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Perspective on R&D Needs for Gas Turbine Power Generation

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Research Requirements

- **Overview**
- **Specific Requirements**

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Overview – Current / Future Challenges

- Society Requirements
  - Adequate Power
  - Availability of Fuel
    - Affordable
    - Minimal Degradation of the Environment
  - “Green”
- Technical Improvements Will Be Harder to Achieve – “Learning Curve”
- Competition for Resources Increased
  - Engineers
    - Training
    - Expertise
    - Commitment
    - Enthusiasm
  - Computer Power – Speed & Cost
  - Funding Limitations

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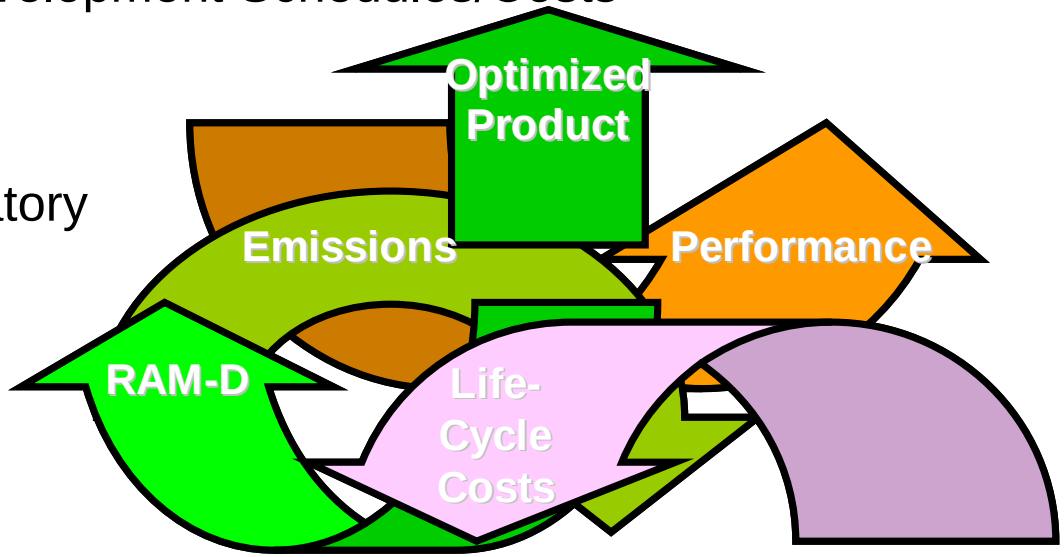
Overview – Required Approach

- Pragmatic Research
  - Address Critical Problems & Requirements
  - Must be Applicable in Industrial Design/Analysis Environment
    - Iterative Multi-Disciplinary Process
    - Demanding Design & Development Schedules/Costs
    - Manufacturability
    - Robust
  - Validation/Calibration Mandatory
  - Transferable
- Collaboration
  - Universities
  - OEM
  - OEM Value Stream
- Train the Next Generation of Turbomachinery Engineers



