HIGH TEMPERATURE METALLIC SEAL/ENERGIZER DEVELOPMENT FOR AEROPROPULSION AND GAS TURBINE APPLICATIONS

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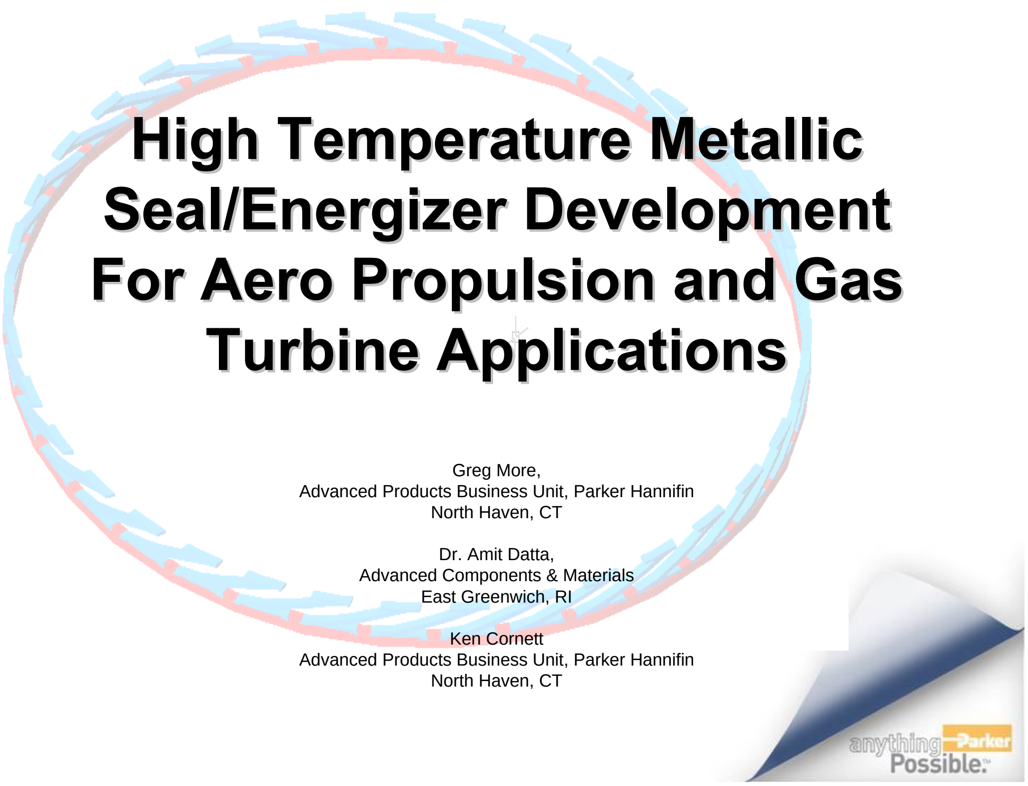
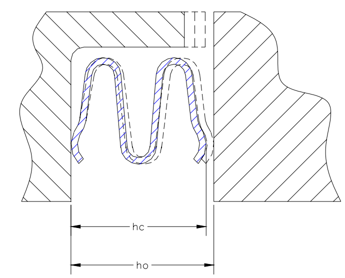
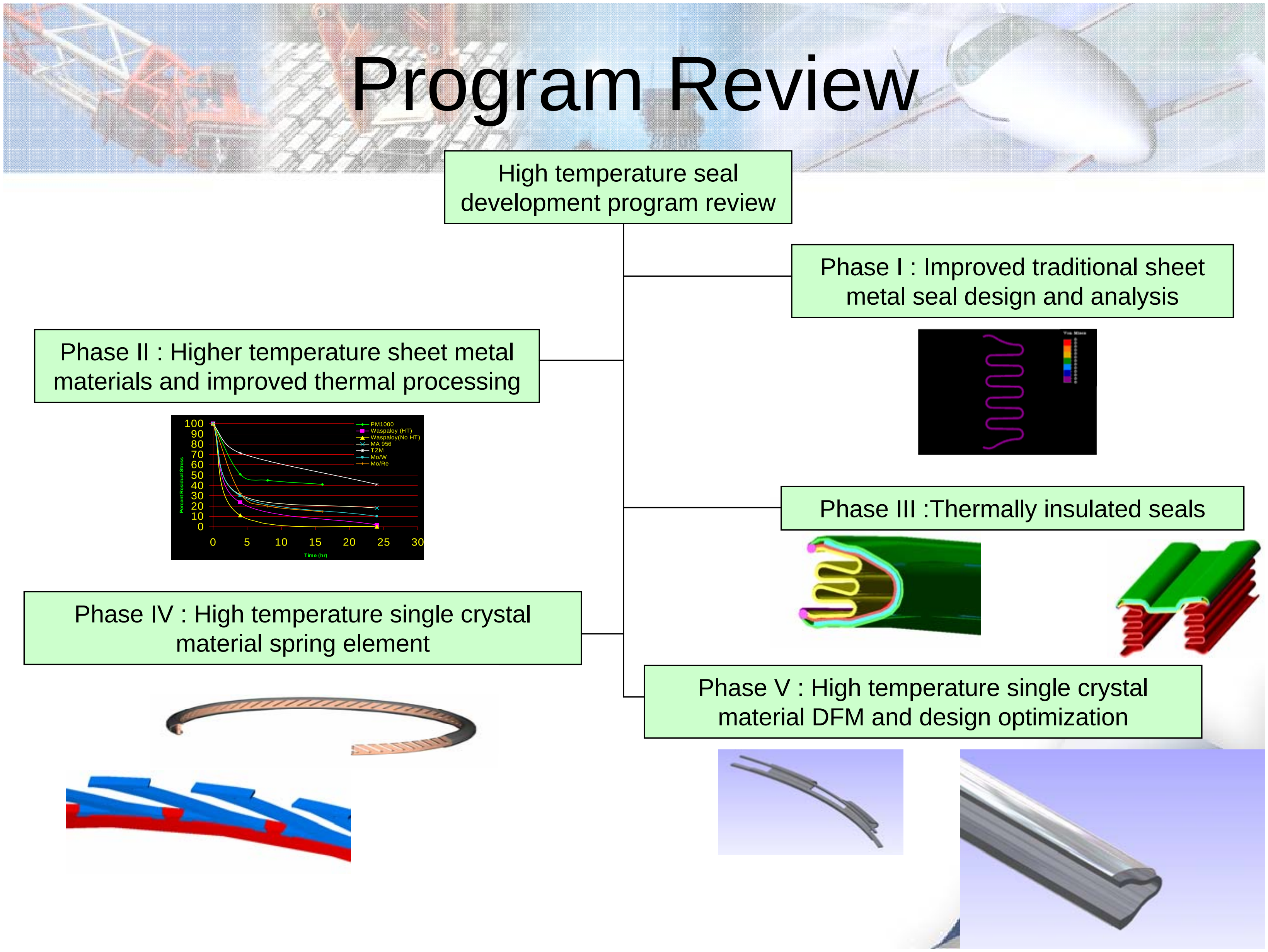


