Additive Manufacturing in Aerospace and Defense

Roland Berger study

May, 2017
Agenda

A Additive Manufacturing in the aerospace ecosystem
Additive manufacturing in aerospace is on the verge of taking off, with market forces and increasing technological maturity enabling greater uptake of AM

B Your way forward into additive manufacturing
In entering AM, you must design a component strategy by weighing the market, your technical capabilities and AM value propositions

C Overview of Roland Berger
Roland Berger can leverage its global expertise in aerospace & defense, and additive manufacturing

Source: Roland Berger
A. Additive Manufacturing in the Aerospace ecosystem
Additive manufacturing in aerospace is on the verge of taking off, with market forces largely enabling greater uptake of AM

Key takeaways

1. **Additive manufacturing is taking off** in multiple industries and encompasses a wide variety of technologies/technical solutions

2. Trends for **additive manufacturing in aerospace** are largely positive, with the increasing impact of enablers and decreasing barriers

3. As companies consider entering or expanding their presence in AM, they must consider a **series of fundamental questions** to ensure engineering and economic success

Source: Roland Berger
Additive manufacturing is a core part of the Industry 4.0 technology ecosystem which is set to interconnect and disrupt business

Industry 4.0 ecosystem

- **Additive manufacturing**
  - Optimization
  - Cost reduction
  - Mass customization
  - Rapid prototyping

- **Nanotechnology/Advanced materials**
  - Smart value added products
  - Technical differentiation
  - Connectivity

- **Robot**
  - Real time - Autonomy - Productivity
  - Full transparency on data reporting

- **Advanced Manufacturing Systems**
  - Give sense to complexity
  - Creativity
  - Collaborative manufacturing

- **Big Data**
  - Cyber Physical Systems (CPS)
  - Numerical command
    - Full automation
    - Totally interconnected systems
    - Machine to machine communication

- **Cloud computing**
  - Stronger protection for internet based manufacturing
  - Technology products with longer life cycle

- **Cyber security**
  - Give sense to complexity
  - Creativity
  - Collaborative manufacturing

- **Mass customization**
  - Object tagging
  - Internet-object communication via low power radio
  - Real time data capture
  - Optimized stocks
  - Reduced waste

- **Internet of Things**
  - Full transparency on data reporting
  - Incremental security
  - Lower costs

- **Client**
  - Customer & marketing intimacy
  - Flexibility
  - Perfect match with customer’s needs with production mass efficiency
  - On demand manufacturing

- **Logistics 4.0**
  - Fully integrated supply chain
  - Interconnected systems
  - Perfect coordination

- **Cluster of suppliers**
  - Zero default/deviation
  - Reactivity
  - Traceability
  - Predictability

- **Cluster of plants**
  - Clean and renewable energies
  - Energy storage
  - Alternative raw materials

Source: Roland Berger
There are a range of additive manufacturing technologies, with varying material properties, processing requirements – and costs

Landscape of additive manufacturing technologies

<table>
<thead>
<tr>
<th>Build principle</th>
<th>PBF(^1)</th>
<th>DED(^2)</th>
<th>Jetting</th>
<th>Extrusion</th>
<th>Binder Jetting</th>
</tr>
</thead>
<tbody>
<tr>
<td>A powerful laser fuses layers of powder on a &quot;powder bed&quot;, with incremental fused layers adding depth and detail</td>
<td>&quot;Depositing&quot; melted powder to create the part directly, with powder material melted during deposition</td>
<td>Deposition of molten metal or metal powder into a carrier liquid</td>
<td>Dispensing of material through nozzle to form a green part(^3)</td>
<td>Using a chemical bonding agent to join metallic or other powder to form a green part(^3)</td>
<td></td>
</tr>
</tbody>
</table>

| AM manuf. readiness                      | Production-ready                                                           | Late-development stage                                                     | Early R&D stages                                                        | Early R&D stages                                                        | Late-development stage |

| Key materials                            | Al, Ti, Ni-alloys, CoCr, Steel                                              | Ti, Ni-alloys, Steel, Co, Al                                               | Aluminum, Steel                                                         | Cu, Inco, Steel, (others incl. Ti in development)                       | CoCr, Steel/ Bronze, Steel, Inco, non-metals |

| Material properties                      |                                                                          |                                                                          |                                                                        |                                                                          |                                                                          |

| Post processing required                 |                                                                          |                                                                          |                                                                        |                                                                          |                                                                          |

| Build costs                              |                                                                          |                                                                          |                                                                        |                                                                          |                                                                          |


1) Powder Bed Fusion, 2) Direct Energy Deposition, 3) Green parts have low material bonding and require a post-processing sintering heat treatment

Source: Company information; Expert interviews; Roland Berger
The global AM market is expected to continue double digit growth into 2022 – market analysts project a growth of up to 35% p.a.

