

Fluid Structure Analysis Using MSC Nastran

NAS115 Course Notes

September 2013



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CONTENTS

Section

- 1 Introduction to Acoustics
- 2 Interior Acoustics
- 3 Acoustic Participation Factors
- 4 Acoustic Absorbers
- 5 Poroelastic Material
- 6 Equivalent Radiated Power
- 7 Virtual Mass
- 8 Exterior Acoustic Analysis
- 9 Special Acoustics Modeling
- 10 Acoustic Optimization

CONTENTS

Appendix

A Exterior Acoustics – Old Technique

B Theory on Acoustics



SECTION 1

OVERVIEW & INTRODUCTION TO ACOUSTICS

COURSE OBJECTIVES

- **In this class, you will be exposed to various aspects of acoustics**
 - Interior Acoustics
 - Exterior Acoustics
 - Coupling of structure to fluid
 - Modal and Direct Approach
 - Participation Factors
 - Equivalent Radiated Power
 - Virtual Mass
 - Acoustic Optimization
- **Some basic knowledge of dynamics is assumed in this class**
 - Normal modes, frequency response, complex eigenvalue (NAS102A, NAS102B, NAS122, or equivalent)

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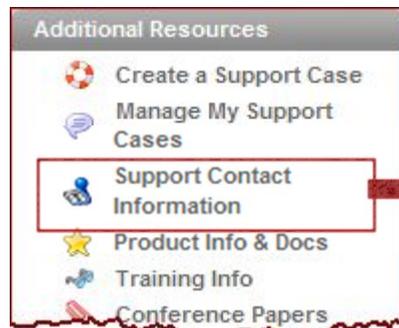
The screenshot shows the SimCompanion website interface. At the top, there is a red header with the MSC Software logo and navigation links for Search, International, Blog, and Contact Us. Below the header is a dark navigation bar with tabs for SOLUTIONS, SERVICES, PRODUCTS, ACADEMIA, RESOURCES, COMMUNITIES, and ABOUT US. The main content area is titled "Welcome to SimCompanion" and features several sections:

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Documentation
Product Information and Documentation

Documentation ID: DOC9275
Status: Published
Published date: 09/25/2009
Updated: 11/29/2011

Description

Please click on desired MSC Product icon, to find the summary of Product Information and Documentation for current and prior versions, such as:

- What's New
- Release Guides
- Hardware & Software Requirements
- Set Up Guides (Installation, Licensing, and Configuration)
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CAE Tools

Documentation
MSC Nastran Product Information & Documentation

Documentation ID: DOC9282
Status: Published
Published date: 09/27/2009
Updated: 02/03/2012
Reported In: MSC Nastran - MSC Nastran Docs

Description
MSC Nastran Product Information & Documentation

For MD Versions, Click here

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Documentation
Patran Product Information & Documentation

Documentation ID: DOC9294
Status: Published
Published date: 09/27/2009
Updated: 03/30/2011
Reported In: Patran - Patran Docs

Description
Patran Product Information & Documentation

	Version 2010.2.3	Version 2010	Version 2008 r2	Version 2008 r1	Version 2007 r2	Version MD R2.1
Release Guide	Release Guide	Release Guide	PDF UNIX & Windows NT			
Hardware & Software Requirements	See the Installation Guide Chapter 5, Page 80	See the Installation Guide Chapter 5, Page 87	PDF UNIX & Windows NT			
Supported Versions of Integration Products	See the Release Guide Chapter 1, Page 8	See the Release Guide Chapter 1, Page 10	PDF UNIX & Windows NT			
Set Up Guides (Installation, Licensing, & Configuration)	Installation Guide	Installation Guide	PDF UNIX & Windows NT			
User's Guides						
Patran User's Guide		DOC9419				
Basic Functions		DOC9408				

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Webinars	Threads	Posts	Last post
Patran Webinars This forums contains webinar details for MSC Software's Patran product line.	0	0	- New forum
General	Threads	Posts	Last post
Patran 2011 Beta Discussions regarding the testing of the Patran 2011 Beta release.	3 (3 new)	4 (4 new)	Re: WildFire 5 (Mahmud_javadi) - 05/31/11 04:33 PM
Interface, CAD, and Geometry Creation Discussions related to the Patran interface, importing of CAD geometry such as ACIS, PARASOLID, and IGES; creation of patran geometry and manipulation of CAD geometry.	373 (6 new)	1149 (7 new)	Patran 2011 External Beta ... (Mahmud_javadi) - 05/23/11 11:00 AM
Elements, Loads, and Boundary Conditions Discussions regarding meshing techniques, element creations (including MPCs, Superelements, ASETS, QSET, etc.), loads and constraints applications.	560 (10 new)	1624 (29 new)	Re: Meshing big, complex S... (lasmorten) - 05/26/11 11:49 AM
Materials, Properties, and Fields Discussions related to materials, properties (including composites), and fields.	175 (2 new)	467 (2 new)	Effective in-plane enginee... (gelievable) - 03/17/11 01:03 AM
Post Processing Discussions dealing with results processing.	261 (168 new)	703 (444 new)	Re: Reading element stress... (Leedom) - 03/31/11 07:27 PM
Flightloads Discussions dealing with the Flightloads aeroelastic graphical user interface. For discussions focussed on the computational aspects of aeroelasticity, please participate in the MSC Nastran Aeroelasticity forum.	14 (14 new)	46 (46 new)	Re: msc flight loads (shiuvkuderu) - 03/15/11 04:56 PM
Nastran Interface Discussions dealing with the creation and import of Nastran files.	99 (4 new)	262 (5 new)	Re: Modal analysis with ac... (Eagle) - 04/19/11 04:50 PM

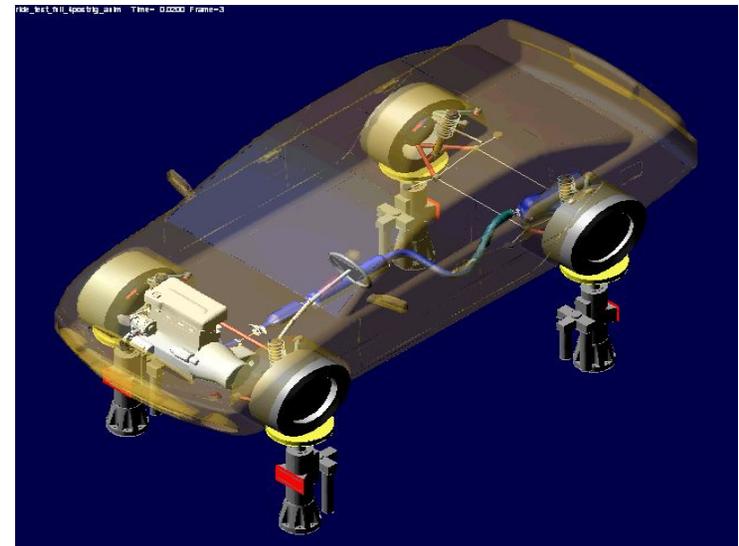
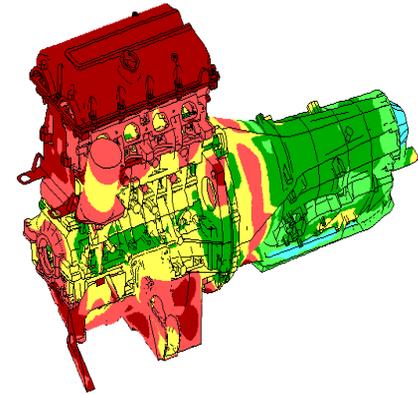
INTRODUCTION

- **What are acoustics?**
 - The study of “noise”
- **Why?**
 - To reduce the amount of noise for a vehicle occupant
 - Legislation to prevent hearing damage
 - Comfort is an important factor when buying a car!
 - To reduce acoustic fatigue
 - Acoustic coupling with a structure can cause structural failure
 - To improve behavior of sensors
 - Precision sensors may be adversely affected by vibration
- **Who?**
 - Currently dominated by car designers.
 - Increase interest from commercial aircraft designers
 - Loudspeaker design

INTRODUCTION

- **Objectives of NVH analysis**
 - Minimize peak and overall vibration
 - Minimize noise
 - Maximize “ride comfort”

- **Targets**
 - Component response
 - Fully assembled vehicle
 - Powertrain



WHAT ARE ACOUSTICS?

- **Changes in “fluid” pressure**
 - Fluid may be air or water
- **Acoustic “waves” move at speed of sound**
- **Fluid moves very small distance**

SOME COMMON TERMINOLOGY

- **SPL**
 - Sound Pressure Level. Usually measured in dB or dBa
- **Octave**
 - 1 octave is a doubling of frequency
- **dB**
 - Logarithmic scale used for SPL
- **dBa**
 - dB adjusted to give human perceived noise level

EXAMPLES OF FLUIDS

Fluid	Density (Kg/M ³)	Speed of sound (M/S)	Wavelength of 100Hz wave
Air	1.29	331	3.3 Meters
Water	1000	1450	14.5 Meters

Will a water or fuel tank cause coupled vibration with the structure? How about air?

THEORY OF ACOUSTIC ANALYSIS

- **Basic fluid equations**

- Euler's momentum equation
- Continuity equation
- Isentropic state
- Compressibility

$$\rho [(\vec{v} \cdot \nabla) \vec{v} + \dot{\vec{v}}] = -\nabla p$$

$$\partial \rho / \partial t + \rho_o \nabla \cdot \vec{v} = 0$$

$$c^2 = \partial p / \partial \rho$$

$$B = \rho_o c^2$$

ρ : Density

v : Velocity

p : Pressure

c : Speed of sound

B : Bulk modulus

THEORY OF ACOUSTIC ANALYSIS

- **Acoustic equations in MSC Nastran are based on following assumption.**

- small motion

$$\vec{v} = \dot{\vec{u}}$$

- negligible convection & net mean flow

$$\rho \ddot{\vec{u}} = -\nabla p$$

- Locally isentropic pressure-density

$$(\partial p / \partial \rho) = \gamma (p / \rho)$$

- Speed-of-sound state equation

$$c = \sqrt{\gamma p_o / \rho_o}$$

- With above assumptions, obtain acoustic wave equation

$$\frac{1}{B} \frac{\partial^2 p}{\partial t^2} - \frac{1}{\rho_o} \nabla^2 p = 0$$

- **Relationship between frequency, speed of sound and wavelength:**

$$\lambda = \frac{C}{f}$$

THEORY OF ACOUSTIC ANALYSIS (CONT.)

- **Structure-Acoustic boundary condition at fluid-structure interface.**

$$\partial P / \partial n = -\rho \ddot{u}_n$$

- **Coupling matrix (A_{ij}) is generated to satisfy it.**

$$A_{ij} = \int_S N_j N_i \vec{d}s \quad (N_i, N_j \text{ are shape functions})$$

- **Equations of motion for coupled fluid-structure**

$$\begin{bmatrix} M_s & 0 \\ -A^T & M_f \end{bmatrix} \begin{pmatrix} \ddot{u}_s \\ \ddot{p} \end{pmatrix} + \begin{bmatrix} B_s & 0 \\ 0 & B_f \end{bmatrix} \begin{pmatrix} \dot{u}_s \\ \dot{p} \end{pmatrix} + \begin{bmatrix} K_s & A \\ 0 & K_f \end{bmatrix} \begin{pmatrix} u_s \\ p \end{pmatrix} = \begin{bmatrix} P_s \\ P_f \end{bmatrix}$$

M_s – structure mass

M_f - fluid mass

A – fluid-structure coupling matrix

Theory of Acoustic analysis (Cont.)

- **Acoustic Boundary Conditions**
 - No structure, No BC → Rigid Wall
 - 1 rigid body mode → $p \neq 0$
 - Fully reflecting $p = \rho RT$
 - No structure, constrained boundary $p = 0$
 - “Open” boundary
 - No rigid body mode
 - “Void” outside boundary
 - Infinite element → Exterior Acoustics
 - Non-reflecting
 - “Far field” simulation
 - Coupled structure
 - Reflection/absorption dependent on structure

PRACTICAL ACOUSTIC ANALYSIS

- **Element size**

- Elements must be significantly smaller than wavelength interested in.
 - Rule of thumb is ~ 6 elements per wavelength
 - Wavelength $\lambda = c/f$

Example 1

- Using SI unit - $c = 340$ m/sec, run up to 100 hz
- $\lambda = 340/100 = 3.4$
- Element size = $3.4/6 = 0.57$ m

Example 2

- Using SI unit - $c = 340$ m/sec, run up to 1000 hz
- $\lambda = 340/1000 = 0.34$
- Element size = $0.34/6 = 0.057$ m

PRACTICAL ACOUSTIC ANALYSIS

- **From a practical standpoint, the FE approach is not feasible for higher frequencies**
 - Model size too big to satisfy previous criteria of element size

WHAT IS SUPPORTED?

- **Features**
 - Structure only analysis
 - Fluid only analysis
 - Coupled fluid/structure analysis
 - Interior and exterior acoustics
 - Solid fluid elements
 - Acoustic sources
 - Acoustic absorbers
 - Acoustic barrier
 - Rigid porous absorbers

- **Solution types**
 - Normal modes
 - Complex Eigenvalues
 - Coupled structure/fluid modes
 - Frequency response (including random)
 - Transient response
 - Optimization



SECTION 2

Interior Acoustics

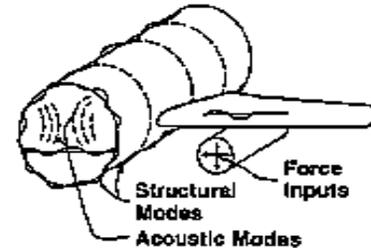
INTRODUCTION

What does coupled fluid-structure analysis mean?

- Both fluid (usually air) and structure are present
- The dynamic response of the structure affects the dynamic response of the fluid, and vice versa.

The coupling effect is important when:

- The structure is relatively flexible
- And, the modal frequencies are similar
- Fluid has significant density (basically for any liquid interacting with a structure)



For example:

- A fuselage where structure/ fluid natural (and forcing) frequencies are similar
- A car with a tailgate resonance close to a cabin resonance
- A submarine shell submerged in water

The coupling may be *neglected*

- When considering sound radiation from an engine block (Weakly coupled acoustics, see section 8)

INTRODUCTION (CONT.)

- **Internal acoustics**
 - Fluid domain is bounded (e.g., automobile interior)
- **Exterior acoustics**
 - Fluid domain is unbounded (e.g., engine exhaust pipe)
- **Finite element analysis is ideal for internal acoustics where the frequency of interest allows a reasonable size for the elements.**
- **One rule of thumb for the element size for the fluid is about 6 elements per wavelength**
- **There is an upper limit (that is constantly being pushed upwards) for when acoustic finite element analysis becomes impractical from a model size standpoint**
 - For automotive body acoustics, NVH people tend to simulate up to 500 Hz
 - For engine noise radiation, the simulation range may extend into kHz range
- **Internal Acoustics is covered in this section**

INTRODUCTION

- ***Fluid/Acoustic Options***

- **3D Fluid/Acoustic Cavity**

- Most common used acoustic option
- Car or Track cabin
- Finite element (HEXA/PENTA/TETRA)

- 3D Virtual Fluid for 2D shell enclosures

- Generates large dense [M] matrix
- FEM mesh of fluid not needed
- Example - Gas tanks

- 2D Axisymmetric Fluid/Acoustic Cavity

- Least used
- Cannot mix with 3D elements
- Old



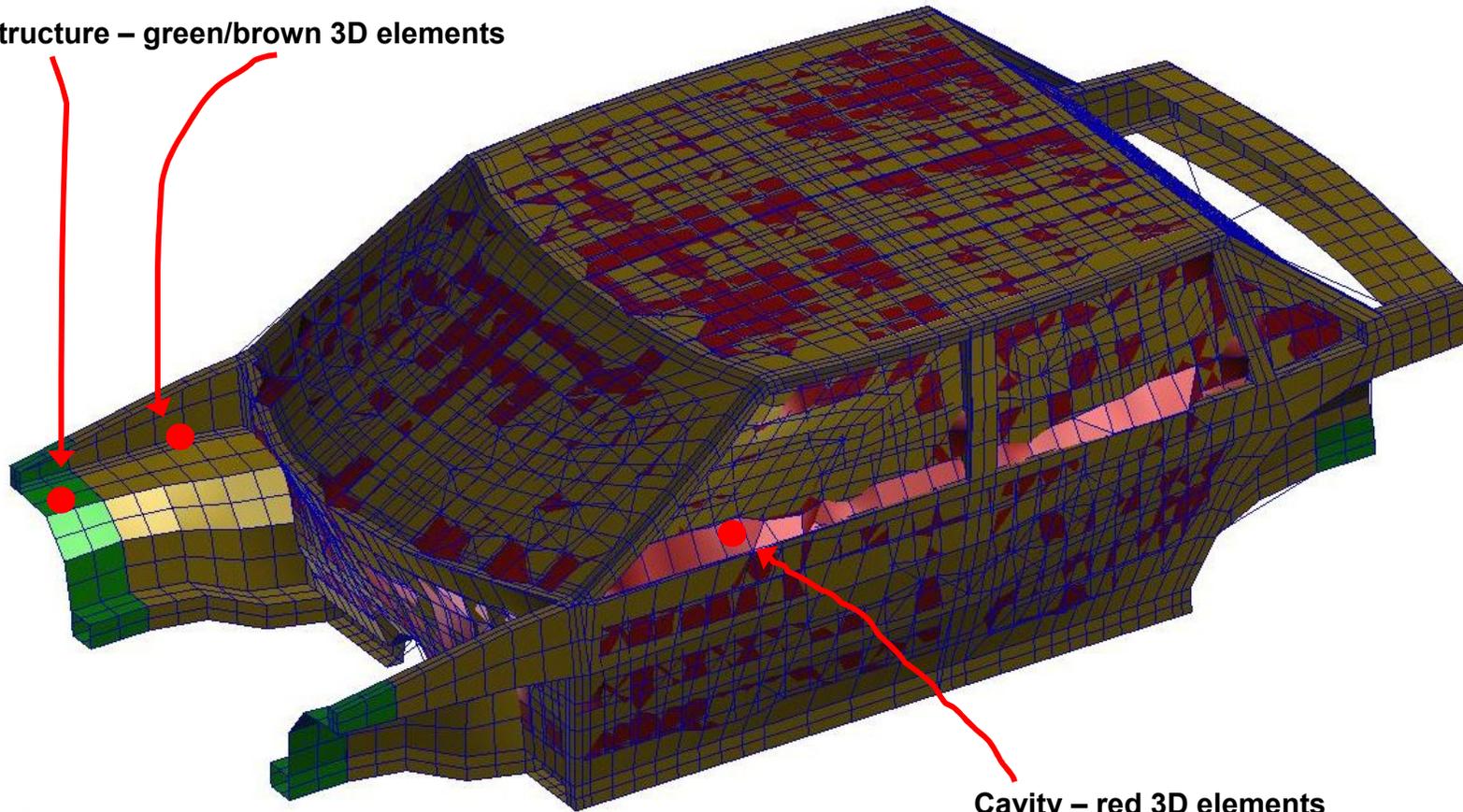
Most
commonly
used

Least
commonly
used

INTERIOR ACOUSTIC - CAR MODEL

- *Structure and Cavity*

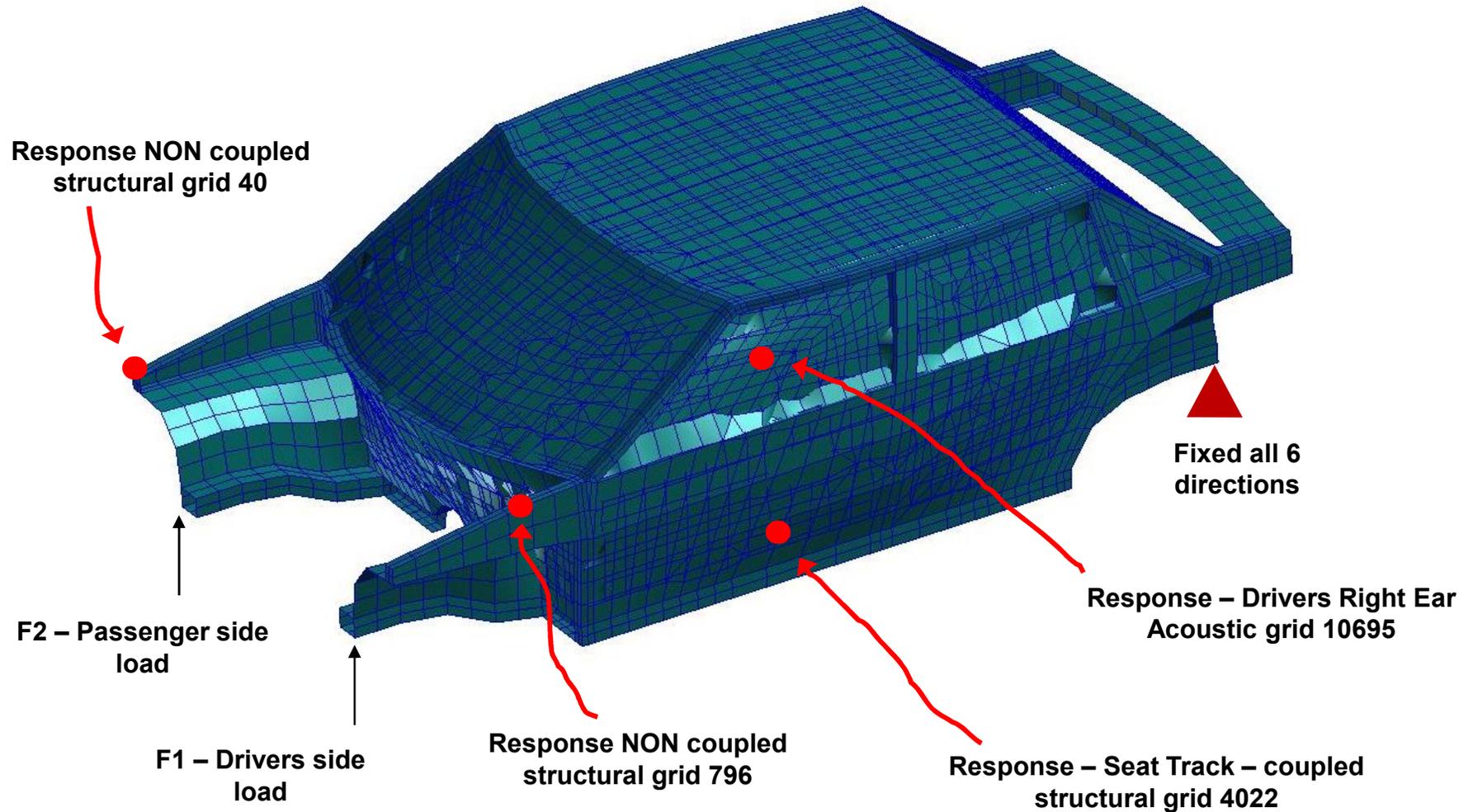
Structure – green/brown 3D elements



Cavity – red 3D elements

INTERIOR ACOUSTIC – CAR MODEL

- Loading, Constraints, Responses**



EQUATIONS – FLUID-STRUCTURE

- **Coupled interior acoustics**

$$\begin{bmatrix} \mathbf{M}_f & -\mathbf{A}^T \\ \mathbf{0} & \mathbf{M}_s \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{p}} \\ \ddot{\mathbf{u}} \end{Bmatrix} + \begin{bmatrix} \mathbf{B}_f & \mathbf{0} \\ \mathbf{0} & \mathbf{B}_s \end{bmatrix} \begin{Bmatrix} \dot{\mathbf{p}} \\ \dot{\mathbf{u}} \end{Bmatrix} + \begin{bmatrix} \mathbf{K}_f & \mathbf{0} \\ \mathbf{A} & \mathbf{K}_s \end{bmatrix} \begin{Bmatrix} \mathbf{p} \\ \mathbf{u} \end{Bmatrix} = \begin{Bmatrix} \mathbf{P}_f \\ \mathbf{P}_s \end{Bmatrix}$$

– f fluid

– s structure

– A (area) coupling matrix – struct-dof x fluid-dof

- **\mathbf{P}_f is acoustic source (ie: flow accel) – SLOAD or ACSRCE**
- **Interior acoustic equation**

$$\mathbf{M}_f \ddot{\mathbf{p}} + \mathbf{B}_f \dot{\mathbf{p}} + \mathbf{K}_f \mathbf{p} = \mathbf{A}^T \ddot{\mathbf{u}} + \mathbf{P}_f$$

- **See Appendix B for additional theory**

3D CAVITY GENERATION

- ***Driven by existing structural mesh***
 - **Fluid cavity mesh**
 - **Does not have to match grid point to grid point with structure**
 - **Larger elements sizes**
 - **May have ‘seat’ shaped areas with higher density**
 - **User/company procedure driven**

