UPDATE ON DOE ADVANCED IGCC/H_2 GAS TURBINE

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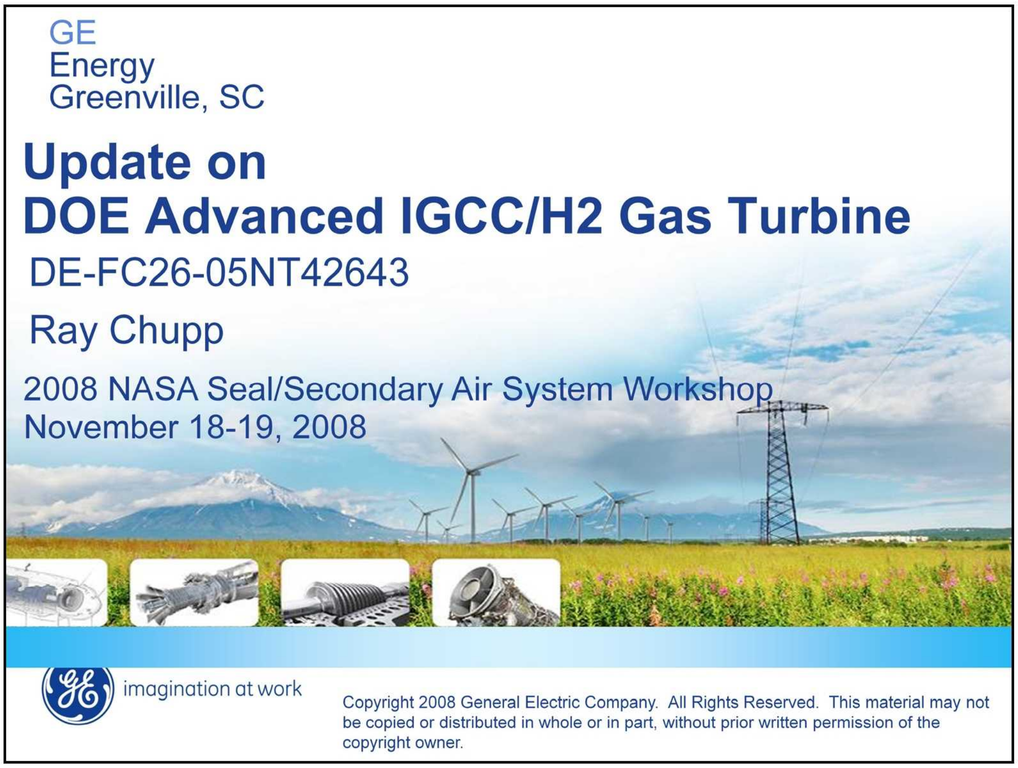

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Update on DOE Advanced IGCC/H2 Gas Turbine

DE-FC26-05NT42643

Ray Chupp

2008 NASA Seal/Secondary Air System Workshop
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IGCC - H_2 Gas Turbine Landscape

Objective

Cleaner Energy from Coal

via

IGCC with Carbon Capture

Approach / Capability

Today

GE existing products: 7FB-H2

- High-H_2 GT fleet
- Successful operation
- Diffusion flame
- Diluent for NOx

FB-H2

Future

Technology Advances - DOE Program

- Reduced NOx (2ppm)
- Increased Performance (+3-5pts)
- Increased Output
- Reduced Cost

	emissions	efficiency	output	cost
Combustion	✓			
Turbine	✓	✓	✓	✓
Materials	✓	✓	✓	✓
Systems	✓	✓	✓	✓

Program Timeline

2005	2006	2007	2008	2009	2010	2011	2012	2013 - TBD
Phase I (CPT) Concept Design		Phase II (Awarded, In Progress) Detailed Design & Component Validation Test					Phase III (Not Yet Awarded) Final Design & Field Evaluation	

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Combustion Technology:

Phase I… focus on fundamentals → Modeling; Subscale testing; Limited full scale, multi nozzle testing