Global AM market

Development of metallic AM market\(^1\) 2000-2022 [EUR bn]\(^2\)

> For 2004 to 2016, the over-all AM market showed an annual growth (CAGR) of ~20%
>  - In 2016 growth softened, mainly due to weak performance of polymer players (Stratasys and 3D Systems)
>  - The market is expected to multiply by a factor of two to five by 2022

Growth estimate source: Wohlers Associates, Canalys, 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); Canalys (2016); MarketsAndMarkets (2016); Smithers Pira (2016); Roland Berger
The US is at the forefront of installed AM equipment/systems, with 37% of the global capacity

AM equipment / systems sales and installed base

**AM Sales through value chain [2016]**

- Materials: 15%
- AM equipment / systems: 30%
- Services: 55%

Σ = EUR 5.5 bn

**Installed AM equipment / systems [1988 – 2016 by country, %]**

- US: 37%
- Germany: 8%
- Japan: 10%
- China: 9%
- Others: 4%

Source: Wohlers, Roland Berger
As of today, AM applications have penetrated manufacturing in many industries – aerospace is the largest single industry using AM.

### Typical applications per industry segment [EUR bn], 2016

<table>
<thead>
<tr>
<th>Industry</th>
<th>EUR (bn)</th>
<th>%</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aerospace</strong></td>
<td>EUR 1 bn</td>
<td>18%</td>
<td>- Production of lightweight parts with complex geometry, e.g. fuel nozzles</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Stationary turbine components</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Reworking of burners</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Small Ti aerostructure components</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- etc</td>
</tr>
<tr>
<td><strong>Automotive</strong></td>
<td>EUR 0.8 bn</td>
<td>15%</td>
<td>- Primarily used for rapid prototyping esp. for visual aids and presentation models</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Production of special components for motorsports sector, e.g. cooling ducts</td>
</tr>
<tr>
<td><strong>Consumer prod./Electronics</strong></td>
<td>EUR 0.7 bn</td>
<td>17%</td>
<td>- Production of tools and manufacturing equipment such as grippers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Production of embedded electronics, e.g. RFID devices</td>
</tr>
<tr>
<td><strong>Medical/dental</strong></td>
<td>EUR 0.6 bn</td>
<td>11%</td>
<td>- Production of dental bridges, copings, crowns, caps and invisible braces</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Customized prosthetics such as hip, head or finger implants</td>
</tr>
<tr>
<td><strong>General industry</strong></td>
<td>EUR 1 bn</td>
<td>19%</td>
<td>- High usage for manufacturing inserts and tools/molds with cooling channels</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Direct tooling (tools made via AM) and indirect tooling (patterns made via AM)</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>EUR 1.3 bn</td>
<td>24%</td>
<td>- Several other industrial areas such as academic institutions, military, architectural, oil &amp; gas, space</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Consumer markets, e.g. customized design objects, collectibles, jewelry</td>
</tr>
</tbody>
</table>
Aerospace professionals are increasingly aware of, and excited about, the potential of additive manufacturing

Selected quotes from professionals and experts in aerospace

"Aerospace is among the early adopters of AM due to the lightweight potential and the higher willingness to pay for better functionality"

Head of Strategy and BD, AM equipment maker

"Additive manufacturing in Aerospace is currently at the stage where computers were in the ’80s... however aerospace justifies the prices... AM will revolutionize all manufacturing; it offers the potential to not compromise on a single material or design requirement"

Global Head of AM, Aerospace Tier 1 supplier

"There is a step-by-step process being applied to adopt AM depending on part complexity, part criticality and process qualification. [We are] starting with individual non-critical parts, eventually going towards more integrated and optimized parts and assemblies"

Production Manager, Space & Defence OEM

"Aviation is the industry with the highest maturity. When GE successfully used metal AM for its fuel injection nozzle, it motivated other companies and industries to follow the AM path. At the same time, the number of parts in series production is still small"

Former CEO, AM equipment manufacturer

"AM is ideal for low-volume parts. We are already using additive manufacturing for flying parts and tooling... eventually the AM business case will get even stronger with new materials and designs"

Senior VP of Engineering, Aero Tier 1

"AM will increase the intricacy of parts. Actuators and hydraulics, for example, are very suited to AM since complex geometries become easy to make, while reducing part count and weight"

Chief Technologist, Aerospace Tier 1

"Smaller parts (up to 400mm cubed) are rapidly being adapted for AM – many are currently in development, but coming into small batches of production... AM will be revolutionary"

