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Perspective on R&D Needs for Gas Turbine Power Generation in a Carbon Constrained World

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Overview - Requirements

- Power
- Efficiency
- Low Emissions
- Durability
- Cost

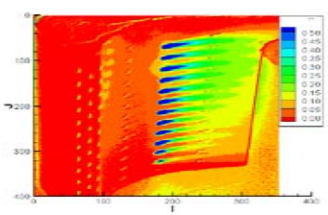
Overview - Current

- Looking at Last 15 Years
  - Requirements Substantially Increased
    - Performance
    - Durability
    - Green Operation
    - Time/Cost to Market (Design, Development & Manufacturability)
  - Significant Accomplishment in Turbomachinery Technology
    - University
    - Private Industry – OEMs & Suppliers
    - Government/Private/University Collaboration, e.g. UTSR

a)M=0.6 b)M=1.0 c)M=1.5 d) M=2.0

Figure 6. Post test images of deposits on C-M1 coupon at various blowing ratios.

UTSR: GT2008-50901



(c)

Figure 7. Local Film effectiveness distributions on the pressure surface-PS2 injection: (a) MFR=0.3%, (b) MFR=0.45%, (c) MFR=0.6%.

Industry: GT2007-27546

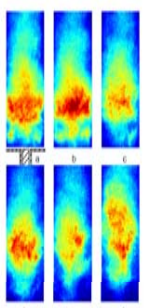


Figure 8: Consecutive images of 80%CH_4-20% H_2 flame under near blowoff conditions (ϕ =0.42; images separation =2ms)

UTSR: GT2007-27308

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Overview - Future

- Looking Forward
  - Technical Challenges Will Be Harder to Meet – “Learning Curve”
  - Competition for Resources Increased
    - Trained Engineers
    - Computer Power – Speed & Cost
    - Funding
  - Time to Market
- Required Approach
  - Collaboration
  - Pragmatic Research
    - Address Critical Problems & Requirements
    - Integrated/Interdisciplinary
    - Validation Mandatory
    - Must be Applicable in Industrial Design/Analysis Environment

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Perspective on R&D Needs for Gas Turbine Power Generation in a Carbon Constrained World – **Combustion**

