2016 ADDITIVE MANUFACTURING BODY OF KNOWLEDGE

The Additive Manufacturing Body of Knowledge was developed by the Additive Manufacturing Leadership Initiative (AMLI). AMLI is a collaborative group consisting of Tooling U-SME, America Makes, the Milwaukee School of Engineering (MSOE), the National Coalition of Advanced Technology Centers (NCATC), and Technician Education in Additive Manufacturing & Materials (TEAMM).

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
1			**OVERVIEW OF AM**	x	x
	1.1		Definition of AM	x	x
		1.1.1	Evolution of AM definitions	x	x
		1.1.2	Current ASTM		x
	1.2		Key Elements of AM	x	
		1.2.1	Sources of Input	x	
		1.2.2	STL File Output and Format	x	
		1.2.3	STL File Post Processing		
		1.2.4	Build Preparation	x	
		1.2.5	Build Process	x	
		1.2.6	Part Inspection		
		1.2.7	Part Post Processing	x	
		1.2.8	Quality Assurance		
		1.2.9	Secondary Processing		
	1.3		Uses of AM Parts	x	
		1.3.1	Conceptual Models	x	
		1.3.2	Form and Fit Models		
		1.3.3	Functional Models		
		1.3.4	Final Product		
	1.4		Industries Using AM		
		1.4.1	Transportation –Vehicle – All Types		
		1.4.2	Consumer Products		
		1.4.3	Medical Device and Products		
		1.4.4	Aerospace		
		1.4.5	Defense		
		1.4.6	Art and Fashion		
		1.4.7	Manufacturing and Industrial		
		1.4.8	Architecture		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
	1.5		Computer Aided Design (CAD) Tools	x	
		1.5.1	Mainstream CAD packages w/STL Export for AM systems	x	
		1.5.2	AMF Standard File Format Conversion		
	1.6		AM Processes – ASTM Standards	x	
		1.6.1	Binder Jetting	x	
		1.6.2	Directed Energy Deposit	x	
		1.6.3	Material Extrusion	x	
		1.6.4	Material Jetting	x	
		1.6.5	Powder Bed Fusion	x	
		1.6.6	Sheet Lamination	x	
		1.6.7	Vat Photo Polymerization	x	
	1.7		Current Technologies that Support each Method/Process	x	
		1.7.1	ProJet Systems		
		1.7.2	iPro Systems		
		1.7.3	Eden Systems		
		1.7.4	Connex Systems	x	
		1.7.5	Desktop Systems		
		1.7.6	Perfactory		
		1.7.7	DraftSight		
		1.7.8	ZPrinter		
		1.7.9	sPro		
		1.7.10	Fortus	x	
		1.7.11	3D Touch		
		1.7.12	Matrix		
	1.8		Key AM Terminology – ASTM Standard	x	x
		1.8.1	3D Printer/Printing		x
		1.8.2	3D Scanning	x	x
		1.8.3	Additive Systems	x	x
		1.8.4	Direct Metal Laser Sintering (DMLS)	x	x
		1.8.5	Directed Energy Deposit		x
		1.8.6	Fused Deposition Modeling (FDM)	x	x
		1.8.7	Laser Sintering (LS)		x
		1.8.8	Rapid Prototyping		x
		1.8.9	Rapid Tooling	x	x
		1.8.10	Selective Laser Sintering (SLS)	x	x
		1.8.11	Stereolithography (SL)	x	x
		1.8.12	Subtractive Manufacturing	x	x
		1.8.13	Surface Model		x
	1.9		AM Materials		
		1.9.1	Engineered Plastics		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
		1.9.2	Photo Polymers		
		1.9.3	Metals		
		1.9.4	Plaster		
		1.9.5	Sand		
		1.9.6	Ceramic		
		1.9.7	Paper		
		1.9.8	Concrete		
		1.9.9	Bio-Materials		
		1.9.10	Wax		
		1.9.11	Thermo-Plastic		
		1.9.12	Other Materials		
	1.10		Secondary Processes	x	
		1.10.1	Investment Casting		
		1.10.2	Silicone Molding	x	
		1.10.3	Urethane Casting		
		1.10.4	Sand Casting	x	
		1.10.5	Composites		
		1.10.6	Cladding		
		1.10.7	Plating		
	1.11		AM advantages over Traditional Manufacturing	x	x
		1.11.1	Design Flexibility	x	x
		1.11.2	Ease of Handling Complexity		x
		1.11.3	Speed		x
		1.11.4	Reduced Tooling	x	x
		1.11.5	Supports Mass Customization	x	x
		1.11.6	Higher Sustainability		x
		1.11.7	Ease of Prototyping		x
		1.11.8	Mobility of Production System		x
		1.11.9	Simplified Set-Up		x
		1.11.10	AM Integration with Traditional Manufacturing	x	x
		1.11.11	AM Limitations		x
	1.12		Foundations of Quality		
		1.12.1	Input Quality		
		1.12.2	Machine Quality Factors		
		1.12.3	Output Quality		
		1.12.4	Finishing Quality	x	
2			**AM INPUTS**	x	x
	2.1		Input Sources and Characteristics	x	x
		2.1.1	Standard Tessellation Language (STL)	x	x
		2.1.2	AMF – STM F2915 File Format	x	x
		2.1.3	MRI/CT Scan Data		x
		2.1.4	Point Cloud Data		x
		2.1.5	VRML		x
		2.1.6	3MF Format		x

