be built: a plate for lateral or shear panels of spacecraft and a tube for central cylinders, payload booms, launcher structures or payload adapters.

Current TRL: 3 **Target TRL:** 6 **Duration (months)** 24

Target Application / Timeframe : Launchers and spacecraft structures
TRL 6 by 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-011QT** **Budget (k€): 1,500**

Title: **Advanced Forming Technologies for Complex Shapes**

Objectives: To develop, test and qualify in a relevant environment advanced forming processes for identified space applications targeting a wide range of metallic tanks. This will allow a new structural architecture as well as performances enhancement of existing designs. Anticipated major improvements include mass and stress reductions, but also dramatic reduction of manufacturing time and complexity, costs and material waste compared to conventional manufacturing processes, combined (in selected cases) with an increased accuracy.

Description: Advanced forming technologies are desirable as they allow complex shapes to be produced with high degrees of accuracy, while reducing the manufacturing steps (and associated costs) and the material waste compared to traditionally used manufacturing routes (i.e. forging or casting followed by machining and/or joining). They can enable revolutionary structural designs to be achieved and they can significantly improve the performances of currently existing design solutions overall leading to large mass and stress reduction.

Some of the most interesting techniques such as Magnetic Pulse Forming and Flowforming (these can also be applied after solid state joining techniques,e. g. Friction Stir Welding) complement and expand the currently used technologies such as Spin Forming and Superplastic Forming (as well as Superplastic Forming Diffusion Bonding).

All the mentioned manufacturing processes will lead to maximum impact in terms of costs/lead time reduction as well as increasing performances if applied to launchers upper stages structural tanks and their interfaces as well as large satellites and spacecraft tanks. Moreover, spin forming could allow the manufacturing of innovative designs such as the Cassini shaped tank and bifurcation, representing a change of architecture compared to existing concepts.
The concept design to maturate consists of a Cassini-shaped dome without a dedicated Y-ring part. Skirt structures are (spot-)welded to the cylinder part. It is known that the Cassini dome shape has the advantage of no compressive hoop stress throughout the entire meridian, when shape parameters are correctly selected. This represents a significant improvement with respect to the state of the art.

The main tasks to be implemented in the frame of this activity can be divided into two phases:

<u>Phase 1:</u>

In the first phase two parallel ways will be investigated. A new tank architecture (Cassini shape) will be defined and the most suitable (current) manufacturing processes will be assesed and optimised for this innovative design. In parallel existing architectures will be assessed with respect to innovative forming technologies (including magnetic pulse forming and flowforming).

The following tasks will be performed:

1) A trade-off of the two options will be performed mainly adressing design performances, costs, manufacturing optimisation, etc.
2) A development and ROM costing plan will be issued based on the above trade-off.

Phase 2:

In Phase 2, the ideal design/manufacturing processes combinations for the product selected in Phase 1 will be assessed.

The following tasks will be performed:

1) A detailed design will be performed for the selected product (Cassini shape or traditional architecture).
2) Selection of the traditional or advanced forming processes required to allow the manufacturing of the costituent parts of the tanks (domes, shells, etc.) and their assembly and optimisation for the product.
3) Material samples testing at subscale level in pre- and post-forming conditions.
4) Modelling of the manufacturing processes for in-production quality monitoring.
5) Manufacturing of full scale domes demonstrators (preferably at 4 meters).
6) Mimensional check of the manufactured demonstrators.
7) Perform state of the art NDI and quality/metallurgical assessment on the manufactured demontrators.
8) Destructive investigation of the tanks and correlation with NDI.

Deliverables: Study reports, breadboards, prototype qualified in a relevant environment

Current TRL: 3 **Target TRL:** 6 **Duration (months)** 24

Target Application / Timeframe : Launchers upper stage tanks, wire rings, upper stages interconnections as well as large satellites and spacecraft tanks.
TRL 6 by 2017.

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-018QT** **Budget (k€):** **1,000**

Title: **Additive Manufacturing Powder Material Supply Chain: Verification and Validation**

Objectives: Validate the procurement of raw material powder used in Additive Manufacturing technology for space: consolidate the list of requirements, establish verification methodology and validate supply chain for European Space Industry.

Description: One of the main challenges in Additive manufacturing is to master all the steps ensuring that the final product is of sufficient quality to be used in a space mission. The first element to take into consideration is the raw material, normally a powder, that will be processed until obtaining a high end part. In this activity, an iterative approach will be used to unambiguously identify the main requirements for metallic powder procurement. The activity will target one of the priority materials identified in the Harmonisation Roadmap (i. e. Titanium, Aluminium, Inconel and Invar), but further materials can be proposed by the Contractor.

The activity will consist of the following tasks:

1) The Contractor will generate the design of a generic space product that
   - benefits from the specific material to be validated
   - has dimensions compatible with the AM machines used to process the powder
   - includes challenging features for processing using those machines.
2) After a survey of the European landscape for 3D printing metallic raw material, several batches of powder will be distributed to institutes/companies having in-depth expertise in powder characterisation for benchmarking their powder characterisation methodology. The outcome of the benchmark will be cross-verified by the Contractor.
3) The European expertise on 3D printing of the specific metal will then be reviewed and the different batches of powder will be processed by selected service providers, i.e. using different machines and different set-ups. Test specimens and generic designed products (Task 0) will be manufactured. The produced specimens will be independently tested by the Contractor prior and after post treatments (HIP, tempering etc.). The generic designed products will also be evaluated.
4) Based on the outcome of Tasks 1 and 2, a powder procurement specification guideline will be prepared and new batches of metallic powders will be procured accordingly. Their characteristics will be determined by a few Institutes/Companies, among the ones selected within Task 1 (based on the work they performed within Task 1) and independently characterised as well by the Contractor. The powder batches will be dispatched to some of the service providers based on the work they performed

within Task 2. Samples and generic designed products will be produced and tested.

5) Based on the outcome of the previous tasks, the Contractor will issue a list of recommendations for metallic powder procurement and verifications to be performed to validate the suitability of the powder for being used for making space hardware using Additive manufacturing technology.

Deliverables: Breadboards, samples, test plans, test reports, guidelines, recommendations, technical notes

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

Target Application / Timeframe : 2017- For all missions and all parts manufactured using AM technologies (e.g. structures, thermal, RF)

Applicable THAG Roadmap: Additive Manufacturing Roadmap (C02, C06, C08, C09, C13)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-019QT** **Budget (k€):** **900**

Title: **Advanced aluminium alloys tailored for Additive Manufacturing space applications, targeting high end structural spacecraft parts**

Objectives: To develop new advanced aluminium alloys which can take full advantage of the Additive Manufacturing (AM) 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. Since the method involves the process of melting and solidification, it is particularly suited to those materials which are readily weldable and have good castability. Since titanium and its alloys are readily weldable by a number of fusion welding techniques, it is not surprising that in the majority of current activities, titanium is the material of choice.

