

TIME DOMAIN SIMULATIONS OF RADIATION FROM DUCTED FANS WITH LINERS

Yusuf Ozyoruk

Assoc. Prof., Middle East Technical University, Turkey

Vineet Ahuja

Research Scientist, CRAFT Inc., USA

Lyle N. Long

Professor, The Pennsylvania State University, USA

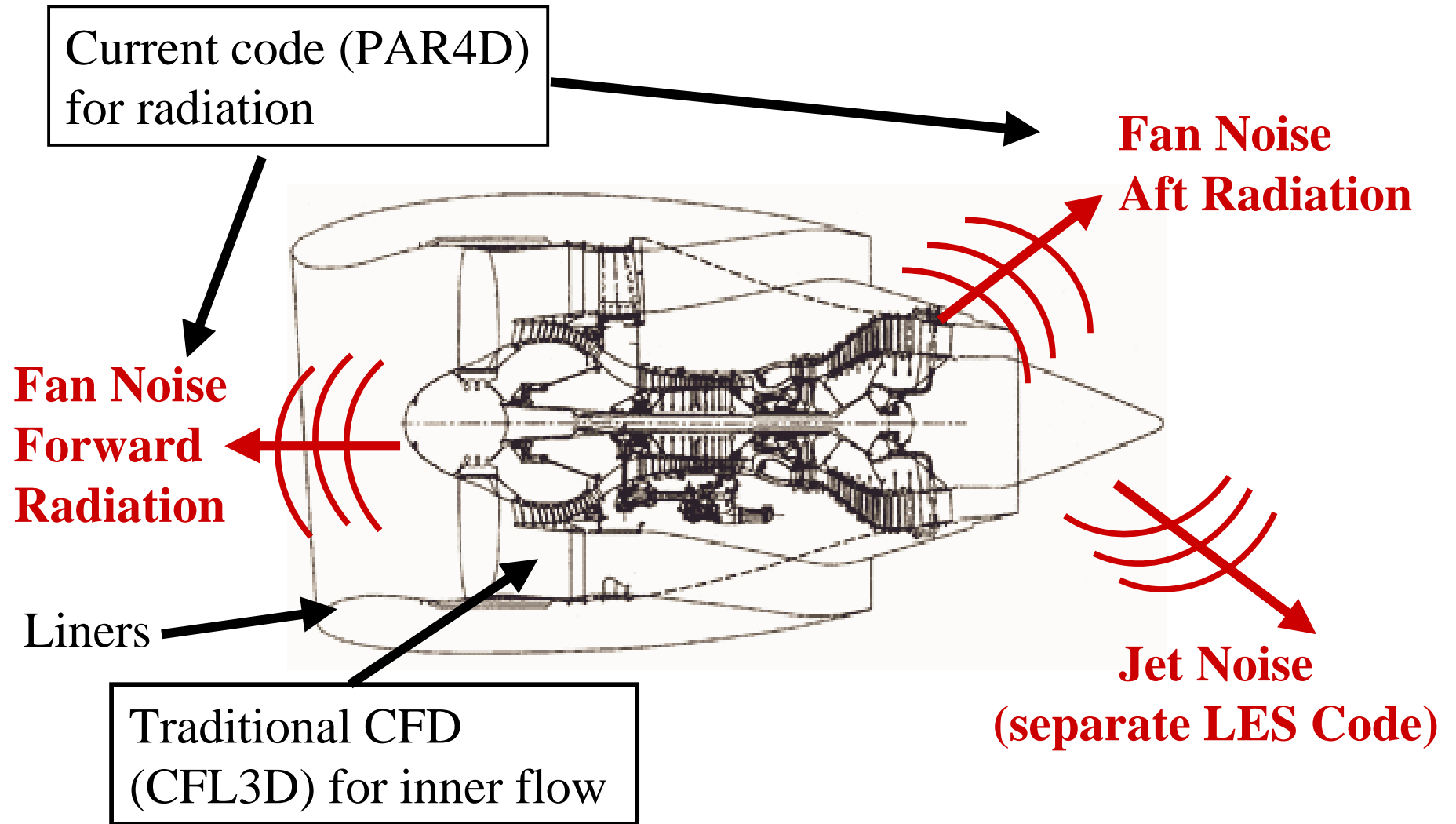
Frederic Souliez

Research Assistant, The Pennsylvania State University, USA

AIAA Paper 2001-2171

Aeroacoustics Conference, Maastricht, Netherlands

Introduction



Introduction

- **Traditional CFD codes cannot accurately model aeroacoustic phenomena**
 - Dispersion & Dissipation Errors (Ref. Tam)
 - Upwind, implicit schemes cannot compute acoustics
 - These cannot even be used to predict the initial steady state !
 - These can be used to obtain source terms though
- **CAA Codes cannot compute steady-state flow efficiently**
 - Poor convergence properties
 - Extremely complicated codes
 - Higher-order accurate Multi-grid is essential

Approach

- **3-D Euler/Navier-Stokes equations**
- **Fourth order spatial and temporal accuracy**
 - Central differencing
 - Runge Kutta time marching
- **Higher order accurate multi-grid**
 - Jameson FAS extended to 4th order spatial accuracy
 - This is only used to compute mean flow
- **Fortran-90 and MPI for parallel computing**
 - Runs on virtually any parallel computer or cluster
 - Uses structured grids