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
	2.2		Creation of Slice Files		x
		2.2.1	Concept of Layered Image		x
		2.2.2	Use of Triangles		x
		2.2.3	Finite Element Analysis and Output		x
	2.3		File Manipulation	x	x
		2.3.1	File Creation	x	x
		2.3.2	Verification		x
		2.3.3	Critical Errors in STL Files		x
		2.3.4	Repair/Modification Post Processing		x
		2.3.5	Software Tools for Modifications/Corrections		x
		2.3.6	Reverse Engineering	x	x
3			**AM SECONDARY PROCESSES**	x	x
	3.1		Definition of Secondary Process		x
	3.2		Investment Casting	x	x
		3.2.1	Investment Casting Patterns	x	x
		3.2.2	Wax Tooling		x
		3.2.3	Example Products – Investment Casting		x
	3.3		Sand Casting		x
		3.3.1	External Patterns		x
		3.3.2	Internal Cores		x
		3.3.3	Loose Patterns		x
		3.3.4	Example Products – Sand Casting		x
	3.4		Die Casting		x
		3.4.1	Direct Tooling		x
		3.4.2	Example Products – Die Casting		x
	3.5		Silicone Molding		x
		3.5.1	Master Patterns for Molds		x
		3.5.2	Tooling for Rubber Parts		x
		3.5.3	Example Products – Urethane Castings		x
	3.6		Composite/Fiber Glass Molding		x
		3.6.1	Lay-Up Tooling		x
		3.6.2	Soluble Cores		x
		3.6.3	Example Products – Composites		x
	3.7		Metal Spraying		x
		3.7.1	Tooling Pattern		x
	3.8		Metal Forming/Stamping		x
		3.8.1	Tool Use		x

