



## Mitigating Risk for Additive Manufacturing Suppliers

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## Acknowledgements

- Ian Luczon – Training, Tools, Technology, and Tracking
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- Derek Garcia – Procurement Quality Assurance
- Andre Pate – Prototype and R&D Machining Services
- Robert Demerjian – Receiving Inspection
- Tonya Bakke – Mechanical Inspection
- John O'Donnell – Quality Assurance
- Craig Bergman – Quality Assurance
- Bryan Mcenerney – Materials and Processing
- Anupam Choubey – Mission Assurance

## Agenda

- Additive Manufacturing - Background
- Additive Manufacturing – Potential
- Additive Manufacturing – Risk
- Standard – Development
- Standard – Body
- Standard – Use
- Conclusion



**Jet Propulsion Laboratory**  
California Institute of Technology

- Office of the Director
- Business Operations
- Engineering and Science
- Solar System Exploration
- Office of Safety and Mission Success
- Mars Exploration
- Astronomy and Physics
- Earth Science and Technology
- Interplanetary Network

Materials and Processing

Manufacturing Engineering

Training, Technology, Tools, and Tracking

Mechanical Inspection

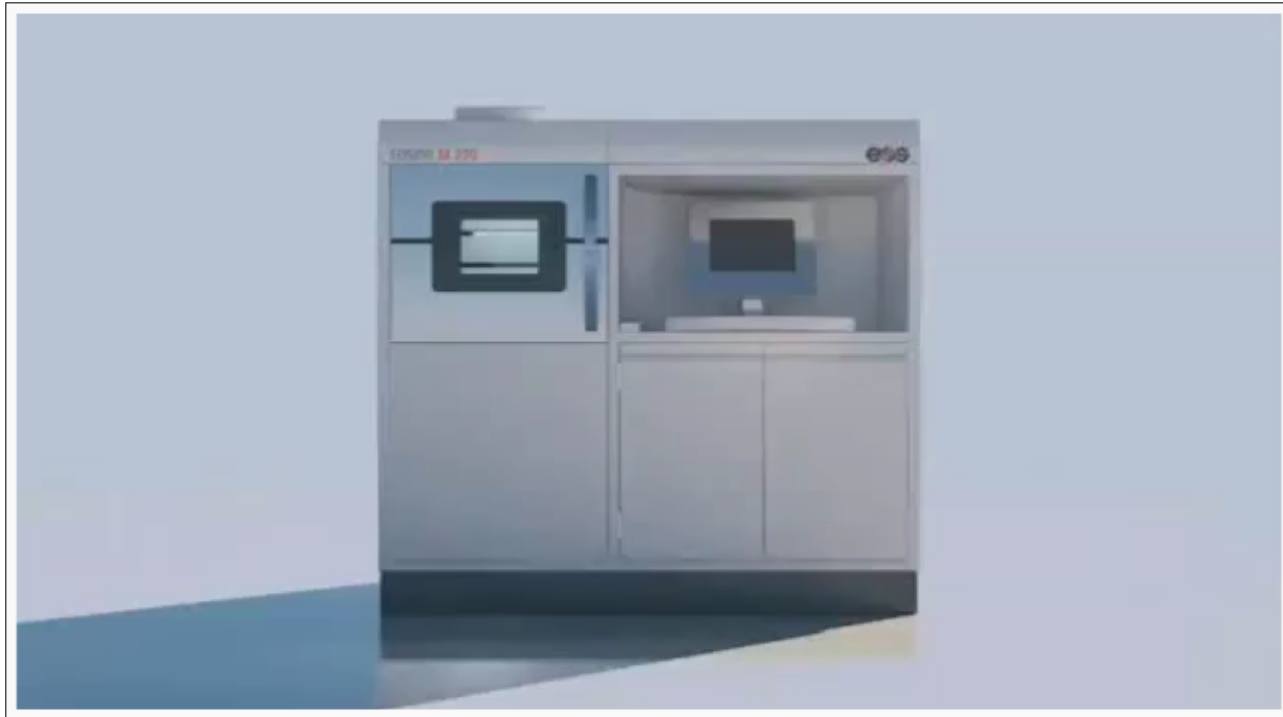
Procurement Quality Assurance

Receiving Inspection

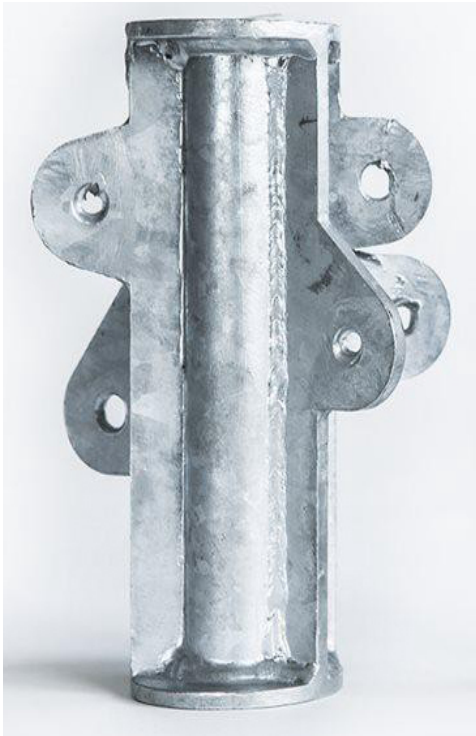
Mission Assurance



## Additive Manufacturing – Background

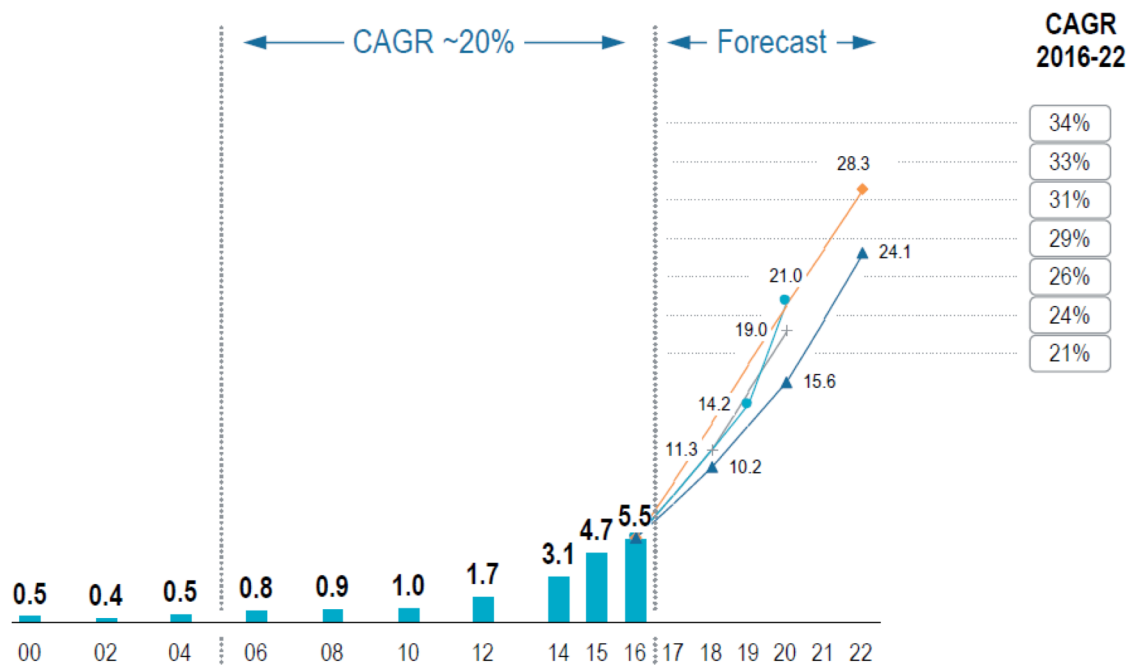


## Additive Manufacturing – Motivation



Mechanical Properties	Equal
Load Supported	Equal
Mass Reduction	75%
Size	Down 50%

