In-Process 3D Geometry Measurement and Reconstruction for Direct Metal Laser Sintering
Prototypes & Lead Time Reduction
Past AM Efforts

Initial development of prototype parts with Morris Technologies

Laser PBF 718 Tangential On Board Injector on flight test bed


Laser PBF 718 swirler on Airbus flight test bed

Began building internal R&D lab for AM and production planning

Success with AM Drives Technology Integration
Honeywell Components Fabricated - Powder Bed AM

Various Part Complexities and Materials Produced
Additive Manufacturing Technology Center

Benefits of Additive Manufacturing
• Rapid prototyping – development lead-time reduction
• Design freedom – high complexity, low volume
• Target markets in Aerospace:
  - Commercial Aerospace, UAVs, electronic housings
  - Engine components, hinges & brackets, housings
  - Spacecraft components

Honeywell Phoenix Focus
• Material and process development
• Prototype fabrication
• Production of AM Components

External Collaboration Underway
• Air Force – Materials Affordability Initiative
  - High temperature Alloys
• DARPA – Integrated Computational Materials Engineering (ICME) related
• University Partnerships
Inspection of Powder With Conventional Technology

Sonic sifter/general sieve analysis

Microtrac

LECO analyzers (O,N,H and C,S)

Hall flowmeter/apparent density

Tap density

Mass balance

There is no correlation between the results of these test and how well the powder flows or fuses in a PBF machine
Quality Systems for Additive Manufacturing

Conventional Systems

Visual

Physical Measurements

In-Process Inspections

Florescent Penetrante Inspection (FPI)

X-Ray

CT (CAT) Scans

Structured Light

Non-Conventional Systems

Inspection by Layer/Slice

Objective Evidence of Compliance to Design Intent
Conventional Methods – Not Going Away

Conventional Methods are not going to go away anytime soon

Photo courtesy of Cromwell UK

Photo courtesy of Renishaw Corporation

Photo courtesy of Brown and Sharp:

Photo courtesy of Cromwell UK
Conventional Method – Florescent Penetrate Inspection (FPI)

Conventional Methods are not going to go away
FPI Indications do not necessarily mean defects
Conventional Method – X-Ray

Conventional Methods are not going to go away
Not every company has access to X-Ray Technology
Need Skilled Operator
Technology can only peer into part a short depth
Structured Light Inspection Technology

White Light

Blue Light

Green Light

Digital Signature of Geometry

Some Human Intervention in Gathering Data

Negative: Can only inspect outside surfaces
Application Issues With Conventional Technology

3D Printing of Complex Geometries That Would Previously been Multiple Parts Can Not Be Inspected Using Conventional Inspection Techniques
Non-Conventional Technology

Objective Evidence of Compliance to Design Intent is the GOAL

Data is Objective

Completely Automated

Digital Signature of Weld Puddle

Digital Signature of Geometry

No Human Intervention in Gathering Data
Technology Development
Objective Evidence of Compliance to Design Intent

Development of Technology Generated Using Multiple Avenues

- Collaboration with Government
  - Defense Advanced Research Projects Agency (DARPA)
    - Small and Large Companies Involved
  - Materials Affordability Initiative (MAI)

- Collaboration with Industry
  - Sigma Labs

- Procurement of Technology from Machine OEM(s)

- Working With Universities
Sigma Labs Public Disclosure of Technology

Non-Destructive Evaluation Techniques for Additive Manufacturing;
Donald Godfrey,¹; Mark Cola, ² ; 1 Honeywell Aerospace, Phoenix, AZ 85034; 2 Sigma Labs, Inc. 3900 Paseo del Sol Santa Fe, NM 87507, RAPID Conference, May 2015

Note:
Sigma Labs has entered into Technology Development Agreements with Materialise NV, Additive Industries BV and 3DSIM, LLC.
Process Monitoring – DARPA – Sigma Labs

• Ensuring quality during build important for Part Quality
  - Metallurgical Properties: PrintRite3D® INSPECT™
    ▪ Melt pool monitoring and defect recognition

• Utilizing a sensor array
  - Photodiodes and Pyrometers
  - Power meters

Advancing In-Process Monitoring to Meet Quality Needs
PrintRite3D® CONTOUR™

Initial Resolution Analysis
PrintRite3D® CONTOUR™

Real-time geometric property measurement software

• Layer-by-layer geometric property measurements.

• Provides for comparison of ‘as-built’ to original digital CAD model ‘should be’.

• Developed by Sigma Labs Inc and validated at Honeywell

• Dimensional variations and resolution accuracy of at least 100μm

Photo courtesy of Sigma Labs, Inc
Application of Software

Objective:
Avoid X-ray CT and CMM through use of in-situ geometric measurements

Photo courtesy of Sigma Labs, Inc
Extract circular hole geometry

Photo courtesy of Sigma Labs, Inc
Geometry

Dimensions of the Part

- .430 R TYP
- .500 TYP
- .300 TYP
- 45° GAGE TYP
- 52° TYP

.4383-.4388 DIA THRU
.4521-.4591 DIA X DEPTH SHOWN
CSK 88°-92° (INCL Â) X .50-.54 DIA
2 HOLES

Photo courtesy of Sigma Labs, Inc

215 μm shoulder
Chamfered layers ignored

11.57 mm dia. (nom)

215 μm shoulder

11.14 mm dia. (nom)

Photo courtesy of Sigma Labs, Inc
Concept Laser Public Disclosure of Technology

Press Release 5-2015

Various public forms such as RAPID and FORMNEXT
1. Powder Bed Fusion Technology machines must apply new powder the same depth (thickness) in each area of the build platform.

