Computational Methods for Structural Acoustics

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Innovative Computational Engineering & Mechanics Laboratory (ICEML)

Director: Lonny L. Thompson

Department of Mechanical Engineering, Clemson University, Clemson, SC, 29634-0921
http://www.ces.clemson.edu/~lonny/cmcu/

Abstract

This project develops fast parallel sparse iterative solution methods on distributed memory computers for time-harmonic structural acoustics. Accurate, efficient, and reliable enhanced finite element and wave-based discretization methods are developed. Applications include: Noise and acoustic predictions; Acoustic radiation and scattering; Interaction of acoustic fluid with structural vibration; Inverse problem of reconstructing sound fields; Noise due to Turbulent Flows; and Ultrasonics. Sponsored by the CMS Division (Dynamic Systems and Control) of the National Science Foundation (NSF).

1. Introduction

- American industry is under increasing pressure to develop analytic and modeling capabilities for designing complex systems with light weight and low noise and vibration.
- Whether the interest is noise in submarines, aircraft, or automobiles, engineers are still not able to predict accurately and reliably the midfrequency behavior of large complex structures.
- This research allows accurate and reliable simulation of the response of complex structures of arbitrary geometry over a wide mid-frequency range for which such modeling has not previously been possible do to limitations on the cost of solution.
- Collectively these technologies show potential to increase the accuracy and reliability of computer simulations and to dramatically enlarge the size of problems that can be solved with a reduction in the computational time required to solve them.

2. Mid-frequency Acoustic Scattering

- For exterior problems, exact non-reflecting boundary conditions, infinite elements, or damping layers used to model the impedance of the exterior region.