High Temperature Static Seal Development

- Industry Requirements – Industry is requiring seals to operate at higher and higher temperatures.
  - Greater efficiency
  - Reduced cooling air requirements
- Seal Problem – Traditional static seal designs and materials experience stress relaxation. Over time seals loose their ability to maintain contact with moving flanges.
- Solution – High temperature seal development program
  - Multiphase program with incremental increases in seal operating temperatures

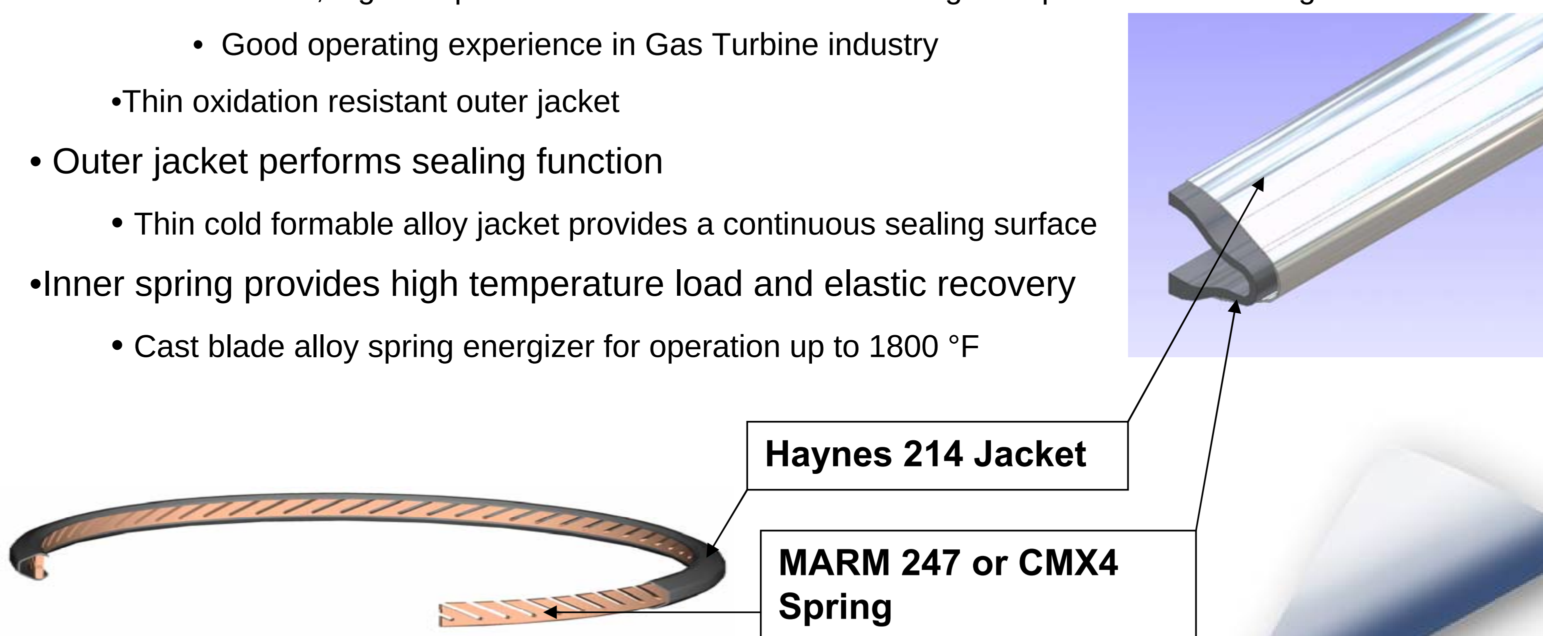


Seal gap is created resulting from stress relaxation at elevated temperatures. The original seal height ho is reduced to hc creating a gap when the flange moves away from the compressed condition.


Program Review
High temperature seal development program review
Phase I : Improved traditional sheet metal seal design and analysis
Phase II : Higher temperature sheet metal materials and improved thermal processing
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
PM1000
Waspaloy (HT)
Waspaloy(No HT)
MA 956
TZM
Mo/W
Mo/Re
Phase III :Thermally insulated seals
Phase IV : High temperature single crystal material spring element
Phase V : High temperature single crystal material DFM and design optimization

Innovative Seal with Blade Alloy Spring

- In order to achieve next temperature range a different, non-traditional sealing, methodology is utilized
  - Separate seal loading and pressure barrier functions
  - A well known, high temperature cast material is used as high temperature seal energizer
    - Good operating experience in Gas Turbine industry
  - Thin oxidation resistant outer jacket
- Outer jacket performs sealing function
  - Thin cold formable alloy jacket provides a continuous sealing surface
- Inner spring provides high temperature load and elastic recovery
  - Cast blade alloy spring energizer for operation up to 1800 °F



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Innovative Seal with Blade Alloy Spring

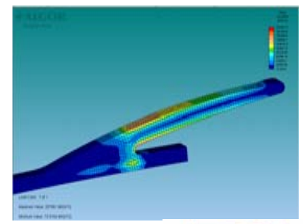
Cast Blade alloys have extremely high strength

Alloy	Temperature,° F	Yield Strength,ksi	Elongation,%
MARM 247, poly crystal	1400	130	12
CMX4, Single crystal	1600	114	18
INCO 718,poly crystal	1472	100	10
Waspaloy,poly crystal	1600	75	35

