Titanium Trends and Usage in Commercial Gas Turbine Engines

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This slide contains no technical data

What is the Future of Aerospace Titanium?

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- Fuel represents ~50% Of airline costs
  - Engines provide significant opportunity for fuel burn reduction
  - Composite airframes also contribute to performance improvements
- Improved efficiency objectives are driving cycle and architecture requirements challenging Ti engine usage
- Airframe applications driven by composite compatibility promoting Ti usage

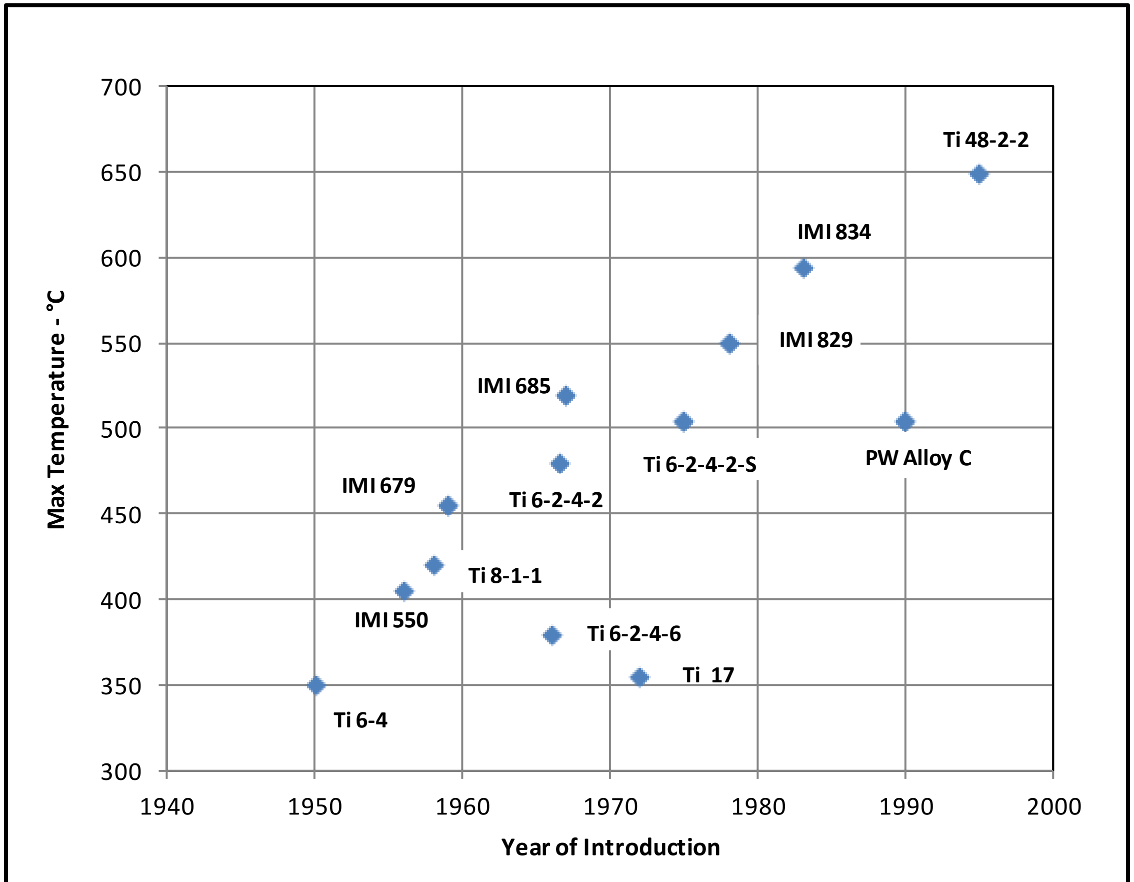
Ti research focus – affordability then performance
…is it the right balance?

Outline

- Historic Titanium Usage
- Trends in Engine Architecture & Cycle
- Impact to Material Usage
- The Challenge - Material Requirements for Next Generation Engines

Historic Titanium Usage

Titanium historically limited by Alpha Case and compressor fire potential (& cost)



Alpha Case
(time dependent)

Ti Fire
(pressure dependent)

Adapted from *"Developments in High Temperature Titanium Alloys"*
Blenkinsop, P.A. Titanium Science & Technology 1984