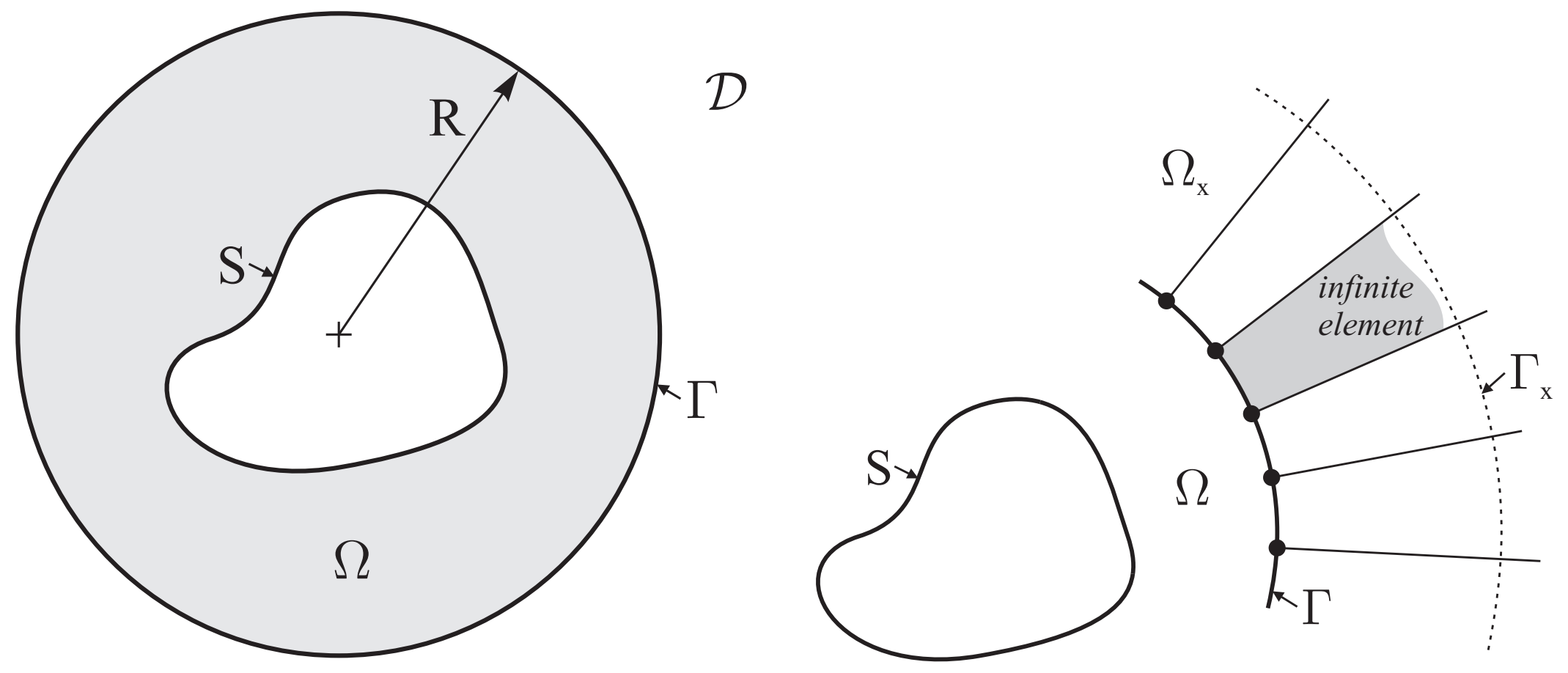


Figure 1: *Nonreflecting boundary* Γ *defining finite computational domain* Ω *for the exterior problem. Infinite element topology.*

- Spheroidal non-reflecting boundaries reduce problem size for elongated scatterers, thus enabling rapid multi-frequency acoustic simulations.

