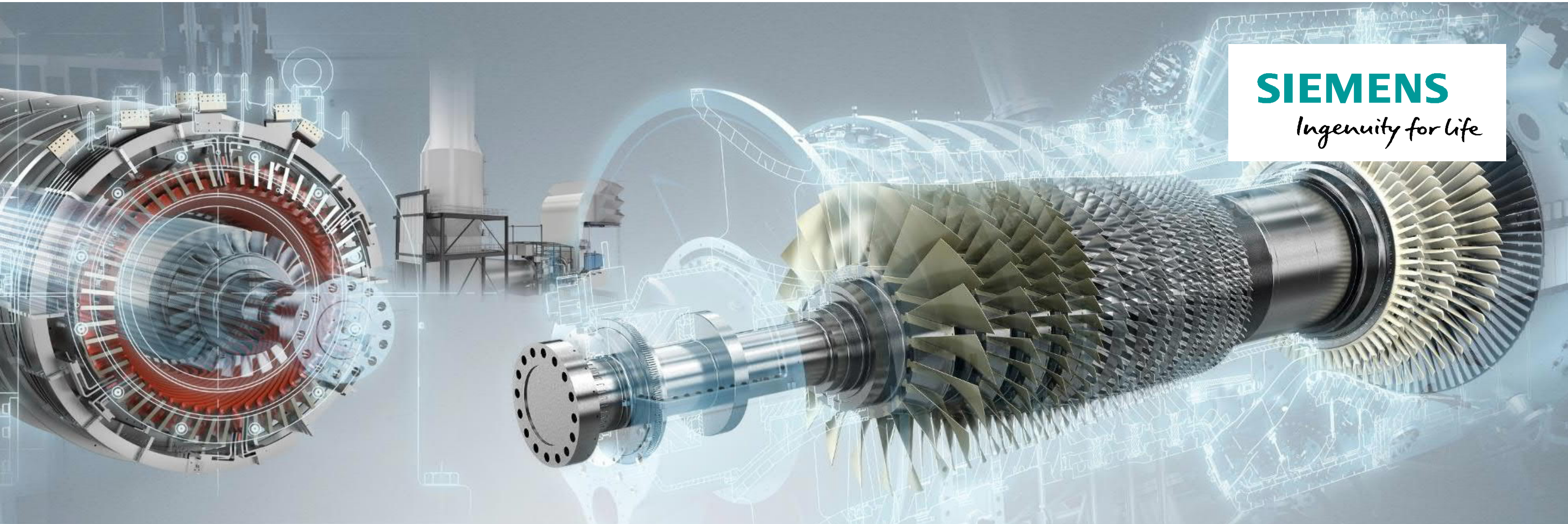

UTSR 2019 Conference

„Design & Development of Low Weight TiAl Airfoils for Industrial Gas Turbines Meeting 65% Combined Cycle Efficiency“ DE-FE0031610