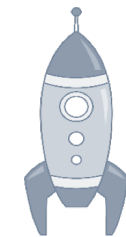
# Additive Manufacturing – Market Growth



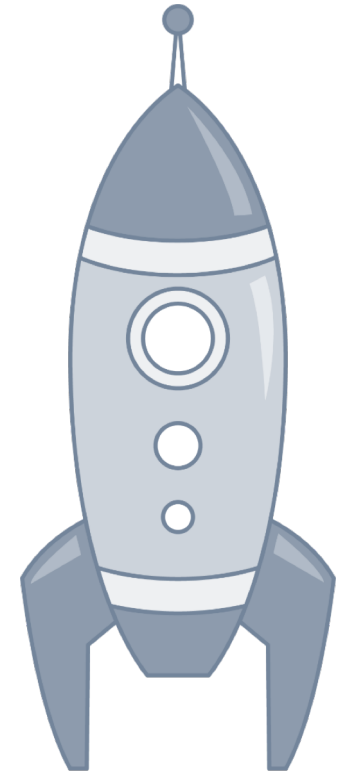
Growth estimate source: —+— Wohlers Associates —●— Canals —●— MarketsAndMarkets —▲— Smithers Pira

1) World production excl. parts/accessories; 2) FX rates as per Bundesbank, forecast based on 05/17 EUR/USD rate

Source: Expert interviews; Wohlers Associates (2017); Canals (2016); MarketsAndMarkets (2016); Smithers Pira (2016); Roland Berger

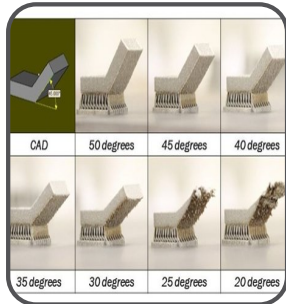
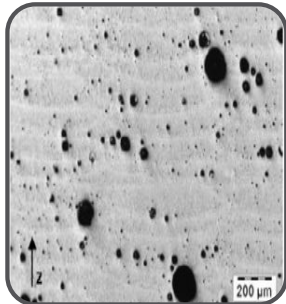
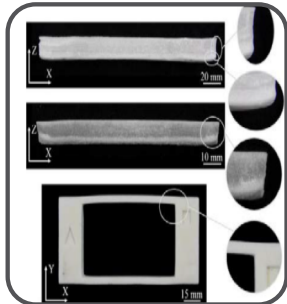


Current



2022

## Additive Manufacturing – Risk Assessment



### Distortion

Mitigation:  
Planning thermal gradients and reduce build speed

### Porosity

Mitigation:  
Ensure correct build parameters are used and HIP part

### Collapse

Mitigation:  
Use support structures and reduce overhang

### Safety

Mitigation:  
ESD, safety plans, and training

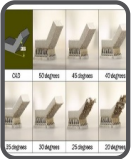


### FOD

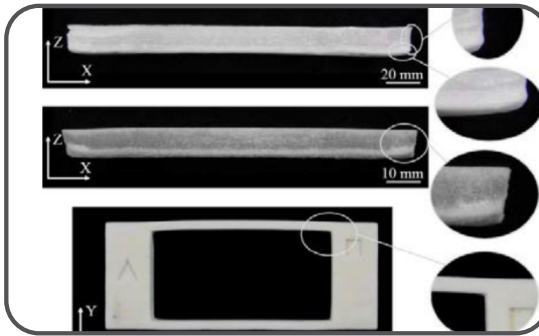
Mitigation:  
Process control, clean powder stock, and NDE