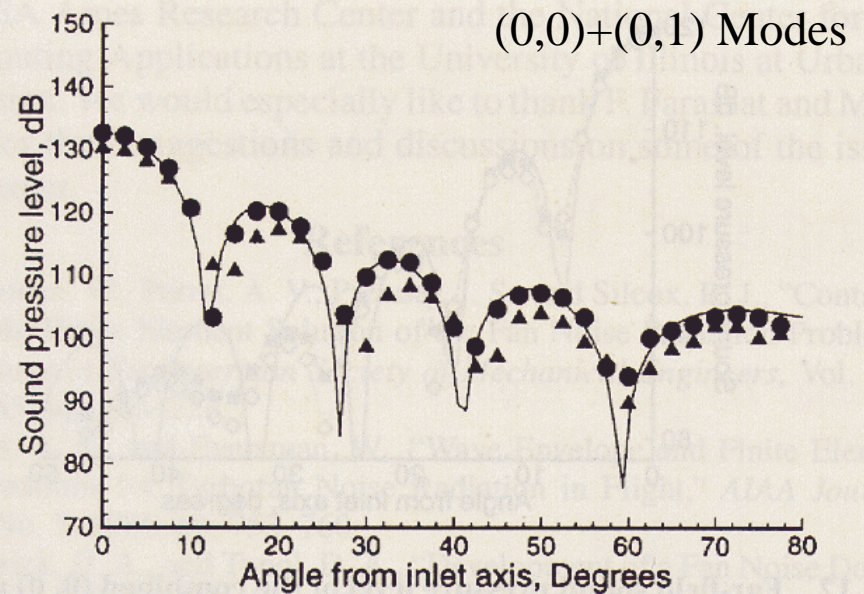
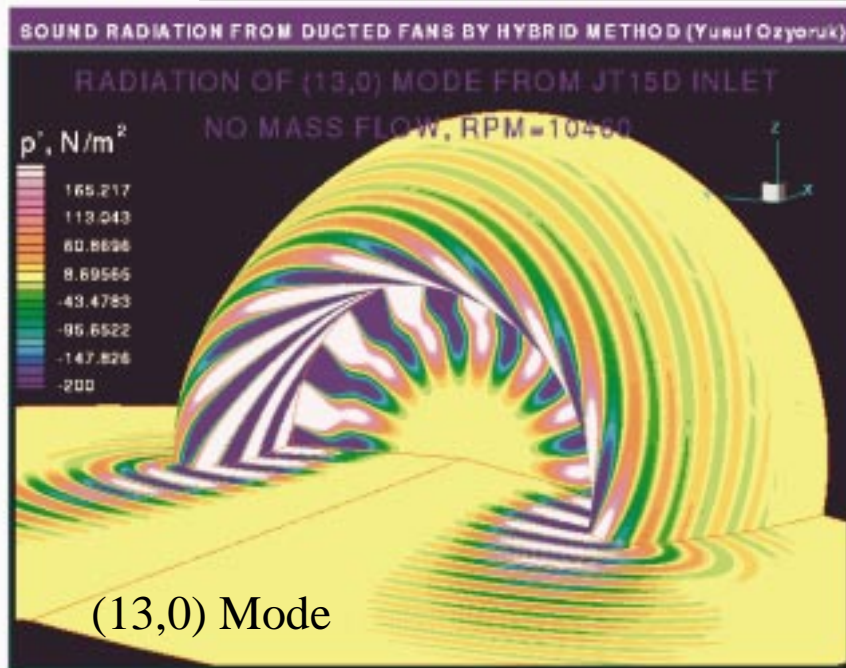
Approach (cont.)

- **Time-dependent Sources on fan face or exhaust given as boundary conditions**
 - from other codes, theory, or experiments
- **Time domain impedance conditions used for liners**
 - Details are given in previous papers (see list of references)
 - Uses z-transform method
- **Kirchhoff method for far-field noise**
 - From Farassat & Myers
 - Will use FW-H in future

Fan Noise Solution

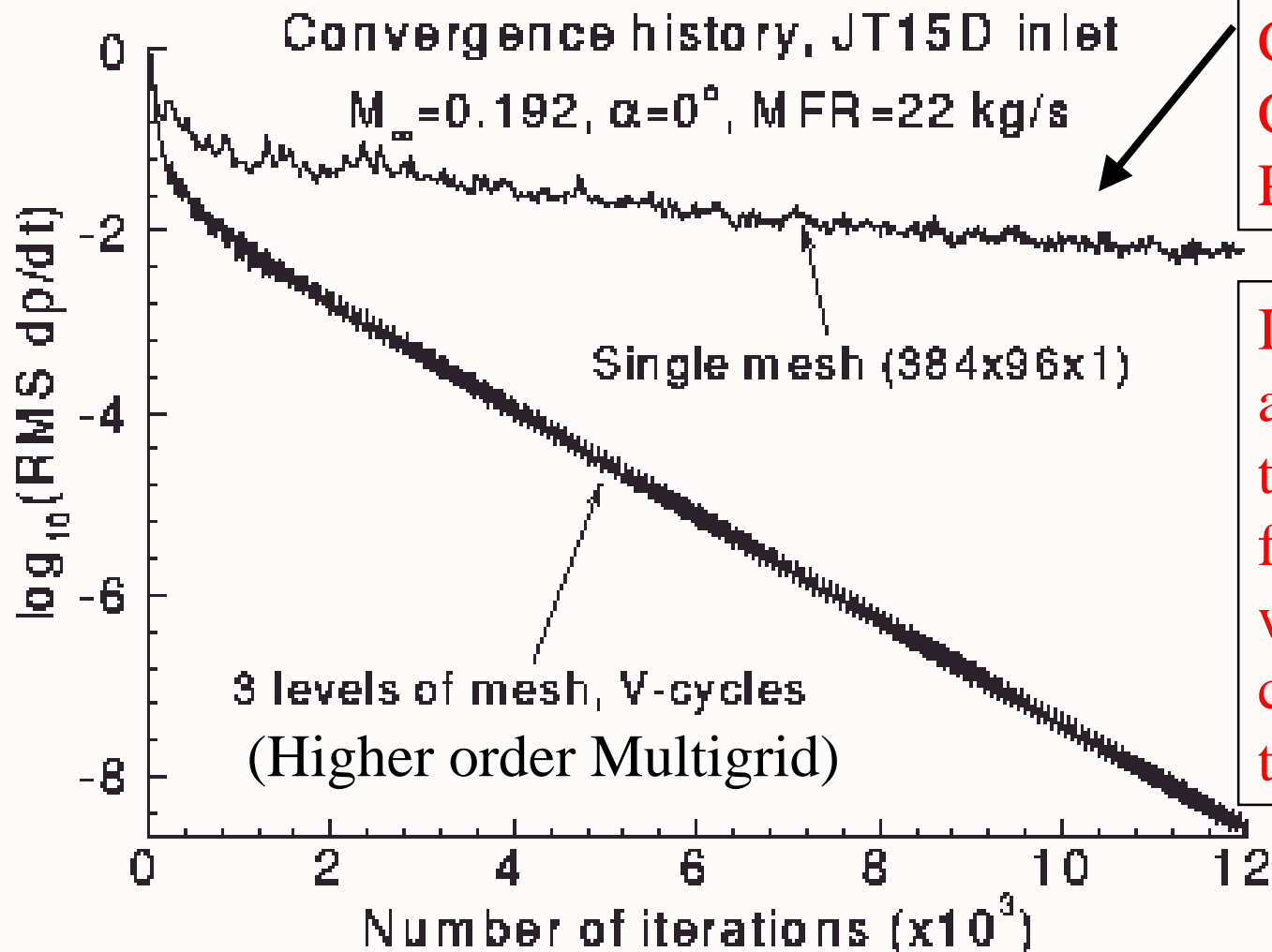
(early CM-Fortran PAR4D code by Y. Ozyoruk and L. Long)

JT15D Engine Inlet, RPM=6750, Mach=0



This code was written in CM-Fortran, and only ran on Connection Machines. Over the last several years we have converted it to Fortran-90 and MPI, which is no easy task.....

