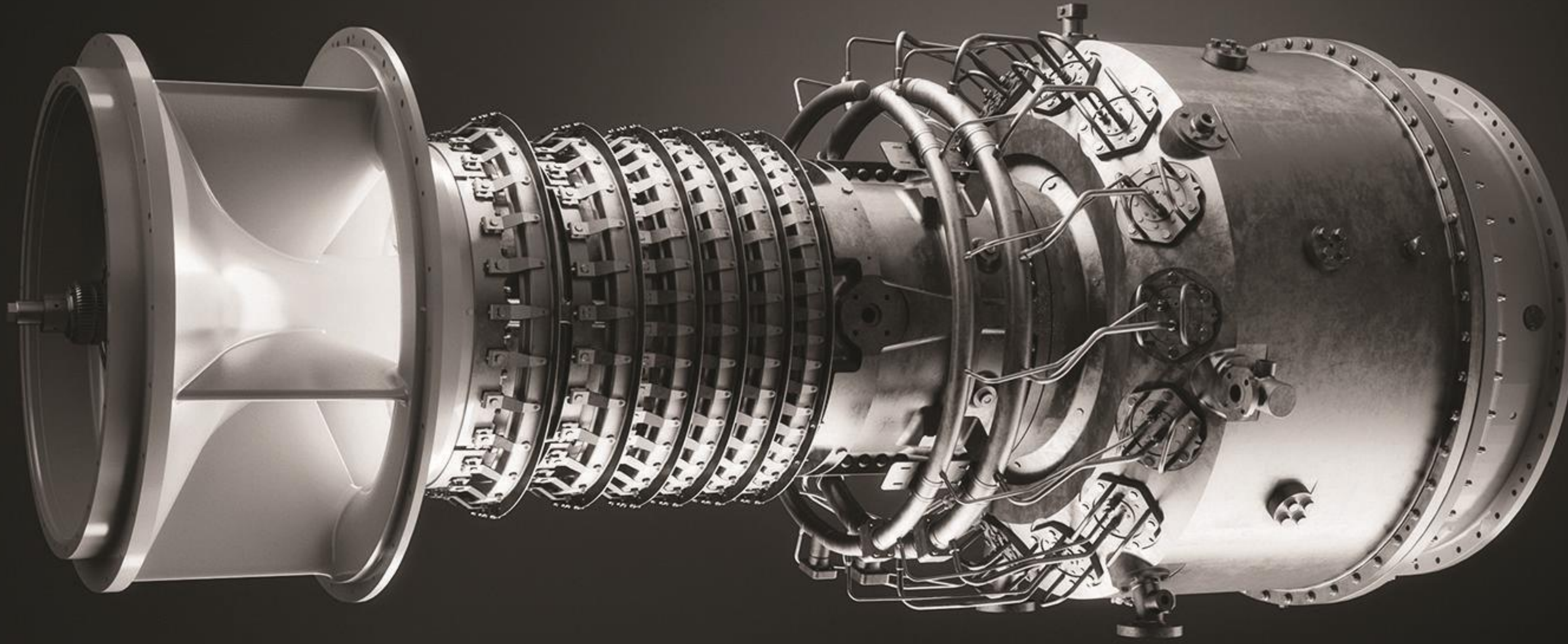
ETN – ADDITIVE MANUFACTURING WORKSHOP

AM ROADMAP DEVELOPMENT

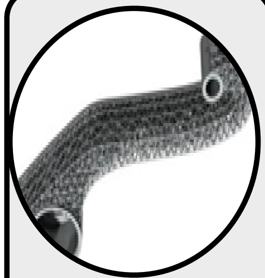


ETN Workshop 2019- Pau,France
March 28, 2019

A CULTURE OF CUSTOMER CARE

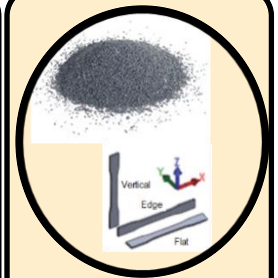
Solar Turbines
A Caterpillar Company

ADDITIVE MANUFACTURING



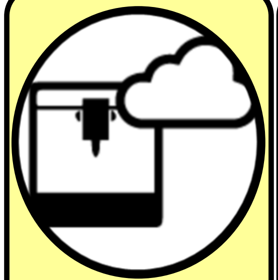
Design for Additive

- Parts strategy
- Evaluation of parts
- Evaluation of Software
- Accelerate use



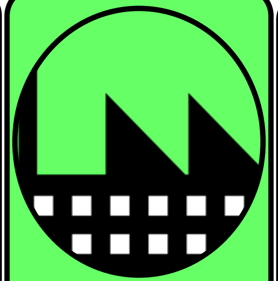
Material

- New Materials development
- Expand Material Property Database



Process

- New additive technology
- Supplier development



Production

- Part provider strategy
- Production and proto-types
- Sourcing Strategy

Skill Development

- Develop our engineers for design for additive

ROADMAP ELEMENTS FROM 2018 OCTOBER WORKSHOP

Design

- Current design
- Future design
- Analysis Software
- Integrated software packages
- Knowledge management
- Modelling to optimise design/support
- Design by platform standardization
- Life cycle costs