### Traceability

Mitigation:  
Require suppliers to track the powder from distribution

# Additive Manufacturing – Risk Assessment

					
<b>Distortion</b> Mitigation: Planning thermal gradients and reduce build speed	<b>Porosity</b> Mitigation: Ensure correct build parameters are used and HIP part	<b>Collapse</b> Mitigation: Use support structures and reduce overhang	<b>Safety</b> Mitigation: ESD, safety plans, and training	<b>FOD</b> Mitigation: Process control, clean powder stock, and NDE	<b>Traceability</b> Mitigation: Require suppliers to track the powder from distribution

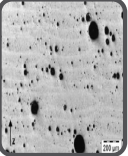



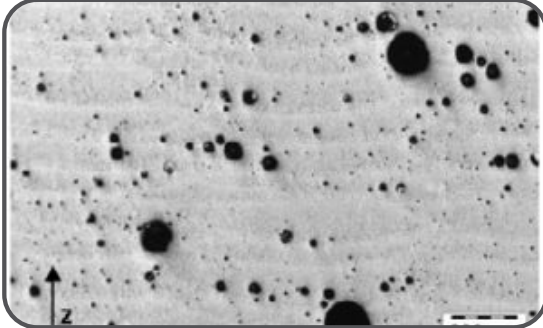
**Distortion**

Mitigation:  
 Planning thermal gradients and reduce build speed



# Additive Manufacturing – Risk Assessment

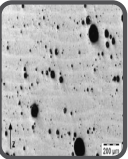
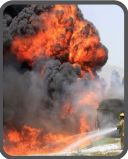


					
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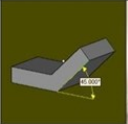
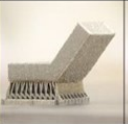

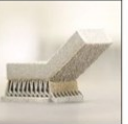
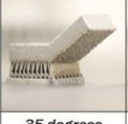





**Porosity**

Mitigation:  
Ensure correct build parameters are used and HIP part


# Additive Manufacturing – Risk Assessment

					
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<b>CAD</b>	<b>50 degrees</b>	<b>45 degrees</b>	<b>40 degrees</b>
			
<b>35 degrees</b>	<b>30 degrees</b>	<b>25 degrees</b>	<b>20 degrees</b>

**Collapse**  
Mitigation:  
Use support structures and reduce overhang

# Additive Manufacturing – Risk Assessment

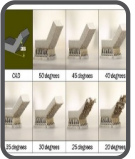

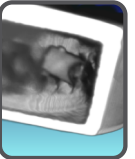

					
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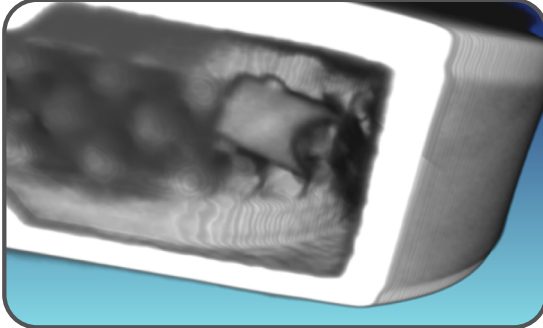


## Safety

Mitigation:  
 ESD, safety plans, and training

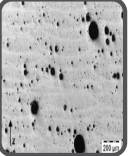
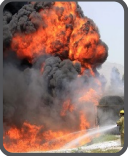

# Additive Manufacturing – Risk Assessment


					
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**FOD**  
Mitigation:  
Process control,  
clean powder  
stock, and NDE

