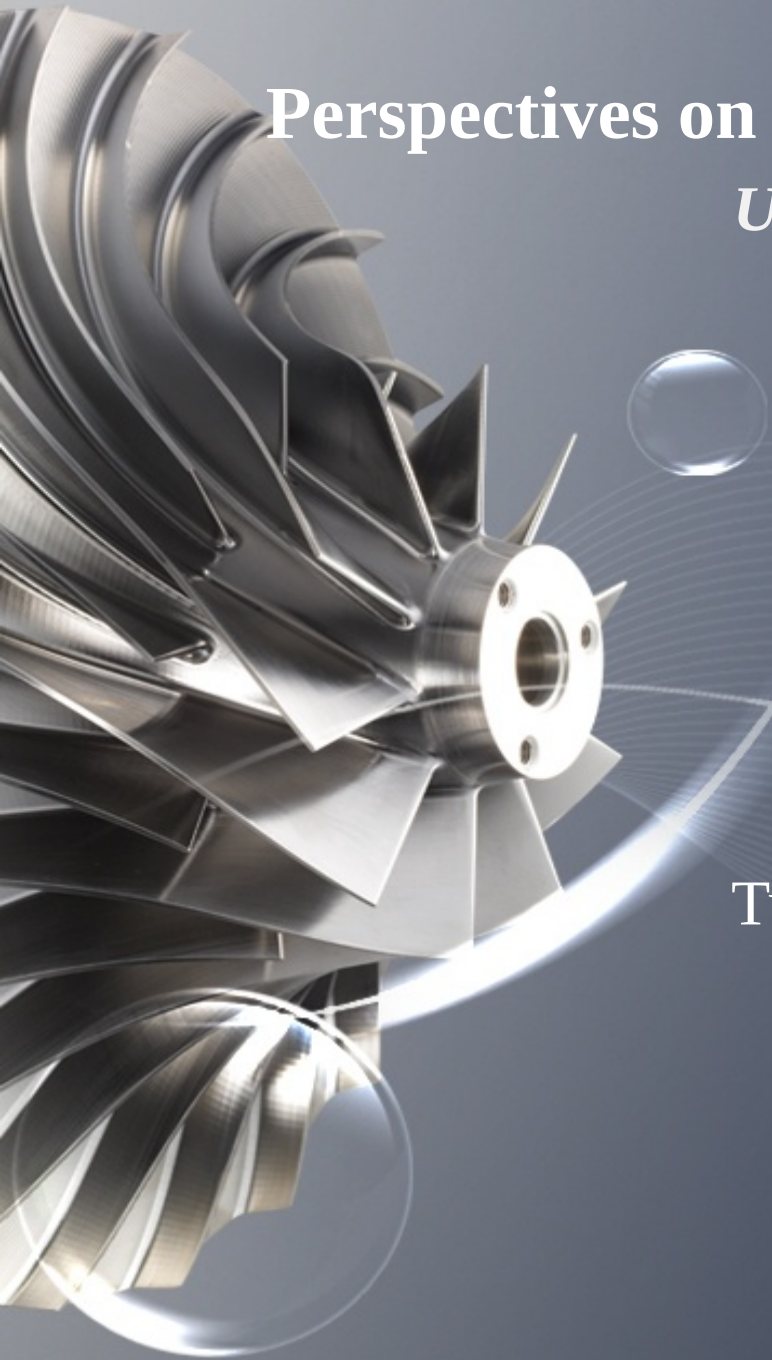


Perspectives on Advanced Manufacturing Technology

University Turbine Systems Research Workshop

Atlanta, GA

Turbomachinery Design and Development Center

Hanwha Techwin

Houston, TX

Karl D. Wygant

November 2, 2015

Power Systems Division is Manufacturer of Wide Range of Turbomachinery Products

Turbomachinery Products Designed for Diverse Applications

Gas Turbine & Compressor Packages

Process & Gas Compressors

Hanwha Techwin

Air Compressors

Turbo-Compressors

Over 30 years experience of compressor technology originally derived from gas turbine business...