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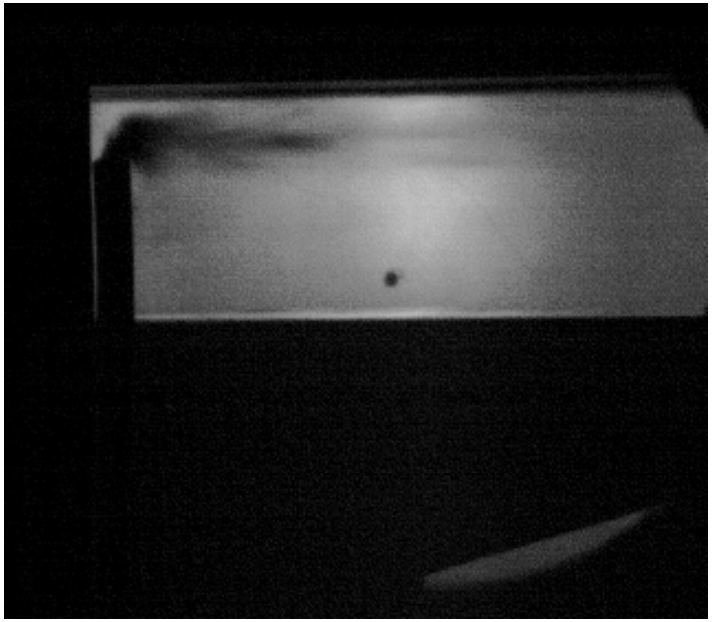
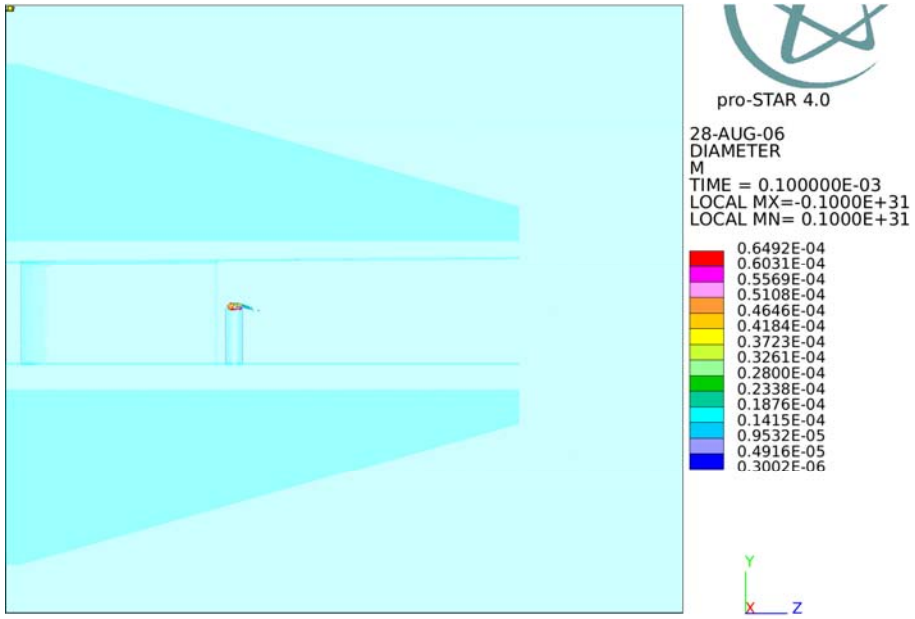
Liquid Atomization Analysis

Liquid Spray Rig
Droplet Animation (UCI)