Titanium Usage – Last Century

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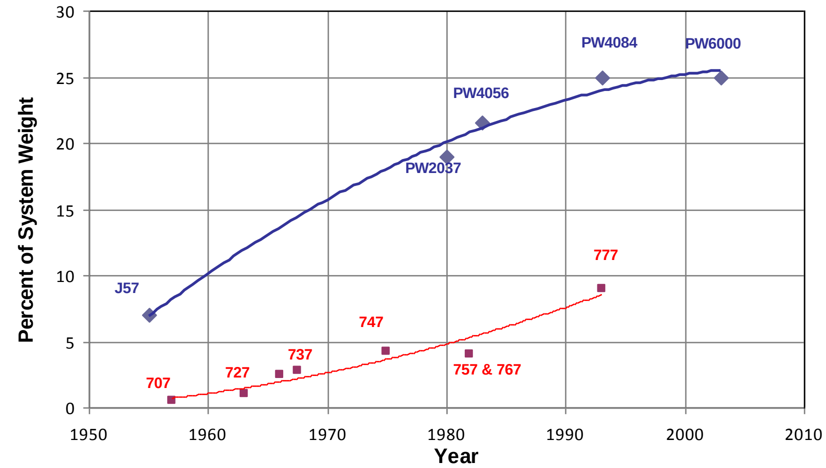
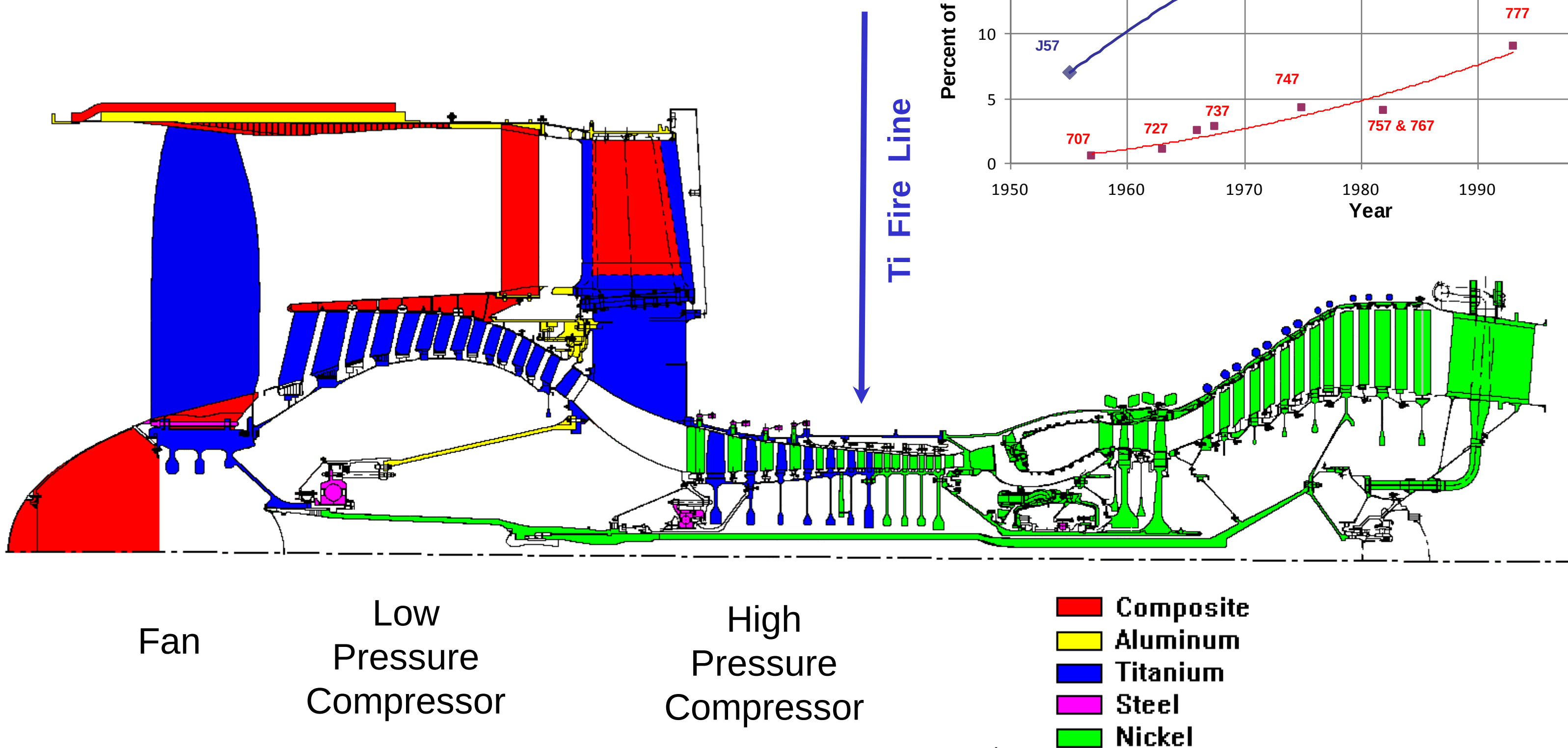
PW 4000 materials of construction