Senior Engineering Consultant, Engine Manufacturer

Source: Interviews with market participants; Roland Berger
Market forces and technological changes are enabling the greater uptake of AM in aerospace

Key market drivers & trends in aerospace additive manufacturing

<table>
<thead>
<tr>
<th>Key drivers</th>
<th>Impact</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2012-16</td>
<td>2016-2022</td>
</tr>
<tr>
<td><strong>Increasing spending on aerospace &amp; defense</strong></td>
<td></td>
<td>&gt; Increased spending in commercial aerospace (due to an ever increasing propensity to travel/trips per capita) and defense (due to global geopolitical trends) are driving investment by A&amp;D companies into new technologies, including AM.</td>
</tr>
<tr>
<td><strong>Increasing efficiency requirements</strong></td>
<td></td>
<td>&gt; Advances in materials and manufacturing processes to increase fuel efficiency and range. AM offers weight reduction and geometry optimization opportunities, such as demonstrated by the GE/Safran burner fuel nozzle.</td>
</tr>
<tr>
<td><strong>Improving AM technology and costs</strong></td>
<td></td>
<td>&gt; As technology improves, larger build sizes, better material properties, and reducing production costs will increase the set of parts that are accessible for additive manufacturing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; Acquisitions of equipment companies by aerospace OEMs may further enable technology to be better adapted to aerospace going forward.</td>
</tr>
<tr>
<td><strong>Increasing design confidence</strong></td>
<td></td>
<td>&gt; As design engineers learn to &quot;design for AM&quot;, greater optimization opportunities will emerge. Increases in design know-how will originate in both universities and aerospace OEMs as both types of organization invest and learn.</td>
</tr>
<tr>
<td><strong>Increasing regulatory acceptance</strong></td>
<td></td>
<td>&gt; Airworthiness authorities have begun to adapt to the emergence of AM, with a number of parts now approved for production and service (e.g., GE/Safran burner fuel nozzle, Airbus Ti bracket).</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; As experience with in-service AM parts increases, regulatory approval can be expected to get easier.</td>
</tr>
</tbody>
</table>

Source: Interviews with market participants; Roland Berger
AM trends in aerospace

While there are promising production examples of aerospace AM, most players are observing the industry and focusing on R&D.

AM industry activity map of selected aerospace OEMs & Tier1s

> All major OEMs are currently investigating and developing AM capabilities, with >70% of OEMs having experience with AM.

> Selected industry examples:
  - GE leads the industry for total capacity and has announced plans to print more than 100k parts by 2020.
  - Safran/GE have issued a full-scale production part: the burner fuel nozzle.
  - RR, GKN, P&W and MTU have established AM competence centers.
  - Moog has bought a 20-printer facility.
  - Airbus (with its affiliates Premium Aerotec/APWorks) has selected 100s of small Ti parts (per aircraft) for AM, and has begun production for the A350.

> However, many players continue to focus on R&D and wait for the industry to mature before investing heavily.

Source: LZN; GE; company websites; Industry interviews; Roland Berger.
Several questions remain to be answered to determine how to enter additive manufacturing in aerospace

Key questions to answer when considering an AM market entry

I. Which **components or assemblies** should you focus on?
II. Which AM **technologies** are most relevant?
III. Should you **make or buy**?
IV. How can you **integrate** AM into your business?
V. Is there a compelling **business case**?

Source: Roland Berger
Companies should consider a suite of criteria – from buy-to-fly ratios to airworthiness certification – when selecting components for AM

Which components or assemblies should you focus on? (1 of 2)

<table>
<thead>
<tr>
<th>Component Attractiveness</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential for optimization</td>
<td>Highly engineered complex parts are attractive for AM and offer potential for geometry optimization with benefits such as part count reduction, manufacturing cost reduction and improved efficiency</td>
<td>Simpler part designs offer less optimization potential and may already be cost-effectively produced</td>
</tr>
<tr>
<td>Current buy-to-fly ratio</td>
<td>A high buy-to-fly ratio implies a high degree of material wastage during subtractive manufacturing – giving AM a cost advantage</td>
<td>Lower buy-to-fly ratios imply that subtractive production is already a relatively efficient production option</td>
</tr>
<tr>
<td>Component volumes</td>
<td>Low volume production is well-suited for AM due to low set up costs, a quick ramp-up rate and high customization potential</td>
<td>High volumes are less suited to AM with existing technology as AM does not offer scale benefits like conventional production</td>
</tr>
<tr>
<td>Job type</td>
<td>R&amp;D / prototyping is very well-suited for AM due to lower volumes and higher customization requirements. Other low volume / high customization jobs types – such as legacy aircraft repair or for ad-hoc in-service production – are equally well-suited for AM</td>
<td>Serial production is currently less accessible for AM due to low cost and high quality requirements – but holds the highest future potential as AM evolves</td>
</tr>
<tr>
<td>Ability to certify AM component</td>
<td>Certification authorities are currently more likely to certify lower criticality components with less of a safety and reliability requirement</td>
<td>Certification authorities will be slower to authorize higher criticality components with a greater of a safety and reliability requirement</td>
</tr>
<tr>
<td>Feasibility for AM manufacture</td>
<td>Smaller, relatively low-loaded and low criticality parts in the correct materials are well-suited for current AM technology</td>
<td>Larger, highly loaded or safety critical parts are less accessible for AM due to higher quality – and may already be cost-effectively produced</td>
</tr>
</tbody>
</table>