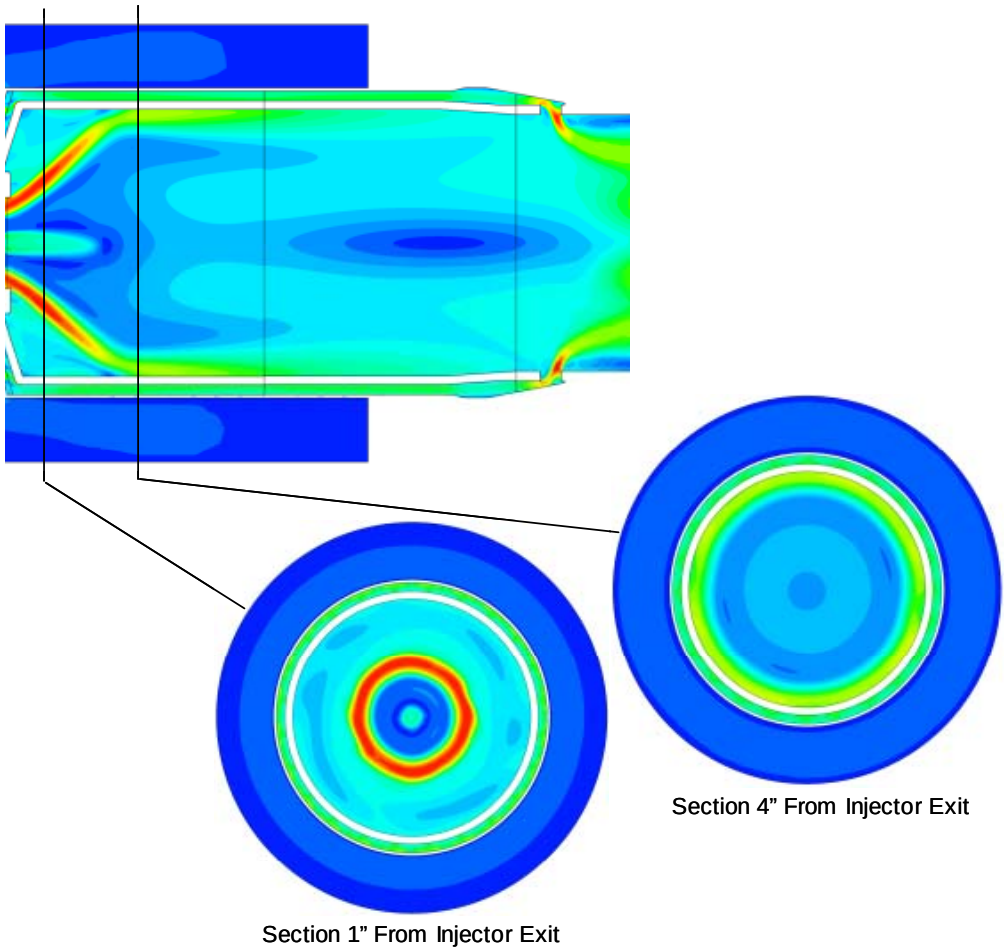
LES Liquid Spray Analysis



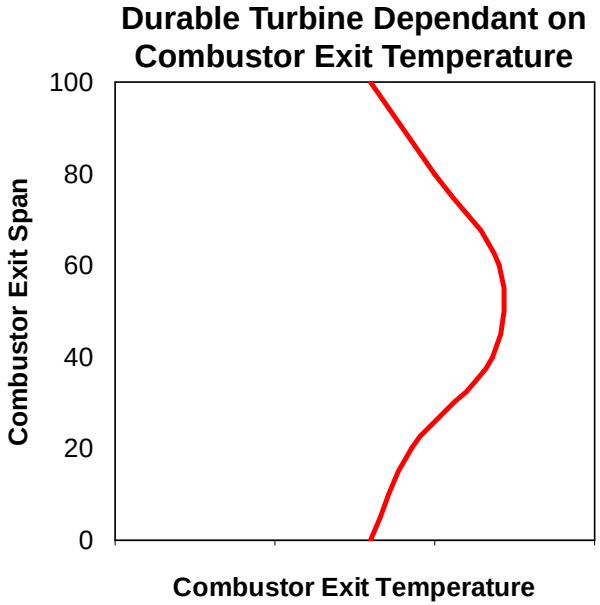
- Challenge to Predict Liquid Spray Atomization for Engine Conditions
- Requirements
  - LES Analysis
  - Test Validation

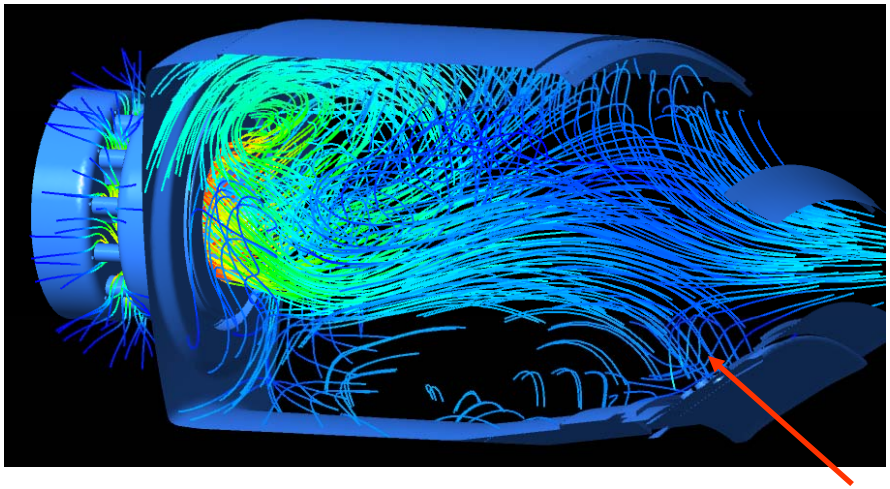
Combustor Liner Durability

- Challenge to Predict Liner Temperature
  - Complex Flowfields
  - Chemical Reaction
  - Cooling
- Requirements
  - External/Internal CFD Analysis – Phase I
  - CFD w/Conjugate HT – Phase II
  - Validation Data