- 'Chemistry' evaluation – fuels, mixing, residence time, EGR
- Benchmark existing NG designs on high H2 fuels
- Evaluate 1st Gen prototypes (based on traditional designs)
- Evaluate 2nd Gen prototypes (more 'out-of-the-box' – designed specifically for high H2)

Phase I Goal Complete: Select top two concepts for further evaluation in Phase II

Phase II… design optimization

- Optimize designs for resistance to flashback, flameholding, dynamics
- Obtain data to minimize risk
- Validate the technology

Status: **Initial full can/larger scale testing of down selected concepts providing promising results, continuing to drive down emissions and extend operability**

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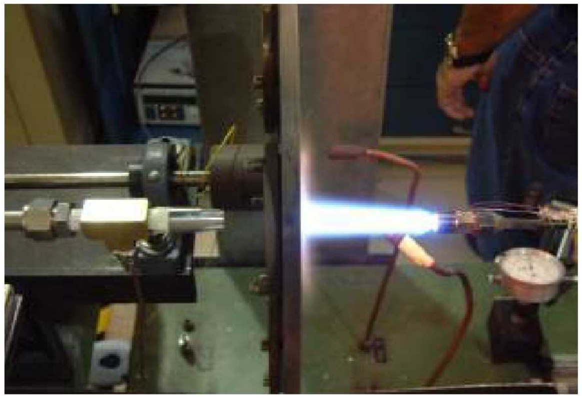
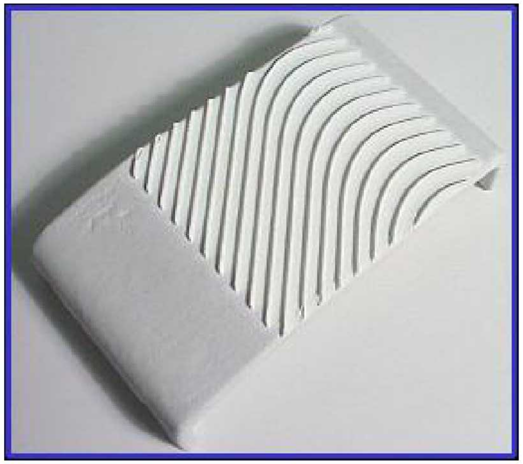
Materials Technology:

Phase I… characterization and development

- Characterizing the environment
- Identification of candidate material/coating systems
- Development of screening tests for material systems (corrosion, erosion, impact)
- CMC/EBC development



Phase I Goal Complete: Screened list of candidate material systems for Phase II



Phase II… enabling turbine technology improvements

- Validation of material systems at component level
- Field testing of components where applicable

Status: **Interim down select completed with significant capability improvements, line of sight to program targets**

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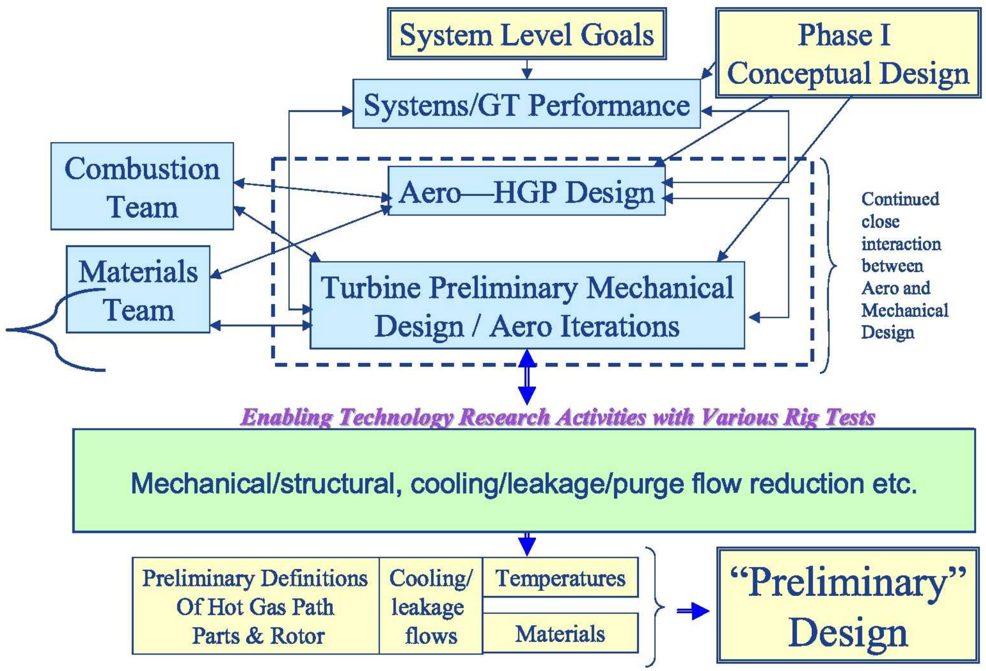
Turbine Technology:

Phase I… identifying turbine technology improvements

<u>Phase I Goal Complete</u>: Technology development plan for Phase II

Phase II effort is an integrated process with other discipline areas to develop turbine technologies to achieve DOE goals



<u>Phase II Goal</u> **: Validated technologies at the component level**

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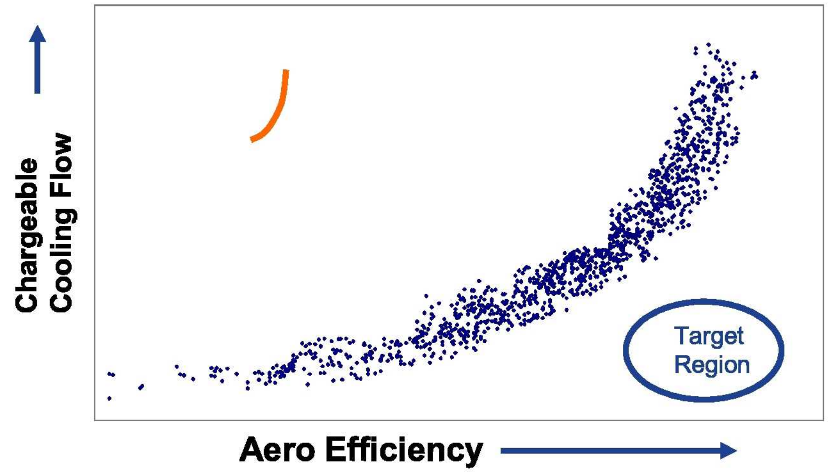
2008 NASA Seal/Secondary Air System Workshop, No. 18, 2008, Ohio Aerospace Institute (OAI)

Turbine - Aerodynamics

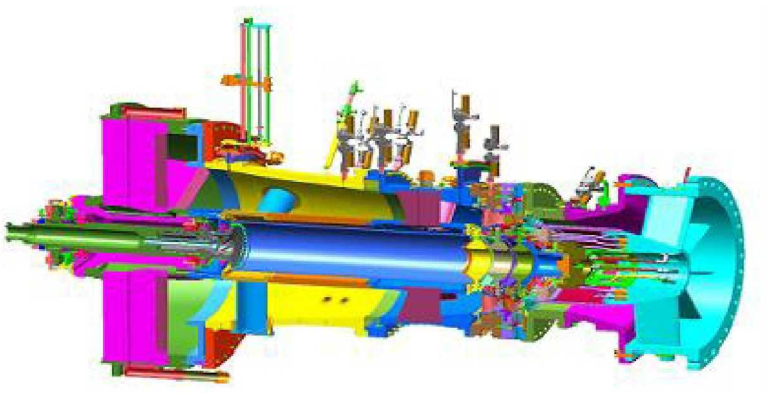


Advanced Design

- work splits, reaction, and airfoil counts.
- 3-D Aero & Endwall Contouring

Turbine Rig Testing

- Learning, Validation



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Turbine - Mechanical

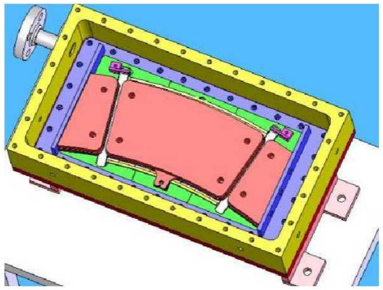
Turbine Goal:

– Higher component efficiency with higher flow rates

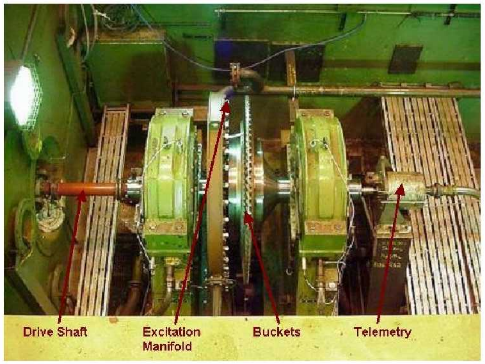
Turbine Efforts Launched:

– Conceptual design studies on different turbine concepts – aerodynamic and mechanical
– Advanced technology development to reduce parasitic leakages
  – Transition Piece/Stage 1 nozzle seal
  – Turbine interstage beneath nozzle
– Advanced technology dev. to address turbine blade durability
  – Damping effect on aeromechanics
  – Fretting and wear

TP/S1N Flow Fixture



Fretting & Wear Test



"Wheelbox" Rig Testing

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Turbine – Heat Transfer/Sealing Plans

- **Cooling Flow Reduction:**
  - Focus on improving turbine hot gas path part cooling efficiency
  - Applicable to current metallic turbine components and synergistic with advance materials
  - Address challenges of IGCC/hydrogen fuel environment (for example, possible cooling hole plugging)
- **Leakage Flow Reduction:**
  - Focus on decreasing turbine parasitic leakages, i.e. between static-to-static, static-to-rotating, and rotating-to-rotating turbine parts
  - Develop improved seal designs in a variety of important areas
- **Purge Flow Reduction:**
  - Focus on decreasing required flows to keep rotor disk cavities within temperature limits
  - Develop improved sealing at the cavity rims and modified flow geometries to minimize hot gas ingestion and aerodynamic impact

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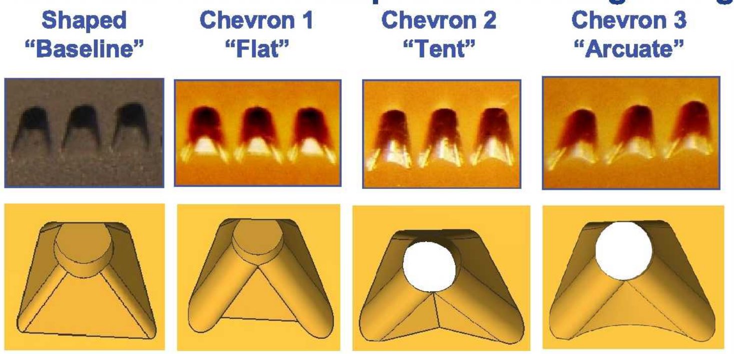
Cooling—Advanced Film Cooling

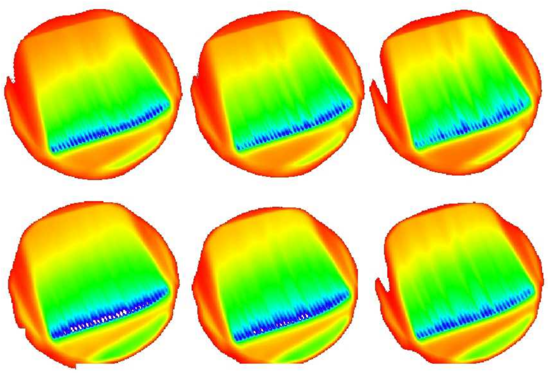
Diffuser and Chevron shaped film cooling hole geometries*



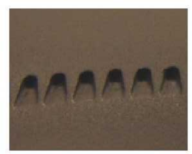
- 0.66 mm diameter
- 30-deg to surface tangent
- 20-deg lateral diffuser
- 10-deg laidback
- 0.46 mm diameter "chevron" edge troughs

