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Best Practices for Aerospace Engine Component Manufacturing

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MANUFACTURING™ TECHNOLOGY SERIES

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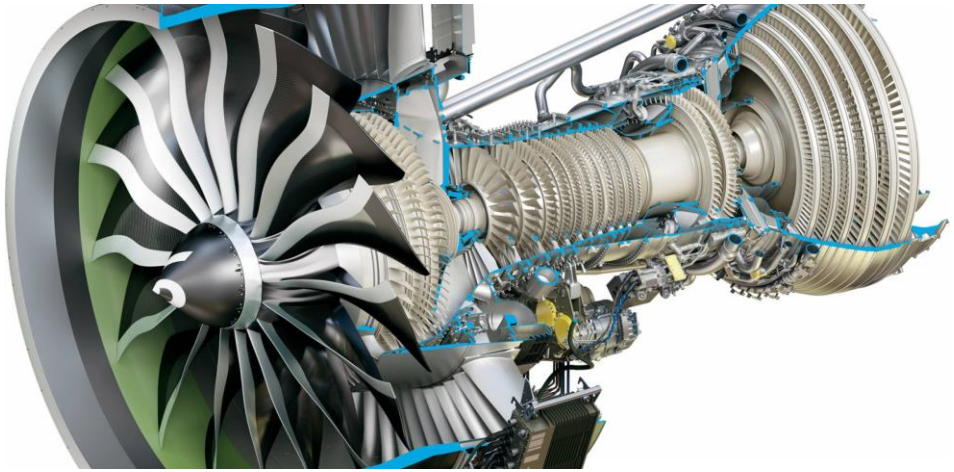
Presentation Outline

- ❑ Aerospace Engine Manufacturing
- ❑ Aerospace Engine Market Strength
- ❑ Machine Selection
- ❑ Process Control
- ❑ Automation



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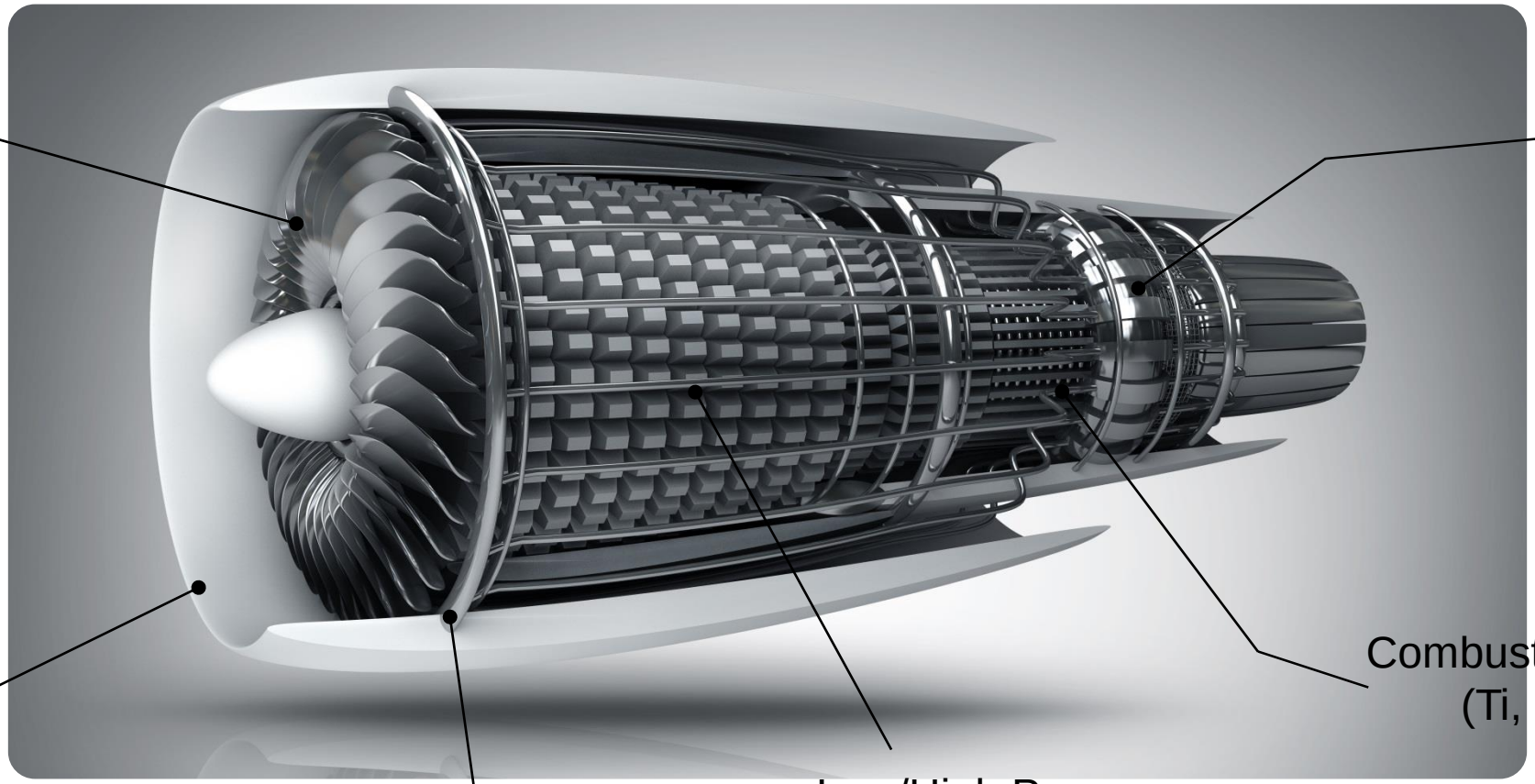
Aerospace Engine Manufacturing