3D CAVITY GENERATION

- **Properties**

- 3D solid elements

- HEXA, PENTA, TETRA
- PSOLID option FCTN set to PFLUID

PSOLID	PID	MID	CORDM	IN	STRESS	ISOP	FCTN		
--------	-----	-----	-------	----	--------	------	------	--	--



- **MAT10**

MAT10	MID	BULK	RHO	C	GE				
-------	-----	------	-----	---	----	--	--	--	--


$$\text{BULK} = C^2 * \text{RHO}$$

COUPLING - STRUCTURE/CAVITY INTERACTION

- ***Requires a list of fluid/structure grid points***
 - Production models rarely have coincident fluid/structure grid points
 - DMAP module ACMG contains algorithms which will find the fluid/structure grid point pairs
 - Selection is done with the BULK DATA ACMODL entry

(METHOD="BW")

1	2	3	4	5	6	7	8	9	10
ACMODL	INTER	INFOR	FSET	SSET	NORMAL	METHOD	SKNEPS	DSKNEPS	
	INTOL	ALLSSET	SRCHUNIT						

Default and preferred method

(METHOD="CP")

ACMODL	INTER	INFOR	FSET	SSET	NORMAL	METHOD			
--------	-------	-------	------	------	--------	--------	--	--	--

Original old method

COUPLING - STRUCTURE/CAVITY INTERACTION

- ***ACMDOL fluid structure grid point pair options***
 - User supplied as FSET/SSET defined by SET1
 - Tedious for production models
 - Automatic search methods
 - CP of Closed Pressure vessel
 - BW for Body in White
 - The selection of the search method also selects the calculation method of the coupling matrix
 - BW is the default and is the most robust search method for fluid structure grid point pairs
 - Each method implies calculation of the A matrix
 - BW A matrix \neq CP A matrix

TYPICAL SETUP AN ACOUSTIC ANALYSIS?

```
SOL 111
CEND
TITLE = Coupled Analysis
METHOD = 1
```

METHOD for fluid part.
Not required, default uses the same method command as for STRUCTURE

```
METHOD(FUID) = 2
SDAMPING(STRUCTURE)=100
SDAMPING(FUID)=200
```

Modal damping for fluid part.
Not required, (provided damping in fluid is very small compared to structure damping)

```
SUBCASE 1
DISP(PRINT, SORT2, PHASE)=ALL
FREQ=200
DLOAD=1013
```

Pressure output request (*optional*)
(disp is analogous to acoustic pressure for fluid grids)

```
$
BEGIN BULK
```

```
$
INCLUDE 'structure_01d.nas' $SPCADD 8
INCLUDE 'cavity_01b.nas'
```

Cavity model (*required*)

- All fluid grids have CID specified as **-1**

GRID	2001	0.0	-100.	1500.	-1
------	------	-----	-------	-------	----

- MAT10 for fluid material props
- PSOLID entry, FCTN option PFLUID

```
MAT10 4 1.2E-12 340000.
PSOLID 16 4
```

PFLUID

```
$
PARAM POST 0
PARAM PREFDB 2e-5
$
ACMODL,DIFF,,,,BW
```

Reference for dB level
Not required

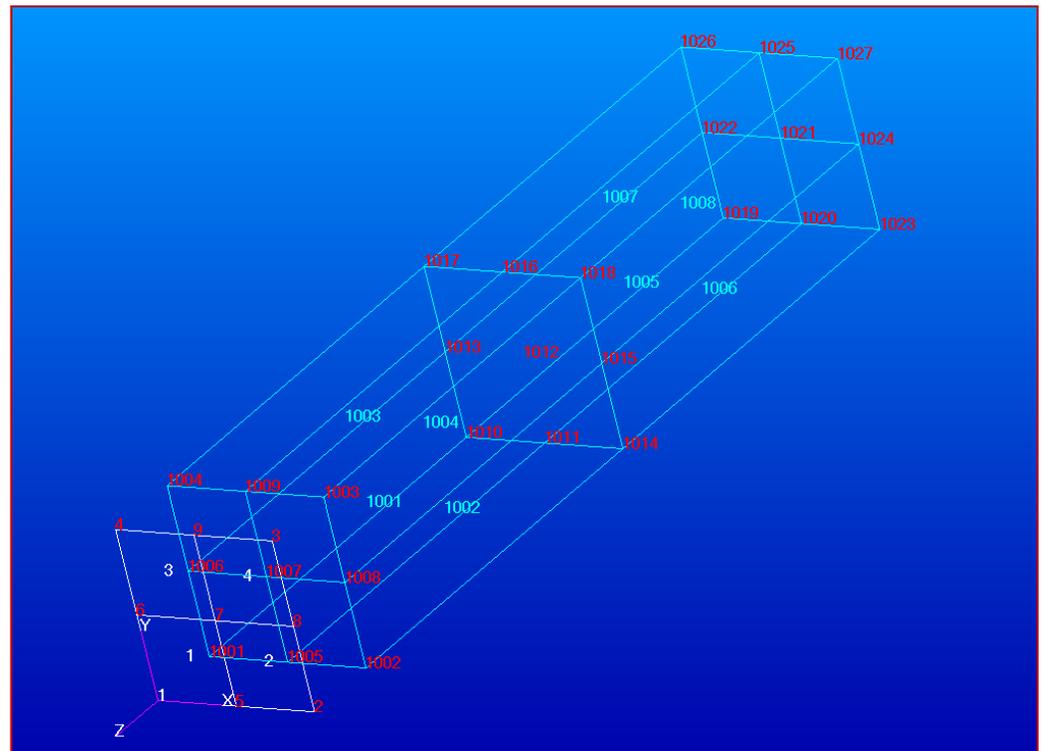
ACMODL entry for controlling the Fluid Structure coupling
NOT required

MSC Nastran will use default ACMODL setting once fluid and structure elements are detected

EXAMPLES

- We will look at 3 configurations:

1. Fluid only (elements 1001-1008)
2. Structure only (elements 1-4)
3. Structure/fluid (elements 1-4, 1008-1008)



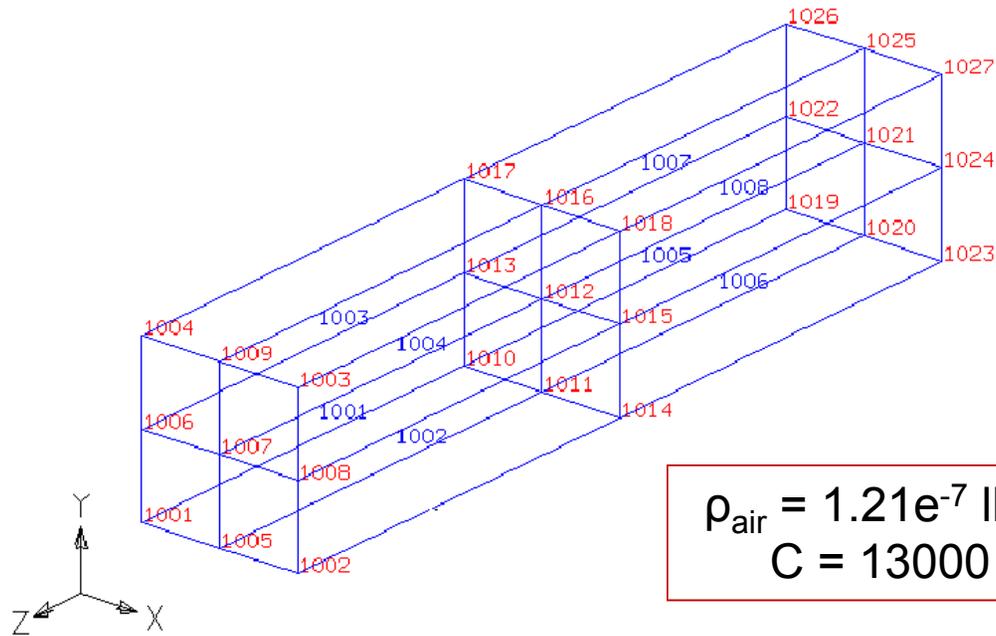
– Note that the structure is moved for clarity

1. FLUID-ONLY MODEL (PROB1FL.DAT)

- Input File

```
SOL      103
CEND
TITLE = prob 1 - Fluid modes
DISP = ALL
method=10
BEGIN BULK
eigr1,10,,,10
PARAM   POST      0
$
GRID    1001      0      0.0      0.0      0.0      -1
GRID    1002      0      20.      0.0      0.0      -1
.
GRID    1025      0      10.      20.     -100.     -1
GRID    1026      0      0.0      20.     -100.     -1
GRID    1027      0      20.      20.     -100.     -1
$
CHEXA   1001      1001      1001      1005      1007      1006      1010      1011      +
+       1012      1013
.
CHEXA   1008      1001      1012      1015      1018      1016      1021      1024      +
+       1027      1025
$
PSOLID  1001      1001                                     PFLUID
$
MAT10,1001,,1.21e-7,1.3e4
$
ENDDATA
```

1. FLUID ONLY MODEL (PROB1FL.DAT)



$$\rho_{\text{air}} = 1.21e^{-7} \text{ lb-sec}^2/\text{in}^4$$
$$C = 13000 \text{ in/sec}$$

1. FLUID ONLY MODEL (PROB1FL.DAT)

- Eigenvalue Table

MODE NO.	EXTRACTION ORDER	REAL EIGENVALUES FOR FLUID			GENERALIZED MASS	GENERALIZED STIFFNESS
		EIGENVALUE	RADIANS	CYCLES		
1	1	6.402843E-10	2.530384E-05	4.027231E-06	1.000000E+00	6.402843E-10
2	2	2.028000E+05	4.503332E+02	7.167276E+01	1.000000E+00	2.028000E+05
3	3	8.112000E+05	9.006664E+02	1.433455E+02	1.000000E+00	8.112000E+05
4	4	5.070000E+06	2.251666E+03	3.583638E+02	1.000000E+00	5.070000E+06
5	5	5.070000E+06	2.251666E+03	3.583638E+02	1.000000E+00	5.070000E+06
6	6	5.272800E+06	2.296258E+03	3.654608E+02	1.000000E+00	5.272800E+06
7	7	5.272800E+06	2.296258E+03	3.654608E+02	1.000000E+00	5.272800E+06
8	8	5.881200E+06	2.425119E+03	3.859696E+02	1.000000E+00	5.881200E+06
9	9	5.881200E+06	2.425119E+03	3.859696E+02	1.000000E+00	5.881200E+06
10	10	1.014000E+07	3.184337E+03	5.068029E+02	1.000000E+00	1.014000E+07

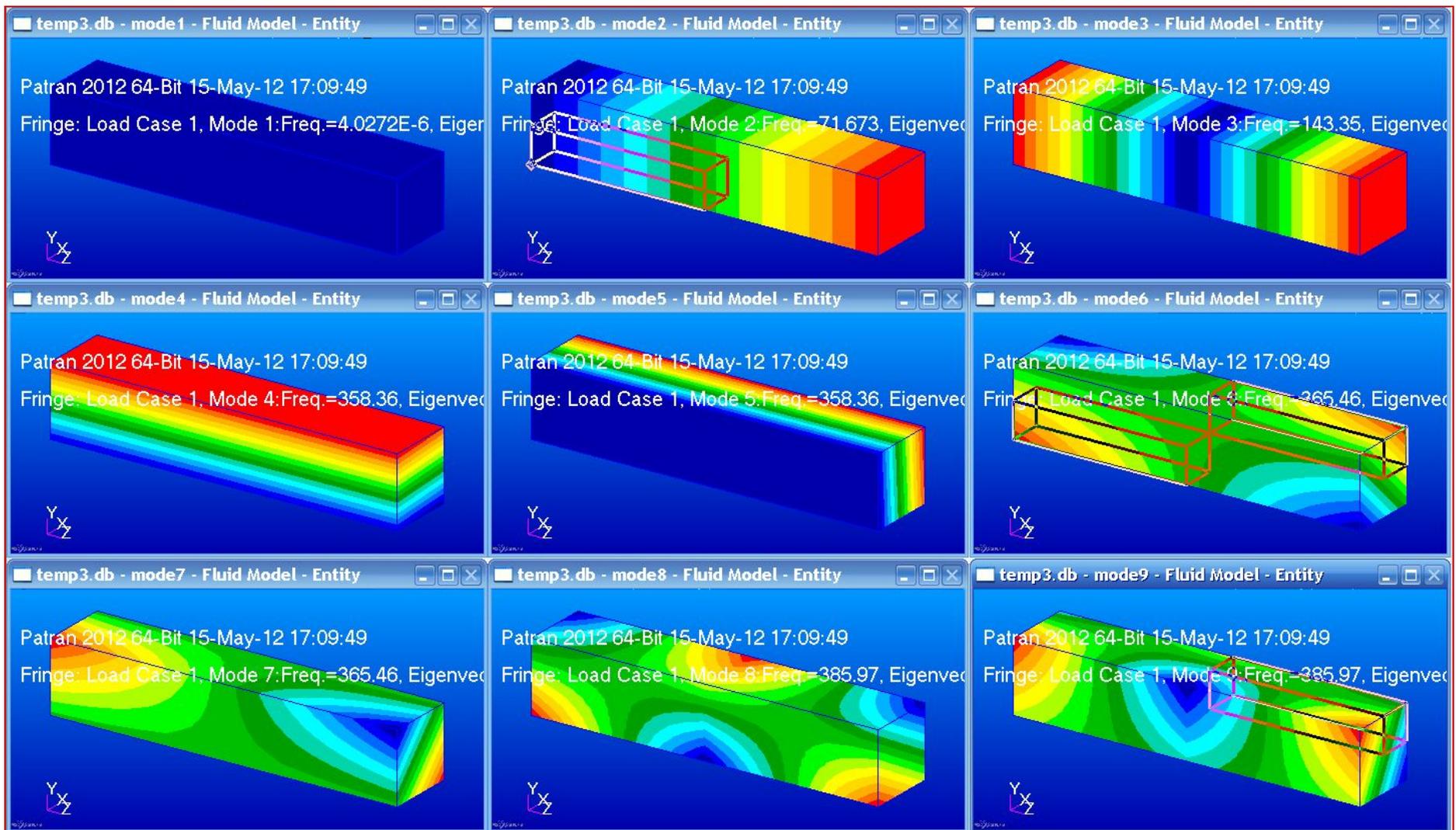
- Eigenvectors

```

0
EIGENVALUE = 6.402843E-10
CYCLES = 4.027231E-06 REAL EIGENVECTOR NO. 1
POINT ID. TYPE T1 T2 T3 R1 R2 R3
1001 S 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02
1007 S 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02
1013 S 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02
1019 S 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02
1025 S 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02 2.261029E-02
1
PROB 1 - FLUID MODES MAY 15, 2012 MSC.NASTRAN 3/30/12 PAGE 10
0
EIGENVALUE = 2.028000E+05
CYCLES = 7.167276E+01 REAL EIGENVECTOR NO. 2
POINT ID. TYPE T1 T2 T3 R1 R2 R3
1001 S 3.916216E-02 3.916216E-02 3.916216E-02 3.916216E-02 3.916216E-02 3.916216E-02
1007 S 3.916216E-02 3.916216E-02 3.916216E-02 -1.701988E-16 -1.799603E-16 -1.699092E-16
1013 S -1.683390E-16 -1.721406E-16 -1.743055E-16 -1.656453E-16 -1.625975E-16 -1.693220E-16
1019 S -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02
1025 S -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02 -3.916216E-02

```

1. FLUID-ONLY MODE SHAPE



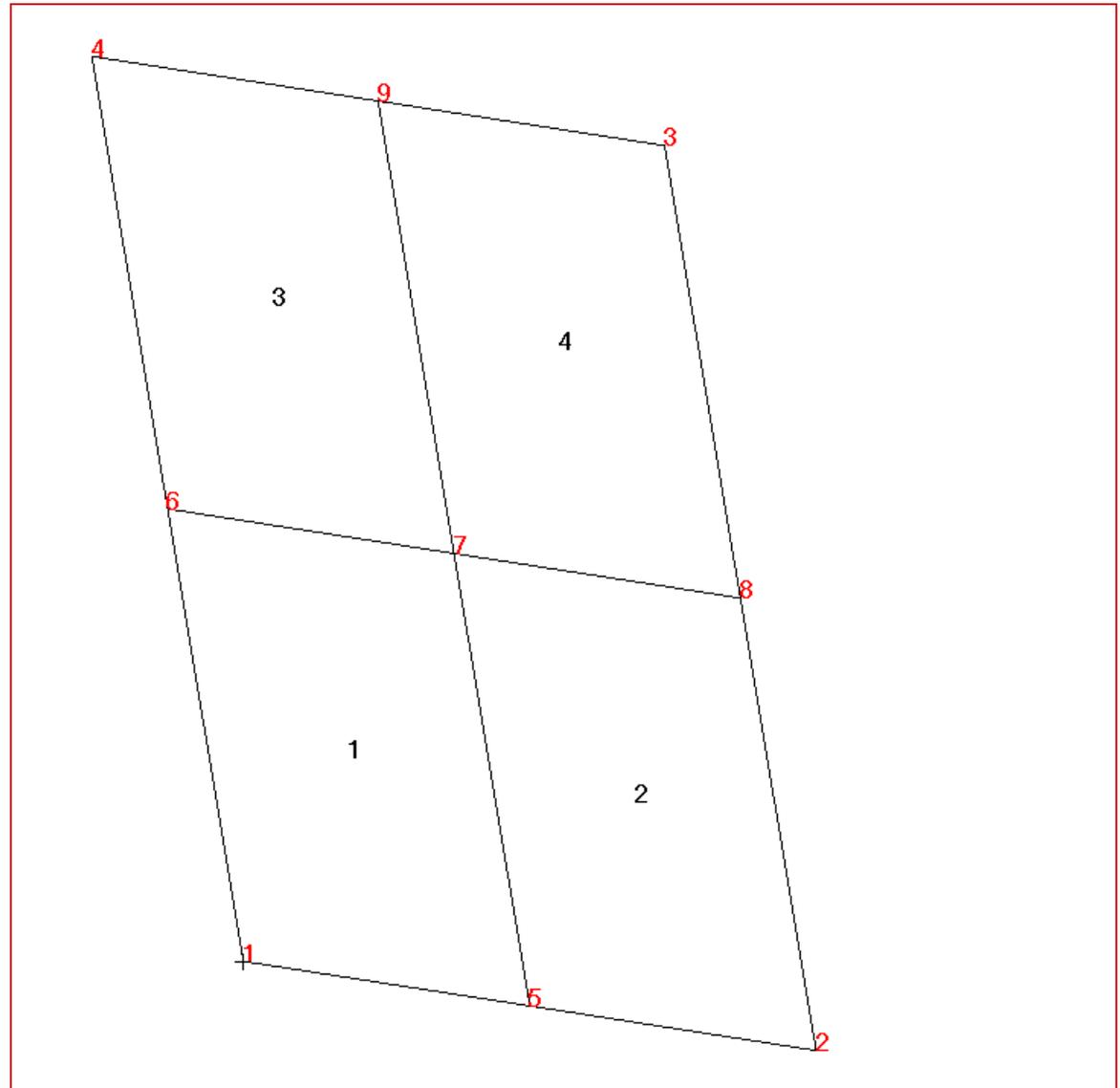


WORKSHOP 1

ACOUSTIC MODAL ANALYSIS

2. STRUCTURE ONLY MODEL (PROB1STR.DAT)

- **Material: Aluminum**
- **Thickness: 0.2"**



2. STRUCTURE-ONLY MODEL (PROB1SRT.DAT)

- Input File

```
SOL      103
CEND
TITLE = prob1Str.dat  Structure only modes
DISP = ALL
method=10
spc=1
BEGIN BULK
eigr1,10,,,10
PARAM   POST      0
$
GRID    1         0         0.0       0.0       0.0       0
GRID    2         0        20.        0.0       0.0       0
GRID    3         0        20.        20.        0.0       0
GRID    4         0         0.0        20.        0.0       0
GRID    5         0         10.         0.0       0.0       0
GRID    6         0         0.0         10.        0.0       0
GRID    7         0         10.         10.        0.0       0
GRID    8         0        20.         10.        0.0       0
GRID    9         0         10.         20.        0.0       0
$
CQUAD4  1         1         1         5         7         6
CQUAD4  2         1         5         2         8         7
CQUAD4  3         1         6         7         9         4
CQUAD4  4         1         7         8         3         9
$
SPC     1         3         3         0.0
SPC     1         4         3         0.0
SPC     1         1        123        0.0
SPC     1         2         23         0.0
$
PSHELL  1         1         .2         1         1
$
MAT1    1         1.+7         .3         2.54-4
ENDDATA
```

2. STRUCTURE-ONLY MODEL (PROB1SRT.DAT)

- Eigenvalue Table

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	6.191918E+04	2.488357E+02	3.960342E+01	1.000000E+00	6.191918E+04
2	2	1.309268E+05	3.618381E+02	5.758832E+01	1.000000E+00	1.309268E+05
3	3	1.450733E+05	3.808849E+02	6.061972E+01	1.000000E+00	1.450733E+05
4	4	1.450733E+05	3.808849E+02	6.061972E+01	1.000000E+00	1.450733E+05
5	5	3.809883E+05	6.172425E+02	9.823719E+01	1.000000E+00	3.809883E+05
6	6	2.539548E+07	5.039393E+03	8.020443E+02	1.000000E+00	2.539548E+07
7	7	6.904348E+07	8.309240E+03	1.322457E+03	1.000000E+00	6.904348E+07
8	8	1.201612E+08	1.096180E+04	1.744625E+03	1.000000E+00	1.201612E+08
9	9	2.968340E+08	1.722887E+04	2.742060E+03	1.000000E+00	2.968340E+08
10	10	4.303983E+08	2.074604E+04	3.301835E+03	1.000000E+00	4.303983E+08

2. STRUCTURE-ONLY MODEL (PROB1SRT.DAT)

- Structure modes



ENGINEERING QUESTIONS

- **Is the first frequency what you would expect?**
- **Is the element size consistent with the frequency range of interest?**
- **Is a fluid/structure analysis necessary for this problem?**

3. FLUID-STRUCTURE MODEL

- Input File (prob1stfl.dat)

```

SOL      107
CEND
TITLE = prob1Str.dat  Structure/Fluid modes
DISP = ALL
CMETHOD = 30
spc=1
BEGIN BULK
eigc,30,hess,,,,,10,,
acmodl ident
PARAM POST 0
PARAM AUTOSPC YES
$
$ Structural model
$
GRID 1 0 0.0 0.0 0.0 0
GRID 2 0 20. 0.0 0.0 0
GRID 3 0 20. 20. 0.0 0
GRID 4 0 0.0 20. 0.0 0
GRID 5 0 10. 0.0 0.0 0
GRID 6 0 0.0 10. 0.0 0
GRID 7 0 10. 10. 0.0 0
GRID 8 0 20. 10. 0.0 0
GRID 9 0 10. 20. 0.0 0
$
CQUAD4 1 1 1 5 7 6
CQUAD4 2 1 5 2 8 7
CQUAD4 3 1 6 7 9 4
CQUAD4 4 1 7 8 3 9
$
SPC 1 3 3 0.0
SPC 1 4 3 0.0
SPC 1 1 123 0.0
SPC 1 2 23 0.0
omit1,45,1,thru,9
$
PSHELL 1 1 .2 1 1
$
MAT1 1 1.+7 .3 2.54-4
$

```

```

$
$ Fluid model
$
GRID 1001 0 0.0 0.0 0.0 -1
GRID 1002 0 20. 0.0 0.0 -1
.
GRID 1025 0 10. 20. -100. -1
GRID 1026 0 0.0 20. -100. -1
GRID 1027 0 20. 20. -100. -1
$
CHEXA 1001 1001 1001 1005 1007 1006 1010 1011 +
+ 1012 1013
.
CHEXA 1008 1001 1012 1015 1018 1016 1021 1024 +
+ 1027 1025
$
$ THIS SECTION CONTAINS THE PROPERTY AND MATERIAL BULK DATA ENTRIES
$
PSOLID 1001 1001 PFLUID
$
MAT10,1001,,1.21e-7,1.3e4
ENDDATA

```


3. FLUID-STRUCTURE MODEL

- **Fluid Structure Complex Eigenvalue Output**

ROOT NO.	EXTRACTION ORDER	COMPLEX EIGENVALUE		SUMMARY		DAMPING COEFFICIENT
		(REAL)	(IMAG)	FREQUENCY (CYCLES)		
1	1	0.0	0.0	0.0	0.0	
2	2	0.0	2.457860E+02	3.911805E+01	0.0	
3	3	0.0	3.617555E+02	5.757518E+01	0.0	
4	4	-1.597894E-12	3.805272E+02	6.056278E+01	8.398317E-15	
5	5	1.597894E-12	3.805272E+02	6.056278E+01	-8.398317E-15	
6	6	0.0	4.633584E+02	7.374578E+01	0.0	
7	7	0.0	6.175912E+02	9.829269E+01	0.0	
8	8	0.0	9.063315E+02	1.442471E+02	0.0	
9	9	0.0	2.251965E+03	3.584114E+02	0.0	
10	10	0.0	2.251965E+03	3.584114E+02	0.0	