Aero-Mechanical Optimization of Turbomachinery

Influence of Manufacturing Technology on Turbomachinery Design

➢ **Goals for commercial gas turbines and compressors are consistent …**

- ✓ Increasing efficiency
- ✓ Increasing reliability
- ✓ Decreasing maintenance cycle
- ✓ Reduced delivery time

End users drive need for reduced OPEX

Competition amongst OEM's fosters lower CAPEX

Regulations drive reduced environmental impact

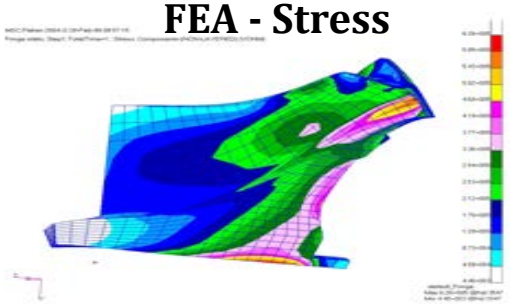
➢ **Each manufacturer has slightly different approach …**
(but all really based on similar philosophies)

➢ **Discussed herein is the following …**

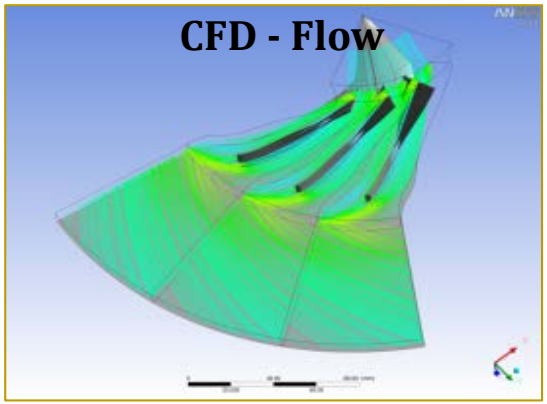
- ✓ OEM's approach to turbomachinery optimization
- ✓ How additive manufacturing can alter that paradigm significantly.
- ✓ Example case to illustrate the impact additive manufacturing can have on turbomachinery design.