2. After each weld (build) layer, a camera captures a digital image of the build platform and stores that image for reference.

3. Then after the re-coater arm has deposited a layer of powder a second digital image of the build platform is taken.

4. The software will then compare the digital images and insure the pass (slice) welded prior to the re-coating does not show through the newly deposited powder layer.

5. If it does, the software will instruct the machine to apply an additional layer of powder.

6. This technology will prevent one area of the part to be grown while another area of the part is not grown due to a lack of powder to be welded.

7. This technology is most useful when there is welding material in the four corners of the build plate such as with a large part or multiple smaller parts.

Photo courtesy of Concept Laser GMBH

Concept Laser Coating Control Technology
Concept Laser Coating Control

Integration of Coating Control

- Coating control integrated in the process flow of the Laser melting process
- Fast image acquisition
- Image processing can be conducted in parallel to the movement of the coater back to the powder platform
- Coating can be repeated
- Feed factor can be influenced by coating control (closed loop control)

Photo courtesy of Concept Laser GMBH
Concept Laser Coating Control Technology

- Feed factor 100% →
- QMcoating switched off

→ Coating problems especially at the corners

Photo courtesy of Concept Laser GMBH
Residual Stresses in Additively Manufactured Inconel 718 Engine Mount; Thomas R. Watkins,¹ Paris A. Cornwell,¹ Ryan R. Dehoff,¹ Vinod Nangia,² Donald G. Godfrey,²; ¹ Oak Ridge National Laboratory, Oak Ridge, TN 37831; ² Honeywell Aerospace, Phoenix, AZ 85034, iSABE Conference, October 2015

Oak Ridge National Laboratory Neutron Diffraction Technology

1. Powder Bed Fusion Technology with lasers create parts with considerable material stresses

2. Measuring the level of stress is difficult

3. Neutron Diffraction is a technology that will measure stress in the microstructure of components

4. The Neutron Diffraction Process is very experimental

5. Goal is to learn how to design components so to minimize stress levels during / after build

6. Process is a destructive technology as part is radioactive
MTU Public Disclosure of Technology

Overview of Additive Manufacturing Activities at MTU Aero Engines;


Note:

MTU has licensed their Optical Tomography Technology to EOS Corporation GMBH
MTU Optical Tomography Technology

1. After a baseline is established for the build process, the optical technology continuously records the process radiation during the welding process.

2. A variation in the measurement of this radiation will then be associated as a variation to the baseline and worthy of further examination.

3. It is important to note that a variation does not mean a quality error has occurred, it only means a quality variation has been recorded and worthy of further examination.

Photo courtesy of MTU GMBH
MTU Optical Tomography Technology

sCMOS-Camera
thermal stabilized
max 100 Hz
5 MegaPixel

Noise reduction
Image processing
Online analysis

1 image / layer

Photo courtesy of MTU GMBH
Electronic Data Must be Calibrated to Material Properties

- Complete material property testing will have to occur across a broad spectrum of temperatures using multiple build orientations:
  - Tensile
  - Creep
  - LCF
  - HCF
  - Other

**NOTE:**

- Without calibrating material property data to the electronic signatures the technology cannot be successful
Process Development 1

Tensile Strength of DMLS 718 vs Wrought In718

Take Away: 3D Printed Material Properties Similar to Wrought Properties
Process Development 1

Tensile Strength of DMLS Hast X vs Wrought Hast X

Take Away: 3D Printed Material Properties Similar to Wrought Properties
Tensile Strength of DMLS 15-5PH vs Wrought 15-5PH

Tensile Strength of DMLS Ti-6-4 vs Wrought Ti-6-4

Take Away: 3D Printed Test Specimens similar to wrought properties
Take Away: 3D Printed 718 Test Specimens Not Influenced by Build Orientation
Additive Manufacturing Will Alter the Defense and Space Supply Chain

• Next 20 Years (Maybe Less)

  ▪ Defense industry will print parts in theater rather than using current supply chain ordering techniques
    – Will companies sell licenses to print designs or will companies print quickly and ship?
    – Long lead times in the supply chain will not be tolerated

  ▪ Space will begin to print components outside of earth’s atmosphere

  ▪ Industry must re-imagine how they will produce and sell components (aftermarket components) to Governments

  ▪ Companies must find a way to insure designs are not counterfeited
    – Less quality material
    – Poor manufacturing technique
Summary

• Honeywell incorporating AM on Global Scale

• Working to be world leader in technology development in the area of NDE

• With regard to quality - Objective Evidence of Compliance to Design Intent is the ultimate goal

• Electronic signatures MUST be correlated to mechanical properties of the material

• Companies must understand and be quick to react to a supply chain that is going to go through a paradigm shift that will have a direct influence on quality