- Titanium ~25% by weight





Increasing Temperature, Pressure

Engine Efficiency Drivers

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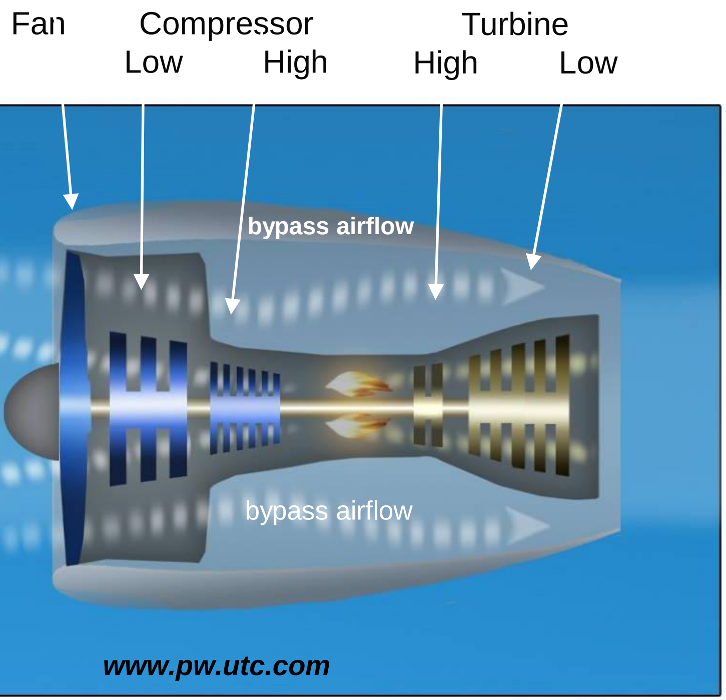
Overall efficiency = Propulsive efficiency x Cycle efficiency

Conventional Turbofan



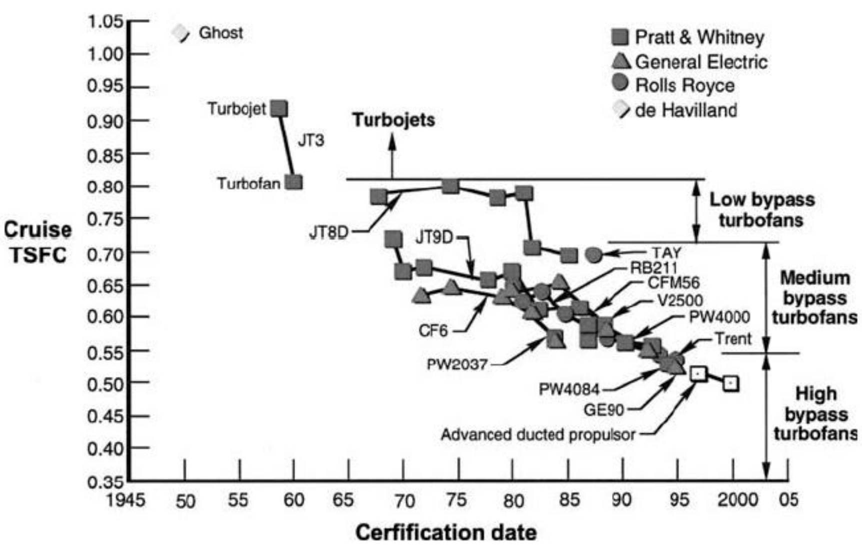
Bypass Ratio = Bypass Airflow / Core Airflow

