Aeroacoustics Calculations on IBM BlueGene: Preliminary Results

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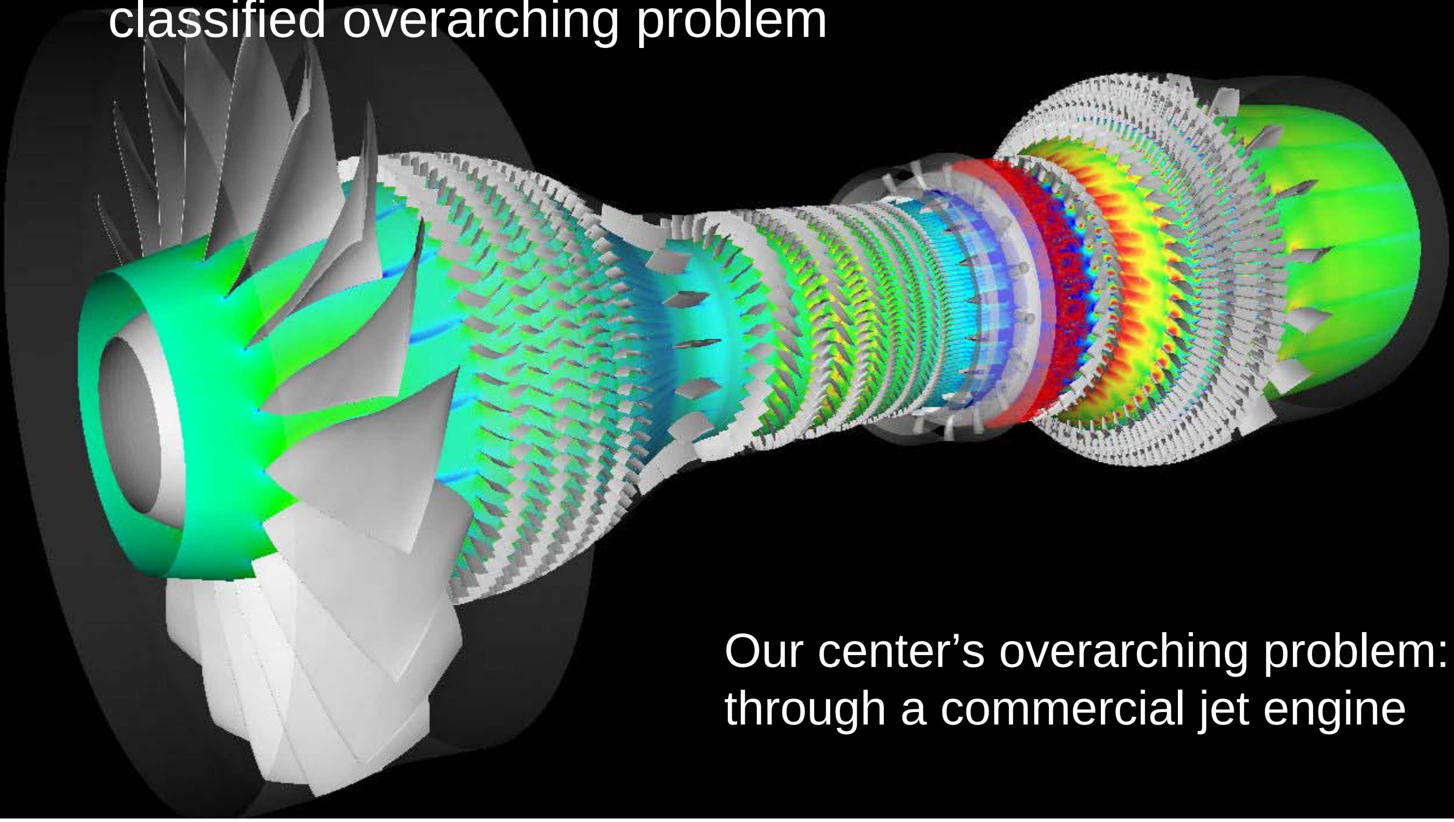
Stanford’s Center for Integrated Turbulence Simulations

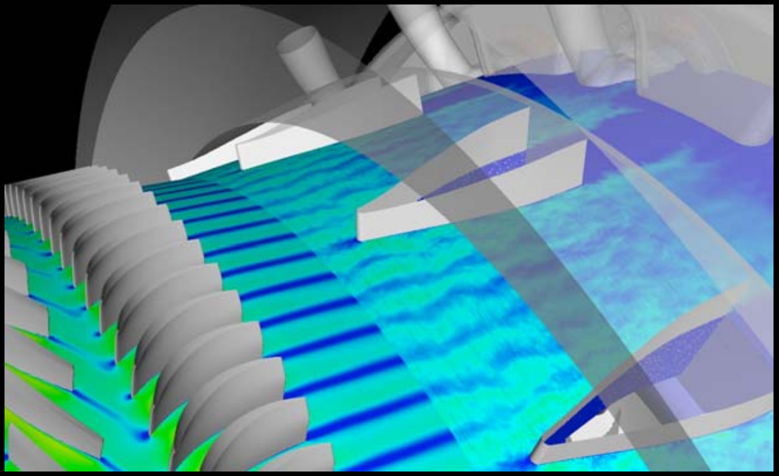
- One of 5 university alliance centers in the DOE’s advanced simulation and computing (ASC) program
- Access to unprecedented compute resources, including LLNL’s BGL (pre-classified days)
- Goal: Develop predictive simulation capability focused on a non-classified overarching problem



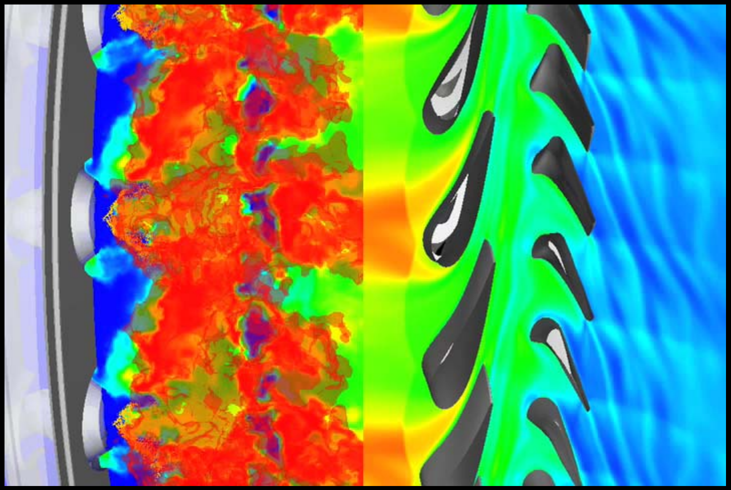
Our center’s overarching problem: flow through a commercial jet engine

