



Additive Manufacturing Briefings (AMB)

Opening Address

Dr. Vivek Saxena

Vice President, ICF International

Leader, Operations & Supply Chain Practice

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Aerospace Manufacturing Conference

April 7, 2015, Palos Verdes



Agenda

Introductions

An Additive Manufacturing Primer

AMB Focus is Aerospace Production

AMB Preview

INTRODUCTIONS

ICF is one of the world's largest and most experienced aviation and aerospace consulting firms



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- **52 years in business (founded 1963)**
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SH&E
an ICF International Company
joined ICF in 2007

AeroStrategy
Management Consulting
joined ICF in 2011

G | H | K
joined ICF in 2012

ICF's thought leadership on AM is recognized in the aerospace markets



ANALYSIS: What is the future for 3D printing in aerospace?

By: STEPHEN TRIMBLE WASHINGTON
Source: **FLIGHT**

Making parts for a jet engine... powder used by the printer to... 3D printer itself has a seven-f... after it emerges from the addi...

However, that has not stopp... printing on a limited – but in... components.



SpeedNews 2nd Annual Aerospace Manufacturing Conference
April 1-2, 2014
The Battle House Renaissance, Mobile, Alabama

Supported by: **ATI**



Contributing columnist Kevin Michaels is a vice president in ICF SH&E's Ann Arbor, Mich., office, where he leads its Aerospace & MRO practise.



Articles by Kevin Michaels

3-D Printing Could Prove Seismic For A&D

There were more than 2,000 exhibitors at last month's Paris air show, and my guess is that at least one-third were involved in metal forming or cutting. And all of these companies depend on "subtractive" manufacturing techniques such as turning, milling and cutting to produce their aerospace parts. It was clear that many senior executives are acutely aware of and talking about the emergence of "additive" manufacturing (AM)—"3D printing"—as the next major change-and-disruptive technology in



Additive Manufacturing in Aerospace: Beyond Hype



Dr. Vivek Saxena, PhD
Vice President, Aerospace Operations & Supply Chain
ICF International

Presented at the Royal Aeronautical Society Meeting
April 17, 2014
Washington D.C.



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Dr. Vivek Saxena
VP, Operations & Supply Chain
Practice Leader
ICF SH&E

ADDITIVE MANUFACTURING – THE END OF THE WORLD AS WE KNOW IT!

Wednesday - April 09, 2014 - 9:15AM - 9:30AM

Description
Additive manufacturing has huge implications for MRO because in many cases spare parts will no longer need to be manufactured, shipped and stored on a shelf. Instead, they will just be printed when needed. Additive manufacturing will help create stronger, lighter, cheaper, and more environmentally responsible aerospace parts. It may also give the OEMs another control point into the spare parts market. This will be an eye-opening session about the future!