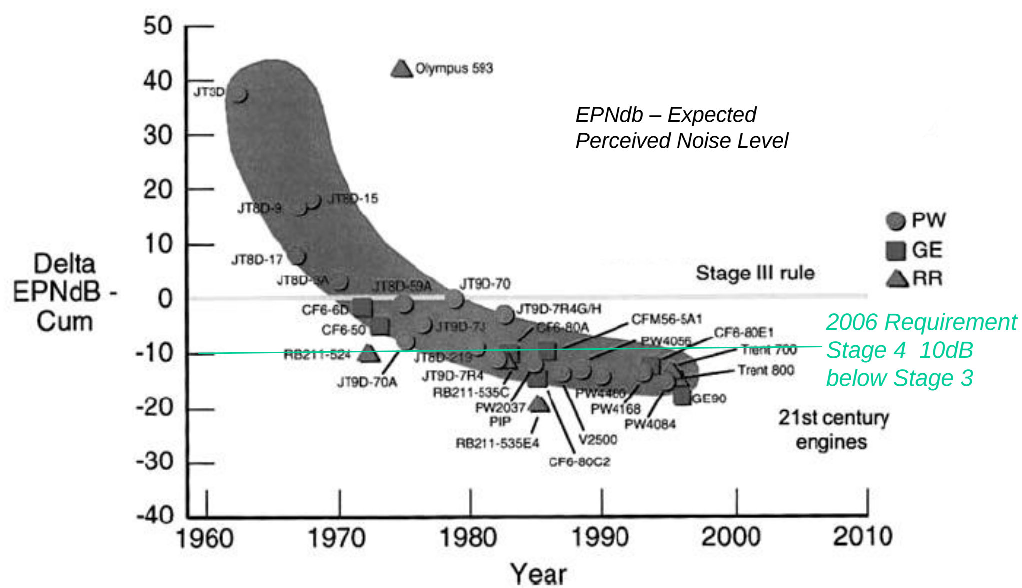
- **Propulsive efficiency**: Driven by increased bypass ratio
  - Higher bypass ratio → larger diameter fan
  - To maximize benefits of a large fan:
    - Need hollow titanium or composite fan blades
    - Need light weight composite static structure
- **Cycle efficiency**: Driven by higher pressure ratio and higher turbine inlet temperature
  - Higher pressure ratios require higher temperature capability in the high pressure compressor
  - Higher turbine inlet temperatures require higher temperature turbine materials and coatings.

Bypass Ratio Drives Efficiency & Noise

As bypass ratios increases

- Thrust Specific Fuel Consumption (TSFC) and noise decrease





Gas Turbine Technology Evolution: A Designer's Perspective
Bernard L. Koff
TurboVision, Inc., Palm Beach Gardens, Florida 33418
JOURNAL OF PROPULSION AND POWER
Vol. 20, No. 4, July–August 2004

Compressor Temperature Trend

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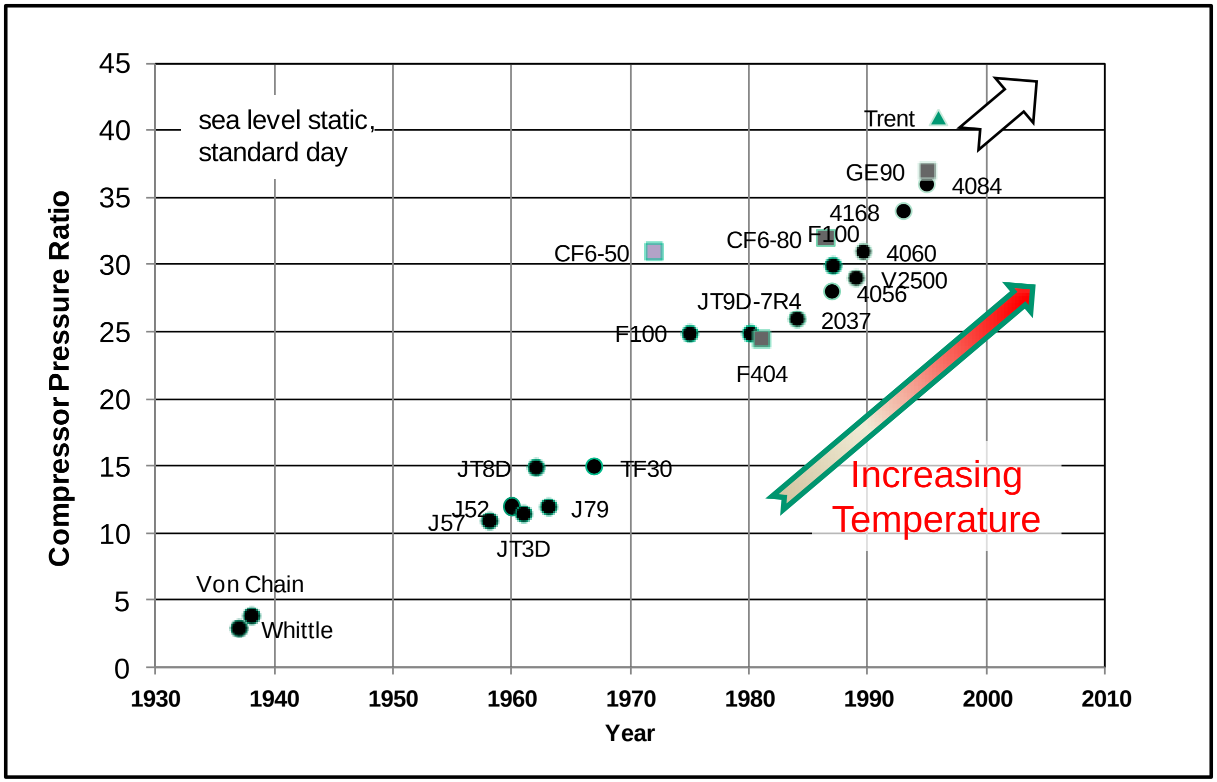
Engine efficiency increases as compressor pressure ratios increase.
Compressor temperature increases with pressure.