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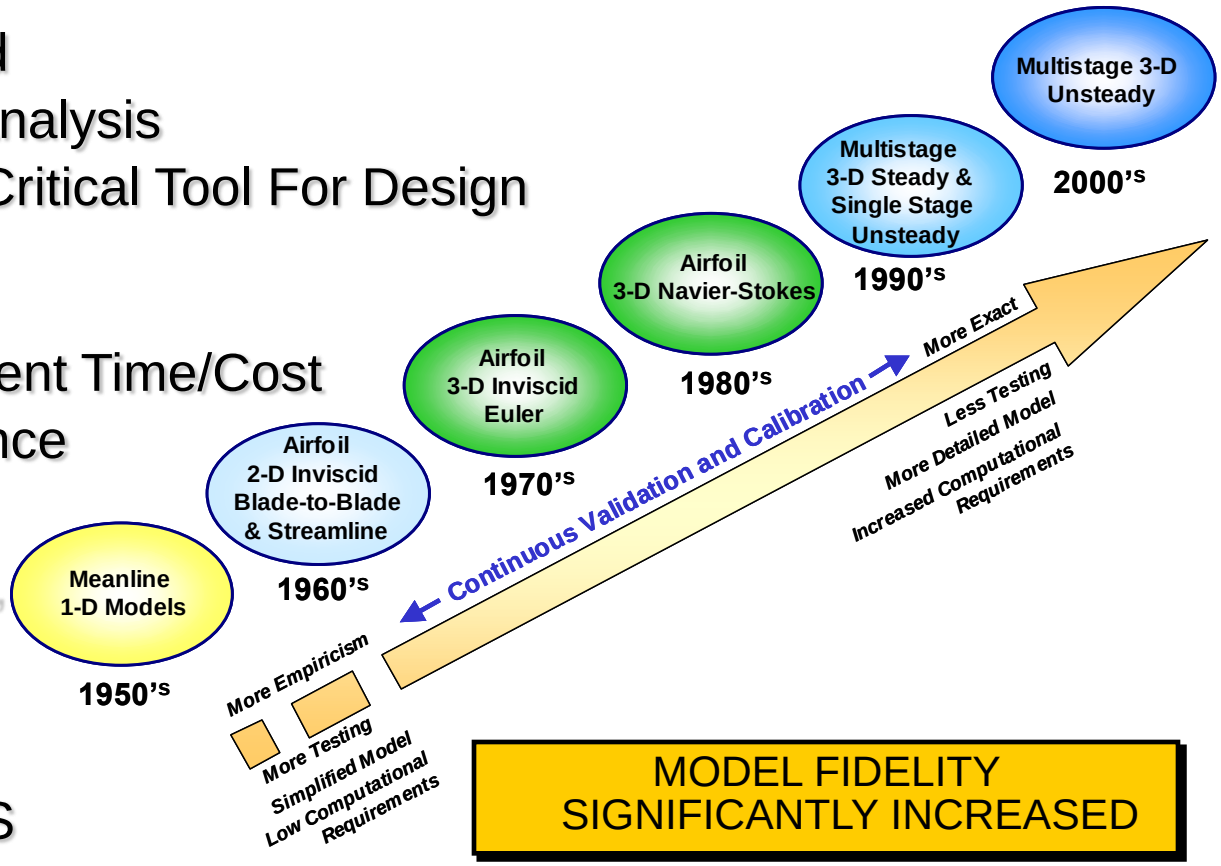
Turbomachinery CFD History

- CFD Capabilities Progressed Significantly
  - Model Fidelity
  - Flow Physics
- Application Transitioned
  - From Post Design Analysis
  - To Fully Integrated Critical Tool For Design of Turbomachinery
- Product Payoff
  - Reduced Development Time/Cost
  - Improved Performance
- Status
  - Still Has Limitations, e.g. Heat Transfer
  - Can't Completely Replace Testing
  - Unsteady, DES, LES Not Practical Yet