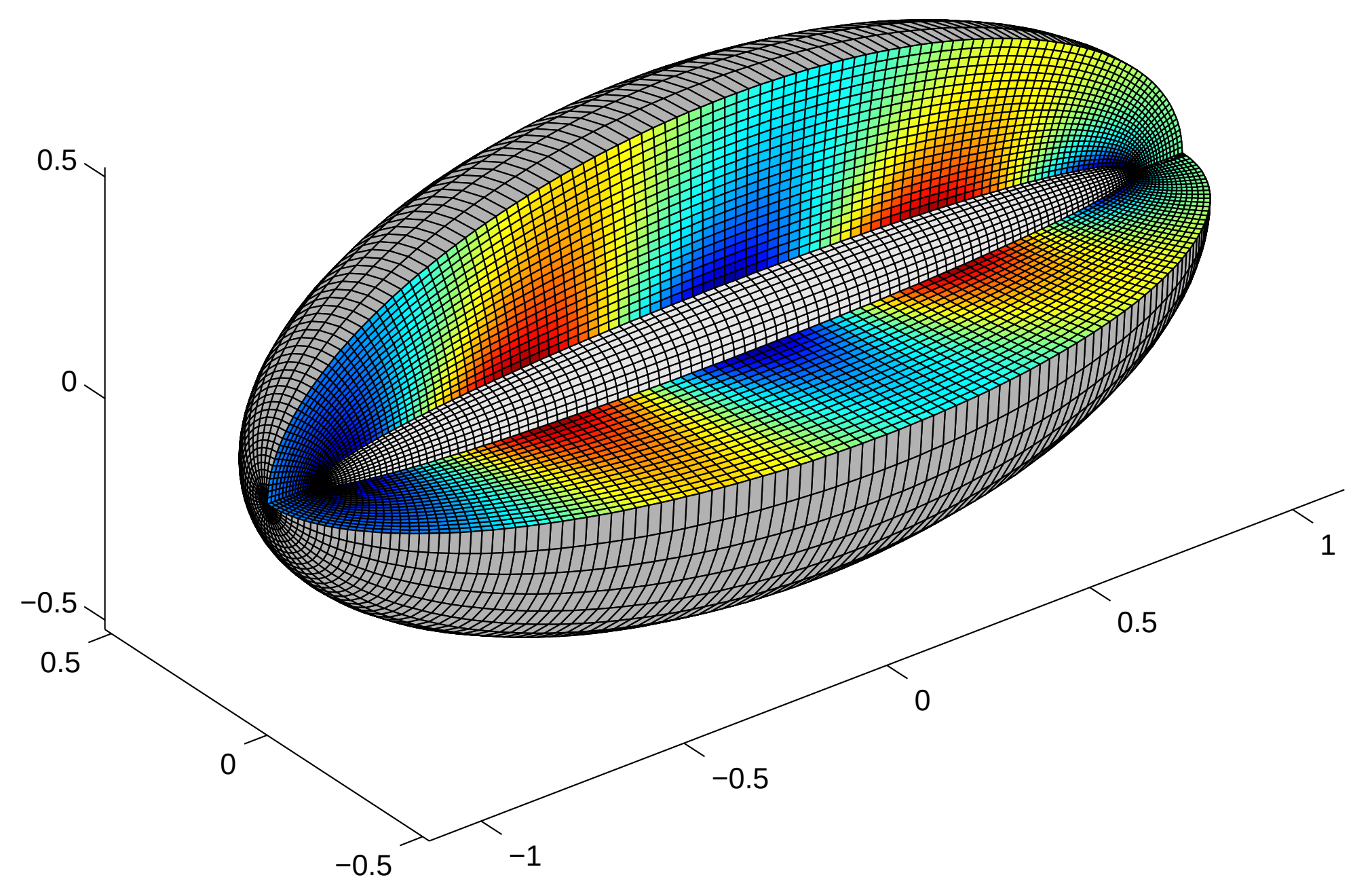
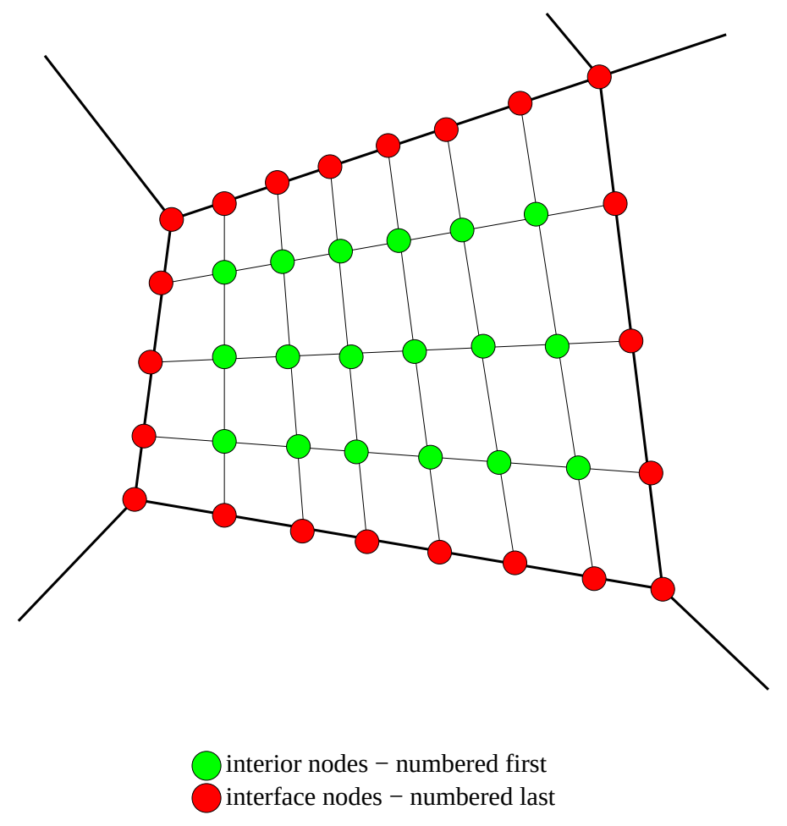


Figure 2: *Scattering of a Plane Wave by a Spheroid. Mesh of wave-enhanced 8-node trilinear 'brick' elements. 1.5 million total grid points. Significant speedup achieved with SSOR preconditioned Bi-Conjugate-Gradient-Stabilized (BiCG-Stab) Iterative Solver with Sparse Matrix Storage.*

3. Parallel Sparse Iterative Solvers

- Domain decomposition used to balance computational load to minimize inter-processor communication.
- Krylov subspace iterative solvers require repeated matrix-by-vector products.
- Inter-processor communication for vector updates need only occur between adjacent subdomains sharing common interface data.



