Manufacturing’s Evolution and Its Impact on Titanium for Aerospace

Program:

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President

ITA Fall Conference – Las Vegas, NV
Presentation will answer four fundamental questions

Why is aerospace unique in terms of materials and manufacturing?

What is the current state of aeromaterial demand?

What are the key manufacturing trends for commercial aerospace?

How will these technologies impact titanium demand?
General Market Structure

Prevailing Technologies
Fundamental differences between aviation and automotive help define their manufacturing strategies.

### Aerospace vs Automotive Industry

<table>
<thead>
<tr>
<th>Category</th>
<th>Aviation</th>
<th>Automotive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units Produced:</td>
<td>5 thousand*</td>
<td>60 million</td>
</tr>
<tr>
<td>Part Count:</td>
<td>2.5 million</td>
<td>30 thousand</td>
</tr>
<tr>
<td>Unit Size:</td>
<td>100 to 200 ft²</td>
<td>5 x 15 ft</td>
</tr>
<tr>
<td>Design Objective:</td>
<td>Airworthiness</td>
<td>Crashworthiness</td>
</tr>
<tr>
<td>Quality Drivers:</td>
<td>Product integrity</td>
<td>Production integrity</td>
</tr>
<tr>
<td>Supplier Base:</td>
<td>Oligopoly</td>
<td>Globally competitive</td>
</tr>
</tbody>
</table>

* Commercial turbine aircraft

Source: analysis, secondary
During past two decades, aerospace has experienced a shift in materials and associated manufacturing methods.

**Aircraft Material Evolution**

**Empennage:**
- Typically carbon composite

**Fuselage:**
- Historically aluminum sheet, & extrusion assembly
- Increasingly carbon composites

**Wing:**
- Historically aluminum plate & extrusion assembly
- Increasingly carbon composites

**Engine:**
- Historically superalloy and titanium
- Increasingly non-metal composites

**Landing Gear:**
- Historically high strength steel
- Increasingly titanium (for wide bodies)
Total aerospace material demand is roughly 1.7 B lb – titanium is approx. 11%, and is forecasted to increase 4% per annum.

Aerospace Raw Material Mill Demand, 2018 (1.7 B lbs)

<table>
<thead>
<tr>
<th>Application</th>
<th>Predominate Alloy</th>
<th>Year introduced</th>
</tr>
</thead>
<tbody>
<tr>
<td>95% aerostructure</td>
<td>NA</td>
<td>1970s</td>
</tr>
<tr>
<td>45% aerostructure</td>
<td>75% 6-4</td>
<td>1950s</td>
</tr>
<tr>
<td>95% engine</td>
<td>65% IN718</td>
<td>1940s</td>
</tr>
<tr>
<td>60% aerostructure</td>
<td>25%/25% 15-5/300M</td>
<td>1960s</td>
</tr>
<tr>
<td>90% aerostructure</td>
<td>60% 7050/7010</td>
<td>1940s</td>
</tr>
</tbody>
</table>

* 10-yr CAGR 0%

Source: ICFI (graph, modified), interviews, analysis
Over past two decades, advances in CNC machining have changed traditional approach to manufacturing components

Design and Production Considerations

Aerostructure: Movement towards larger “monolithic” structures to reduce part count and weight*

Engine: Increased machined tolerances for components for greater operational efficiency*

Both: More near-net shape: hard alloys are difficult to machine, and scrapping parts is expensive (titanium forgings $100Ks)

A key enabler is increasing five-axis CNC machining

* Predominant but not exclusive to category
Most constraints in titanium supply chain appear downstream – particularly involving special processes – both for aerostructures and aeroengine.

Titanium Supply Chain Schematic

Industry invested $5B from 2005-2009 in melt capacity – yet is likely now operating at capacity – especially given complications at TIMET UK.

* Close die forging estm. as 60% of total Ti demand.
There are four technologies driving aerospace manufacturing – all digitally enabled

Four Fundamental Technologies in Aerospace

Automation

Digital Connectivity

Laser Fabrication

Additive Manufacturing
Automation has three basic subcategories – most prominent of which is carbon fiber placement

1 Automation

Most Prevalent Forms of Automation*

- **Automated Tape Laying** or **Fiber Placement** is the most prominent area of automation.
- Second most significant is **robotic drilling** and fastening for metallic structures.
- Third area is small scale with **automated pallet** systems and robotic CNC tool exchange.

* Part of the justification is aging workforce.

Source: interviews, secondary
Laser fabrication is becoming increasingly more common in aerospace due to its high precision

2 Laser Fabrication

- Three most common laser fabrication techniques are: **welding**, **cutting** and **drilling**
- Welding is used to mate materials when a minimal *heat effect zone* is required, thus reducing embrittlement
- Cutting is used for metal, polymers and some ceramics
- Drilling is used for extremely small holes, such as the cooling channels in investment casted blades
Metal additive manufacturing has become incredibly popular, yet actual applications are lagging.

Additive manufacturing or “3D printing” is the process of adding material – as opposed to removing material – to create a structural part.

Ultimate benefit is ability to “lightweight” a part, as known as topology optimization.
Digital connectivity is impacting most areas of manufacturing, with varying degrees of success

Examples of Digital Connectivity

- Phrase “Industry 4.0” originated in Germany in 2011
- Is less widely adopted in aerospace than in other industries mainly due to scale/complexity
- Other common terms are IIoT (Industrial Internet of Things) and Computer-integrated Manufacturing
- One US-base related initiative is MTConnect
Additive manufacturing will likely have greatest impact on future titanium consumption, although its extent and timeline are not well understood.

Technology’s Impact on Supply Chain

<table>
<thead>
<tr>
<th>Automation</th>
<th>Laser Fab</th>
<th>Additive Mfg</th>
<th>Digital Conct</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impacted:</strong></td>
<td>Airframe OEM</td>
<td>Engine OEM</td>
<td>OEM</td>
</tr>
<tr>
<td></td>
<td>Tier 1</td>
<td>Tier 1</td>
<td>Tier 1</td>
</tr>
<tr>
<td></td>
<td>Tier 2</td>
<td>Tier 2</td>
<td>Tier 2</td>
</tr>
<tr>
<td></td>
<td>----</td>
<td>----</td>
<td>Tier 3</td>
</tr>
<tr>
<td><strong>Comments:</strong></td>
<td>Capital intensive, scale is important</td>
<td>Focus is detailed parts fabrication</td>
<td>Consolidation of parts/assemblies</td>
</tr>
<tr>
<td><strong>Titanium Demand:</strong></td>
<td>N/A</td>
<td><strong>Moderate Increase</strong></td>
<td><strong>Decrease</strong></td>
</tr>
</tbody>
</table>

* Bold (primary), gray (secondary)
Aerolytics LLC - Aerospace Analytical Market Research & Consulting

materials, manufacturing and supply chain for aerospace

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