Combustor Exit Profile





- Challenge to Trim Combustor Exit Profile to Meet Durability Requirements
- Requirement
  - CFD Based Methodology
  - Improved Turbulence Modeling

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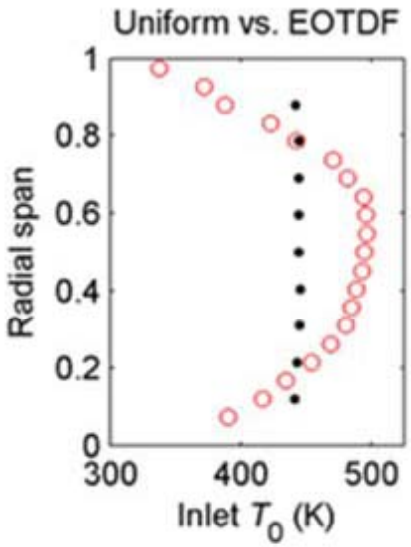
Perspective on R&D Needs for Gas Turbine Power Generation in a Carbon Constrained World – **Heat Transfer**

Adiabatic Wall Temperature



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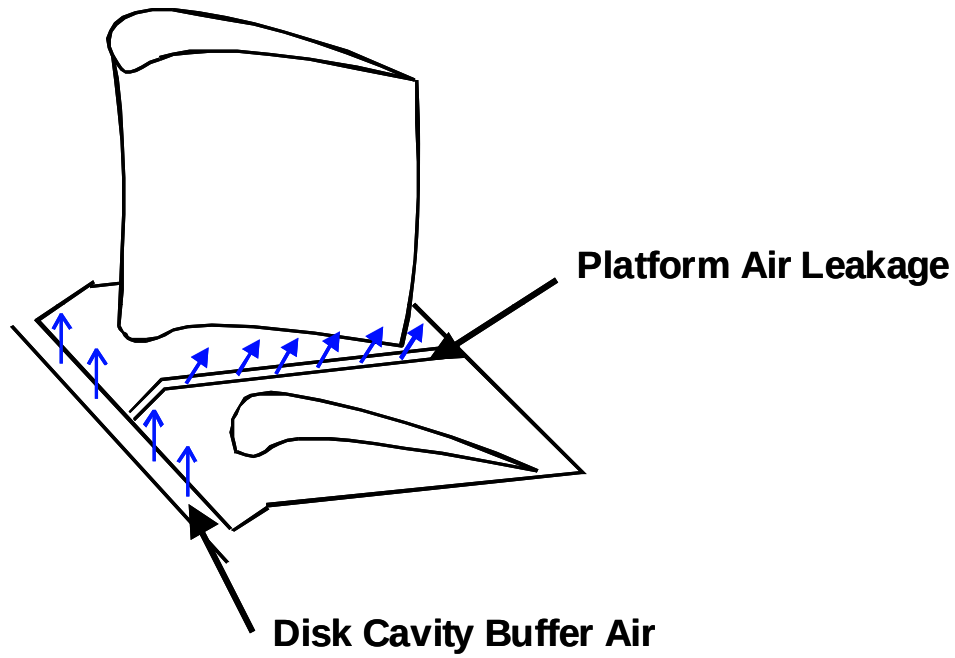

- Challenge To Predict Adiabatic Wall Temperature and Heat Transfer Coefficient Accounting for Inlet Temperature Profile and Buffer/Leakage Air Effects
- Require
  - CFD Based Models
  - Experimental Validation