$$\begin{bmatrix} \mathbf{A}_1 & & & \mathbf{B}_{1v} \\ & \ddots & & \vdots \\ & & \mathbf{A}_p & \mathbf{B}_{pv} \\ \mathbf{B}_{1v}^T & \cdots & \mathbf{B}_{pv}^T & \mathbf{A}_v \end{bmatrix}$$

Figure 3: *Nodal partition and corresponding structure of the sparse matrix problem.*

4. Scalable Parallel Speedup on Multiple Processors

Submarine shaped 3-dimensional rigid scatterer subject to a plane-wave incident field. Computational domain enclosed by prolate spheroidal DtN boundary.

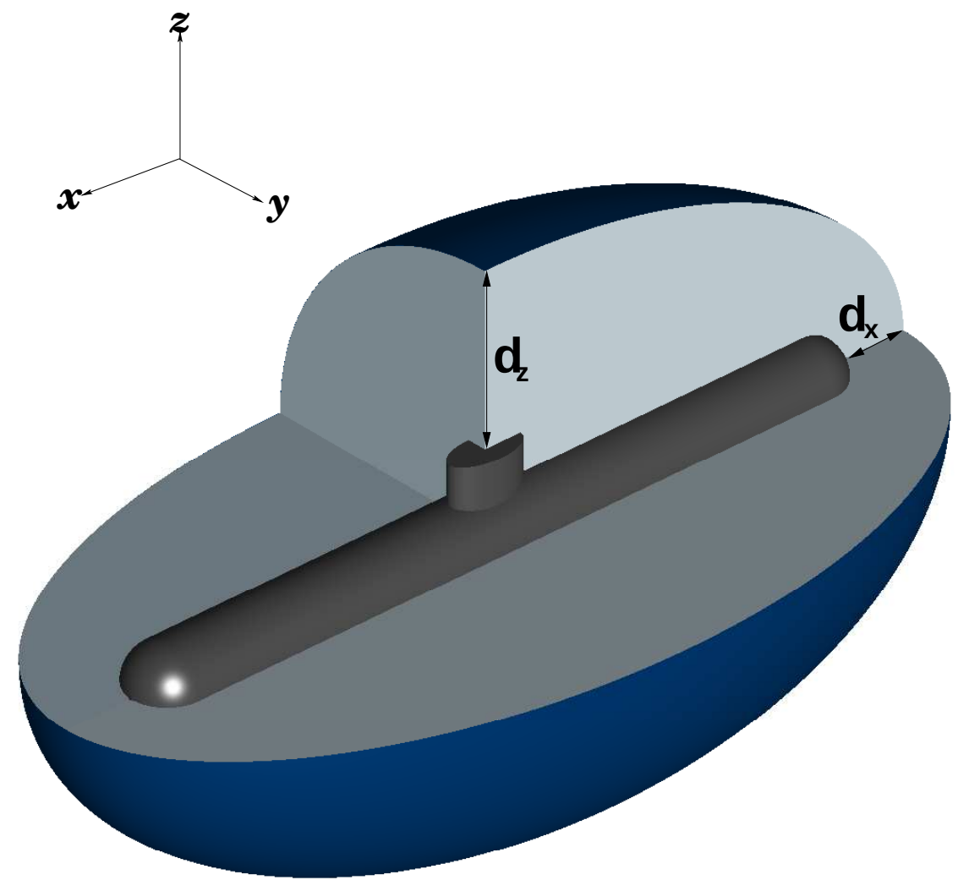


Figure 4: *Computational domain enclosed by a spheroidal truncation boundary placed at* $d_x = s_x\lambda$ *and* $d_y = s_y\lambda$ *from the submarine-shaped scatterer.*