Our Approach

- Couple Multiple codes with different descriptions of turbulence:
  - Unsteady block-structured RANS for rotating machinery
  - Unstructured Large Eddy Simulation (LES) for combustor
- Develop Stable and Accurate interface treatments



Velocity at Compressor/Diffuser interface: consistent turbulence structure is added to LES based on RANS solution



Temperature at Combustor/Turbine interface: averaging performed to provide Turbine inlet conditions

Our Approach

Did not exist!

- Couple Multiple codes with different descriptions of turbulence:
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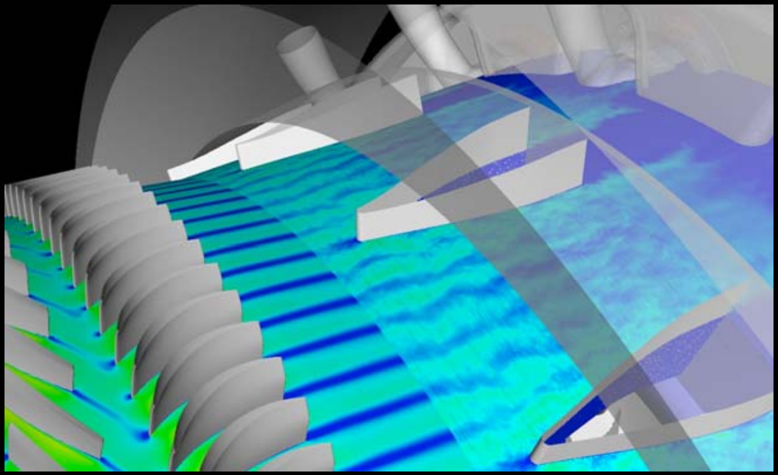

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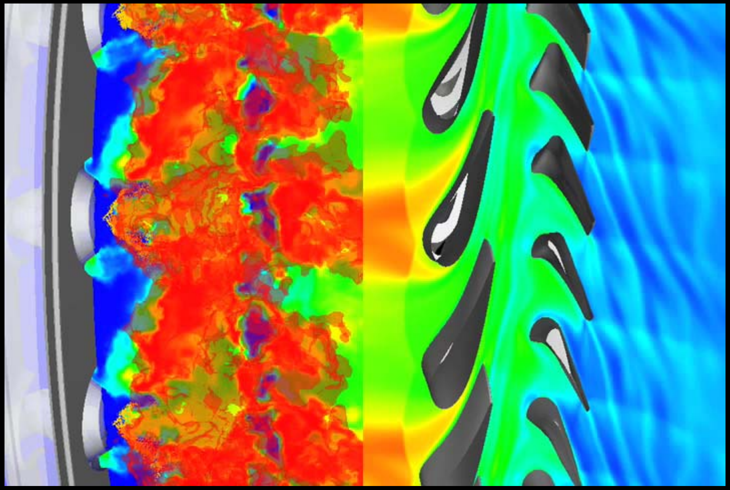


Temperature at Combustor/Turbine interface: averaging performed to provide Turbine inlet conditions

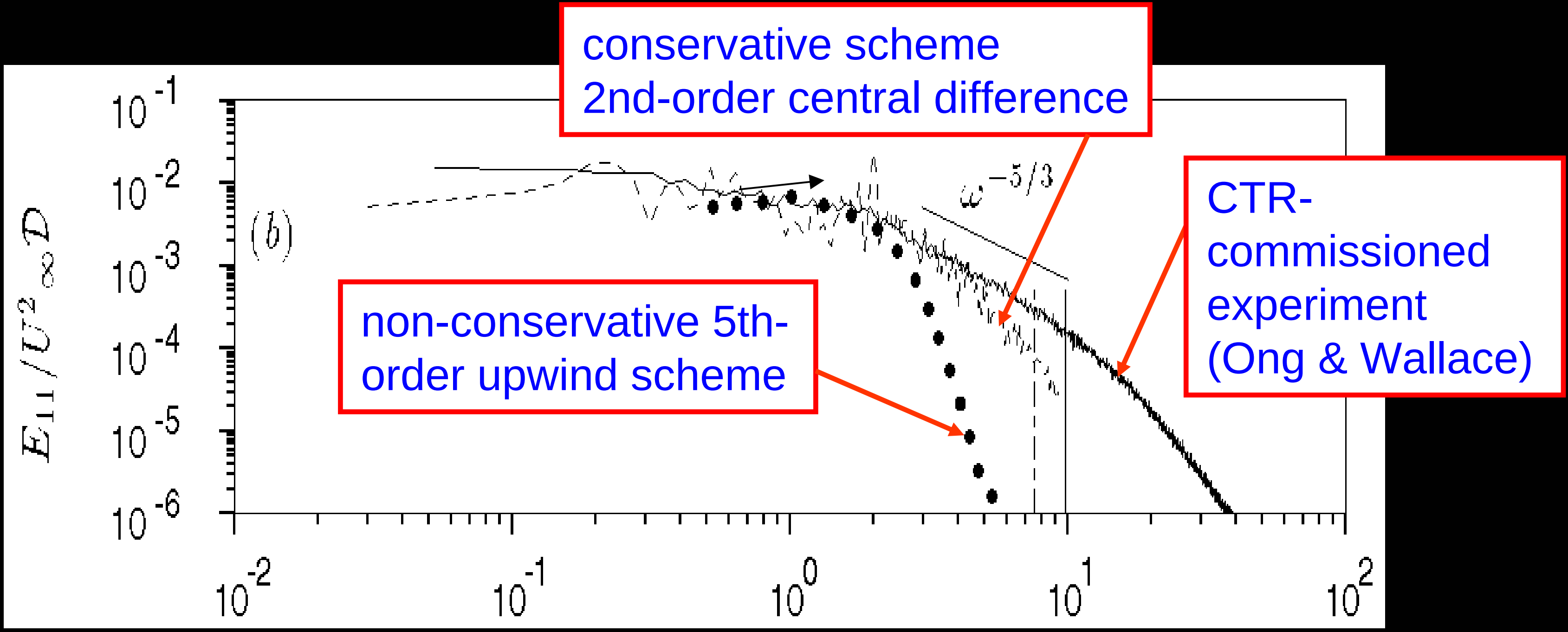
What is LES?