As technology improves and airworthiness authorities adapt to AM, market access will increase

Source: Interviews with market participants; Roland Berger
A strong component strategy prioritizes components on the basis of their attractiveness and access – and evolves with technology

Which components or assemblies should you focus on? (2 of 2)

**Indicative**

> In judging various components, companies must consider market access and a component's attractiveness for AM

> Attractiveness for AM depends on:
  - Potential for optimization through re-design (weight/cost reduction, efficiency)
  - Value/weight and buy-to-fly ratios of current manufacturing process
  - Volumes (AM is more attractive for low volumes as set-up times are low)

> Access depends on:
  - Part of lifecycle (ie: new build, MRO, legacy)
  - Job type (with current trends, AM is heavily used for development, and less so for production jobs – however, longer term potential lies in production)
  - Feasibility of manufacture by AM:
    - Nature of the component
    - Loading levels and materials involved
    - Size of component
  - Ability to certify the component AM

> As technology evolves, more and different components may become more accessible, increasing the potential for AM

**Prioritized components**

- **Misc. Titanium bracket**: Ti alloy, currently high buy-to-fly ratio makes and relatively low loading conditions make AM attractive
- **Burner fuel nozzle**: Ti alloy, already certified and in production for CFM Leap engine
- **Shroud blade segment**: Ti or IN alloy, built as assembly of multiple parts – AM offers potential to reduce part count
- **Compressor titanium blisk**: Ti alloy, currently high buy-to-fly ratio makes conventional machining expensive
- **Aluminum fuselage panel**: low potential as current manufacturing process is cost-efficient and parts are too large for existing AM machines
- **High pressure turbine blade**: Ni super alloy, AM offers reduced cost due to currently very high manufacturing complexity
- **Compressor titanium blisk**: Ti alloy, currently high buy-to-fly ratio makes conventional machining expensive

**Access**

**Attractiveness for AM**

**High**

**Low**

**High**

**Low**

Source: Roland Berger
Each AM technology offers different value propositions, with PBF by laser leading the industry's capabilities

Which additive manufacturing technologies are most relevant?

<table>
<thead>
<tr>
<th>Build principle</th>
<th>AM manuf. readiness</th>
<th>Key materials</th>
<th>Material properties</th>
<th>Post processing required</th>
<th>Build costs</th>
<th>Suppliers (selection)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBF&lt;sup&gt;1&lt;/sup&gt;</td>
<td>By Laser</td>
<td>Thermal energy by laser fuses regions of a powder bed</td>
<td>High</td>
<td>Low</td>
<td>$$$$$</td>
<td>Concept Laser, EOS, SLM, DMG MORI, Trumpf, Renishaw, Realizer</td>
</tr>
<tr>
<td>DED&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Powder by laser</td>
<td>Fusion of powdered material by melting during deposition</td>
<td>High</td>
<td>Low</td>
<td>$$ $$</td>
<td>Optomec, DMG MORI, Mazak, RPM Innovations, Trumpf, BeAM</td>
</tr>
<tr>
<td>Wire by laser/EB</td>
<td>Fusion of wire fed material by melting in carrier liquid</td>
<td>Low</td>
<td>High</td>
<td>$</td>
<td>Sciaky, Trumpf, OR Laser, Norsk Titanium</td>
<td></td>
</tr>
<tr>
<td>Jetting</td>
<td>Deposition of molten metal or metal powder to form a green part&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Low</td>
<td>High</td>
<td>$</td>
<td>Vader Systems, X-Jet</td>
<td></td>
</tr>
<tr>
<td>Extrusion</td>
<td>Dispense of material through nozzle to form a green part&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Low</td>
<td>High</td>
<td>$</td>
<td>Desktop Metal</td>
<td></td>
</tr>
<tr>
<td>Binder Jetting</td>
<td>Joining powder by bonding agent to form a green part&lt;sup&gt;10&lt;/sup&gt;</td>
<td>Low</td>
<td>High</td>
<td>$</td>
<td>Desktop Metal, ExOne, Voxeljet</td>
<td></td>
</tr>
</tbody>
</table>