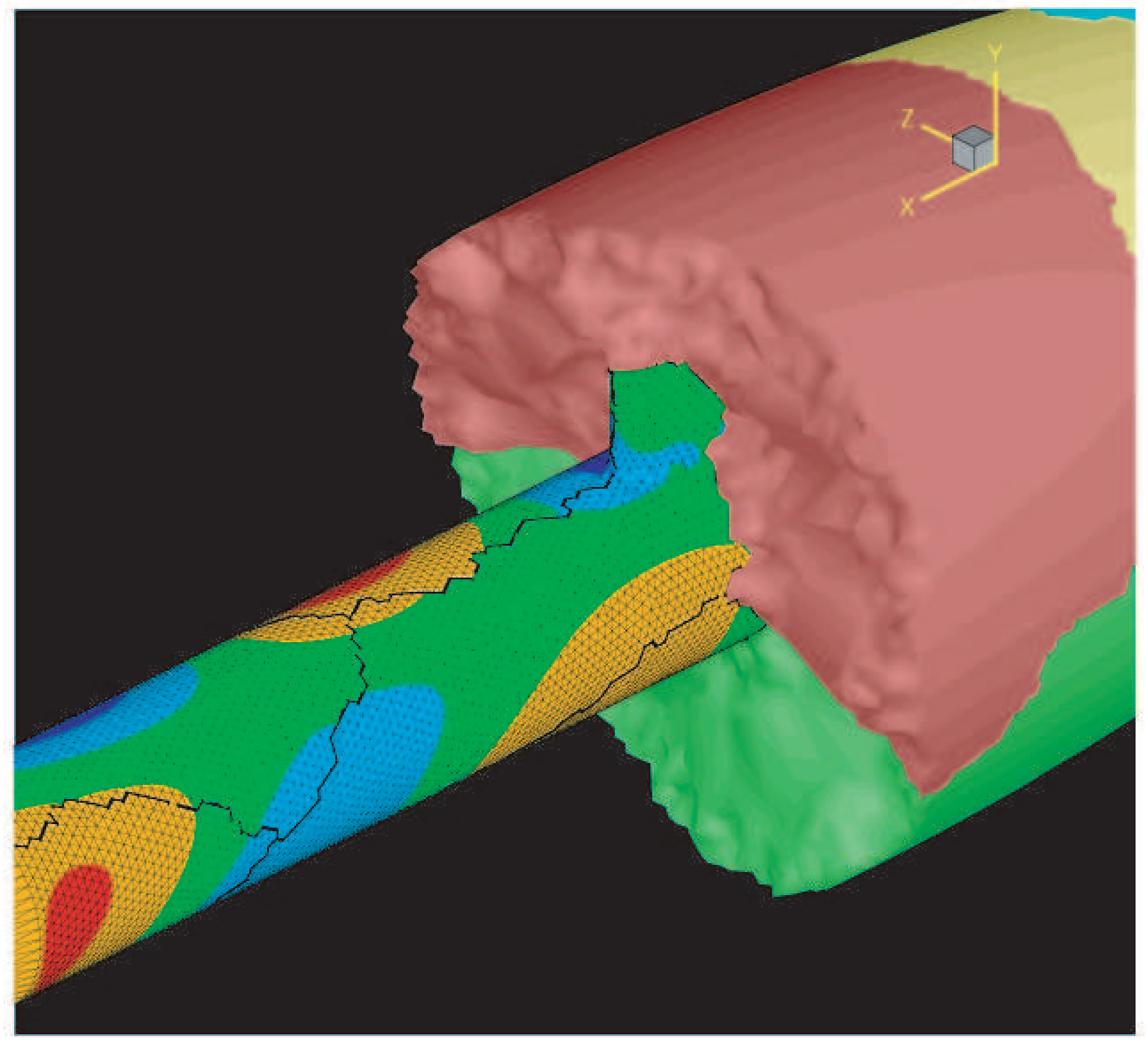


Figure 5: *Example of large-scale problem of scattering from a submarine. Sample grid partition:* $N \approx 350,000$ *grid points; 1 million tri-linear tetrahedra elements,* $\frac{D}{\lambda} = 0.4$; $\frac{\lambda}{h} = 50$. $p = 10$ *sub-domains; 1 processor per sub-domain; I-DEAS tetrahedron mesh generator.*