For applications in aerospace and space which require structural performance (high strength, toughness and/or damage tolerance), the choice of aluminium is usually limited to 2000 series (Al-Cu-Mg and Al-Li-Cu) and 7000 series (Al-Zn-Mg-Cu) alloys. Unfortunately the majority of these alloys are not recommended for fusion welding as they deliver welded joints which either have issues concerning the formation of defects (cracks, pores etc.) or poor mechanical performance. A strong need therefore exists, to develop a new generation of advanced aluminium alloys which can take full advantage of the AM 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:

1) Identification of possible structures within spacecraft and launchers applications which can take advantage of the AM process.
2) Comprehensive literature review targeting the field of Rapid Solidification of aluminium alloys, particularly focusing on inert gas atomization of powders.
3) Microstructural modelling to develop relationships between the AM process and the microstructure of advanced aluminium alloys (extended solid solubility, formation of metastable structures etc).
4) Grain size control using optimised AM process parameters in combination with dopants such as TiB2 and TiC.
5) Strength and performance improvement through the use of alloying additions based on Sc, Hf etc.
6) Manufacturing of samples and demonstrators of the identified structural applications for comparison with a) state of the art

manufacturing routes and b) non-optimised AM aluminium powders.

Deliverables: TNs, breadboards, prototype tested in a relevant environment, test reports, test plans

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

Target Application / Timeframe : TRL 5 in 2018 –Parts made using Additive Manufacturing techniques with high requirements (mainly structural but also thermal or stability)

Applicable THAG Roadmap: Additive Manufacturing Roadmap (C03)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-020QT** **Budget (k€):** **2,500**

Title: **Development of large 3D printed structures: tank shells joined by Friction Stir Welding (FSW) for ultimate cost reduction**

Objectives: Development of enhanced large spacecraft and launchers structures by applying / developing an industrialised Additive Manufacturing supply chain in combination with advanced joining techniques.

- Reduction of costs.
- Industrialisation of supply chain.
- Reduction of lead time.
- More careful use of limited resources.

Description: Additive Manufacturing (AM) is seen as one of the key enabling technologies for space hardware. Significant developments in the field were made within the last years, enhancing the maturity of these manufacturing techniques. Beside powder bed fusion, which is the most common metal AM process (mainly adopted for small volumes and geometries), technologies for large dimensions – in the range of 1 meter – are advancing rapidly, already enabling the manufacture of large titanium alloy structures.

Spacecraft propellant tanks are currently manufactured using Ti-6Al-4V. Large forgings are procured with a long lead time (usually more than 12 months) which are then worked, machined and heat treated to the final shape of the tank shell. The propellant tank is one of the most costly items on the spacecraft and the high cost is primarily due to the excessive amount of machining and the discarding of a high volume of machined chips. After machining, the tank shells are then joined by traditional welding techniques such as TIG and Electron Beam. The use of Additive Manufacturing in replacement of the current manufacturing route would allow to address those limitations while also enabling the direct manufacturing of the fluidic and mounting bosses. With Additive Manufacturing, the simplicity of the manufacturing route can be maximised (fewer steps, less part handling), allowing to further increase quality. The tank shells would then be joined using the solid state welding technique of Friction Stir Welding, maximising the reduction of manufacturing steps (and costs), the joint strength and the environmental friendliness of the whole process.

The activity will be performed in two Phases:

Phase 1 (1500 kEuro):

1) Review of spacecraft tanks, unveiling the potential for mass and cost reduction by AM (comparing with e.g. traditional casting or sheet forming methods).
2) Redesign of selected components, incorporating Additive Manufacturing and advanced joining techniques like Friction Stir Welding.
3) Critical assessment of the applicable requirements (structural, materials, processes, etc.) of safety critical structures, including the need for e.g. the equivalent of a casting factor.
4) Optimisation of the AM manufacturing process for the identified large

structures with dedicated test campaign at sub-scale samples level.
5) Optimisation of the Friction Stir Welding Process for the AM produced samples with dedicated test campaign.
6) Definition and selection of appropriate NDI methods (including in-process monitoring) for both AM and FSW-AM samples.

Phase 2 (1 MEuro):
1) Manufacturing of (large) representative structures, including process development/tailoring.
2) Non-destructive testing of samples, including residual stress determination.
3) Mechanical and microstructural characterisation of samples/large structures, including the assessment of critical strength and fracture properties
4) Bread-boarding (e.g. a tank made of 2 shells, joined with e.g. FSW, to be pressure tested).
5) Assessment of the technical and economic impact of the project.
6) Definition of a roadmap for further development.

Deliverables: Study reports, breadboards, prototype tested in a relevant environment

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

Target Application / Timeframe: 2017 , Large structures

Applicable THAG Roadmap: Additive Manufacturing Roadmap (D18 or A09)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-021QT** **Budget (k€):** **1,200**

Title: **Primary Structures made by Additive Manufacturing**

Objectives: Select, design, manufacture and test a Fail-Safe primary structure using Additive Manufacturing (AM) technology as a main-stream manufacturing technique.

Description: The current status of AM shows that secondary and ternary structures can be designed, made, qualified and flown using Titanium or Aluminium. These achievements however are not enough to use the technology for highly loaded and critical structures where the benefit would also be very important. In this activity, it is intended to perform all tasks required to guaranty that a fail-safe element of primary structure can be used safely in spacecraft and/or launchers applications.

The activity will consist of the following tasks:

1) Selection of the structural element and establishment of the structural requirements.
2) Re-design of the part toward maximising its performances i.e. using the design freedom offered by AM technologies.
3) Define an end-to-end materials and process verification route to be adopted as standard for primary structural applications.
4) Derive a test plan taking into consideration Task 1 and Task 2 and 3 and including in-process sampling, bread-boarding, NDI and controls, to closely monitor the manufacturing process and to assess the materials properties.
5) Manufacture and test samples according to the test plan derived in Task 3. If needed, perform delta re-design and delta testing.
6) Manufacture and test at least 3 parts according to the final design and assess the reliability of the procedure. This shall be performed by 2 service providers.

Deliverables: Test plans, test samples, TNs, structural elements

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

Target Application / Timeframe: 2018

Applicable THAG Roadmap: Additive Manufacturing Roadmap (F01, F06, A23)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-022QT** **Budget (k€):** **500**

Title: **Enhanced contamination control for Additive Manufacturing**

Objectives: To develop contamination control methods for Additive Manufacturing so that the final product complies with typical spacecraft requirements from a contamination point of view.

Description: Additive Manufacturing (AM) is emerging as an advanced manufacturing technique with many possible applications but so far, not much focus has been given to contamination aspects. Therefore, the suitability of products manufactured by such processes with respect to cleanliness requirements for S/C missions is not yet well understood.

The activitywill consist of the following tasks:

1) Review of state of the art of existing ALM process and base/raw material used (both metals and polymers). Critical review of existing process versus contamination requirements:
    - raw material: outgassing properties including influence of eventual additives, molecular and particulate contamination, generation of particles.
    - process: influence of process parameters, analysis of the morphology of manufactured parts and their impact on cleanliness, influence of environmental conditions during manufacturing .
2) Selection of most promising processes and identification of possible improvements on contamination aspects. This should not be limited to the manufacturing but shall take into account all the environment variables affecting the processes.
3) Evaluation through testing of cleanliness levels of the manufactured parts e.g. surface particulate and MOC levels, outgassing properties of selected processes (both metals and polymers). Iteration to be implemented after improvements of process.
4) Measures to improve the cleanliness of final products whereas satisfactory contamination levels cannot be obtained under manufacturing process including surface finishing (e.g. polishing), cleaning procedure and bakeouts.
5) Definition of a roadmap and list of recommendation on process improvement and corrective actions to be performed to obtain compliance to the cleanliness requirements.