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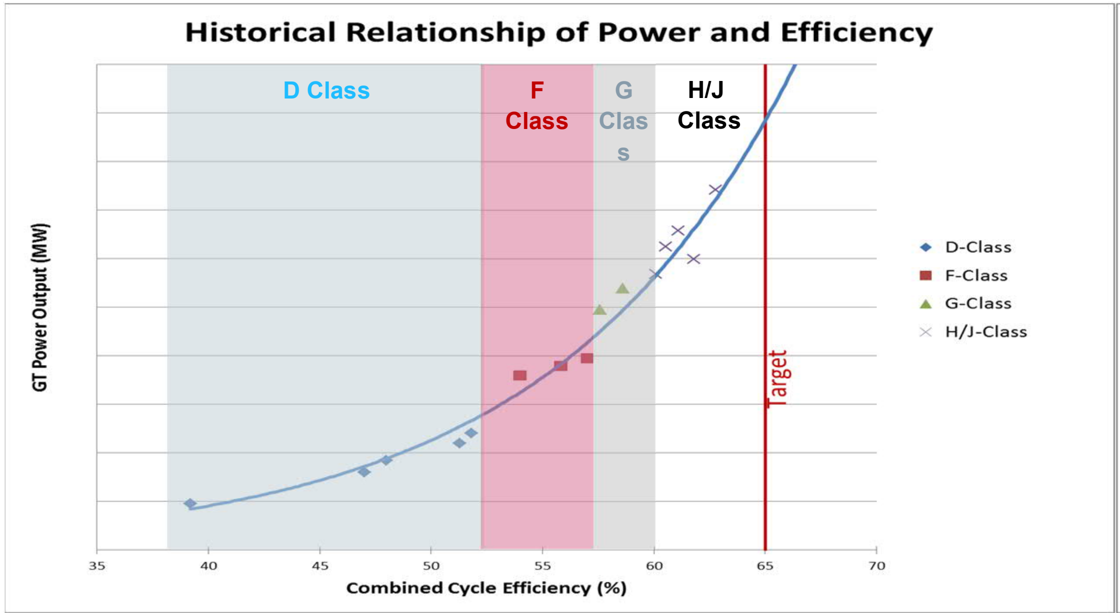
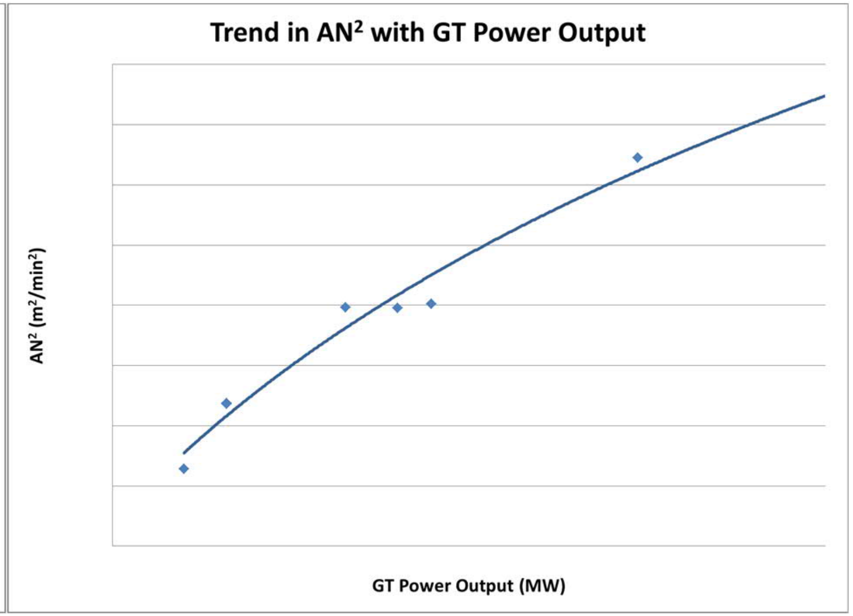
Background –



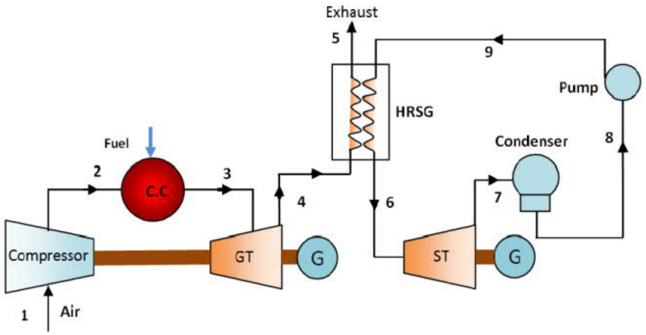


AN^2 = Area of blade annulus x square of rotational speed; characterizes blade size and flow capacity

Historical trends of increasing performance indicate that power output will increase at similar pace to η_{CC} driving need to increase size of last stage turbine blades

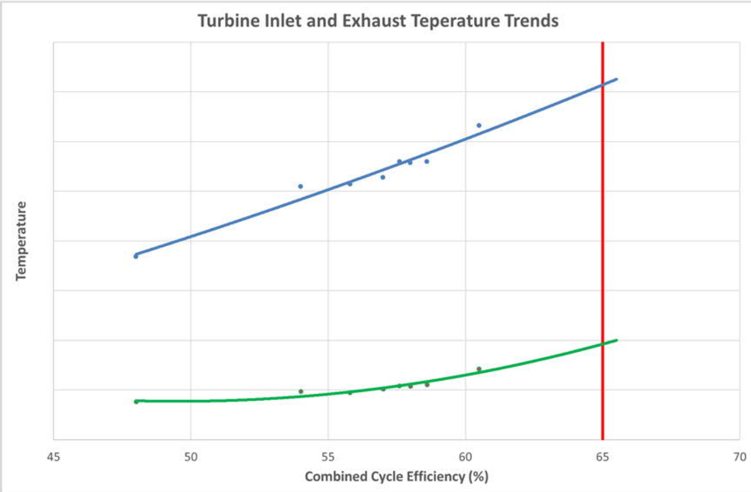
Background – Toward a 65% CC System

Combined Cycle Power Plant



Brayton Cycle **Rankine Cycle**

Source: Ibrahim et. al (2012)