- Time-accurate realization of large-scale flow structure + simple models for unresolved (sub-grid) structure
- Predictive rather than calibrated
- Results can be very sensitive to numerical errors: Doing LES well is much more than a traditional CFD code run in transient mode

Understanding mixing in buoyant plumes

Must re-think our notions of accuracy:

- In the inviscid limit, the incompressible N-S equations conserve mass, momentum, kinetic energy (i.e. perfectly non-dissipative)
- For accurate LES, the choice of discretization must reflect (mimic) these properties of the continuous operators
- e.g. turbulent wake behind a circular cylinder*:



conservative scheme
2nd-order central difference

CTR-commissioned experiment (Ong & Wallace)

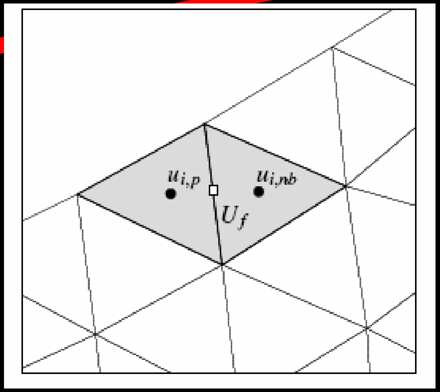
non-conservative 5th-order upwind scheme

*from Mittal & Moin (AIAA J., 1997, 8:1415 – 1417)

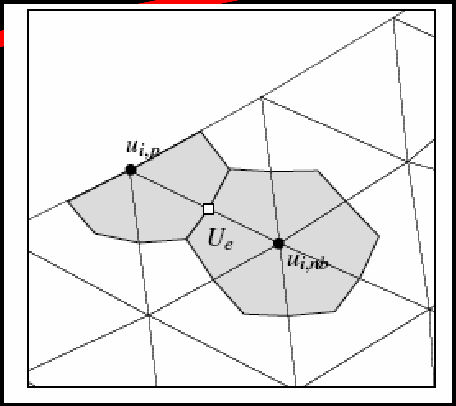
Unstructured LES History

- For almost 10 years, Stanford’s Center for Integrated Turbulence Simulations has been developing LES for unstructured grids
- Resulted in the CDP software: an infrastructure for building massively parallel unstructured low-dissipation solvers

unstructured staggered formulations



control volume formulations



node-based formulations

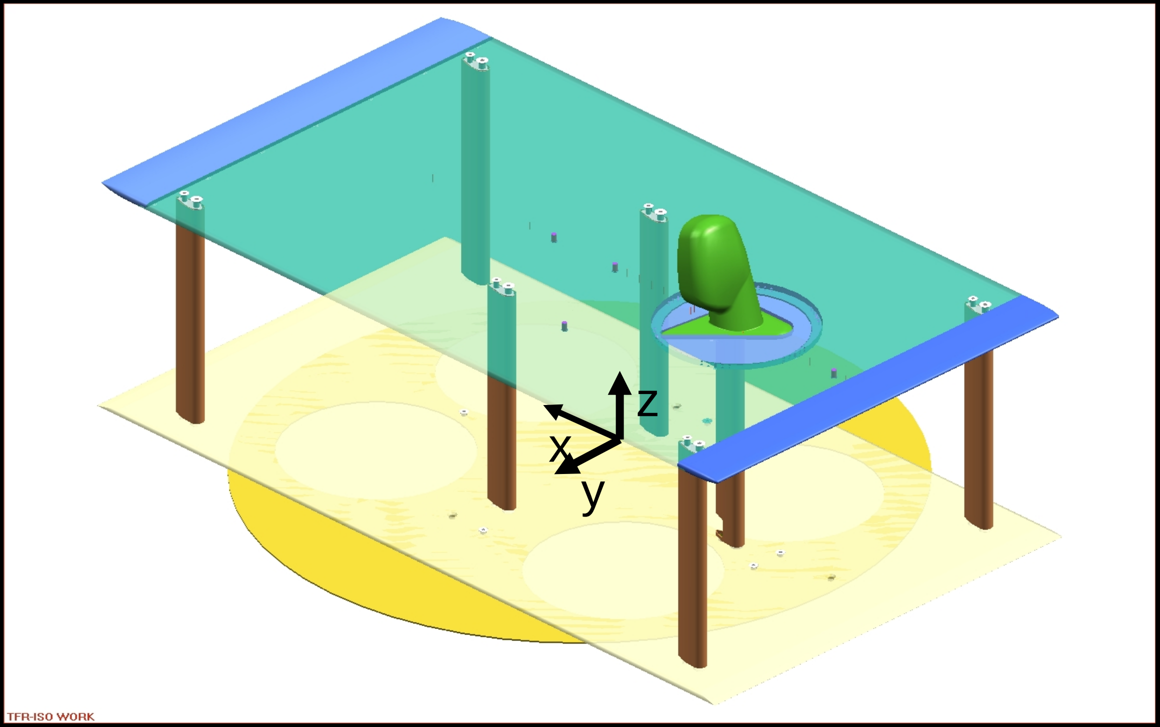
CDP: current status

“Production” incompressible, compressible, & variable density solvers use a node-based finite-volume formulation:

- Accuracy
  - Low dissipation
  - significantly reduced “bad-grid” sensitivity relative to non-dissipative cv-based formulations
- Provable stability by the energy method
  - Summation-By-Parts/Simultaneous-Approximation-Term approach
- Reasonable cost
  - Relatively expensive (many time steps), but can be balanced by massive parallelism (scalable to 1000 processors or more)
- Supports accurate and stable coupling
  - e.g. RANS/LES, structured/unstructured

GM Wind Noise Project

- Combined experimental/computational program to predict mirror noise
- Validation experiments at Notre-Dame
- Simulations at Stanford



Predicting Noise is Tricky

- Tricky because noise carries a very small fraction of the flow energy, and can be easily overwhelmed by numerical errors

=

The energy of sound from a stadium cheering in a football match is only enough to boil an egg!

