NASA/CP—2010-216112

# Breaking CFD Bottlenecks in Gas-Turbine Flow-Path Design

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# Bottlenecks in Design

- **Simulations for design are at <u>least an order of magnitude more challenging</u> than their counterparts in analysis *due to time constraints***
- **Bottlenecks exist in all aspects of simulation**
  – Setup (model manipulation and grid generation)
  – Solution (accuracy and solution time)
  – Post-processing (visualization, engineering figures, etc.)
- **Our R&D has been focusing on how to break some of these bottlenecks through**
  – Automation
  – Large-scale parallelization
  – Advanced modeling

# Example Areas

- **Examples of bottlenecks for simulations used in design:**
  - Complex flow paths such as secondary-air and cooling systems
  - Complex aerothermal problems such as film-cooled, high-pressure turbines
  - Complex flows with mixing such as secondary/endwall flows

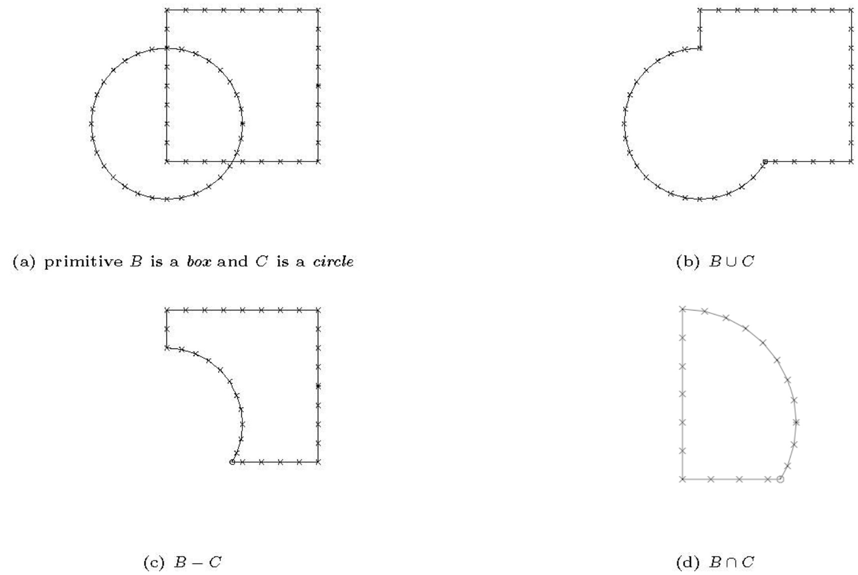
- **Similar bottlenecks exist in other Air Force, Navy, and NASA design problems**
  - Our intent is to show new ideas that might be used in a broad range of applications

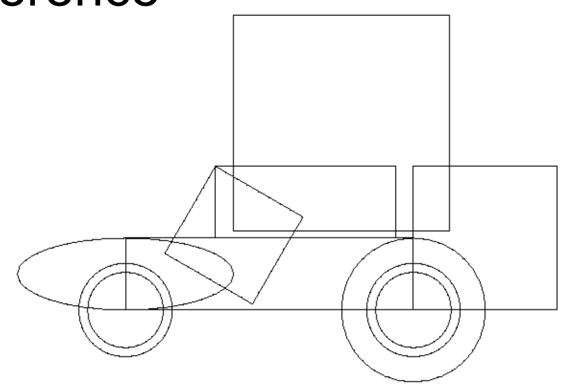
# IDEA

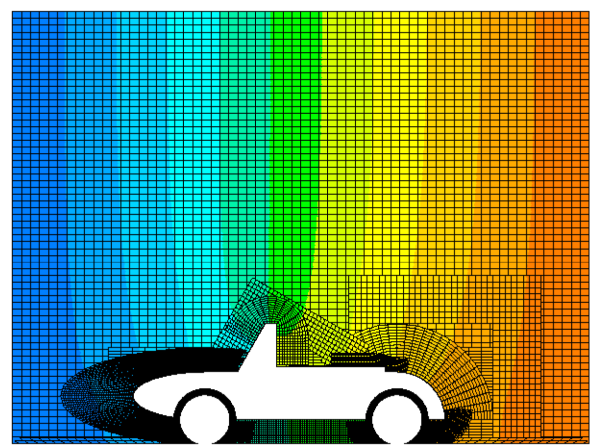
- **Instead of generating a computational grid after the model is created, why not generate it at the same time and take advantage of the CAD operations???**