1) Powder Bed Fusion  2) Electron Beam  3) Direct Energy  4) Deposition  5) Hot isostatic pressing  6) might not be needed for X-Jet process  7) Cost effectiveness potential by claim, so far no proof in context  8) VADER process (Magnetetojetting)  9) X-jet process (Nanoparticle Jetting)  10) Green parts have low material bonding and require a post-processing sintering heat treatment

Source: Company information; Expert interviews; Roland Berger
It is cheaper, but more risky, to outsource additive manufacturing; the leading OEMs have a significant "make" position.

Should you make or buy?

<table>
<thead>
<tr>
<th>Make</th>
<th>Buy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages for AM applications</strong></td>
<td><strong>Disadvantages for AM applications</strong></td>
</tr>
<tr>
<td>&gt; Greater control over product lifecycle, certification process, and associated intellectual property</td>
<td>&gt; Greater upfront expense</td>
</tr>
<tr>
<td>&gt; Greater profit margin</td>
<td>&gt; Potentially longer timeframe required to develop capability and achieve payback</td>
</tr>
<tr>
<td>&gt; Internal R&amp;D and talent development allows internal cross-pollination</td>
<td>&gt; Requirement to delegate authority, share risk/revenues</td>
</tr>
<tr>
<td></td>
<td>&gt; Potential for developed capabilities to be shared with competitors via supplier</td>
</tr>
</tbody>
</table>

"As the technology matures, most companies are choosing to do a mix of in-house and external development. Eventually the make-buy situation will be the same as it is today for regular manufacturing – even if in the short term things may be quite complex with multiple companies doing different things."

CEO, mid-sized AM supplier

Strategies adopted by aerospace incumbents

<table>
<thead>
<tr>
<th>GE</th>
<th>AIRBUS</th>
<th>SAFRAN</th>
<th>MTU</th>
<th>Rolls-Royce</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; GE is focusing on developing in-house capabilities, through acquisitions and investment in AM capacity</td>
<td>&gt; Airbus has developed a make-buy strategy, working with AM suppliers on development for most parts, making the decision on a part-by-part basis – with most divisions buying their AM components</td>
<td>&gt; Safran has chosen to keep the most strategic parts in-house, while outsourcing less critical components</td>
<td>&gt; MTU is currently not outsourcing any AM work, but may consider outsourcing manufacturing only</td>
<td>&gt; Rolls-Royce’s make-buy matrix:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>License</th>
<th>Make in-house</th>
</tr>
</thead>
<tbody>
<tr>
<td>Many</td>
<td>Few</td>
</tr>
<tr>
<td>Outsource and encourage supplier competition</td>
<td>Control production through JVs and/or LTAs</td>
</tr>
</tbody>
</table>

"As the technology matures, most companies are choosing to do a mix of in-house and external development. Eventually the make-buy situation will be the same as it is today for regular manufacturing – even if in the short term things may be quite complex with multiple companies doing different things."

CEO, mid-sized AM supplier

Source: Interviews with industry experts; Roland Berger
Companies will have to adapt their business quickly to benefit fully from a transition to additive manufacturing.

### How can you integrate AM into your business?

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>How will you recruit the right talent?</td>
<td>With universities and research institutions not much further ahead than aerospace companies, engineering education has not caught up with additive manufacturing design techniques. It is thus difficult to recruit in AM talent and companies must become adept at developing it in-house.</td>
</tr>
<tr>
<td>How do you adapt your factories for AM?</td>
<td>Parts manufactured – under current technologies – with AM have very different pre- and post-processing requirements, as well as validation/measurement requirements, as compared with conventional manufacturing. A future AM-focused manufacturing line will necessarily look very different from today’s factories, with different levels of automation, factory layouts, and maintenance needs.</td>
</tr>
<tr>
<td>What software will you use?</td>
<td>As the relatively slower-paced aerospace industry catches up to modern levels of software use (from design, to manufacturing, to fleet management), companies will have to rapidly pivot to AM-friendly tools, such as for PLM software.</td>
</tr>
<tr>
<td>How will AM fit into your supply chain?</td>
<td>With different qualification and certification requirements, companies will need to invest in AM-specific processes – and potentially invest in educating suppliers on how to deal with AM parts.</td>
</tr>
</tbody>
</table>

Source: Roland Berger
Throughout the process, companies must constantly question their decisions and analyze the strength of their business case.