- **Plotting of the mode shapes is a bit tricky**
 - Structure has potentially 6 DOFs per grid
 - Fluid has 1 DOF (normal direction)
 - Output type labeled as “S”
 - May list up to 6 of them per row of output

3. FLUID-STRUCTURE MODEL - EIGENVECTORS

Mode 1

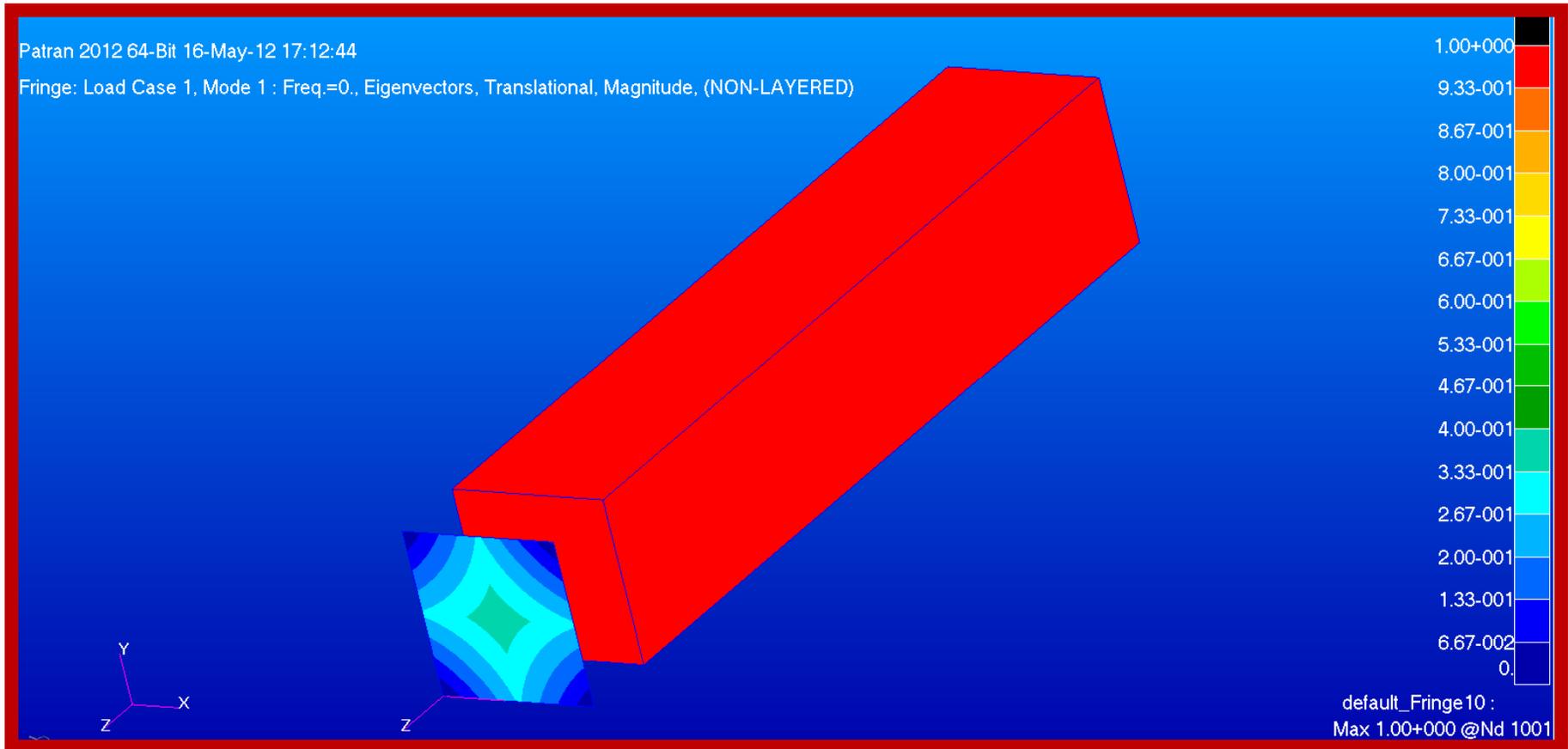
```

0
  COMPLEX EIGENVALUE = 0.000000E+00, 0.000000E+00
                        C O M P L E X   E I G E N V E C T O R   N O .       1
                        (REAL/IMAGINARY)

  POINT ID.  TYPE      T1      T2      T3      R1      R2      R3
0           1      G      0.0      0.0      0.0      4.325581E-02 -4.325581E-02 0.0
           1      G      0.0      0.0      0.0      0.0      0.0      0.0
0           2      G      0.0      0.0      0.0      4.325581E-02 4.325581E-02 0.0
           2      G      0.0      0.0      0.0      0.0      0.0      0.0
0           3      G      0.0      0.0      0.0      -4.325581E-02 4.325581E-02 0.0
           3      G      0.0      0.0      0.0      0.0      0.0      0.0
0           4      G      0.0      0.0      0.0      -4.325581E-02 -4.325581E-02 0.0
           4      G      0.0      0.0      0.0      0.0      0.0      0.0
0           5      G      0.0      0.0      2.754819E-01 9.244186E-03 -4.731778E-18 0.0
           5      G      0.0      0.0      0.0      0.0      0.0      0.0
0           6      G      0.0      0.0      2.754819E-01 -1.133841E-12 -9.244186E-03 0.0
           6      G      0.0      0.0      0.0      0.0      0.0      0.0
0           7      G      0.0      0.0      3.764060E-01 7.155863E-12 3.113251E-19 0.0
           7      G      0.0      0.0      0.0      0.0      0.0      0.0
0           8      G      0.0      0.0      2.754819E-01 -1.133841E-12 9.244186E-03 0.0
           8      G      0.0      0.0      0.0      0.0      0.0      0.0
0           9      G      0.0      0.0      2.754819E-01 -9.244186E-03 9.487898E-18 0.0
           9      G      0.0      0.0      0.0      0.0      0.0      0.0
0          1001     S      1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00
           1001     S      0.0      0.0      0.0      0.0      0.0      0.0
0          1007     S      1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00
           1007     S      0.0      0.0      0.0      0.0      0.0      0.0
0          1013     S      1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00
           1013     S      0.0      0.0      0.0      0.0      0.0      0.0
0          1019     S      1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00
           1019     S      0.0      0.0      0.0      0.0      0.0      0.0
0          1025     S      1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00 1.000000E+00
           1025     S      0.0      0.0      0.0      0.0      0.0      0.0
  
```

3. FLUID-STRUCTURE MODEL FLUID - EIGENVECTORS

- **Mode 1**



3. FLUID-STRUCTURE MODEL FLUID - EIGENVECTORS

Mode 2

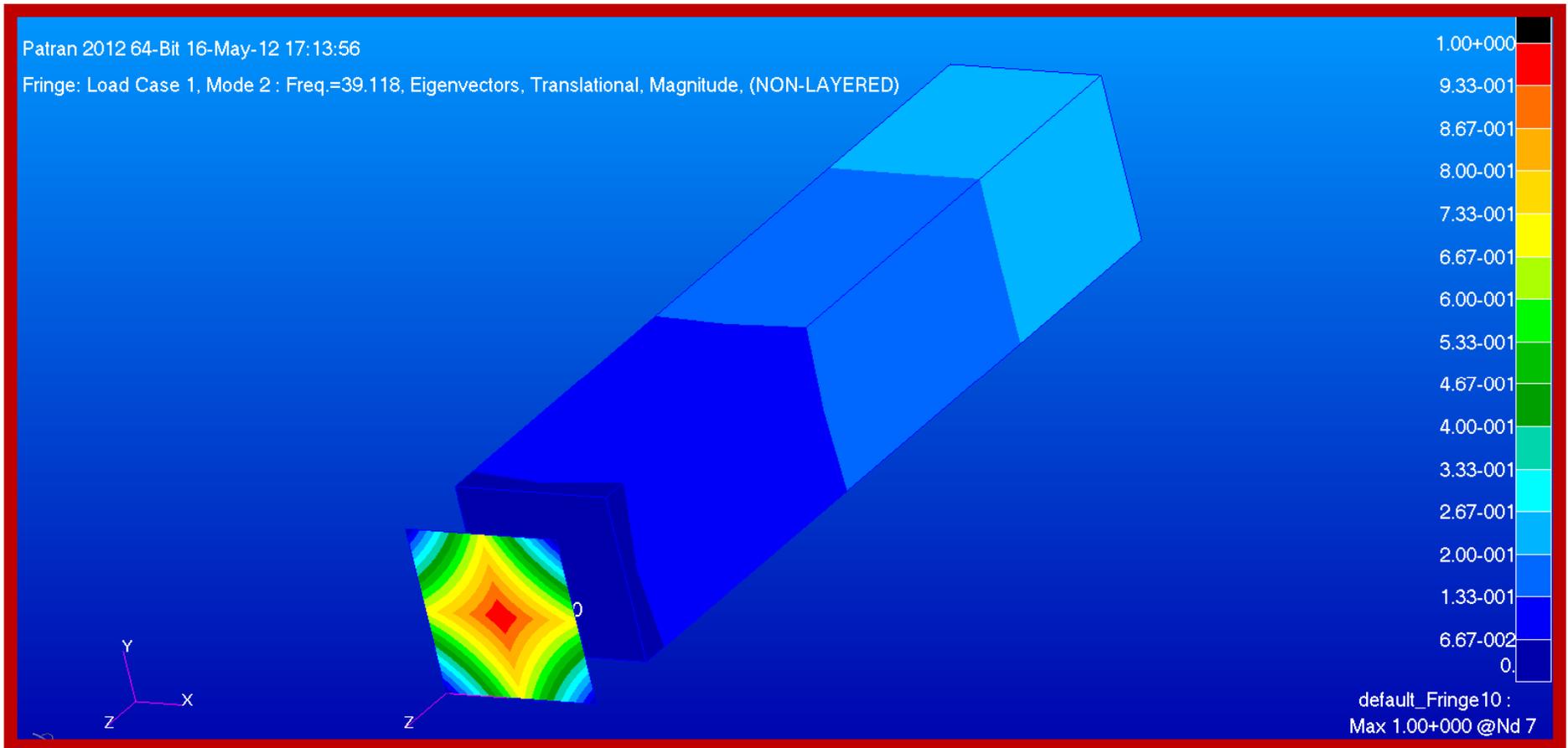
COMPLEX EIGENVALUE = 0.000000E+00, 2.457860E+02

COMPLEX EIGENVECTOR NO. 2
(REAL/IMAGINARY)

	POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
0	1	G	0.0	0.0	0.0	1.068331E-01	-1.068331E-01	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	2	G	0.0	0.0	0.0	1.068331E-01	1.068331E-01	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	3	G	0.0	0.0	0.0	-1.068331E-01	1.068331E-01	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	4	G	0.0	0.0	0.0	-1.068331E-01	-1.068331E-01	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	5	G	0.0	0.0	6.903805E-01	3.264394E-02	-5.079560E-17	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	6	G	0.0	0.0	6.903805E-01	-1.838807E-16	-3.264394E-02	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	7	G	0.0	0.0	1.000000E+00	2.046974E-16	2.368292E-16	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	8	G	0.0	0.0	6.903805E-01	-1.812786E-16	3.264394E-02	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	9	G	0.0	0.0	6.903805E-01	-3.264394E-02	-1.534773E-17	0.0
			0.0	0.0	0.0	0.0	0.0	0.0
0	1001	S	6.028644E-02	6.028644E-02	6.028644E-02	6.028644E-02	6.278256E-02	6.278256E-02
			0.0	0.0	0.0	0.0	0.0	0.0
0	1007	S	6.447428E-02	6.278256E-02	6.278256E-02	-1.504580E-01	-1.511464E-01	-1.516093E-01
			0.0	0.0	0.0	0.0	0.0	0.0
0	1013	S	-1.511464E-01	-1.504580E-01	-1.511464E-01	-1.511464E-01	-1.504580E-01	-1.504580E-01
			0.0	0.0	0.0	0.0	0.0	0.0
0	1019	S	-2.475502E-01	-2.472155E-01	-2.469918E-01	-2.472155E-01	-2.475502E-01	-2.472155E-01
			0.0	0.0	0.0	0.0	0.0	0.0
0	1025	S	-2.472155E-01	-2.475502E-01	-2.475502E-01			
			0.0	0.0	0.0			

3. FLUID-STRUCTURE MODEL FLUID - EIGENVECTORS

- **Mode 2**



3. FLUID-STRUCTURE MODEL FLUID - EIGENVECTORS

Mode 9

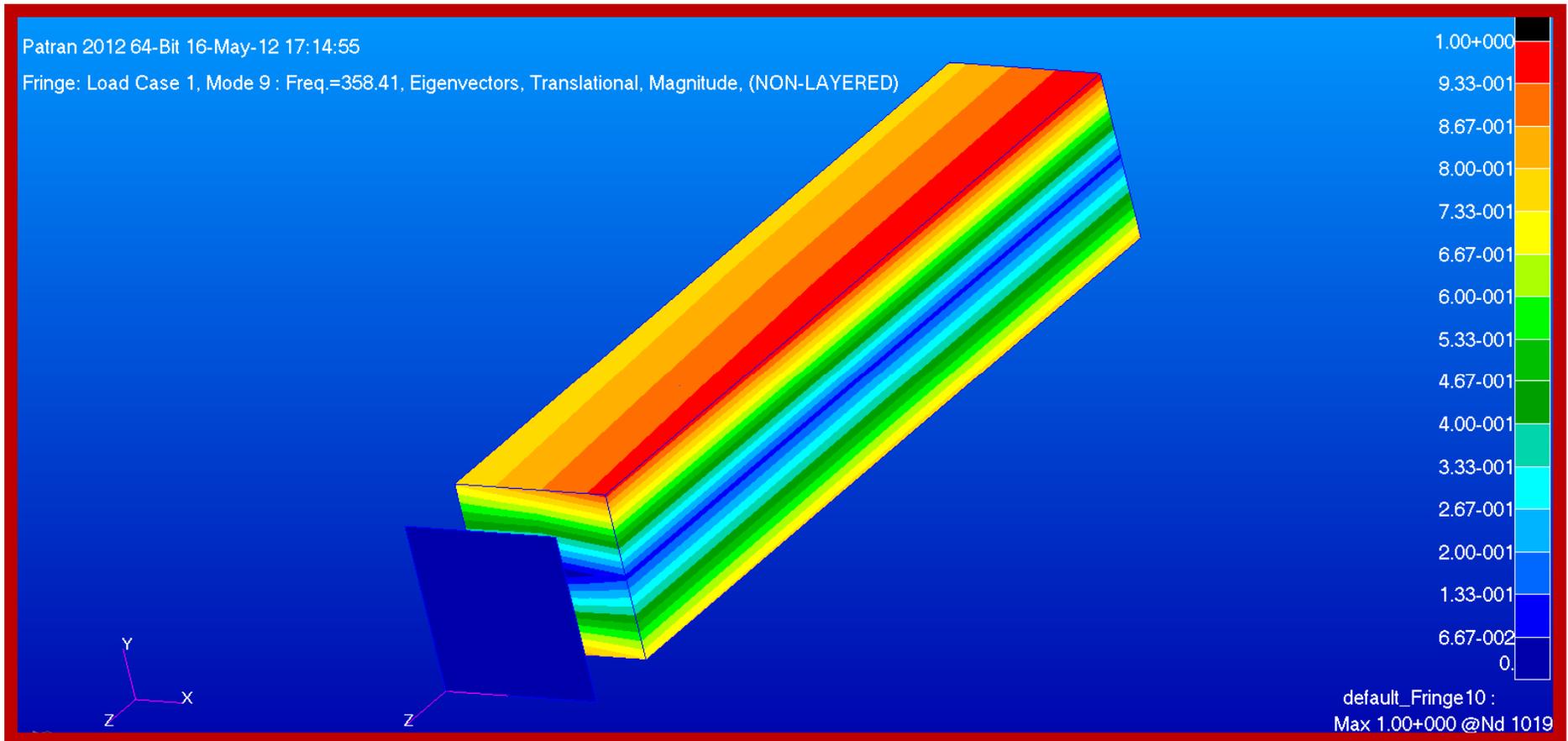
```

0
  COMPLEX EIGENVALUE = 0.000000E+00, 2.251965E+03
                        C O M P L E X   E I G E N V E C T O R   N O .           9
                        (REAL/IMAGINARY)

  POINT ID.   TYPE      T1          T2          T3          R1          R2          R3
0             1       G          0.0          0.0          0.0          -2.094286E-05  4.287815E-04  0.0
0             2       G          0.0          0.0          0.0          8.997793E-05 -4.376197E-04  0.0
0             3       G          0.0          0.0          0.0          -2.094286E-05  4.287815E-04  0.0
0             4       G          0.0          0.0          0.0          8.997793E-05 -4.376197E-04  0.0
0             5       G          0.0          0.0          -2.267815E-03  2.572441E-04  3.899961E-06  0.0
0             6       G          0.0          0.0          -2.903365E-04 -3.046255E-05 -3.293361E-05  0.0
0             7       G          0.0          0.0          -3.158589E-13  1.922640E-04 -2.461455E-05  0.0
0             8       G          0.0          0.0          2.903365E-04 -3.046255E-05 -3.293361E-05  0.0
0             9       G          0.0          0.0          2.267815E-03  2.572441E-04  3.899961E-06  0.0
0            1001     S          9.608821E-01  7.427722E-01 -9.608821E-01 -7.427722E-01  8.510321E-01  1.089532E-01
0            1007     S          1.842974E-13 -1.089532E-01 -8.510321E-01  9.898911E-01  8.777623E-01 -6.658411E-14
0            1013     S          1.123753E-01  7.651964E-01 -1.123753E-01 -8.777623E-01 -7.651964E-01 -9.898911E-01
0            1019     S          1.000000E+00  8.863993E-01  3.955960E-14  1.134811E-01  7.730107E-01 -1.134811E-01
0            1025     S          -8.863993E-01 -7.730107E-01 -1.000000E+00  0.0          0.0          0.0
  
```

3. FLUID-STRUCTURE MODEL FLUID - EIGENVECTORS

- **Mode 9**





WORKSHOP 2

SPEAKER INTERIOR ACOUSTICS

COUPLING MATRIX

- ***The A matrix***
 - Represents the physical coupling of the cavity and structure
 - Requires a list of surface fluid grids and closest structural grid
 - Production models rarely have coincident fluid/structure grid point locations
 - Generated using the list of fluid/structure grid points
 - NASTRAN ACMG module
 - BW couples all 6 structural DOF

COUPLING MATRIX

- ***Direct input of A matrix***
 - **This is controlled by the A2GG Case Control command**
 - **The format of the A2GG input is similar to the other G-type DMIG input (e.g., K2GG)**

MODAL SPACE SOLUTIONS

- ***SOL Driven Mode Extraction***
 - **Separate extraction of fluid and structure modes**
 - **Complex Modal space (SOL 110)**
 - **Modal frequency response (SOL 111) and modal transient response (SOL 112)**
 - **Optimization ANALYSIS=MFREQ or MTRAN**
 - **Combined modes extraction**
 - **Normal modes (SOL 103)**
 - **Note METHOD Case Control defaults**

$$\text{METHOD} \begin{bmatrix} \text{BOTH} \\ \text{STRUCTURE} \\ \text{FLUID} \end{bmatrix} = n$$

SUPPORTED ANALYSES

- **Modal analysis**
 - Real eigenvalue analysis for fluid only (SOL 103)
 - Complex eigenvalue analysis for fluid/structure analysis
 - Direct (SOL 107)
 - Modal (SOL 110)
- **Frequency response analysis**
 - Direct (SOL 108), modal (SOL 111) and mixed, i.e., modal fluid, direct structure, and vice versa
- **Transient Response Analysis**
 - Direct (SOL 109), modal (SOL 112) and mixed, i.e., modal fluid, direct structure, and vice versa
- **Design optimization (sol 200) supporting all of the above analysis disciplines (except for direct transient)**

FLUID ELEMENTS

- Use solids to model fluid:
 - 8- to 20-noded HEXA
 - 4- to 10-noded TETRA
 - 6- to 15-noded PENTA
- **Use the existing Bulk Data entries CHEXA, CPENTA, and CTETRA to specify topology.**
- **Use PFLUID in the eighth field of the PSOLID entry.**
 - Use the default for the other fields.
- **Use a MAT10 to specify bulk modulus and the mass density of the fluid.**
- **Use a CD=-1 for the fluid GRIDs (field 7 on the GRID card)**
 - Avoid use of the GRDSET Bulk Data entry because it affects both fluid and structural grids.

GRID

GRID POINT

Defines the location of a geometric grid point, the directions of its displacement, and its permanent single-point constraints.

Format:

1	2	3	4	5	6	7	8	9	10
GRID	ID	CP	X1	X2	X3	CD	PS	SEID	

Example:

GRID	2	3	1.0	-2.0	3.0		316		
------	---	---	-----	------	-----	--	-----	--	--

Field	Contents
ID	Grid point identification number. (0 < Integer < 100,000,000, see Remark 9.)
CP	Identification number of coordinate system in which the location of the grid point is defined. (Integer ≥ 0 or blank*)
X1, X2, X3	Location of the grid point in coordinate system CP. (Real; Default = 0.0)
CD	Identification number of coordinate system in which the displacements, degrees-of-freedom, constraints, and solution vectors are defined at the grid point. (Integer ≥ -1 or blank, see Remark 3.)*
PS	Permanent single-point constraints associated with the grid point. (Any of the Integers 1 through 6 with no embedded blanks, or blank*.)
SEID	Superelement identification number. (Integer ≥ 0; Default = 0)

*See the GRDSET entry for default options for the CP, CD, PS, and SEID fields.

GRID

GRID POINT

Remarks:

1. All grid point identification numbers must be unique with respect to all other structural, scalar, and fluid points.
2. The meaning of X1, X2, and X3 depends on the type of coordinate system CP as follows (see the CORDij entry descriptions):

Type	X1	X2	X3
Rectangular	X	Y	Z
Cylindrical	R	θ (degrees)	Z
Spherical	R	θ (degrees)	ϕ (degrees)

See [Grid Point and Coordinate System Definition](#) (Ch. 2) in the *MD Nastran Reference Guide*, for a definition of coordinate system terminology.

3. The collection of all CD coordinate systems defined on all GRID entries is called the global coordinate system. All degrees-of-freedom, constraints, and solution vectors are expressed in the global coordinate system. Be careful not to use a cylindrical or spherical coordinate system for CD if the point is on line A-B that defines the system, as results are unpredictable.
4. The SEID field can be overridden by use of the SESET entry.
5. If CD = -1, then this defines a fluid grid point in coupled fluid-structural analysis (see [Additional Topics](#) (Ch. 13) in the *MD Nastran Reference Guide*). This type of point may only connect the CAABSF, CHACBR, CHACAB, CHEXA, CPENTA, and CTETRA elements to define fluid elements.
6. A zero (or blank if the GRDSET entry is not specified) in the CP and CD fields refers to the basic coordinate system.
7. In p-version analysis, the hierarchy set to resolve the conflicts arising in the global system input data is described under Remark 10 of the GMBC entry description.
8. CID can reference GMCORD type coordinate systems only when the GRID is connected to p-version elements.
9. For SOL 600, ID may range from 1 to $2^{31} - 1$ (2147483647) if there are no OUTR options specified on the SOL 600 entry. If any OUTR option is specified the limit is 100000000.
10. For RC network solver in thermal analysis, the CD, PS and SEID are ignored.

PSOLID

PROPERTIES OF SOLID ELEMENTS

Defines the properties of solid elements (CHEXA, CPENTA, and CTETRA entries).

Format:

1	2	3	4	5	6	7	8	9	10
PSOLID	PID	MID	CORDM	IN	STRESS	ISOP	FCTN	COROT	

Example:

PSOLID	2	100	6	TWO	GRID	REDUCED			
--------	---	-----	---	-----	------	---------	--	--	--

Field	Contents
PID	Property identification number. (Integer > 0)
MID	Identification number of a MAT1, MAT4, MAT5, MAT9, or MAT10 entry. (Integer > 0)
CORDM	Identification number of the material coordinate system. See Remarks 3. and 4. (Integer; Default = 0, which is the basic coordinate system; see Remark 3.)
IN	Integration network. See Remarks 6., 7., 8., and 10. (Integer; Character, or blank)
STRESS	Location selection for stress output. See Remarks 9. and 10. (Integer; Character, or blank)
ISOP	Integration scheme. See Remarks 6., 7., 8., and 10. (Integer; Character, or blank)
FCTN	Fluid element flag. (Character: "FFLUID" indicates a fluid element with frequency dependent rigid absorber properties, "PFLUID" indicates a fluid element, "SMECH" indicates a structural element; Default = "SMECH.")
COROT	Corotational request. MD Nastran SOL 700 only. (Integer; Default = 0): 0 Do not rotate 1 Force local coordinate system to rotate with element

PSOLID

PROPERTIES OF SOLID ELEMENTS

Remarks:

1. PSOLID entries should have unique identification numbers with respect to all other property entries.
2. Isotropic (MAT1 or MAT4), anisotropic (MAT5 or MAT9), or fluid (MAT10) material properties may be referenced. **If FCTN = "PFLUID" or "FFLUID", then MID must reference a MAT10 entry.** PFLUID and FFLUID are not available for SOL 600 and MD Nastran SOL 700.
3. See the CHEXA, CPENTA, or CTETRA entry for the definition of the element coordinate system. The material coordinate system (CORDM) may be the basic system (0 or blank), any defined system (Integer > 0), or the element coordinate system (-1). The default value for CORDM is zero unless it is overridden by the NASTRAN statement with the CORDM keyword. See [nastran Command and NASTRAN Statement, 1](#).
4. If MID references a MAT9 entry, then CORDM defines the material property coordinate system for Gij on the MAT9 entry.
5. Nonlinear solid elements identified through an additional PSLDN1 entry in MD Nastran SOL 400 do not support IN, ISOP, and FCTN. Also, in this case, CORDM=-1 is only supported for CHEXA elements.