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Disk Cavity and Seal Flow

1D Flow Network

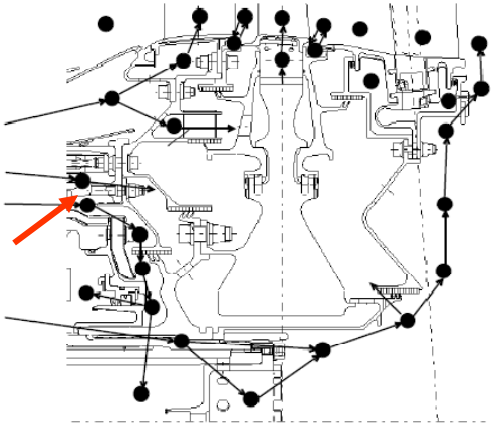

Figure 2 The 'Compact Thermal Model' linked with the main conjugate solution domain

3D CFD

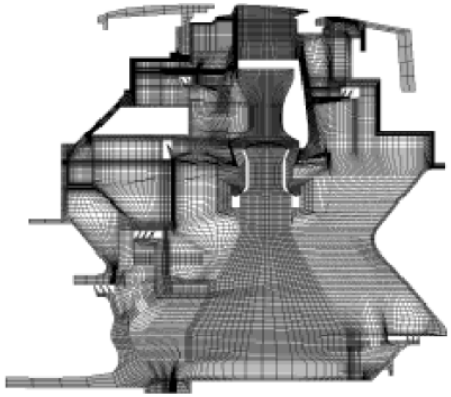

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Figure 1 Computational grid for conjugate analysis of the turbine rotor-stator system (meridional section)

- Challenge to Predict Heat Transfer HTC & Flow for Internal Secondary Flow
  - Seal Effectiveness for Various Configurations
  - High Swirl (Windage Effect)
  - Disk Pumping
  - Ingress/Egress
  - Radial Inward Flow (Little Available Data)
- Requirements
  - 1D Modeling
  - CFD Analysis
  - Test Validation

Airfoil Durability

- Challenge
  - 10 – 20 ^{o}F is Significant
  - 1D Flow Network and Finite Element Analysis Do Not Provide Details and Accuracy for Temperature - Especially at Airfoil Trailing Edge
  - Pure Convective Analysis No Longer Good Enough
  - HT Affected by Local Phenomena & Lateral Conduction
- Require Conjugate HT Analysis
  - Efficient Modeling
  - Experimental Validation

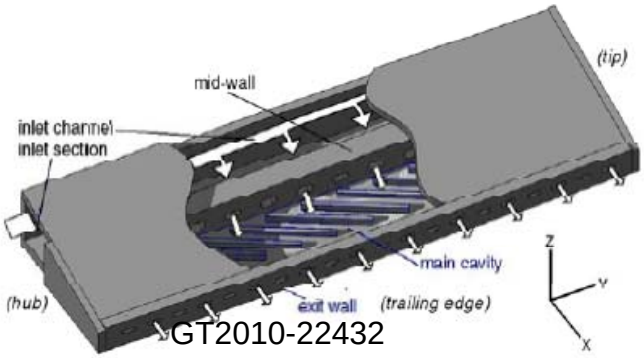

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FIG. 3 TEST SECTION

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Perspective on R&D Needs for Gas Turbine Power Generation in a Carbon Constrained World – **Materials**