Higher Order Explicit Schemes Converge Slowly



Typical
CAA Code
Convergence
Problem

If there are any errors in the mean flow, these will contaminate the acoustics

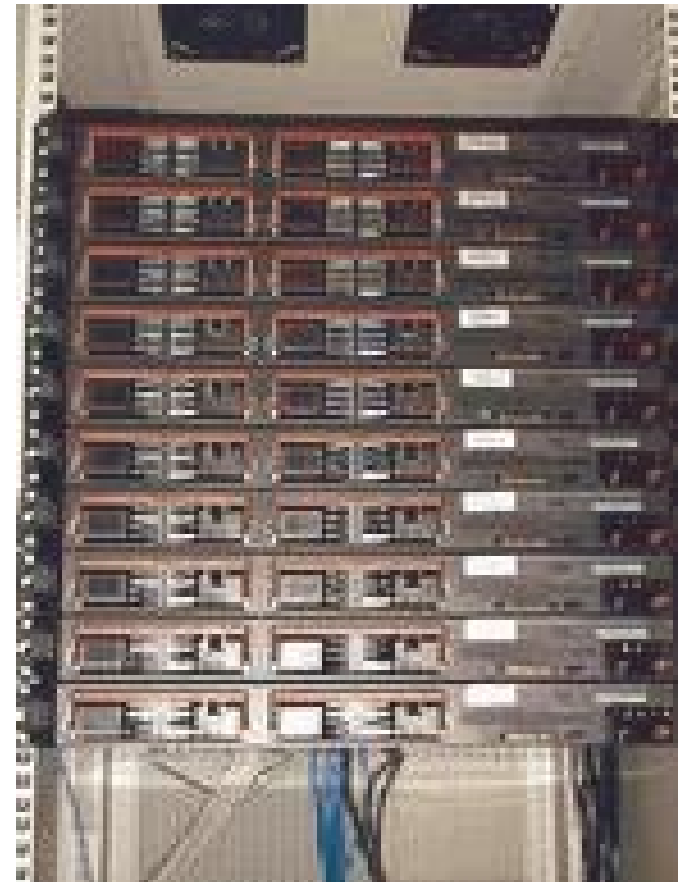
Inexpensive PC Clusters

Most people use 16-32 processors since it is too difficult to obtain more than this regularly at supercomputer centers.

You can build a 16-processor machine yourself :

- 8 dual-processor workstations
- 800 MHz Pentium III processors
- 1 GB RAM each (8 GB total)
- 20 GB disk each (160 GB total)
- Fast Ethernet Switch
- Linux, MPI, DQS, F90, C, ...

This would only cost \$25,000 and would give you 140,000 CPU hours per year. Far more than you can get at a supercomputer center. (Penn State Aerospace has 92 processors)



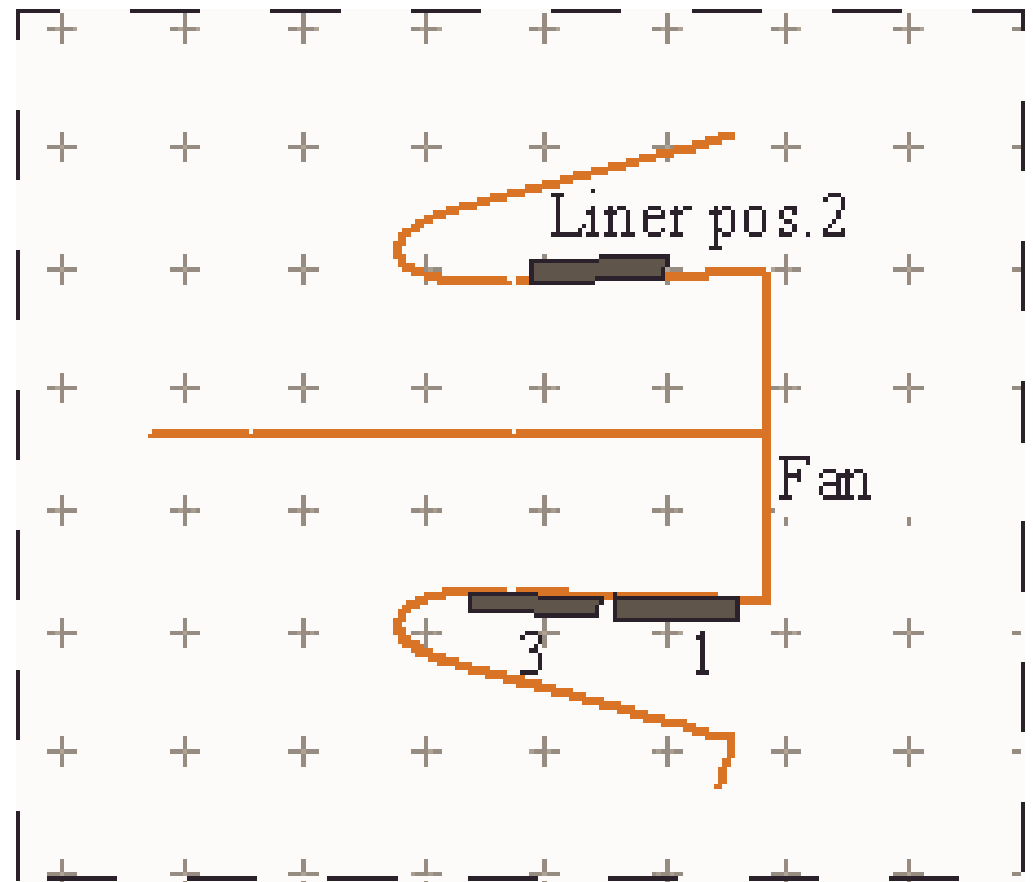
Our rack-mounted system
<http://cocoa2.ihpca.psu.edu/>