The following Remarks, DO NOT APPLY TO SOL 600 or MD Nastran SOL 700.

6. For CHEXA and CPENTA elements with no midside nodes, reduced shear integration with bubble functions (ISOP = blank or "REDUCED" and IN = blank or "BUBBLE") is the default. This is recommended because it minimizes shear locking and Poisson's ratio locking and does not cause modes of deformation that lead to no strain energy. The effects of using nondefault values are as follows:
 - a. IN = "THREE" or 3 produces an overly stiff element.
 - b. If IN = "TWO" or 2 and the element has midside nodes, modes of deformation may occur that lead to no strain energy.
 - c. Standard isoparametric integration (ISOP = "FULL" or 1 and IN = "TWO" or 2; or "THREE" or 3) produces an element overly stiff in shear. This type of integration is more suited to nonstructural problems.

PSOLID

PROPERTIES OF SOLID ELEMENTS

7. IN = "BUBBLE" is not allowed for CTETRA elements or for CHEXA and CPENTA elements with midside nodes.
8. If you use IN = "BUBBLE" for CTETRA elements, NASTRAN internally switch to IN=2 if you have 4-noded CTETRA element and IN=3 greater than 4 nodes.
9. Stress output may be requested at the Gauss points (STRESS = "GAUSS" or 1) of CHEXA and CPENTA elements with no midside nodes. Gauss point output is available for the CTETRA element with or without midside nodes.
10. The following tables indicate the allowed options and combination of options. If a combination not found in the table is used, then a warning message will be issued and default values will be assigned for all options.
11. The gauss point locations for the solid elements are documented in [Nonlinear Analysis](#) (p. 568) in the *MD Nastran Reference Manual*.

MAT10

FLUID MATERIAL PROPERTY DEFINITION

Defines material properties for fluid elements in coupled fluid-structural analysis.

Format:

1	2	3	4	5	6	7	8	9	10
MAT10	MID	BULK	RHO	C	GE	ALPHA			

Example:

MAT10	103	0.656	0.011						
-------	-----	-------	-------	--	--	--	--	--	--

Field	Contents
MID	Material identification number. (Integer > 0)
BULK	Bulk modulus. (Real > 0.0)
RHO	Mass density. (Real > 0.0)
C	Speed of sound. (Real > 0.0)
GE	Fluid element damping coefficient. (Real)
ALPHA	Normalized admittance coefficient for porous material. See Remark 7. (Real or blank)

There is a relationship between the bulk modulus (B), rho and c

$$B=C^2*\rho$$

Only two out of the three values need to be specified. If all three values are specified, MSC Nastran will issue a warning message

Remarks:

1. MAT10 is referenced, with MID, by the PSOLID entry only.
2. The material identification numbers must be unique for all MAT1, MAT2, MAT3, MAT9, and MAT10 entries.
3. The mass density RHO will be used to compute the mass automatically.
4. BULK, RHO, and C are related by

$$\text{BULK} = C^2 \cdot \text{RHO}$$

Two out of the three must be specified, and the other will be calculated according to this equation. If all three are specified and are inconsistent in values, the supplied values of BULK and RHO are used in the computations.

5. To obtain the damping coefficient GE, multiply the critical damping ratio C/C_0 , by 2.0.
6. If PARAM,W4FL is not specified, GE is ignored in transient analysis. See [Parameters, 675](#).
7. If a value of ALPHA is entered, BULK RHO and GE may have negative values.
8. The value defined in the ALPHA field always defines the normalized admittance coefficient for porous material but it is differently interpreted depending on the value defined in the FCNT field of the referencing PSOLID entry.
 - a. If the MAT10 entry is referenced in a PSOLID entry where FFLUID option is selected, the value defined for ALPHA is considered as the normalized admittance coefficient calculated at unit circular excitation frequency ($\omega = 1$). Its value will be automatically calculated by the program, at each excitation frequency, considering the current circular excitation frequency as scaling factor.
 - b. If the MAT10 entry is referenced in a PSOLID entry where PFLUID option is selected, the value defined for ALPHA has no special meaning but it is only the normalized admittance coefficient calculated by the user at the most appropriate excitation frequency (defined in order to have good results in the frequency range of interest).



LOADINGS

FLUID LOADINGS

- **Enforced Pressure**
 - Constant
 - Frequency-dependent
 - Time-dependent
 - Large mass method
 - Large stiffness method
 - Lagrange Multiplier method
 - The SPCD method (used in structure) is not supported
- **Acoustic Source**
 - ACSRCE - frequency-dependent power
 - RLOAD1 - particle acceleration
- **Most common way to apply a load to a cavity is indirectly, transmitted through boundaries from structure model excitation**
- **Reciprocity is sometimes more efficient and ACSRCE loading is used**

ENFORCED PRESSURE - CONSTANT

- **SPC fluid point with pressure value.**
- **Constrain degree of freedom 1 on the fluid point boundaries.**
- **P=0.0 is used as an anti-symmetric boundary condition.**
- **No constraint creates a rigid wall which is a symmetric boundary condition.**

ENFORCED PRESSURE – FREQUENCY DEPENDENT

- **RLOAD1 force.**
- **Large mass**
 - Large mass for fluid is $\sim M_L = \frac{\text{total fluid volume}}{\text{bulk modulus}} \times 10^3$
 - Use CMASSi or conm2

Value of force:

$$F = \pm \omega^2 (M_L) * (\text{pressure})$$

- **FORCE APPLIED WITH FOLLOWING ENTRIES**
 - OLOAD – PRESSURE
 - RLOAD, DAREA – MASS
 - TABLED4 – to input ω^2

ENFORCED PRESSURE – FREQUENCY DEPENDENT

- **Large stiffness:**

- Large stiffness for fluid ~ $K_L = \frac{\text{Total fluid volume}}{\text{Fluid density}} \times 10^3$
- Put large stiffness fluid elements to ground.
- Value of FORCE $\longrightarrow F_L = K_L * (\text{PRESSURE})$
- RLOAD1, DAREA applies FORCE

ENFORCED PRESSURE - LARGE MASS EXAMPLE

```

SOL 111
$ Direct Text Input for Executive Control
CEND
SEALL = ALL
SUPER = ALL
TITLE = MSC.Nastran job created on 05-Jun-02 at 11:04:28
ECHO = NONE
MAXLINES = 999999999
$ Direct Text Input for Global Case Control Data
SUBCASE 1
$ Subcase name : Default
  SUBTITLE=Default
  METHOD (struct)= 1
  METHOD (Fluid)=2
  SPC = 1
  DLOAD=5
  FREQ=13000
  SET 1= 585
  DISP(SORT2,PHASE)=1
  $ACCE(PHASE)=ALL
  $SPCFORCES(SORT1,REAL)=ALL
BEGIN BULK
$
$MAT10,2,,1.2E-12,3.43E+5
MAT10,2,1.2E-12,,3.43E+5

acmod1,ident
RLOAD1,5,55,,,,555
DAREA      55      585      1  1.E+6
$
CMASS1    177000    177    585      1
PMASS     177  1.0E+6
TABLED4   555      0.0      1.0      0.    5000.
           0.0      0.0-39.4784  ENDT
$TABLED1  555
           0.      1.    250.    1.    ENDT
FREQ1     13000    1.0    2.0    10
$PANEL,p,1
$
$SET1     1      31      THRU    36      48    54      60      66
           72     120     126     132     138     144

```

POINT-ID =		585		C O M P L E X	
	FREQUENCY	TYPE	T1	T2	
0	1.000000E+00	S	1.199996E-12	90.0000	
0	3.000000E+00	S	1.199976E-12	90.0000	
0	5.000000E+00	S	1.199936E-12	90.0000	
0	7.000000E+00	S	1.199876E-12	90.0000	
0	9.000000E+00	S	1.199801E-12	90.0000	
0	1.100000E+01	S	1.199699E-12	90.0000	
0	1.300000E+01	S	1.199579E-12	90.0000	
0	1.500000E+01	S	1.199439E-12	90.0000	
0	1.700000E+01	S	1.199279E-12	90.0000	
0	1.900000E+01	S	1.199100E-12	90.0000	
0	2.100000E+01	S	1.198900E-12	90.0000	

ENFORCED PRESSURE – TIME DEPENDENT

- **TLOAD1**
- **Enforced displacement option.**
- **Large mass for fluid is:**

$$\frac{\text{Total fluid volume}}{\text{Bulk modulus}} \times 10^3$$

- **Multiplier on DAREA equals large mass.**
- **Pressure value on TABLEDi.**
- **See the *MSC NASTRAN Dynamics User's Guide, Section 7, Enforced Motion.***

STRUCTURAL – ACOUSTIC ANALOGY

Structures	Acoustics
Elastic Constants (E,G)	(Density) ⁻¹
Density	(Bulk Modulus) ⁻¹
Displacements (U _x)	Pressure
Force (σ)	Particle Accelerations

- **At free surfaces (open boundary), set $u_x = P = 0$**
- **At rigid walls (default, natural boundary condition)**
- **Where the pressure is known, set $u_x = P$**
- **Where the normal component of the particle acceleration is known, apply a grid point load of $-A*P$ where A is the contributing area.**

ASSUMPTIONS

- **No rotational effects:**
 - No shear waves
 - No turbulence
 - No sloshing
 - No viscosity
- **The pressure/density ratio is constant locally**
- **Small motion theory**

ACOUSTIC SOURCE

- **POINT source**
- **Power versus frequency (frequency response only)**
- **DLOAD points to ACSRCE which contains:**
 - Set ID.
 - DAREA entry.
 - Material properties for \dot{Q} calculation.
 - Table ID, which is used to supply the power versus frequency curve.
 - Phase angle.

ACOUSTIC SOURCE (CONT.)

- **MSC NASTRAN converts power to \dot{Q} for use in the finite element equation using the following relationship:**

$$\dot{Q} = \sqrt{\frac{8\pi c P(f)}{\rho}}$$

Where: \dot{Q} = fluid acceleration -
loads in fluid/structure finite
element equations (volume/sec²)
Q = volume change/time (volume/sec)
 ω = frequency (radians/sec)
c = speed of sound in fluid (length/sec)
P(f) = power (energy/sec)
 ρ = density of fluid (mass/length³)

ACOUSTIC SOURCE (CONT.)

- **RLOAD1 (or RLOAD2) can also be used as a simple source.**
 - Use equivalent \dot{Q} from above equation.
 - Force is analogous to \dot{Q} , particle acceleration (volume/sec²)
 - If Q is known, \dot{Q} is calculated as follows:

$$\dot{Q} = i\omega Q$$

ACSRCE

ACOUSTIC SOURCE SPECIFICATION

Defines acoustic source as a function of power vs. frequency.

$$\text{Source Strength} = \{A\} \cdot \left[\frac{1}{2\pi f \sqrt{\rho}} \sqrt{8\pi C P(f)} \right] e^{i(\theta + 2\pi f \tau)}$$

$$C = \sqrt{B/\rho}$$

Format:

1	2	3	4	5	6	7	8	9	10
ACSRCE	SID	EXCITEID	DELAYI/ DELAYR	DPHASEI/ DPHASER	TP	RHO	B		

Example:

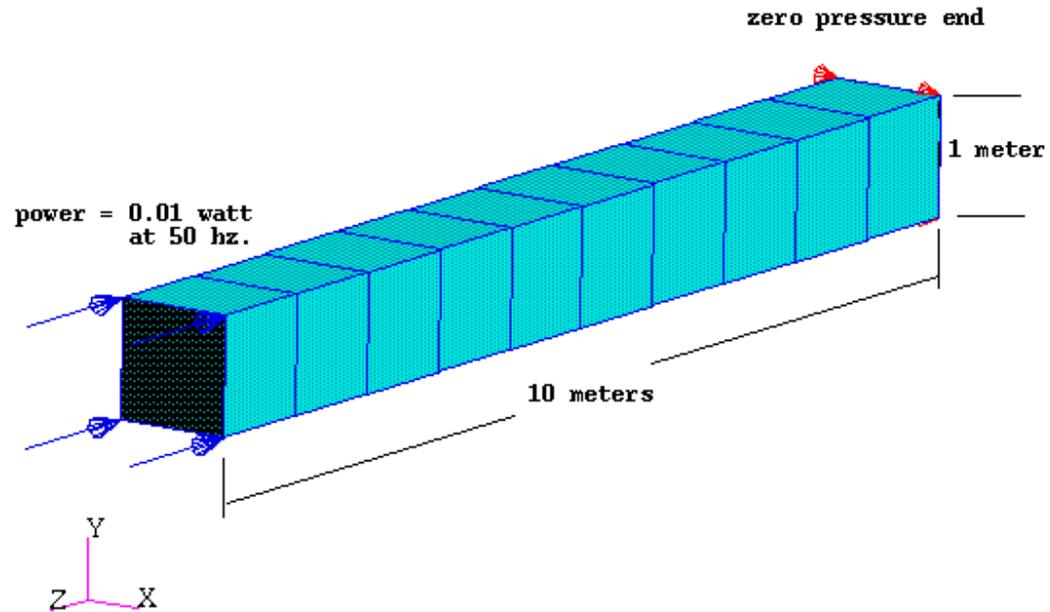
ACSRCE	103	11	20	5.0	12	1.0	15.0		
--------	-----	----	----	-----	----	-----	------	--	--

Field	Contents
SID	Load set identification number. (Integer > 0)
EXCITEID	Identification number of DAREA, FBALOAD (in FRF Based Assembly or FBA process) or SLOAD entry set the defines {A}. See Remark 6. (Integer > 0)
DELAYI	Identification number of DELAY or FBADLAY (in FRF Based Assembly or FBA process) Bulk Data entry that defines time delay τ . See Remarks 4. and 5. (Integer > 0 or blank)
DELAYR	Value of time delay τ that will be used for all fluid degrees-of-freedom that are excited by this dynamic load entry. See Remark 5. (Real or blank)
DPHASEI	Identification number of DPHASE or FBAPHAS (in FRF Based Assembly or FBA process) Bulk Data entry that defines phase angle θ . (See Remarks 4. and 5. (Integer > 0 or blank)
DPHASER	Value of phase angle θ (in degrees) that will be used for all fluid degrees-of-freedom that are excited by this dynamic load entry. See Remark 5. (Real or blank)
TP	Identification number of a TABLEDi entry that defines power versus frequency, $P(f)$. (Integer ≥ 0 or blank)
RHO	Density of the fluid. (Real > 0.0)
B	Bulk modulus of the fluid. (Real > 0.0)

Remarks:

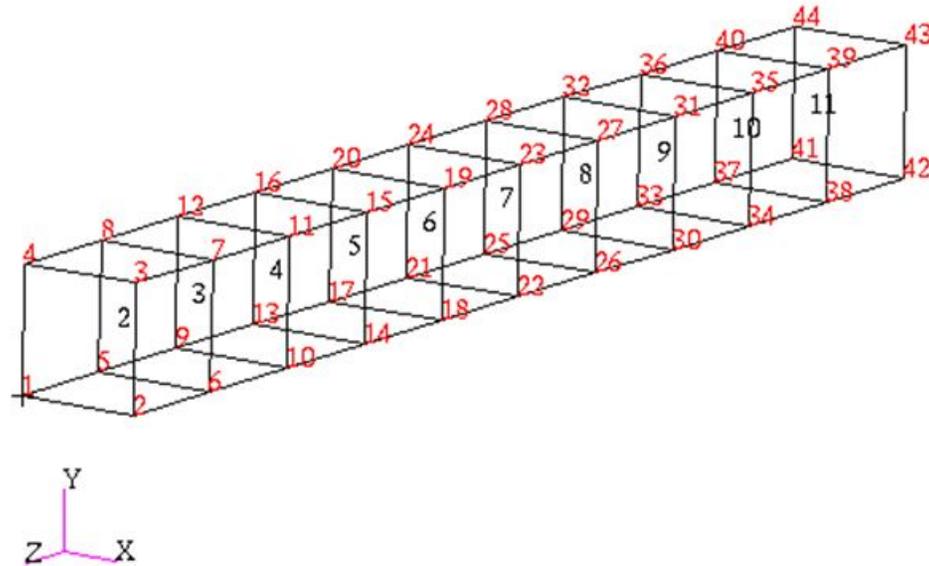
1. Acoustic sources must be selected in the Case Control Section with DLOAD = SID.
2. For additional remarks, see the RLOAD1 entry description.
3. SID must be unique for all ACSRSE, RLOADi, and TLOADi entries.
4. The referenced EXCITEID, DELAY, and DPHASE entries must specify fluid points only.
5. If any of the DELAYI/DELAYR or DPHASEI/DPHASER fields are blank or zero, the corresponding τ or θ will be zero.
6. If there is no LOADSET Case Control command, then EXCITEID may reference DAREA and SLOAD entries. If there is a LOADSET Case Control command, then EXCITEID may reference DAREA entries as well as SLOAD entries specified by the LID field in the selected LSEQ entry corresponding to EXCITEID.

ACOUSTIC SOURCE EXAMPLE - PROB2.DAT



- **1 dimensional fluid**
- **Acoustic sinusoidal power source**
- **Compare the resulting pressure distribution to a theoretical solution.**
- **One end of the tube has the power applied to it, and the other side is constrained to a zero pressure.**
 - density = 1.21 kg/meter³
 - speed of sound = 343 meters/sec

ACOUSTIC SOURCE EXAMPLE - ACSRCE



- The power is spread over GRIDs 1, 2, 3, and 4 by the combination of the following ACSRCE, TABLED1, DAREA, and FREQ bulk data entries:

```

acsrce 10 100 100200 1.21 142355.3
tabled1,100200
,0., 0., 49.9, 0., 50.0, 0.01, 50.1, 0.
,1000., 0., endt
darea,100,1,0,.25,2,0,.25
darea,100,3,0,.25,4,0,.25
freq,15,50.
    
```

ACOUSTIC SOURCE EXAMPLE - ACSRCE

```
sol 108
cend
$
title = Verify ACSRCE with analytical solution for a straight sector
subti = 10 inches long with 10 elements - constraint at end - 50 hz.
disp = all
set 5 = 1
oload = 5
dload = 10
freq = 15
spc = 1
BEGIN BULK
$
PARAM POST -1
$
psolid,1,1000,,two,,full,pfluid
mat10,1000,,1.21,343.
$
acsrce 10 100 100200 1.21 142355.3
tabled1,100200
0. 0. 49.9 0. 50.0 0.01 50.1 0.
1000. 0. endt
$
darea,100,1,0,.25,2,0,.25
darea,100,3,0,.25,4,0,.25
$
freq,15,50.
$
$ THIS SECTION CONTAINS BULK DATA FOR SE 0
$
GRID 1 0 0.0 0.0 0.0 -1
GRID 2 0 1. 0.0 0.0 -1
.
$
CHEXA 2 1 1 2 3 4 5 6 +
+ 7 8
CHEXA 3 1 5 6 7 8 9 10 +
+ 11 12
.
$
spc1,1,1,41,42,43,44
ENDDATA
```

ACOUSTIC OUTPUT

- Acoustic Output are single value.
- The f06 acoustic output under the displacement output uses the same output format as the grid, which potentially has six values
 - Implies 6 acoustic values per line
 - Grid 1, Grid 2, etc.

FREQUENCY = 5.000000E+01

COMPLEX DISPLACEMENT VECTOR
(REAL/IMAGINARY)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
1	S	-7.219056E+00 0.0	-7.219056E+00 0.0	-7.219056E+00 0.0	-7.219056E+00 0.0	-1.352279E+01 0.0	-1.352279E+01 0.0
7	S	-1.352279E+01 0.0	-1.352279E+01 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0
13	S	1.042300E+00 0.0	1.042300E+00 0.0	1.042300E+00 0.0	1.042300E+00 0.0	1.119126E+01 0.0	1.119126E+01 0.0
19	S	1.119126E+01 0.0	1.119126E+01 0.0	1.310348E+01 0.0	1.310348E+01 0.0	1.310348E+01 0.0	1.310348E+01 0.0
25	S	5.371571E+00 0.0	5.371571E+00 0.0	5.371571E+00 0.0	5.371571E+00 0.0	-6.313799E+00 0.0	-6.313799E+00 0.0
31	S	-6.313799E+00 0.0	-6.313799E+00 0.0	-1.335223E+01 0.0	-1.335223E+01 0.0	-1.335223E+01 0.0	-1.335223E+01 0.0
37	S	-1.056345E+01 0.0	-1.056345E+01 0.0	-1.056345E+01 0.0	-1.056345E+01 0.0	0.0 0.0	0.0 0.0
43	S	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0

ACOUSTIC OUTPUT

FREQUENCY = 5.000000E+01

COMPLEX DISPLACEMENT VECTOR
(REAL/IMAGINARY)

POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
1	S	-7.219056E+00 0.0	-7.219056E+00 0.0	-7.219056E+00 0.0	-7.219056E+00 0.0	-1.352279E+01 0.0	-1.352279E+01 0.0
7	S	-1.352279E+01 0.0	-1.352279E+01 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0	-9.873789E+00 0.0

FREQUENCY = 5.000000E+01

COMPLEX ACOUSTIC PRESSURE RESULTS
(MAGNITUDE/PHASE)

POINT ID.	TYPE	P	P (RMS)	DB	DB(A)
1	S	7.219056E+00 180.0000	5.104643E+00 180.0000	1.716961E+01 180.0000	-1.303039E+01 180.0000
2	S	7.219056E+00 180.0000	5.104643E+00 180.0000	1.716961E+01 180.0000	-1.303039E+01 180.0000
3	S	7.219056E+00 180.0000	5.104643E+00 180.0000	1.716961E+01 180.0000	-1.303039E+01 180.0000
4	S	7.219056E+00 180.0000	5.104643E+00 180.0000	1.716961E+01 180.0000	-1.303039E+01 180.0000
5	S	1.352279E+01 180.0000	9.562058E+00 180.0000	2.262133E+01 180.0000	-7.578672E+00 180.0000
6	S	1.352279E+01 180.0000	9.562058E+00 180.0000	2.262133E+01 180.0000	-7.578672E+00 180.0000
7	S	1.352279E+01 180.0000	9.562058E+00 180.0000	2.262133E+01 180.0000	-7.578672E+00 180.0000
8	S	1.352279E+01 180.0000	9.562058E+00 180.0000	2.262133E+01 180.0000	-7.578672E+00 180.0000
9	S	9.873789E+00 180.0000	6.981823E+00 180.0000	1.988968E+01 180.0000	-1.031032E+01 180.0000
10	S	9.873789E+00 180.0000	6.981823E+00 180.0000	1.988968E+01 180.0000	-1.031032E+01 180.0000
11	S	9.873789E+00 180.0000	6.981823E+00 180.0000	1.988968E+01 180.0000	-1.031032E+01 180.0000
12	S	9.873789E+00 180.0000	6.981823E+00 180.0000	1.988968E+01 180.0000	-1.031032E+01 180.0000

ACOUSTIC SOURCE EXAMPLE – RLOAD1

- Alternately, an RLOAD1 can be used to specify power by inputting \dot{Q} as a force on the fluid GRIDs.

```
rload1,10,100,,,100100
tabled1,100100
,0., 0.,49.9,0.,50.0,8.44061,50.1,0.
,1000.,0.,endt
darea,100,1,0,.25,2,0,.25
darea,100,3,0,.25,4,0,.25
freq,15,50.
```

- The “8.44061” on the TABLED1 entry is the \dot{Q} equivalent to a power of 0.01 watts.

ACOUSTIC SOURCE EXAMPLE – RLOAD1

```
sol 108
cend
$
title = Use RLOAD1 instead of ACSRCE
subti = 10 inches long with 10 elements - constraint at end - 50 hz.
disp = all
set 5 = 1
pload = 5
dload = 10
freq = 15
spc = 1
BEGIN BULK
$
PARAM POST -1
$
psolid,1,1000,,two,,full,pfluid
mat10,1000,,1.21,343.
$-----$
$ This RLOAD1 is an alternate way to enter power by putting Qdot in the load $
$ vector. $
$-----$
rload1,10,100,,100100
tabled1,100100
      0.      0.      49.9      0.      50.0      8.44061950.1      0.
      1000.      0.      endt
$
darea,100,1,0,,.25,2,0,,.25
darea,100,3,0,,.25,4,0,,.25
$
freq,15,50.
$
$ THIS SECTION CONTAINS BULK DATA FOR SE 0
$
GRID 1 0 0.0 0.0 0.0 -1
GRID 2 0 1. 0.0 0.0 -1
GRID 3 0 1. 1. 0.0 -1
.
$
CHEXA 2 1 1 2 3 4 5 6 +
+ 7 8
CHEXA 3 1 5 6 7 8 9 10 +
+ 11 12
.
$
spc1,1,1,41,42,43,44
ENDDATA
```

ACOUSTIC SOURCE EXAMPLE (CONT.)