Within Turbomachinery Multiple Engineering Disciplines are All Coupled

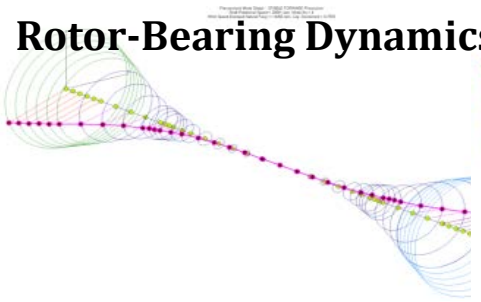
FEA - Stress

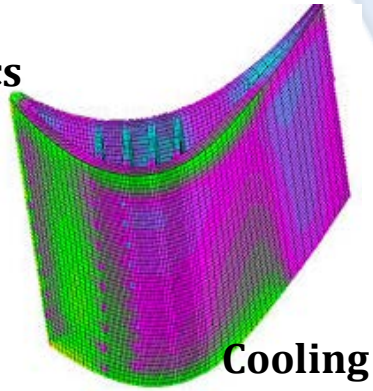


CFD - Flow



Rotor-Bearing Dynamics

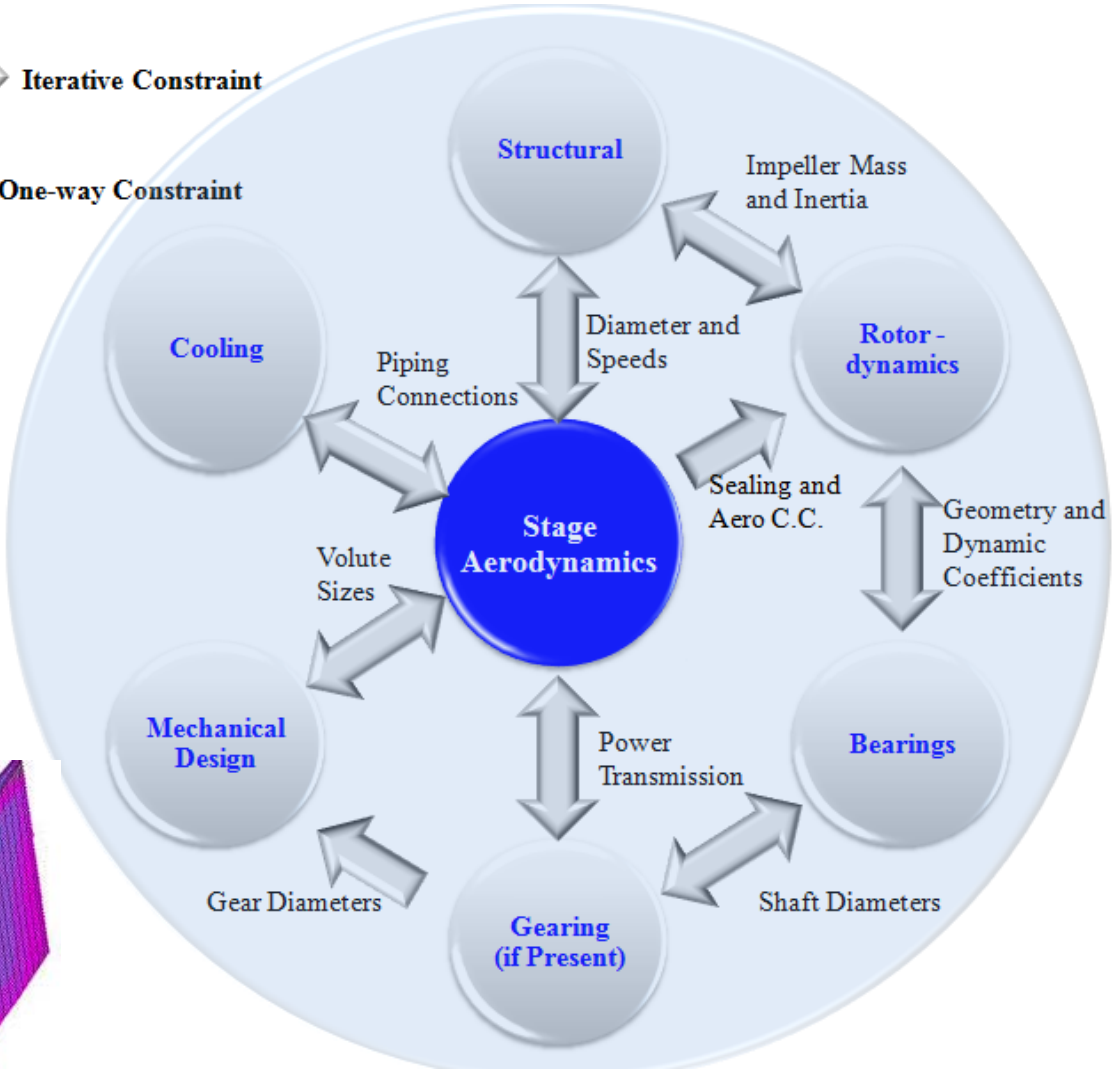




Cooling

Iterative Constraint

One-way Constraint



Hanwha Techwin

Example … in part from Joint Program between Hanwha Techwin and Southwest Research Institute

DMLS in Turbomachinery

- Stationary and rotating parts
- Published application of DMLS to rotating parts limited mostly to development test rigs
  - 100,000 rpm 1380 °F Inconel GT wheel (Inconel 718)
  - SwRI experience with micro-turbomachine closed impellers and turbines
    - Overspeed test successful at 1140 ft/s
    - Overspeed test to failure at 1403 ft/s

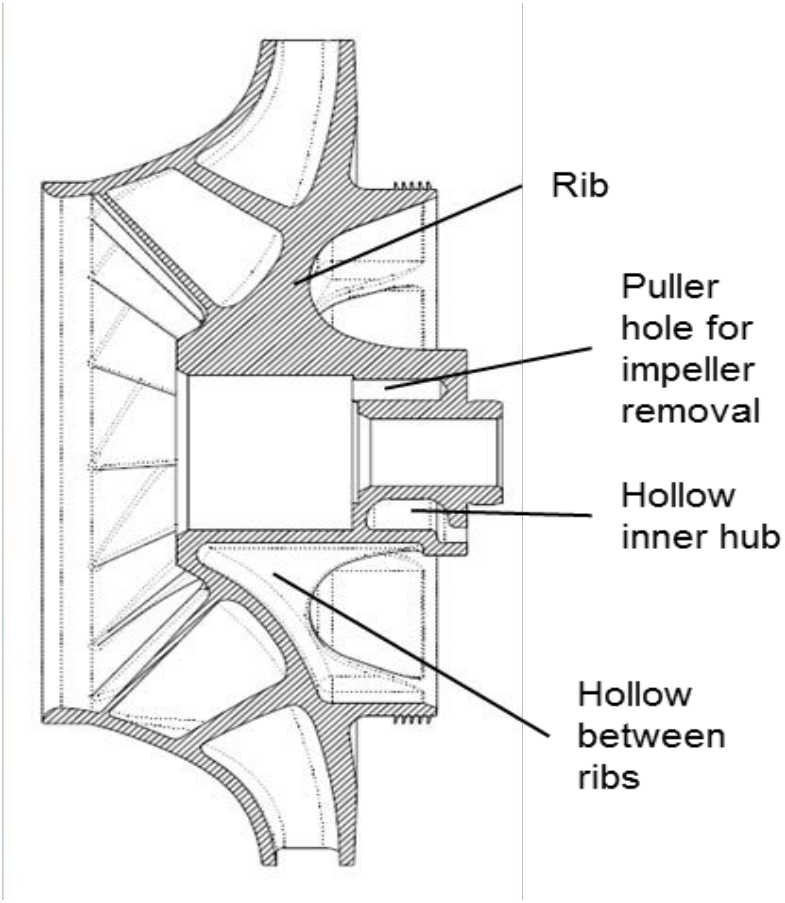
Flow Straightener for Helicopter Engine (Killian 2013)