Deliverables: Study report – guidelines for contamination control – guidelines for designing Additively manufactured parts with contamination control.

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

Target Application / Timeframe : All applications

Applicable THAG Roadmap: Additive Manufacturing Roadmap (E06)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-023QT** **Budget (k€):** **700**

Title: **Development of a manufacturing process for large conductive polymer structures for spacecraft applications: high strength electrical and/or thermally conductive polymers for Additive Manufacturing**

Objectives: The objective of this activity is to develop a polymer-based Additive Manufacturing (AM) process that will enable the production of large parts. The activity shall focus on the use of engineering plastics (e.g. thermoplastics composites based on PEEK or PEI).

Description: The size of objects produce by Additive Manufacturing yet doesn't exceed 1 m in size, irrespective of the orientation with the commercial device available. Development of a 3D printing process that will enable the manufacturing of large objects with the same quality as what is achieved for small object has been identified as highly beneficial for space related product. The development of such technology on ground is intended to promote the production of polymer based space related products (e.g. spacecraft primary structure, panel, antennas, masts). The materials to be used shall fall into the category of the so-called engineering/advanced plastics providing enhanced thermal and electrical conductivity, mechanical properties as well as compatibility and resistance to specific space conditions. The ability to use engineering plastics for in-orbit manufacturing of parts with unlimited size (in one dimension) by 3D printing is actually covered by one TRP activity – "Breadboard development for in-orbit demonstration of additive layer manufacturing technologies".
The proposed activity shall take advantage of these findings in term of material processing and extend the manufacturing process to allow the production of large parts where x > 1 m, y > 1 m and z > 1 m.

The activity will consist of the following tasks:

1) Performance of a trade-off regarding the type of component to be produced, taking into account the added value of such a manufacturing process
2) Optimisation of the manufacturing process to fit the large volume/size requirement and to allow the production of the selected component
3) Testing of the produced component, focusing on the final functional properties
4) Assessment of process stability, cost, mass and lead time, definition of a roadmap to increase versatility

Deliverables: Study Report, Breadboard, samples, test plans, test reports, TNs

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

Target Application / Timeframe : TRL 5 by Q2 2017

Applicable THAG Roadmap: Additive Manufacturing Roadmap (D13)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-024QT** **Budget (k€):** **700**

Title: **Integrated recycling and manufacturing process for on planet manufacturing using polymers materials**

Objectives: To develop a user friendly Additive Manufacturing and recycling process using polymers for in-orbit and planetary applications. Emphasis will be placed on the simplification of use and on the capability to re-use materials from parts previously manufactured.

Description: Key challenges for using Additive Manufacturing (AM) for in orbit and planetary applications include the availability of the base material necessary to produce parts and the operational use of the 3D printer. The objective of this proposal is to develop an AM process that will be easy to operate and will be able to re-use polymer material from parts, in order to optimise the quantity of on-board raw material.

The activity will consist of the following tasks:

1) Review of the state-of-the-art of existing ALM processes and base/raw polymer materials used. Trade-off to include available technologies that allow to fully reuse raw material.
2) Critical assessment on how to take human spaceflight constraints into account including ISS environment and potential planetary applications (safety, microgravity and gravity, radiation...) for this application. Inputs from HSO (astronauts) to be taken into account for user I/F definition and type of parts targeted.
3) Breadboard development taking into account the operational constraints of human spaceflight. Manufacturing of samples using pristine raw material and reused material.
4) Functional and performance characterisation of the samples produced in point 3. Evaluation of the evolution of the properties when manufacturing with reused raw material (number of reuse).
5) Definition of a roadmap for further development.

Deliverables: Study report, test samples, test reports, guidelines

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

Target Application / Timeframe : TRL 5 by 2017

Applicable THAG Roadmap: Additive Manufacturing Roadmap (D14).

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-025MS** **Budget (k€):** **900**

Title: **Development of Design Methods for AM including CAD Design / FEM analysis / Manufacturing features**

Objectives: To develop structural design methods for parts and supporting structures made by Additive Manufacturing (AM) and their software implementation. The design tool shall include CAD design, FEM analysis of the part and its manufacturing features, accounting for the part orientation in the build volume. The design methods shall take into account Additive Manufacturing design and manufacturing rules.

Description: Additive Manufacturing is seen as one of the key enabling technologies for a significant number of space applications. However, currently available design tools were created for state-of-the-art manufacturing processes including for example casting, milling, and turning. AM offers a wide range of geometrical freedom, which, however, can only be exploited in a limited way with current state-of-the-art CAD / FEM / Manufacturing tools. Furthermore, AM design and manufacturing rules are not well defined and established, hindering the wide spread application of this technology.

In an optimal process, these rules shall be taken into account at a very early stage of the design loop. They need to be combined with Finite Element Analysis, but also with manufacturing guidelines on aspects such as the required orientation of the part in the building chamber and the design of a supporting structure. All of these specific features shall be available in one software tool or in several combined tools with suitable interfaces.

This will significantly shorten the part optimization process and enable high performance products to be manufactured.

The activity will consist of the following tasks:

1) Review of the applicability of state of the art Design / FEA / Manufacturing tools for AM, including design optimisation algorithms
2) Identification of needs and potential improvements
3) Analysis and optimisation of currently available software tools, taking into account:
   - The identified needs and potential improvements
   - The development of CAD/FEM software tools to include the AM specific features
   - The topological optimisation of the part, directly assessing the manufacturability of the final product
   - The compatibility of the design files with the AM machine
   - The manufacturability of the part
   - The orientation of the part in the building chamber, as well as the identified need of minimization of supporting structure
4) Specifications of new software tools based on the analysis performed. These can be new tools, macros or routines in existing software platforms.
5) Production of a software tool prototype conforming to the specifications.
6) Validation of the prototype to selected benchmark cases.
7) Definition and drafting of design/manufacturing guidelines for AM space hardware

Deliverables: Study report, Software, breadboards and design guidelines

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

Target Application / Timeframe : TRL 5 by 2018

Applicable THAG Roadmap: Additive Manufacturing Roadmap (B11)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*19 Propulsion*

Ref. Number: **G61A- 026MP** **Budget (k€):** **2,000**

Title: **Additive Manufacture of In-space Engine chambers**

Objectives: To assess through demonstration the applicability of additive manufacturing and high temperature combustion chambers for space applications

Description: Material selection for space combustion chambers has converged on a limited set of materials. These include platinum alloys that are the subject of a parallel activity. There the objective is to use additive manufacturing to reduce the cost of an existing design. The objective of this activity is much broader. It is to revisit material selection as a whole in the frame of additive manufacturing. For example several candidate materials were deselected due to workability/machine hardening issues. In the light of near-net-form additively manufactured chambers, such candidates may become viable. Another example is an old activity that required the use of powder metallurgy. This left chambers with unacceptable porosity and required hot isostatic pressing. This in turned added cost and challenges of maintaining the required geometry. This ultimately lead to the demise of the activity. Current additive techniques may be a more successful approach. There are two phases of this activity:

The first is to survey available material to meet the specified needs of radiatively cooled chambers as a minimum (regeneratively cooled materials are not excluded but may prove difficult to validate and implement); starting with direct replacements of current designs and extending into the higher performance domains. Once a selection of candidate materials has been made the activity will proceed to the demonstration phase.
There chambers will be fabricated and hot fire tested. The intent is to demonstrate the manufacturability of these materials using modern additive techniques. This shall be augmented by direct hot fire testing to validate the preliminary design assumptions of the material applications. It is not expected that the chambers be tested with propellants. Simple gas driven test benches will suffice but it is expected that the hot gas conditions will simulate in-space engines and verify the candidate materials immunity to the erosive effects of these high temperature gases. These samples will then be made available for destructive inspection and test.

