Additive Manufacturing Ecosystem

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Additive Manufacturing ... a 4 step process

1. Digital design
2. Digital slicing
3. Layer-wise manufacturing
4. Final part
Direct Metal Laser Melting (DMLM)
Transformational Power of Additive

The Additive Advantage

1. **Expands What is Possible** ... opens up new design capability to optimize part & system designs in a way we cannot with traditional manufacturing processes

2. **Improves Quality** ... eliminates design trade offs; reduced cycle times, digital v. analog control, reduced braze/weld/rivet/bolted joints

3. **Simplifies Systems** ... more robust designs, reduced part counts and assemblies; shortened supply chains
It started with 1 part...

Capabilities of full production

**35,000 – 40,000** per year

25% **WEIGHT REDUCTION**

20 → 1 **PARTS**

5x **MORE DURABLE**

LEAP is a trademark of CFM International, a 50/50 JV between GE and Safran Aircraft Engines.
and now we’re building an engine ... the Advanced Turboprop engine (ATP)

55% of major structures additively manufactured

Sumps, bearing housings, frames, exhaust case, combustor liner, heat exchangers

855 → 12

PARTS

25%

PART WEIGHT REDUCTION

50 → 1

PARTS

1%

FUEL BURN REDUCTION

5%

ENGINE WEIGHT REDUCTION

ATP engine for new Cessna aircraft - Denali

Each major component eliminates many sub-parts
Acetabular Cup

Trabecular Structure

Tailored and bespoke designs
<table>
<thead>
<tr>
<th>Barrier</th>
<th>Technical Opportunity</th>
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</thead>
<tbody>
<tr>
<td>Immature design-for-additive tools</td>
<td>Topology optimization &amp; analysis tools</td>
</tr>
<tr>
<td>Limited materials base</td>
<td>Materials development</td>
</tr>
<tr>
<td>Uncertain material properties</td>
<td>Process modeling</td>
</tr>
<tr>
<td>Machine size and speed limitations</td>
<td>In-process monitoring</td>
</tr>
<tr>
<td>Post-processing complexity</td>
<td>Rapid qualification techniques</td>
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<tr>
<td>Part qualification, evolving industry</td>
<td>Scaling machine capability – machine design, laser technologies, control systems</td>
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<tr>
<td>standards</td>
<td>Non-destructive evaluation techniques</td>
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Rapidly Expanding Materials Capability

- Inco 718
- Inco 625
- SS 316L
- A205
- 17-4 PH
- SS 15-5
- MS-1
- F357
- Bronze
- AlSi10Mg
- W
- HS188
- 6061 T6
- CoCr
- Hast X
- Rene 80
- Ti 6242
- Ti 64
- TiAl
Understanding Structure-Property Relationships

Co-28Cr-6Mo

DMLM
- Melt Pool Directionality
- Vertical Grain Growth

Wrought
- Solution Heat Treatment
- Similar to Wrought Isotropic / Homogeneous
- Typical Equiaxed Grain Structure

Graph:
- YS (ksi)
- UTS (ksi)
- Elongation (%)
- Hardness (HRC)

Bar graph showing:
- DMLM - V
- DMLM - H
- Wrought Low
- Wrought High

Comparison with ASTM standards.
Additive Manufacturing Development Process

100+ Material & Machine Parameters

**Powder Specification**
- Powder Source
- Powder Size
- Powder Composition
- Reuse Procedures

**Laser Parameters**
- Spot Size
- Laser Power
- Laser Travel Speed
- Laser Dwell Time

**Calibration & Maintenance**
- Preventative Maintenance
- Pre-build Calibration
- Factory Environment Controls

**Thermal Processes**
- HIP Cycle Parameters
- Heat Treat Atmosphere
- Braze HT Parameters
- Solution Temperature

**Hatch Strategy**
- Contour Pass
- Sky Writing
- Line Spacing & Overlap

**Recoat Parameters**
- Layer Thickness
- Recoater Arm Design

**Post Processing**
- Mechanical Finishing
- Thermal Exposures

**Build Chamber**
- Build Atmosphere
- Purge Gas
- Airflow
- Preheat Temp
Supply Chain Shift In Progress
# Building the next generation workforce

<table>
<thead>
<tr>
<th>Primary and secondary schools</th>
<th>Two- and four-year colleges and universities</th>
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<tbody>
<tr>
<td>$2 million for 3D-printing equipment and curriculum</td>
<td>$8 million for metal additive manufacturing equipment</td>
</tr>
<tr>
<td>Focus on <strong>STEM/STEAM</strong> programs</td>
<td>Focus on <strong>additive learning</strong> efforts</td>
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</tbody>
</table>
Supporting Industry Initiatives
Some of the opportunities ...

Specifications

Industry Groups