Material

- Modelling / simulation
- Multi materials
- HSE
- Optimise powders for AM (chemistry) and morphology
- Knowledge of powder characterization
- Component inspection and life prediction

Process

- Modelling / Simulation
- Hybrid machines
- Data handlings
- Data security

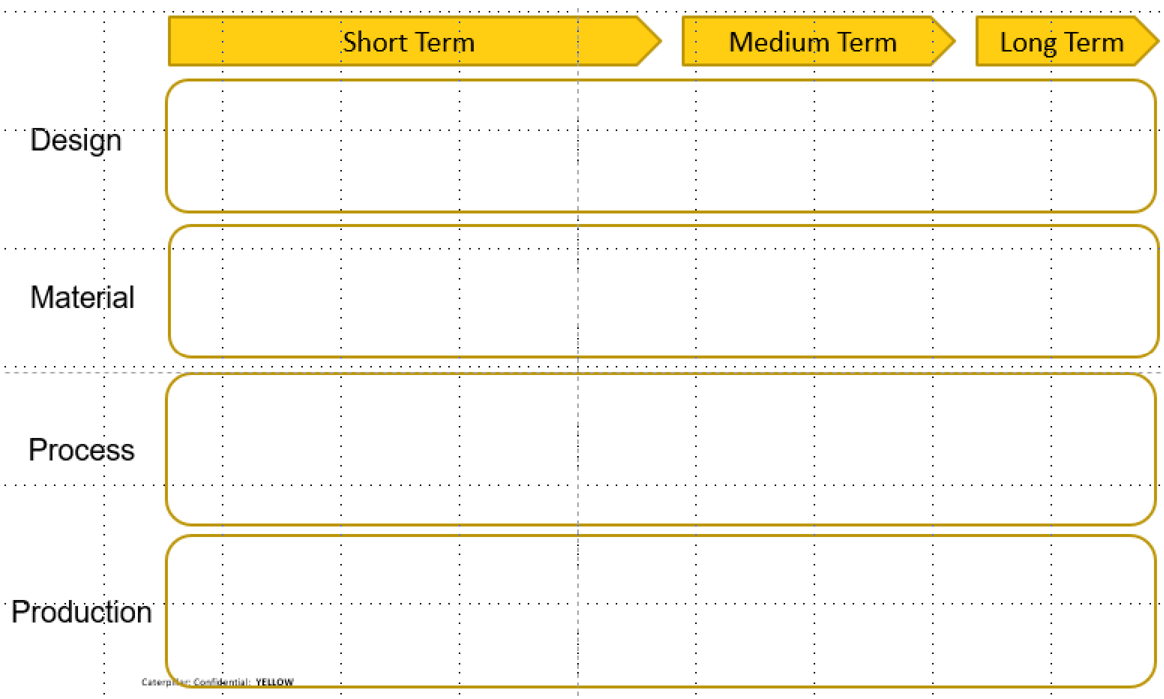
Production

- Modelling / Simulation
- Q.A. in situ

DEVELOPMENT PROCESS

Step1 - The timeline for the proposed actions is also indicated considering the following:

- Short term: 2019-2022
- Medium term: 2022–2027
- Long term: 2027-beyond



Step 2 – Develop the actions proposal:

- Identify actions specific to a Industrial Gas Turbine value chain, addressing both technological and non-technological gaps
- Moreover, technical gaps include the current Technology Readiness Level (TRL). TRLs are based on a scale from 1 to 9 with 9 being the most mature technology