Increasing aerodynamic efficiency, decreasing turbine cooling & leakage air (TCLA) consumption and increasing pressure ratio improve gas turbine efficiency but also increase temperatures at the back end of the turbine

Brayton Cycle

- Plant output and efficiency improved by raising the top of the cycle
- i.e. **Higher firing temperature** and **pressure**.

Rankine Cycle

- Plant output and efficiency improved with better utilization of GT Exhaust energy.
- i.e. **Higher bottoming steam temperatur**e and pressure.

Increased firing and bottoming cycle temperatures to improve efficiency are driving to increased exhaust temperatures and need to cool last stage turbine blade

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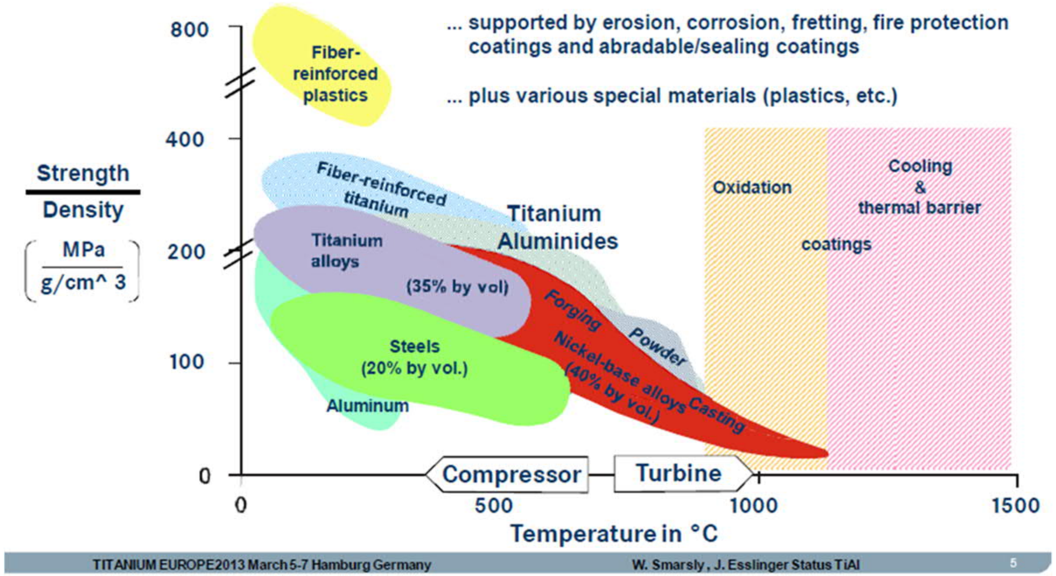
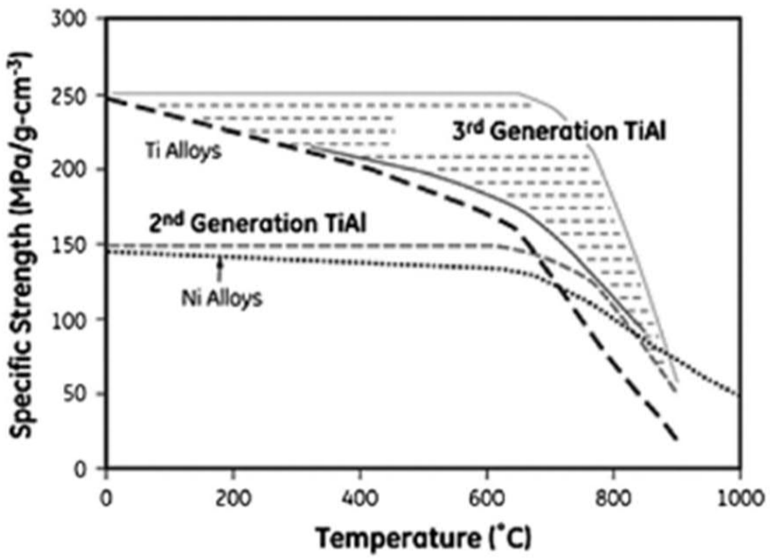
Background – Benefits of TiAl Materials