# Additive Manufacturing – Risk Assessment

					
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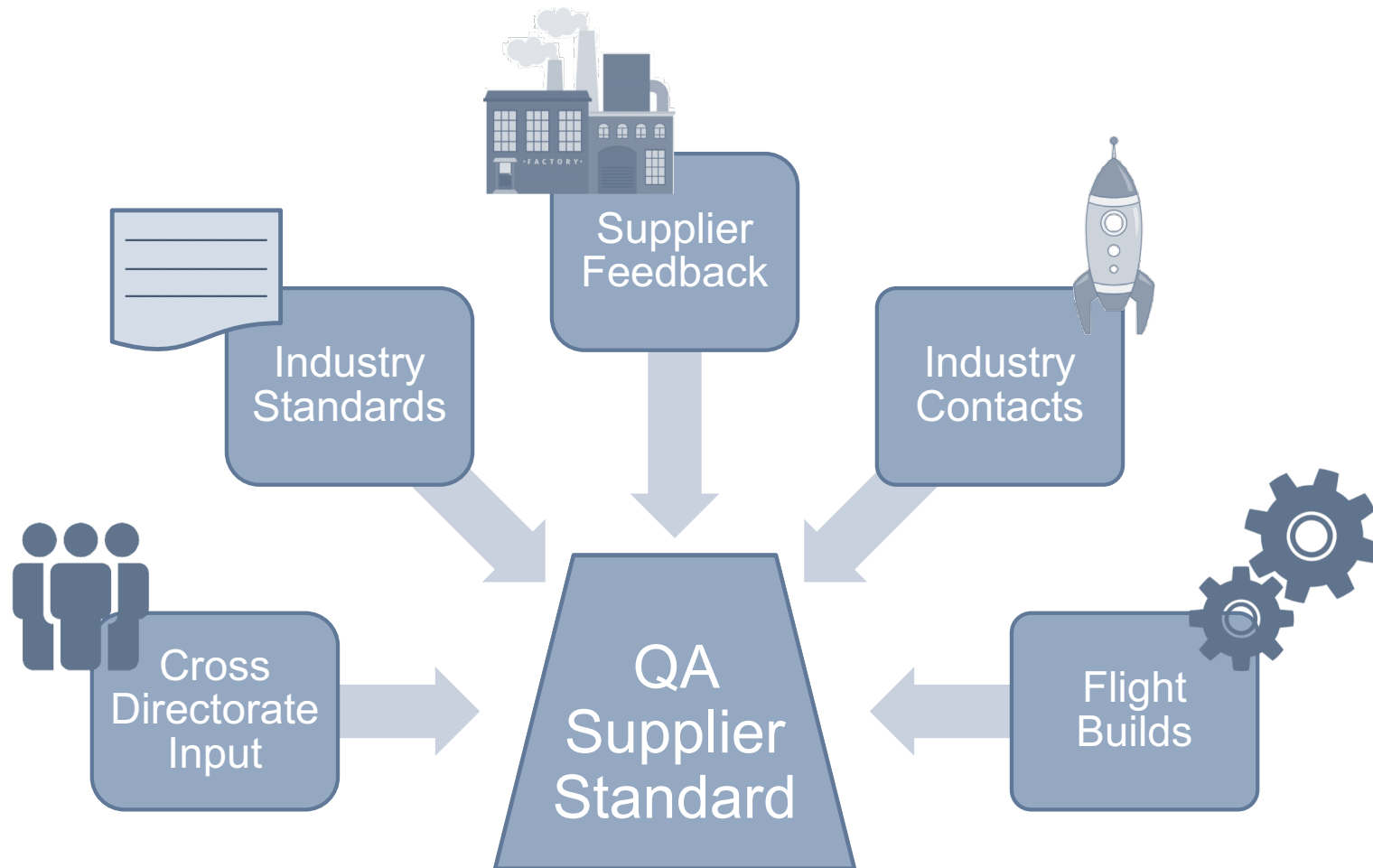


## Traceability

Mitigation:  
Require suppliers to track the powder from distribution



## Standard – Development





x Lack of Defined Requirements for Suppliers



x Lack of inspection criteria



x Lack of QA integration



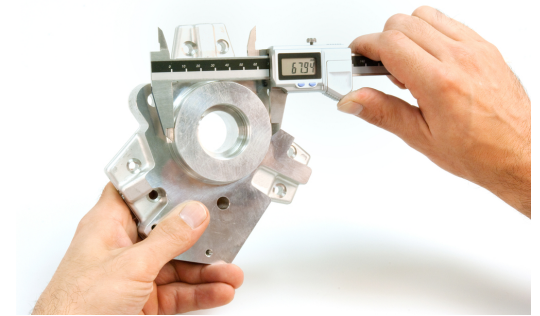
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Powder