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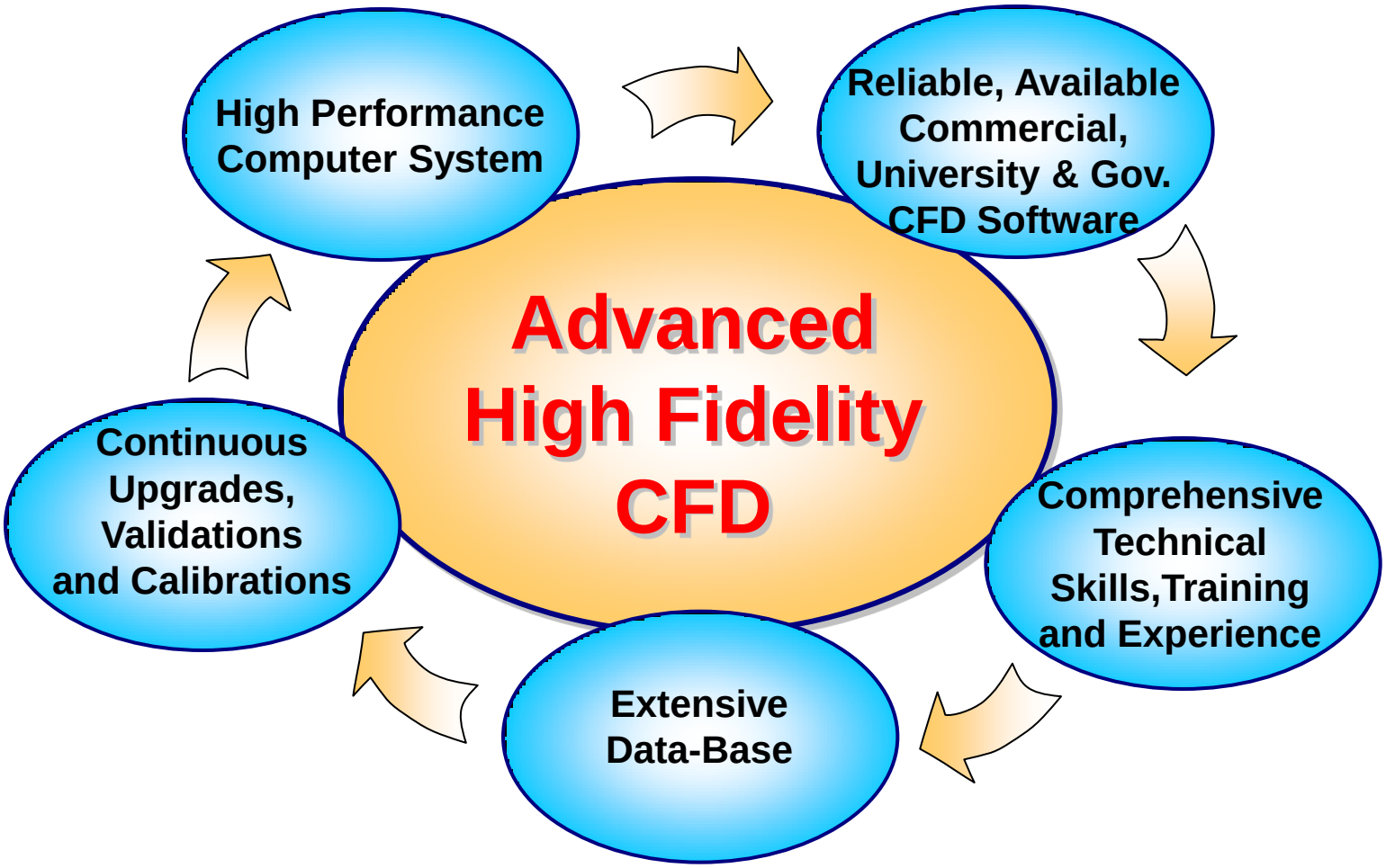
Turbomachinery CFD – Future



CFD Future Success Can be Greatly Enhanced by Committed Integrated Approach

Perspective on R&D Needs for Gas Turbine Power Generation – **Combustion**

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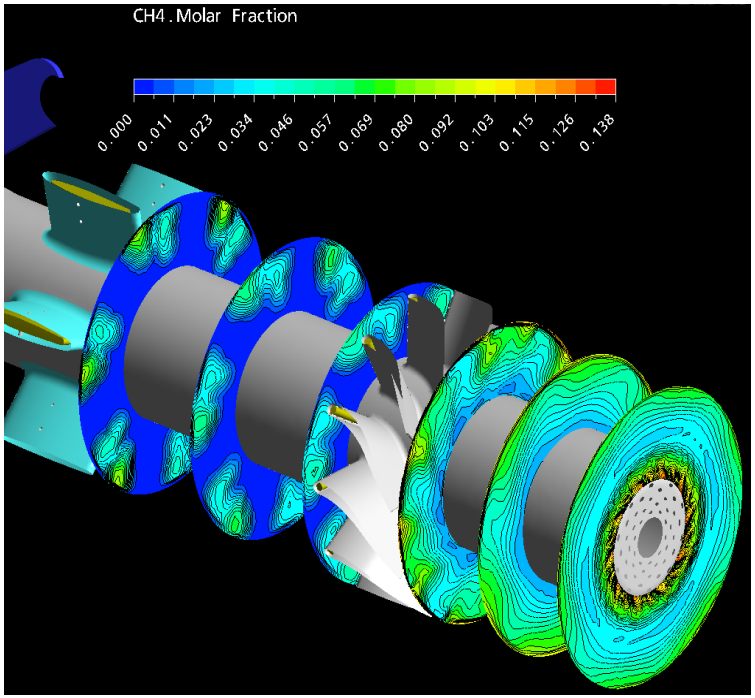
Fuel Injector - Jets In Crossflow