# CAD-Based Grid Generation

- **For each CAD primitive, construct a grid inside and outside**
- **When CAD operations are performed to construct model, apply them to the computational grids as well**
- **CAD operations consist of**
  - Union
  - Intersection
  - Difference





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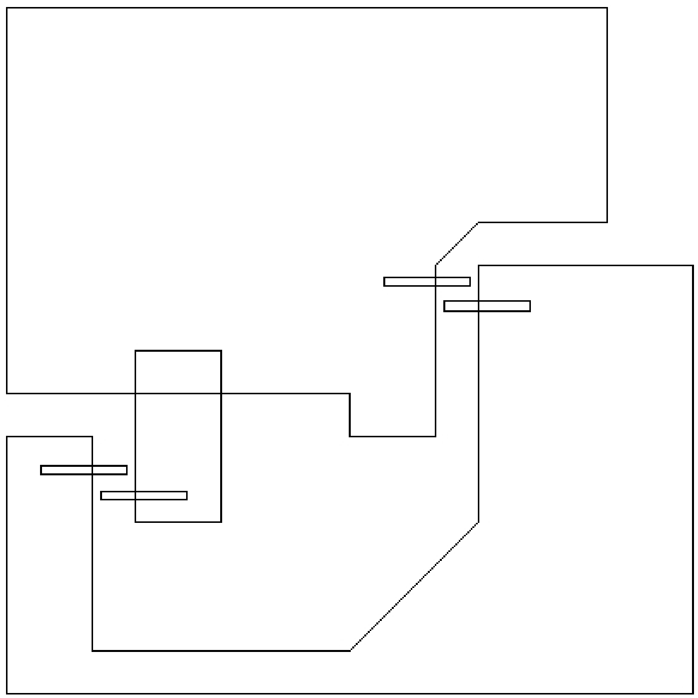
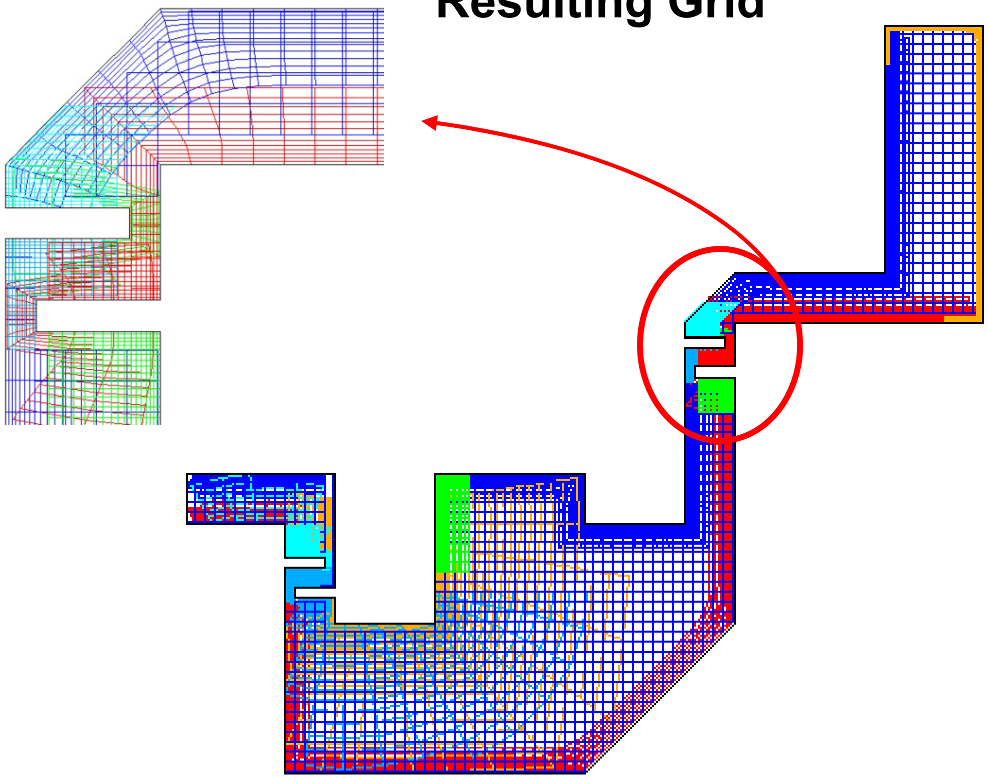
# Application to Gas-Turbines