Fan
(Al, SS, Ti, CFRC)

Turbine
(Ti, & INCO)

Shroud
(Al & Steel)

Engine Case
(Al & Composite)

Low/High Pressure
Compressor
(Ti, INCO, etc.)

Combustion Chamber
(Ti, & INCO)

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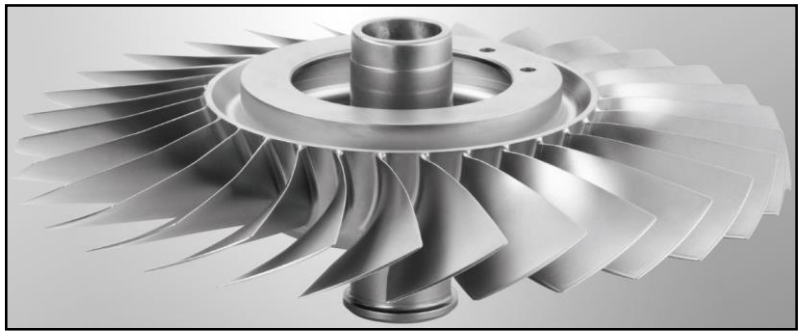
Aerospace Engine Manufacturing

❑ Critical Engine Components



Blisk (Bladed Disk)

Mfg Challenges:
1. Contour leading/ trailing edge at higher speeds while maintaining tolerances
2. Leave no surface defects to eliminate honing/benching

Impeller

Mfg Challenges:
1. Optimize process to produce a high quality surface and minimize post-machining operations

Single Blades

Mfg Challenges:
1. Increase productivity in emerging materials such as TiAl

Combustor Case

Mfg Challenges:
1. Reduce cycle time
2. Improve productivity and tool life

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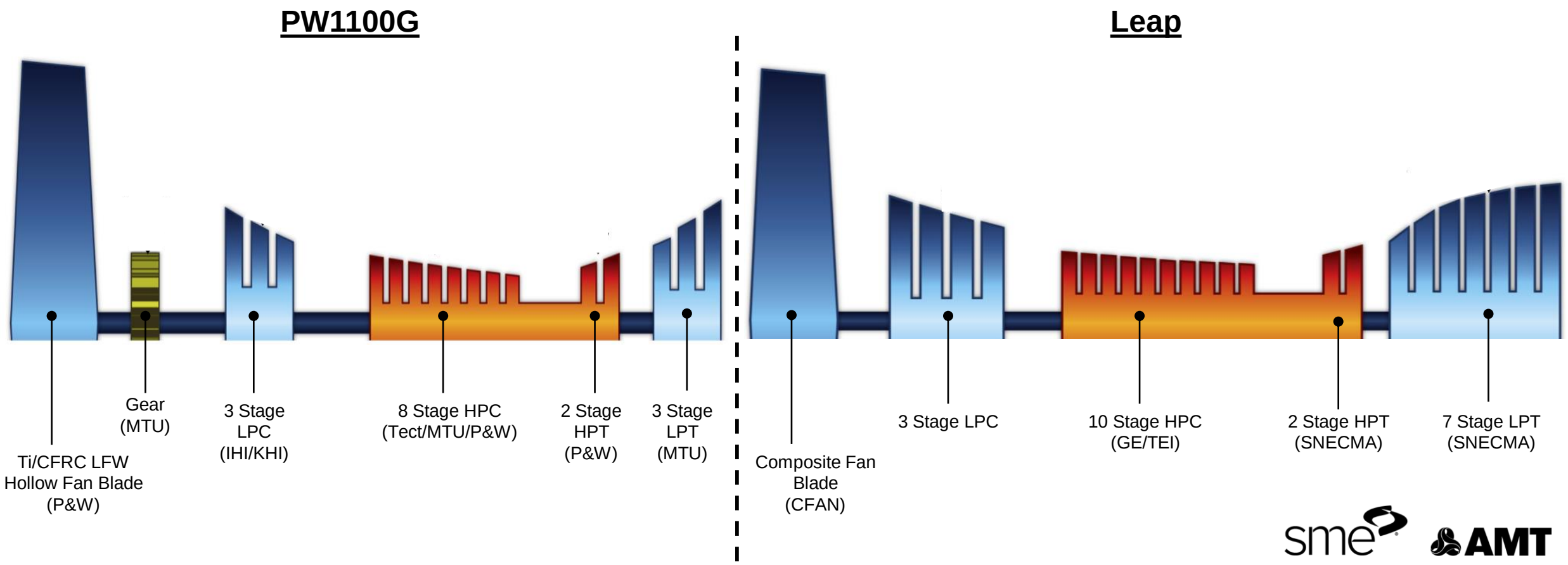
Aerospace Market Strength