- Challenge to Simulate Fuel Injector Passage with Jets of Methane Fuel Injected into Air Passage
- Requirements
  - Analysis Varying Fuel Hole Location and Diameter to Produce Optimal Fuel/Air Profile at the Exit of the Injector
  - CFD Analysis with LES Since Process is Transient
  - Test Validation/Calibration



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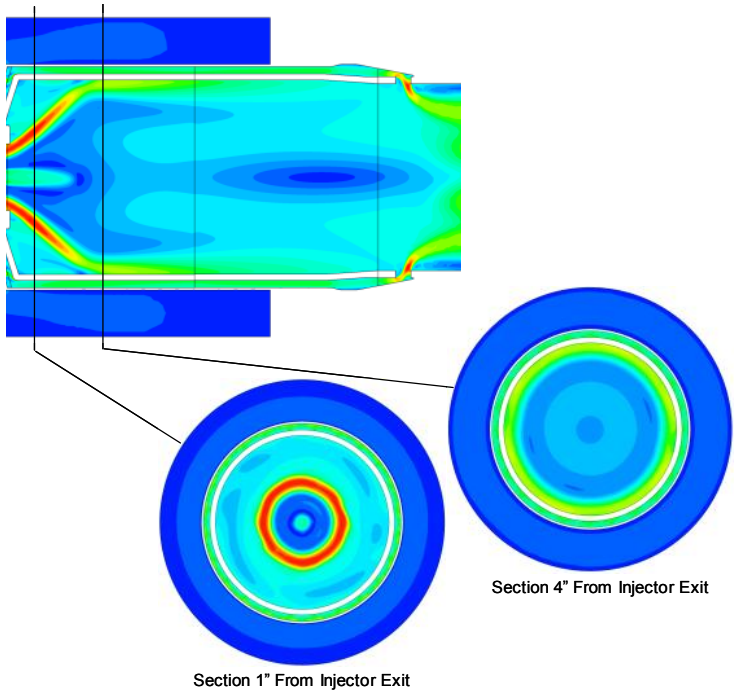
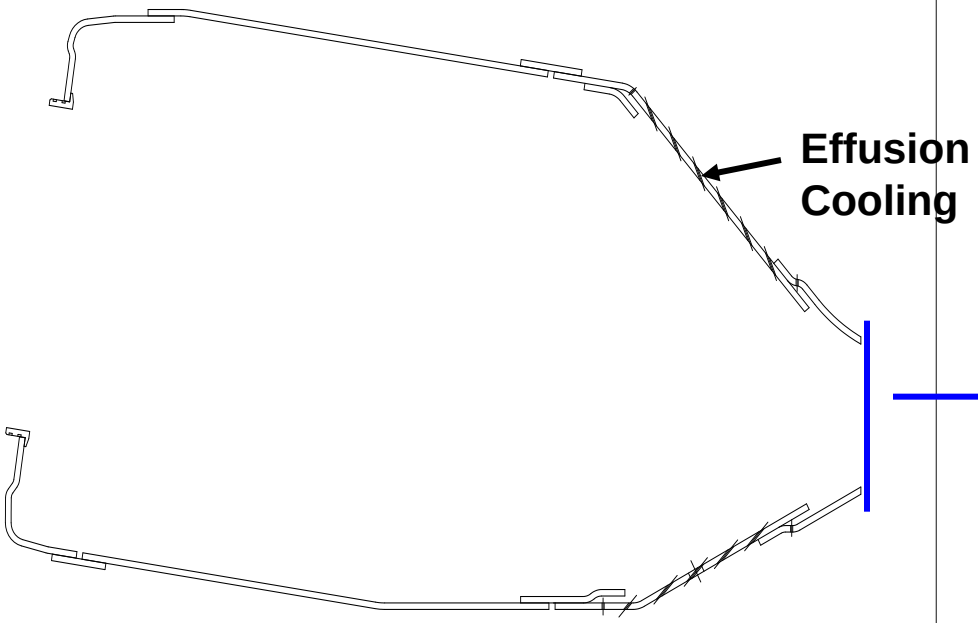
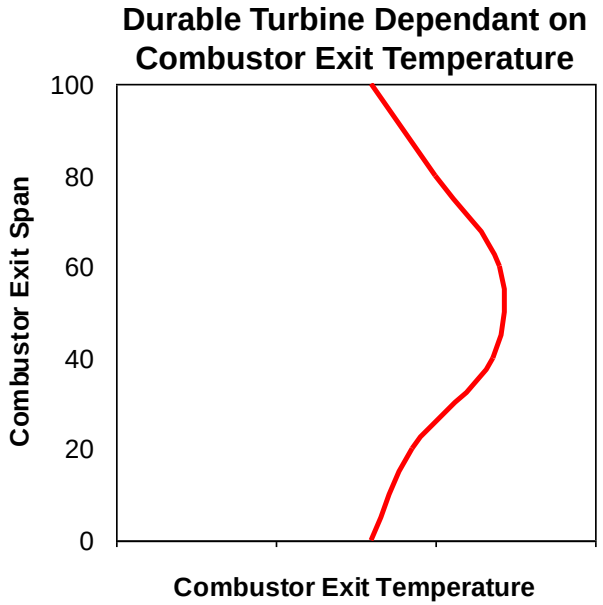
Combustor Liner Durability