Blowing Ratio or Pressure Ratio

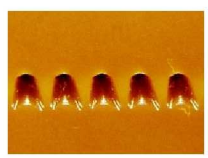
Low Moderate High



Shaped Holes



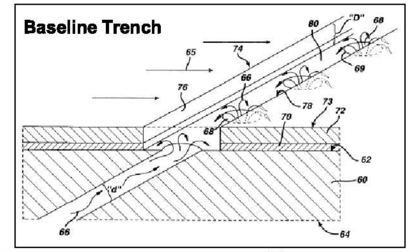
Chevron Holes

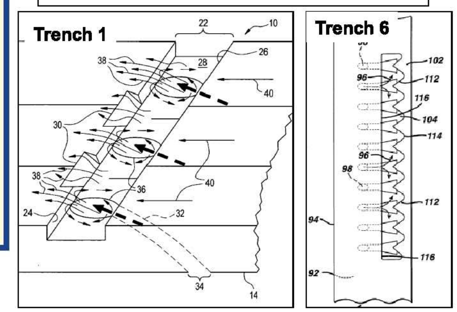


Full-surface film effectiveness data for diffuser shaped holes and chevron holes.

* Hole shapes based on US patents: 7,328,580, 6,234,755, 6,234,755, and 2008/0057271A1.

Example geometries for shallow trench film cooling*

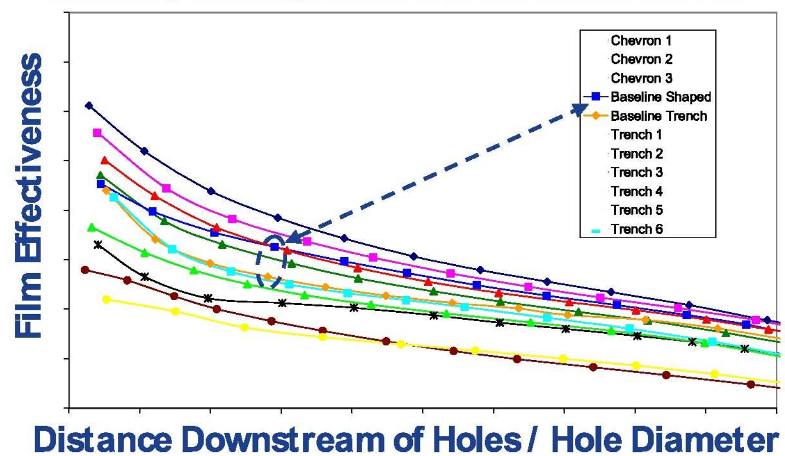




Results to date show:

- Some hole/trench configurations provide up to 20% higher average film effectiveness than diffuser shaped holes.
- Aerodynamic mixing losses were also measured

Laterally averaged film effectiveness curves



Advanced Sealing—Four Focus Locations

Transition Piece/Stage 1 Nozzle Seal

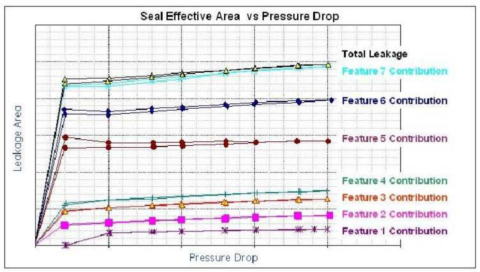


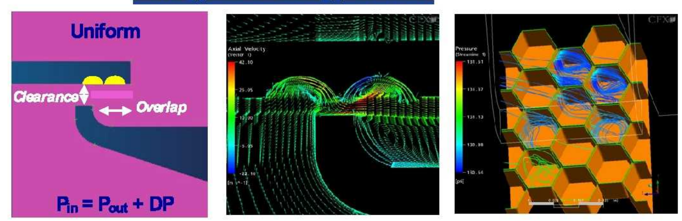
Figure 2. TP/S1N Seal Test Results – Component Contributions to Overall Leakage

- New flow fixture built to test engine size seals.
- Relative axial movement modeled.
- Leakage through various paths measured.
- Current and new seal designs tested to optimize seal design