This activity will be performed in two phases:

Phase 1 (600 kEuro):

1) Review of currently available materials for radiatively and regeneratively cooled materials for space combustion chambers and definition of requirements
2) Selection of a minimum of 5 materials and one chamber design, fulfilling the defined requirements
3) Definition of a suitable end-to-end manufacturing process
4) Manufacture of critical sections of the combustion chamber using Additive Manufacturing to demonstrate the applicability of the selected materials

Phase 2 (1400 kEuro)

5) Manufacture of a minimum of 5 full combustion chambers using the identified materials and the end-to-end manufacturing process
6) Hot fire tests of the fabricated chambers using gas driven test benches
7) Inspection of the tested combustion chambers using NDI and destructive testing methods
8) Assessment of the impact of using AM on performance, cost, mass, and lead time

Deliverables: Study reports, breadboards

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

Target Application / Timeframe : TRL 5 by 2018

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A14)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-027MS** **Budget (k€):** **900**

Title: **Development of embedded thermal functions in structural parts using 3D printing**

Objectives: Design and testing of structural multifunctional panels for spacecraft platforms and payloads including thermal functions. Development of the parts by use of Additive Manufacturing (AM) methods, their integration into the assembly and the verification of structural and thermal performances with relevant breadboards and demonstration models.

Description: Multifunctional structures have been developed in prior ESA activities focussing on the integration of electrical or thermal functions into the structure. These have included housings of electronic units built in lightweight CFRP with improved electrical and thermal conductivities, as well as multifunctional panels for spacecraft side walls with embedded electrical harness or heat pipes within the core. The thermal performances in those cases have not been optimal due to the limitations of manufacturing and assembly processes and the complexity of the inclusion of the heat pipes.

Additive Manufacturing (AM) has enabled the production of complex elements with significant mass savings, a reduced number of parts and therefore less bonded or bolted junctions. This can play a positive role in the heat transport mechanisms. In particular it can be foreseen to develop new sandwich core constructions based on lattice or foam-like geometries with improved conductance, embedding structural inserts without bonded joints, as well as the heat pipes themselves, all produced with AM in one single process.

In this activity the focus is on the thermal functions to be included in structural elements such as spacecraft side walls and payload/equipment support plates. Due to the AM capabilities, the integration of heat pipes within the sandwich core material can result in efficient two-phase structures, including as well their mechanical interfaces (joint to the sandwich skins and inserts). The current limitations of the size of AM parts (25 x 25 cm typically) may result in the need to limit the study to the available dimensions and to consider joining methods based on EB welding or similar techniques. A significant size increase of the AM machines is expected in the coming years.

The activity will consist of the following tasks:

1) Selection of the configuration of structural panel with thermal function.
2) Selection of the aluminium alloys and AM process, including characterisation of mechanical (stiffness, strength, stability, damage tolerance, fatigue, leak tightness) and thermal properties (conductivity, heat capacity, Ammonia compatibility). Other properties such as corrosion resistance and weldability will also be characterised.
3) Design and development of parts, including lattice/foam-like core with tailorable density.
4) Design and development of the two-phase structure (heat-pipe network)
5) Design and development of the combination of core, mechanical interfaces and two-phase structure with the skins.
6) Development and optimisation of the Additive Manufacturing route for

the intended application.

7) Manufacturing and characterisation of a demonstration model for structure and thermal functions.

Deliverables: study reports, breadboards, demonstrator model

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

Target Application / Timeframe : TRL 5 by 2018 and TRL 6 by 2020

Applicable THAG Roadmap: Additive Manufacturing Roadmap (B16)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-028QT** **Budget (k€):** **1,000**

Title: **Development of a gradient sized mesh cryocooler by Additive Manufacturing**

Objectives: To design, manufacture and test an advanced regenerator using Additive Manufacturing (AM) capabilities.

Description: This activity will be focused on advanced regenerator for space applications. The regenerators have been flagged as a highly promising type of products that would benefit from an increased design freedom during the AM roadmap exercise. Furthermore, applying AM to this product will allow increasing the TRL of lattice structures, thin walls, surface quality and associated cleaning methods. As such the activity will develop manufacturing technologies and capabilities highly beneficial for developing other types of hardware with lattices or graded structures.

The activity will be performed in two phases:

Phase 1 (400 kEuro):

1) The requirements of the regenerators shall be established and a preliminary design shall be proposed taking into account the possibilities offered by Additive Manufacturing.
2) A material shall be selected, together with three “end to end” manufacturing processes based on AM.
3) The Additive Manufacturing process shall be developed and optimised for manufacturing lattice structures of the specified requirements.
4) Verification of the adequacy of the processes applied to the selected material shall be assessed by a dedicated test campaign at samples and subscale demonstrators level. A trade-off based on the most adequate combination of material and end-to-end process shall be performed.

Phase 2 (600 kEuro):

1) based on the output of Tasks 1 & 2, the final design of the regenerator shall be performed.
2) A test plan allowing verifying the performances of the regenerator shall be established considering the “end to end” process limitation/capabilities
3) The regenerator shall be manufactured and tested according to the test plan established in Task 4. The capabilities of the material / process shall also be verified through testing all samples defined in Task 4
4) The impact on performance, cost, mass and lead time shall be assessed to determine the capability to produce regenerators with a high reliability and performance.

Deliverables: TNs, Test plans, test reports Samples and generator produced during the activity.

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

Target Application / Timeframe : TRL 5 by 2017

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A06)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*6 RF Systems, Payloads and Technologies*

Ref. Number: **G61A- 029ET** **Budget (k€):** **1,000**

Title: **Development of one single part integrating waveguide filter, bends, coupler, supporting structures by Additive Manufacturing**

Objectives: Within this activity, the integration of multiple structures (filters, couplers, bends, etc.) and of multiple functions (RF, thermal and mechanical functions) shall be developed by applying Additive Manufacturing processes to metallic and dielectric materials. Multiple samples shall be designed and tested, corresponding to several frequencies and applications.

Description: Satellite payloads are becoming very complex. Several frequency bands are commonly embarked in the same satellite, consequently resulting in accommodation issues. Mass and size reduction together with stringent RF performance requirements and demanding environmental conditions (thermal and mechanical) are constantly faced challenges.