"As the operating temperature of turbine engines increases, titanium will struggle to maintain its foothold in aircraft high pressure compressor disks."

- G.Vroman, Sr. VP, ATI-Ladish, from American Metal Market,*1998*

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Engine Changes – Material Impacts

Engine architecture and cycles driving material changes away from titanium:

- Bypass Ratios Increasing = Larger Diameter Fans
  - Organic matrix composites (OMCs) replacing Ti in fan blades and containment cases
- Compressor pressure ratios increasing = Hotter compressors and turbines
  - Transition to integrally bladed rotors results in material selected by gas path requirements
  - Nickel replacing titanium in earlier stages of the high pressure compressor (HPC)
  - High temperature turbines reduce stages where gamma alloys work
- Core diameters are decreasing
  - The volume (size) of Ti & Ni components is decreasing

Bypass Ratio & Fan Blade Materials

Materials play a key role in enabling higher bypass ratios by enabling larger diameter light weight fans.

1960 - 1980s
Solid Ti

JT3D
BPR = 1.3

1990s
Hollow Ti

PW 4084
BPR = 6.4

2000s
Composite

GE 90
BPR = 9

2010s
Composite / Hybrid Metallic

PW 1524G
BPR = 12

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Bypass Ratio & Fan Case Materials

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Solid steel and titanium fan containment cases being replaced by Kevlar composite and all composite designs to reduce weight.

1980s

PW 4056
BPR = 4.8
Solid Steel

1990s

V2500
BPR = 4.5 - 5.4
Solid Titanium

2000s

GP7200
BPR = 8.8
Kevlar/Aluminum

2010s

PW1524G
BPR = 12
Composite

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Engine Changes

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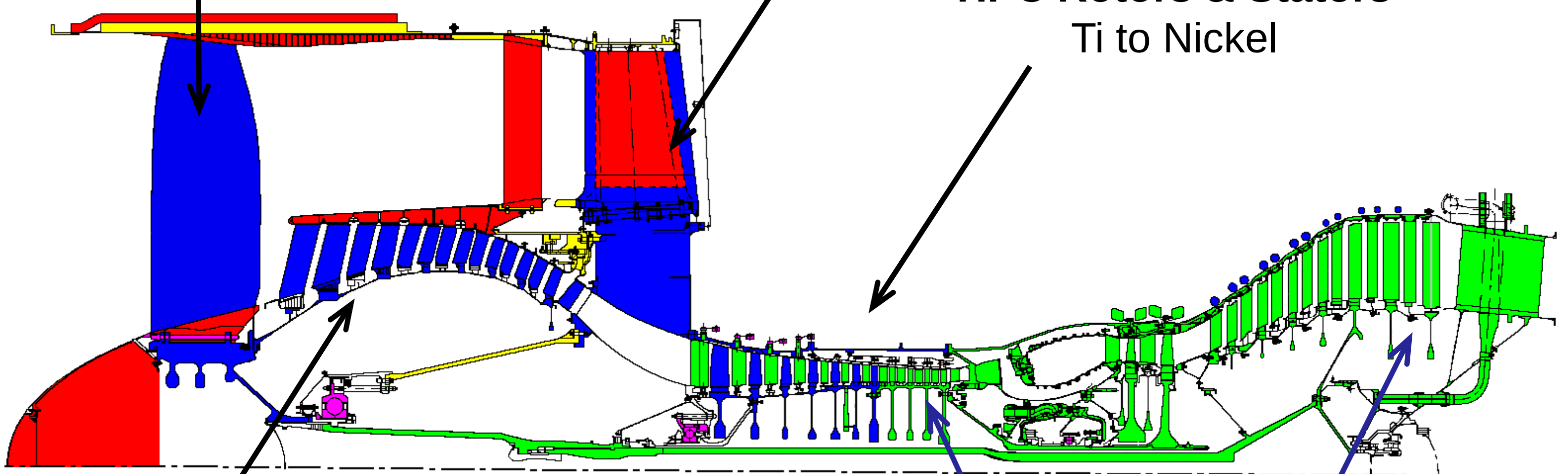
Engine architecture/cycle drives material changes