Turbine Interstage Seal

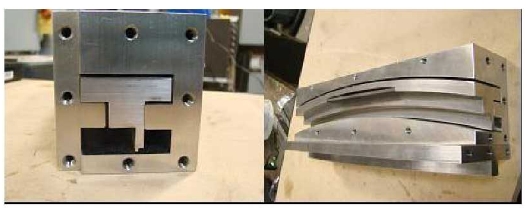
- New seal approaches investigated.
- Initial testing on 5-in flow rig.
- Intermediate size rig being built

Angel Wing Seal



- Identified optimum abradable geometry/material vs. location
- Flow resistance quantified via. CFD
- Honeycomb ➔ good flow restriction for engine radial closures
- Studying aluminizing honeycomb material to increase oxidation resistance

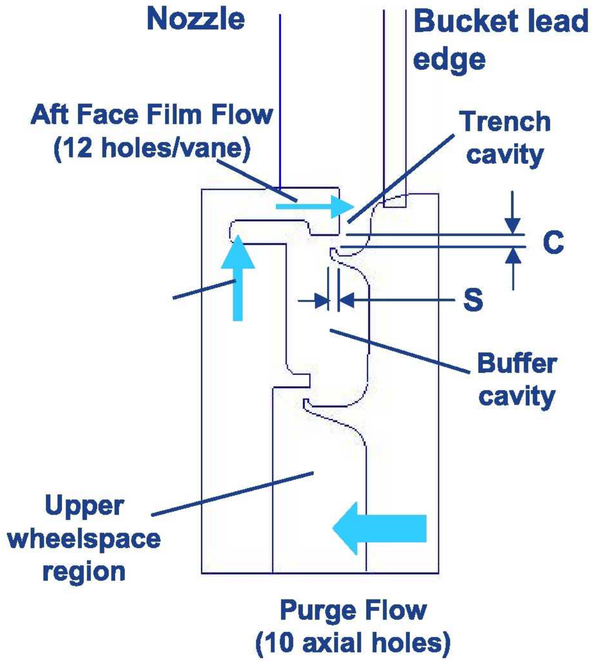
High Pressure Packing Seal

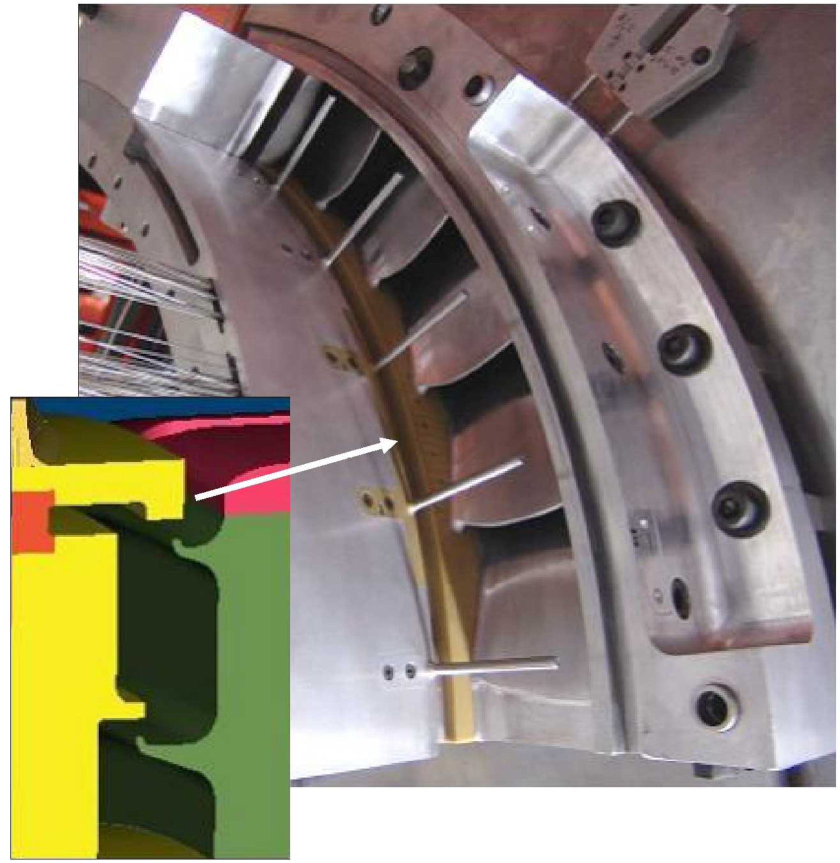


- Passive retractable brush seal design based on successful GE steam turbine retractable seals
- Testing at full pressure conditions