- Case Study: PW1100G vs. Leap-X



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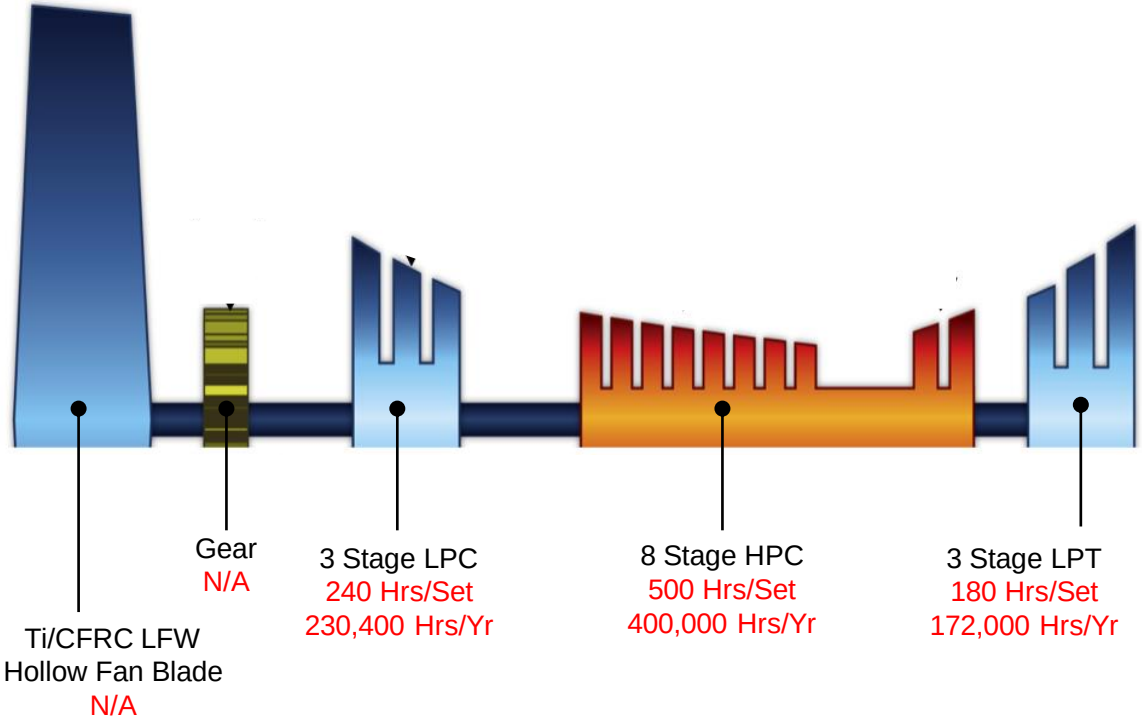
Aerospace Market Strength