## Secondary-Air System Flow Path



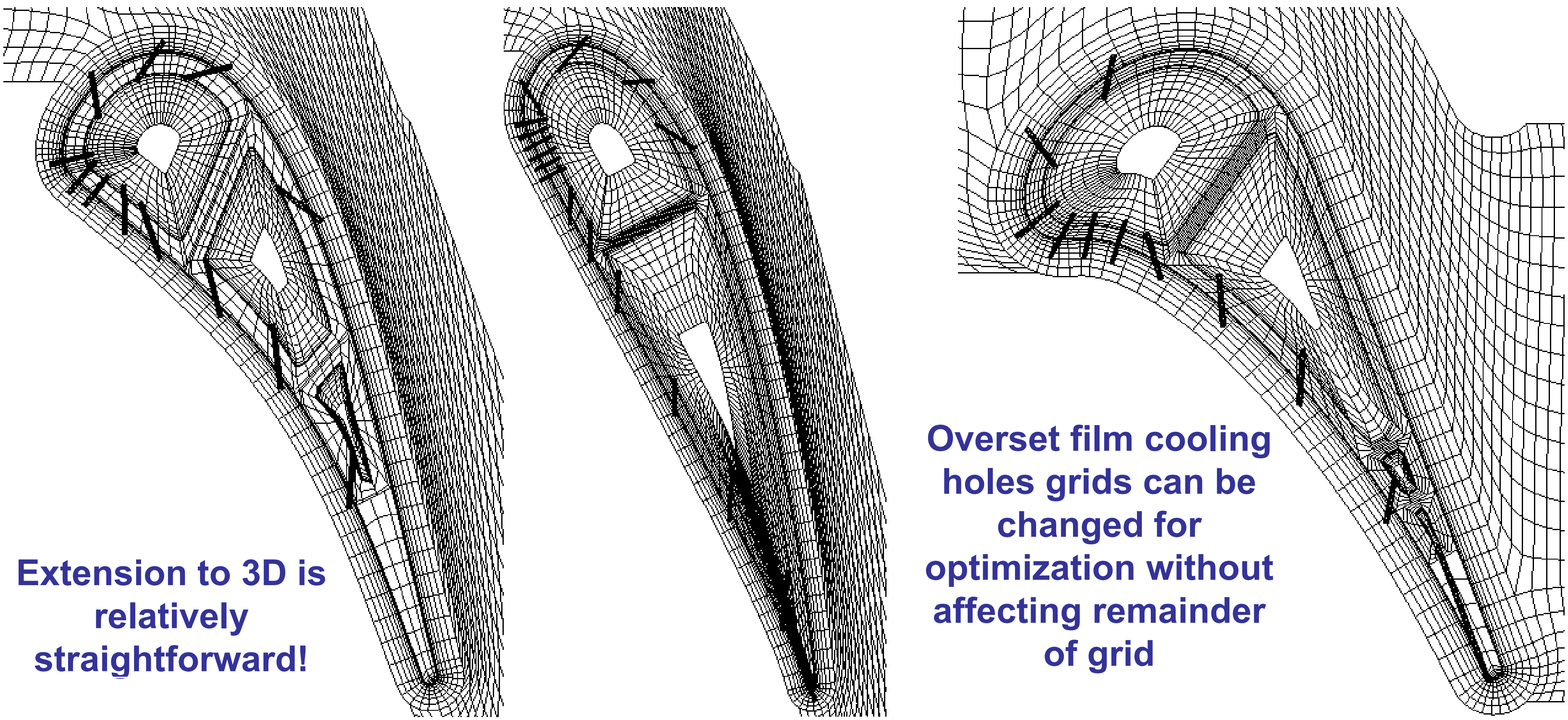

- **For more details: AIAA-2009-3991 "Automated Creation of Overset Grids Directly from Solid-Model Feature Trees"**

# IDEA

- **Why not use similar embedded, overset grid technology for multi-disciplinary problems such as conjugate heat transfer of film-cooled turbines???**

# Automated Model/Grid Generation of Turbine Airfoil Sections

- **Conjugate heat transfer of various HPTs including TBC, cooling holes, walls, and plenums**