Is there a compelling business case?

### Component strategy
- What are the end-market size and growth rates?
- Do you have or can you gain access to the right material suppliers?
- Do you have or can you gain access to the best customers?
- What will be your competitive advantage in the market?
- What are the product-level profit margins and unit economics?
- What volumes can be expected?
- Have you considered the financial impact of technological safety and reliability risks?

### Technology selection
- Can you afford the technology that meets your quality requirements?
- Have you set up a support agreement from the AM equipment company?

### Make-buy decision
- If you choose to make, can you afford the upfront investment? What is the payback period?
- If you choose to buy, can you set up a long-term supplier agreement?
- Are there other options available, eg: can you set up a joint venture?

### Business integration
- How much factory space will you need? How will this impact the rest of your production?
- Do you have the brand reputation and reach to recruit the right talent?
- What synergies can you generate with your existing business?

---

Aspire and work towards a strong business case. A successful business in aerospace should aspire to:

- A 3-5 year payback period
- A 15-20% and higher profit margin
- Meet – and beat – stock market and investor expectations

Source: Interviews with industry experts; Roland Berger
B. Your way forward into additive manufacturing
Roland Berger has built a comprehensive approach to develop your additive manufacturing footprint

Your potential next steps with Roland Berger

**DESIGN** your component strategy

- **Prioritize** components based on AM attractiveness and access
- **Evolve** with changing technology

**SELECT** the right technology and supplier

- **Find** the right quality-cost mix
- **Develop** a supplier relationship
- **Ensure** your IP is secure

**DECIDE** whether you should make or buy

- **Decide** on your risk-revenue tradeoff – and whether you should operationalize or capitalize AM

**DECIDE** how you will adapt your business

- **Prepare** your recruiting, IT, manufacturing and procurement departments
- **Develop** your cultural change management strategy

**ENSURE** you have a strong business case throughout

- **Make** the business case a core part of your decision making
- **Consider** availability and cost of funding, as well as your investment payback period
- **Encourage** and enable cost and revenue synergies with your larger business

**IMPLEMENT**

- **Design** development
- **Training**
- **Material selection & qualification**
- **Factory planning**
- **Software transition**
- **Delivery and support**

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However far you are into your additive manufacturing journey, Roland Berger is here to support you and can start the project at any stage

Source: Roland Berger
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Source: Roland Berger
C. Overview of Roland Berger
Roland Berger can leverage its global expertise in aerospace & defence, and additive manufacturing

Roland Berger added value

1. **Leading global management consulting firm** of European origin, with rapid international expansion

2. **Global expertise in aerospace & defense**, with a dedicated team of more than 30 seasoned professionals worldwide

3. **Deep functional know-how in aerospace & defense**, acquired through a wide range of projects for various players along the value chain (OEM, suppliers, financial investors)

4. **Cutting edge expertise in additive manufacturing**, working at the vanguard of technology development in industries including aerospace, medical, automotive and tool making

Source: Roland Berger
Roland Berger is the only leading global consultancy of European origin

Roland Berger at a glance

- Founded in 1967 in Germany by Roland Berger
- 50 offices in 34 countries, with around 2,100 employees
- Nearly 220 Partners currently serving over 1,000 international clients
- Broad spectrum of services based on 3 solid pillars: Knowledge, Technology, Capital
- Terra Numerata™ digital ecosystem joining forces with more than 30 leading digital firms
- Global Expert Network of 500 industry specialists

Source: Roland Berger
In addition to our European heritage, we have significant experience in emerging markets, particularly in Asia and Africa.
We have broad expertise in Engineered Products & High Tech industries combined with functional know-how.

**Joint teams**

**Joint solutions**

**Industry**
- Automotive
- Consumer Goods & Retail
- Energy & Chemicals

**Function**
- Corporate Development
- Information Management
- Marketing & Sales
- Operations Strategy
- Restructuring
- Corporate Finance

**Thorough understanding of the industry and its major players**

**Strong networks within EPHT client industries**

**Creative functional solutions and approaches**

**Complementing industry know-how with functional expertise**

Source: Roland Berger
We support aerospace & defense clients with strategic and operational transformations

