GasTurbnLab

A. PROBLEM SOLVING ENVIRONMENT FOR GAS TURBINES

Sanford Fleeter, Mechanical Engineering
Elias Houstis, Computer Science
John Rice, Computer Science
Chenn Zhou, Mechanical Engineering-Calumet

ASCI: Accelerated Strategic Computing Initiative
U.S. Department of Energy

Slide 1

ULTIMATE GOALS

- **Full Simulation of Gas Turbines**
  - Decrease design costs, design time, pollutants
  - Increase efficiency, power and safety
- **Computing Methodology for Complex Simulation**
  - Effective use of parallel computing power
  - Ability for "ordinary" engineers to make designs
  - Control of software development costs
- **Validation of the Simulation**
  - Correctness of the computations
  - Correctness of the Physics/Chemistry models

Slide 2

Gas Turbine Picture

Slide 3

LONG TERM FOCUS

- **To Better Control Stall and Surge**
  - Determine patterns of malfunctions.
  - Determine early warning signs.
  - Identify critical variables to measure and remedial actions to take.
- **To Better Predict and Detect Blade Failure**
  - Determine effects of transients and defects on blade environment; identify those especially threatening.
  - Determine effects of weakening blades on engine.
  - Determine patterns of malfunction and early warning signs of failure.
  - Identify critical variables to measure and remedial actions to take.

Slide 4

WHY THESE GOALS ARE REMOTE

- Huge efforts under way by industry and government teams.
  - BIG computers, BIG budgets.
  - Modest simulation capabilities so far.
- Huge complexity of the device.
  - Spatial scales from 5 meters (whole engine) to 1 micron (droplets in fuel spray) to several angstroms (cracks in blades).
  - Time scales from many minutes (a plane's maneuver) to a millisecond (one revolution) to micro-seconds (combustion front movement, crack formation) to nanoseconds (chemical reactions).
  - Thousands of mechanical parts, thousands of chemical species, millions of drops and turbulent eddies.

Slide 5

WHY THESE GOALS ARE REMOTE (con't)

- Unknown physics
  - What makes fuel sprays form drops?
  - What chemical reactions take place?
  - What makes a crack form at a particular place?
  - What exactly is a defect in materials?

Slide 6

RESEARCH TEAM FOR GasTurbnLab

Sanford Fleeter, Distinguished Professor of Mechanical Engineering. A national authority on gas turbine engines. He runs both experimental labs for turbines and uses/develops simulations. He has extensive industrial and academic experience with prolific publications in analytical, computational, and experimental research.

Elias Houstis, Professor of Computer Sciences. An expert in numerical methods for solving differential equations and a leader in developing problem solving environments for scientific computing. He is one of the first to apply knowledge based methodology to scientific computing.

John R. Rice, Distinguished Professor of Computer Sciences. A national authority on numerical methods, mathematical software, and scientific computing. He founded the field of mathematical software and has spent 30 years studying the performance and quality of algorithms, machines, and software. He is a member of the National Academy of Engineering.

Chenn Zhou, Associate Professor of Mechanical Engineering. An expert in reactive flows and combustion products. Has strong experience in industrial and academic research using computational analysis of multiphase flows and aerodynamics.

Slide 7

GASTURBIN SCHEMATIC AND MODEL

Slide 8

OVERALL SCIENTIFIC APPROACH

- Encapsulate scientific, engineering, simulation, and computing expertise into well understood components. Use a hierarchical structure for the project.
- Integrate algorithm and computing power into high level, application specific problem solving environments.
- Systematic validation of the correctness of complex simulations.
- Systematic measurement of the performance of mathematical models, numerical models, solvers, software architecture, and hardware configurations.

Slide 9

THE ENGINEERING COMPONENTS

- Multi-phase, reactive flow simulation
  - transients
- Turbulent combustion, mixing flows, eddies
  - aerosols, vaporization, spray structure, flame fronts
  - chemistry/turbulence/radiation interactions
- Combustion products, soot, and pollutants
- Heat transfer: release, conduction, convection, radiation
- Stress/strain in complex geometry, rapid motion
  - unsteady stresses, airfoil coupling, interface damping
- Engine start-up effects
- Structural dynamics and energy transport interactions

Slide 10

THE COMPUTATION COMPONENTS-I

- **Problem Specification**
  - full 3-D geometry models with multiple representations and interactive displays
  - high level, visual, and natural engineering terminology
  - expert systems support for specification correctness
- **Simulation Specification**
  - high/low order discretization for PDEs, adaptive methods
  - parallel and/or distributed solvers and algorithms
  - expert system support for specification correctness

Slide 11

THE COMPUTATION COMPONENTS-II

- **Software Architecture**
  - high modularity, object-oriented technology, agents
  - software bus infrastructure
  - portability across machines and networks
- **Hardware Specification**
  - parallel program decomposition of domains and/or arrays
  - dynamic reallocation, threads of control
  - heterogeneous hardware and networks

Slide 12

VALIDATION AND PERFORMANCE

CORRECTNESS:

- Exchange software components (using different models/methods)
- Comparison with experimental data and analytical solutions
- Validation by physical models

PERFORMANCE:

- Algorithms and numerical models can have huge effects
  - models: high order versus low order, discrete versus symbolic
  - automatic versus user guided
  - dynamic (adaptive) versus static
- Scalability
  - evaluate models, algorithms, software, and hardware
- Human costs
  - value of high level problem solving environments
  - value of agent based computation control

Slide 13

GasTurbnLab: INITIAL FOCUS

- **GAS TURBINE ENGINE OPERABILITY**
  - High-cycle fatigue
  - Coupled fluids and structures
  - Combustion and pollutants
- **PROBLEM SOLVING ENVIRONMENTS (PSE)**
  - **GasTurbnLab**: A multidisciplinary PSE
  - Component-based simulation for multidisciplinary problems
  - Coupling intelligence and simulation technologies
- **SIMULATION RELIABILITY AND VALIDATION**
  - Validation by experiments
  - Validation by physical models

Slide 14

GasTurbnLab: SIMULATIONS USED

- **Full Annular - Unsteady Flow Combustor Analysis**

  Include airblast fuel nozzle, dome, liner walls (with holes), cooling louvers.

  Focus effects:

  - Fuel schedule
  - Potential for rich-hot combustor due to stall
  - Feedback system control
- **Unsteady Fluid-Thermal-Structure Interactions**

  Analysis of time varying coupling of combustor and turbomachinery components to determine operability of complete engine. Study of turboblades (high cycle fatigue failures) and stability margins (rotating stall and surge).

Slide 15

GasTurbnLab: NOVEL SIMULATION METHODS

- *Interface Relaxation*. A mathematical method to solve multiple partial differential equation (PDEs) problems with completely independent PDE solvers.

- *SciAgents*. A computing methodology to distribute large, complex, dynamic computations over multiple computers.

Slide 16

GasTurbnLab: Simulation Scenario

The following animated "slide" shows how a user creates an environment for a simulation, how the agents in GasTurbnLab reflect this environment, how SciAgents creates and manages a computing environment tailored for this simulation.

Slide 17

GasTurbnLab: The Network of PDE Solvers

Slide 18