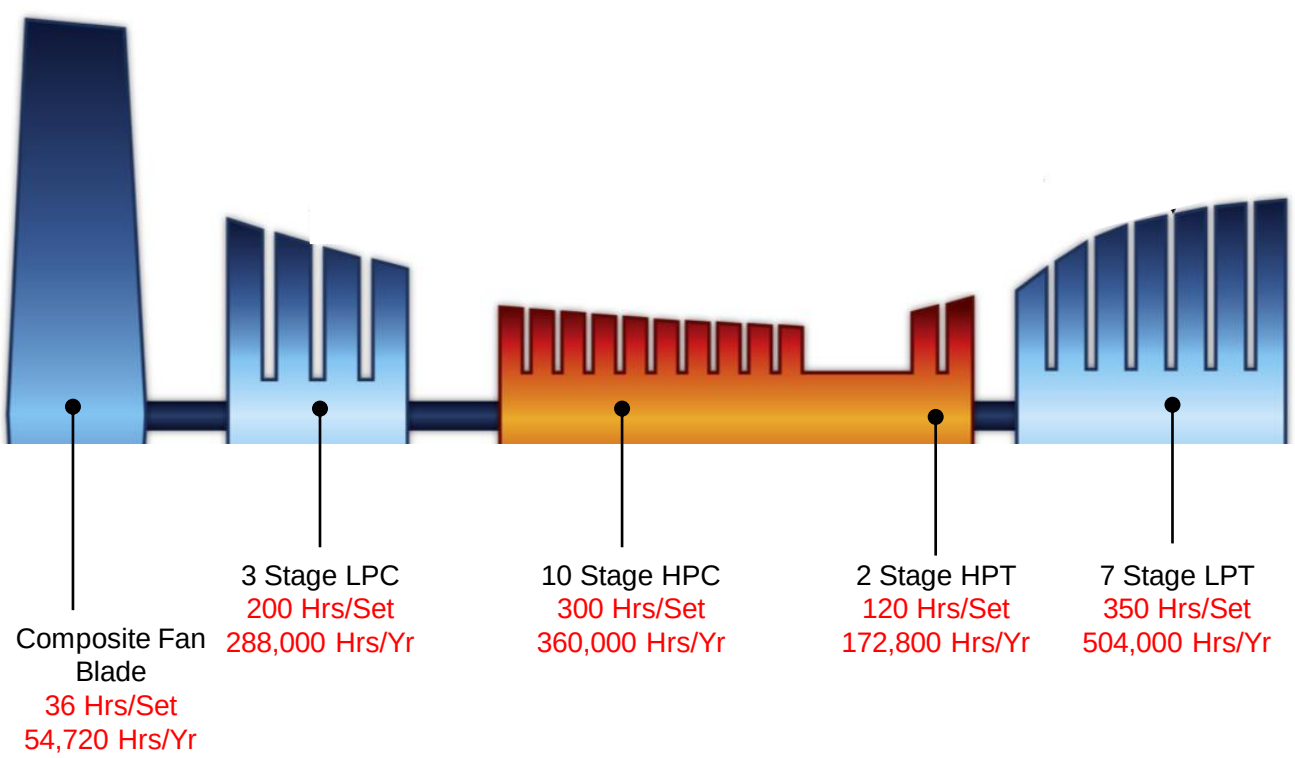
❑ Cycle Time Comparison

PW1100G



Total Milling Time: >800,000 Hrs (At Peak Production)

Leap



Total Milling Time: >1,375,000 Hrs
(At Peak Production)

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Aerospace Market Strength

- Increased part quality
  - Tolerances/requirements for Tier 1 and Tier 2 suppliers may be more strict than the OEMs.
- Rate Readiness
  - Ready to support peak build rates
- Demand Management
  - Necessity to meet large demands
  - On time delivery
- Capitalization
  - Ability to increase capacity

Machine Selection

❑ Initial Considerations:

- Type and size of components
  - Blisk/IBR & Impellers → Small to Medium build envelope
  - Fan blades & Cases → Medium to Large build envelope
  - There is no one size fits all solution!
- Tolerances, surface finish requirements, and volume
  - High tolerance requires a high quality machine
  - Fine surface finish requires precise motion control
  - Volume determines cycle/tact time and number of required machines
- Floor Space
  - This is a premium commodity
- Spindle
  - Speed vs. Power

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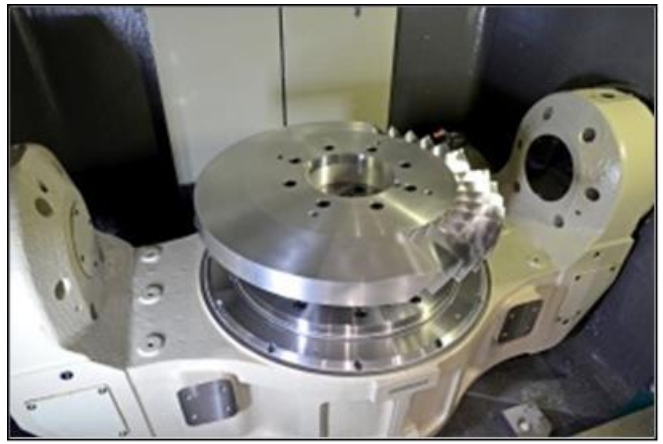
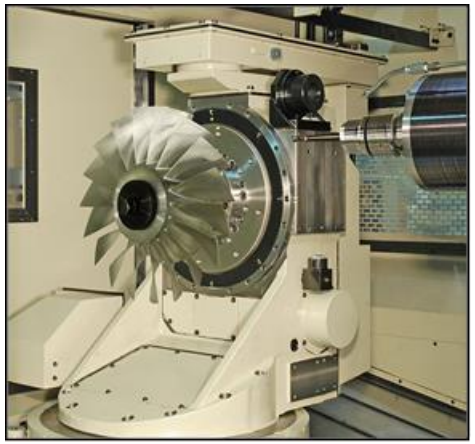
Machine Selection