Source: Smarsly et al, "Status of Titanium Aluminides for Aero Engine Applications", Titanium Europe2013 (2013)



Source: Bewlay et al, "TiAl alloys in commercial aircraft engines", Materials at High Temperatures (2016)

TiAl alloys useable strength and temperature capabilities are approaching Ni based alloys for lower temperature turbine components – reduced density improves margins on disk pull loads

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Project Objective -

Develop a prototype Titanium Aluminide (TiAl) Cooled blade design for large turbine last stage blade applications –

- Select and evaluate an available TiAl material suitable for investment casting
- Evaluate design implications and challenges required to design a large cooled turbine blade utilizing the selected material
- Identify technology gaps remaining to implementing such a material for the intended purpose
- Perform design optimization with the goal to provide a suitable prototype design for the baseline application

Objectives defined to identify process and potential prototype design for potential engine testing

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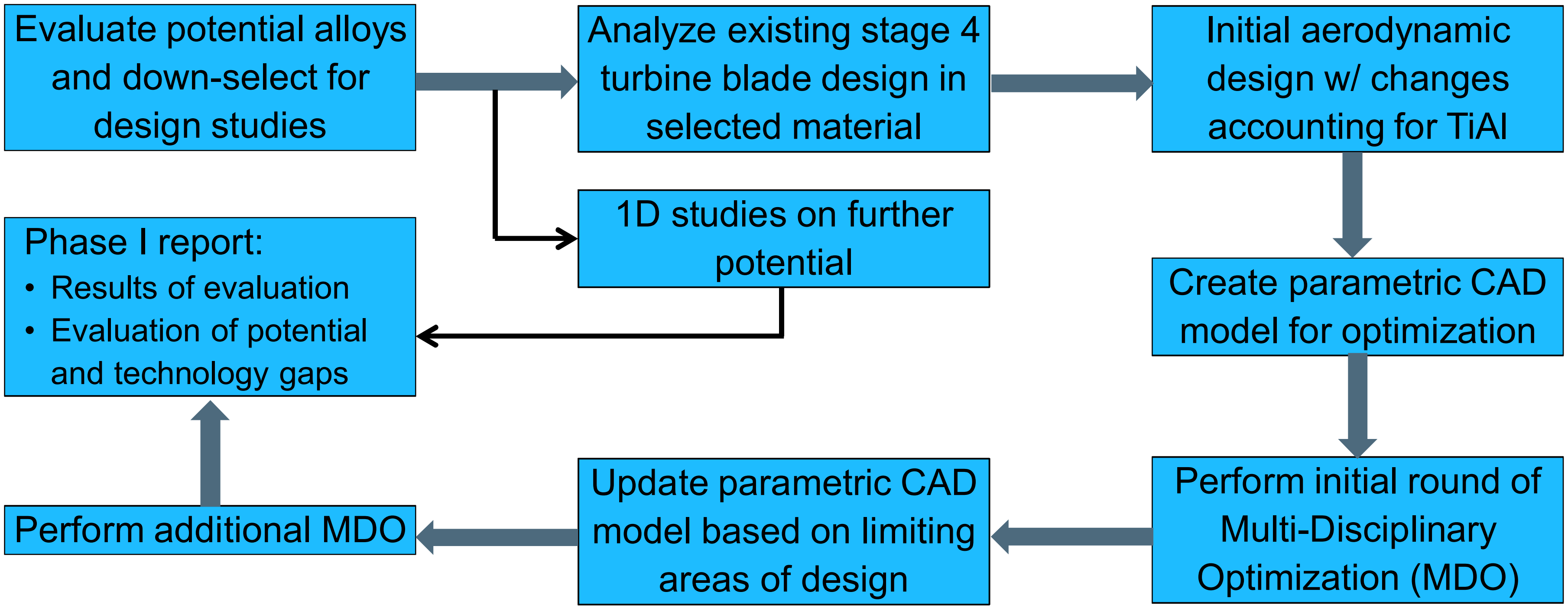
Technical Approach - Process