<table>
<thead>
<tr>
<th>Strategy/M&amp;A</th>
<th>Global A&amp;D Practice</th>
<th>Operations</th>
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<tbody>
<tr>
<td>&gt; Corporate strategy and portfolio management</td>
<td>&gt; 30+ senior industry experts</td>
<td>&gt; Post merger integration</td>
</tr>
<tr>
<td>&gt; Services and support development strategy</td>
<td>&gt; Coverage of civil and defense sectors</td>
<td>&gt; R&amp;D efficiency/product policy and innovation</td>
</tr>
<tr>
<td>&gt; Marketing/business capture</td>
<td>&gt; Adept at working with top management and operational teams</td>
<td>&gt; Program management efficiency</td>
</tr>
<tr>
<td>&gt; Mergers &amp; acquisitions/alliances</td>
<td>&gt; Expertise of the industry's core and functional processes</td>
<td>&gt; Supply chain optimization</td>
</tr>
<tr>
<td>&gt; Corporate/BU organization redesign</td>
<td>&gt; Experience based on more than 30 projects p.a. since 2000</td>
<td>&gt; Purchasing and supplier management optimization</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt; Manufacturing performance optimization</td>
</tr>
</tbody>
</table>

Source: Roland Berger
Our A&D practice lives the passion for the industry working with industry leaders and operational teams on a global basis.

**Senior Core Team of Roland Berger’s Global Aerospace & Defense Practice**
We were among the first movers into key A&D growth markets and have built a significant footprint and successful track record.

Our capabilities and references in the Americas and Asia

**Americas capabilities**

- **Team of ~150** partners and consultants
- **Strong offices** in the US/Canada and Brazil plus project offices (on demand) in all major markets
- **Strategic partnership** with Renaissance Strategic Advisors with a focus on the US defense market

**Asian capabilities**

- **Strong presence** in China for more than 35 years
  - With five offices Roland Berger is ranked as the leading consultancy in Greater China
  - Team of ca. 300+ dedicated consultants with a strong local expertise; dedicated A&D team
- **Strong focus on Aerospace & Defense in India**
  - Only top tier consulting firm in India with specialist A&D expertise and 40+ Consultants
  - Strong exposure to the defense industry and government: Track record of delivery with OEMs, suppliers, local companies and government
  - Specialist know-how on offset and working with top national political leadership to define key defense procurement policy changes
- **Middle East team** with ~60 partners and consultants

Source: Clients, Roland Berger
For example, in India, we are one of the strongest teams in the A&D sector advising Western and Indian players as well as Governments

Zoom on Roland Berger India – credentials in Aerospace and Defense

1. **India Defense Bid**: Supported India's largest conglomerate to bid on a USD 20 bn programme – Largest ever programme issued in India

2. **India Strategy**: For all operations of the world's largest aerospace company – strategy across functions and products including investment plans

3. **India Defense Transformation Plan**: for the Honorable Prime Minister of India – all aspects of national strategy for the sector including FDI, focus areas, export promotion, etc.

4. **Offset structuring of over EUR 4 bn**: Including offset strategy for some of the largest military procurement programmes in India

5. **India Defense Export Strategy**: for the Ministry of Commerce and Industry – definition of the blueprint of A&D exports for next 10 years

6. **Acquisition Linked Transaction Advisory**: for the largest A&D acquisition transaction in India related to a major port asset

> Our Indian team has strong exposure of working with the defense industry and government

> Our local Partner, Rahul Gangal, is currently the only industry representative on the apex A&D co-ordination committee

> We are known for our specialist know-how and are currently working with top national political leadership to define key procurement policy changes

> State governments we are currently engaged with: Maharashtra, Andhra, Gujarat

Source: Roland Berger
Our insights are based on a deep understanding of the industry across the entire value chain.

Clients in the Aerospace & Defense industry – non-exhaustive

OEM/prime contractors

Tier-1 players

Governments/institutions

Source: Roland Berger
We deliver tangible results – broad range of topics covered in projects in the aerospace & defense industry

Recent project experiences – Extract

### Strategy & M&A
- Growth strategy for a leading global defense OEM
- M&A target screening in the field of cyber security
- Benchmarking of satellite manufacturers
- Growth options for a tier-1 supplier
- Strategic review in the field of cabin interiors
- Strategic review of an aero structures tier-1
- Strategic plan for a new business of an A&D tier-1
- Strategic review of an A&D engineering service provider
- Securing of a strategic bid for a systems integrator
- M&A scenarios for a tier-1 in aero structures
- Due diligences for private equity funds on A&D tier-1s, tier-2s, MRO and engineering service providers

### New collaborative models
- More than 15 joint improvement plans between an aircraft OEM and a tier-1 on key critical development programs
- Design of collaborative business models
- Implementation of supplier support in aircraft manufacturer FAL to support ramp-up
- Supply chain readiness for industrialization for a major systems provider
- Design of convergence plans between OEMs and tier-1s
- End-to-end process optimization between suppliers and tier-1s