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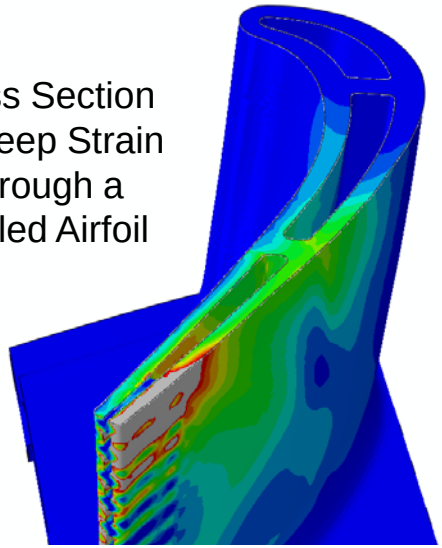
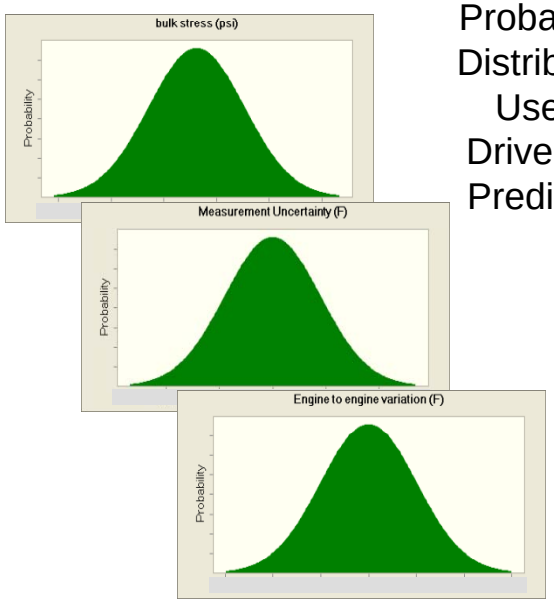
Materials Needs for the Future

- Challenge
  - Accumulation of Creep Damage in a Component can Lead to Deformation and Rupture with Catastrophic Results
  - Often Creep Damage Difficult to Monitor During Operation and Difficult to Predict Accurately
- Requirements
  - More Accurate Creep Damage Models
    - Damage Initiation
    - Progression in Single Crystal Materials
  - Faster More Cost Effective Methods for Developing Creep Material Data
    - Virtual Test Rigs
  - Improved Data Driven Probabilistic Lifing Models

Cross Section of Creep Strain Through a Cooled Airfoil





Probabilistic Distributions Used to Drive Lifing Predictions

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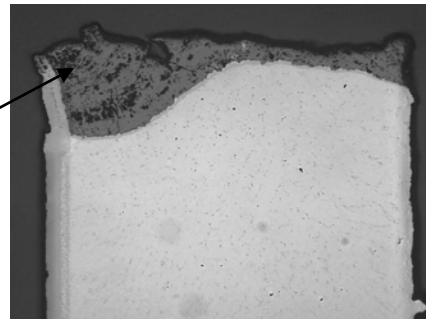
Materials Needs for the Future

- Challenge
  - Material Durability when Exposed to Various Combustion Gas Environments
    - H_2S/H_2/Offshore
    - Coke Oven Gas
    - Na_2SO_4, $CaSO_4$ & $MgSO_4$
  - Degradation Mechanisms Including High Temperature Oxidation, Hot Corrosion, Sulfidation and Thermal Degradation



Turbine blade Tip hot corrosion

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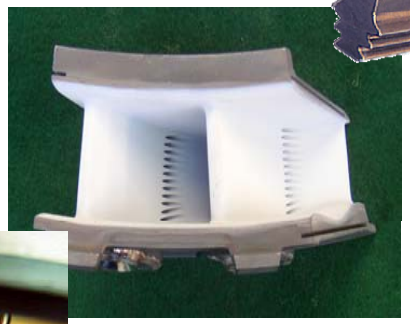
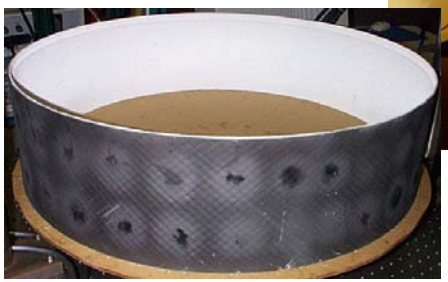
Materials Needs for the Future

- Requirements
  - High Cr Alloys (with Strong Creep Properties)
  - Coatings
    - Environmental
    - Thermal
  - Improved Testing Systems
    - Rig Tests that Demonstrate Engine Environment