- The theoretical pressure distribution is (ref. Dave Herting, Internal document)

$$P = [(\dot{Q} * \rho * c) / (\omega * A)] * [\sin(\omega * x / c) + \tan(\omega * L / c) * \cos(\omega * x / c)]$$

where:

\dot{Q} = fluid acceleration (volume/sec²) calculated from power (see below)

ρ = density of the fluid

c = speed of sound in the fluid

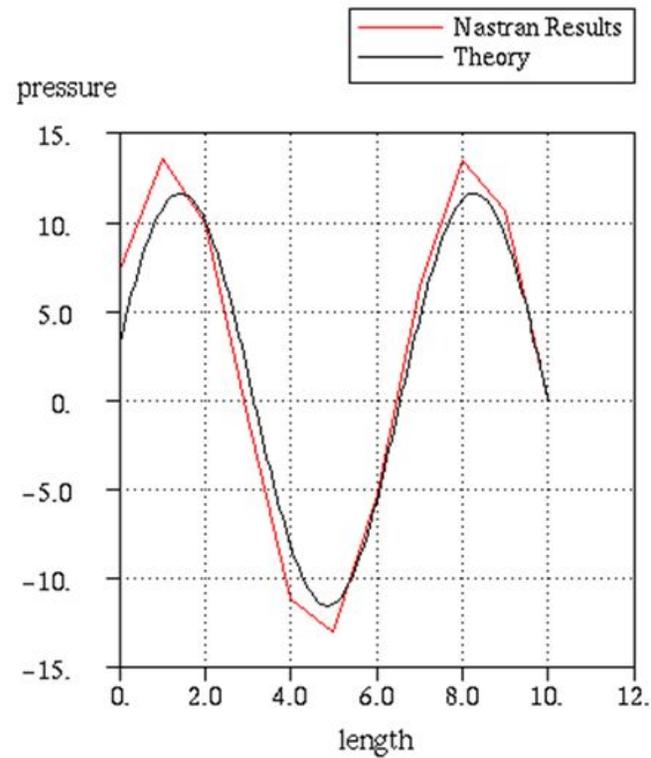
ω = rotational speed in radians

x = distance from power source

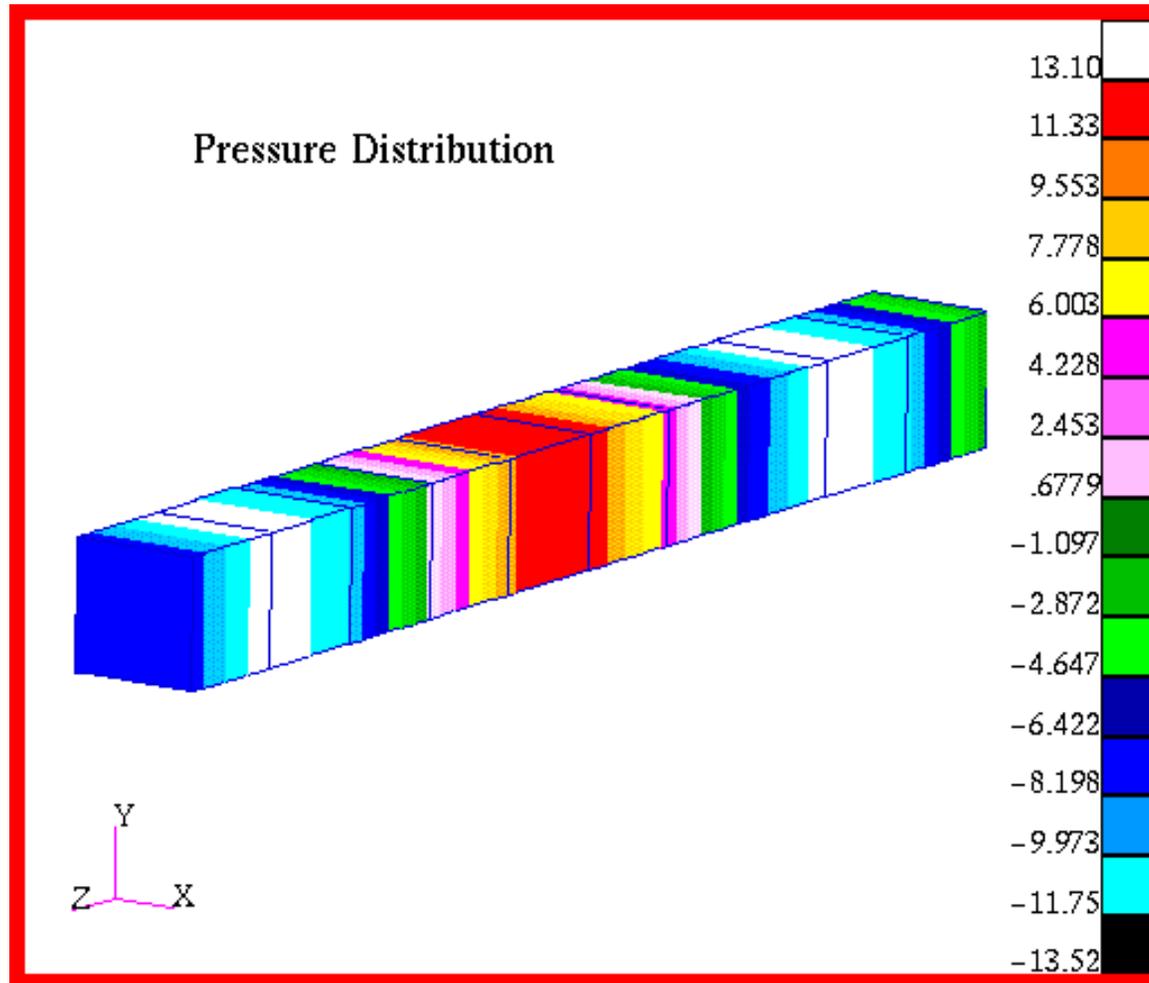
L = length of the 1 dimensional tube

A = cross sectional area of 1 dimensional tube

ACOUSTIC SOURCE THEORETICAL EXAMPLE (CONT.)

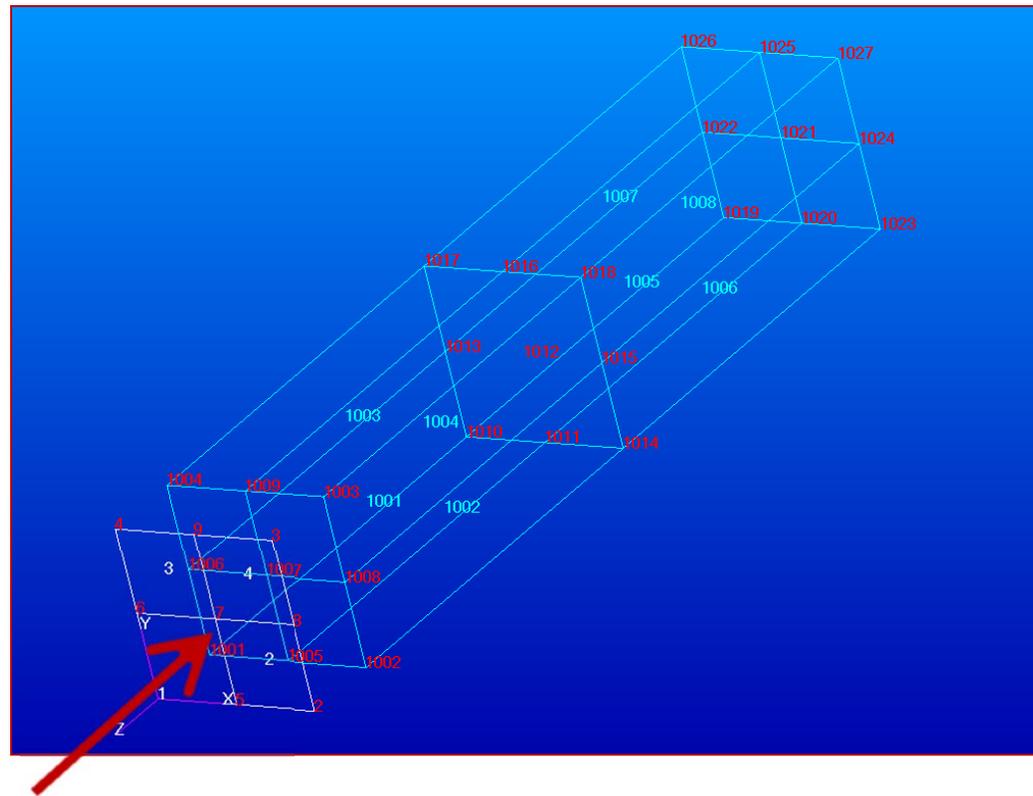


ACOUSTIC SOURCE THEORETICAL EXAMPLE (CONT.)



FREQUENCY RESPONSE ANALYSIS

- **Modify the file prob1StFl.dat to perform a frequency response analysis.**
- **Use Sol 108 (acoustic2.dat)**
- **Apply a sinusoidal structural force.**

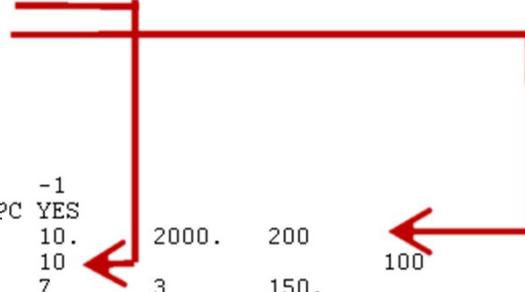


FREQUENCY RESPONSE ANALYSIS

acoustic2.dat

- “Similar” to structural frequency response analysis setup

```
$
SOL      108
CEND
TITLE   = FREQUENCY RESPONSE FOR STRUCTURE AND FLUID
DLOAD   = 1
FREQ    = 10
DISP    = ALL
SPC     = 1
$
BEGIN BULK
ACMODL  IDENT
PARAM   POST      -1
PARAM   AUTOSPC   YES
FREQ2   10        10.    2000.    200
RLOAD1  1         10     3         150.    100
DAREA   10        7
TABLED1 100
+       0.        1.     1000.    1.     ENDT
$
$ STRUCTURAL MODEL
$
GRID    1         0         0.0     0.0     0.0     0
GRID    2         0         20.     0.0     0.0     0
.
$
CQUAD4  1         1         1         5         7         6
.
$
PSHELL  1         1         .2         1         1
MAT1    1         1.+7      .3         2.54-4
$
$ FLUID MODEL
$
GRID    1001      0         0.0     0.0     0.0     -1
GRID    1002      0         20.     0.0     0.0     -1
.
$
CHEXA   1001      1001     1001     1005     1007     1006     1010     1011     +
+       1012     1013
.
$
PSOLID  1001      1001
MAT10,1001,,1.21E-7,1.3E4
ENDDATA
```





GENERAL ADDITIONAL OUTPUT

OUTPUT REQUESTS, POST-PROCESSING

- Particle velocity is obtained using FORCE=n or FLUX=n Case Control Command
 - These two outputs are equivalent)
- PARAM,PREFDB,p_ref is used for reference in pressure dB levels [default is 1.0]
- PARAM,ACOUT,[RMS/PEAK] controls whether rms or peak(default) is output

Example: SET 20=1

FLUX(PRINT,REAL)=20

or FORCE(PRINT,REAL)=20

- This output is calculated as element output!!
- Currently not supported in Patran or SImX.

1 TEST FLUX OUTPUT

SEPTEMBER 25, 2011 MD NASTRAN 7/15/10 PAGE 11

0

SUBCASE 1

FREQUENCY = 1.000000E+01

C O M P L E X A C C E L E R A T I O N S				(P E A K) V E L O C I T I E S A N D P R E S S U R E L E V E L S (R E A L / I M A G I N A R Y)				
ELE-ID	EL-TYPE	X-ACCELERATION	Y-ACCELERATION	Z-ACCELERATION	X-VELOCITY	Y-VELOCITY	Z-VELOCITY	PRESSURE (DB)
1	HEXPR	2.804122E-02	-6.290808E-02	4.687929E-02	2.012792E-04	3.041776E-04	1.307545E-04	5.411077E+01
		1.264674E-02	1.911204E-02	8.215548E-03	-4.462898E-04	1.001213E-03	-7.461071E-04	

OUTPUT REQUESTS, RESISTANCE, REACTANCE, ABSORPTION

- Resistance, Reactance and absorption may be calculated using the STRESS=n command
- EXAMPLE SET 30=5125
STRESS(PRINT,REAL)=30
- This output is calculated as element output!!
- Currently not supported in Patran or SimX

```
1 TEST FLUX OUTPUT SEPTEMBER 25, 2011 MD NASTRAN 7/15/10 PAGE 15
0 SUBCASE 1
FREQUENCY = 1.000000E+01
COMPLEX FIELDS IN A ABSF ELEMENTS (C A A B S F)
(REAL/IMAGINARY)
ELEMENT ID IMPEDANCE ABSORPTION COEFFICIENT
0 5125 9.700000E+00 /-2.746000E+01 9.588432E-02
```

FLUID-STRUCTURE EQUATION

- The general fluid-structure equation of motion is unsymmetric

$$\begin{bmatrix} M_s & 0 \\ -A^T & M_f \end{bmatrix} \begin{Bmatrix} \ddot{u}_s \\ \ddot{p} \end{Bmatrix} + \begin{bmatrix} B_s & 0 \\ 0 & B_f \end{bmatrix} \begin{Bmatrix} \dot{u}_s \\ \dot{p} \end{Bmatrix} + \begin{bmatrix} K_s & A \\ 0 & K_f \end{bmatrix} \begin{Bmatrix} u_s \\ p \end{Bmatrix} = \begin{Bmatrix} P_s \\ P_f \end{Bmatrix}$$

- For efficiency, by default, MSC Nastran solves a symmetrized version of the above equation based on Everstine's work (See Chapter 13 of the MSC Nastran Reference Manual for further details)

$$\begin{bmatrix} M_s & 0 \\ 0 & -M_f \end{bmatrix} \begin{Bmatrix} \ddot{u}_s \\ \ddot{q} \end{Bmatrix} + \begin{bmatrix} B_s & A \\ A^T & -B_f \end{bmatrix} \begin{Bmatrix} \dot{u}_s \\ \dot{q} \end{Bmatrix} + \begin{bmatrix} K_s & 0 \\ 0 & -K_f \end{bmatrix} \begin{Bmatrix} u_s \\ q \end{Bmatrix} = \begin{Bmatrix} P_s \\ G \end{Bmatrix}$$

EQUATION SOLVED

- ACYSM**

Unsymmetric coupled equation

$$\begin{bmatrix} M_s & 0 \\ -A^T & M_f \end{bmatrix} \begin{Bmatrix} \ddot{u}_s \\ \ddot{p} \end{Bmatrix} + \begin{bmatrix} B_s & 0 \\ 0 & B_f \end{bmatrix} \begin{Bmatrix} \dot{u}_s \\ \dot{p} \end{Bmatrix} + \begin{bmatrix} K_s & A \\ 0 & K_f \end{bmatrix} \begin{Bmatrix} u_s \\ p \end{Bmatrix} = \begin{Bmatrix} P_s \\ P_f \end{Bmatrix}$$

- Solving the unsymmetric equation is time consuming

This is the fluid structure equation solved in MSC.Nastran. Note that this equation is nonsymmetric. By default, MSC.Nastran solves a symmetric version of this equation developed by Everstine as follows:

Let the velocity potential q be defined as

$$p = \dot{q} \tag{Eq. 13-59}$$

and note the following:

$$\begin{aligned} \ddot{u}_s &= \frac{d\dot{u}_s}{dt} \\ \ddot{p} &= \frac{d\dot{p}}{dt} \\ \dot{p} &= \frac{dp}{dt} \\ p &= \frac{dq}{dt} \end{aligned}$$

and define G as

$$G = -\int_0^t P_f(\tau) d\tau \tag{Eq. 13-60}$$

Substitute \dot{q} for p in the structure equation and for the fluid equation replace the vector terms with their derivative equivalents. Then multiplying the fluid equation by -1 and integrating with respect to time and recombining, we get the symmetric equation

$$\begin{bmatrix} M_s & 0 \\ 0 & -M_f \end{bmatrix} \begin{Bmatrix} \ddot{u}_s \\ \ddot{q} \end{Bmatrix} + \begin{bmatrix} B_s & A \\ A^T & -B_f \end{bmatrix} \begin{Bmatrix} \dot{u}_s \\ \dot{q} \end{Bmatrix} + \begin{bmatrix} K_s & 0 \\ 0 & -K_f \end{bmatrix} \begin{Bmatrix} u_s \\ q \end{Bmatrix} = \begin{Bmatrix} P_s \\ G \end{Bmatrix} \tag{Eq. 13-61}$$

The output from the solution is, however, expressed in terms of u_s and p .

In the frequency domain, we assume a harmonic function of the form $q = Q_0 e^{i\omega t}$ as a solution. Then the load integral becomes $\int G_0 e^{i\omega t} d\tau = G_0 / (i\omega) e^{i\omega t}$. The pressure is recovered from the relationship $p = i\omega q$.

POSTPROCESS RESULT, FLSTCNT

- **FLSTCNT (Case Control) can be used to control the acoustic analyses and their output:**

$$\text{FLSTCNT} \left[\text{ACSYM} = \left\{ \begin{array}{c} \text{YES} \\ \text{NO} \end{array} \right\}, \left[\text{ACOUT} = \left\{ \begin{array}{c} \text{PEAK} \\ \text{RMS} \end{array} \right\} \right] \right. \\
 \left. \left[\text{PREFDB} = \left\{ \begin{array}{c} 1.0 \\ \text{prp} \end{array} \right\}, \left[\text{ASCROUP} = \left\{ \begin{array}{c} \text{YES} \\ \text{NO} \end{array} \right\} \right] \right. \right. \\
 \left. \left. \left[\text{SKINOUT} = \left\{ \begin{array}{c} \text{NONE} \\ \text{PUNCH} \\ \text{PRINT} \\ \text{ALL} \end{array} \right\} \right] \right. \right.$$

ACSYM	<u>YES</u> NO	requests symmetric or nonsymmetric solution for fluid-structure analysis
ACOUT	<u>PEAK</u> RMS	specifies the type of output to be used with the FORCE Case Control Command
PREFDB	Real <u>1.0</u>	defines the reference pressure for sound pressure levels in dB given by the FORCE command. In order to get standard dB levels, a value of 2.E-5Pa has to be given together with PARAM, ACOUT, RMS
ASCROUP	<u>YES</u> NO	requests a coupled or non-coupled fluid-structure analysis
SKINOUT	<u>NONE</u> PUNCH PRINT ALL	requests sets of grid and element lists to be output for both the fluid and structure at the fluid-structure interface

- **Note that many of the options can also be specified as parameters**
 - **Example - param,acysm,no**

POSTPROCESS RESULT, FLFSEL

- **FLFSEL (Case Control) can be used to control the output frequencies and modes**

$$\begin{aligned}
 \text{FLSFSEL} \quad & \left[\text{LFREQFL} = \left\{ \frac{0.0}{fl_1} \right\} \right], \left[\text{HFREQFL} = \left\{ \frac{1. + 30}{fl_2} \right\} \right], \\
 & \left[\text{LFREQ} = \left\{ \frac{0.0}{fs_1} \right\} \right], \left[\text{HFREQ} = \left\{ \frac{1. + 30}{fs_2} \right\} \right], \\
 & \left[\text{LMODESFL} = \left\{ \frac{0}{mf} \right\} \right], \left[\text{LMODES} = \left\{ \frac{0}{ms} \right\} \right], \\
 & \left[\text{FLUIDSE} = \left\{ \frac{0}{seidf} \right\} \right]
 \end{aligned}$$

LFREQFL	Real <u>0.0</u>	lower frequency bound on acoustic modes to be retained
HFREQFL	Real <u>1.E+30</u>	upper frequency bound on acoustic modes to be retained
LFREQ	Real <u>0.0</u>	lower frequency bound on structural modes to be retained
HFREQ	Real <u>1.E+30</u>	Upper frequency bound on structural modes to be retained
LMODESFL	Integer <u>0</u>	defines the number of acoustic modes to be used in modal reduction. If 0, the retained modes are determined by parameters LFREQFL and HFREQFL
LMODES	Integer <u>0</u>	defines the number of structural modes to be used in modal reduction. If 0, the retained modes are determined by parameters LFREQ and HFREQ
FLUIDSE	Integer <u>0</u>	defines a specified superelement to be used for fluids only

- **Note that many of the options can also be specified as parameters**
 - **Example - param,lfreq,0.1**

OUTPUT REQUESTS, POSTPROCESSING

- **Acoustic power is the output of the power radiated from the wetted surface.**
 - Developed for exterior acoustic, but is also available for interior acoustics.
 - There need to be a dissipation (damping) in the cavity in order for the ACPOWER to have non-zero values.
 - For exterior acoustic, all energy radiated to exterior will be dissipated (no reflections)

Example

ACPOWER(SORT1,PRINT,CSV=50)=ALL

```
1  TEST FLUX OUTPUT                               SEPTEMBER 25, 2011  MD NASTRAN  7/15/10  PAGE  16
0
  FREQUENCY =  1.000000E+02                                SUBCASE 1
                                R A D I A T E D   A C O U S T I C   P O W E R
  PANEL-NAME      POWER    PANEL-NAME      POWER    PANEL-NAME      POWER    PANEL-NAME      POWER
  -TOTAL-        9.075571E-04
```

POSTPROCESSING - LIMIT AMOUNT OF OUTPUT

- **Result files may be very large in a frequency response analysis.**
- **The following output request can generate tremendous amount of output:**
 - Deflections (that is, the deformed shape for all grids (or significant part of the model)
 - Mode, panel, or grid participation factors (see Section on Acoustic Panel Participation Factors)
 - Element strain, stress, or strain energy output.
- **Often, this output is only required for a few discrete frequencies, even though other responses may be requested for a broader frequency range.**
- **Use the OFREQUENCY (or OFREQ) Case Control Command for these cases.**
- **With OFREQ=set_i, only these frequencies are output for the referenced subcase**

Example:

```
SUBCASE =1
```

```
SET 100= 10.4, 48.0, 256.3
```

```
OFREQ=100
```

```
DISP(PLOT,SORT1,REAL)=ALL
```

- **In example above, the displacements are written to the op2 only for freqs 10.4, 48., and 256.3 Hz**
- **Or simply reduced the frequencies specified on the FREQ_i entry**



DAMPING

FLUID DAMPING

- **Direct damping (proportional to the fluid stiffness)**
- **Modal damping for the fluid modes.**
- **Following are new fluid damping commands.**

Fluid	Structural Equivalent	Description of Fluid Entry
Case Control		
SDAMPING(FLUID)=n	SDAMPING	Points to a TABDMP1 Bulk Data entry which is used to specify modal damping for fluid modes.
Bulk Data		
PARAM GFL	PARAM G	Specifies overall damping applied to the K matrix of the fluid.
PARAM W3FL	PARAM W3	Required for PARAM,GFL to be effective in transient response. W3FL is typically the dominant frequency of the fluid part at which damping is active.
MAT10 "GE" Field	MAT1 "GE" Field	Specifies fluid element damping coefficient.

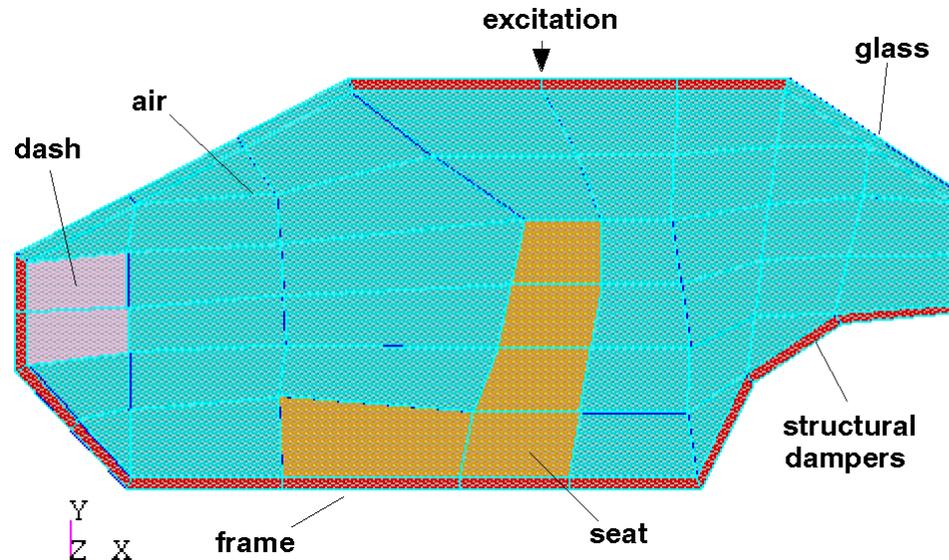
FLUID DAMPING

Fluid	Structural Equivalent	Description of Fluid Entry
PARAM W4FL	PARAM W4	Required for "GE" on MAT10 entry to be effective in transient response. W4FL is typically the dominant frequency of the fluid part at which damping is active.
PARAM LMODESFL	PARAM LMODES	Specifies the number of lowest fluid modes to be used in the modal response. The retained fluid modes are determined by PARAM,LFREQFL and PARAM, HFREQFL. Used with SDAMPING.
PARAM LFREQFL PARAM HFREQFL	PARAM LFREQ PARAM HFREQ	Specifies the frequency range in cycles per unit time and the fluid modes to be used in modal response. Used with SDAMPING.
PARAM KDAMPFL	PARAM KDAMP	Allows viscous modal fluid damping to be entered into the complex fluid stiffness matrix.

