Advanced Manufacturing for Large Industrial Gas Turbines
- Drivers for LGT manufacturing innovation
- Key components for Advanced Manufacturing
- Testing, validation and implementation
- Challenges & requirements for implementation of SLM in turbine production
- Conclusions
Drivers for Large Gas Turbine Manufacturing Innovation

Business drivers/
Customer requirements

**Cost**
- First cost
- Life cycle cost
- Operation cost

**Performance**
- Plant power
- Plant efficiency

**Capabilities**
- Emissions
- Operational flexibility
- Regulatory compliance
- Upgradeability
- Reliability, availability
- Time-to-market

Turbine Inlet Temperature °C

- 1956
- 1966
- 1976
- 1986
- 1996
- 2006
- 2016

- 800
- 1200
- 1600
- 2000
- 2400

- F (56% Combined Cycle efficiency)
- G (58% Combined Cycle efficiency)
- H (>60% Combined Cycle efficiency)

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Key Components for the Development of Future Gas Turbines

- Compressor
  - Increase of mass flow
  - Increase of pressure ratio
  - 3D aerodynamics
  - Reduction of aerodynamic losses

- Combustion
  - Higher combustion temperatures
  - Optimized burner (fuel flexibility)
  - Reduced emission
  - Increased efficiency

- Turbine
  - Higher turbine inlet temperatures
  - New materials and coatings
  - Improved cooling and sealing
  - 3D aerodynamics, loss reduction

These goals can not be reached with conventional development methods, conventional designs and conventional manufacturing technologies!
### Use Cases for SLM as AM Technology

*Lead time and performance gains are the major drivers*

#### Technology Validation
- **Rapid Development**

#### Production
- **Rapid Tooling**
- **Rapid Manufacturing**

#### After Market
- **Rapid Repair / Spare Parts**

<table>
<thead>
<tr>
<th>Category</th>
<th>Technology Validation</th>
<th>Production</th>
<th>After Market</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lead time &amp; Availability</strong></td>
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<td><strong>Costs</strong></td>
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<td><strong>Performance &amp; Innovation</strong></td>
<td>⬆️</td>
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</tbody>
</table>

#### Combustion
- Injectors and nozzles
- Mixer/Swirler
- Heat shields
- Instrumentation
- Bending tools for fuel pipelines
- Customized tool holders
- Injection nozzles
- Mixer/Swirler
- Burner heads
- Burner repair
- Spare parts on demand
- Upgrades

#### Turbine
- Mock-up parts for process development
- Technology and product validation
- Special tools
- Seals for test rigs
- Expandable parts for coating
- Blades/vanes with advanced cooling schemes
- Heat exchangers
- Seal plates
- Coupons for the repair of complex components
- Refurbishment
SLM Rapid Manufacturing and Rapid Repair
Additive manufacturing has arrived in customer engines

### Rapid Manufacturing

<table>
<thead>
<tr>
<th>Driver</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long lead times</td>
<td>Lead time reduction by six months</td>
</tr>
<tr>
<td>Long time line for implementation of new designs</td>
<td>short term implementation of re-designs</td>
</tr>
</tbody>
</table>

### Rapid Repair

<table>
<thead>
<tr>
<th>Driver</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long repair times</td>
<td>Significant lead time reduction by 90 %</td>
</tr>
<tr>
<td>Costs for repair</td>
<td>Significant cost reduction (-30 %)</td>
</tr>
</tbody>
</table>
Testing and Validation Chain
Change in R&D paradigms

Integrated development: accelerated iteration cycles in few months

3D Design ▶ SLM processing ▶ Post processing ▶ Instrumentation ▶ Testing

Conventional process
“Testing is final validation at the end of development process”
- Sequential development processes
- Conservative development approach
- Moderate development goals
- Long development cycles

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Novel paradigm
“Testing is integrated part of development process”
- Parallel and integrated development processes
- Radical development approaches
- Ambitious development goals
- Accelerated development goals, short iteration cycles
Conventional development cycle corresponds with standard manufacturing processes

Rapid Development

Benefits:
- Reduced risk in critical path development steps
- Design optimization
- Reduced development time
SLM Process Chain for Production

Line integration is the prerequisite for industrialization

Challenges:
- Integration of horizontal AND vertical process chain
- Industrial machine standards
- Standardized processes, materials, and interfaces
- **Costs:** Implementation, validation and production
- Component size & complexity
- **Location:** Ability to source locally on globally basis; Export compliance
- **Skill base:** Qualified labor
- **Incoming material:** Quality control; storage; handling; mixing/blending
- **Sourcing:** Sole Source vs multi-source – stability, competition
- **Inspection & Acceptance criteria:** Destructive; NDE; sampling
- **Vendor qualification and surveillance**
- Compatibility/co-location with other manufacturing processes
- **Re-work and non-conformance** – scrap rates
- **Residual powder / Revert**
- **Intellectual property:** Component designs; process parameters
- ...
Conclusions
AM is not just a trend! It has already changed the way of producing and testing components.

Opportunities

- SLM offers unique potential for the development of future gas turbines:
  - **Design innovations** → gain in performance
  - **Efficient repair** and refurbishment applications
  - **Paradigm change** in **development** and **validation**
Conclusions

AM is not just a trend! It has already changed the way of producing and testing components.

Challenges

- Industrial implementation of SLM has successfully started **BUT** additional development needs are substantial:
  - Capacities, build chamber sizes
  - **Costs**
  - Productivity → accelerated SLM processes (multiple lasers, laser arrays)
  - **Quality**
  - Robustness and repeatability → process control
  - Standardized processes, machines and materials
  - Industrial health and safety standards
  - **Line integration** → standardized interfaces are required
  - …
Thank you
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