Approach evaluates impact of TiAl alloy selection on existing stage 4 turbine blade design, identifies necessary improvements and undertakes a MDO approach to design improvement

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TiAl Material - Initial Literature Screening

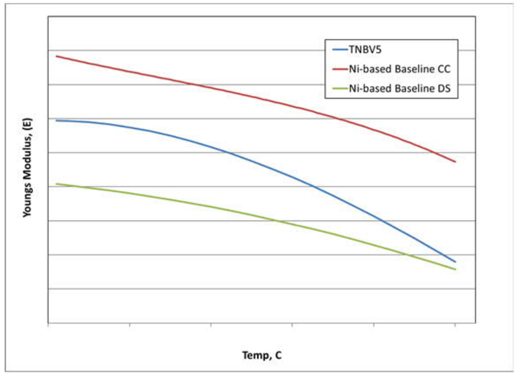
Mechanical Properties	TNBV5	45XD	47XD	ABB-INM2	WMS	Ti-47Al-2Cr-0.2Si	48-2-2	Ti44Al4Nb 4Zr0.2Si1B	γ-TAB	NCG 359
RT Yield Strength	Green	Green	Yellow	Yellow	Yellow	Yellow	Red	Green	Yellow	Red
HT Yield Strength	Green	Green	Red	Yellow	Red	Red	Red	Grey	Yellow	Grey
RT UTS	Green	Yellow	Red	Red	Red	Red	Red	Yellow	Red	Red
HT UTS	Green	Red	Red	Red	Red	Red	Red	Grey	Red	Grey
RT EL%	Yellow	Green	Green	Yellow	Red	Red	Green	Red	Green	Yellow
HT EL%	Green	Yellow	Grey	Green	Red	Green	Green	Grey	Green	Grey
LCF	Green	Yellow	Grey	Grey	Grey	Grey	Red	Grey	Grey	Grey
HCF	Green	Red	Yellow	Green	Grey	Grey	Red	Grey	Grey	Grey
Creep	Green	Green	Green	Yellow	Green	Red	Yellow	Green	Grey	Green

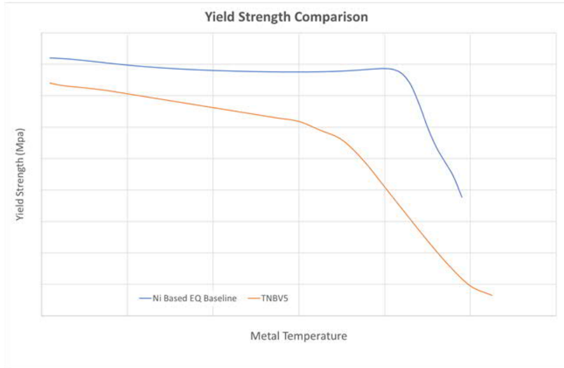
Property Tiers	
Best	Green
Better	Yellow
Good	Red

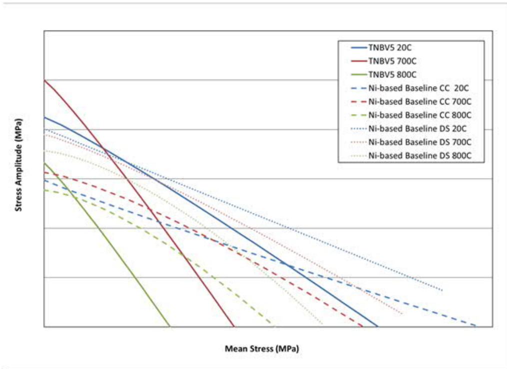
TNBV5 showed the most promising balance of properties for a cast alloy that gave an application temperature potentially over 700° C.