Speakers



Joe Anselmo
Editor-in-Chief
Aviation Week & Space Technology
Moderator



Mike Cloran
Marketing Director, Additive Development Center
GE Aviation
Speaker

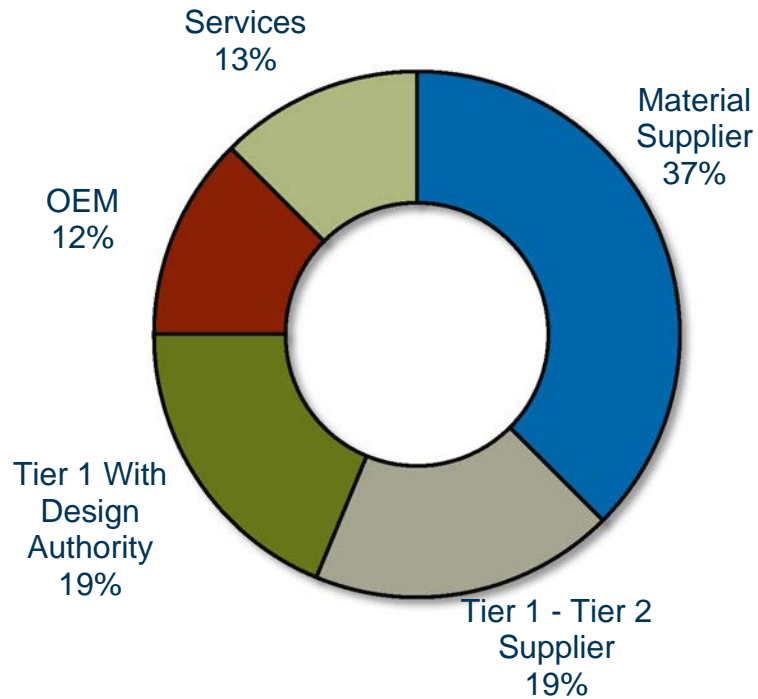


Peter Zimm
Principal
ICF SH&E
Speaker

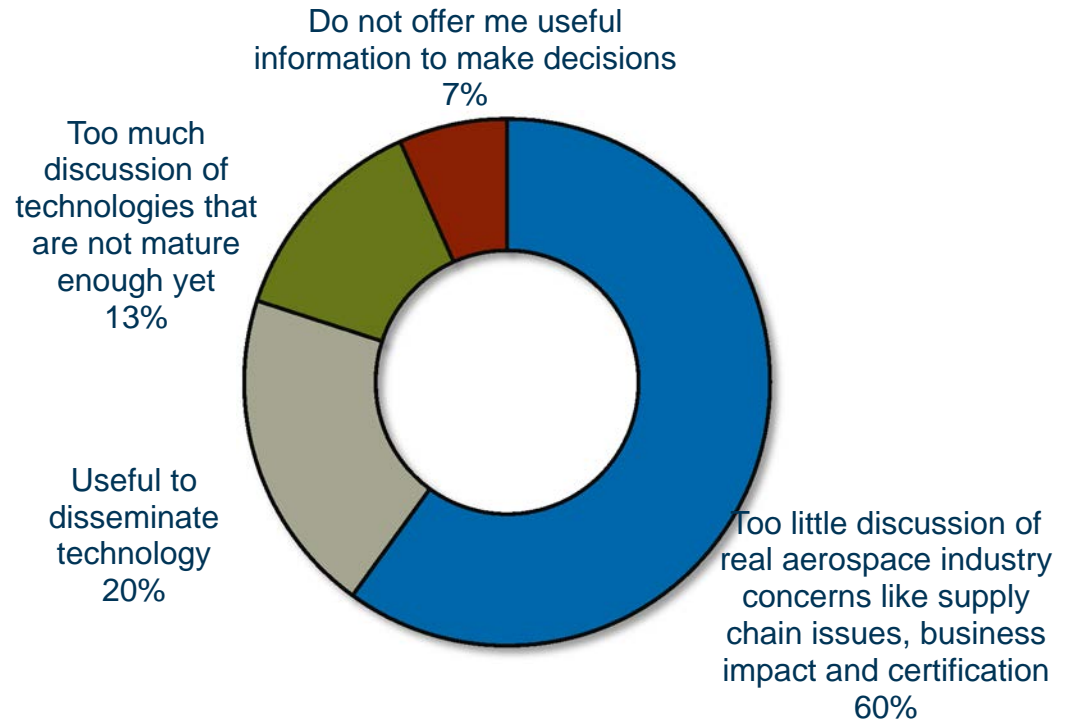


In our AM survey, 80% participants want a conference like AMB

Survey Participants

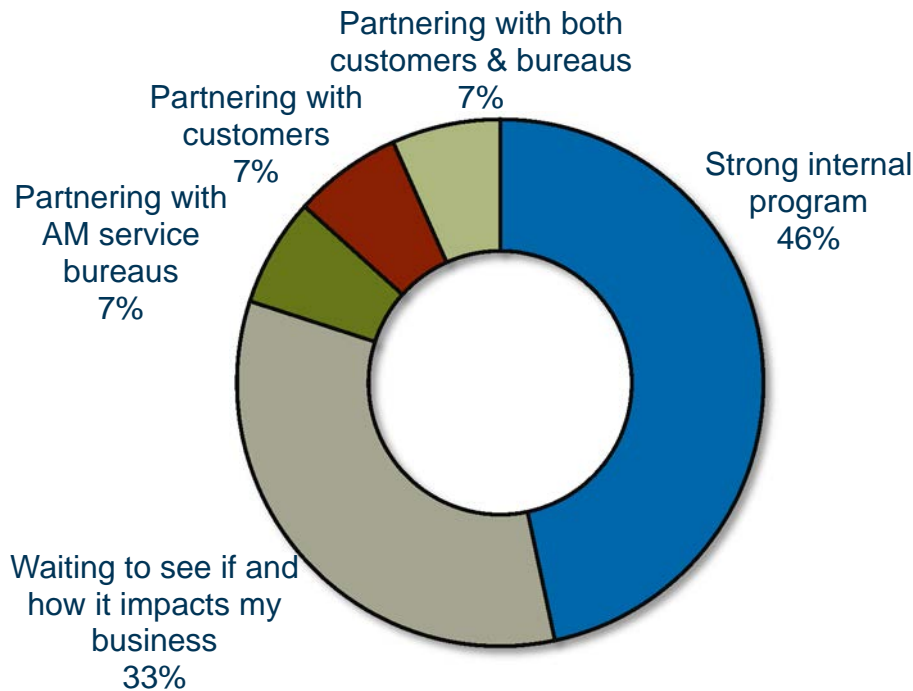


View on AM conferences

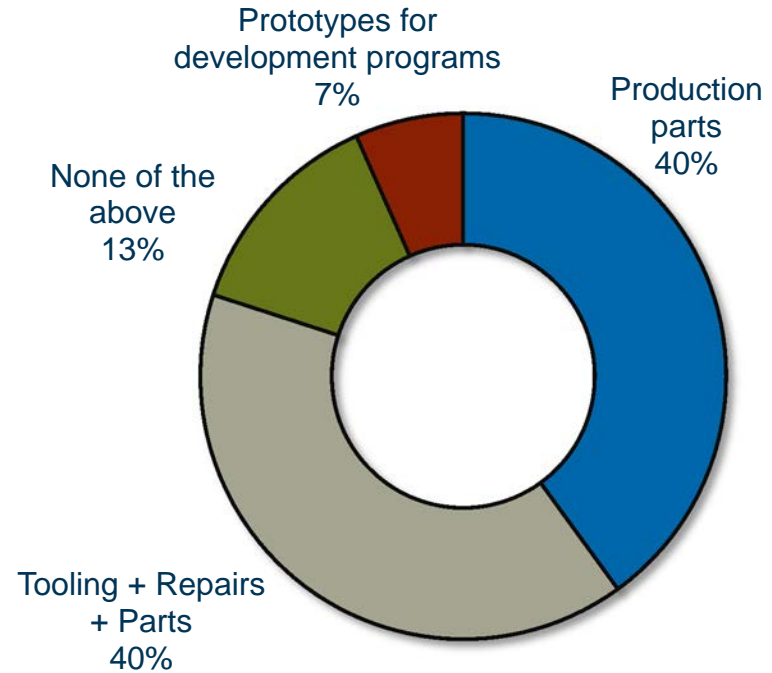


Almost half are pursuing AM capabilities in-house and 80% are working on production parts

How are you pursuing AM?



What is the focus of your AM?



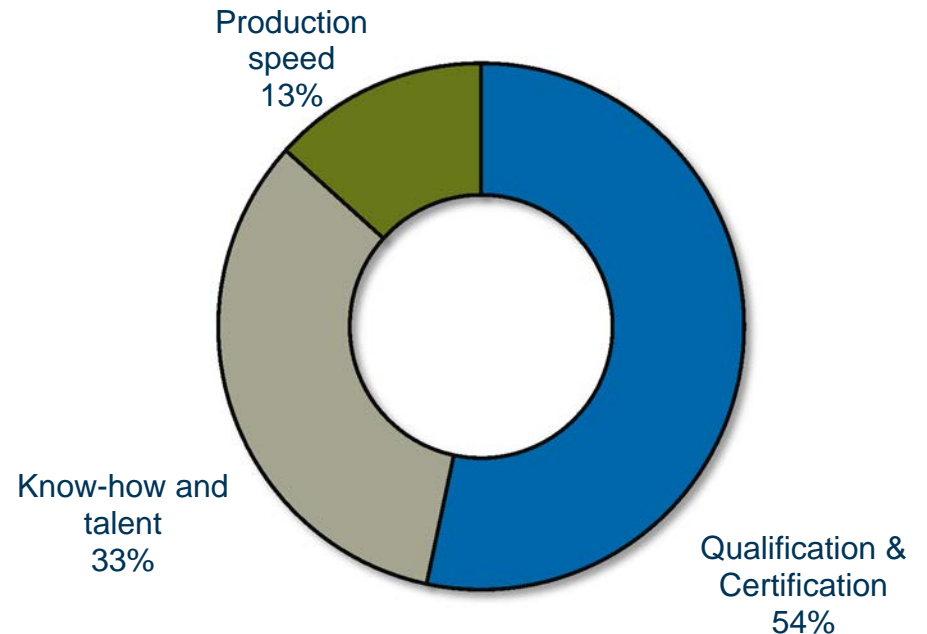
Certification and lack of skilled talent are considered a major barrier to AM adoption

Question: What is the biggest challenge for your business in adopting AM?

Possible Answers

- a) Affordability (Capex and NRE)
- b) Know-how and talent