Fan Blades
Ti to Composite/Hybrid Metallic
(Ti leading edge sheaths)

SGV
Ti to Composite/Aluminum

HPC Rotors & Stators
Ti to Nickel

Larger Diameter Fans



Smaller Diameter, Higher Pressure & Hotter Cores

- Composite
- Aluminum
- Titanium
- Steel
- Nickel

LPT Blades
Ni to Gamma Ti

LPC Rotors & Stators
Ti to Composite/Aluminum

HPC Rotors & Stators
Gamma *potential*

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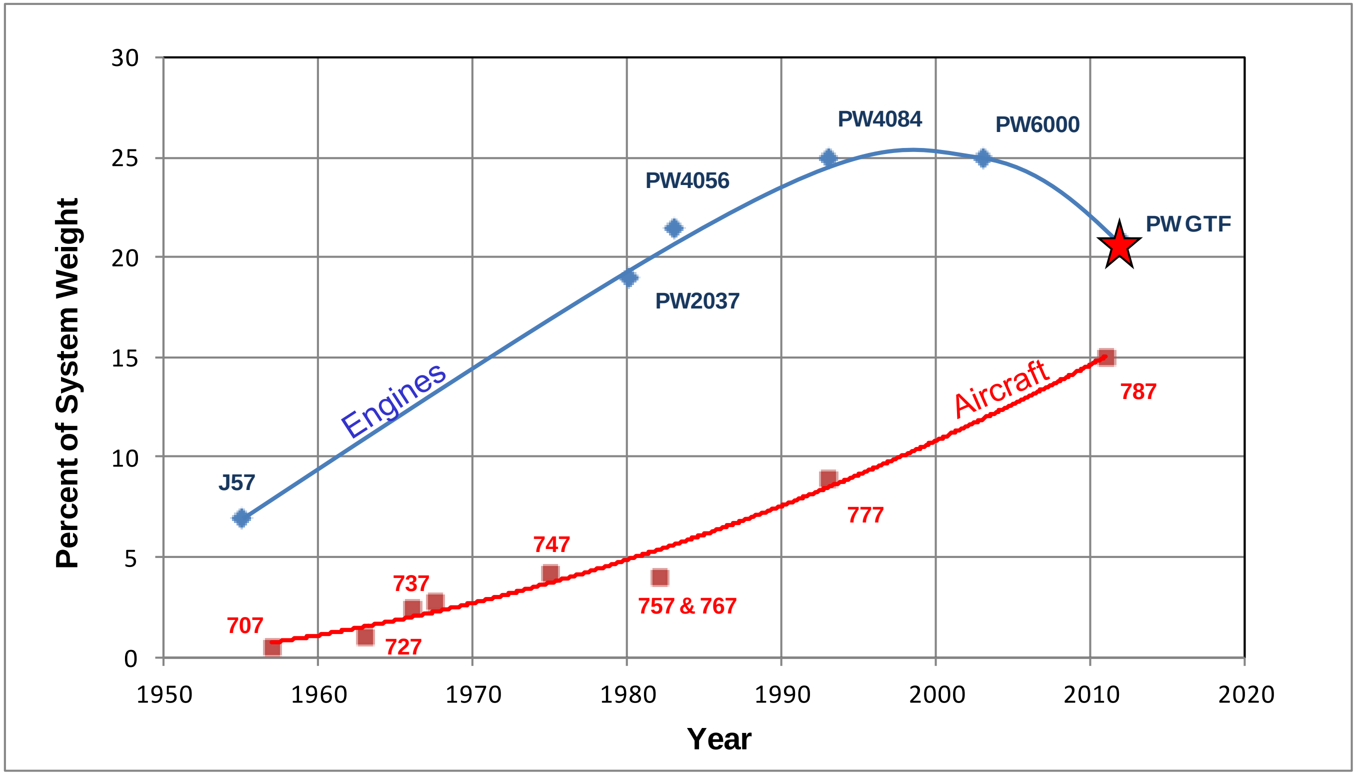
Titanium Usage – This Century