-Sir James Lighthill

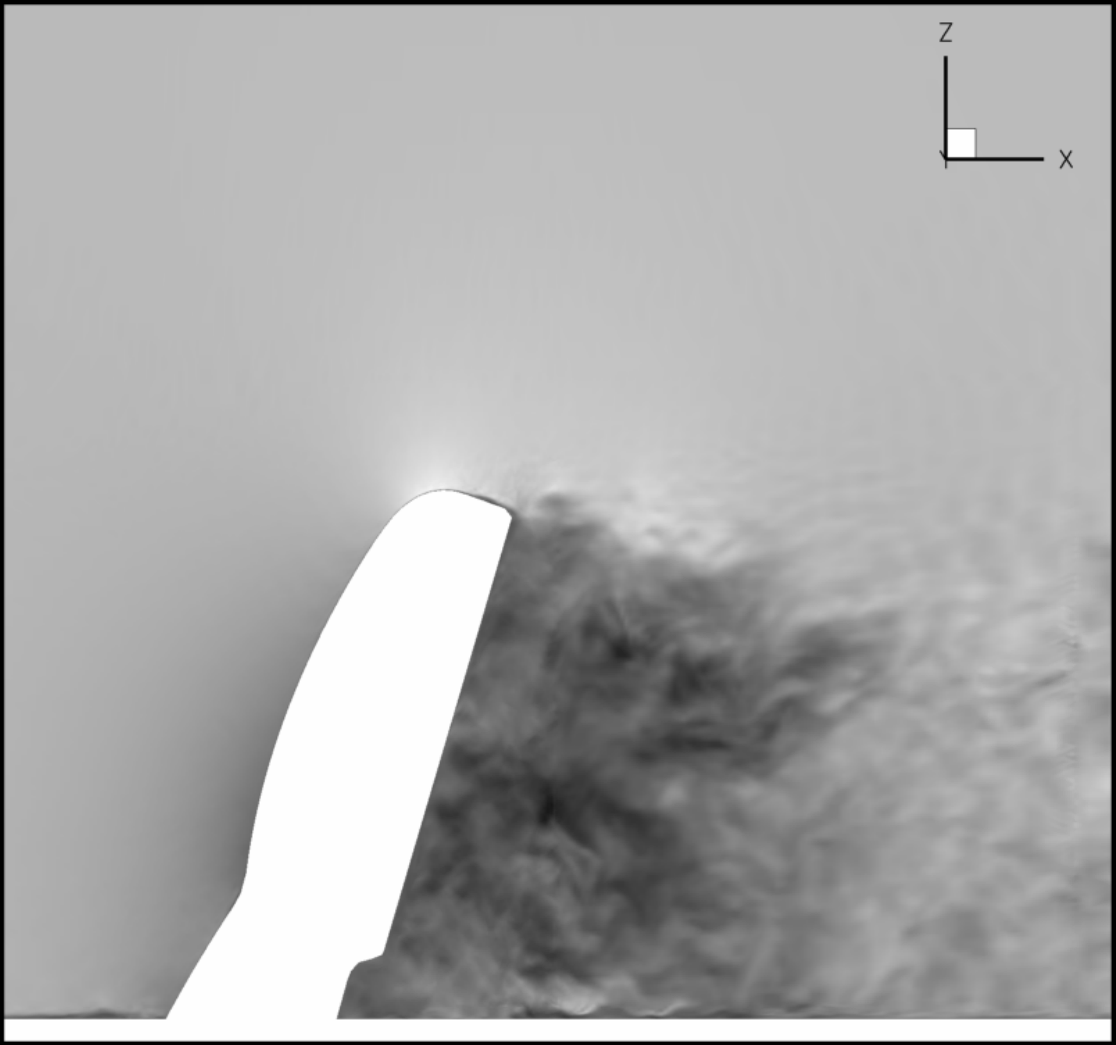
Our Approach: Indirect Method

1. Sound sources are captured using an incompressible flow solver
2. far-field noise is calculated using acoustics analogy

- Advantages
  - Time stepping is dictated by flow CFL number rather than acoustic CFL number: Efficiency for low-Mach
  - Sound is carried separately from flow: Accuracy