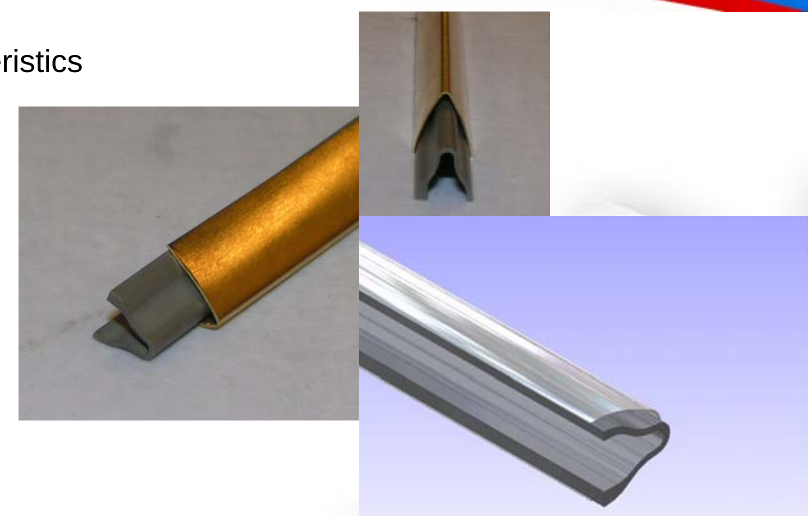
- Blade alloys also have superior creep and stress rupture strength compared to cold formable superalloys. Hence, blade alloys have higher resistance to stress relaxation.
- Manufacturing Challenge - Blade alloys are only available in the cast condition (poly or single crystal)

Spring Design Evolution

- Prototype I
  - Solid ring machined from a single casting
  - Basic finger design, not optimized with FEA
  - Opportunities for design and manufacturability enhancements



- Prototype II
  - Independent finger and support ring configuration
    - Improved DFM and lower manufacturing cost
    - Fine tune spring load and seal load
      - Adjust number of the number of fingers
  - FEA optimized finger configuration
  - Significantly improved stress relaxation characteristics
- Prototype III
  - Build from successes of PI and PII
  - Thorough FEA optimization
  - DOE optimized DFM program
    - Standard length U-Spring
    - U-Spring lengths to be joined into a hoop



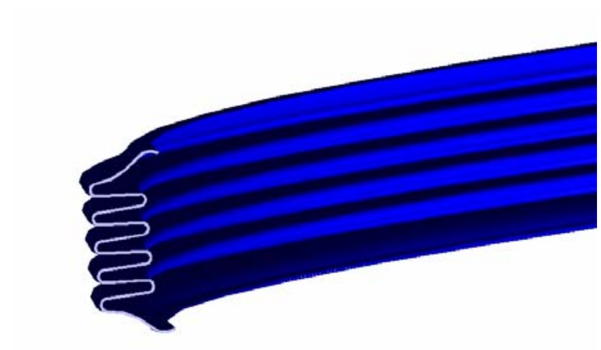
Comparative Relaxation and Leakage Testing

Cross Sectional comparison of high temperature sealing designs

High temperature modular seal

- Standard E-Seal with blade alloy spring

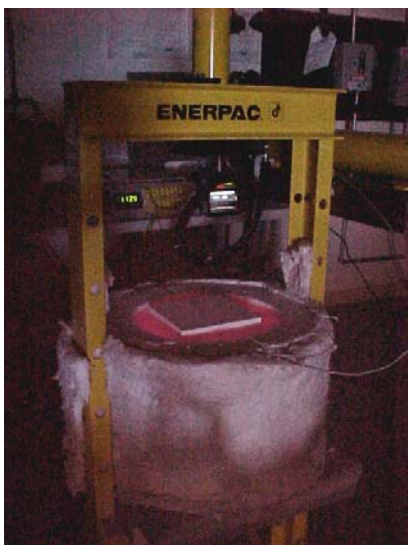
Traditional E-Seal produced from high temperature Waspaloy alloy



Stress Relaxation And Leakage Rate Testing

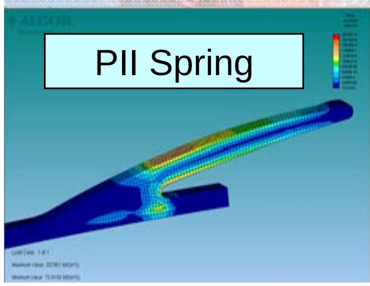
Performance testing experimental procedure:

- Stress relaxation
  1. Seals were compressed 15% between flanges and heated to 1600 ^{o}F for specified time periods
  2. After each exposure, seals were cooled to room temperature to measure change in seal free height
  3. Change in seal free height is then used to calculate usable seal springback
- Leakage testing
  – Identical to steps 1 – 3 above and seals were room temperature leakage tested as step 4