Results

- **Code has been thoroughly validated in the past (see references in paper) by comparing to other methods, theory, and experiments.**
- **JT15D engine inlet**
 - **With and without mass flow**
 - **With and without liners**
- **Generic inlet with center body**
 - **With mass flow**
 - **With and without liners**

Liner Locations on JT15D Inlet

- JT15D engine inlet
- Liner material was applied at 3 different locations, to determine the effect this would have



Impedance used in Liner

(Frequency kHz)	$Z/(\rho_0 c_0)$
0.5	$0.406 - 1.587i$
1.0	$0.476 + 0.113i$
1.5	$1.078 + 1.638i$
2.0	$5.009 - 0.276i$
2.1	$4.008 - 1.601i$

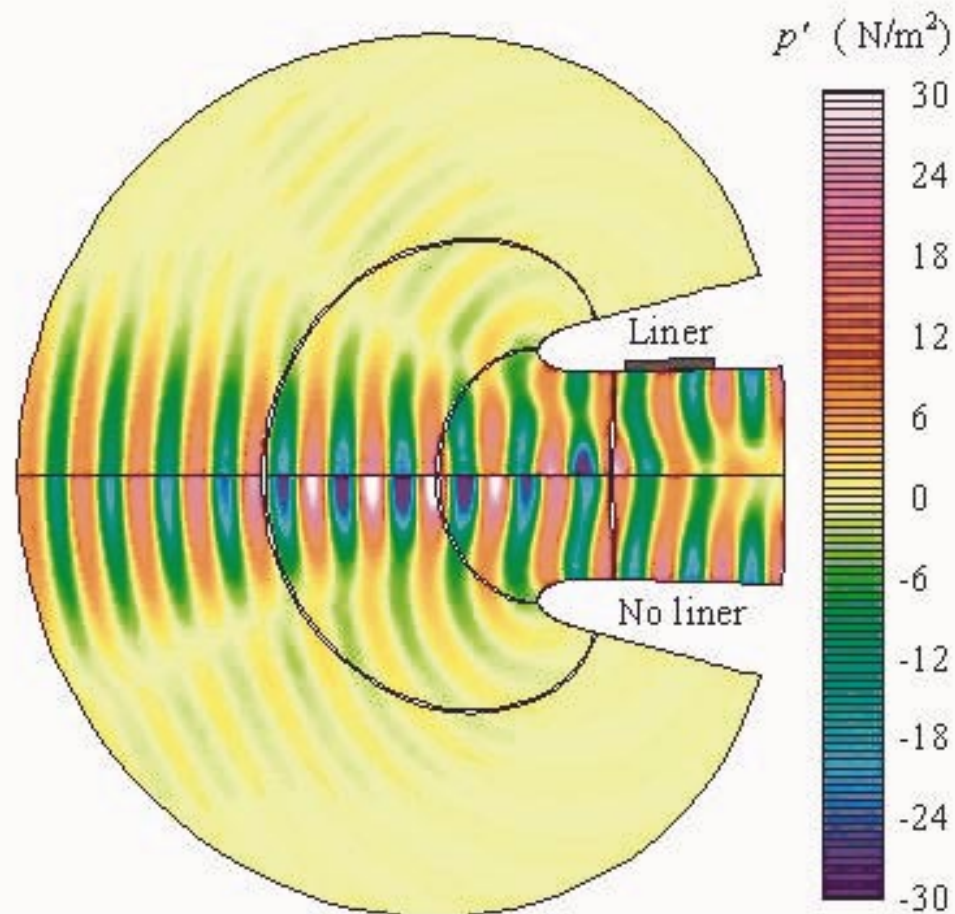
Frequency dependent impedance can be modeled in our time-dependent z-transform method