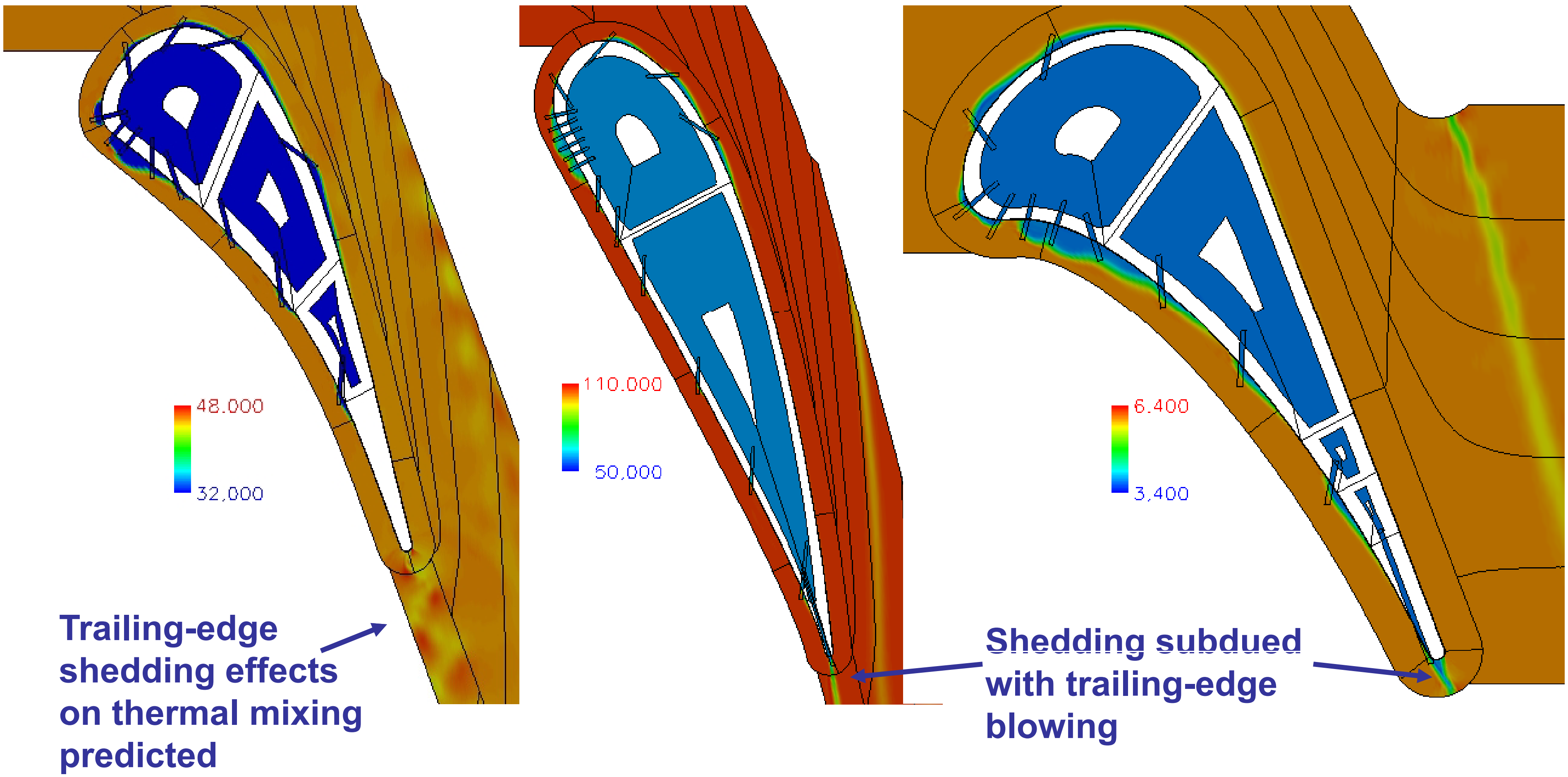



Every 4th grid point shown for clarity

**Completely General: Can also be used for flow control**

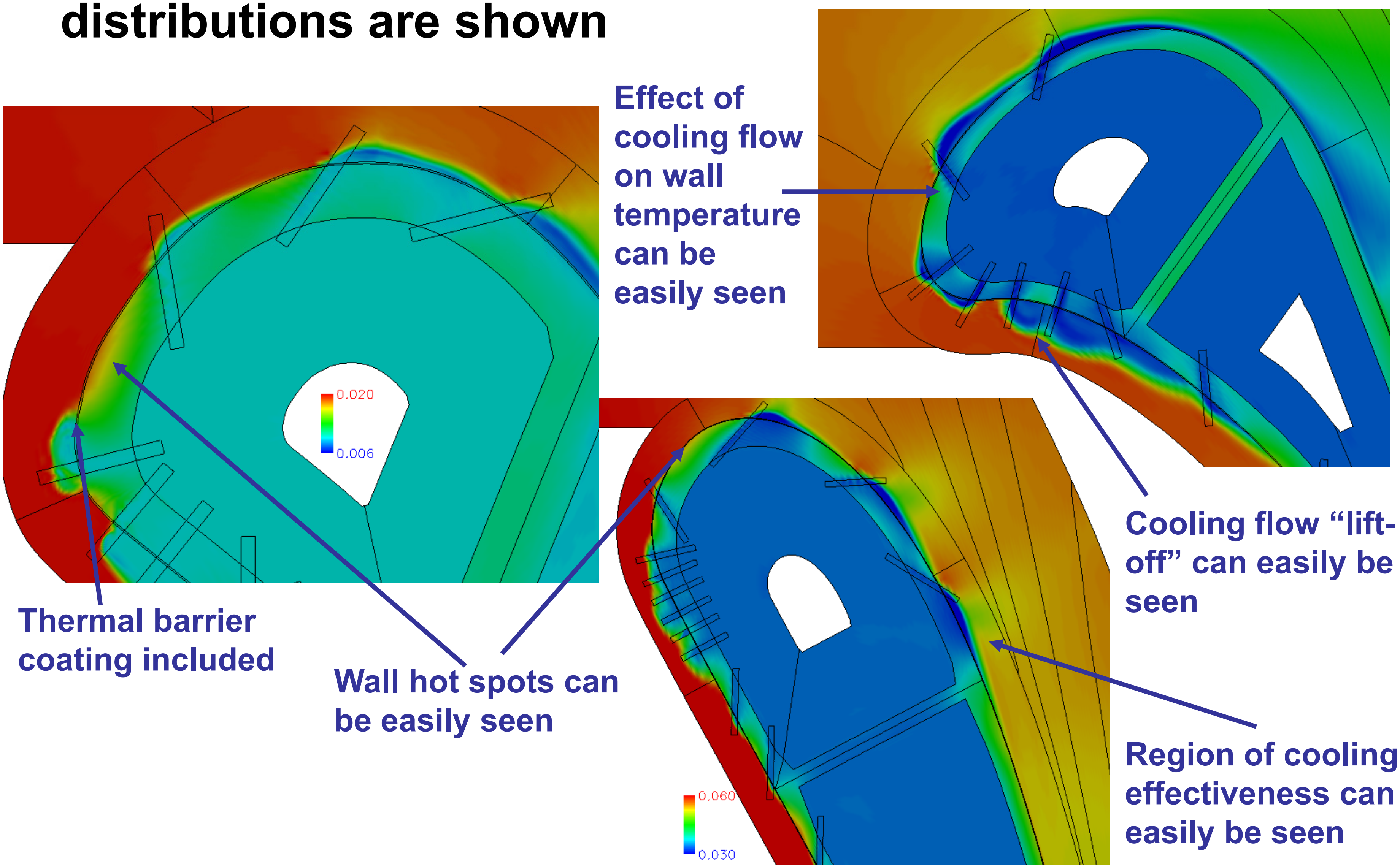
# Stagnation Temperature Contours

- **Time-averaged Detached-Eddy Simulations are the Norm!**
  - Enables effects of self-excited unsteadiness on aerothermal performance to be predicted
  - Shown here: Instantaneous DES results