TNBV5 – Material Property Analysis

Property	Data Collected	Data Fully Analyzed and Package Prepared	Estimated Curves Uploaded to Material Center for use in Design
Physical	✓	✓	✓
Elastic	✓	✓	✓
Creep	✓	✓	✓
Tensile	✓	✓	✓
LCF/TMF	✓	✓	✓
HCF	✓	✓	✓
Fracture Mechanics	✓	✓	✓







Material properties have been estimated for design studies and optimization for design feasibility

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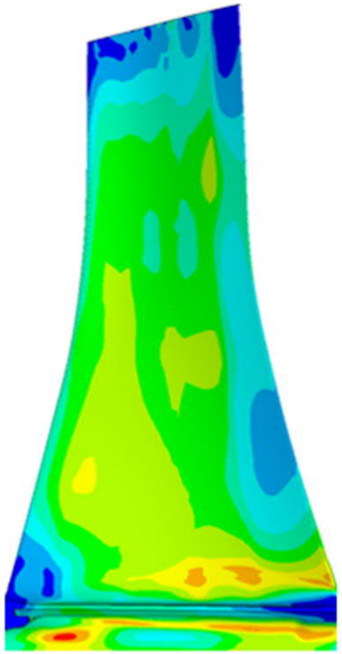
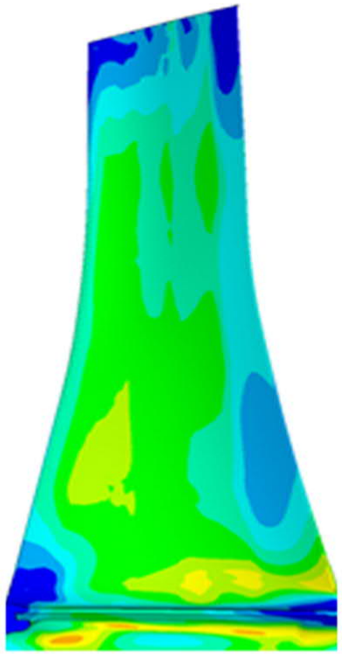
Baseline Design Evaluation – Steady Stress



Ni based

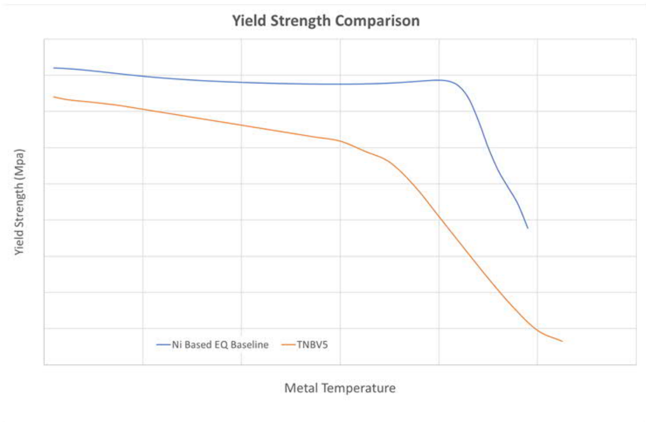


TNBV5

Scale reduced 0.6x

Baseline Design Evaluation –

- Baseline boundary conditions used
  - Thermal
  - Pressure
  - Mechanical
- Comparison to Ni-based Equiax results
- Estimated elastic material properties utilized
- Contours plotted at reduced scale to account for density differences



Steady stress behavior closely follows conventional nickel based alloy accounting for reduced density of TiAl

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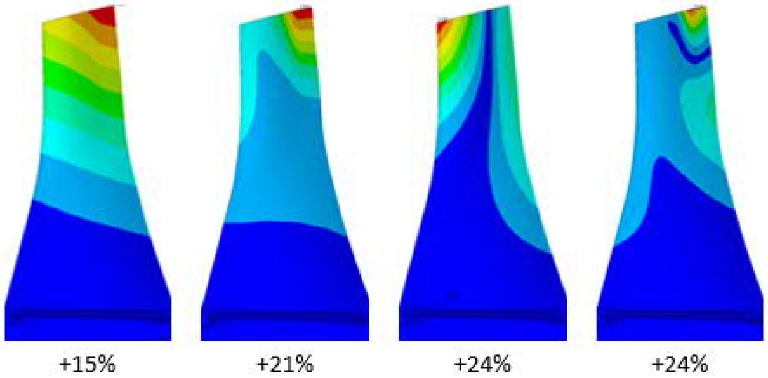
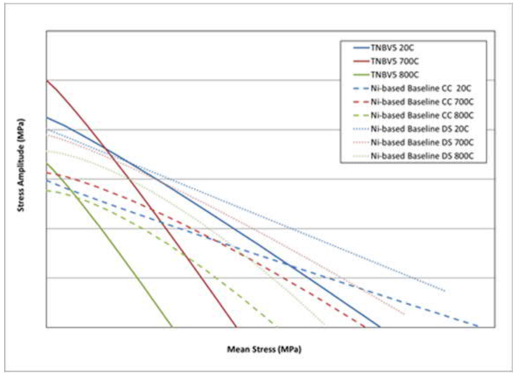
Baseline Design Evaluation – Modal & HCF