### Support and services
- Development of digital services for a major defense electronics company
- Growth strategy in the field of digital imaging
- Strategic reviews/growth plans in the areas of support and services
- Market assessment for a new service offering to airlines
- Development of support & services offer for a key military program
- Set-up of joint ventures in the area of support and services
- Post merger integration in services business for an aerospace platformist
- Ramp-up of MRO activities for an OEM
- Optimization of tech pub function

### Operations
- Comprehensive cost reduction program for a leading rotorcraft OEM
- (Re)design-to-cost projects for OEMs and tier-1s
- Industrialization and manufacturing ramp-up preparation
- Manufacturing footprint optimization projects incl. site relocation and ramp-up planning
- Deployment of a modular platform policy for a leading cabin supplier
- Full strategic and operational review of an engine manufacturer
- Transformation plans for aerostructure tier-1s
- Recovery plan to meet entry into service planning
- Marketing & sales optimization for a tier-1 supplier
- Engineering efficiency plan for a leading aircraft OEM

### Program management
- Recovery plan for a military helicopter program
- Ramp-up securing plan for a large tier-1 systems supplier
- Recovery plans at different stages in civil and military aeronautics
- Optimization of planning on a major aeronautics program
- New planning principles for a military aircraft manufacturer
- Impact assessment of planning drift on a space program
- Recovery plan to reach technical performance target on a major aeronautics program
- Cost @ completion optimization project
- Deployment of a program management function at a major tier-1
- Design and set up of a program management function for an emerging market player

### Organization
- Review of the organization of a defense OEM
- Optimization of the marketing & sales organization of a leading defense player
- Harmonization of engineering competence models and organizations in a post merger context
- Benchmarking of support & services organizations in aerospace and adjacent industries
- Organization of supplier management (engineering and industrial activities)
- Plateau organization in FAL to support industrial ramp up
- Reorganization of the finance and control function
- Reorganization of the engineering center of excellence of a space player
- International engineering footprint strategy

Source: Roland Berger
We continuously publish on key industry topics of interest for our clients.

Recent studies and knowledge building – Extract

- Management issues radar Study
- High Value Design for aircraft Study
- European A&D industry Study
- Digital transformation Study
- Cyber security Point of view
- Cyber security in A&D Point of view
- Global aerospace supply chain Speech
- Digital aerospace supply chain Speech
- Industry 4.0 in Chinese aviation Speech

Source: Roland Berger
In AM, we stand in close exchange with industry experts – our publications are highly valued by the global AM community

Publications and speeches (selection)

Print publications

Study 2013

Study 2016

> 3D Printing Inspires Imagination
   (Frankfurter Allgemeine Zeitung)
> Smooth Printing (VDI Nachrichten)
> Additive Manufacturing (VDW)
> 3D Printing with Metallic Structures on the Threshold of Serial Production
   (Economic Engineering)
> Additive manufacturing on its way to industrialisation
   (Cecimo magazine)
> Introduction to Additive Manufacturing Technology (EPMA)
> 3D-Printing (medizin & technik)

Opening day keynote speech

Further speeches

> Inside 3D Printing
> European Powder Metallurgy Association (European Congress)
> VDMA High Pressure Die Casting Manufacturers Meeting
> RapidTech

1) Presentation by Bernhard Langefeld (Roland Berger partner) at Formnext 2016
( Formnext is one of the world’s leading exhibition and conference on the future of manufacturing technology)

Source: Roland Berger
Our project experience in the field of AM is wide reaching, from strategy development, potential assessment and M&A projects.

Selection of references of additive manufacturing-focused projects

**AM industrialization strategy**
Development of an AM industrialization strategy ("make" vs. "buy") for a turbine manufacturer

**Potential assessment in mold making**
Technology scouting for the tool making division of a large consumer goods manufacturer

**AM serial concept development**
Identification of suitable production parts and AM manufacturing process design for an IGT supplier

**Market strategy for ceramic AM**
Strategic analysis and market entry options setting for turbine blade production for an engine Tier 2 supplier

**Analysis of AM equipment market**
AM equipment market assessment for a major powder supplier, and identification of acquisition targets

**AM component manufacturing growth**
Market entry strategy for a large powder and materials technology specialist into Medtech/IGT/Aero

**Commercial DD on AM equipment maker**
Market and competitive assessment of an acquisition target in the AM equipment market for a PE fund

**Commercial DD on AM part manufacturer**
Market dynamics and competitive analysis for core verticals Medtech/Auto/Aero

Source: AIRBUS APWORKS (Photo); Roland Berger
50 YEARS

navigating complexity