- c) Unit cost with AM
- d) Production speed
- e) Qualification & Certification

Results





Agenda

Introductions

**An Additive Manufacturing
Primer**

AMB Focus is Aerospace Production

AMB Preview

Additive manufacturing can provide competitive advantage

Additive Manufacturing



1. **Reduced Lead Times**
2. **Reduced Weight**
3. **Reduced Cost**

Whole Parts

Assemblies and complex parts are prime candidates



Tooling / Fixtures

AM is well suited to low volume, high lead time items such as tooling



Add Features

Protrusions, bosses, and flanges could be added to simplified forged rings



Repair

Blade tips and other traditional additive repairs



Two main types of processes are used for aerospace additive manufacturing

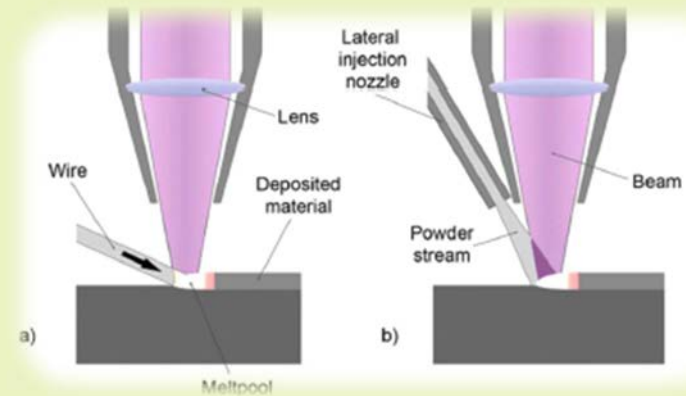
Powder Bed Process



- **Examples: SLS, EBM, LM**
- **Size limited by processing chamber**
- **Good surface finish and resolution**