- **Cannot be used as design variables in optimization analysis.**

FLUID DAMPING EXAMPLE (PROB4A.DAT)

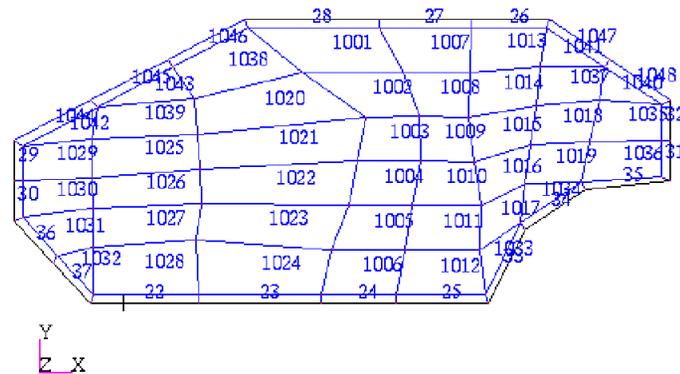
- The model consists of a simple car-body structure enclosing the fluid cavity.



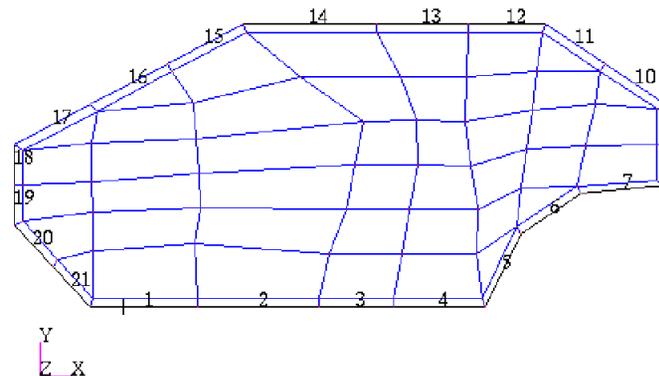
- The fluid cavity consists of the air, dash, and seat.
- The structure consists of the frame, glass and dampers
- An excitation is applied to the roof of the car to simulate a noise external to the car.

FLUID DAMPING EXAMPLE (CONT.)

- The fluid and structural damping elements are shown below:

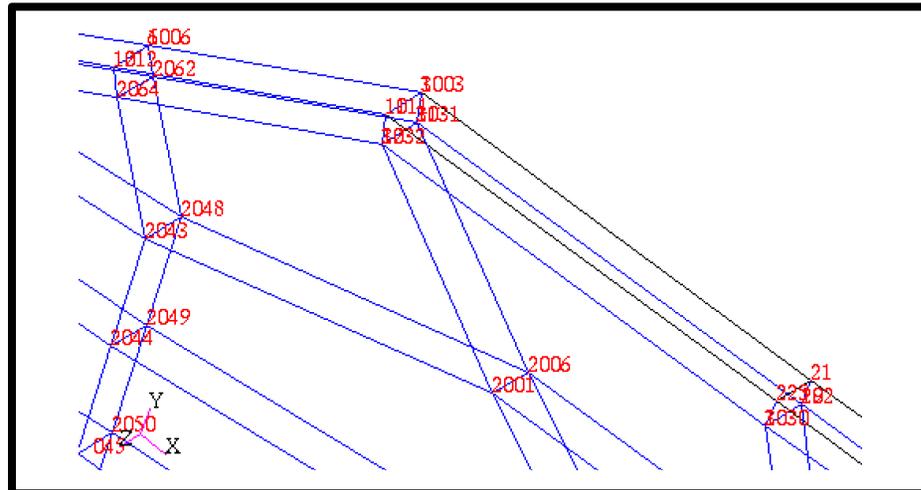


- The frame and glass structure elements are shown below:

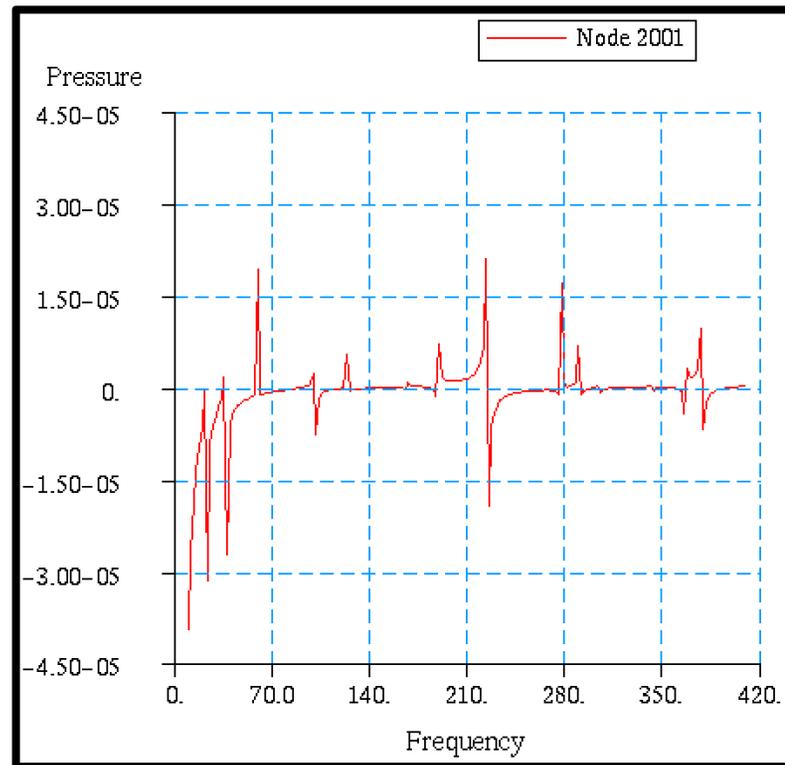


FLUID DAMPING EXAMPLE (CONT.)

- Fluid grid 2001 is selected for XY plotting of undamped pressure versus frequency.



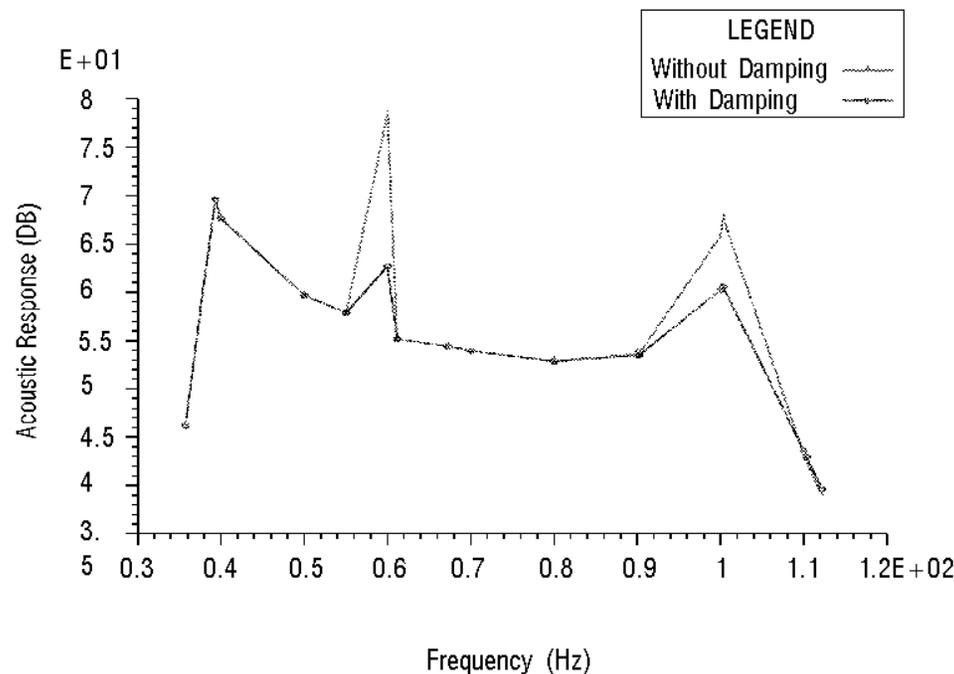
FLUID DAMPING EXAMPLE (CONT.)



- **From this curve, 220 Hz. seems a likely point for investigation of potential for noise reduction.**

FLUID DAMPING EXAMPLE (CONT.)

- The seats are modeled as a heavily damped fluid body by specifying a large value for "GE" in the sixth field of the MAT10 entry.
- The figure below shows the acoustic response, in decibels, of a point near the top of the seat for the model with and without the additional damping of the seats.



OUTPUT REQUESTS, POSTPROCESSING

The following information is available for postprocessing:

- **Pressure values** is obtained with the **DISP=n** or **PRESS=n** commands in the **Case Control**.
- **Particle velocity** is obtained using **FORCE=n** or commands in the **Case Control**. **FLUX=n**
- **RMS sound pressure level**. The user requests this data by using **PARAM,ACOUT,RMS**
- **Sound pressure level in dB and dBA** is available when the user provides the reference pressure in **PARAM,PREFDB**.
- **Participation Factor Output**
 - See section on Participation Factor



WORKSHOP 3

VEHICLE INTERIOR ACOUSTICS





SECTION 3

Acoustic Participation Factors

DEFINITION OF PARTICIPATION FACTORS

- **Participation factors describe the contribution of one single effect to the response considered.**
- **If the system is linear, the total response is the sum of the contributions of the single effects.**

PARTICIPATION FACTORS CASE CONTROL COMMANDS

- **PFMODE**
 - Controls computation and output of all types of modal participation factors
- **PFPANEL**
 - Controls computation and output of panel participation factors
 - Panels define logical groups of elements
 - Ptype property ID
 - Element ID list
 - Gridpoint ID list
- **PFGRID**
 - Controls computation and output of grid participation factors

EQUATIONS

- **PFMode(Structure) & MCFraction**

$$\mathbf{u} = \mathbf{\Phi}\mathbf{q} \rightarrow \tilde{u}_i(f_k) = \sum_j \phi_{ij} \tilde{q}_j(f_k)$$

- **Each $\phi_{ij} \tilde{q}_j(f_k)$ term is the response MPF**
- **If the system is linear, the total response is the sum of the contributions of the single effects.**

EQUATIONS – FLUID-STRUCTURE

- **Coupled interior acoustics**

$$\begin{bmatrix} \mathbf{M}_f & -\mathbf{A}^T \\ \mathbf{0} & \mathbf{M}_s \end{bmatrix} \begin{Bmatrix} \ddot{\mathbf{p}} \\ \ddot{\mathbf{u}} \end{Bmatrix} + \begin{bmatrix} \mathbf{B}_f & \mathbf{0} \\ \mathbf{0} & \mathbf{B}_s \end{bmatrix} \begin{Bmatrix} \dot{\mathbf{p}} \\ \dot{\mathbf{u}} \end{Bmatrix} + \begin{bmatrix} \mathbf{K}_f & \mathbf{0} \\ \mathbf{A} & \mathbf{K}_s \end{bmatrix} \begin{Bmatrix} \mathbf{p} \\ \mathbf{u} \end{Bmatrix} = \begin{Bmatrix} \mathbf{P}_f \\ \mathbf{P}_s \end{Bmatrix}$$

- **A (area) coupling matrix – struct-dof x fluid-dof**
- **\mathbf{P}_f is acoustic source (ie: flow accel \dot{Q}) – SLOAD or ACSRCE**
- **Interior acoustic equation**

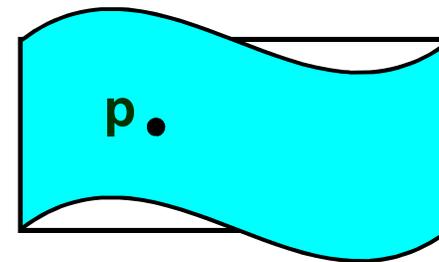
$$\mathbf{M}_f \ddot{\mathbf{p}} + \mathbf{B}_f \dot{\mathbf{p}} + \mathbf{K}_f \mathbf{p} = \mathbf{A}^T \ddot{\mathbf{u}} + \mathbf{P}_f$$

TYPES

		Response	
		Structural Displacements	Acoustic Pressure
Effect	Modes	Structural Mode	Acoustic Fluid Mode Acoustic Structural Mode
	Geometry		Acoustic Panel Acoustic Grid
	Load		Acoustic Load

MODE PARTICIPATION FACTORS

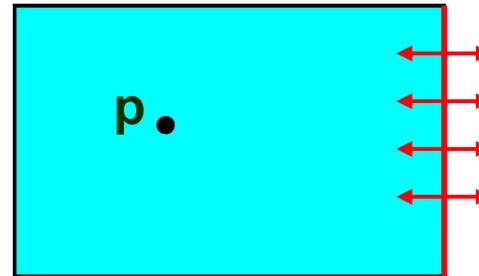
- **Structural Mode Participation Factors** indicate the contribution of the structural modes to the structural displacement.
- **Acoustic Fluid Mode Participation Factors** indicate the contribution of the fluid modes to the acoustic pressure.
- **Acoustic Structural Mode Participation Factors** indicate the contribution of the structural modes to the acoustic pressure.



GEOMETRIC PARTICIPATION FACTORS

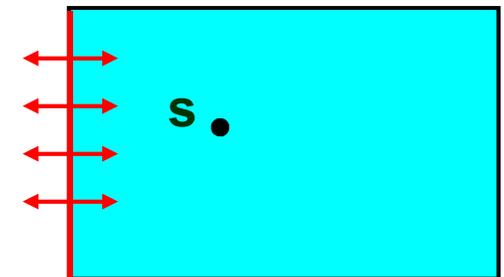
- **Panel participation factors to the acoustic response**

- Describe the contribution of different structural regions of the fluid-structure interface to the acoustic pressure.



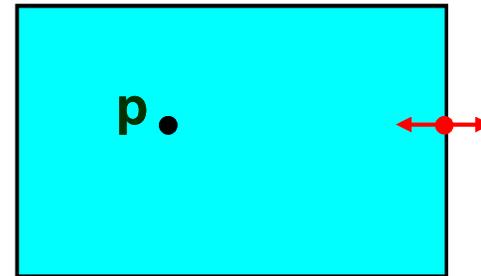
- **Panel participation factors to the structure response**

- Describe the contribution of different acoustic regions of the fluid-structure interface to the structure response.



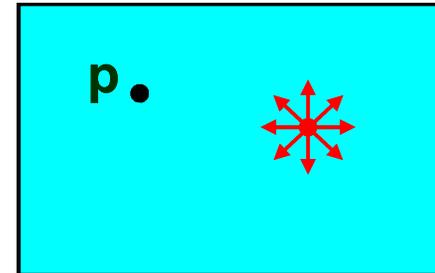
GEOMETRIC PARTICIPATION FACTORS (CONT.)

- **Grid participation factors describe the contribution of the different structural grids in the fluid-structure interface to the acoustic pressure.**

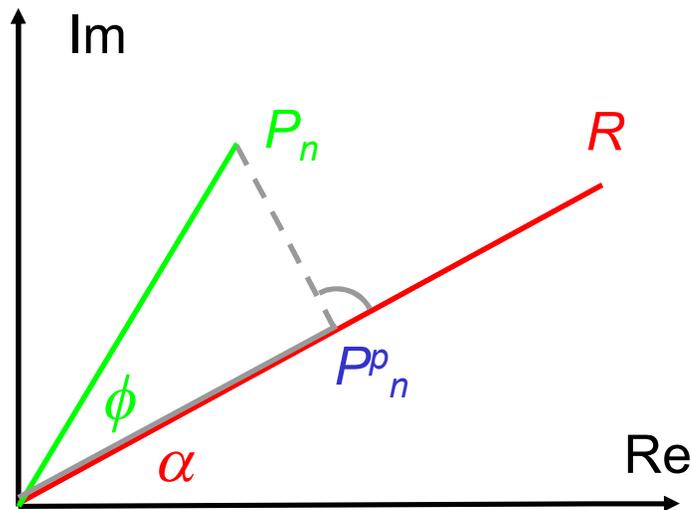


LOAD PARTICIPATION FACTORS

- **Load Participation Factors indicate the contribution of an acoustic source to the acoustic pressure.**
- **This is the pressure due to the acoustic source in a rigid cavity.**



REPRESENTATION



- $R = \text{Response}$
- $\alpha = \text{Phase of Response}$
- $P_n = \text{Participation Factor}$
- $\phi = \text{Phase relative to Response}$
- $P_n^p = \text{Projected Participation Factor}$
- $P_n / R = \text{Normalized Participation Factor}$
- $P_n^p / |R| = \text{Normalized Projection}$

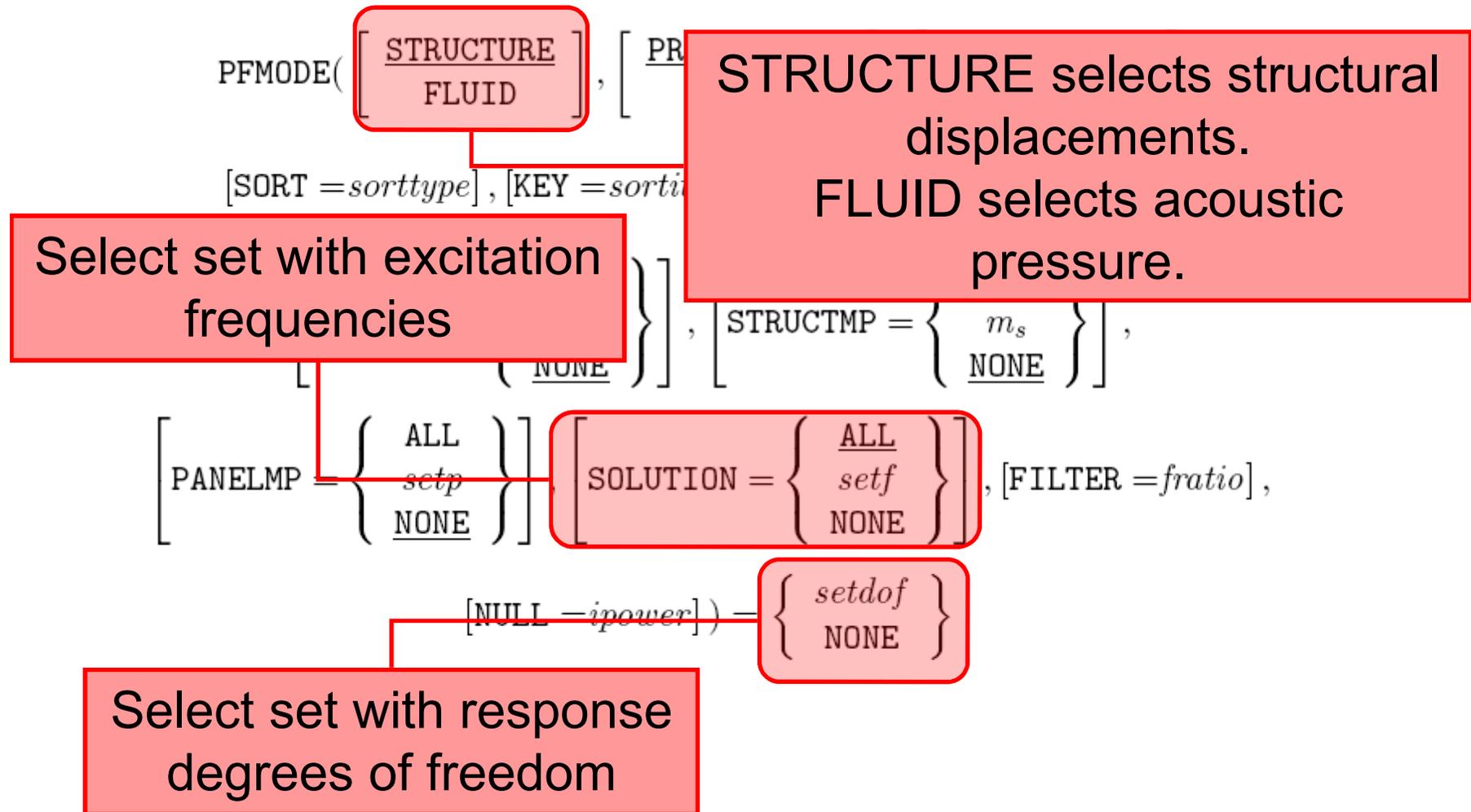
SOLUTION SEQUENCES

108	111
	PFMODE
PFPANEL	PFPANEL
PFGRID	PFGRID

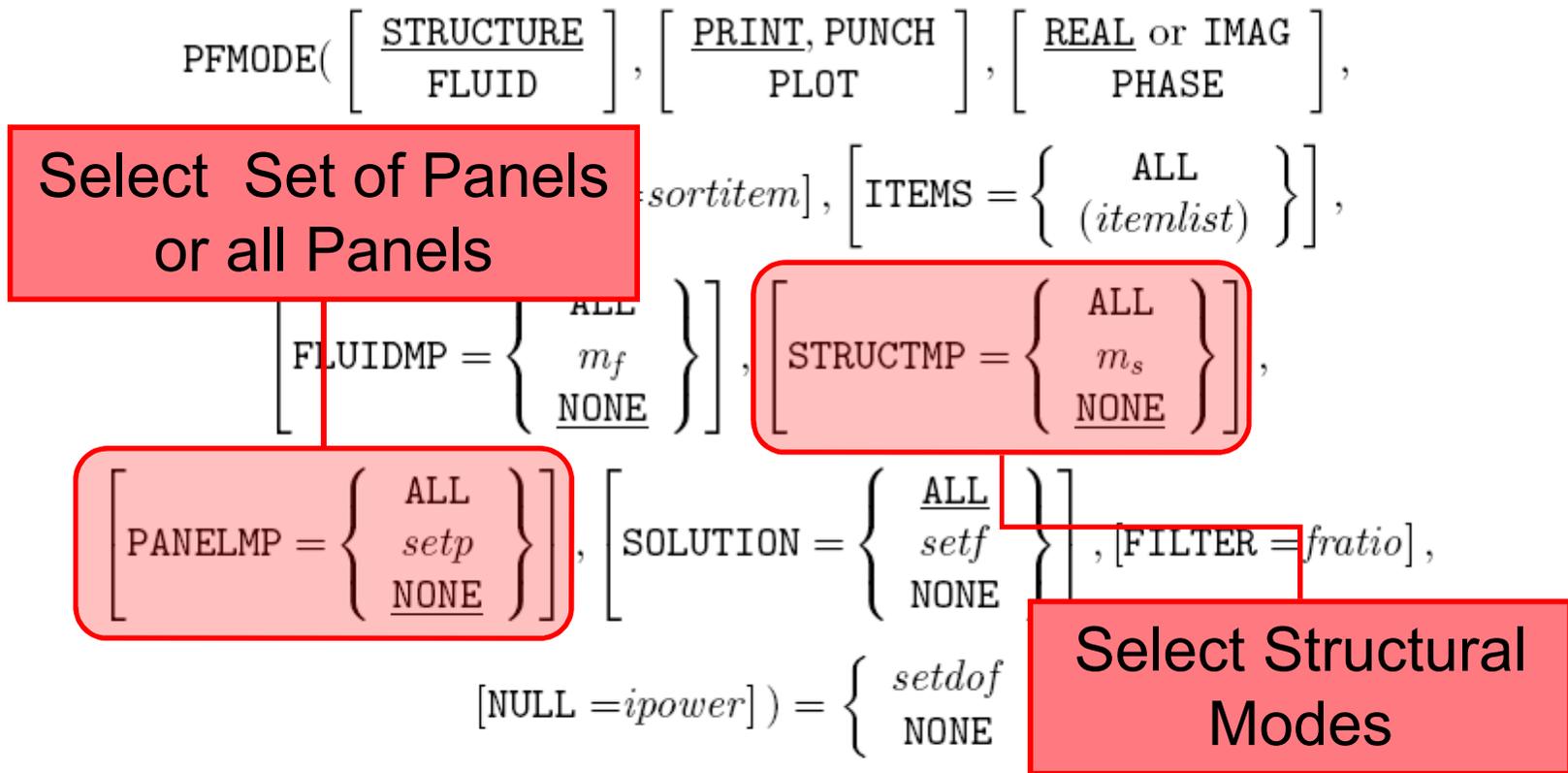
THE PFMODE COMMAND

$$\begin{aligned} & \text{PFMODE} \left(\left[\begin{array}{c} \text{STRUCTURE} \\ \text{FLUID} \end{array} \right], \left[\begin{array}{c} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right], \left[\begin{array}{c} \text{REAL or IMAG} \\ \text{PHASE} \end{array} \right], \right. \\ & \left. [\text{SORT} = \textit{sorttype}], [\text{KEY} = \textit{sortitem}], \left[\text{ITEMS} = \left\{ \begin{array}{c} \text{ALL} \\ (\textit{itemlist}) \end{array} \right\} \right], \\ & \left[\text{FLUIDMP} = \left\{ \begin{array}{c} \text{ALL} \\ m_f \\ \text{NONE} \end{array} \right\} \right], \left[\text{STRUCTMP} = \left\{ \begin{array}{c} \text{ALL} \\ m_s \\ \text{NONE} \end{array} \right\} \right], \\ & \left[\text{PANELMP} = \left\{ \begin{array}{c} \text{ALL} \\ \textit{setp} \\ \text{NONE} \end{array} \right\} \right], \left[\text{SOLUTION} = \left\{ \begin{array}{c} \text{ALL} \\ \textit{setf} \\ \text{NONE} \end{array} \right\} \right], [\text{FILTER} = \textit{fratio}], \\ & \left. [\text{NULL} = \textit{ipower}] \right) = \left\{ \begin{array}{c} \textit{setdof} \\ \text{NONE} \end{array} \right\} \end{aligned}$$