- Challenge to Predict Liner Temperature
  - Complex Flowfields
  - Chemical Reaction (CR)
  - Cooling
- Requirements
  - Conduct Combustor Testing
    - Obtain Liner and Heat Flux
    - Effect of CR on Heat load
    - Effect of Primary Zone Conditions
  - Conduct **Blind Test** CFD Conjugate Heat Transfer
    - **CFD by Partner Universities?**
    - CFD Options
      - RANS, LES etc.
      - Different Reaction Mechanisms



Combustor Exit Profile

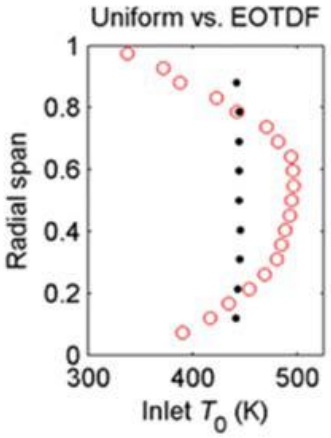




- Effusion Cooling Plays Dual Role
  - Impacts Exit Cone Metal Temperature
  - Impacts Combustor Exit Temperature Profile
- Need to Characterize Effect of Effusion Cooling Blowing Ratio & Number of Rows on Combustor Exit Temperature Profile
- CFD Validation/Calibration