Traditional manufacturing approaches imply certain design limitations within RF hardware. The RF section is composed of different functions such as cascaded filters, routings or power splittings. The various functions are manufactured separately and integrated later on. The integration and test of each section is an important part of the AIT tasks and increases the risk of, for example, generation of intermodulation products. Flexible sections or complex routings to connect different elements are challenges in terms of manufacturing, when relying on conventional fabrication processes. The architecture of the RF hardware is, in most of the cases, strongly linked to its supporting structure. Additionally, for high power devices, an adequate thermal design is required too.

Ceramic and polymer materials are extensively used in RF devices, in most of the cases as support material to provide electrical insulation and also for a certain degree of mechanical flexibility. In other cases such as dielectric filters, they are the core elements of the RF hardware where every cavity of the filter is loaded with a puck of dielectric material. Some studies have shown the feasibility to build all the dielectric resonators in a single piece, with obvious design and manufacturing simplifications. However, this evolution is hindered by limitations of state of the art manufacturing techniques.

Additive Manufacturing provides unrivalled design freedom within available production techniques, and a wide range of materials, including metals and dielectrics, are already available today. The use of ceramic materials is seen as a very promising concept to fulfil the stringent design requirements for this specific application.

Substantial mass savings could be achieved by optimising the supporting and thermal link structures, together with the implementation of advanced waveguide shapes, and alternative harness architectures, potentially improving the RF performance. Consequently, AIT schedules will be decreased, leading to significant cost reductions.

The activity will consist of the following tasks:

1) Review of current RF hardware design
2) Review of available manufacturing techniques and materials
3) Identification of components which can benefit from a re-design for AM
4) Development and manufacture of identified parts
5) Characterisation of manufactured parts (e.g. RF performance, accuracy,

surface finish, electrical properties...)

6) Assessment of impact on performance, cost, mass and lead time

Deliverables: study reports, breadboards,

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

Target Application / Timeframe : TRL 5 by 2018

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A18)

Specific Areas	*ADVANCED MANUFACTURING – SHAPING*
Technology Domain	*16 Optics*

Ref. Number: **G61A-031MM** **Budget (k€):** **500**

Title: **Development of thermally ultra-high stable compact grating spectrometer mirrors via Additive Manufacturing**

Objectives: To use Additive Manufacturing (AM) technology for the construction of an engineering model of a compact grating spectrometer housing that is stable against thermo-optical induced distortions of the optical elements within the system.
This shall be achieved by the design and development of either a thermal optical system (structure and mirrors) made of the same material, e. g. Aluminium) or a system made of a low CTE material such as Invar, which would provide a robust solution against both temperature changes and gradients.

Description: The activity will include a survey of the market and the selection of the best available AM technology and manufacturing capability in Europe for the objectives set in this activity. A design of an opto-mechanical structure and housing in line with typical stability and stiffness requirements of a grating spectrometer for Earth Observation shall be made. Based on that an engineering model using AM for the housing and structure shall be produced, tested and verified for its performance under representative thermal vacuum and vibration environment.

The activity will consist of the following tasks:

1) Review of currently available AM processes and materials, suitable for opto-mechanical structures and definition of requirements
2) Selection of components which benefit from a re design for Additive Manufacturing
3) Development an end-to-end manufacturing process for the selected materials and processes
4) Manufacturing of the selected components using the established end-to-end process
5) Testing of the manufactured parts in the representative environment
6) Assessment of the impact on performance, cost, mass, and lead time.

Deliverables: Study report, Engineering Model, breadboards and any remainders of samples

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

Target Application / Timeframe : TRL 5 by 2017

Applicable THAG Roadmap: Technologies for Optical Passive Instruments (Stable & Lightweight Structures) (2013), Additive Manufacturing Roadmap (A17)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*16 Optics*

Ref. Number: **G61A- 032MM** **Budget (k€):** **400**

Title: **Development of low areal density Aluminium alloy mirrors using Additive Manufacturing**

Objectives: To shorten the development cycle and increase the cost effectiveness of the procurement cycle per element for high precision space optical instruments, by using Additive Manufacturing technology for the production of Aluminium alloy mirrors.

Description: Additive manufacturing (AM) is a manufacturing technology that is growing in both reach and capability. Areal density (kg/m^2) is a parameter of importance for space optics, where mass is always a constraint and high performance always a requirement. AM shall be used in this activity to drive the areal density and the cost down, while maintaining or improving the optical performance.

The activity will consist of the following tasks:

1) Review currently used designs for Aluminium alloy mirrors and available AM techniques. Establish product requirements for the Aluminium alloy mirror.
2) Design and implement an AM manufacturing process to produce a lightweight Aluminium alloy mirror.
3) Manufacture and optically test the mirror to verify its performance under representative mechanical and thermal environment conditions.
4) Deliver the mirror and the development report, with a roadmap for the application of the developed AM technology for space optics.

Deliverables: study reports, breadboards,

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

Target Application / Timeframe : TRL 5 by 2018 , Applications requiring mirrors

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A12)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*15 Mechanisms*

Ref. Number:	**G61A-033MS**	**Budget (k€):**	**500**

Title: **Development of a Compliant Mechanism Based on Additive Manufacturing**

Objectives: Development of a topologically optimized Compliant Mechanism, taking into account opportunities and limitations of the powder-based Additive Manufacturing process for metallic materials.
The development shall aim at an optimized flexibility in the compliant degree(s) of freedom and an improved stiffness in the constraint degree(s) of freedom. Furthermore, complexity and weight of the device shall be reduced.

Description: Compliant mechanisms (e.g. flexural joints) are applied where the relative motion of parts can be accomplished without using traditional bearings. Slender structures can be properly arranged to provide functions like accurate guiding, speed reduction, or change of motion direction. Compared to traditional mechanisms using bearings, significant improvements are expected. These include a decrease of part count number, frictionless motion transmission, which decreases losses, higher motion ranges, enhanced stiffness, and improved accuracy due to the avoidance of backlash.
The complex monolithic shapes require highly sophisticated manufacturing methods. Traditional techniques like Electro-Discharge-Machining or machining are hardly applicable. Additive Manufacturing provides exactly these requirements and is seen as a key enabling technology for space. The achievable geometrical complexity is unrivalled today. Furthermore, the technique was matured rapidly over the past years, allowing the manufacturing of fully dense parts with mechanical properties comparable to wrought materials.

The activity will consist of the following tasks:

1) Review of the compliant mechanism design, identifying potential areas which benefit from a re-design for AM.
2) Optimisation of the selected joints in the compliant mechanism using FEM and CAD methods, taking into account the opportunities and restrictions of Additive Manufacturing.
3) Development and optimisation of the Additive Manufacturing process for miniaturised flexural joints and verification of the obtained properties by dedicated test campaign at samples level.
4) Manufacturing and post processing of the optimized components.
5) Testing of the produced hardware.
6) Assessment of the impact on cost, mass, lead time, efficiency.