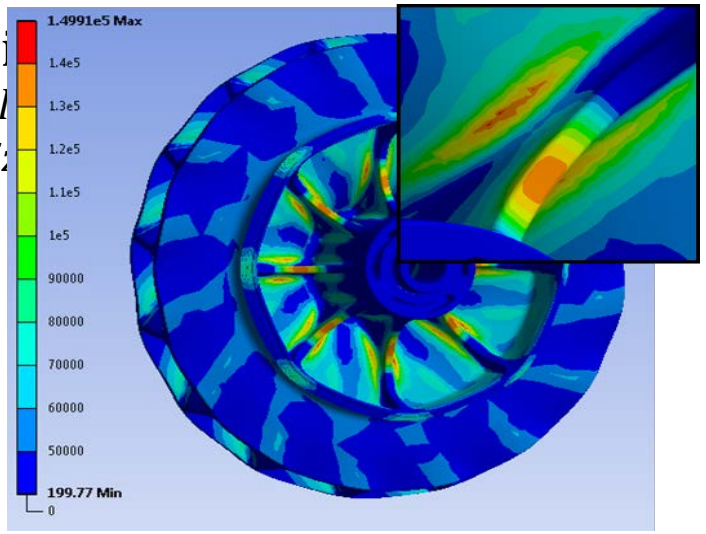
EOSINT M 280 (Source: EOS)

100 krpm GT wheel (Killian 2013)

DMLS Impeller Design Considerations

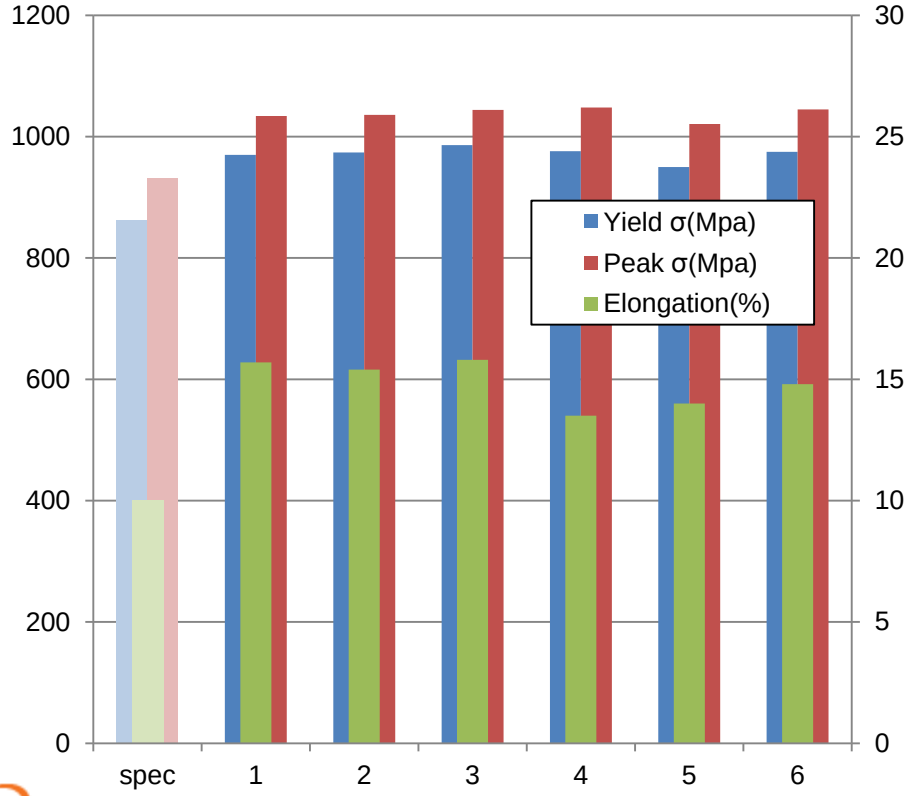
The Direct Metal Laser Sintering process works best to mi
- *Thicker parts can build internal stresses that lead to fracture during buil*
- *Excellent rotordynamic characteristics as weight and inertia are minimi*
- *Reduced material minimizes build time and cost.*