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
	3.9		Other Secondary Processes/Impact		x
		3.9.1	Metal Spraying		x
		3.9.2	Metal Forming/Stamping		x
		3.9.3	Jigs and Fixtures		**x**
		3.9.4	Thermoforming		x
		3.9.5	Paper Pulp Tooling		x
		3.9.6	EDM Tools		x
4			**AM TECHNOLOGY & METHODS**	x	X
	4.1		Vat Photopolymerization	x	x
		4.1.1	Description		x
		4.1.2	Applications		x
		4.1.3	Strengths		x
		4.1.4	Weaknesses		x
	4.2		Powder Bed Fusion		x
		4.2.1	Description		x
		4.2.2	Applications		x
		4.2.3	Strengths		x
		4.2.4	Weaknesses		x
	4.3		Material Extrusion	x	x
		4.3.1	Description		x
		4.3.2	Applications		x
		4.3.3	Strengths		x
		4.3.4	Weaknesses		x
	4.4		Material Jetting	x	x
		4.4.1	Description		x
		4.4.2	Applications		x
		4.4.3	Strengths		x
		4.4.4	Weaknesses		x
	4.5		Binder Jetting		x
		4.5.1	Description		x
		4.5.2	Applications		x
		4.5.3	Strengths		x
		4.5.4	Weaknesses		x
	4.6		Sheet Lamination	x	
		4.6.1	Description		
		4.6.2	Applications		
		4.6.3	Strengths		
		4.6.4	Weaknesses		
	4.7		Hybrid Systems		
		4.7.1	Description		
		4.7.2	Applications		
		4.7.3	Strengths		
		4.7.4	Weaknesses		
	4.8		Directed Energy Deposition	x	
		4.8.1	Description		
		4.8.2	Applications		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
		4.8.3	Strengths		
		4.8.4	Weaknesses		
	4.9		Direct Write		
		4.9.1	Description		
		4.9.2	Applications		
		4.9.3	Strengths		
		4.9.4	Weaknesses		
	4.10		Combining Additive and Subtractive methods		x
5			**AM DESIGN**		x
	5.1		Role in Direct Manufacturing		
	5.2		AM Design Strengths		
	5.3		AM Design Weaknesses		
	5.4		AM Design Considerations		x
	5.5		Re-training Design Engineers		
	5.6		Computational Modeling		x
	5.7		Design for Direct Digital Manufacturing		
	5.8		Legacy Parts Optimization		
	5.9		Specification of Customer Requirements		
	5.10.		Design Verification		x
		5.10.1	Mechanical Property Testing		x
		5.10.2	Achievable dimensions and tolerances		x
	5.11		Risk management		
6			**AM BUSINESS & ECONOMICS**	x	x
	6.1		Capital Purchase		x
		6.1.1	Machine	x	
		6.1.2	Facility Build/Modification		
		6.1.3	Ancillary Equipment		
		6.1.4	QA System		
	6.2		Labor		x
		6.2.1	Dedicated Employee Potential		
		6.2.2	Roles and Shared Responsibility		
		6.2.3	Skill Level(s) Required		
		6.2.4	Initial/On-going Training		
	6.3		Materials		
		6.3.1	Build Materials - Deliverable		
		6.3.2	Support Cost - Consumed		
		6.3.3	Perishable Cleaning Materials		
		6.3.4	Waste Stream		
	6.4		Maintenance Costs		
		6.4.1	Maintenance/Support Structure		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
		6.4.2	Downtime Risk		
		6.4.3	Energy Consumption		
		6.4.4	Depreciation Classification & Implications		
		6.4.5	Technology Commitment Costs		
		6.4.6	Cost of Consumables/Upgrades		
	6.5		Return on Investment		
		6.5.1	Percent of Utilization		
		6.5.2	Uptime		
		6.5.3	Installation Costs		
		6.5.4	Employee Turnover/Re-training		
		6.5.5	Capacity/Throughput		
	6.6		Outsource Economics		
		6.6.1	Vendor Qualification/Expertise		
		6.6.2	Expediting Premiums		
		6.6.3	Loss of Schedule Control		
		6.6.4	Uncontrolled Quality		
		6.6.5	Variable Pricing		
		6.6.6	Cost of time to obtain quotes		
		6.6.7	Risk of IP Leak		
		6.6.8	Diverse Technology Selection		
		6.6.9	Flexible Manufacturing/Vendors		
		6.6.10	Access to Current Technology		
		6.6.11	Distributed Manufacturing		
	6.7		Production Cost Drivers		
		6.7.1	Volume (Cubic Inch)		
		6.7.2	Build Height		
		6.7.3	Process Selection		
		6.7.4	Layer Thickness		
		6.7.5	Scan Speed		
		6.7.6	Quantity		
		6.7.8	Material Type		
		6.7.9	Post Processing		
	6.8		Direct Manufacturing Production		
		6.8.1	Quantity Sensitive		
		6.8.2	High Value		
		6.8.3	Low Part Volume (Cubic Inch)		
		6.8.4	Mass Customization		
		6.8.5	Design for Process Required		
		6.8.6	Flexibility in Design		
		6.8.7	Support for Secondary Process		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
	6.9		Risk Management		x
	6.10		Legal Implications of AM		x
	6.11		Managing Change from Traditional to AM		
7			**AM QUALITY SYSTEMS**		
	7.1		Key Quality Factors		x
		7.1.1	Digital File Configuration and Control		
		7.1.2	Vendor Management		
		7.1.3	Raw Material Management		x
		7.1.4	Device Inspection/Control		x
		7.1.5	Machine Calibration		x
		7.1.6	Preventive Maintenance		x
		7.1.7	Sample Testing		x
		7.1.8	Quote and Order Review		
		7.1.9	Production Process Flow		
		7.1.10	Consultation for “Production Ready” Projects		
		7.1.11	Final Part Inspection		x
		7.1.12	Material and System Monitoring		
		7.1.13	Process File Management		
		7.1.14	Dimension Verification		x
		7.1.15	Void Detection		
		7.1.16	Post Processing		
		7.1.17	Verification of Customer Need Fulfillment		
8			**EMERGING TOPICS/ISSUES IN AM**		
	8.1		AM Design Topics		
		8.1.1	Design Representation Limitation		
		8.1.2	New Methods for Design Qualification		
	8.2		AM Start Ups		
		8.2.1	AM Industry Opportunities		
		8.2.2	AM Investment Sources		
		8.2.3	AM Business Planning		
	8.3		AM Software Development		
		8.3.1	New Software Applications		
		8.3.2	Software Development needs in AM		
	8.4		Evolution of Current Technologies/Methods		
	8.5		Integration of AM in Emerging Fields		
		8.5.1	Robotics		
		8.5.2	Internet of Things		

RUBRIC			DESCRIPTION	FUNDAMENTALS	TECHNICIAN
		8.5.3	Cloud Computing		
		8.5.4	Remote and Autonomous Operations		
9			**AM POST PROCESSING**	x	
	9.1		Materials		
	9.2		Methods		x
	9.3		Automating Processes		
	9.4		Processes for Parts and Components		
	9.5		Processes for Final Products/Use	x	x
10			**AM MATERIALS**		x
	10.1		Description		x
		10.1.1	Polymers		x
		10.1.2	Metals		x
		10.1.3	Ceramics		x
		10.1.4	Hybrid		x
	10.2		Microstructure		x
	10.3		Properties		x
	10.4		Qualification		x
	10.5		Vendor Considerations		x
	10.6		Material life cycle		x
11.1			**AM SAFETY**	x	x
	11.1		Hazards Associated with AM Processing	x	x
		11.1.1	Mechanical		x
		11.1.2	Electrical	x	x
		11.1.3	Thermal	x	x
		11.1.4	Airborne Particles	x	x
	11.2		Personal Protective Equipment	x	x
	11.3		Hazard Communication and Labeling	x	x
	11.4		Use of Safety Data Sheets	x	x
	11.5		Maintenance and Lockout/Tag-Out	x	x