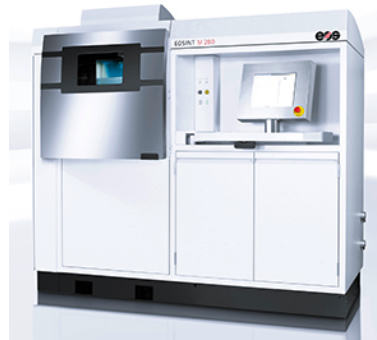
Supplier Quality Document



Inspection / Testing



Build



Machine



Post-Processing



Materials and  
Processing Document



Designers



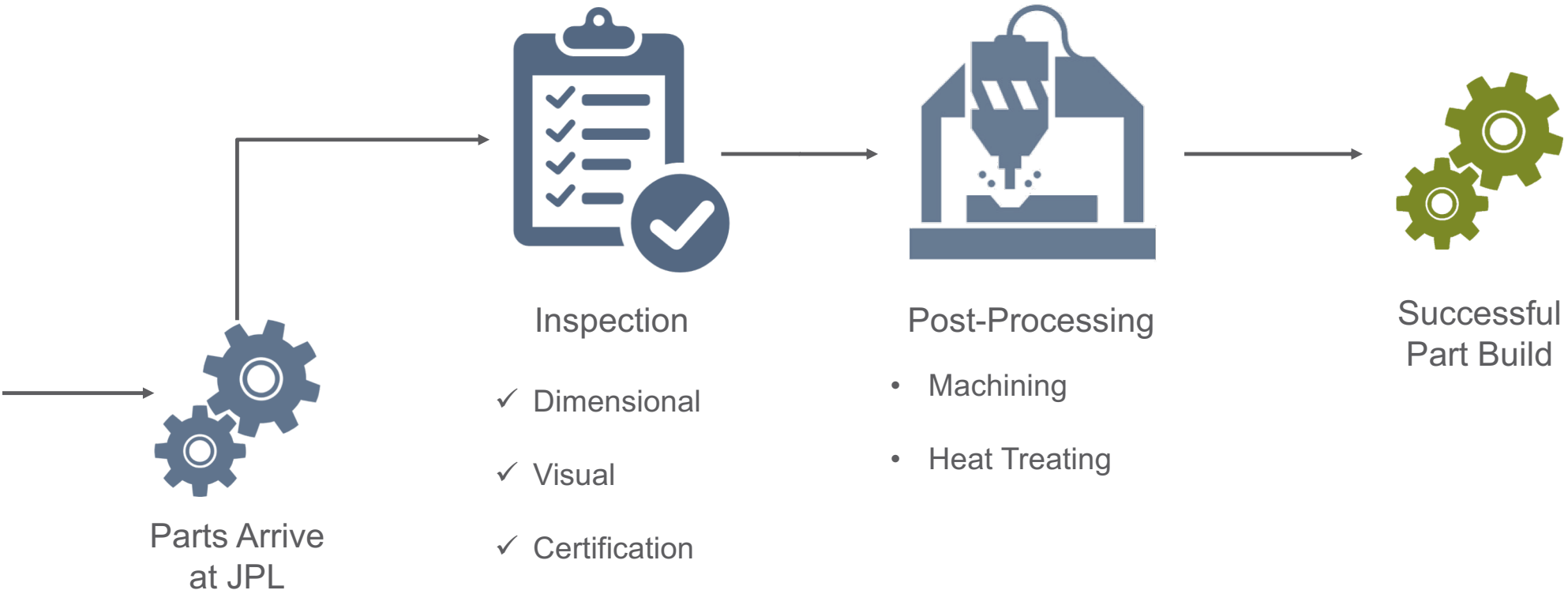
Mission Assurance  
Document



Supplier Quality  
Document

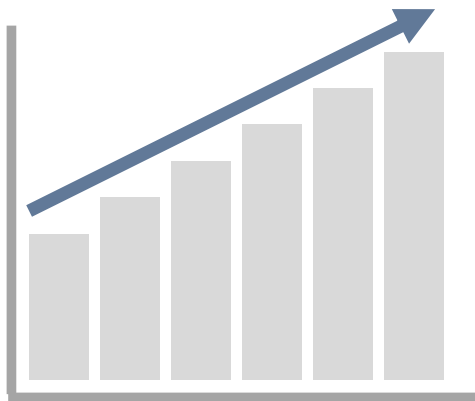


Supplier





## Conclusion



Market Growth



Supplier Quality Standard



Production



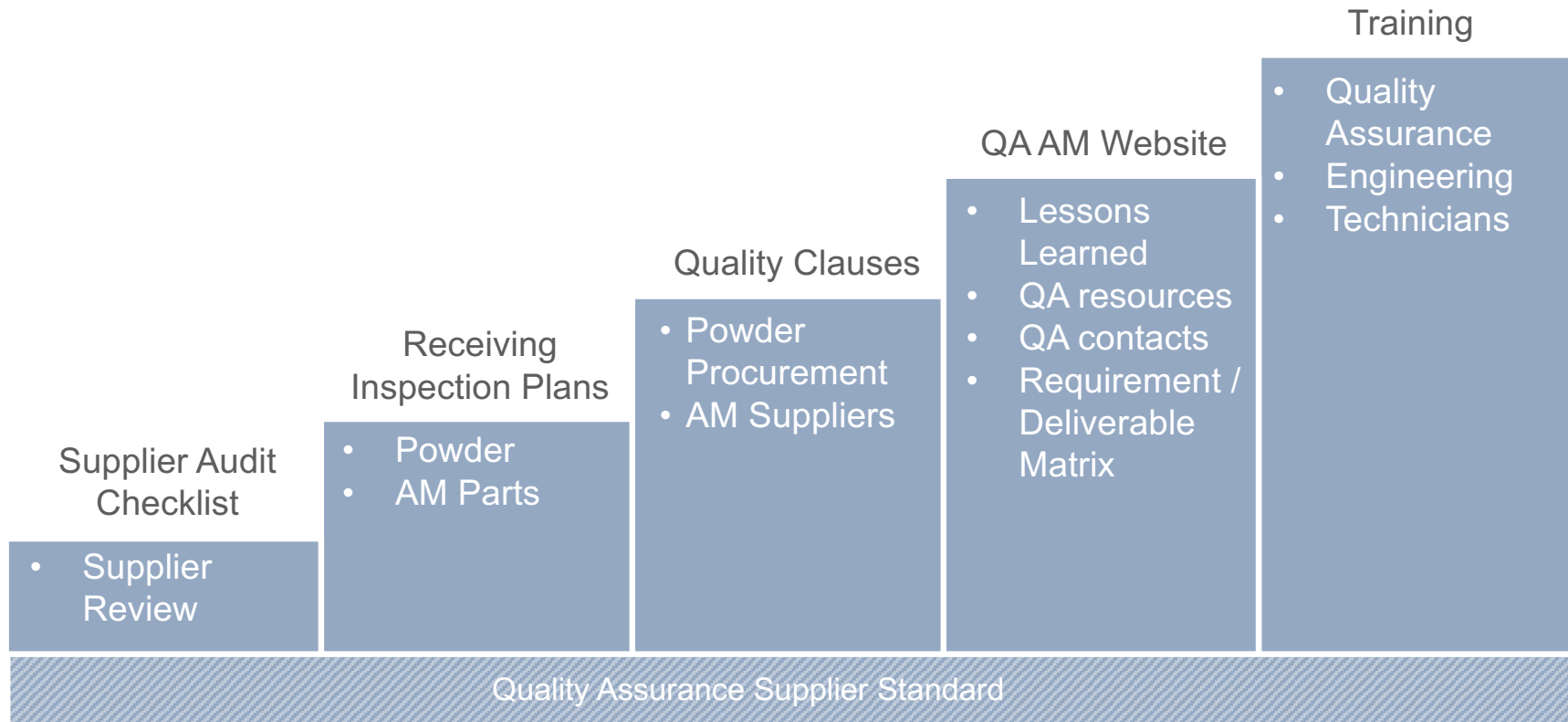
Questions

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# Backup Slides

## JPL AM Framework – QA Next Steps



## Requirement Tailoring Matrix

Requirement Tailoring Matrix				
Requirement	Section	Contract	Drawing	SOW
1 Powder sampling will follow ASTM B215	5.1.2	X		
2 Particle size distribution (following ASTM B214)	5.1.2.1	X		
3 Powder composition match material spec	5.1.2.2	X		
4 Rheology measurements	5.1.2.3	X		
5 Raw material for powder composition	5.2.1	X	X	
6 Powder reusal not allowed	5.4.1	X		
7 Single lot requirement	5.4.2	X	X	
8 JPL support structure and/or orientation	7.1		X	
9 Process relying on use of inert gas	7.3.4			X
10 Heat treatments specification (including stress relief)	8.2		X	X
11 HIP cycle of only JPL parts	8.2.1	X		
12 Source inspection	9.1	X		