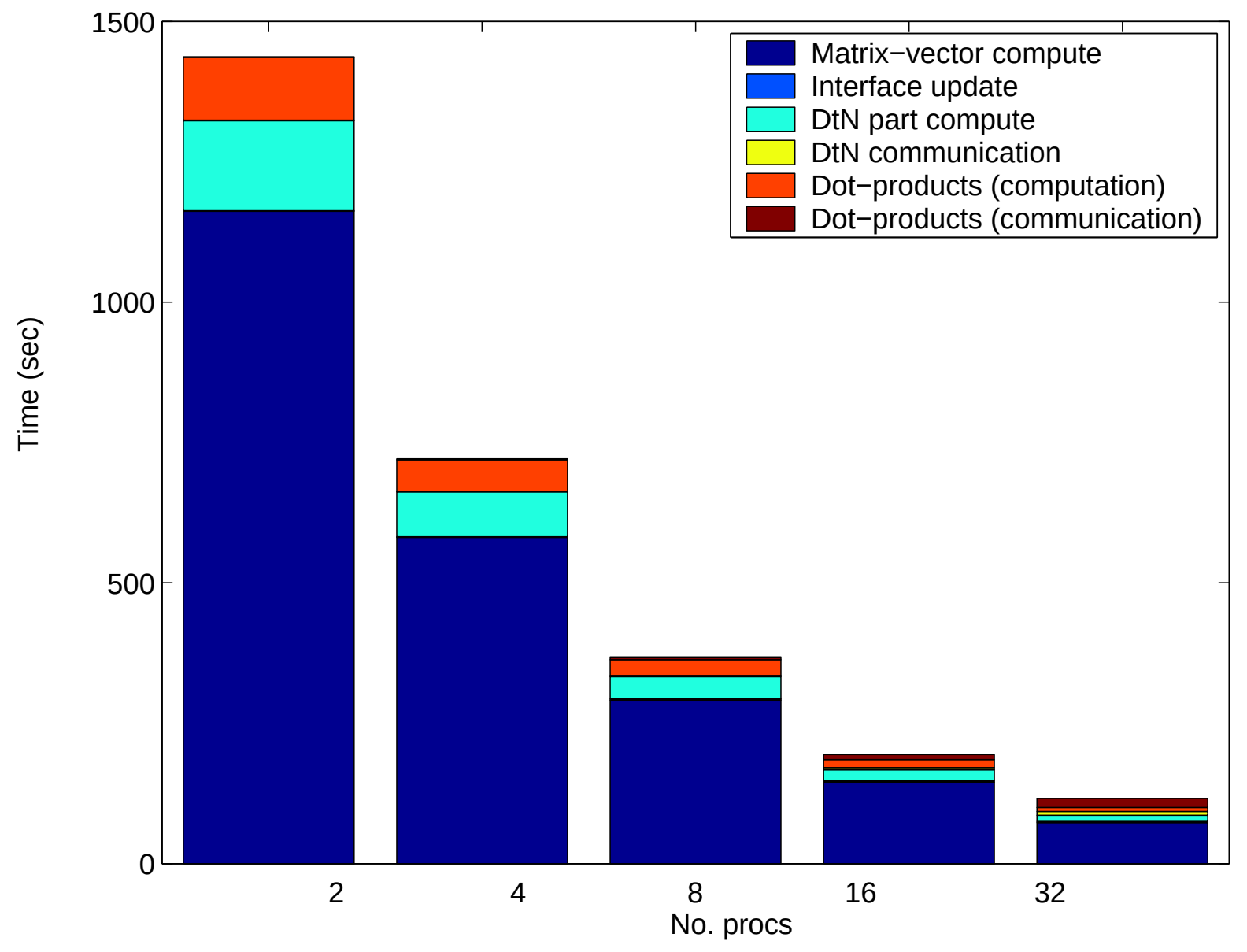


Figure 6: *Parallel Speedup for 200 iterations for mesh with* $N \approx 350,000$ *grids on PIII-1Ghz Beowulf Linux cluster with Myrinet II network; MPICH Message Passing Interface (MPI) library; METIS graph partitioning package. The parallel implementation of DtN is effective in achieving the near optimal speedup.*