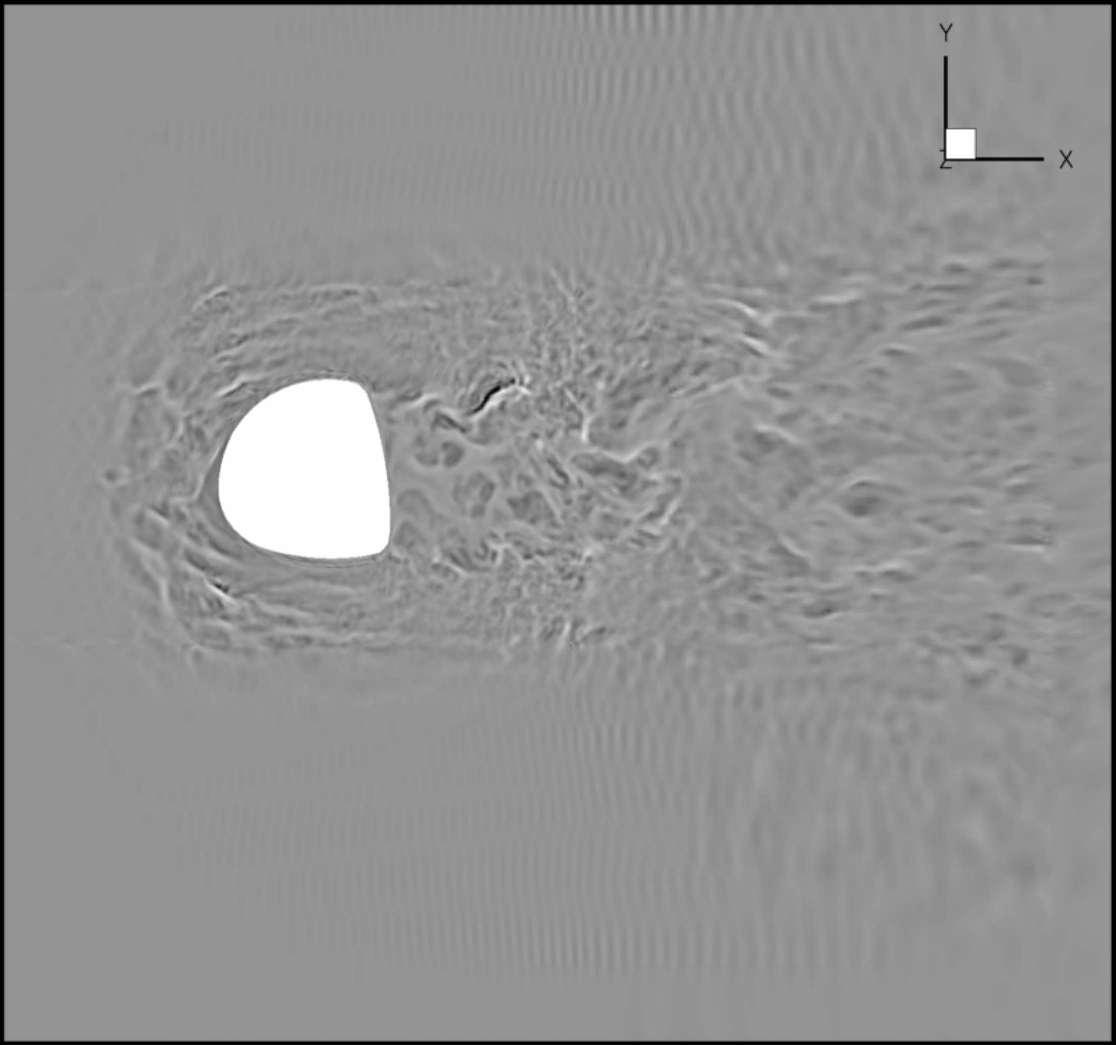
- Disadvantages
  - Valid only for Low Mach numbers
  - An additional equation needs to be solved to calculate far field sound

Step 1:
Simulate flow past the mirror



Axial velocity on
vertical mid-plane

Simulations helped to design experimental instrumentation



Wall-normal velocity just above table: used to anticipate flow structure in wake and select microphone sizes

Flow Simulation Summary

- 3 resolutions: 700K, 5.2M 40M element models, unstructured hex-dominant (produced using recursive refinement of coarse model)
- 3 speeds: 30, 50, 70mph

- For each fine case:
  - 16K time steps, dt=1.25E-5s
  - Each case runs in 30 hours on 500 “traditional processors” (LLNL’s uP, IBM SP Power5, AIX 5.3, GPFS)
  - Write full field data every 8 steps: 2000 files, 1.8 TB data per case
  - Physical time: 0.2s

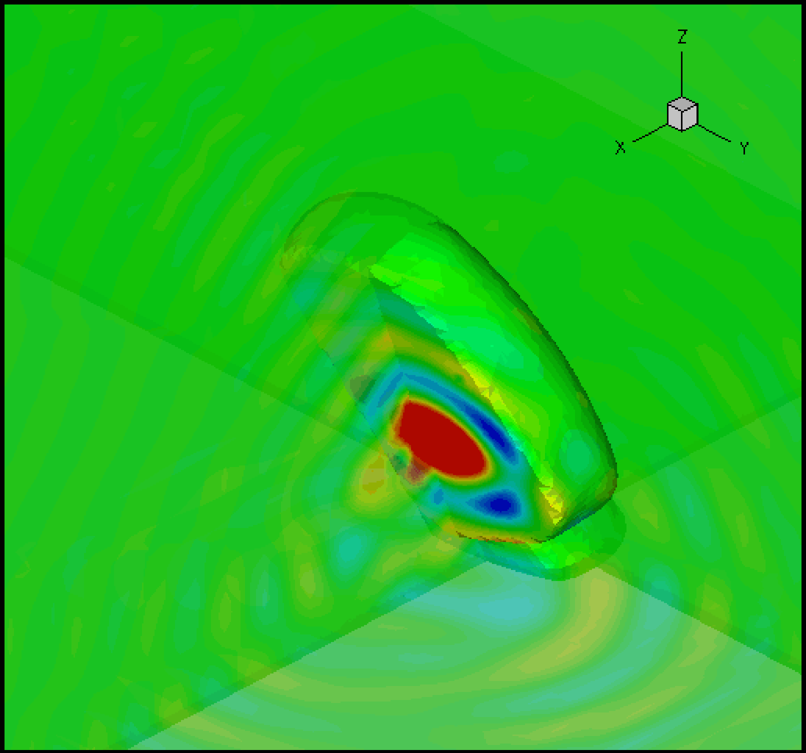
Step 2: Noise Calculation by Acoustic Analogy

- Navier-Stokes equations can be written as a wave equation (Lighthill, 1952):

$$\frac{1}{c_0^2}\frac{\partial^2 p}{\partial t^2}-\frac{\partial^2 p}{\partial x_i \partial x_i}=\frac{\partial^2 T_{ij}}{\partial x_i \partial x_j}$$