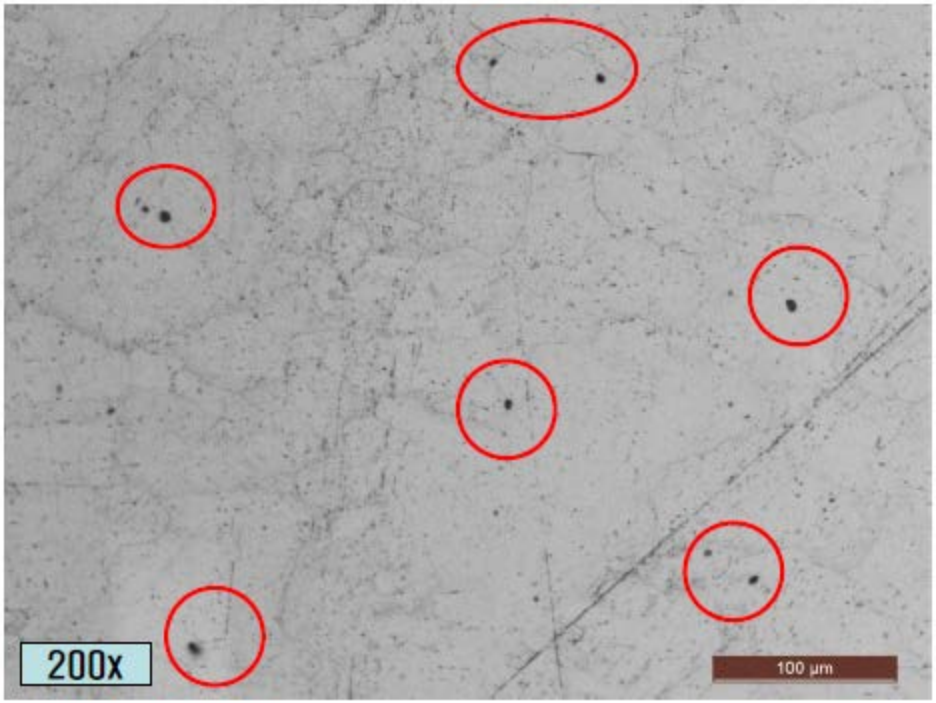


Ribbed Design Produces Non-uniform Seal Clearance and High Stresses in Ribs – Tested Inconel 718 Part Instead