5. Accurate Shell Elements for Acoustic-Structure Interaction

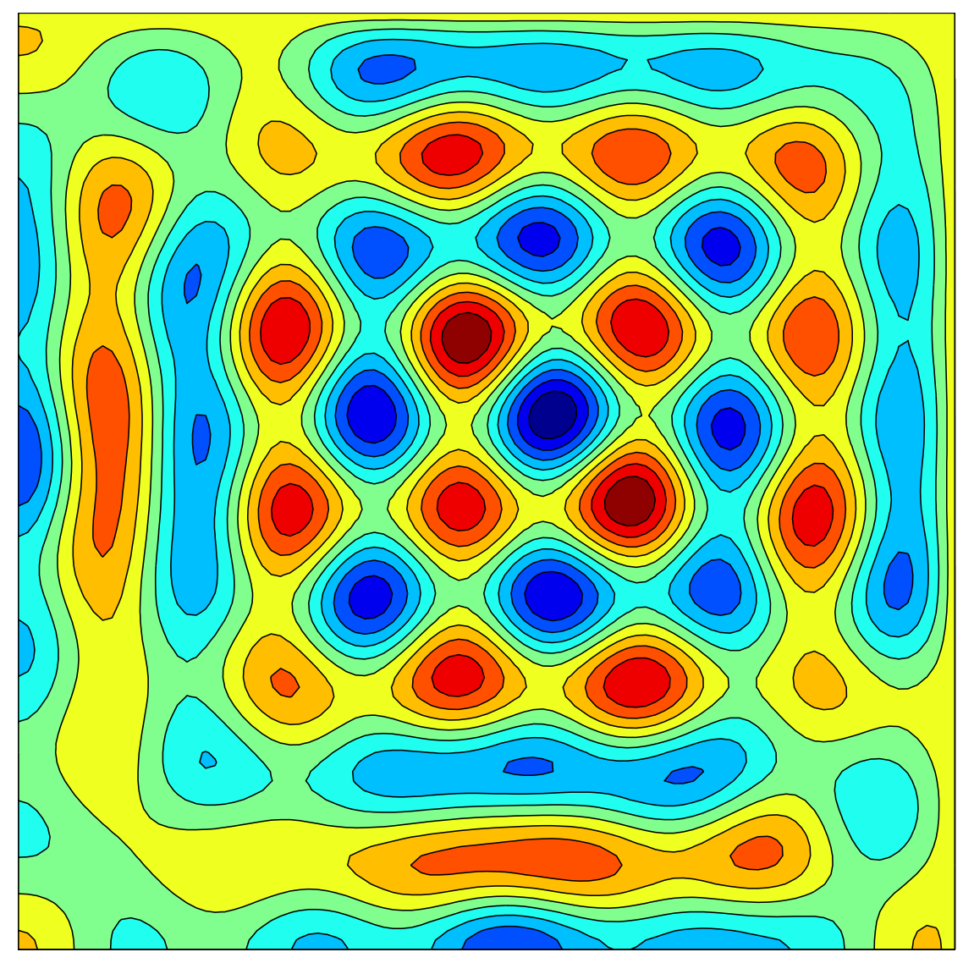


Figure 7: *Forced-vibration of clamped plate at frequency* $f = 1750$ *Hz.*

- *Problem:* When modeling frequency response of shell structures finite elements are needed which accurately model both propagating (real wavenumber) and evanescent (imaginary) wave types. Standard plate and shell elements exhibit poor accuracy at high frequencies.
- *Solution:* Using complex wavenumber dispersion analysis as a tool for selecting mesh parameters which match exact wavenumber-frequency relation for a given wave angle, new shell elements are developed which improve dispersion accuracy by a factor of three.
- *Impact*: Reduces mesh resolution requirements by more than one-half, enabling accurate and reliable solutions over a wide range of frequencies with significantly reduced cost.