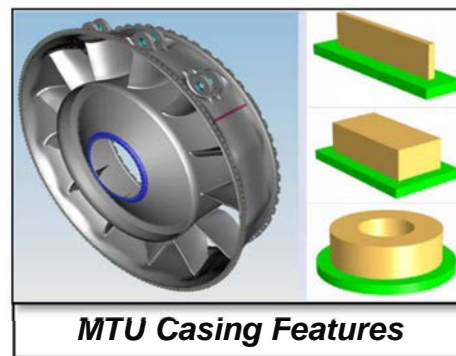
Source: ICF SH&E secondary research, interviews

Direct Energy Deposition



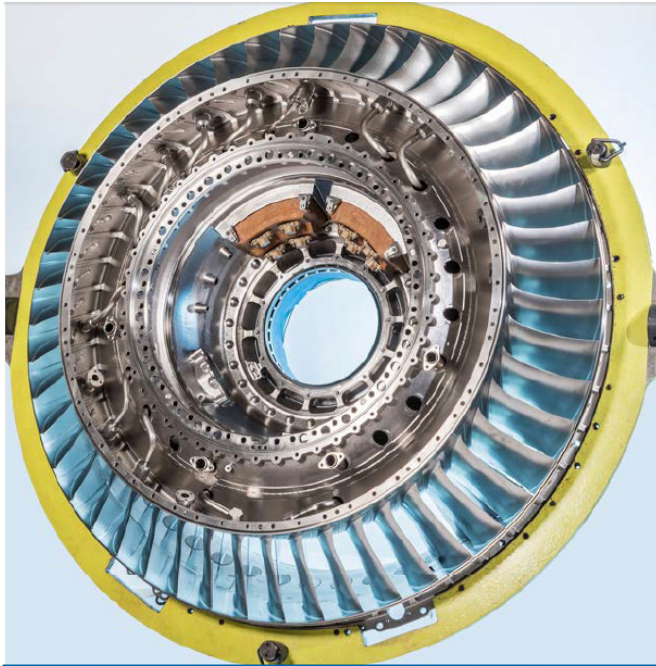
- **Examples: EBWM, PBWM, LENS**
- **Material deposited during processing**
- **Relatively high material deposition rates**
- **May require more post-processing**

While AM technology focus has been on small and complex parts (e.g. aero-engine components)



Source: ICF SH&E analysis, interviews and published sources

Current technologies also allow the additive manufacture of large parts



Trent XWB Front Bearing Housing



GENX Ti-Al LPT Blade (Avio)



Norsk Titanium Aerostructures Preform

Target applications are complex-geometry high BTF parts

Source: ICF SH&E analysis, GE Aviation, Avio, Rolls Royce and NTi

Applications with less stringent certification or safety requirements such as spacecraft and UAVs heavily use AM

Examples of AM Spacecraft and Experimental Aircraft Parts

Spacecraft Components



SpaceX Engine Chamber

- Chamber for production SpaceX rocket engine made by AM

UAV Components



SelectTech UAV

- Using AM for many components allowed SelectTech to shorten test & redesign cycle

Experimental Aircraft



Evektor Experimental Aircraft

- Many military and experimental aircraft OEMs use AM to rapidly iterate designs and reduce lead times for low-volume parts

Space & experimental vehicles have been prime candidates for near-term AM adoption

Source: SpaceX, Stratasy, ICF SH&E research

Additive manufacturing is just beginning to improve aftermarket support to operators

RAF Tornado



- BAE producing protective covers for cockpit radios and guards for power take-off shafts to sustain RAF Tornados via AM
- Parts first flew in December 2013
- These AM parts could cut RAF's maintenance costs by \$1.9M over four years

Air Transat A310

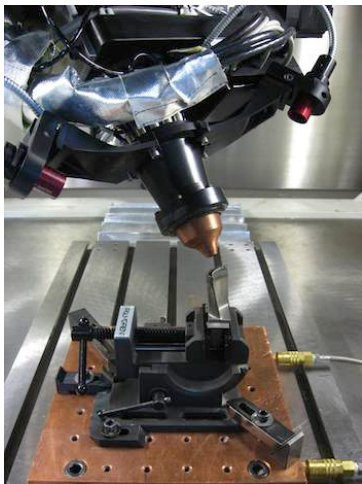


- In February 2014 the first AM component – a small plastic crew seat panel – flew on an Airbus customer jetliner
- The aircraft was an A310 operators by Air Transat
- Like most aircraft OEMs, Airbus is working towards “on demand” spare parts