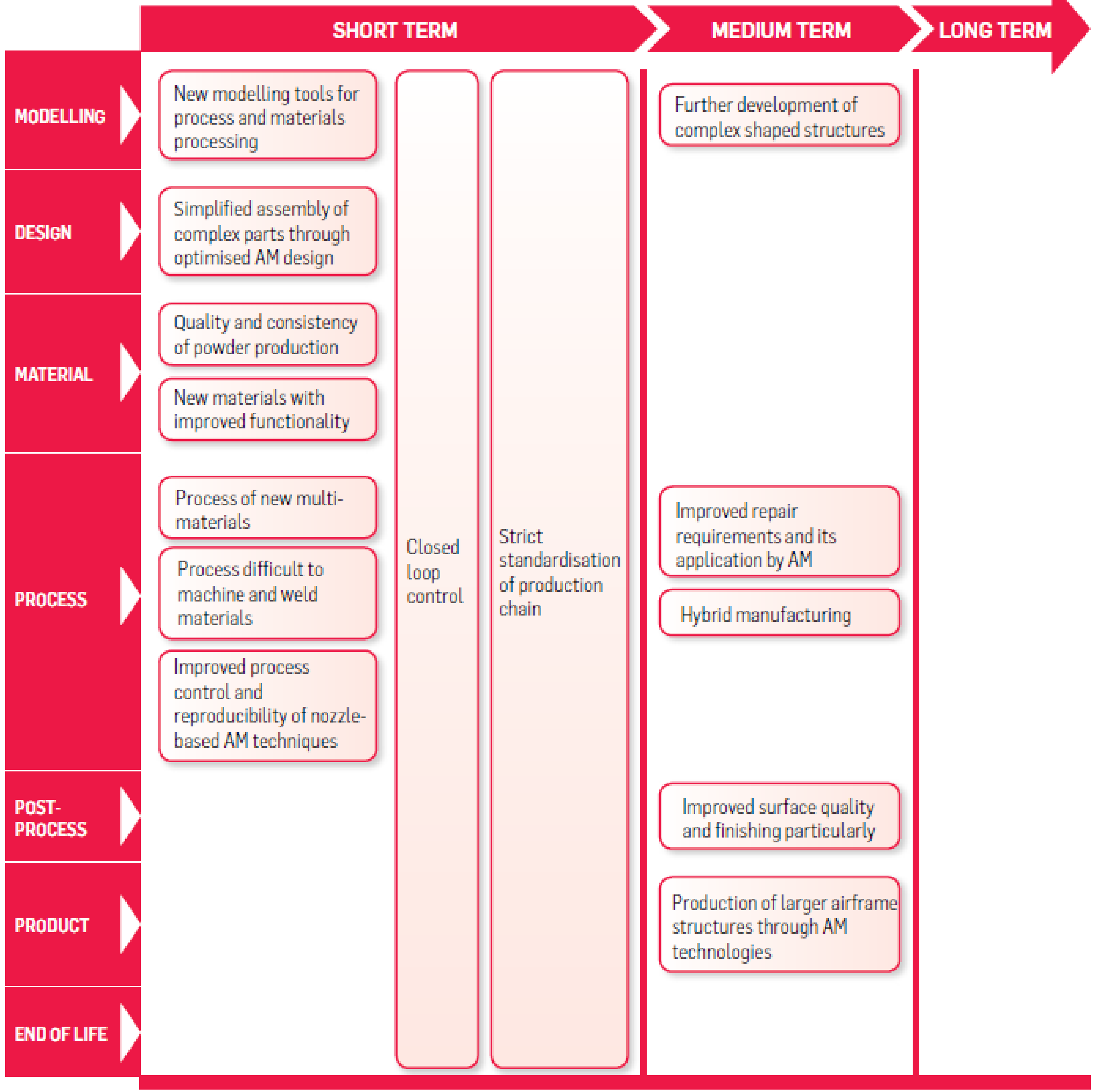
TECHNOLOGY READINESS LEVEL	DESCRIPTION
TRL 1.	Basic principles observed
TRL 2.	Technology concept formulated
TRL 3.	Experimental proof of concept
TRL4.	Technology validated in lab
TRL5.	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6.	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7.	System prototype demonstration in operational environment
TRL 8.	System complete and qualified
TRL 9.	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

	Short Term	Medium Term	Long Term
Design			
Material			
Process			
Production			

ACTION ITEMS DEVELOPMENT

Category	Gap Name	Description	Action	Current TRL	Ansaldo Energia	BHGE	Chromalloy	Cranfield University	ENEA	ENEL	Engie	ETN	European Commission	Frazer-Nash Consultancy	Hieta Technologies	Julich Research Centre	MAN Energy Solutions	Mapna Europe	PSI	Shell	Siemens	Solar Turbines	Sulzer Turbine Services
Design	Current Design	Convert existing component designs to AM with minimal optimization.																					
	Future Design	Design components optimized for AM, including part consolidation.																					
	Analysis Software	Design software to model the AM build process including resultant stresses, strains, deformations, and grain structure.																					
	Integrated Software Packages	Integration of CAD, analysis, and 3D printer machine command language																					
	Knowledge Management	Knowledge capture and traceability of design parameters, specifications, assumptions, providence, linkage to other designs, etc. in a system where the knowledge can be retrieved and used.																					