PFMODE COMMAND: RESPONSE SELECTION



PFMODE COMMAND: PANEL MODE



PFMODE COMMAND: PUNCH FILE REQUESTS

```

PFMODE( [ STRUCTURE ] , [ PRINT PUNCH ] , [ REAL or IMAG ]
        [ FLUID ] , [ PLOT ] , [ PHASE ] ,
        [ SORT = sorttype ] , [ KEY = sortitem ] , [ ITEMS = { ALL
        ( itemlist ) } ] ,
        [ FLUIDMP = { ALL
        mf
        NONE } ] , [ STRUCTMP = { ALL
        ms
        NONE } ] ,
        [ SOLUTION = {
        [ NULL = ipower ] ) = { setdof
        NONE }
    
```

List of Items to be punched (see next page)

Punch File Format: Real/Imaginary or Magnitude/Phase

PFMODE COMMAND: LIST OF ITEMS

Identifier	Description
RESPONSE	Participation Factor P
PROJECTION	Projected Participation Factor P^p
FRACTION	Normalized Projection P^p/ R
SCALED	P^p divided by Largest Magnitude of all P^p
MODEDISP	Real and Imaginary Part of P
MODERESP	Magnitude and Relative Phase of P

PFMODE COMMAND: SORT OPTIONS

Option	Description
ABSA	Absolute Value in Ascending Order
ABSD	Absolute Value in Descending Order
ALGA	Algebraic Value in Ascending Order
ALGD	Algebraic Value in Descending Order

PFMODE COMMAND: EXAMPLES

```
SET 20 = 25/T3, 33/T3
```

```
PFMODE (STRUCTURE, STRUCTMP=ALL, SORT=ABSD) = 20
```

Compute Structural Mode Participation Factors
for z-Translations at Grid Points 25 and 33

```
SET 20 = 11217
```

```
SET 90 = 25., 30., 35.
```

```
PFMODE (FLUID, STRUCTMP=ALL, FLUIDMP=ALL,  
        SORT=ABSD, SOLUTION=90) = 20
```

Compute Acoustic Structural and Fluid Mode
Participation Factors for Pressure at Grid Point 11217
for excitation frequencies 25Hz, 30Hz and 35Hz

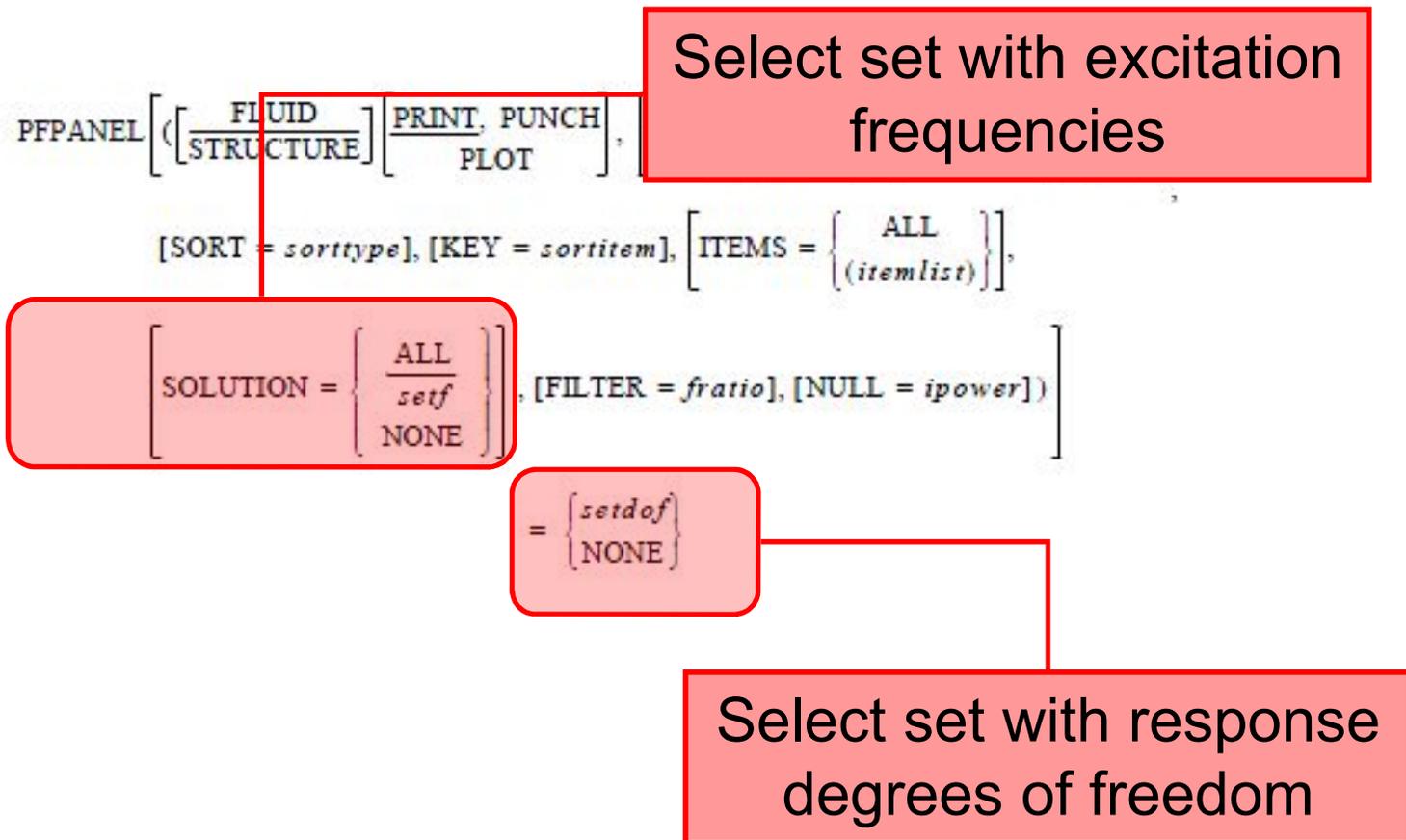
THE PFPANEL COMMAND

- **General Format**

$$\begin{aligned} & \text{PFPANEL} \left(\left[\begin{array}{c} \text{FLUID} \\ \text{STRUCTURE} \end{array} \right] \left[\begin{array}{c} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right], \left[\begin{array}{c} \text{REAL or IMAG} \\ \text{PHASE} \end{array} \right], \left[\text{PANEL} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setp} \end{array} \right\} \right], \\ & \left[\text{SORT} = \text{sorttype} \right], \left[\text{KEY} = \text{sortitem} \right], \left[\text{ITEMS} = \left\{ \begin{array}{c} \text{ALL} \\ (\text{itemlist}) \end{array} \right\} \right], \\ & \left[\text{SOLUTION} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setf} \\ \text{NONE} \end{array} \right\} \right], \left[\text{FILTER} = \text{fratio} \right], \left[\text{NULL} = \text{ipower} \right] \\ & = \left\{ \begin{array}{c} \text{setdof} \\ \text{NONE} \end{array} \right\} \end{aligned}$$

PFPANEL COMMAND: RESPONSE SELECTION

- **Keyword description**



PFPANEL COMMAND: PANEL SELECTION

- **Keyword description**

PFPANEL $\left(\left[\frac{\text{FLUID}}{\text{STRUCTURE}} \right] \left[\frac{\text{PRINT, PUNCH}}{\text{PLOT}} \right], \left[\frac{\text{REAL or IMAG}}{\text{PHASE}} \right], \left[\text{PANEL} = \left\{ \frac{\text{ALL}}{\text{setp}} \right\} \right], \right.$
 $\left. \left[\text{SORT} = \text{sorttype} \right], \left[\text{KEY} = \text{sortitem} \right], \left[\text{ITEMS} = \left\{ \frac{\text{ALL}}{(\text{item list})} \right\} \right], \right.$
 $\left. \left[\text{SOLUTION} = \left\{ \frac{\text{ALL}}{\text{setf}} \right\} \right], \left[\text{FILTER} = \text{fratio} \right], \left[\text{NULL} = \text{ipower} \right] \right)$
 $= \left\{ \frac{\text{setdof}}{\text{NONE}} \right\}$

Select Set of Panels
or all Panels

PFPANEL COMMAND: PUNCH FILE REQUESTS

- Keyword description

$$\text{PFPANEL} \left(\left[\frac{\text{FLUID}}{\text{STRUCTURE}} \right] \left[\frac{\text{PRINT}}{\text{PLOT}} \right] \left[\frac{\text{PUNCH}}{\text{REAL or IMAG}} \right] \left[\frac{\text{PHASE}}{\text{PHASE}} \right] \left[\text{PANEL} = \left\{ \frac{\text{ALL}}{\text{setp}} \right\} \right] \right. \\
 \left. \left[\text{SORT} = \text{sorttype} \right], \left[\text{KEY} = \text{sortitem} \right], \left[\text{ITEMS} = \left\{ \frac{\text{ALL}}{\text{(item list)}} \right\} \right] \right. \\
 \left. \left[\text{SOLUTION} = \left\{ \frac{\text{ALL}}{\text{setf}} \right\} \right], \left[\text{FILTER} = \text{fratio} \right], \left[\text{NULL} = \text{ipower} \right] \right) \\
 = \left\{ \frac{\text{setdof}}{\text{NONE}} \right\}$$

List of Items to be punched (see PFMODE Command)

Punch File Format:
Real/Imaginary or
Magnitude/Phase

PFPANEL COMMAND: FILTERING

- **Keyword description**

PFPANEL $\left(\left[\frac{\text{FLUID}}{\text{STRUCTURE}} \right] \left[\frac{\text{PRINT, PUNCH}}{\text{PLOT}} \right], \left[\frac{\text{REAL or IMAG}}{\text{PHASE}} \right], \left[\text{PANEL} = \left\{ \frac{\text{ALL}}{\text{setp}} \right\} \right], \right.$
 $\left. \left[\text{SORT} = \text{sorttype} \right], \left[\text{KEY} = \text{sortitem} \right], \left[\text{ITEMS} = \left\{ \frac{\text{ALL}}{(\text{item list})} \right\} \right], \right.$
 $\left. \left[\text{SOLUTION} = \left\{ \frac{\text{ALL}}{\text{setf}} \right\}, \left[\text{FILTER} = \text{fratio} \right], \left[\text{NULL} = \text{ipower} \right] \right) \left[\frac{\text{ALL}}{\text{setdof}} \right]$
 $\left. \left[\text{NONE} \right] \right)$

Only participation factors with normalized projection $> \text{fratio}$ are output.

Participation factors are output only if the response is larger than $10^{-\text{ipower}}$.

PFPANEL COMMAND: EXAMPLE

```
SET 20 = 11217  
SET 90 = 25., 30., 35.  
PFPANEL (SOLUTION=90, SORT=ABSD) = 20
```

Compute Panel Participation Factors for Pressure at Grid Point 11217 for excitation frequencies 25Hz, 30Hz and 35Hz

THE PFGRID COMMAND

$$\text{PFGRID} \left(\left[\begin{array}{c} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right], \left[\begin{array}{c} \text{REAL or IMAG} \\ \text{PHASE} \end{array} \right], \left[\text{GRIDS} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setg} \end{array} \right\} \right], \right. \\ \left. \left[\text{SOLUTION} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setf} \\ \text{NONE} \end{array} \right\} \right] \right) = \left\{ \begin{array}{c} \text{setdof} \\ \text{NONE} \end{array} \right\}$$

PFGRID COMMAND: RESPONSE SELECTION

PFGRID([PRINT, PUNCH
PLOT] , [REAL or IMAG
PHASE] , [GRIDS = { ALL
setg }] ,

[SOLUTION = { ALL
setf
NONE }]) = { setdof
NONE }

Select set with excitation
frequencies

Select set with response
degrees of freedom

PFGRID COMMAND: GRID POINT SELECTION

$$\text{PFGRID} \left(\begin{array}{c} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right), \left[\begin{array}{c} \text{REAL or IMAG} \\ \text{PHASE} \end{array} \right], \left[\text{GRIDS} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setg} \end{array} \right\} \right], \\ \left[\text{SOLUTION} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setf} \\ \text{NONE} \end{array} \right\} \right] = \left\{ \begin{array}{c} \text{setdof} \\ \text{NONE} \end{array} \right\}$$

Select set of Grid Points
or all Grid Points

PFGRID COMMAND: OUTPUT FORMAT

$$\text{PFGRID} \left(\left[\begin{array}{c} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right], \left[\begin{array}{c} \text{REAL or IMAG} \\ \text{PHASE} \end{array} \right], \left[\text{GRIDS} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setg} \end{array} \right\} \right], \right. \\ \left. \left[\text{SOLUTION} = \left\{ \begin{array}{c} \text{ALL} \\ \text{setf} \\ \text{NONE} \end{array} \right\} \right] \right) = \left\{ \begin{array}{c} \text{setdof} \\ \text{NONE} \end{array} \right\}$$

Output Format: Real/Imaginary Part or
Magnitude/Phase of Normalized Grid
Participation Factors

PFGRID COMMAND: EXAMPLE

```
SET 20 = 11217  
SET 90 = 25., 30., 35.  
PFGRID (PLOT, SOLUTION=90) = 20
```

Compute Grid Participation Factors for Pressure at Grid Point 11217 for excitation frequencies 25Hz, 30Hz and 35Hz

PANEL DEFINITION

- **Panels can be defined using grid point sets, element sets or property sets.**
- **Grid point sets are defined using SET1 or SET3 bulk data entries.**
- **Element and property sets are defined using SET3 bulk data entries:**
 - Descriptor "ELEM" indicates an element set.
 - Descriptor "PROP" indicates a property set.

PANEL DEFINITION: EXAMPLE

```
SET3, 120, ELEM, 104, THRU 110  
SET3, 130, PROP, 1, 2  
PANEL, PANEL1, 120, PANEL2, 130
```

Panel PANEL1 consists of elements 104 to 110.

Panel PANEL2 consists of all elements with property identifier 1 or 2.

OUTPUT FORMAT

- **The printed output of mode and panel participation factors is similar to the printed output obtained with the MCFRACTION command used in the Modal Frequency Response, Modal Transient Response, & Modal Complex Response**
- **The printed output of grid participation factors is similar to the output of displacements.**

OUTPUT FORMAT

- **The printed output of mode and panel participation factors is similar to the printed output obtained with the MCFRACTION command**
 - Excessive file size is easily obtained
- **The printed output of grid participation factors is similar to the output of displacements**

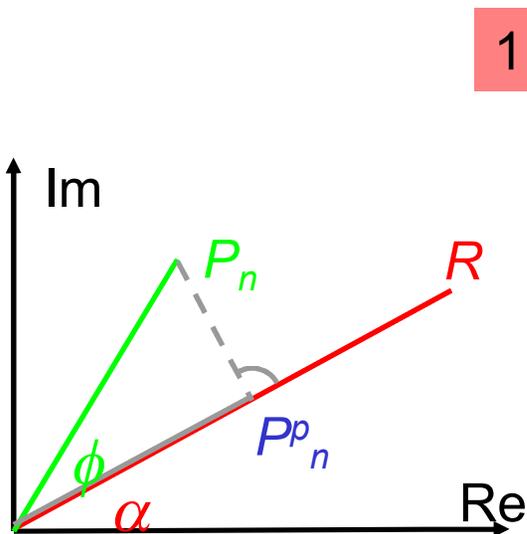
MODE PARTICIPATION FACTOR OUTPUT

```

AC OUSTIC STRUCTURE MODAL PARTICIPATION FACTORS

GRID POINT = 11217, TOTAL RESPONSE (R/I) = -1.48382E-01 / 4.54827E-02, (M/P) = 1.55196E-01 / 162.96
LOAD FREQUENCY = 3.70248E+01, (SUBCASE 1, DLOAD = 200)
MAXIMUM MODAL RESP = 1.49945E-01 FOR MODE ID = 7, SORTKEY = FRACTION, SORT = ABS VALUE DESCENDING, FILTER = 1.00000E-03
  
```

MODE ID	NATURAL FREQ (HZ)	MODAL RESPONSE		MODAL RESPONSE		PROJECTION		REL. PHASE	MODAL FRACTION	SCALED RESPONSE MAGNITUDE
		REAL	IMAGINARY	MAGNITUDE	PHASE	MAGNITUDE	PHASE			
7	3.72109E+01	-1.39853E-01	5.40776E-02	1.49945E-01	158.86	1.49561E-01	-4.10	9.63689E-01	9.97442E-01	
3	4.39822E-05	-2.32498E-02	1.01341E-04	2.32501E-02	179.75	2.22587E-02	16.79	1.43423E-01	1.48446E-01	
15	8.55370E+01	1.32441E-02	-1.87084E-03	1.33756E-02	351.96	-1.32108E-02	189.00	-8.51234E-02	-8.81048E-02	
14	8.21214E+01	1.01071E-02	-3.14886E-03	1.05863E-02	342.70	-1.05861E-02	179.74	-6.82113E-02	-7.06004E-02	
5	8.39858E-05	-6.39700E-03	2.32039E-05	6.39704E-03	179.79	6.12292E-03	16.83	3.94528E-02	4.08346E-02	
9	6.72277E+01	-5.58743E-03	-1.82762E-03	5.87874E-03	198.11	4.80649E-03	35.15	3.09704E-02	3.20551E-02	
18	1.06001E+02	2.36007E-03	-3.72660E-04	2.38931E-03	351.03	-2.36566E-03	188.07	-1.52430E-02	-1.57769E-02	
4	4.77127E-05	2.07077E-03	3.64267E-06	2.07077E-03	0.10	-1.97878E-03	-162.86	-1.27502E-02	-1.31967E-02	



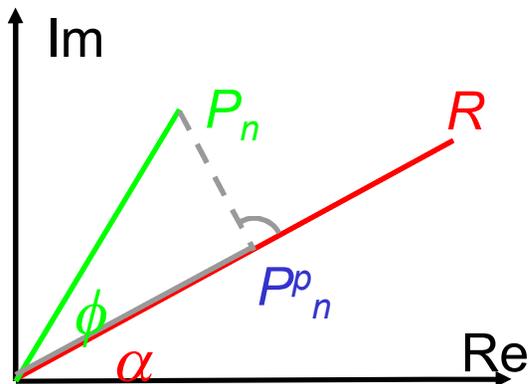
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8

1	Real Part of P_n	5	P_n^p
2	Imag. Part of P_n	6	ϕ
3	Magnitude of P_n	7	$P_n^p / R $
4	Phase of P_n	8	$P_n^p / \max P_n $

PANEL PARTICIPATION FACTOR OUTPUT

ACOUSTIC PANEL PARTICIPATION FACTORS									
GRID POINT =	11217,	TOTAL RESPONSE (R/I) =		-1.48382E-01 /	4.54827E-02,	(M/P) =	1.55196E-01 /	162.96	
		LOAD FREQUENCY =		3.70248E+01,	(SUBCASE	1, DLOAD =	200)		
MAXIMUM PANEL RESP =	1.60744E-01	FOR PANEL =		REAR	, SORTKEY =	FRACTION, SORT =	ABS VALUE DESCENDING,	FILTER = 1.00000E-03	
PANEL NAME	PANEL RESPONSE		PANEL RESPONSE		PROJECTION		REL.	PANEL SCALED RESPONSE	
	REAL	IMAGINARY	MAGNITUDE	PHASE	MAGNITUDE	PHASE		FRACTION	MAGNITUDE
REAR	-1.52091E-01	5.20276E-02	1.60744E-01	161.12	1.60661E-01	-1.84	1.03521E+00	9.99482E-01	
BOTTOM	-1.28920E-01	5.65755E-05	1.28920E-01	179.97	1.23276E-01	17.02	7.94325E-01	7.66911E-01	
TOP	6.44526E-02	3.64824E-04	6.44536E-02	0.32	-6.15157E-02	-162.63	-3.96374E-01	-3.82694E-01	
FRONT	4.43994E-02	7.87691E-03	4.50927E-02	10.06	-4.01415E-02	-152.90	-2.58649E-01	-2.49723E-01	
RIGHT	1.47896E-02	-6.90789E-03	1.63234E-02	334.96	-1.61647E-02	172.01	-1.04157E-01	-1.00562E-01	
LEFT	1.47889E-02	-6.90798E-03	1.63228E-02	334.96	-1.61641E-02	172.00	-1.04152E-01	-1.00558E-01	

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8



1	Real Part of P_n	5	P_n^p
2	Imag. Part of P_n	6	ϕ
3	Magnitude of P_n	7	$P_n^p / R $
4	Phase of P_n	8	$P_n^p / \max P_n $

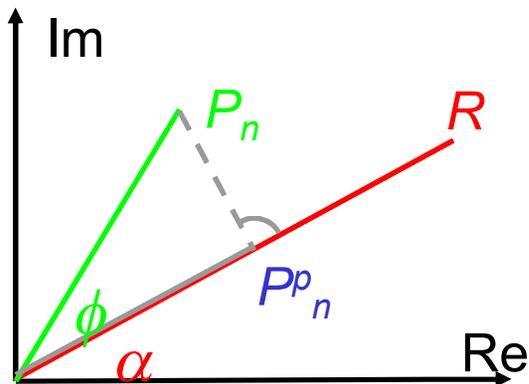
GRID PARTICIPATION FACTOR OUTPUT

```

0
FREQUENCY = 3.707886E+01, FLUID GRID POINT = 11217
NORMALIZED GRID PARTICIPATION FACTORS
(REAL/IMAGINARY)

```

	POINT ID.	TYPE	T1	T2	T3	R1	R2	R3
0	1	G	-1.227388E-03	-7.835577E-06	3.192602E-03	5.298424E-08	-1.137150E-06	3.031731E-08
			-1.937030E-04	-3.449941E-07	9.830291E-04	-6.015977E-09	-4.666158E-07	8.107695E-09
0	2	G	-2.451404E-03	-4.157740E-16	6.398413E-03	6.321835E-15	-3.375352E-06	-2.460994E-15
			-3.867402E-04	-3.576813E-17	1.967880E-03	-1.602187E-15	-1.208831E-06	-4.439928E-16
0	3	G	-2.449937E-03	8.598291E-24	6.398364E-03	-1.616146E-15	-4.257703E-06	-3.839641E-17
			-3.863729E-04	9.147064E-25	1.968658E-03	-7.198935E-17	-1.431066E-06	-3.576531E-17
0	4	G	-2.449655E-03	-4.416014E-27	6.399379E-03	-2.594894E-19	-4.581274E-06	-2.391980E-19
			-3.862857E-04	-1.795742E-27	1.968798E-03	-8.923359E-20	-1.512403E-06	-7.294159E-20
0	5	G	-2.449939E-03	6.102095E-24	6.398367E-03	-1.101957E-15	-4.257703E-06	-8.464838E-17
			-3.863735E-04	6.598512E-25	1.968659E-03	-4.933439E-17	-1.431066E-06	-7.821964E-17
0	6	G	-2.451408E-03	6.493559E-21	6.398419E-03	7.010387E-15	-3.375352E-06	-2.926491E-15
			-3.867414E-04	5.486240E-22	1.967883E-03	-1.774349E-15	-1.208831E-06	-5.279344E-16
0	7	G	-1.227391E-03	-7.844055E-06	3.192607E-03	5.298349E-08	-1.137149E-06	3.027685E-08
			-1.937039E-04	-3.484462E-07	9.830308E-04	-6.016375E-09	-4.666160E-07	8.095050E-09



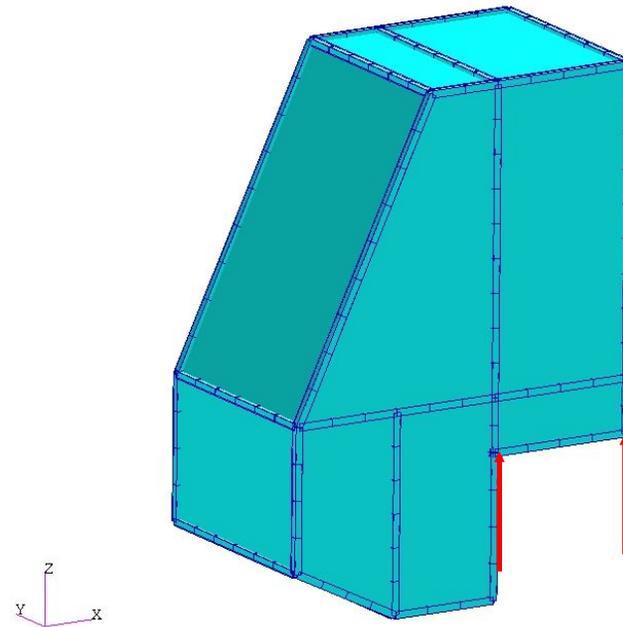
Values printed are P_n / R where P_n is the pressure at fluid grid point 11217 due to an acceleration at the corresponding degree of freedom.

