GE Aviation

Titanium Utilization & Vision For The Next Decade: An Aircraft Engine OEM Perspective

David Linger
September 16, 2009

Aviation Ti-Team
Jon Blank       Mike Peretti
David Linger   Andy Woodfield
Eric Ott
Agenda…

• Business Update
• Material Trends & Case Study
• Novel Ti Manufacturing
• Additive Manufacturing
• A Perfect Storm…
• Supply Chain
A global provider of engines, systems and services

Segments
- Commercial
- Military
- Business & General Aviation
GE Aviation portfolio … $19.2B

Commercial engines

'08 Revenue $5.2

Commercial engine services

$6.8

Military engines & services

$4.2

Systems

Business & General Aviation

'08 Revenue $5.5

Unison Engine Components

'317

A leading aviation technology business
### Commercial outlook … strong

#### Commercial engines

- Most popular on regional … \( \text{1,230} \) engine backlog
- Most popular on single-aisle … \( \text{5,850} \) engine backlog
- Most popular on Boeing 787 … \( \text{730} \) engine backlog
- Most popular on wide-bodies … \( \text{2,300} \) engine backlog

#### Commercial installed base

<table>
<thead>
<tr>
<th>Year</th>
<th>CFM</th>
<th>GE</th>
<th>EA</th>
</tr>
</thead>
<tbody>
<tr>
<td>'97</td>
<td>5,200</td>
<td>4,500</td>
<td>8,300</td>
</tr>
<tr>
<td>'07</td>
<td>13,300</td>
<td>8,300</td>
<td>14,000</td>
</tr>
<tr>
<td>'17F</td>
<td>22,400</td>
<td>14,000</td>
<td>14,000</td>
</tr>
</tbody>
</table>

Source: CASE, GE internal studies

GP7000 developed by GE/P&W Engine Alliance

CFMI is a 50/50 joint company between GE and Snecma.
Material Trends…

- Composites
- Titanium
Gamma TiAl Turbine Blades – World’s First Certified Intermetallic Material Application
Material Options...

Gamma TiAl ~ 50/50 Ti and Al
- Ti – good to ~ 550C
- Al – good to ~ 250C
Gamma TiAl – good to ~ 800C

It’s a miracle!!!
LPT Blade Manufacturing Sequence

Casting Ingot Production
- Melt and cast parts
- Pre HIP Solution
- HIP

Post HIP Heat Treat
- X-ray/FPI (repair as necessary)

Machining and coating

LPT Assembly
Pre Introduction Test Components

All three cast gamma components successfully machined and engine tested.
Novel Manufacturing...
BlueArc™ ECDM Rapid Roughing…

A new high speed electro-erosion process:

- Simultaneous Discharge/arcing
- High Current
- Abundant Flushing
- Added relative interelectrode surface motion for process stability improvement

Achieved 4X cycle time/75% tooling cost reduction as compared with the mechanical milling

Rapid material removal rates, 5-15 in³/min, with low HAZ, 0-5 mil.
Projection Welding of Bosses

Solid state fabrication process for hollow bosses/ports…
Bulk Deposition Technologies…

- Spray Casting-
- Metal Injection Molding-
- Electron Beam Melting-
- Cold Spray-
- Metal Powder Laser Sintering-
Feature Deposition Technologies...

- Plasma Transferred Arc Solid Free Form Fabrication-

- Electron Beam Free Form Fabrication-

- Laser Net Shaped Manufacturing-
History Tells Us…
The emergence of aluminum in the market

Pre-1852 Hall-Heroult & Bayer Processes

Revolutionized aluminum production from a precious metal to a common material.

1886 Hall-Heroult Process - Aluminum smelting
1888 Bayer Process - Alumina extraction from ore

Average Price (2006$/lb)

Demand (Metric Tonnes)

1 $/lb
4 $/lb
9 $/lb
350 $/lb
>10,000 $/lb

1852-1885
1886-1914
1919-1967
1967-2005

2005 $/lb
4 $/lb
9 $/lb
350 $/lb
10,000 $/lb

Average Price (2006$/lb)
Meltless Ti Alloy Powder is…

- Alternative to Ti sponge - lower cost, higher quality, and more versatile
- New breakthrough chemical and electrochemical powder synthesis
- Vital for more efficient downstream processing
- Enables new novel Ti alloys
-Accelerates & broadens use of direct metal powder consolidation

The Vision for Meltless Ti …
Meltless Ti Alloy Eco Benefits

- 2/3 Less Energy Consumption
- 50% Less CO₂ emissions
- Processing infrastructure
- Transportation energy

GE Aviation
Annual Energy Savings

Material Synthesis
>341 billion BTU/yr.
* benefit vs. Kroll thru billet

Component Processing
>55 billion BTU/yr.
* Assuming only 20% yield

Product Use
0.2-0.5% Specific Fuel Consumption
Novel Meltless Alloys

Meltless Ti

Meltless Novel Titanium Alloys

Meltless Ti approach enables revolutionary new alloys and capabilities

Kroll Ti + Melting
New Capabilities = Market Growth
<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Booster spool and blades</td>
<td>CP Ti</td>
</tr>
<tr>
<td>HPC spool disks/blades</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Outer duct (Military)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Engine mount</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Outer turbine static parts (Military)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Ti HPC case / vanes</td>
<td>CP Ti</td>
</tr>
<tr>
<td>MLE</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Tip cap</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Trailing edge</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Fan disks (not visible)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Fan case (Military)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Fan frame (not visible)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>Bearing housing (not visible)</td>
<td>CP Ti</td>
</tr>
<tr>
<td>HPC disks/blades further back in compressor</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
<tr>
<td>Nozzle case (Military)</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
<tr>
<td>Afterburner case (Military)</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
<tr>
<td>Tail cone (not visible)</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
<tr>
<td>Heat shield</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
<tr>
<td>Tubing/Ducts (Military)</td>
<td>CP Ti/Ti-64/Ti-3.2.5</td>
</tr>
</tbody>
</table>
Novel Ti Alloy Enables Expanded Use

• Weight Ti Cases
  - Replace steel cases
  Lower stator weight
  Improved clearances

• Temperature Ti Disks/Shafts
  - Replace Ni/steel components
  Lower rotating weight
  Lighter stator weight
  Improved designs

• Temperature Ti Airfoils
  - Replace Ni/steel blades/vanes
  Lower rotating weight
  Lighter stator weight
Meltless Ti Alloy Technology
A New Titanium Supply Chain

Material Synthesis
- Efficient chemical processing
- Direct alloying

Component Processing
- 40% improvement in material yield
- 50% reduction in process steps

Substitute mill products
- 50% less mfg cost

Net shape processing
- 75% less mfg cost

Novel alloys
- enhanced properties
Thank you!