Tensile Test Results
DMLS Ti 6AL-4V



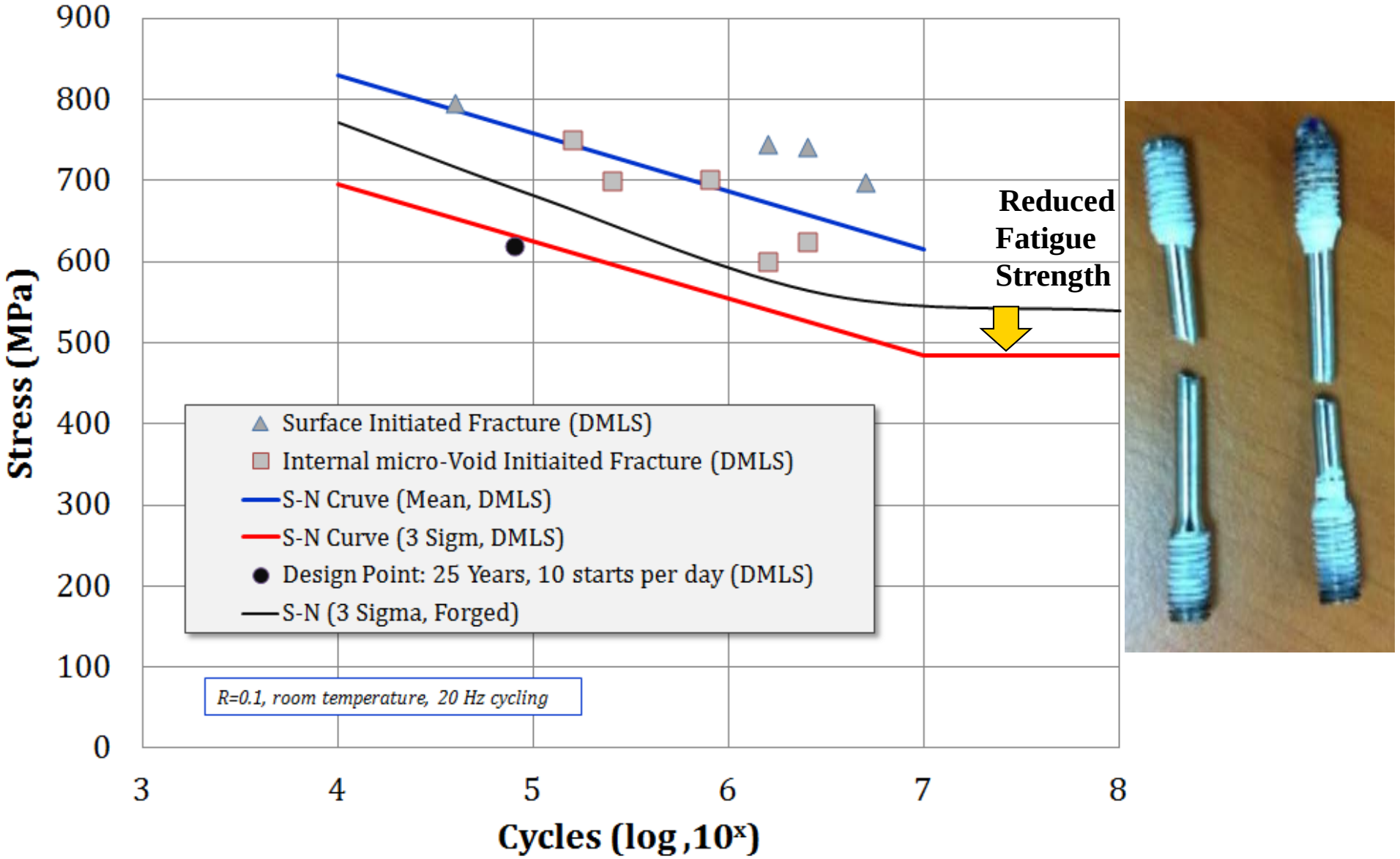
- **Under 200 X magnification micro-porosity is present:**
  - ✓ Investigated implication on fatigue strength
  - ✓ Investigate dimensionality
- **Reduced grain size:**
  - ✓ Slight increase in yield and ultimate strength
  - ✓ Increased material hardness