Deliverables: Study report, demonstrator, samples

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

Target Application / Timeframe : 2018

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A24)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	*20 Structures*

Ref. Number: **G61A-034MS** **Budget (k€):** **600**

Title: **Development of shock absorbing protection made of crushable materials (lattice / cellular structure) using Additive Manufacturing**

Objectives: The objective is the demonstration of AM technology for a crushable material, encompassing the identification of appropriate manufacturing processes, the adequate design definition and justification, the manufacturing and verification by tests.Applications identified: re-entry capture with crushable Thermal Protection System made by AM ensuring that the sample container is not damaged: micrometeoroid impact protection based on crushable core.

Description: Available technology for crushable materials are honeycombs, hollow spheres or foams (polymeric, syntactic, metal, ceramic), with their main applications as shock absorbers for pre-tensioned elements of Hold Release Mechanisms or shock absorbers integrated in the Thermal Protection System for re-entry capsules. These applications would benefit from crushable materials using AM, due to the highly tunable properties of the energy absorbing material. Alternative applications include hyper-velocity impact protection hardware, with latice/foam core made by AM acting as energy dissipating element.

The crushable material to be developed shall:

1) Keep the sample container under a certain G load when landing.
2) Keep the sample container below a certain temperature during the whole mission.
3) Be connected to both the cold structure and to an ablative TPS.
4) Be tuned for maximum energy absorption for different impact angles.
5) For micrometeoroid impact protection, the size and mass of the core shall be studied.

The activity will consist of the following tasks:

1) Requirement definition for crushable material made by AM, used for energy absorption during landing of a re-entry capsule.
2) Design methodology for highly tunable properties of the energy absorbing material.
3) Process development for manufacturing the AM crushable material and establishing its process limits.
4) Manufacturing of absorbing material samples, and characterization of energy absorbing properties for various impact angles and velocities.
5) Demonstrator manufacturing, including a dummy of sample container and dummy heat shield, to be submitted to representative crash test condition.

Deliverables: Study report, breadboards

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

Target Application / Timeframe : TRL5 in 2017

Applicable THAG Roadmap: Additive Manufacturing Roadmap (A27)

Specific Areas	*ADVANCED MANUFACTURING - SHAPING*
Technology Domain	6 RF Systems, Payloads and Technologies

Ref. Number: **G61A-035ET** **Budget (k€):** **1,000**

Title: **Evaluation and consolidation of Additive Manufacturing processes and materials for the manufacturing of RF hardware**

Objectives: Within this activity different AM processes, materials and post-processes for RF/microwave applications in space will be characterized. Multiple samples shall be designed and tested corresponding to several frequencies and applications.

Description: Additive Manufacturing (AM) is starting to be used for space applications. For future missions, many components could be manufactured using AM, also including primary structures or other mission-critical parts such as RF hardware. Final products such as feed components, beam forming networks, low and high power filters and RF harness can benefit from the advantages provided by AM.

The overall maturity of this manufacturing technique has been increased in the last years offering a great variety of materials, processes and post-processes required to achieve the final part. The major efforts have been so far focused on mechanical and thermal aspects. Very promising results have been already presented based on, for example, SLM in titanium or aluminium and stereolithography for ceramics.

Alongside the significant weight reduction, lead time and production cost, an important improvement for the RF performance (losses and PIM) can be potentially achieved through AM. The requirements imposed by the RF performance to AM need to be adequately considered for the selection of the best end-to-end AM-based process.

In order to select the adequate end-to-end AM-based processes for RF hardware, the assessment and screening of materials, processes and post-processes need to be performed. This activity aims to characterise different AM processes, materials and post-processes already available in the market in order to pre-select the best candidates for RF hardware manufacturing. As a minimum, the following primary points shall be covered:

- Geometrical issues: accuracy, geometry complexity, maximum and minimum size, roughness, etc.
- Process robustness e.g. repeatability.
- Electrical issues: need of coating, electrical conductivity, SEY, outgassing, loss tangent, dielectric constant
- Post-processing methods

The pre-screening of manufacturing techniques must show the suitability of the end-to-end process based on previous in-house heritage considering the following secondary points:

- Physical properties: Density, porosity, thermal conductivity.
- Mechanical properties: static and dynamic
- Environmental issues: maximum/minimum temperature range, radiation, life time.

In order to perform this assessment and screening, a number of samples (RF samples and coupons) will be designed, manufactured and tested allowing the assessment of the feasibility for each set of [materials, AM process, post-process].

The test shall comprise RF measure and inspections (destructive and non-destructive) to verify the structural characteristics.

Deliverables: Study report, breadboards

Current TRL: 2 **Target TRL:** 4 **Duration (months):** 30

Target Application / Timeframe : TRL6 in 2021

Applicable THAG Roadmap: Additive Manufacturing Roadmap 2014

Specific Areas	*ADVANCED MANUFACTURING - JOINING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-012QT** **Budget (k€): 400**

Title: **Dissimilar transition joints for aluminium demisable structures**

Objectives: To develop, test and qualify in a relevant environment Metal/Metal and Metal/Matrix Composite (MMC) joints for Aluminum demisable structures.

Description: Since April 2008 all ESA satellites and launcher upper stages are due to be disposed by atmospheric reentry at the end of their operational life. As a general requirement the risk of fragments surviving reentry should be less than one in 10,000. In this regard, demisable materials (that it will completely burn up, or ablate, during uncontrolled atmospheric re-entry) are assuming a growing importance. Among them, demisable aluminum alloys structure seem to be the most promising ones for both launchers as well as satellites applications.

Propellant tanks, which are currently manufactured from titanium forgings, may need to be replaced with aluminium ones. Consequently an ITI activity is studying the possibility of manufacturing aluminium propellant tanks, and a GSTP activity is already running which is developing an aluminium-titanium tube-to-tube joint using Rotary Friction Welding (RFW) so that the aluminium tank can be successfully interfaced with titanium tubes and pipes.

In the future, it is likely that other parts of launchers and spacecraft will have to be manufactured from aluminum alloys, therefore a strong need exists to develop metallic interfaces across a number of material combinations (eg. Al-steel, Al-MMC, Al-Copper) and formats (sheet, plate extrusions etc). A TRP activity is adressing this need for launchers. Although there has been some development in dissimilar metal joining performed outside and within the space industry (for example in the automotive industry) most techniques have been limited to brazing, explosion bonding and friction welding. It is worth noting that friction welded stainless steel parts to aluminum are now available commercially and different brazing processes have been developed to join aluminum to stainless steel. However, the tendency of aluminum to form intermetallic compounds with other metals complicates the production of dissimilar transition joints, as these intermetallic compounds are usually brittle. This can be overcome with the application of an interlayer (usually titanium) to the stainless steel which limits the formation of the brittle phase and acts as a diffusion barrier.

The proposed technology will support all low-orbit space missions as well as launchers and re-entry vehicle where demisability is an applicable requirement, with particular focus (but not limited to) on structural elements both internal and external.
The activity will consist of the following steps:

1) State of the art and trade-off of the possible dissimilar transition joining methods based on the results of the performed activities.
2) Identification of the most promising technologies for the target applications.
3) Identification of ideal applications covering both launchers as well as satellites structures including (but not limited to) large external launchers/spacecraft structures and brackets.
4) Manufacturing of dissimilar metal-CFRP/metal (including dissimilar

Aluminium/Aluminium) and metal/MMC joints and process optimisation via test campaign at samples level.