Modal & HCF Impacts –

- Modal frequencies increased 15% - 24%
- Additional tuning required
- Reduced endurance limit compared to Ni-based baseline indicate additional reductions of steady stress required

Design modifications required for TiAl to meet HCF

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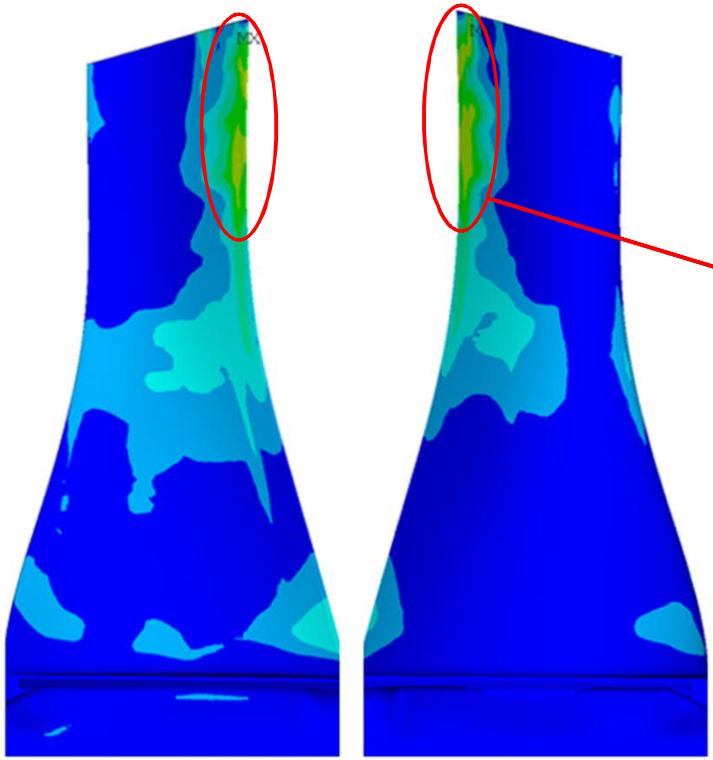
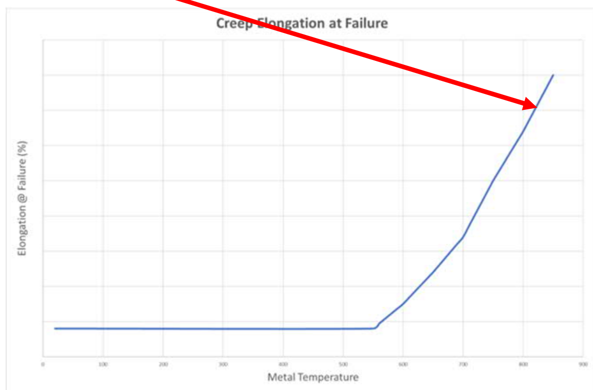
Baseline Design Evaluation – Creep Deflection



Baseline Design Evaluation –

- Baseline boundary conditions used
  - Thermal
  - Pressure
  - Mechanical
- Creep at full life shown
- High creep regions within allowable



Baseline evaluation of creep shows acceptable results for TNBV5

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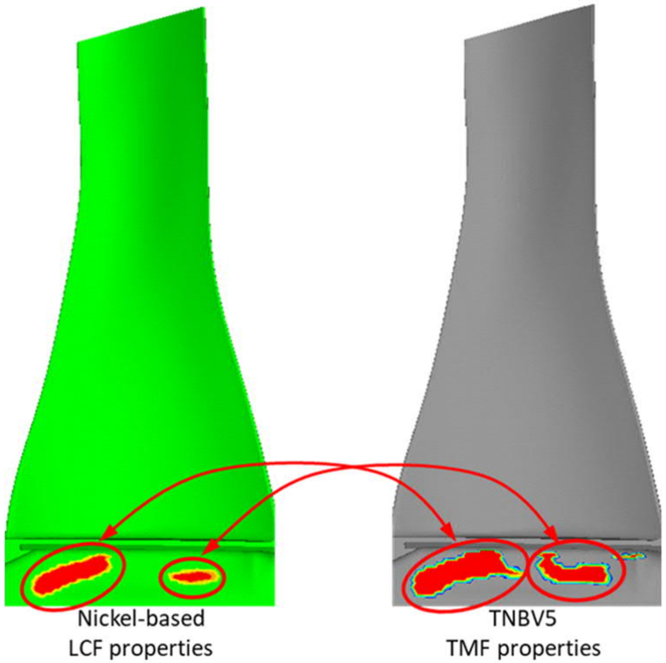
Design Optimization