JT15D: With and Without Liner

No mass flow

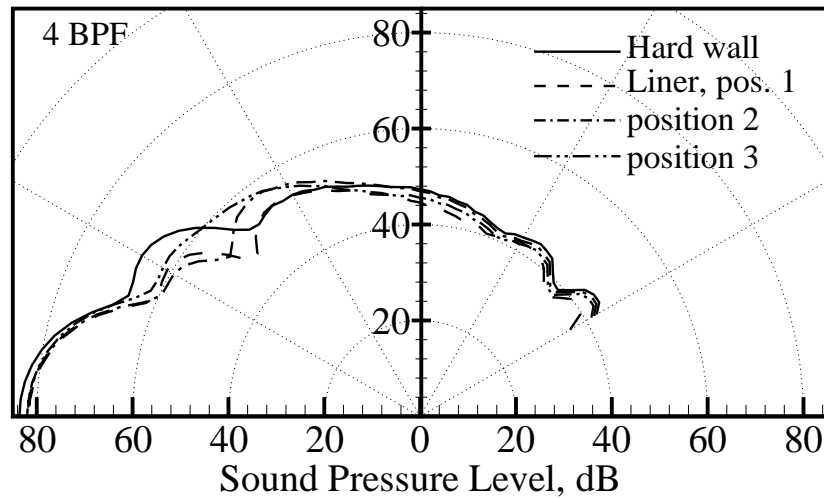
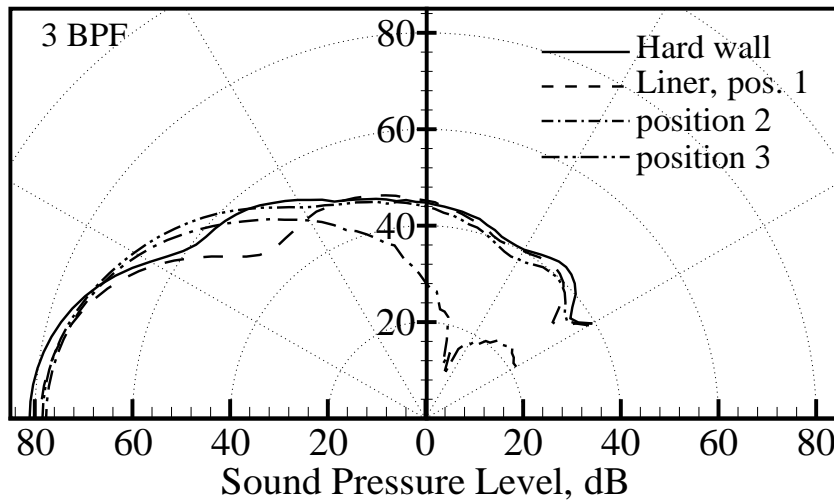
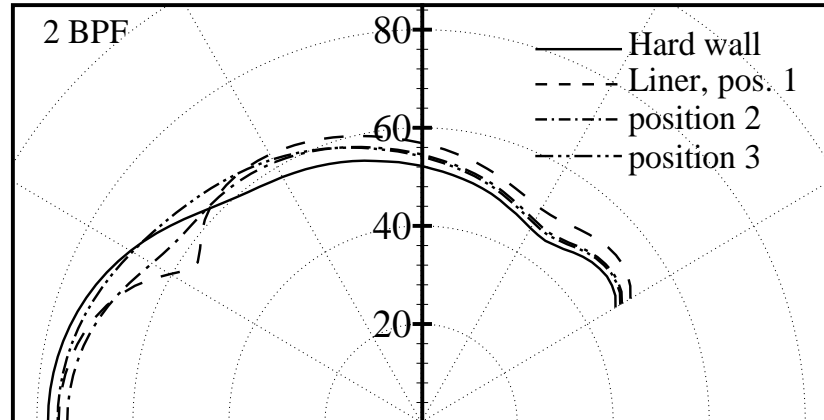
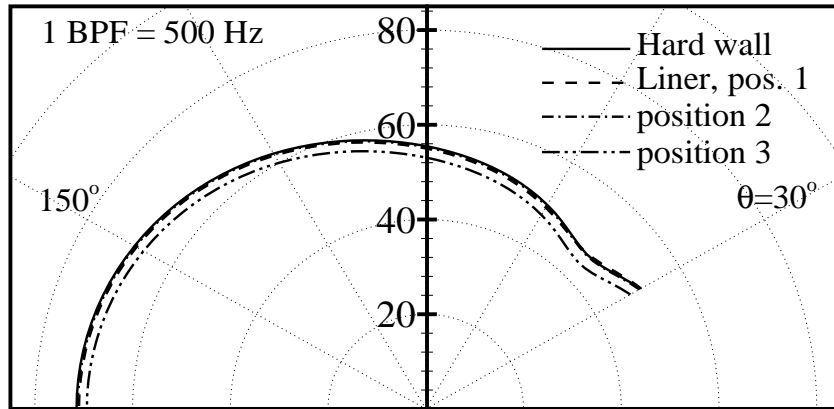
Plane wave modes
(0,0) and (0,1) at
BPF

Sound level along
centerline is reduced
when liner is present



(liner in position 1)

JT15D Far-Field Predictions (for several harmonics of the BPF)