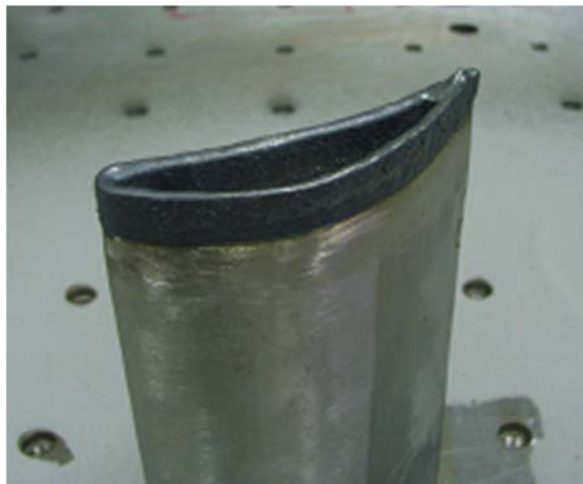
Sources: Daily Mail, Airbus

A class of repairs have historically been additive

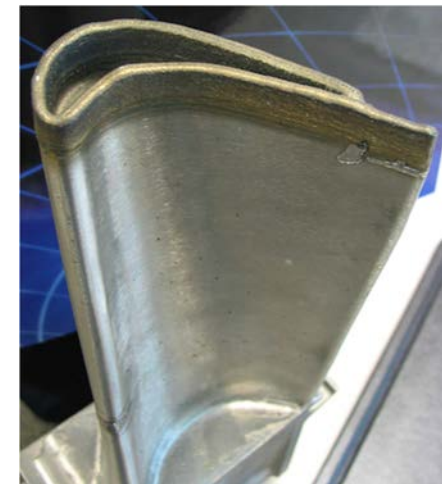
Repair of Turbine Components Using Direct Metal Deposition (DMD)



**Turbine blade
squealer tip is built
up using DMD**



**As deposited DMD
turbine blade tip**

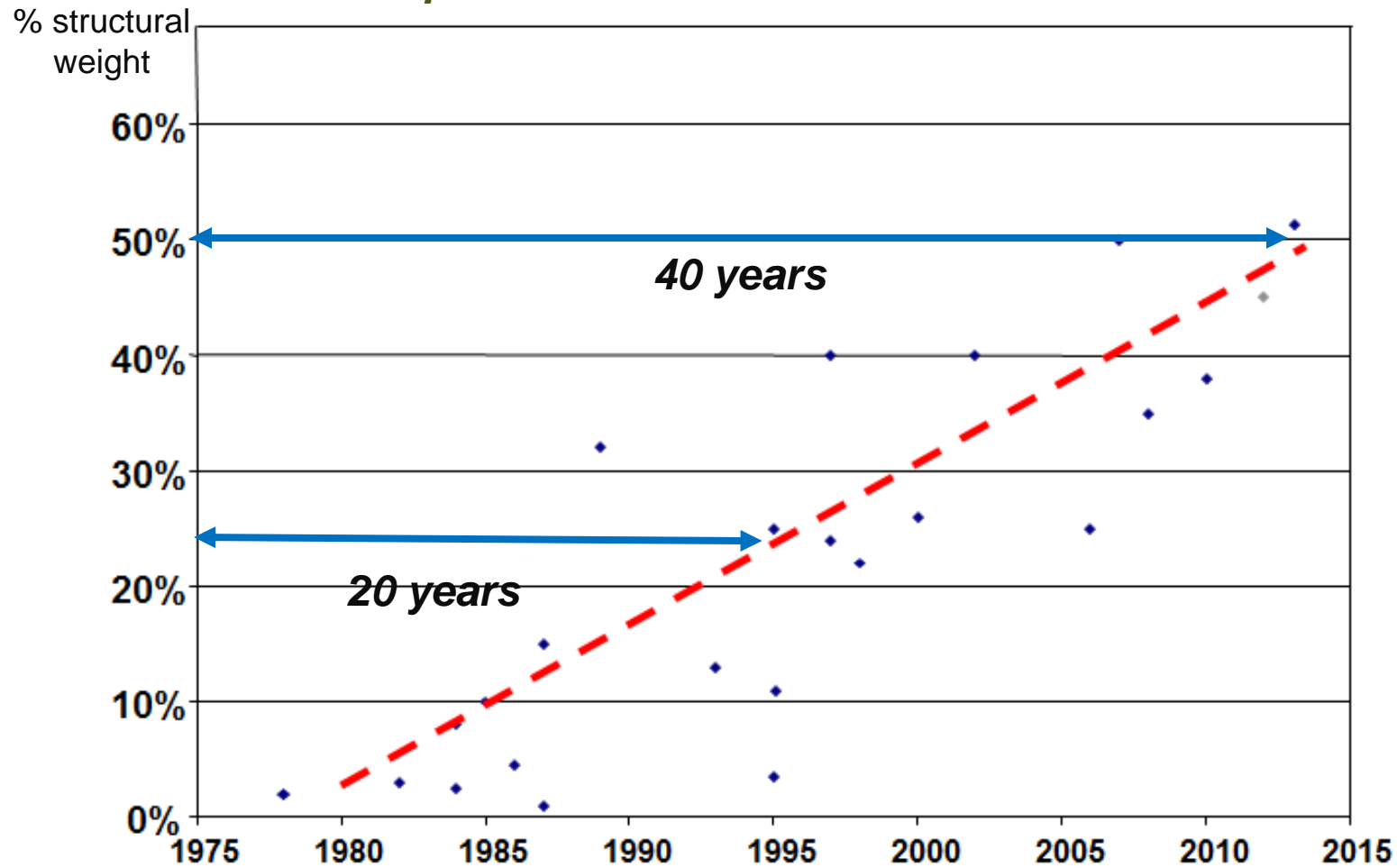


**Rebuilt turbine
blade tip**

DMD includes a patented closed loop feedback control of the deposition process

Disruptive technologies in the long-cycle aerospace industry take time to develop as evidenced by composites