Perspective on R&D Needs for Gas Turbine Power Generation – **Aero/Thermal**

Blade/Platform Heat Load Assessment



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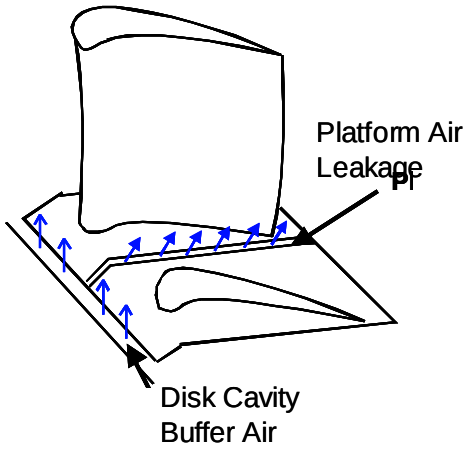
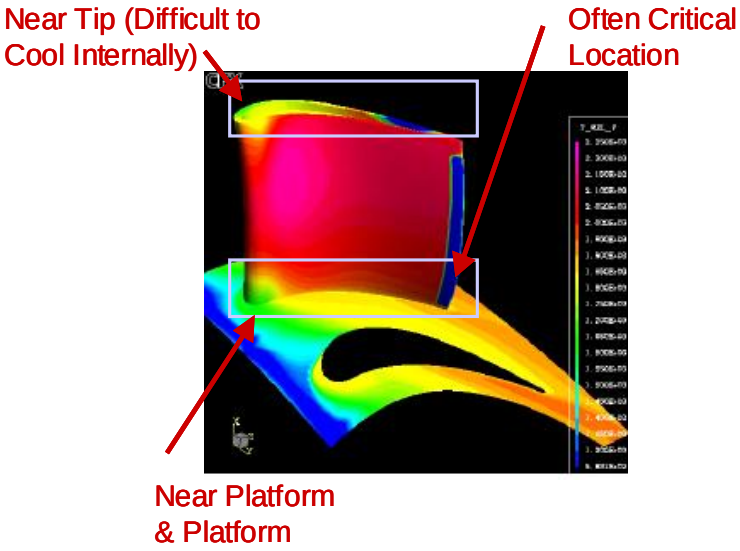
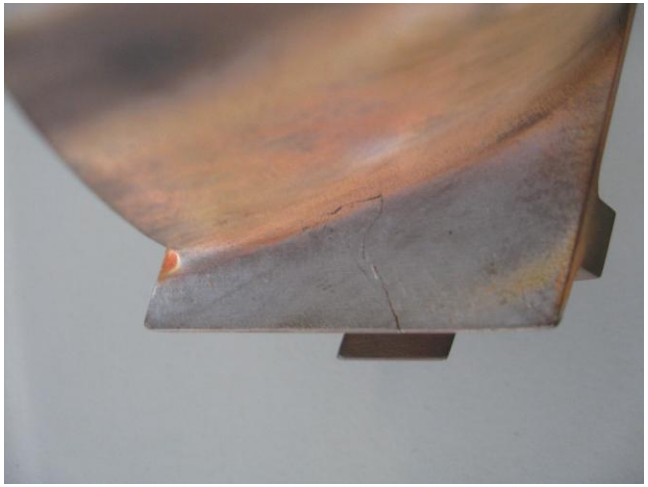
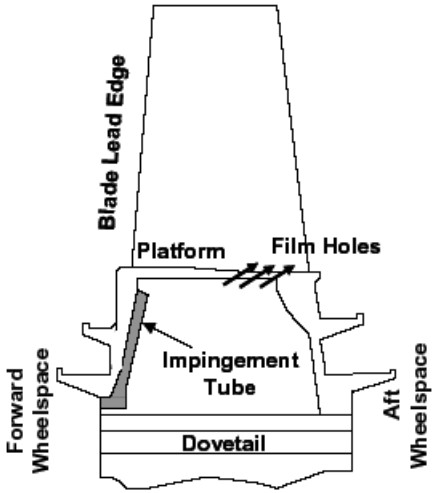




- Challenge To Predict Adiabatic Wall Temperature and Heat Transfer Coefficient Accounting for
  - Inlet Temperature Profile
  - Buffer/Leakage Air Effects
  - Hot Streaks etc.
- Require
  - Models to Account for Effects Early in Design Cycle
  - CFD Based Modeling for Detailed Design
  - Experimental Validation/Calibration

Blade/Platform Cooling Configuration Design





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- High Heat Load Due to the Flat Combustor Outlet Temperature Profile (Premixed Lean)
- Large Heat Load Variation
- Heat Load Prediction is Difficult
- Few Papers Related to the Platform Heat Transfer (External/Internal)
- Casting Challenges
- Need Innovative Cooling Design Concepts & Validation/Calibration

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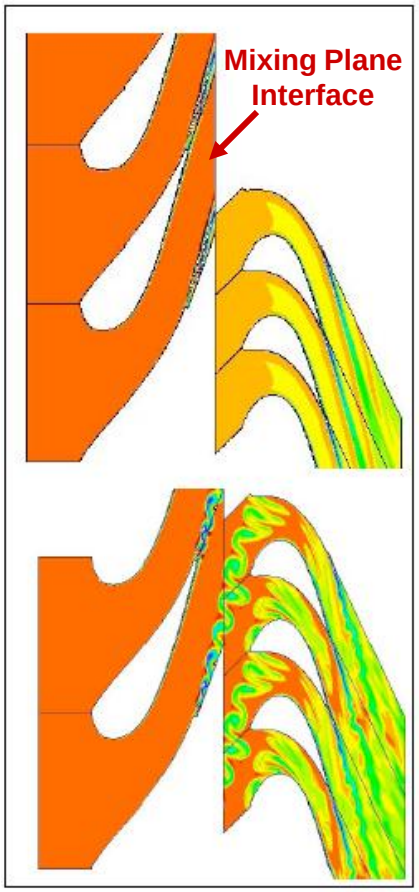
Multistage CFD For Design Environment