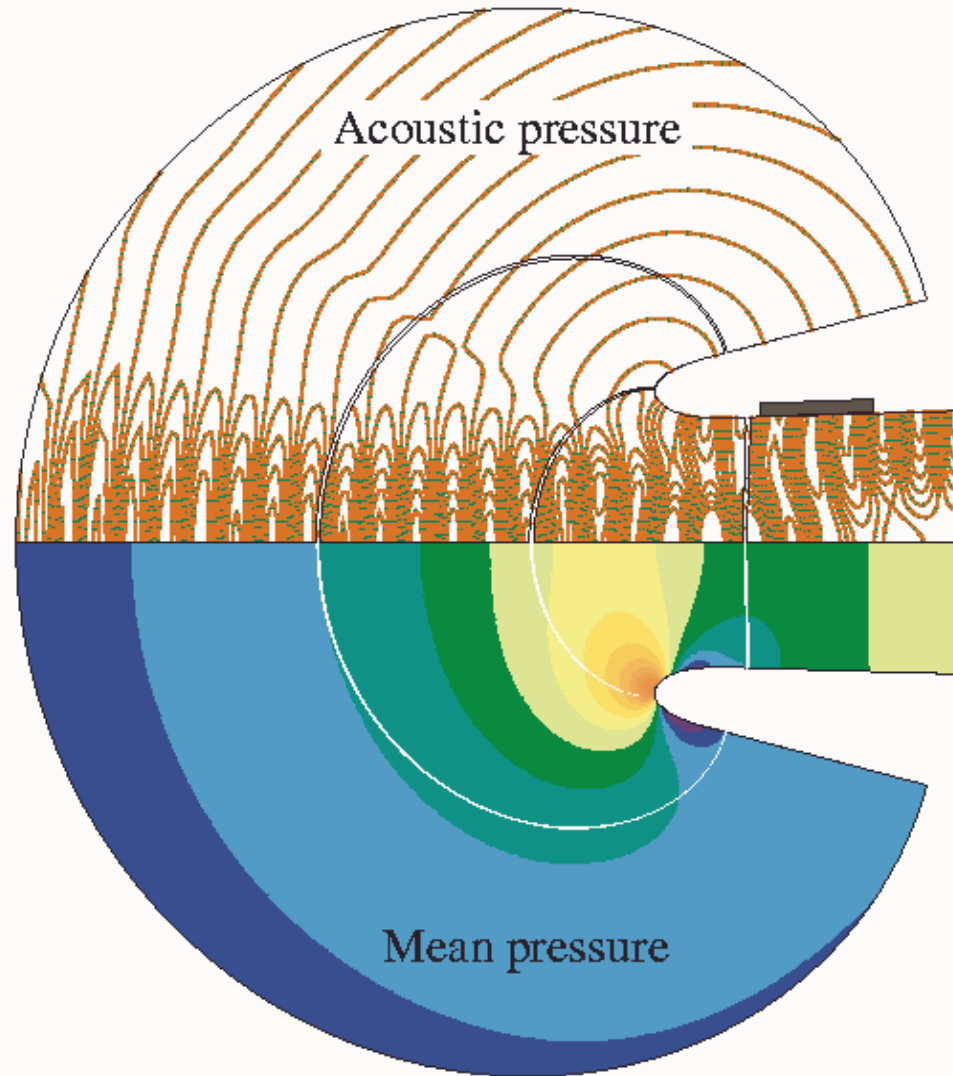
(0,0) + (0,1) Modes

JT15D with Mass Flow

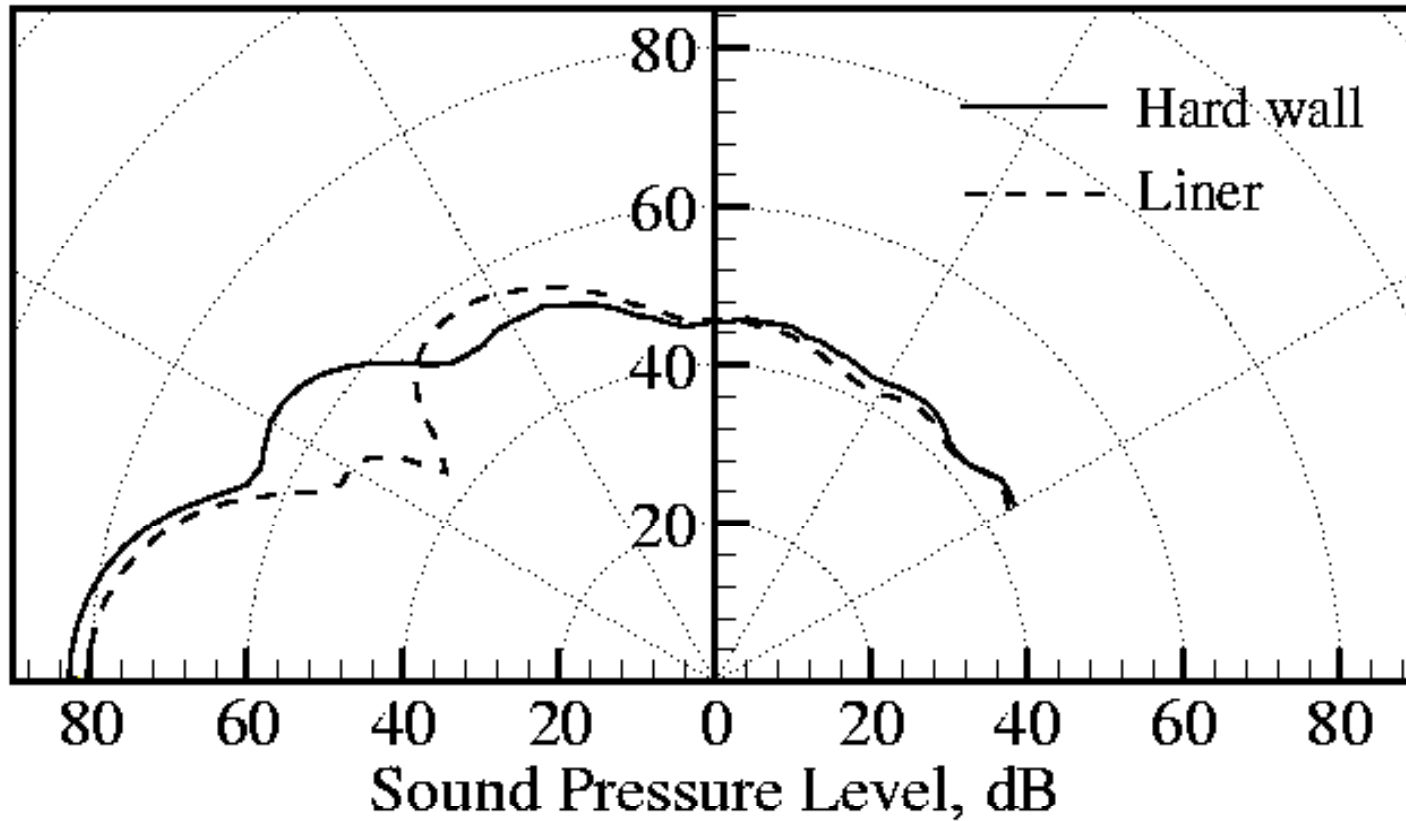
Plane wave modes (0,0)
and (0,1) at 2 kHz (BPF)

Mach = 0.2

Mass flow = 15 Kg / sec



JT15D with and without Liner



(with mass flow)

Generic 3-D Engine Inlet

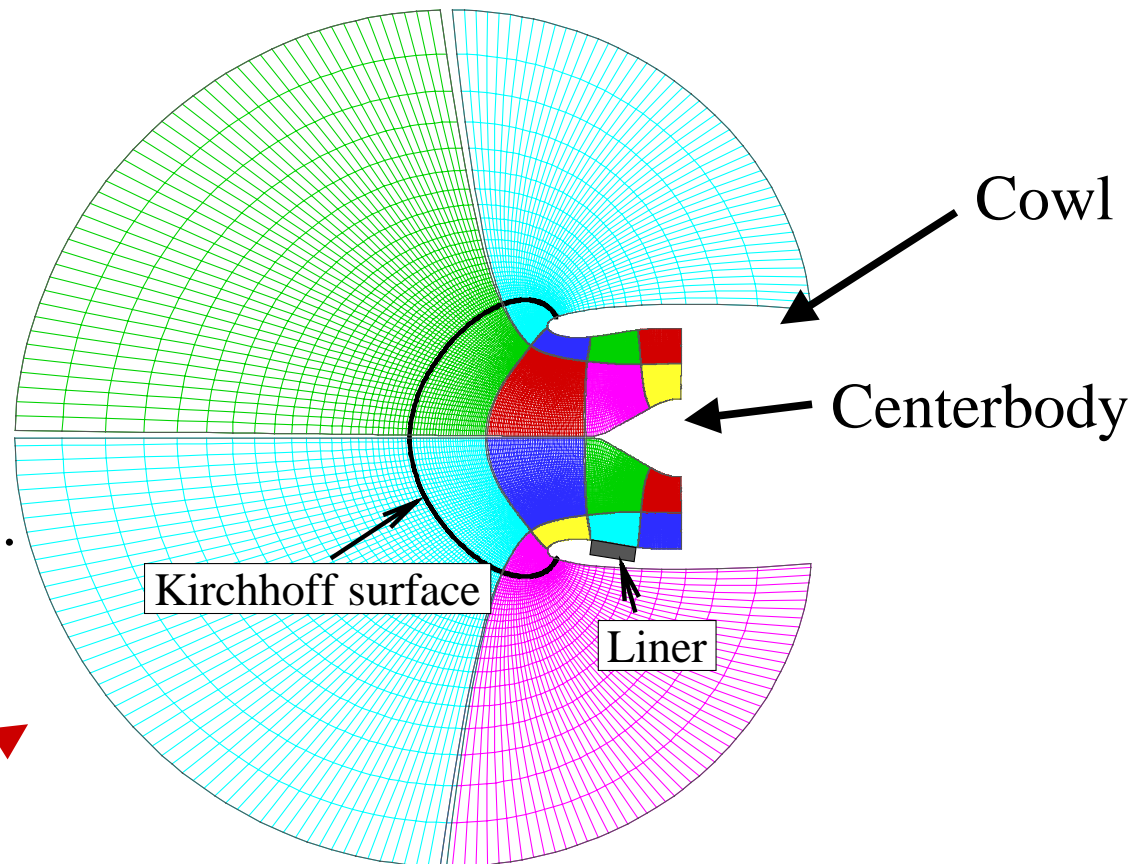
Key conditions:

5200 RPM

3120 Hz (2 BPF)

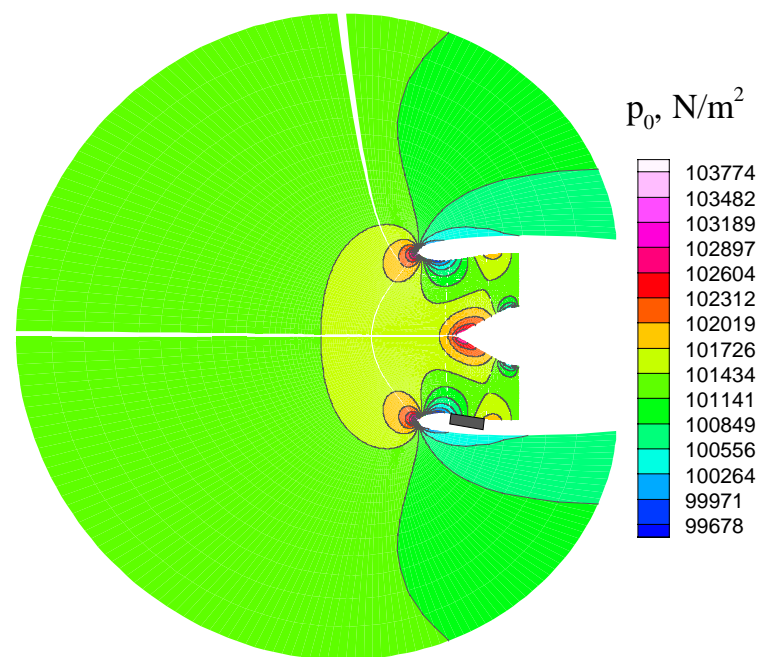
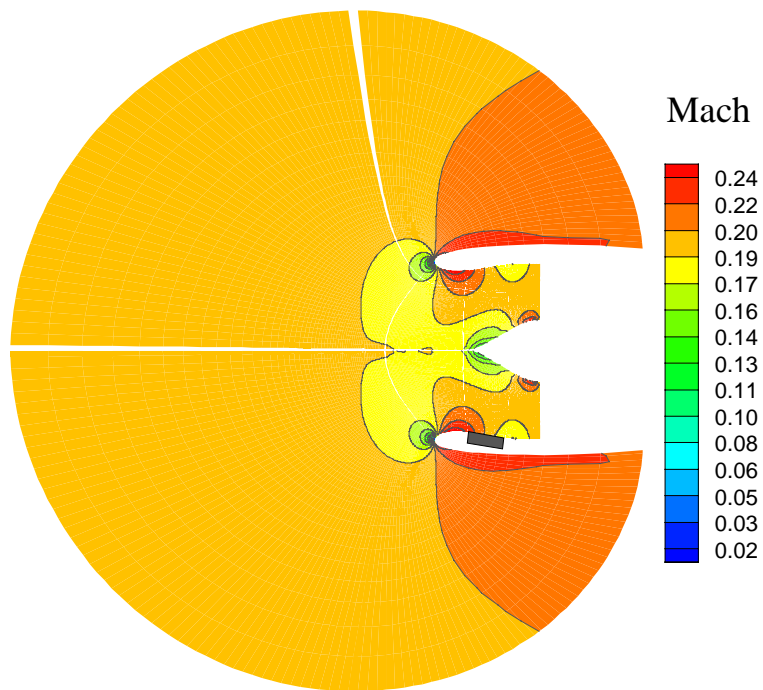
Mach = 0.2

Mass flow = 17.8 Kg/sec.