Initial Round of Optimization –

- 982 geometries created
- 476 solutions generated
- Criteria based on –
    - Mode 1 & mode 2 eigenfrequencies
    - HCF utilization relative to endurance limit
    - Aerodynamic parameters (efficiency, flow angle, 1D flutter criteria)
    - Allowable pull load (reduced from baseline)
- 19 cases met defined criteria
- Optimization target → maximize cyclic life
    - Low ductility requires avoidance of cracks

Status –

- Cyclic life requirement met in optimized regions of blade
- Low cyclic life – high compressive stress – attachment related
- Excessive creep deflection near tip TE (high temperature location)



Lowest life locations indicated through use of surrogate LCF model for Ni alloy

Additional optimization needed to address areas not included in round 1 of optimization

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Next Steps and Technology Gaps-

Next Steps -

- Parameterize limiting locations identified in initial optimization round
- Evaluate fracture life for high compressive stress limiting location
- Final Reporting

Technology Gaps –

- More complete characterization of material needed
- Wear properties w/ potential damper materials needed
- Environmental protection – oxidation / corrosion resistance – need not determined

Initial optimization resolved issues identified in baseline evaluation – additional optimization required to resolve additional topics

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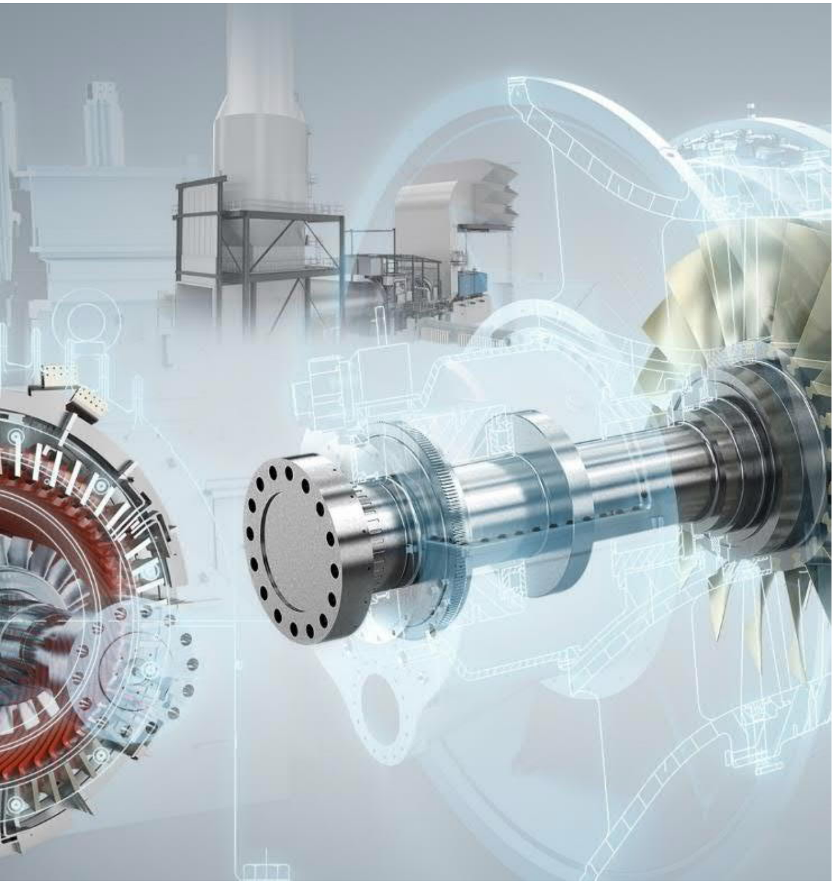

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