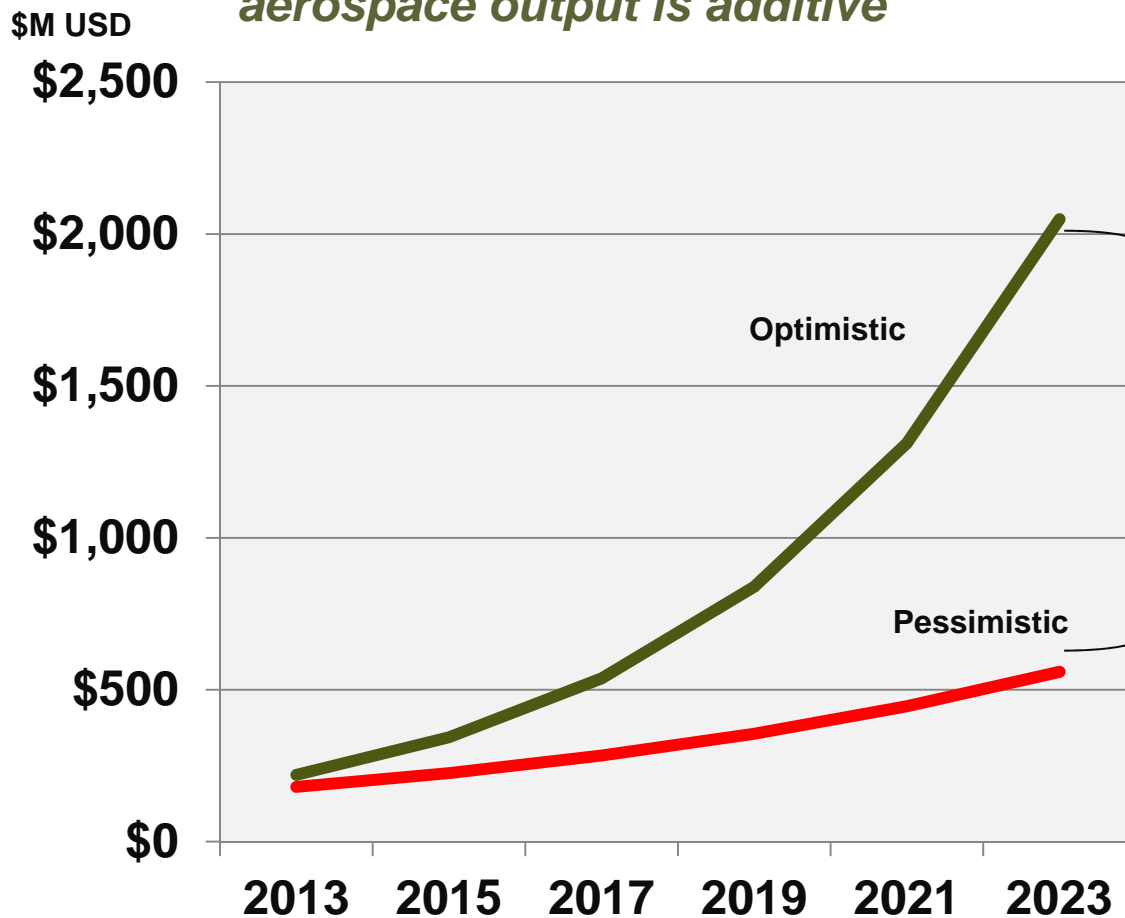
Composites Penetration In Aerostructures



Sources: ICF International analysis, Boeing, Airbus, secondary research

Additive manufacturing aerospace market projections vary wildly

Roughly \$250M out of \$150B global aerospace output is additive



- Uncertainties reflect the embryonic stage of AM development
- Just a few high-volume parts in production have the potential to greatly increase total market size
- Early adoption will be in applications with lower certification barriers
- Adoption of composites offers a good learning experience

Source: ICF International analysis, interviews, Wohler's, Credit Suisse
Market size includes machine sales and parts production