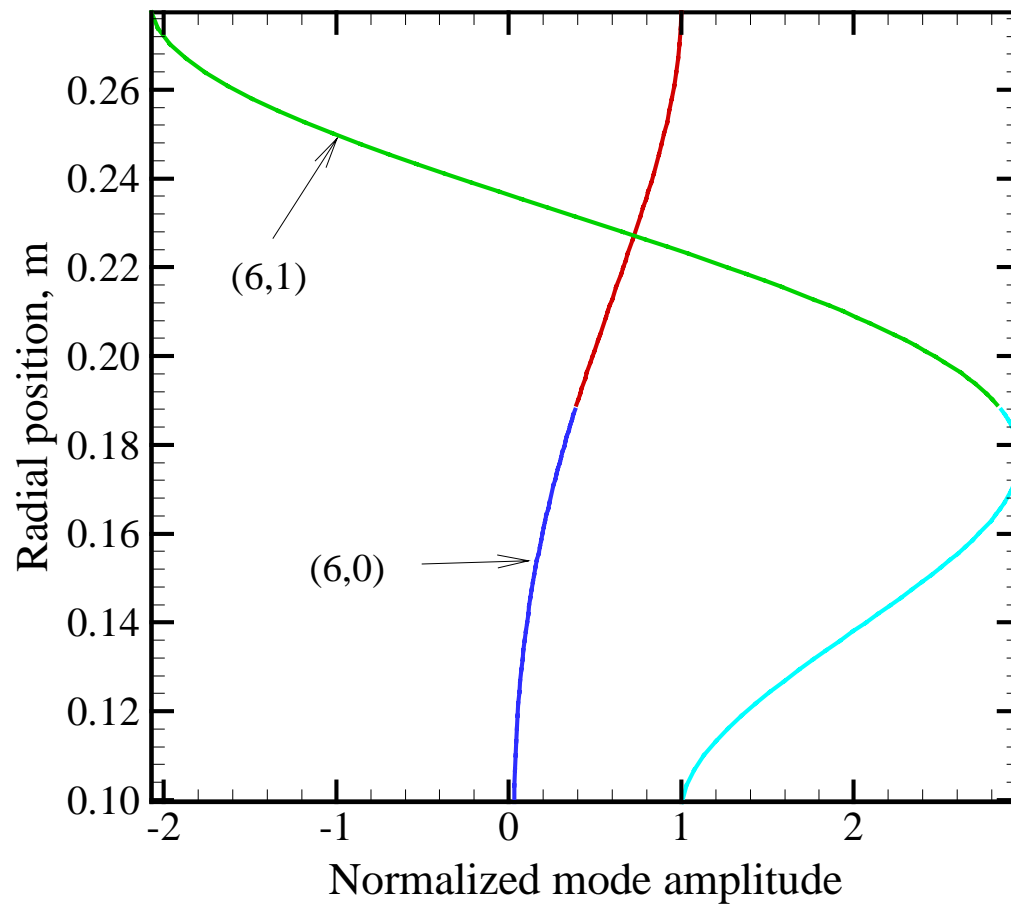


Colors indicate
different processors

Generic Inlet Steady-State Mach and Pressure Contours



Modes used for Generic Inlet

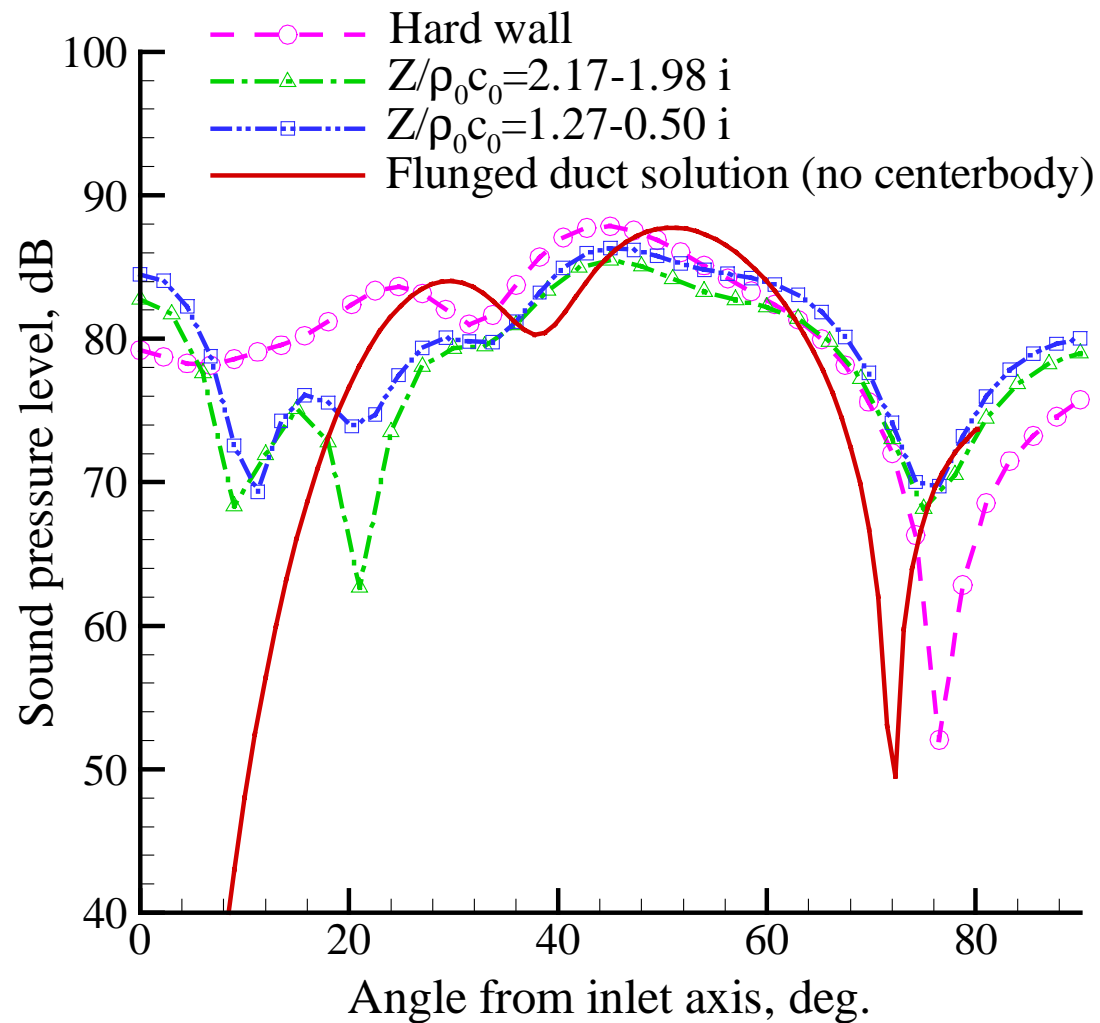


(6,0) and (6,1) Modes, Effect of Liner



$$\text{Impedance} = 2.17 - 1.98 i$$

Effect of Impedance



Conclusions

- **A higher-order accurate general-purpose 3-D engine radiation code has been developed using Fortran-90 and MPI**
- **Impedance boundary conditions have been implemented to simulate liners**
- **Fore and aft radiation can be simulated**
- **Aeroacoustics codes run very well on inexpensive clusters of PC's and massively parallel computers**

Future Work

- **Simulations of aft radiation (with liners) will be done in the future (none were shown here, but there are some in AIAA 2000-1943)**
- **Aft radiation simulations will also allow us to investigate sound propagating thru the exhaust shear layer**
- **Will stop using Kirchhoff method and will incorporate FW-H method for far-field noise**

World-Wide Web and Email Addresses

- **Prof. Yusuf Ozyoruk**
 - yusuf@ae.metu.edu.tr
 - <http://www.ae.metu.edu.tr/>
- **Dr. Vineet Ahuja**
 - vineet@craft-tech.com
 - <http://www.craft-tech.com/>
- **Prof. Lyle Long**
 - lnl@psu.edu
 - <http://www.personal.psu.edu/lnl/>