- Temperature limitations – Ceiling for utilization in engines
- New engines - Higher bypass ratios, smaller cores, increased temperature / larger Fans → reduced Ti content



Commercial aircraft and engines

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Ti Development Challenges…From an Engine Perspective

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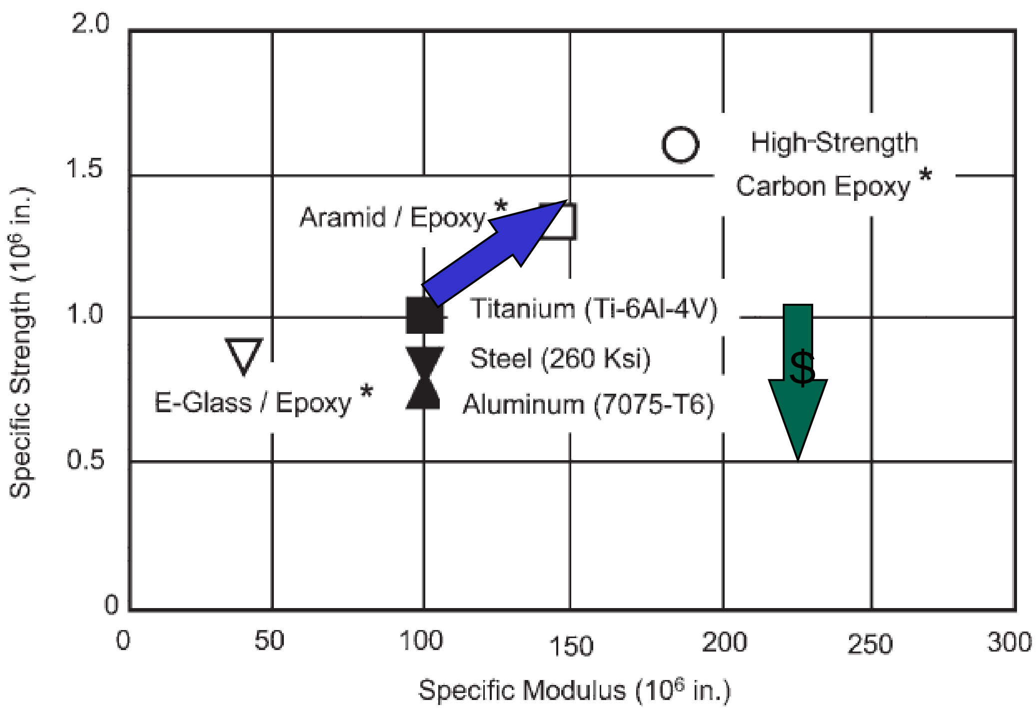
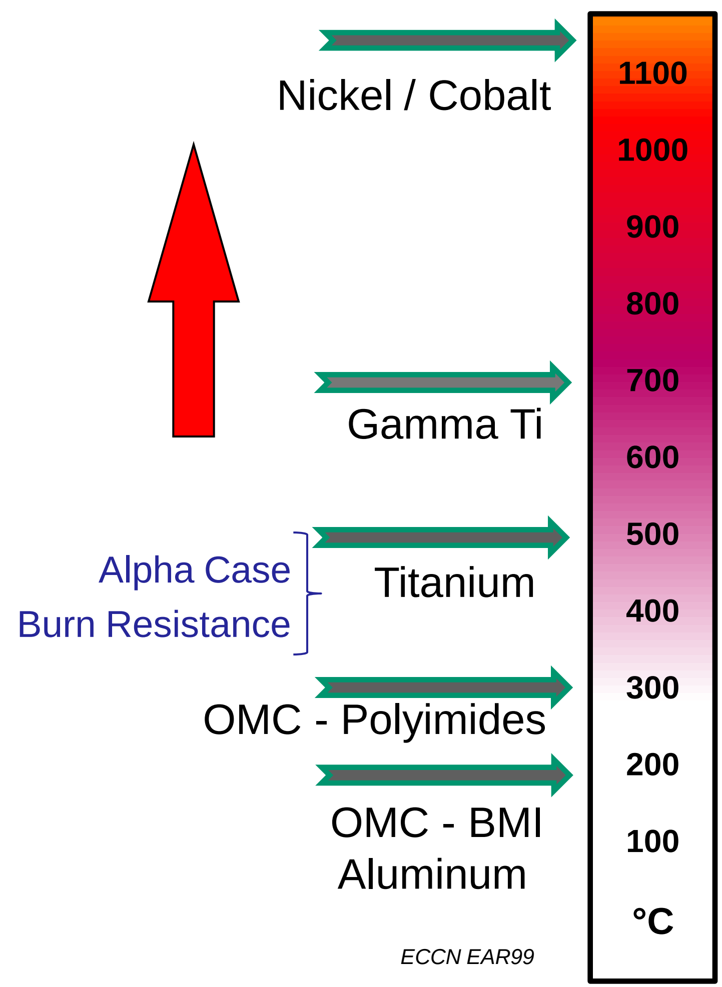
- Cost (always of great interest)
  - Compete with Al & steel
- High specific capability (propulsive efficiency)
  - Compete with composites
- Environmental resistance (thermal efficiency)
  - Compete with superalloys