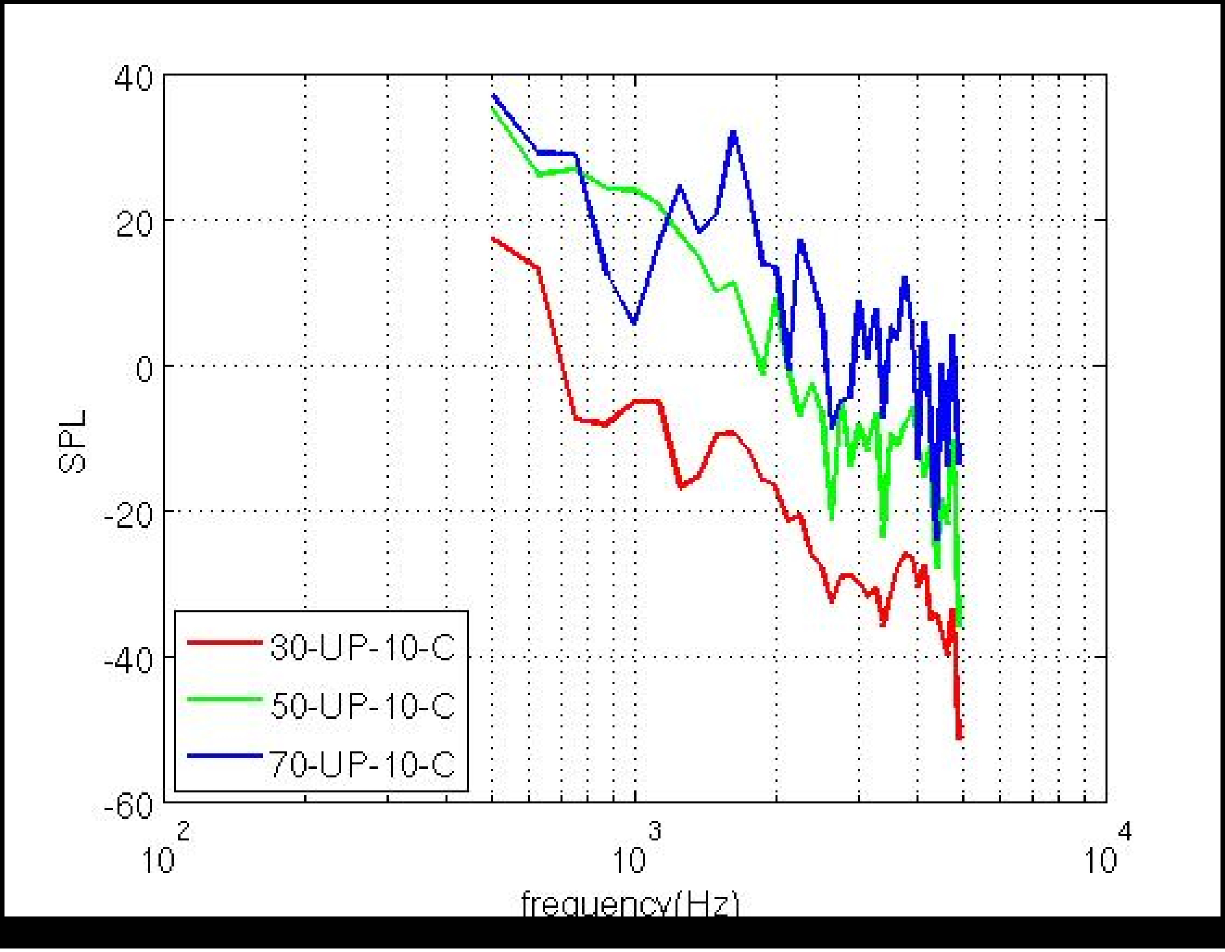
$$T_{ij}=\rho u_i u_j-\xcancel{\sigma_{ij}}+\xcancel{(p-c_0^2\rho)\delta_{ij}}$$

- Solve using a semi-analytic approach: Modified Green's Function Boundary Element Method
  - Accurate and efficient, but
  - Very memory intensive



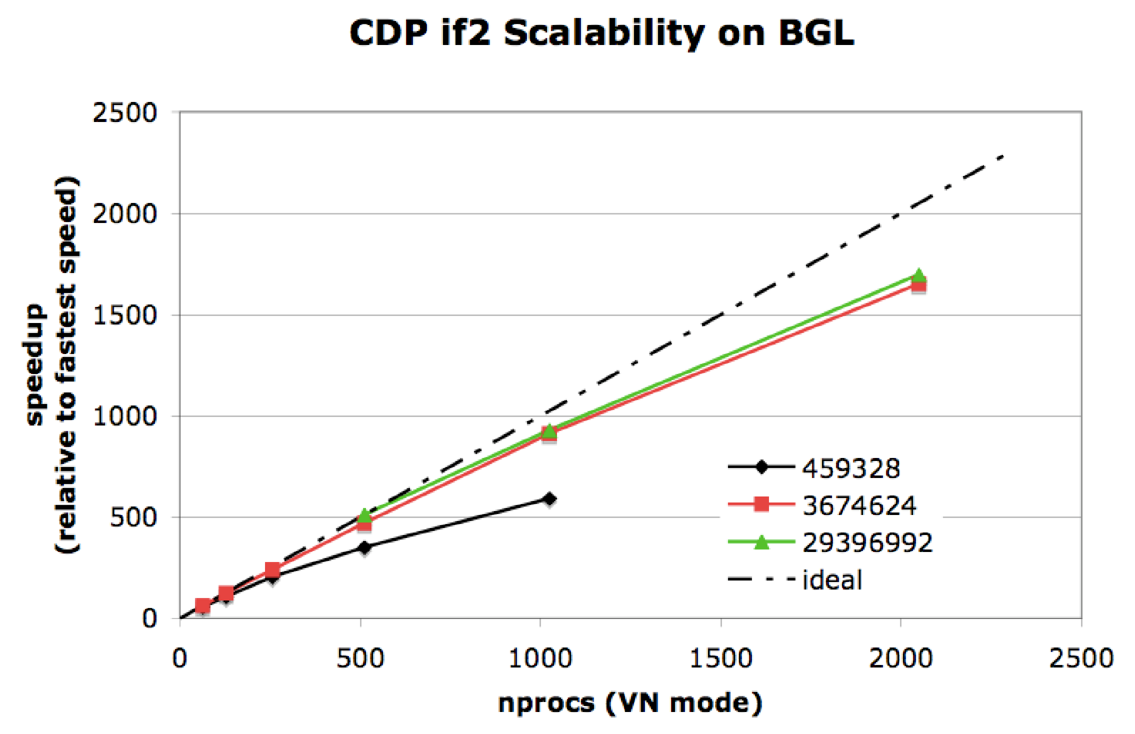
Result

- Predicted sound at different speeds
- No experimental data yet!