Hanwha Techwin

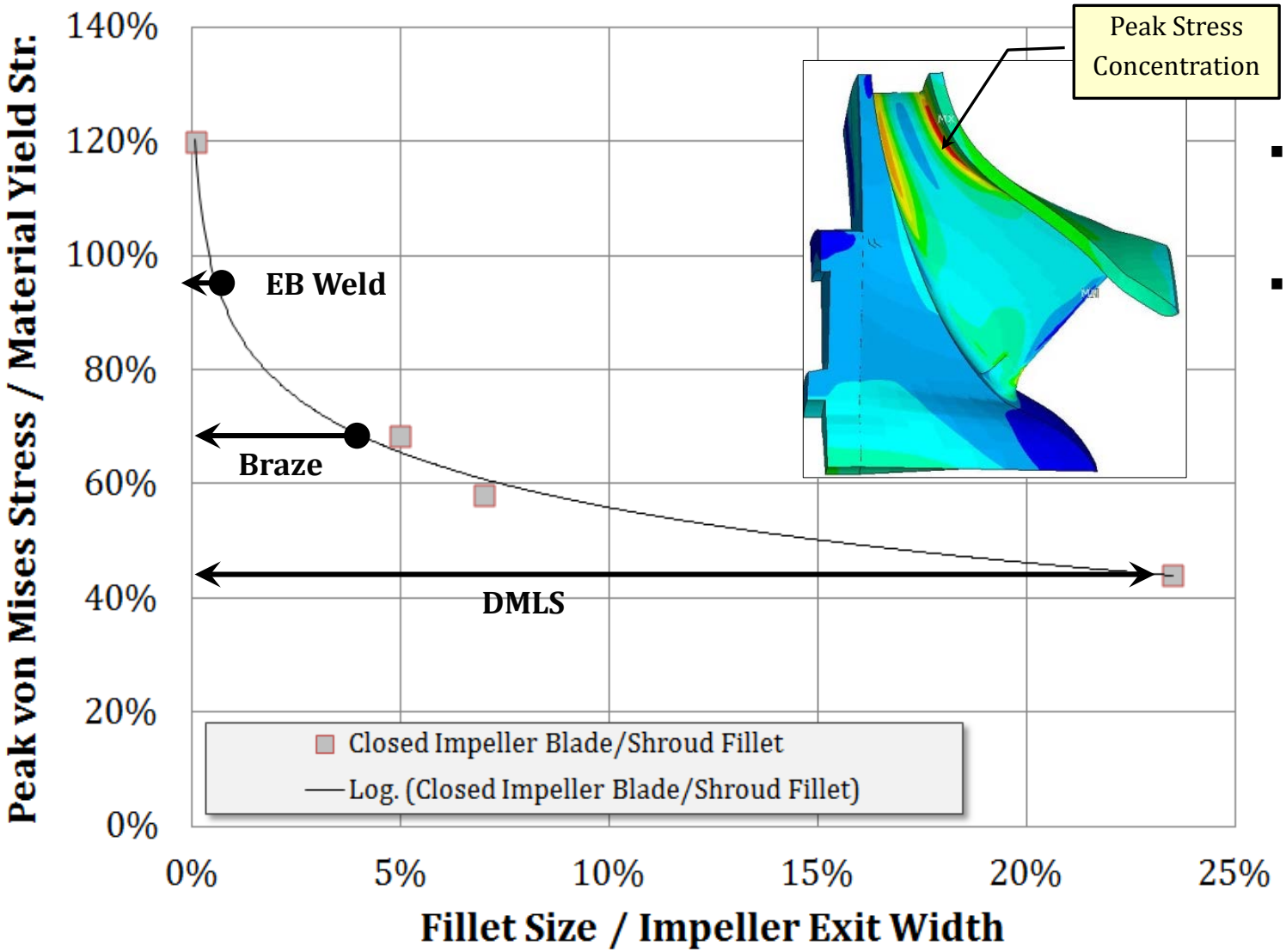
Test Results Show Reduced Fatigue Life

S-N Diagram for DMLS Ti 6AL-4V



Manufacturing Flexibility Significantly Outweighs Fatigue Limit

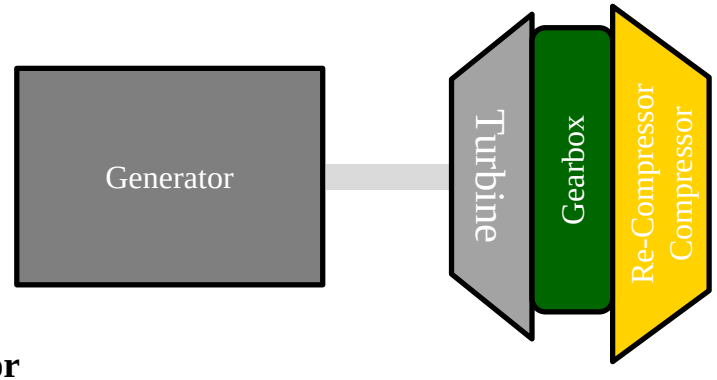
DMLS Ti 6AL-4V

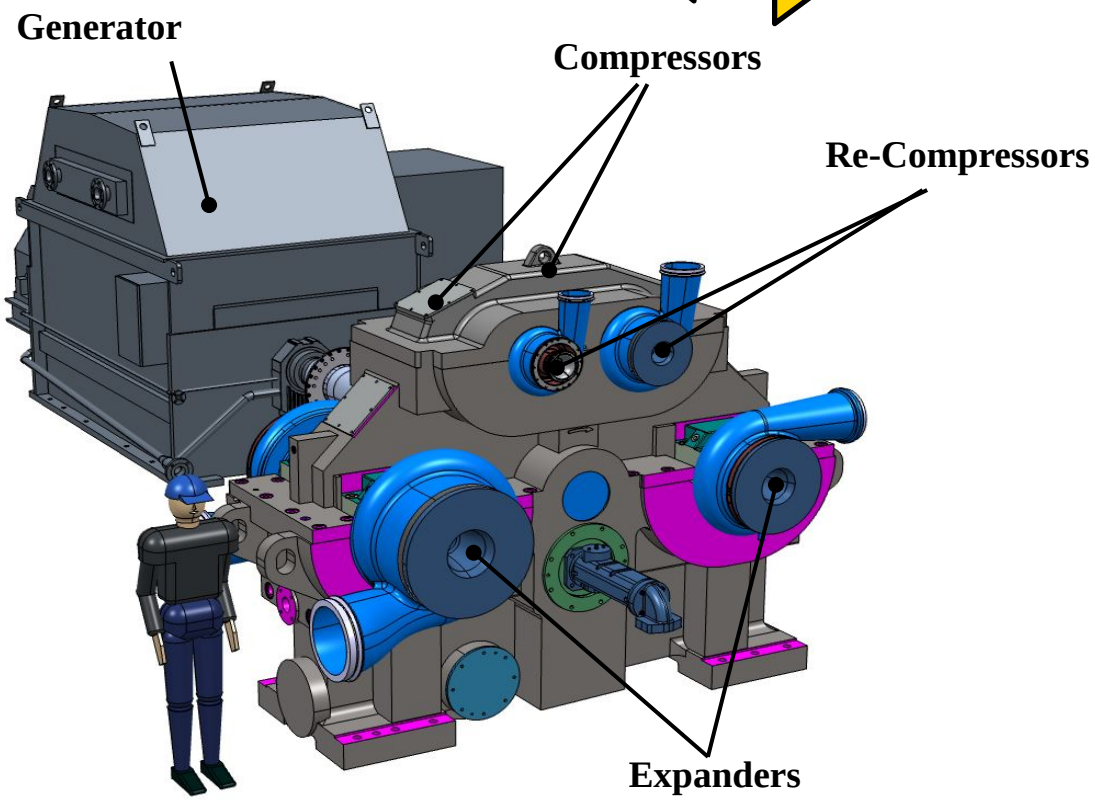


- **15% decrement due to strength**
- **35% reduction in stress due to increased design flexibility.**

Relationship to Integrally Geared sCO_2

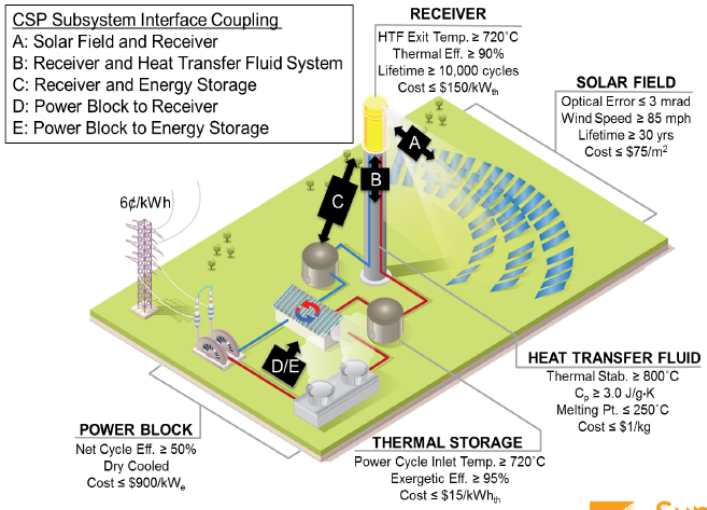
Advanced 10 MW_e Integrally Geared Compressor-Expander Configuration





Technology Demonstrator

Advanced Impeller Concepts



Conclusions and Future Needs

Conclusion

Advantages of Direct Metal Laser Sintering:

- Process lends it self to reduced material waste
- Process lends itself to minimizes weight … improved rotordynamics.
- Process removes some previous constraints … can reduce “effective” stress and improve component life.
- Or with lower effective stresses it becomes possible to re-stagger the design optimization and achieve high efficiency and/or high compressor ratios.

Opens Up New Design Possibilities:

- Can we build in new and advanced forms of integrated blade damping mechanisms ?
- Can we develop internal flow paths that were not feasible before?
- Add ability to add internal cooling pssages in novel ways

Going Forward

Some of the practical issues facing OEM:

- **Inspections …**
  - QA practices are lagging technology.
  - Technology allows ability design components with internal structures that are difficult to inspect.
- **Material Properties …**
  - Fatigue properties are key to design process.
  - Some vendors are using “propriety” powder blends
- **Build Process …**
  - Fractures can develop during build process.
  - Surface roughness has drastically reduced.
  - Substantial post build work required.