Blisk/IBR & Impellers



Vertical 5X Trunnion

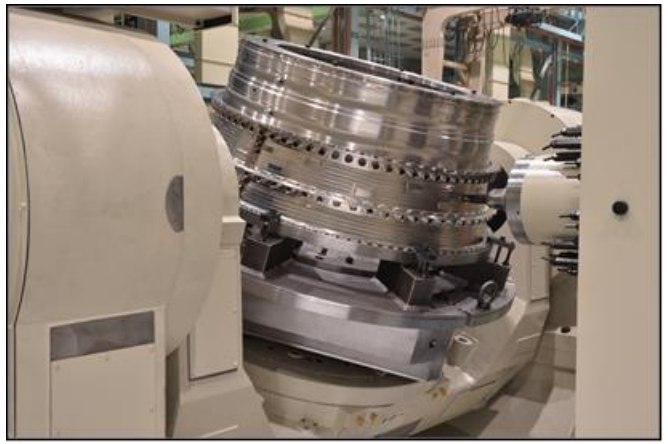


Horizontal 5X TT

- LM Guides
- DD Motor Rotaries
- Agile, High Speed

Fan Blades & Cases

Tilt-Spindle



Horizontal 5X Trunnion

- Box Ways
- Gear Driven Rotaries
- Rigid, Heavy Cutting

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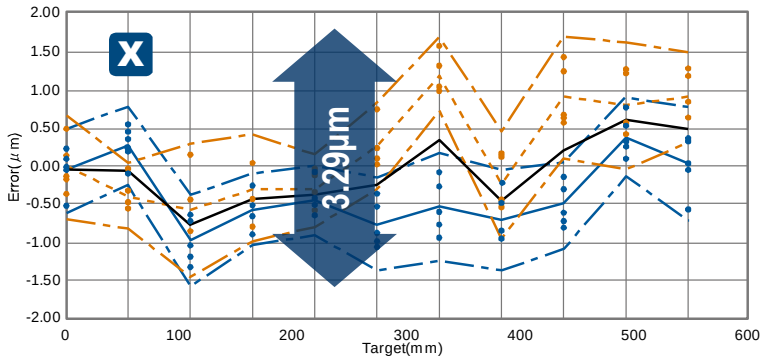
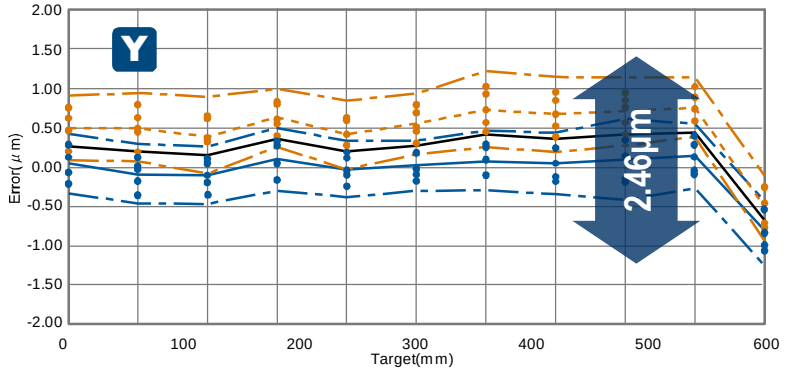
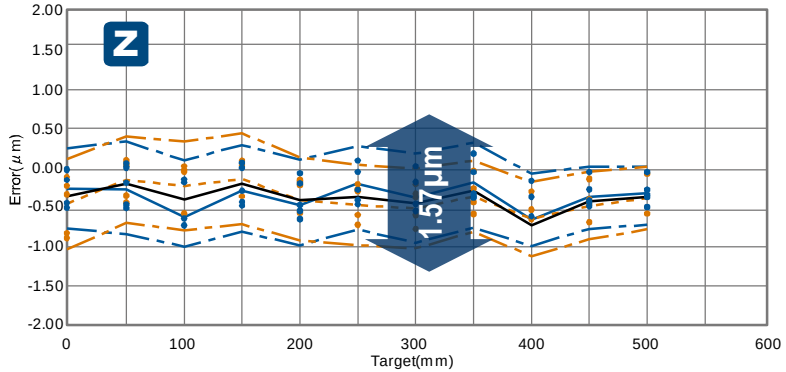
Machine Selection