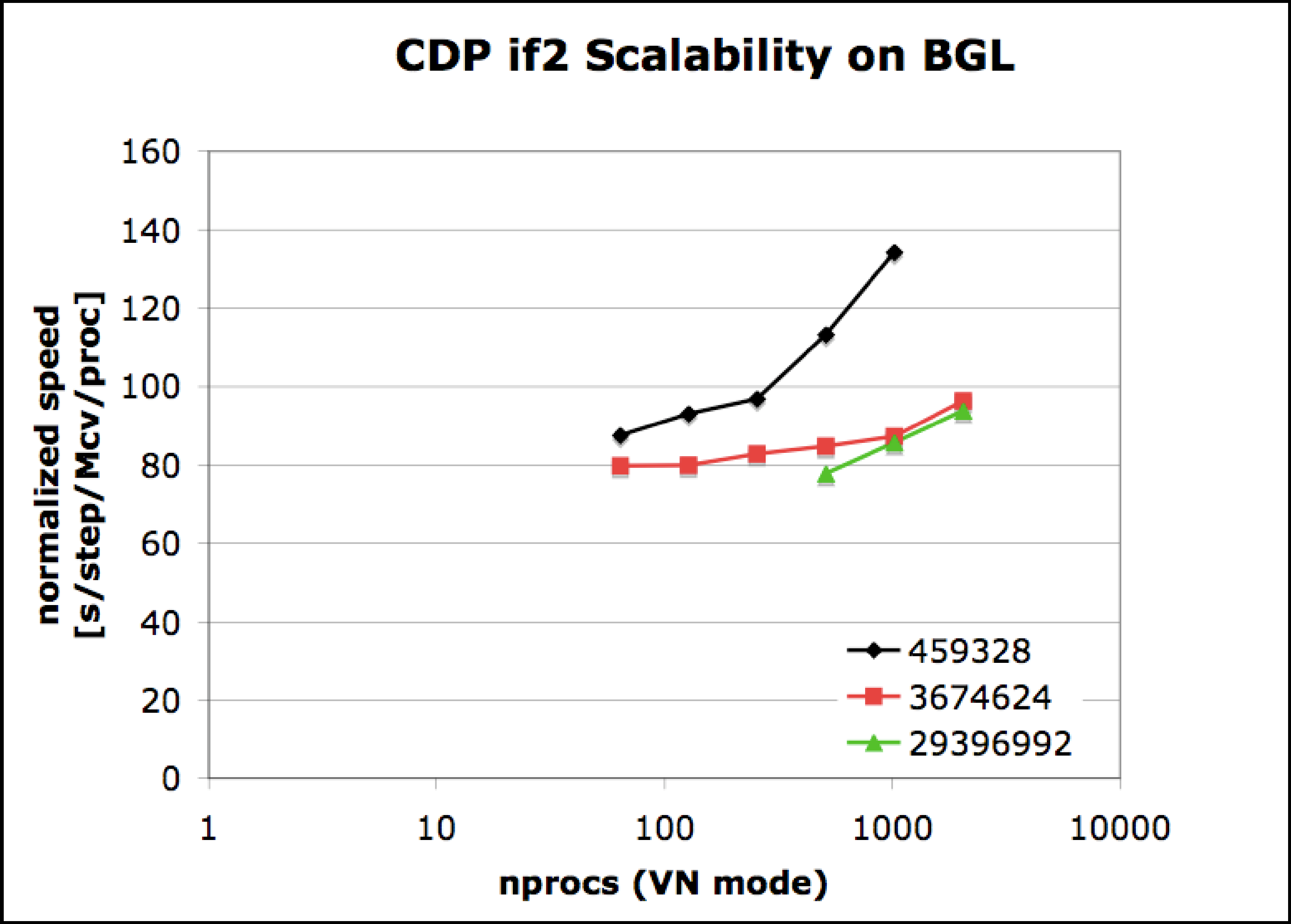


Experiences on BGL

- CDP flow solver tested on IBM Rochester "Capacity on Demand Center"
- no significant I/O
- Required modification of memory-intensive AMG Poisson solver to PCG