- Current CFD Options
  - Unsteady RANS (Sliding Mesh)
    - High Fidelity Modeling of Flow Through Blade Rows
    - Requires Full Model
    - Unacceptable Computational Time for Iterative Design Environment
  - Steady RANS (Mixing Plane)
    - Flow Assumed Mixed Out Circumferentially
      - Step Increase in Entropy
      - Mixing Plane Losses Are Not Same As Loss Generated In Real Unsteady Flow Downstream
    - Computational Time Acceptable
- Need Improved, Verified Steady State "Mixing Plane" Model - Open Documentation for Application
  - Flux Conservation
  - Indifference to Local Flow Direction
  - Robust
- Blind Test Validation/Calibration



Comparison of Entropy with Mixing Plane & Unsteady Calculations (Denton GT2010-22540)

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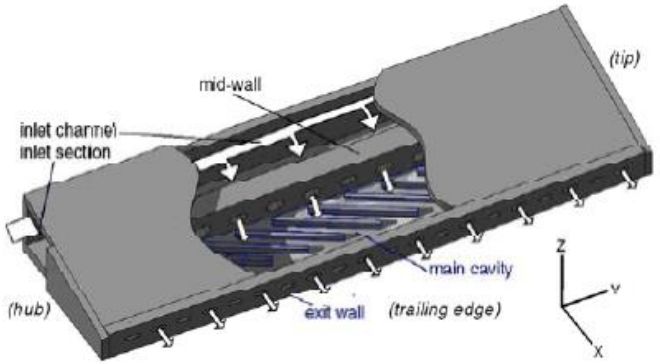
CFD Aero/Thermal Challenges

- Challenge – Temperature Prediction Error of 10 to 20 ^{o}F is Significant
- Require
  - Efficient Modeling
  - Experimental Validation
- Conjugate HT Analysis of Airfoils
  - Pure Convective Analysis No Longer Good Enough
  - HT Affected by Local Phenomena & Lateral Conduction
- Disk Cavity
  - Ingress/Egress
  - Seal Effectiveness for Various Configurations
  - High Swirl (Windage Effect)
  - Disk Pumping



TEST SECTION

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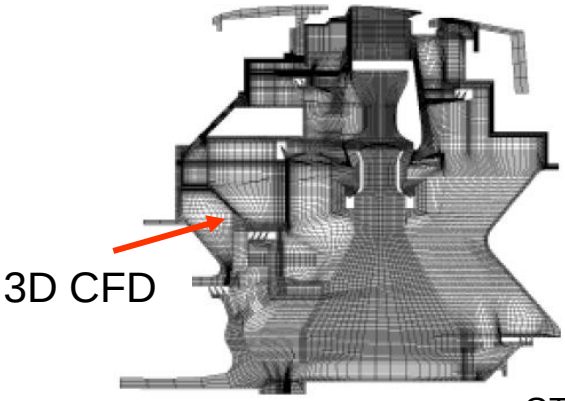

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Figure 1 Computational grid for conjugate analysis of the turbine rotor-stator system (meridional section)