5) Identification of a potential demisable structure application and breadboard manufacturing.
6) Verification test campaign at breadboard level and evaluation of test results.

Deliverables: Development of a representative breadboard manufactured of dissimilar transition joints for Al demisable structures tested and qualified in a relevant enviroment.

Current TRL:	4	**Target TRL:**	6	**Duration (months)**	18

Target Application / Timeframe : All low-orbit space missions as well as launchers and re-entry vehicle where demisability is an applicable requirement, with particular focus (but not limited to) on propulsion systems.
TRL 6 by 2016

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING - JOINING*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-013QT** **Budget (k€): 600**

Title: **Surface Nano-Texturing of Metals for Adhesive Bonding Improvement in Metal/CFRP and Metal/Metal Structural Joining**

Objectives: To design, manufacture, test and qualify induced surface nano-structuring and plasma surface treatments for adhesive bonding of Metal/CFRP and Metal/Metal Structural Joining.

Description: Titanium and Titanium alloys are widely used for space primary applications thanks to the very attractive strength to weight ratio as well as the excellent corrosion resistance. In particular, Titanium alloys are preferred over Aluminum alloys when used in combination with Carbon Reinforced Plastics (CFRP) due to their galvanic compatibility.

Currently, the connection of Titanium and CFRP is realized by means of riveting which is mainly limited by the high notch sensitivity of CFRP and by adhesive bonding. Adhesive bonding of such hybrid joints attractive and widely used since it allows a significantly increased design flexibility removing the notch sensitivity limitations.

However, Titanium and metallic materials in general can exhibit significant criticalities related to long term adhesion. The main limitations of the bonding performances are related to the surface contamination. Mechanical (e. g. sanding, grit blasting) or chemical (e. g. alkaline etching, anodizing) surface treatments are currently used in order to remove surface contamination and promote adhesion, however they present different restrictions in terms of bonding performances as well as environmental friendliness.

Laser patterning and Plasma surface treatments are available on the market which offer significant improvements in comparison with the traditionally used methodologies. Main advantages are related to the exceptional improvement of bonding performances (the increased surface area and roughness is promoting the bonding mechanism), the very accurate control of the process, the easy implementation in automatic and production machinery as well as their intrinsic environmental friendliness (dry processes).

The proposed activity will therefore consist of the following steps:

1) Identification of the most promising technologies including (but not limited to) laser induced surface nano-structuring and plasma surface treatments;
2) Identification of the targeted materials on which the selected processed will be applied (including e.g. Titanium/CFRP and a combination of aluminium, steels, ceramics, Metal Matrix Composites);
3) Identification of the targeted applications where the expected benefits will be most relevant (including e. g. structural bonding of Titanium/CFRP structural panels for satellites/launchers structures, a Ti/CFRP strut and a Ti/CFRP optical bench);
4) Application of most suitable laser and plasma surface treatments to the metallic substrate and characterisation of the ideal surface roughness/texturing and optimal energy utilisation;

5) Process optimisation test campaign to be performed on the two best candidates processes and on the materials combination defined in 2) and 3). Process optimisation will be targeted on properties including: surface roughness/geometry of the metallic substrate, surface energy, wettability, mechanical performances of the bonded joints (including static strength as well as Mode I, Mode II and Mode III fracture mechanics properties) as well as applicability of the process to 3D complex shapes;
6) Production of reference samples with traditional surface treatments processes (including chemical and mechanical treatments) on all different materials combinations;
7) Manufacturing of characterisation test samples of all different materials combinations with optimised processes (judged based on the highest mechanical and fracture mechanics performances delivered);
8) Maturation and adaptation of optimal NDI technique to be used on the manufactured samples.
9) Characterisation test campaign on samples defined in 6) and 7) covering static as well as dynamic (fatigue and fracture mechanics) testing of all samples manufactured with optimised plasma and laser surface treatments as well as traditional processes;
10) Manufacturing of a demonstrator of selected spacecraft and launcher structures using the optimal process parameters;
11) NDI assessment of the manufactured demonstrators;
12) Mechanical proof test of the demonstrator.

Deliverables: Qualified Nano-Texturing process for bonding Metal/CFRP and Metal/Metal structural joining.

Current TRL:	4	**Target TRL:**	7	**Duration (months)**	24

Target Application / Timeframe : TRL 7 by 2017

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING - ASSEMBLY*
Technology Domain	*20 Structures*

Ref. Number: **G61A-014MS** **Budget (k€): 700**

Title: **Integral Manufacturing of Full CFRP Sandwich Structures for Optical Benches**

Objectives: Development of the manufacturing process of full carbon ultra stable structures for payloads. Demonstration of sandwich plates with CFRP skins, inserts and core.

Description: Optical Benches for earth observation and science missions are often produced in hybrid sandwich construction (CFRP skins and Aluminium core) due to the cost of the manufacturing processes, despite the lower performances.

The possibility to offer a cost-effective integrated process of full carbon plates is feasible nowadays and would enable a large performance improvement.

The separate elements are available in European companies (CFRP skins, CFRP core, CFRP inserts and fasteners). The integrated manufacturing process and the characterisation of the structures are still not available.

A demonstrator of an optical bench for optical instruments for earth observation or science missions shall be manufactured and tested.

Deliverables: Demonstrator for optical instruments.

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

Target Application / Timeframe : Earth Observation/Science missions
TRL 5 by 2017

Applicable THAG Roadmap: Composite Materials (2014)

Specific Areas	*ADVANCED MANUFACTURING - ASSEMBLY*
Technology Domain	*20 Structures*

Ref. Number: **G61A-015MS** **Budget (k€): 1,200**

Title: **Manufacturing of Large Friction Stir Welded Structures for Satellites and Launchers Applications**

Objectives: The aim of this activity is to design, manufacture and test large FSW structures for launchers and satellites applciations.

Description: Friction Stir Welding (FSW) is considered to be the most significant development in metal joining in decades. Industrial (non-space) trendsetters were the Scandinavian Aluminum extruders for the manufacture of hollow Aluminum deep freezer panels and ship decks. Further European industrial applications range from oil and gas industry, to automotive, aircraft, railway and defense providing a mature industrial and R&D infrastructure readily available in Europe.

FSW guarantees the high quality, high performance and eco-friendly joining of materials that have been traditionally troublesome and even impossible to weld in conventional manners such as high strength aerospace Aluminum alloys, Titanium, Magnesium and their alloys, Stainless Steels and Nickel alloys as well as Metal Matrix Composites (MMC) reinforced materials. It has also been demonstrated for several thermoplastics.

ESA has started a GSTP activity which is focused on developing a low cost titanium propellant tank, using Friction Stir Welding. The focus of the Titanium GSTP activity is on the development of the friction stir welding process for titanium alloys which is not as mature as for aluminum, and also addresses the design and manufacturing of such a tank (including e.g. fixtures and jigging).

Despite FSW of aluminum is considered a mature joining process, the application of FSW to launchers and satellites large structures (and the related major advantage) is still to be exploited and scaled to an industrial manufacturing level.