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Introductions

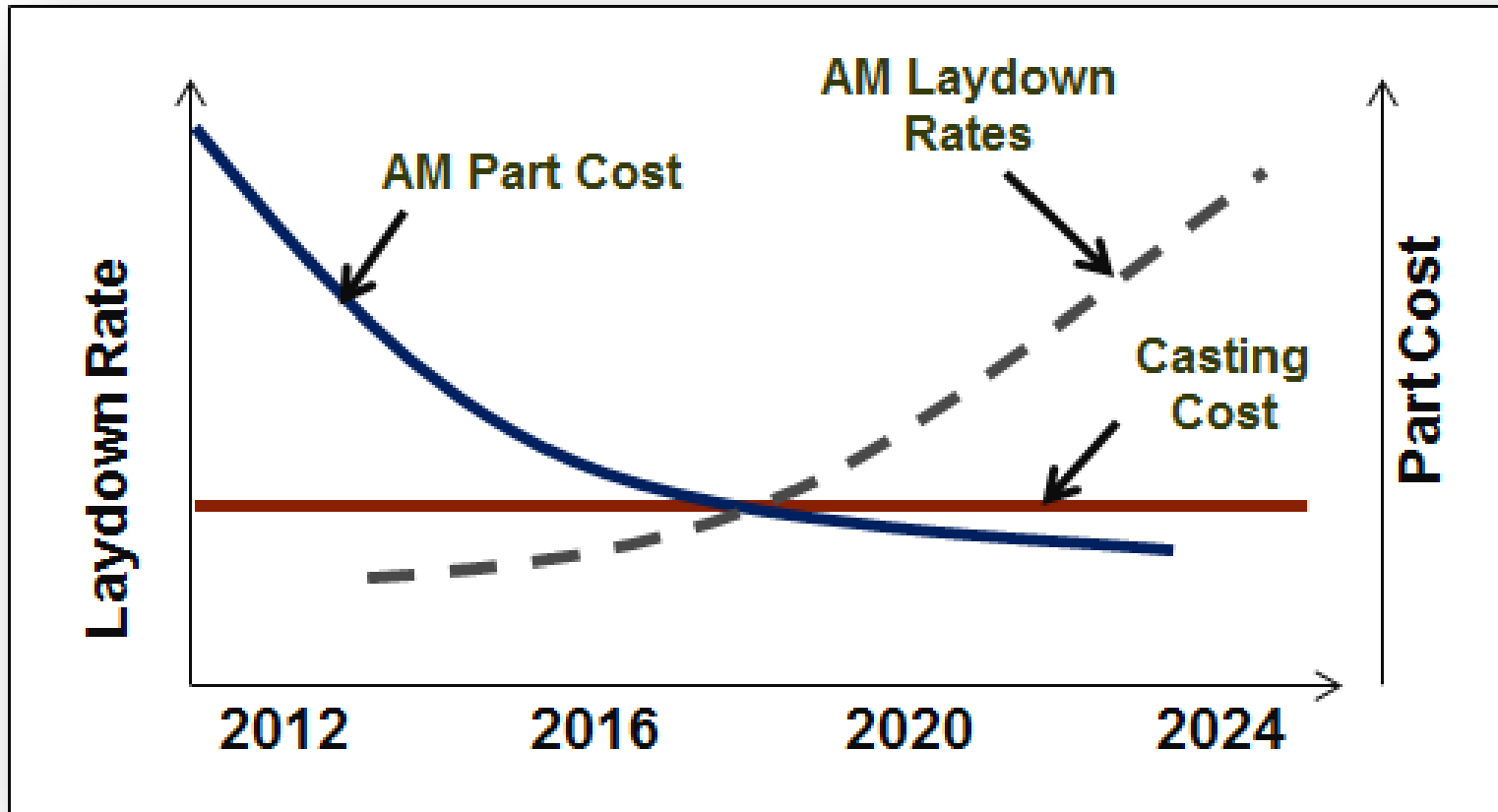
An Additive Manufacturing Primer

AMB Focus is Aerospace Production

AMB Preview

Ultimately, AM parts will have to buy their way on to the aircraft

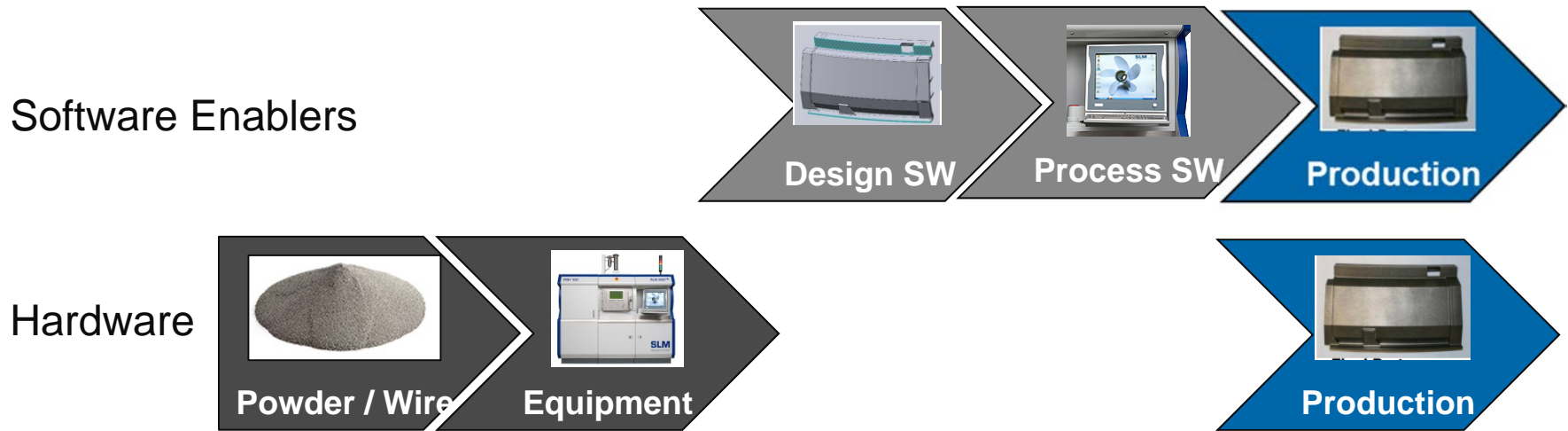
Projected AM Cost For Complex Titanium Casting