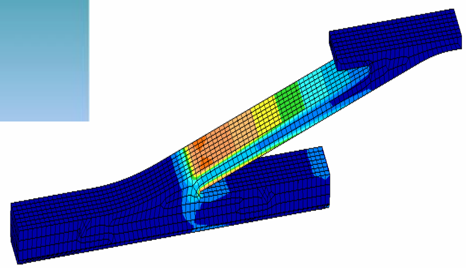


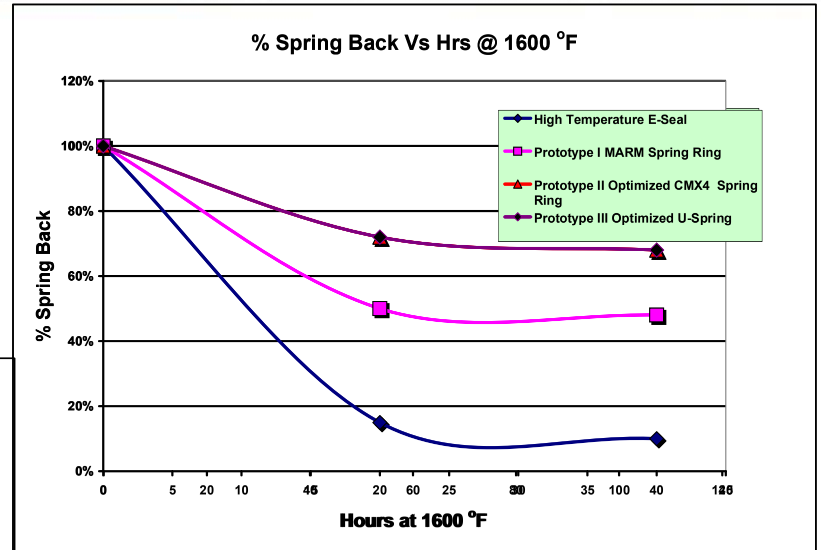
Phase V : Testing Results

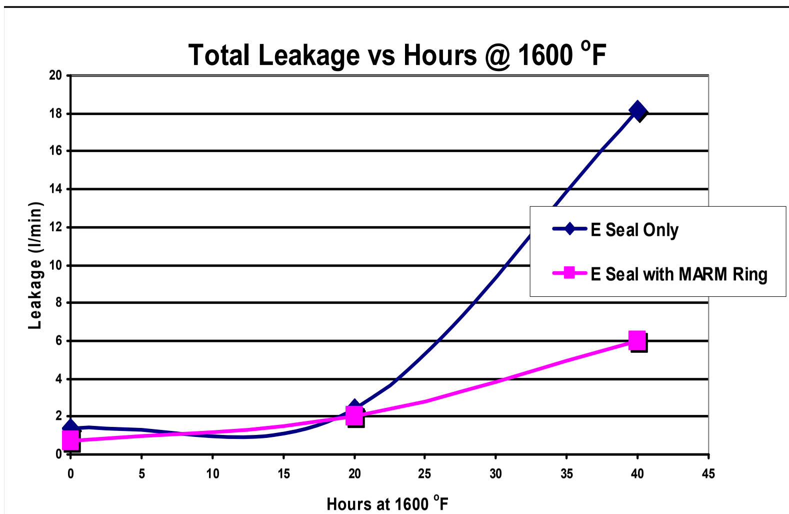
PII Spring



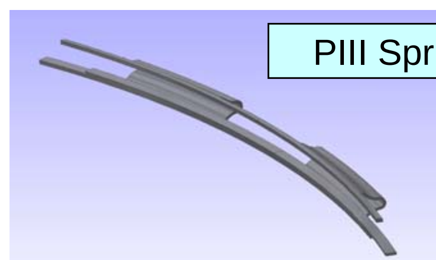
PI Spring







PIII Spring



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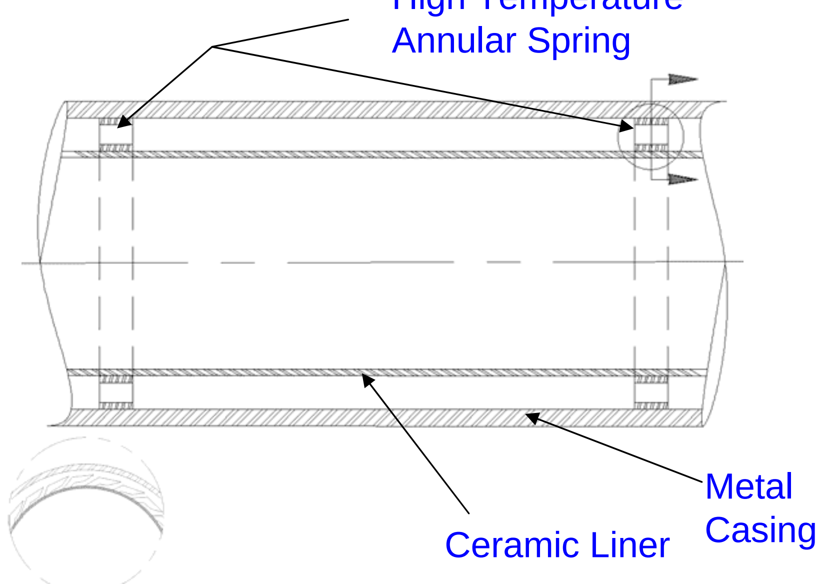
Spring Seal Manufacturing

- Optimization for manufacturability has been the primary program goal for 2006
  - Convert the fundamental concept into a commercially viable design with similar performance characteristics to Prototype II
- Through FEA analysis and design DOE an improved design configuration was developed
- Modular manufacturing approach
- Standard U-Spring configuration has been developed, produced, and tested
- U-Spring nests nicely within thin sheet metal jacket
  - Jacket serves as primary pressure barrier
  - Standard formed sheet metal jacket

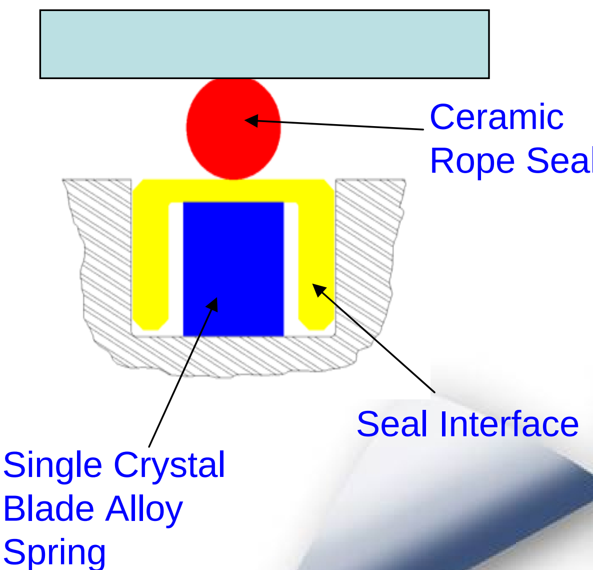
- Standard U-Spring configuration allows for cost effective linear seals and hoop seals
  - By joining multiple U-Springs, any diameter seal can be cost effectively produced
  - Cast as a single crystal material
  - Design will use as cast near net shape to keep manufacturing costs low
- Patent pending manufacturing and processing approach

Other Applications for High Temperature Spring Design