Purge Flow—Transonic Annular Cascade Screening Tests

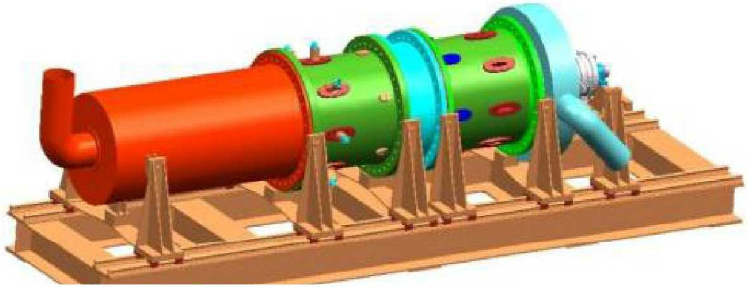
Regional static pressure distributions, Infrared surface temperature maps, trench and buffer cavity cooling effectiveness.



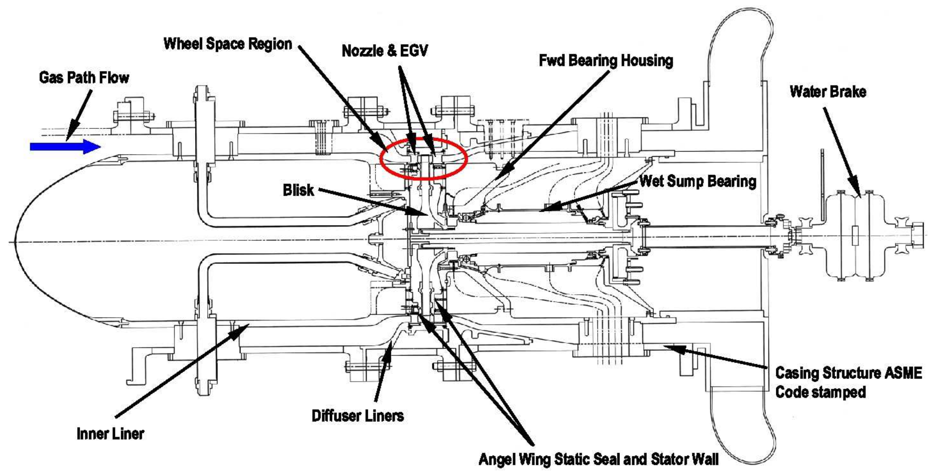


- Annular sector cascade rig run to gather data on rim seal region pressures, temperatures, and hot gas ingestion for various geometries.
- Data used to validate detailed CFD model analysis.
- Potential improved rim seal configurations being tested.

Purge Flow—Rotating Wheelspace Rig Development



Wheelspace Rig Schematic



Test Section Features

- Scaled baseline geometry with flexibility to model other engine configurations
- Features to allow testing variations.
- Rotating and static instrumentation
- Configurations will be tested to achieve optimum designs.
- Data will be used to validate detailed CFD models with rotation.

Summary and Conclusions

1. Strong program – structured to meet DOE goals on efficiency, emissions, and capital cost
2. Phase I completed – all milestones met and significant progress made:
   - Obtained near-entitlement NOx emissions at temperatures of interest for this program
   - Turbine technologies identified to achieve DOE goals – development will expand in Phase II
3. Phase II Underway:
   - Combustion focus narrowed to two concepts
   - Materials focus on optimization of materials/coating systems for environment
   - Heavier turbine effort on mechanical and aero aspects plus:
     - Cooling—initially looking at advanced film cooling
     - Sealing—focusing on four key leakage areas
     - Purge flow—initially using a cascade rig to screen configurations & validate CFD, rotating rig being developed

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