❑ High Tolerance Construction







- Hand scraped mating surfaces
- High geometric accuracies can only be achieved by continuous work measuring and hand-scraping
- Within 4 microns band of positioning accuracy in ISO230-2 standards
- Top-class accuracy within the 5 axis category

Machine Selection

❑ High Accuracy Performance

❑ Taper Cone Machining

- The tapered portion will be machined by a 5-axis simultaneous cut and then the roundness will be measured at three locations. By measuring the roundness at three locations, it will tell the overall performance of the machine such as following characteristics of each axis and backlash.

Roundness Results of 10 machines

	Unit	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	Max.	Min.	Ave.
Top	μm	2.4	3.8	3.6	3.6	5.0	3.9	3.5	3.0	2.9	3.3	5.0	2.4	3.6
Middle	μm	3.1	3.4	3.8	3.4	4.8	3.7	3.7	3.4	3.7	3.3	4.8	3.1	3.63
Bottom	μm	3.9	3.1	3.7	4.4	4.7	3.3	4.1	3.4	4.1	3.5	4.7	3.1	3.82

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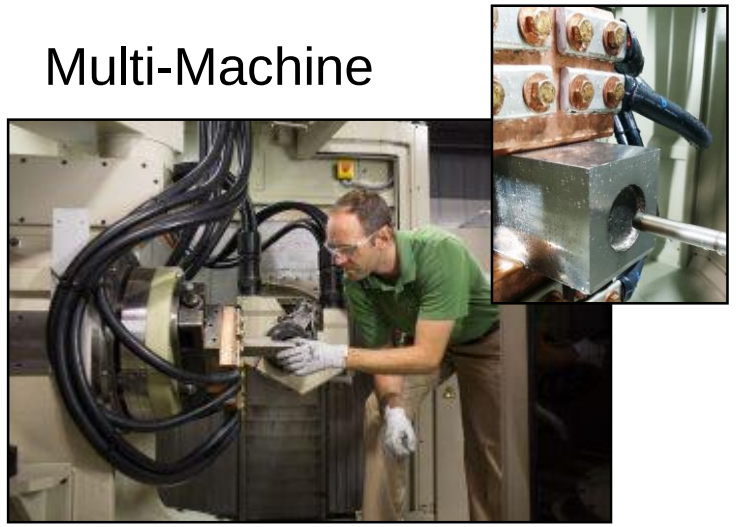
Machine Selection

❑ Volume

- Single Machine

- Roughing and Finishing
- High cycle time
- Possibility for more machines
- Lower sources for setup error
  - Initial setup and machine errors

- Multi-Machine



Blue Arc™ Roughing Process

- Roughing then Finishing
- Low cycle time per machine
- Multiple machines
  - At least one finishing machine/roughing machine
- Higher sources for setup error

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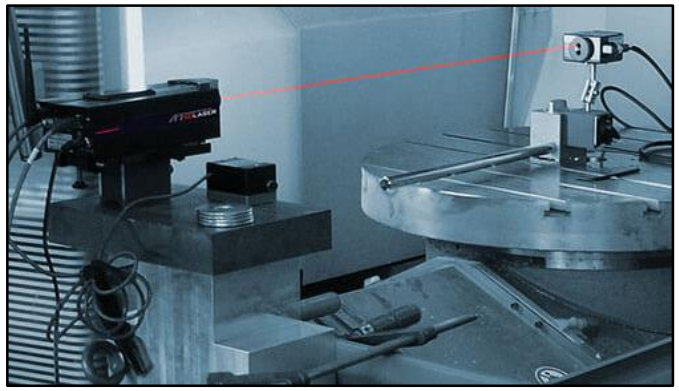
Process Control

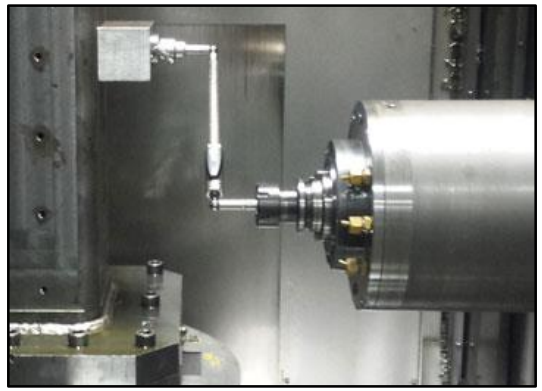
- Machine Calibration, In-Process Gauging, and Health
  - Geometric Error Mapping
  - Gauging & Machine Health
- Programming
  - Traditional Methods
  - Emerging Methods
- Tooling Selection
- Servo Tuning
  - X, Y, Z-Axis Resonance Frequency
  - A/C-Axis Rotary Positioning Error