- Transition fastener between metal and ceramic components with a large α-mismatch
- Combustor CMC liner– low load, large deflection spring at 1800F

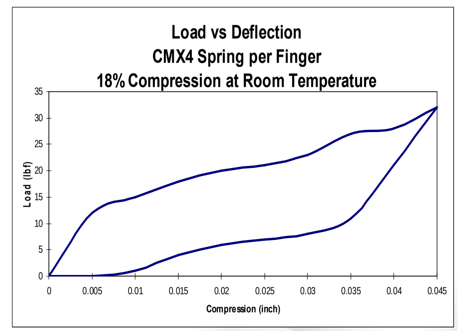


- Low-load/ high deflection spring energizer for extremely high temperature (>2000F) ceramic sliding seal



Conclusions

- The Ultra High Temperature seal program has successfully progressed and developed a high temperature static seal solution
- The third prototype has successfully combined the first and second prototypes high performance capabilities in a commercially viable solution
- Prototype II and Prototype III are viable solutions
  - Prototype II offers flexible load tune ability and seating load adjustment
  - Prototype III offers commercial viability for continuous hoop seals
- Moving forward
  - Better understanding of 100 hr data
  - Invest in production tooling
  - Develop final manufacturing process
  - Develop a production product technical performance data sheet
- Future activities
  - Stress relaxation testing at 1600 °F shows good usable performance, next phase will be to perform testing at 1700 °F and 1800 °F
  - Better characterization of longer test periods
  - Other designs for operation at higher continuous operating temperatures are currently under development



Questions ?