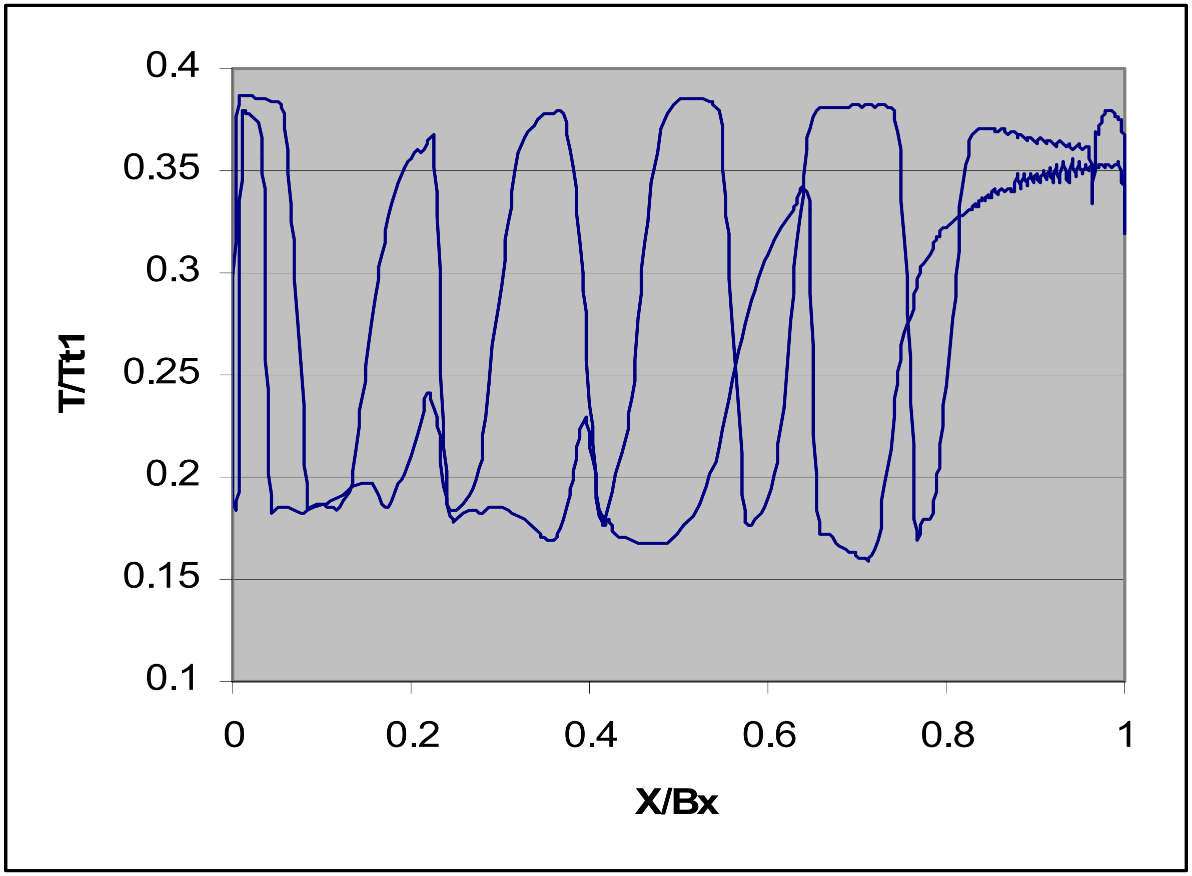
# Temperature Contours

- **Interaction effects on both flow and wall temperature distributions are shown**



# Wall Temperature Distribution

- **Wall temperature distributions show extent of cooling effectiveness**



# For More Details

- **See:**

  **AIAA-2010- “Conjugate Design/Analysis Procedure for Film-Cooled Turbine Airfoil Sections” to be published January 2010**

  **AIAA-2009-913 “A Conjugate Heat Transfer RANS/DES Simulation Procedure”**

  **AIAA-2008-4407 “Transitional RANS/DES Computations of Turbine Heat Transfer”**

  **AIAA-2008-534 “A Detached-Eddy Simulation Procedure Targeted for Design”**

# IDEA

- **Why not use the latest parallel computing technology to turn around complex multi-disciplinary solutions fast enough for automated design optimization???**

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# Let's Use GPUs with CPUs!

- **Graphical processing units (GPUs) have proven success for gaming applications**
- **We have recently shown GPUs to also be useful for scientific simulations**
- **GPU Costs:**
  - ~$500 for 128 floating-point units
  - Example: Our GPU cluster in ECE
    - 8 nodes of single quad-cores (32 cores)
    - 1 GPU per core → 32 GPUs
    - 12 Teraflops of peak performance, ~$25,000-$30,000
  - Low space and power requirements