Normalized Speed - no I/O



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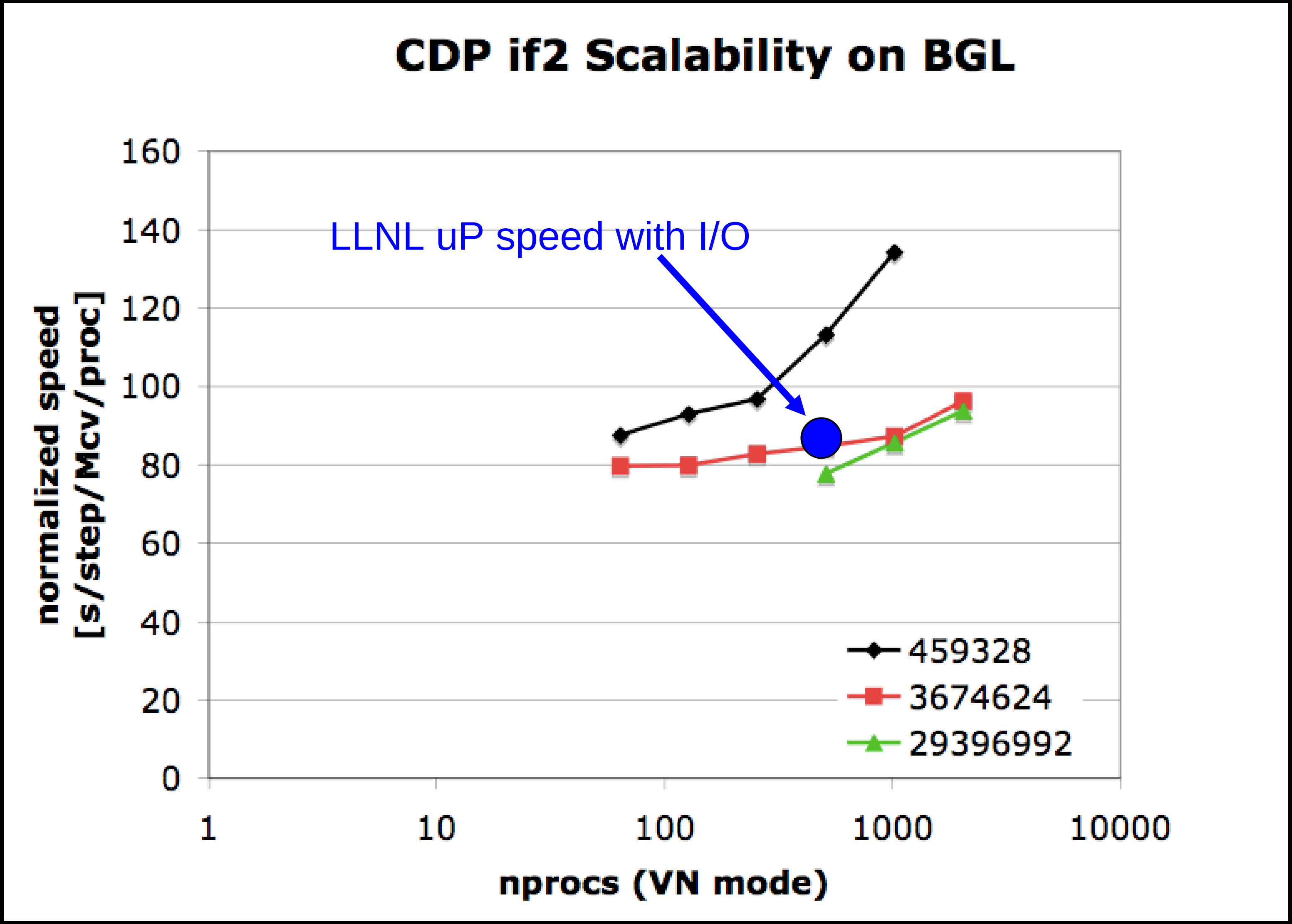
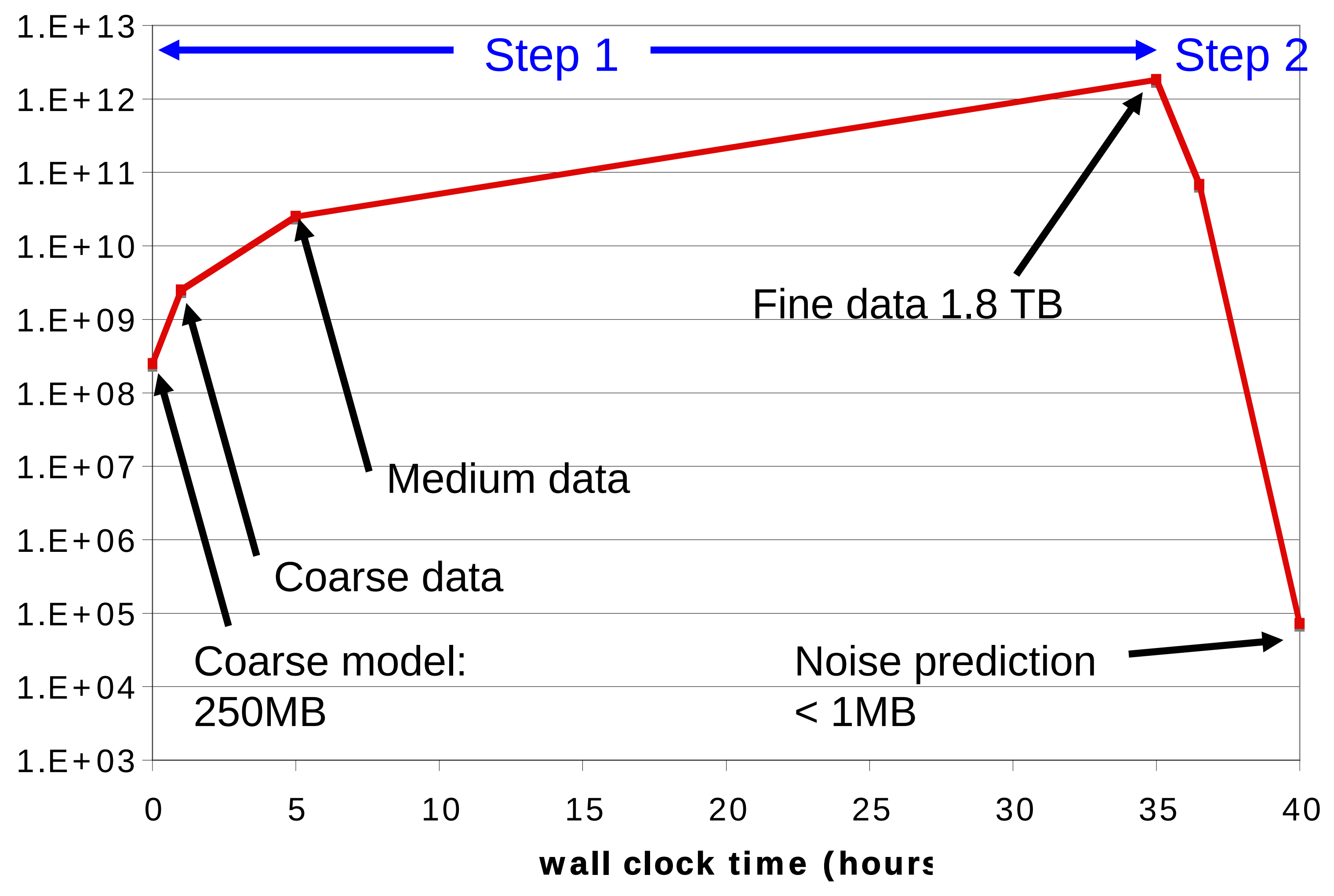


Data Envelope



Summary

- BGL appears competitive for flow solution, although I/O penalty unknown
- Presently not suitable for memory-intensive noise calculations, although we are investigating other solution techniques
- Regular noise simulations would require switching platforms at most data-intensive stage of computation (e.g. 1.8 TB per case)
- call Fedex

References

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