Source: ICF SH&E analysis, interviews,

The AM value chain is evolving and the traditional supply base may not be ready for the impact

The Additive Manufacturing Value Chain

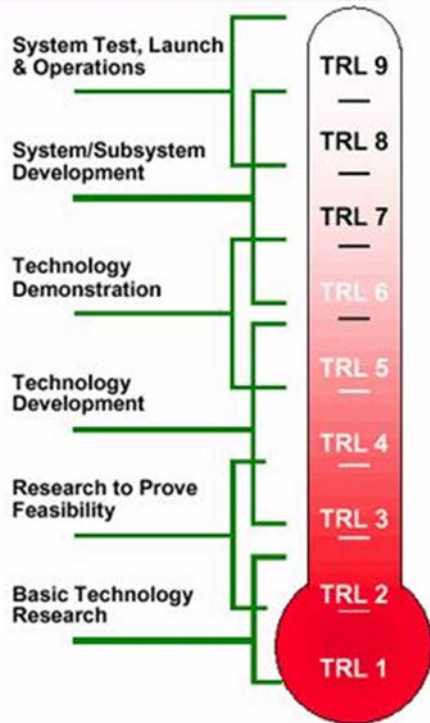


| | | | | | |
|---------------------------------|--|---|---|---|--|
| <p>Example Companies</p> | <ul style="list-style-type: none"> • ATI • Carpenter Technology • Special Metals (PCC) • Perryman • RTI | <ul style="list-style-type: none"> • Sciaky • 3D Systems • Arcam • EOS • ExOne • Renishaw • Stratasys • SLM | <ul style="list-style-type: none"> • Altair • Autodesk • Dassault • Witnin labs | <ul style="list-style-type: none"> • Geomagic • Materialise • Netfab | <ul style="list-style-type: none"> • Airbus • Boeing • GE • Pratt & Whitney • MTU • GKN • Service bureaus like Sciaky |
|---------------------------------|--|---|---|---|--|

Source: Roland Berger, ICF International research

Quality assurance and certification

1. Technology Readiness



2. Process Repeatability

- Standardization / specs
- Material characterization
- Machine variables
- Resolution, accuracy
- Process control

3. Regulatory Approval



Source: ICF SH&E analysis, interviews,



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Case Studies Presentations

The logo for MOOG, featuring the word "MOOG" in a bold, red, sans-serif font.

Mr. Paul DellaNeve
Corporate VP, Business Development



Ms. Laura Ely
Manager, Additive Manufacturing



Mr. Francisco Vega
VP, Sales & Marketing



Mr. Jesse Boyer
Fellow, Additive Manufacturing

Material Usage Panel



Mr. Art Kracke
VP, R&D and Business Development



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Mr. William Wellock
Director, Strategic Customer Development



Mr. Dean Hackett
Vice President, AM&P

Material Usage Panel Themes

- 1. Emerging developments in materials**
- 2. Price of Powder Metal (PM) and other AM materials**
- 3. Material supply chain evolution in the future**
- 4. Material suppliers influence on process / repeatability challenges**
- 5. Intellectual property issues in AM**
- 6. Industry standards and specs**

Productivity Panel



Mr. Scott Sevcik
Manager, A&D Business Development



Mr. David Wilckens
Director of Business Development, Aerospace



Mr. Andrew Snow
SVP, EOS North America



Dr. Ming Zhou
VP, FE Solvers & Optimization

Productivity Panel Themes

- 1. Laydown / build rate improvement**
- 2. Set up / changeover time reduction**
- 3. Post processing reduction**
- 4. Inspection time reduction / In-situ imaging etc.**
- 5. Efficient design / optimization**

Certification Panel



Dr. Michael Gorelik
Chief Scientist & Technical Advisor



Mr. David Hills
Director, Research & Technology



Mr. Michael Hayes
Technical Lead Engr., AM R&D



Mr. Richard Merlino
President, ADDAERO

Certification Panel Themes

- 1. Challenges in AM metal part certification**
- 2. Lessons from history**
- 3. Industry standards & specs**
- 4. Safety margins**
- 5. Assembly vs. part certification**

Thanks and Questions



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