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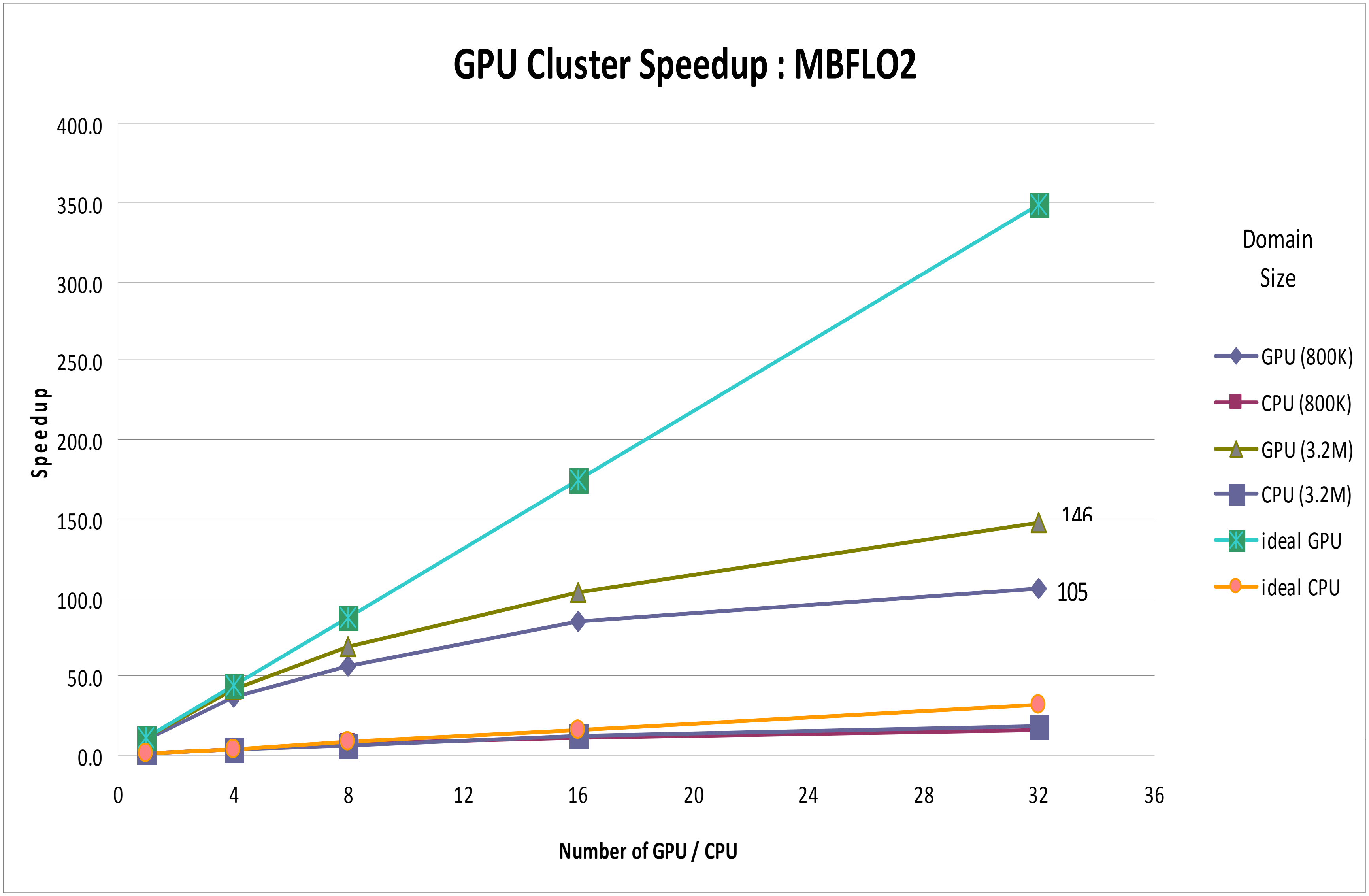
- **Cost Effective Means of Achieving our Goals!**

# Our Latest Results

- **Argonne National Laboratories 32 CPU/GPU cluster**



# Summary of Performance Gains

- **For 32 CPU/GPU combined processors**
  - MBFLO speed-up increased to ~146 over single CPU (66% improvement over 16 combined processors) on Argonne National Laboratory cluster.
    - A factor of 5.4 over 32 CPUs at 85% efficiency.
    - Over a factor of 30 in performance/price ratio!
- **Greater speed-ups with larger data sets and more computing**
  - Great performance for 3D turbulent computations!
- **Goal to turn-around conjugate heat-transfer DES simulations in a few minutes so that automated optimization can be used**
  - Currently at ~30 minutes solution time for TA'd DES

# For More Details

- **See:**

  **AIAA-2009-565 "Rapid Aerodynamic Performance Prediction on a Cluster of Graphical Processing Units"**

# Overall Summary

- **New ideas are forthcoming to break existing bottlenecks in using CFD during design**
  - CAD-based automated grid generation
  - Multi-disciplinary use of embedded, overset grids to eliminate complex gridding problems
  - Use of time-averaged detached-eddy simulations as norm instead of “steady” RANS to include effects of self-excited unsteadiness
  - Combined GPU/Core parallel computing to provide over an order of magnitude increase in performance/price ratio

- **Gas-turbine applications are shown here but these ideas can be used for other Air Force, Navy, and NASA applications**