Calibration, Gauging, and Health

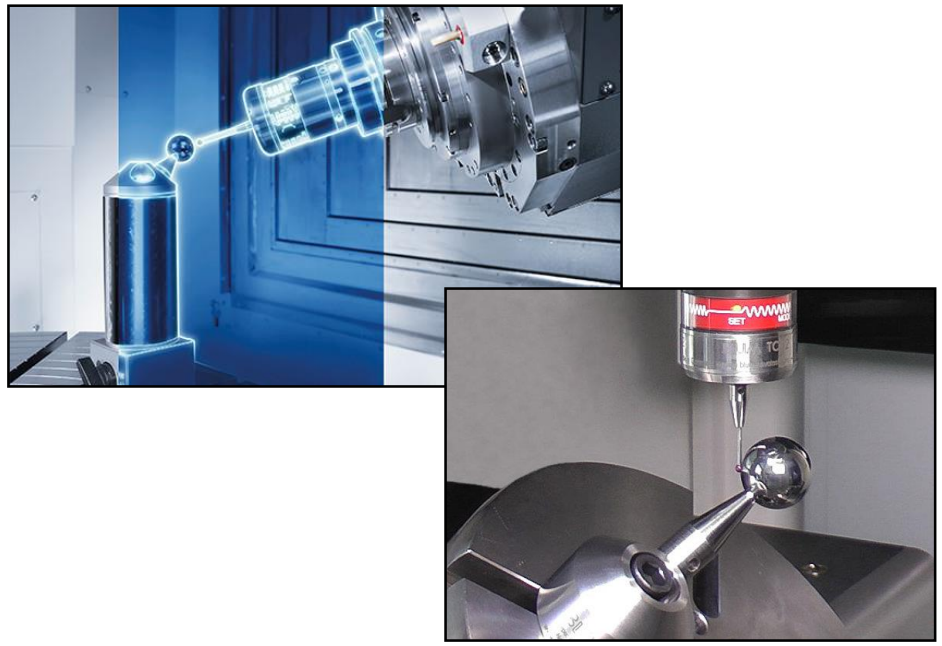
❑ Geometric Error Mapping



Laser Interferometer



Double Ball Bar

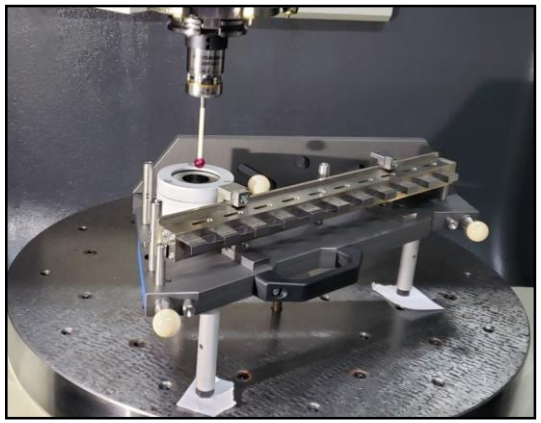
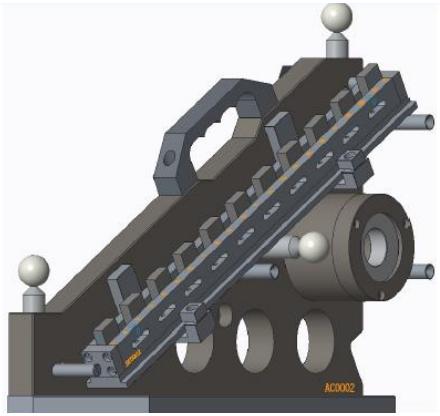


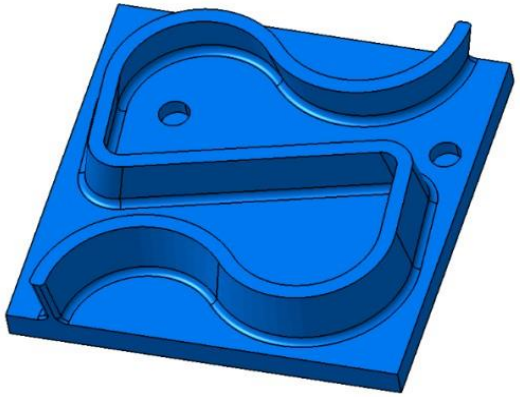
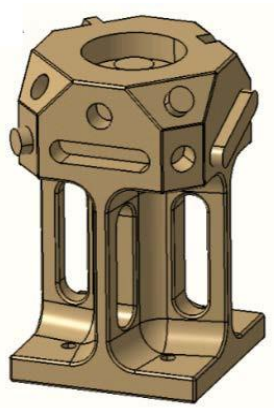
Kinematic Setting