Therefore the central aim of this new activity is to build on the work of the mentioned GSTP, to design, manufacture and test a full size aluminum demonstrator for launchers and large satellites spacecraft applications. The emphasis of the new activity will be placed on the manufacturing of the shells/sheets and domes as well as the combination with advanced forming techniques such as magnetic pulse forming and flow forming. Moreover, a strong focus will be devoted to the optimization of the FSW welding technique itself on advanced aluminum alloys including 2195, 2198, and 2099 as well as Metal Matrix Composites (MMCs).

The following tasks will be performed:

1) Identification of launchers and large satellites structural applications covering upper stages and platform applications.
2) Selection of most promising and performing advanced aluminium alloys for the intended applications (including 2195, 2198, 2099 as well as MMCs).
3) Identification of the most promising technologies required to allow the production of the constituent parts of the selected structures (domes, shells, stiffeners, stages) covering (but not limited to) magnetic pulse forming and

flow forming.
4) Modelling of the manufacturing process for in-production quality monitoring.
5) Development and qualification of dedicated NDI techniques for the anticipated large structures and related manufacturing processes (including forming and welding).
6) Manufacture of two launcher/satellite demonstrators, where possible taking advantage of the fixtures, tooling, jigging and lessons learned from the Titanium GSTP activity.
7) Definition of testing strategy for the two structures (including initial flaws/repairs/etc.).
8) Testing of the demonstrators and evaluation of test results.
9) Post testing destructive inspection of the tank and correlation with NDI.

Deliverables: Launchers and large satellites structural demonstrators made by advanced FSW aluminium alloys covering upper stages and platform applications. The structures would then be tested to evaluate their performances.

Current TRL: 4 **Target TRL:** 7 **Duration (months)** 18

Target Application / Timeframe: Large satellites and launchers structures/stages.
TRL 7 by 2017

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING - ASSEMBLY*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-016QT** **Budget (k€): 900**

Title: **Rigid-flex PCB interconnections**

Objectives: The aim of the activity is to assess current and alternative materials and manufacturing processes to improve manufacturing capability and reliability of the technology and to evaluate manufacturing processes for the production of long flex interconnections as a potential replacement for harnesses.

Description: Rigid-flex PCB technology allows designers to replace multiple PCBs interconnected with connectors, wires and ribbon cables to create a single circuit board while improving performance and reliability. Furthermore, because rigid-flex PCBs can be bent, folded or twisted, they provide a solution for optimizing applications with tight space limitations.

The use of rigid-flex boards in space applications has been increasing to about 30% share. Nevertheless, rigid-flex PCBs comprise of manual manufacturing processes which reduce the yield and the delicate balance of the rigid-flex manufacturing processes may involve an increased reliability risk. Several advanced manufacturing processes need to be optimised, such as lamination of heterogeneous materials, registration of flex laminates that lack mechanical enforcement. Several material properties need to evaluated, such as thermal expansion, glass transition, adhesion and viscosity of acrylic adhesives and prepreg. The manufacture of long flex layers requires large panel sizes and its accommodation in processing equipment.

The following tasks will be performed:

a) Assess current and alternative materials and manufacturing processes to improve manufacturing capability and reliability of the technology. (500 keuro).
Within this task the following shall be carried out :

1) Identify candidate materials and process to replace current ones with identified benefits in manufacture and reliability.
2) Manufacture test samples with current and new materials and processes.
3) Perform evaluation tests on samples and characterisation of essential material properties.
4) Analyse results, down select materials and processes, reiterate test flow.

b) Evaluate manufacturing processes for the production of long flex interconnections as a potential replacement for harnesses. This development is an evaluation with the aim to qualify in 3-5 year.(400 keuro).

Within this task the following shall be carried out:

1) Identify materials, processes, flex PCB manufacturers and designs that can meet the requirements for space applications.
2) Manufacture test samples covering several applications.
3) Perform evaluation tests and characterisation of materials.
4) Analyse results.

Deliverables:	Study report, breadboard, prototype, rigid-flex PCB technology qualified for space, long flex interconnection evaluated for space.

Current TRL:	4	**Target TRL:**	8	**Duration (months)**	36

Target Application / Timeframe :	Target application: Improved reliability and ease of manufacturing of rigid-flex PCB to replace short harness, wires, connectors. Long flex interconnection to replace cable harness.

Applicable THAG Roadmap: Not related to a Harmonisation subject

Specific Areas	*ADVANCED MANUFACTURING - ASSEMBLY*
Technology Domain	*24 Materials & Processes*

Ref. Number: **G61A-017QT** **Budget (k€): 1,800**

Title: **High Density PCB assemblies**

Objectives: This activity aims to develop and qualify in a relevant environment PCBs that are capable of providing a platform for assembly and the routing of high density interconnnect (HDI) components.

Description: High density interconnnect (HDI) components have a higher number of interconnects which are spaced at a small pitch. The routing in the PCB becomes more complex because of signal integrity for high speeds and because of the dense volume for interconnecting the high number of I/Os. This necessitates the use of laser drilled microvias, high aspect ratio core vias and small track width and spacing. The manufacturing processes are a delicate balance of capability and reliability, as changes to accommodate benefits in one area, typically cause disadvantages elsewhere. Several advanced manufacturing processes need to be developed such as plating in high aspect through-holes, crack-free drilling and de-smear, layer registration, laser drilling, copper filling, via plugging, clean lamination and fine line etching. This technology is used in other electronics industry. The highest capability can be found in smart phones. A reasonable balance between capability and reliability can be found in military industry. Space has limited heritage for few projects and can benefit from spinning in.

Examples of electronic equipment for space projects that used HDI are: GAIA Video Processor Unit, GAIA Maxwell processor board, Alphasat processors, Sentinel 2 FMM, Inmarsat 4 DSP, EDRS DPU.

The following tasks will be performed:

1) Qualify HDI PCBs with a design in accordance with ECSS-Q-ST-70-12C. This is driven for example by Virtex 5 component with a pitch of 1 mm for 1752 I/Os. This development targets qualification as soon as possible. (400 keuro)

2) Evaluate HDI PCB with designs that exceed ECSS-Q-ST-70-12C. This includes 2 layers of microvias and 60 micron track width and spacing. This is driven by component pitch of 0.5-0.8 mm. This development targets evaluation to prepare for qualification in 3 to 5 years. (400 keuro)

3) Develop an HDI capability sample that can be used to assess PCB manufacturer's capabilities and reliability of the technology. Today's standard qualification vehicle is outdated and the new capability sample would better challenge the capabilities of the manufacturer in a similar way as the so-called PCQR2 sample that has been developed in US. (300 keuro)

4) Benchmark the IST (Interconnect Stress Test) performance for typical manufacturers, materials and HDI designs and compare with newly developed HDI designs. (300 keuro).

5) Verify the assembly of HDI components on HDI PCBs. (400 keuro)

Deliverables:	Study report, breadboard, prototype, HDI PCB interconnect technology qualified for space				
Current TRL:	3	**Target TRL:**	8	**Duration (months)**	36
Target Application / Timeframe :	Target application: Assembly of advanced area array devices (AAD) typically used for FPGA and processor chips for high computing power.				

Applicable THAG Roadmap: Not related to a Harmonisation subject