2.2.4 Technological actions for aerospace value chain



SHORT TERM ACTIONS

VC SEGMENT	GAP NAME	CONTEXT	ACTION	CURRENT TRL
Modelling	**New modelling tools for process and materials processing**	Design optimization in combination with process reliability Fully integrate AM process modelling in state of the art software systems for efficient and optimized modelling. Linked with cross-cutting gap.	• Address simulation of the thermal conditions in the part in combination with topological optimization of the support structure and fixturing • Conduct a state-of-art literature survey of existing models and models that are currently being developed. Integration of state of the art tools emerging from FP7 programs • Deployment towards higher TRL • Encourage modelling using machine parameters as entry parameters, and establish links with mechanical properties	5-6
Design	**Simplified assembly of complex parts through optimised AM design**	Advanced design tools to help utilize the advantages of AM.	• Introduce topology optimization methodologies in the design phase to move from feature-based to function-based design • Topology optimization and CAD return	6-7
Material	**Quality and consistency of powder production**	Raw material quality control is key in aerospace business. Moreover, having the right requirement for powder batch acceptance is required for certification compliance. Connected to automotive sector gap.	• Work on material quality, shape for powder and size in order to have a well-controlled material for the 3D process • Quality and consistency of powder production. Improve processes for powder production with better distribution size control	6-7

SHORT TERM ACTIONS

VC SEGMENT	GAP NAME	CONTEXT	ACTION	CURRENT TRL
Material	**New materials with improved functionality**	Reliability of AM produced parts during their life time is essential for aerospace applications. Reliable high performance materials (light weight, strong, high temperature, reliable) and special materials. Linked with cross-cutting gap.	• Development of shape memory alloys (thermal and magnetic) piezoelectric actuators and electro active polymers • Lightweight materials (e.g. titanium alloys) • Extreme operating temperatures superalloys for turbine components • Improved dynamic (fatigue) materials properties: Development of new alloys with improved dynamic properties and the development of advanced composites including high mechanical resistance ceramic particles in metal matrix • Development of materials with improved creep and oxidation resistance • Development of new routes for powder production to enable cheaper powders • Development of wire feedstock with chemistry tailored for AM applications	4-6
Process	**Process of new multi-materials**	Enabling the use of multi material, graded material including reliable modeling tools and optimized processes.	• Development of "smart" parts by embedding sensors and/or effectors • Development of new machine concepts e.g. for graded material properties and multi material combinations and the development of modelling tools to support this activity • Fatigue and fracture toughness properties; effect of defects • Residual stress in materials, caused by AM process and mismatch of different material properties (i.e. elastic modulus and coefficient of thermal expansion)	1-3

SHORT TERM ACTIONS

VC SEGMENT	GAP NAME	CONTEXT	ACTION	CURRENT TRL
Process	**Process difficult to machine and weld materials**	Machining and welding of super alloys produced by AM (Ni and Ti based) can be very difficult. Specific problems that occur should be solved to make more use of AM in combination with other processes.	• Establish methodology with machine parameters through defined design of experiments • New optimized cutting tools (in terms of materials and geometry) for AM parts • Use of ceramics • Development of appropriate modelling tools to support this activity	1-3
Process	**Improved process control and reproducibility of nozzle-based AM techniques**	It is required to demonstrate that the key process parameters are under control for certification in this sector. Repeatability, reproducibility and performance of AM processes can be improved using knowledge and tools, in order to get predictable outcome of the process. Lack of availability of suitable monitoring systems for AM; Incorporation into existing machines to control quality during building process. Linked with cross-cutting gap.	• Implement real thermal field mapping (from machine sensors) to determine residual stresses • Data regarding mechanical properties, dimensional accuracy, surface roughness etc. coupled with the respective machine characteristics and process parameters • Develop in-situ multiscale analysis methods by vision systems and image processing • In line control towards zero defects • Make use of established know-how in polymer FDM, injection moulding and PIM • Interaction with the "design" and "modelling" VC segments, i.e. design and process iterations • Structural integrity analysis: design against fatigue and design for damage (defect) tolerance	4-6

SHORT TERM ACTIONS

VC SEGMENT	GAP NAME	CONTEXT	ACTION	CURRENT TRL
Complete VC	**Closed loop control**	Closed loop control for yield optimised processes. This is necessary for processing and equipment right performance, and the ability to qualify and certify parts and processes. Current building processes often perform the printing without recognizing errors during the fabrication.	• Create closed-loop and adaptive control systems with feedback capabilities • Directly identify errors in the process and try to repair them on the spot without losing the whole build job • Efficient modelling tools to provide intelligent feedback control	4-5
Complete VC	**Strict standardisation of Production chain**	Increased reliability by standardisation of all production steps and process control.	• Analysis of solidification/cooling rate + defects of the bulk material properties • Understanding of the influence coming from mass/size of product and predictions for scalability of AM processes • Assessment of final heat treatment	4-6

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