*[± 45°, 0° 90°]$_S$ Structural Composite Materials, Chapter 1
F.C. Campbell, 2010, ASM International

Max use temperature



Airframe Technology Examples

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Aluminum industry's response to composites: <u>increase performance</u>

- High strength corrosion resistant alloys
  - Increased strength & design compatible
- 3rd Generation Al-Li alloys
  - Increased specific strength & stiffness
- Novel manufacturing methods (FSW)
- Hybrid materials (GLARE)
  - GLARE® (GLAss fiber REinforced aluminum)

➢ *<u>Similar advances/approach required for Titanium</u>*

Next Generation Engine Opportunities

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- Fan & LPC - Specific strength vs. OMCs
    - Cost Effective MMCs, Ti + B (P/M), Hybrid Ti / OMCs
- HPC - Temperature capability and burn resistance
    - Higher Temperature Capable & Burn Resistant Alloys and Coatings, Expanded Use of Gamma Ti
- LPT - Creep and oxidation (Gamma Ti)
    - Higher Temperature Capable Alloys / Coatings
- Low cost material and manufacturing processes
    - Low Cost Raw Materials – Ti Reduction, Melting, Conversion
    - Additive Manufacturing to Enable Hybrid & Low Cost Solutions

Summary

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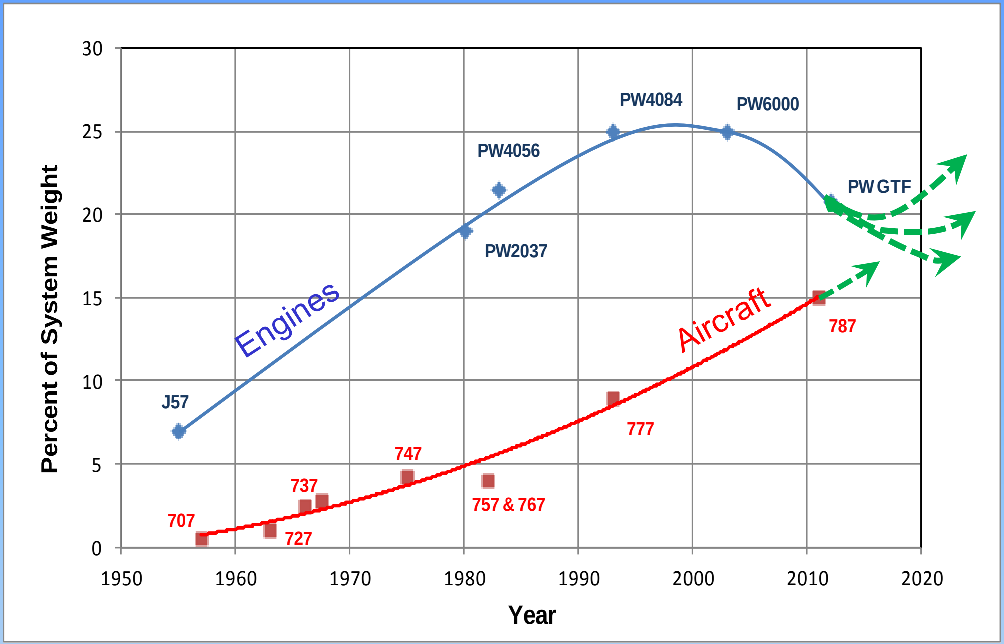
- Titanium usage decreasing in engine applications
  - Driven by cycle and architecture changes
  - Displaced by organic matrix composites and super alloys
- Aluminum industry response to composite threat is increased performance / advanced fabrication technologies
- Technology opportunities for Titanium
  - Increased specific capability
  - Advanced manufacturing for high performance structures
  - Improved temperature capability systems (coatings)
  - Continued work on cost reduction

Thank You



QUESTIONS ?