Perspective on R&D Needs for Gas Turbine Power Generation – **Materials**

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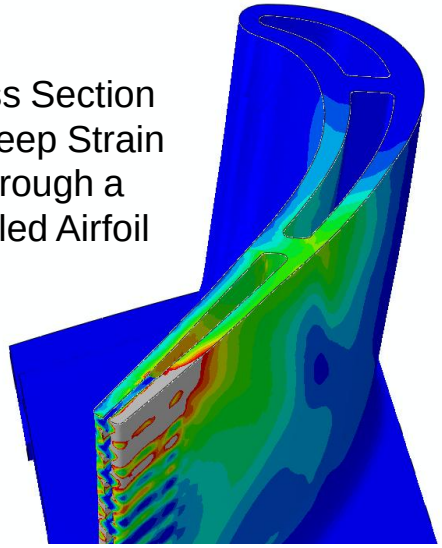
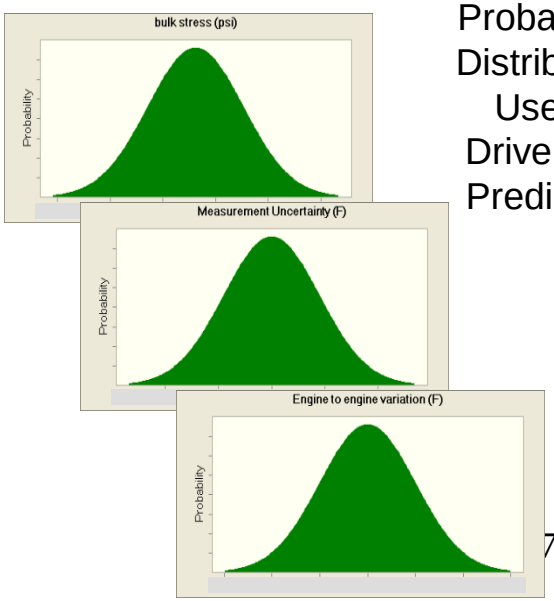
Materials Needs for the Future

- 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
  - Creep-Fatigue Interaction
- 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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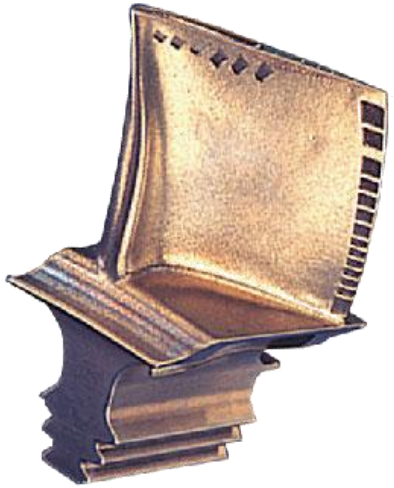
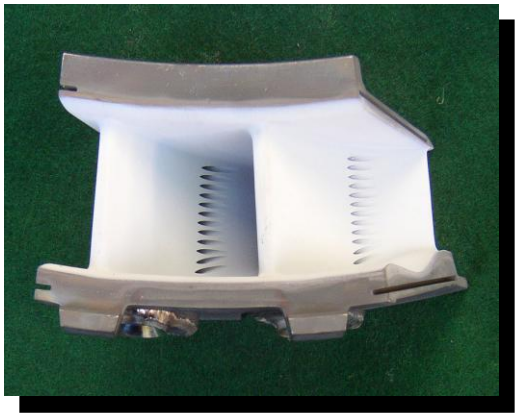
Materials Needs for the Future

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





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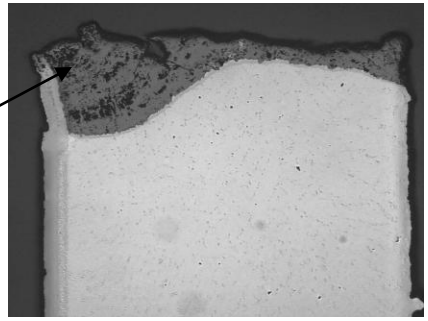
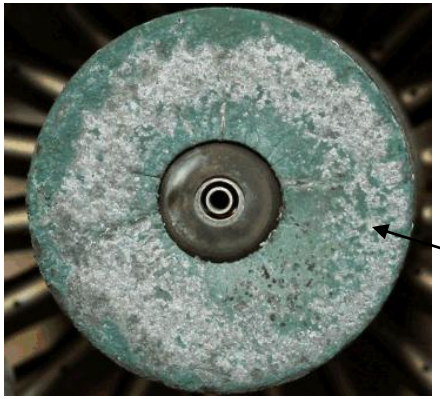
Materials Needs for the Future

- Material Durability when Exposed to Various Operating Environments
  - H_2S/H_2/Offshore
  - Coke Oven Gas
  - Na_2SO_4, K2SO4, $CaSO_4$ & $MgSO_4$
- Degradation Mechanisms Including High Temperature Oxidation, Hot Corrosion, and Sulfidation
- Require New Metals, Coatings & Cooling



Turbine Blade Tip
Hot Corrosion



Injector Tip
Degradation


Thanks