13 Mechanical Testing	10.1	X		
14 Chemical composition testing	10.2	X		
15 Radiographic Inspection	10.3	X		
16 Density	10.4	X		
17 Surface Finish	10.5	X		

# Deliverable Matrix

Deliverables Matrix			
Deliverable	Section	Type of Document	Notes
Particle Size distribution measurements	5.1.2.1	Test Results	If required by contract
Powder Composition	5.1.2.2	Test Results	Powder Composition results from pre-build
Rheology measurements	5.1.2.3	Test Results	If required by contract
Single Powder Lot	5.4.2	CoC	If required by contract or drawing. Contract supersedes drawing
Part Orientation and Support Structure	7.1	FAI Report	Approval required on FAI Report
Final Part Orientation and Support Structure	7.1	Build Report	
Pre-build Checklist	7.3	Pre-build Checklist	Including but not limited to 7.3.1 - 7.3.5
Critical Parameters from build	7.4	Build Report	Critical parameters listed in standard (environmental and machine)
Part and Witness Coupon Identification	7.7	Build Report	Traceability to individual build location required (witness samples also listed in 9.4)
Heat treat Certifications	8.2	CoC	See standard for required information
HIP Certifications	8.2.1	CoC	See standard for required information
Visual Inspection	9.2	Inspection Report	Prior to and after post-processing
Dimensional Inspection	9.3	Inspection Report	Final post processed part shall meet the requirements, but before post-processing is a should
Mechanical Testing	10.1	Test Results	If required by contract. Test records including actual test values and standard used
Chemical Composition on as-built parts	10.2	Test Results	Shall meet the requirements in the contract and/or drawing
Radiographic Inspection	10.3	Test Results	If required by contract. ASTM E1742, Sensitivity 2-2T
Density	10.4	Test Results	If required by contract. In accordance with ASTM B311
Surface Finish	10.5	Test Results	If required by contract. In accordance with ASTM B946



## Standard Scope Comparison

### Marshall 3716

- Policy Framework Focused
- Process Dependent
  - Laser
- Independent:
  - Material
  - Supplier

### Marshall 3717

- Qualified Metallurgical Process focused
- Process Dependent
  - Laser
- Independent of:
  - Material
  - Supplier

### JPL 512 Standard

- Quality Assurance
- Vendor focused
- Independent of:
  - Design
  - Material
  - Process
  - Supplier

### JPL Mission Assurance Standards

- Material Dependent
  - Ti6-4
  - AlSi10Mg
- Process Dependent
  - Laser
  - E-Beam

# Personal Introduction