- X/Y/Z + A/C geometric identification and compensation
- DBB – Backlash and reversal error compensation
- Kinematic setting – Establish rotary centers and the error between

Calibration, Gauging, and Health

❑ In-Process Gauging & Health

- Allows for geometric calibration checks and calibration to ISO 10360
  - CMM Comparison
- In-process artifact checking to ensure machine “health”
  - Will the machine make this part?
  - Check machine accuracies, setup errors, etc.

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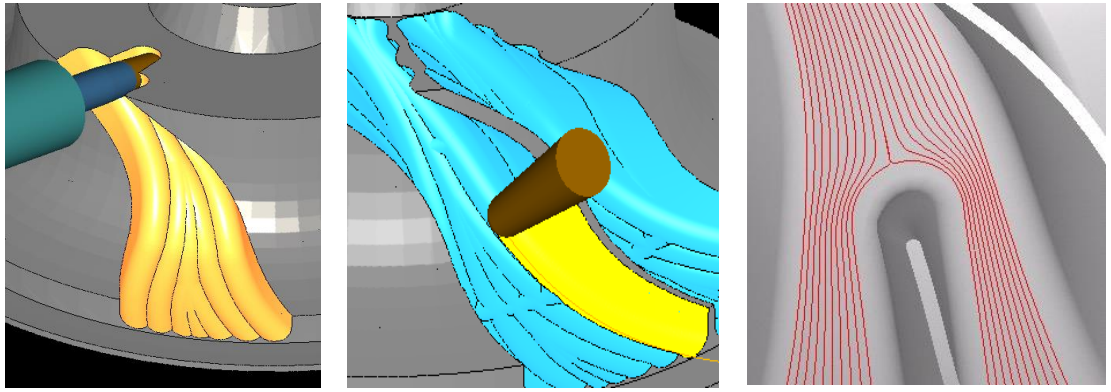
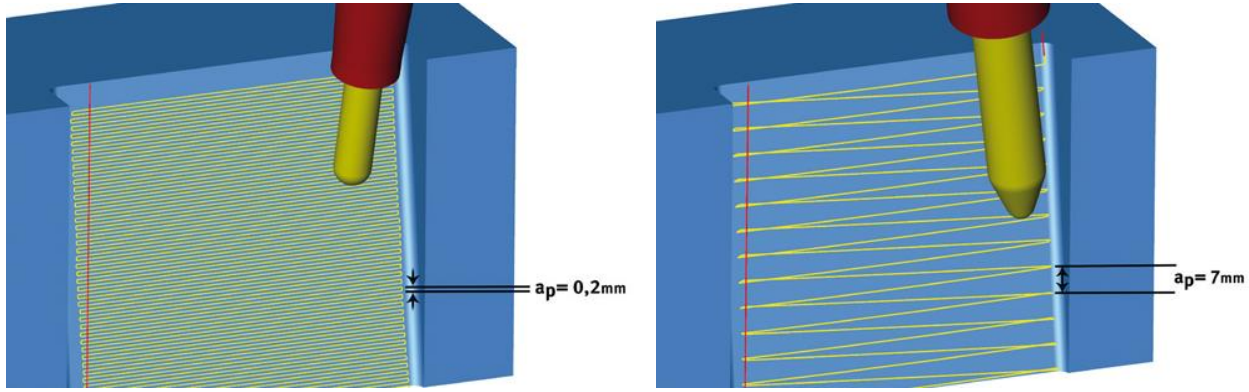
Programming

Traditional Methods



- 4/5 Axis Roughing – Slot milling
- Flank milling/Point milling
  - Semi/finishing operations
  - Airfoil surfaces
  - Fillets
  - Hub

Emerging Techniques



- Barrel/Conical Multi-radius tools
  - Roughing and finishing
- Higher step downs than ball end mills
  - Higher tool engagements
  - Higher MRR

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Summary

- With the growing market, nearly 500 additional machines are required to meet the demand;
- Many OEMs are relying on Tier 1 and Tier 2 suppliers to help meet their needs
- There is no one size fits all solution for an aero-engine machine
  - Small to medium sized parts can be produced on a VMC
  - Medium to Large parts can be produced on an HMC
- High tolerances and fine surface finishes require a high accuracy machine with dynamic motion control