INTERPRETING GRID PARTICIPATION FACTORS

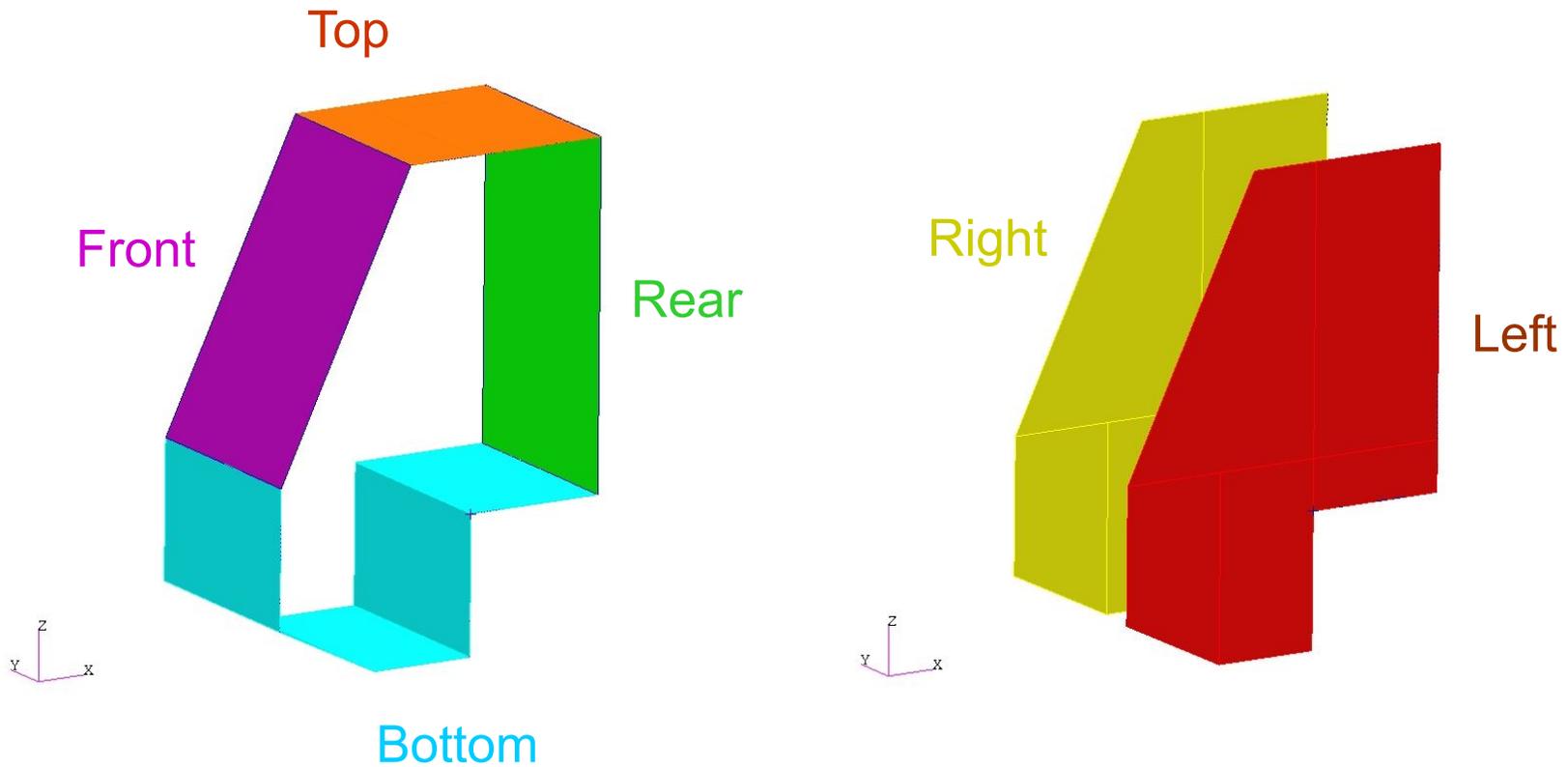
- **Fringe plots of grid participation factors allow to qualitatively identify the regions that make the largest contribution**
- **The values depend on the mesh size. The finer the mesh, the smaller the value**

EXAMPLE: PROBLEM DESCRIPTION

- **Cabin is excited by four forces at the corners of the seat.**
- **Result of interest is the pressure at the driver's ear.**
- **Frequency response shows that 37Hz is a critical frequency.**



EXAMPLE: PANEL DEFINITION



EXAMPLE: INPUT DECK

```
$ Participation Factor Test Problem: Cabin
$
$ Coupled Modal Frequency Response Analysis
$
$ Participation Factor Example - Cabin
$
$ Illustrates use of
$   o Acoustic Fluid Modal Participation Factors
$   o Acoustic Struct. Modal Part. Factors
$   o Acoustic Panel Part. Factors
$
$ =====
$
SOL 111
DIAG 8
CEND
$
ECHO=SORT (EXCEPT ,CBEAM ,CQUAD4 ,CHEXA ,CPENTA ,GRID)
AUTOSPC (NOZERO) = YES
$
METHOD (STRUCTURE) =1
METHOD (FLUID)      =2
$
FREQ  = 100
DLOAD = 200
$
```

**Highly recommended to ALWAYS
separately define METHODS for
FLUID and STRUCTURE**

EXAMPLE: INPUT DECK (CONT.)

```
SET 1 = 11217
SET 20 = 11217
SET 90 = 37.
$
DISP(PHAS) = 1
$
PFMODE(FLUID, STRUCTMP=ALL, FLUIDMP=ALL,
        SOLUTION=90, SORT=ABSD) = 20
PFPANEL(SOLUTION=90, SORT=ABSD) = 20
$
OUTPUT(XYPLOT)
  XPAPER=29.
  YPAPER=21.
  XGRID=YES
  YGRID=YES
  XTITLE = Frequency
  YTITLE = Pressure
  XYPLOT DISP RESPONSE / 11217(T1)
$
BEGIN BULK
$
$ Request OP2 for PATRAN
PARAM, POST, -1
$
$ Define Structural Damping
PARAM, G, 0.02
$
```

EXAMPLE: INPUT DECK (CONT.)

```
$ Define Fluid Damping
PARAM, GFL, 0.002
$
$ Define Reference Pressure for dB (in Pa)
PARAM, PREFDB, 2.8284-5
$
PARAM, GRDPNT, 0          $ Request Weight Output
$
$ Structural and Acoustic Modes up to 300Hz
EIGRL, 1,,300.
EIGRL, 2,,300.
$
$ Frequency Range: 25Hz to 100Hz by Steps of 5Hz
FREQ1, 100, 25., 5., 15
$ Additional Frequencies around Resonance Frequencies
FREQ4, 100, 25., 100., 0.01, 5
$
$ Excitation Forces
RLOAD1, 200, 210,,, 220
DAREA, 210, 1, 3, 1., 7, 3, 1.
DAREA, 210, 29, 3, 1., 35, 3, 1.
TABLED1, 220          , 0., 1., 1000., 1., ENDT
$
```

EXAMPLE: INPUT DECK (CONT.)

```
$ Nonmatching Fluid-Structure Interface
ACMODL, DIFF
$
$ Include Structural and Acoustic Model
INCLUDE 'cabin_structure.bdf'
INCLUDE 'cabin_fluid.bdf'
$
$ Panels
$
SET3, 101, ELEM, 127, THRU, 162, 667, THRU, 738
SET3, 201, ELEM, 37, THRU, 72, 739, THRU, 810
SET3, 301, ELEM, 331, THRU, 384
SET3, 401, ELEM, 25, THRU, 36, 73, THRU, 126
SET3, 501, ELEM, 271, THRU, 294, 601, THRU, 612
SET3, 601, ELEM, 1, THRU, 24, 455, THRU, 478,
, 497, THRU, 562
$
PANEL, LEFT, 101, RIGHT, 201, FRONT, 301, REAR, 401
PANEL, TOP, 501, BOTTOM, 601
$
ENDDATA
```

EXAMPLE: RESULTS

```
ACOUSTIC STRUCTURE MODAL PARTICIPATION FACTORS
GRID POINT = 11217, TOTAL RESPONSE (R/I) = -1.48382E-01 / 4.54827E-02, (M/P) = 1.55196E-01 / 162.96
LOAD FREQUENCY = 3.70248E+01 (SUBCASE 1, DLOAD = 200)
MAXIMUM MODAL RESP = 1.49945E-01 FOR MODE ID = 7, SORTKEY = FRACTION, SORT = ABS VALUE DESCENDING, FILTER = 1.00000E-03
```

MODE ID	NATURAL FREQ (HZ)	MODAL RESPONSE		MODAL RESPONSE		PROJECTION MAGNITUDE	REL. PHASE	MODAL FRACTION	SCALED RESPONSE MAGNITUDE
		REAL	IMAGINARY	MAGNITUDE	PHASE				
7	3.72109E+01	1.39853E-01	5.40776E-02	1.49945E-01	158.86	1.49561E-01	-4.10	9.63689E-01	9.97442E-01
3	4.39822E-05	2.32498E-02	1.01341E-04	2.32501E-02	179.75	2.22587E-02	16.79	1.43423E-01	1.48446E-01
15	8.55370E+01	1.32441E-02	-1.87084E-03	1.33756E-02	351.96	-1.32108E-02	189.00	-8.51234E-02	-8.81048E-02
14	8.21214E+01	1.01071E-02	-3.14886E-03	1.05863E-02	342.70	-1.05861E-02	179.74	-6.82113E-02	-7.06004E-02
5	8.39858E-05	6.39700E-03	2.32039E-05	6.39704E-03	179.79	6.12292E-03	16.83	3.94528E-02	4.08346E-02
9	6.72277E+01	5.58743E-03	-1.82762E-03	5.87874E-03	198.11	4.80649E-03	35.15	3.09704E-02	3.20551E-02
18	1.06001E+02	2.36007E-03	-3.72660E-04	2.38931E-03	351.03	-2.36566E-03	188.07	-1.52430E-02	-1.57769E-02
4	4.77127E-05	2.07077E-03	3.64267E-06	2.07077E-03	0.10	-1.97878E-03	-162.86	-1.27502E-02	-1.31967E-02

- **Structural Mode #7 is responsible for the peak:**
 - Modal fraction is close to 1.
 - Relative phase is close to 0.
 - Natural frequency is close to excitation frequency.

EXAMPLE: RESULTS (CONT.)

ACOUSTIC PANEL PARTICIPATION FACTORS								
GRID POINT =	11217,	TOTAL RESPONSE (R/I) =		-1.48382E-01 /	4.54827E-02,	(M/P) =	1.55196E-01 /	162.96
		LOAD FREQUENCY =		3.70248E+01,	(SUBCASE	1,	DLOAD =	200)
MAXIMUM PANEL RESP =	1.60744E-01	FOR PANEL =		REAR	,	SORTKEY =	FRACTION,	SORT = ABS VALUE DESCENDING, FILTER = 1.00000E-03
PANEL NAME	PANEL RESPONSE		PANEL RESPONSE		PROJECTION	REL.	PANEL	SCALED RESPONSE
	REAL	IMAGINARY	MAGNITUDE	PHASE	MAGNITUDE	PHASE	FRACTION	MAGNITUDE
REAR	-1.52091E-01	5.20276E-02	1.60744E-01	161.12	1.60661E-01	-1.84	1.03521E+00	9.99482E-01
BOTTOM	-1.28920E-01	5.65755E-05	1.28920E-01	179.97	1.23276E-01	17.02	7.94325E-01	7.66911E-01
TOP	6.44526E-02	3.64824E-04	6.44536E-02	0.32	-6.15157E-02	-162.63	-3.96374E-01	-3.82694E-01
FRONT	4.43994E-02	7.87691E-03	4.50927E-02	10.06	-4.01415E-02	-152.90	-2.58649E-01	-2.49723E-01
RIGHT	1.47896E-02	-6.90789E-03	1.63234E-02	334.96	-1.61647E-02	172.01	-1.04157E-01	-1.00562E-01
LEFT	1.47889E-02	-6.90798E-03	1.63228E-02	334.96	-1.61641E-02	172.00	-1.04152E-01	-1.00558E-01

- **Largest contribution is from panel REAR.**
- **Contribution from panels REAR and BOTTOM is in phase with response.**
- **Contribution of remaining panels is out of phase with response.**



WORKSHOP 4

ACOUSTIC PARTICIPATION FACTORS



SECTION 4

Acoustic Absorbers & Barriers

WHAT ARE ACOUSTIC ABSORBERS OR BARRIERS?

- **Absorbers**

- Material that absorbs sound pressure level. The acoustic wave is not transmitted through the absorber material

- **Barriers**

- Reduce sound transmission.
- Transmission loss per ASTM
 - $TL = 20 \log (P_i/P_t)$
 - P_i and P_t are the incident and transmitted pressures

WHY DO WE NEED ACOUSTIC ABSORBERS OR BARRIERS?

- **Why not use structure elements with damping?**
 - Some materials absorb acoustic energy, but is not designed for structural purposes.
- **Some examples of absorbers**
 - Car seats
 - Car interior trim
 - Ski cabin Interior trim
 - Foam
 - etc.
- **Some examples of barriers**
 - Engine fire wall in a car
 - Interior walls in the house
 - etc.

ACOUSTIC ABSORBERS AND BARRIERS

- **MSC Nastran has 4 different types of absorber/barrier elements**
 - Solid acoustic absorber
 - CHACAB
 - Frequency-dependent surface acoustic absorber
 - CAABSF
 - Frequency-dependent rigid porous absorber
 - PSOLID (FCTN=FFLUID)
 - Solid acoustic barrier
 - CHACBR

ACOUSTIC ABSORBERS AND BARRIERS

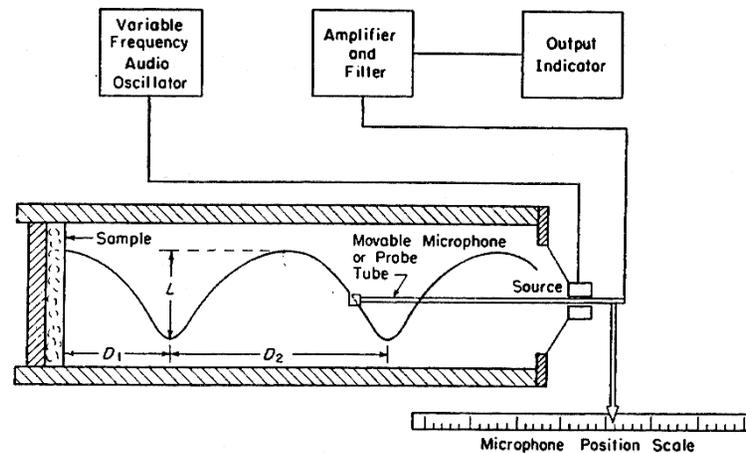
- **CHACAB**
 - Hexahedral element
 - Faces separated by $> \text{NORMAL}$ (see ACMODL entry)
 - Converted to an equivalent mass/spring/damper system
- **CAABSF**
 - Shell element attached to fluid boundary (can reduced down to line and point)
 - Massless absorber
 - Resistance and reactance specified as frequency-dependent tables
- **Rigid Porous Absorber**
 - Triggered by $\text{FCTN}=\text{FFLUID}$ on PSOLID entry
- **CHACBR**
 - Hexahedral element
 - “sandwich” construction
 - 2 masses separated by spring
 - “tuned barrier”

SOUND ABSORPTION

- **Industry tests to determine absorption material properties:**
 - Impedance and Absorption of Acoustic Materials by the Tube Method.
 - Transmissibility
- **MSC NASTRAN elements that approximate the above:**
 - Absorbers
 - CHACAB, hexagonal acoustic absorber
 - CAABSF, frequency dependent acoustic absorber
 - Barriers
 - CHACBR, hexagonal acoustic barrier
 - Fluid damping
 - SDAMPING(FLUID)
 - PARAMs GFL, W3FL, W4FL, and KDAMP
 - MAT10, GE field

ACOUSTIC ABSORPTION

- Measured Using ASTM Standards Part 14, "Impedance and Absorption of Acoustic Materials by the Tube Method", ASTM Designation C 384-58, pp. 134.
- The schematic of the test apparatus is shown below:



- Calculates specific acoustic impedance (z):

$$z = r + ix$$

where:

r = specific normal acoustic resistance

x = specific normal acoustic reactance

ACOUSTIC ABSORPTION (CONT.)

- Resistance (r) and reactance (x) are calculated from the test results as follows:

$$z / \rho c = \coth(A + iB)$$

where:

A = $\coth^{-1} [\log_{10}^{-1} (L/20)]$

B = $\pi(1/2 - D_1/D_2)$

L = Difference in decibels between the maximum and minimum sound pressure levels in the standing wave pattern

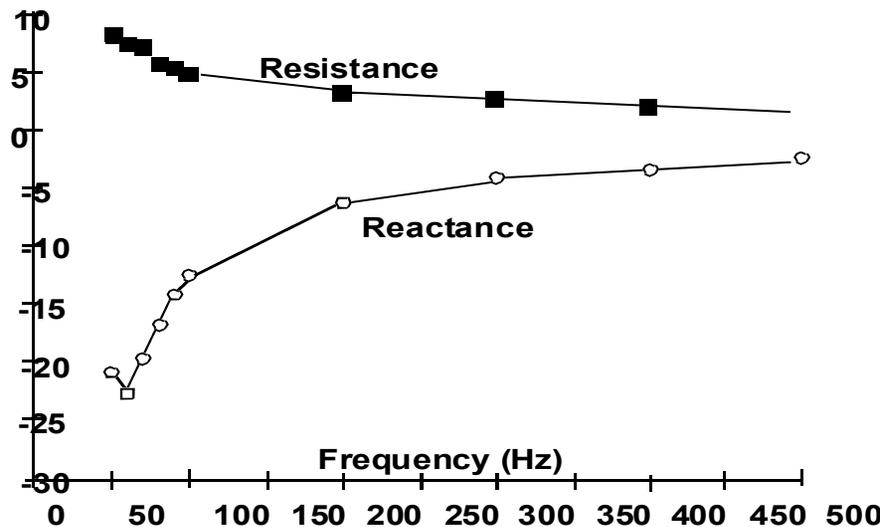
D₁ = Distance to the nearest minimum

D₂ = Distance from the first minimum to the second

**ρc = characteristic acoustic impedance of free air,
= 41.5 cgs units.**

ACOUSTIC ABSORPTION (CONT.)

- The figure below shows an example of resistance and reactance curves. These curves are for instructional purposes only, not for use in actual analyses.



- To properly check how close you are matching the absorbing qualities of your material using MSC NASTRAN elements, model the standing wave tube and calculate your acoustic impedance from MSC NASTRAN results.

MSC NASTRAN CHACAB ACOUSTIC ABSORBER

- **8 to 16 structural grids**
- **Two surfaces at least a distance of NORMAL apart (see ACMODL)**
- **Points to PACABS**
 - Points to 3 TABLEDi entries which contain the following functions of frequency:
 - Resistance
 - Reactance
 - Weighting value

CHACAB

ACOUSTIC ABSORBER ELEMENT CONNECTION

Defines the acoustic absorber element in coupled fluid-structural analysis.

Format:

1	2	3	4	5	6	7	8	9	10
CHACAB	EID	PID	G1	G2	G3	G4	G5	G6	
	G7	G8	G9	G10	G11	G12			
			G17	G18	G19	G20			

Example:

CHACAB	95	12	1	2	5	7	8	9	
	24	23							

Field	Contents
EID	Element identification number. (0 < Integer < 100,000,000)
PID	Property identification number of a PACABS entry. (Integer > 0)
Gi	Grid point identification numbers of connection points. (Integer ≥ 0 or blank)

Remarks:

1. Element identification numbers should be unique with respect to all other element identification numbers.
2. Grid points G1 through G4 must be given in consecutive order about one quadrilateral face. G5 through G8 must be on the opposite face with G5 opposite G1, G6 opposite G2, etc.
3. The edge points, G9 to G20, are optional. Any or all of them may be deleted. If the ID of any edge connection point is left blank or set to zero (as for G9 and G10 in the example), the equations of the element are adjusted to give correct results for the reduced number of connections. Corner grid points cannot be deleted.
4. The second continuation is optional.
5. It is recommended that the edge points be located within the middle third of the edge.
6. The face consisting of grid points G1 through G4 and G9 through G12 is assumed to be in contact with the structure.

PACABS

ACOUSTIC ABSORBER PROPERTY

PACABS Acoustic Absorber Property

Defines the properties of the acoustic absorber element.

Format:

1	2	3	4	5	6	7	8	9	10
PACABS	PID	SYNTH	TID1	TID2	TID3		CUTFR	B	
	K	M							

Example:

PACABS	12		1	2	3	3.5	500.0		
--------	----	--	---	---	---	-----	-------	--	--

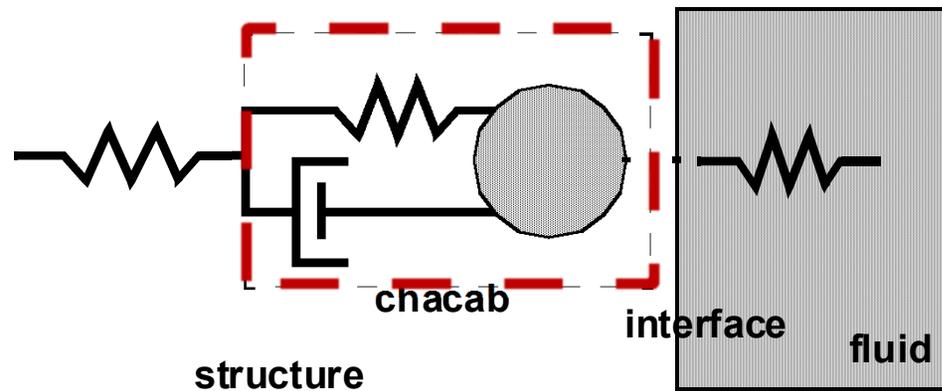
Field	Contents
PID	Property identification number. (Integer > 0)
SYNTH	Request the calculation of B, K, and M from the tables TIDi below. (Character = "YES" or "NO"; Default = "YES")
TID1	Identification of the TABLEDi entry that defines the resistance. See Remark 2. (Integer > 0 or blank)
TID2	Identification of the TABLEDi entry that defines the reactance. See Remark 2. (Integer > 0 or blank)
TID3	Identification of the TABLEDi entry that defines the weighting function. See Remark 2. (Integer > 0 or blank)
CUTFR	Cutoff frequency for tables referenced above. (Real > 0.0)
B, K, M	Equivalent damping, stiffness and mass values per unit area. (Real ≥ 0.0)

Remarks:

1. PACABS is referenced by a CHACAB entry only.
2. If SYNTH = "YES", then TID1 and TID2 must be supplied (TID3 is optional) and the equivalent structural model will be derived from tables TIDi. If TID3 is blank, then the weighting function defaults to 1.0.
3. If SYNTH = "NO", then the equivalent structural model will be derived from one of B, K, or M.
4. The continuation entry is optional.
5. All data defined in tables TIDi must be a function of frequency in cycles/unit time.

CHACAB (CONT.)

- MSC NASTRAN changes the tabular information into a single mass (M) in conjunction with a spring (K) and damper (C) in parallel.



- **C = Average of resistance table values**
- **K and M are calculated as a least squares fit to the reactance table curve using the following equations:** $M\omega - K / \omega$
- **From equation for structural impedance** $z = B + i(\omega M - K/\omega)$

CHACAB (CONT.)

which results in

$$M = \frac{\sum \omega_i^{-2} W_i \sum \omega_i W_i X_i - \sum W_i \sum \omega_i^{-1} W_i X_i}{\sum \omega_i^2 W_i \sum \omega_i^{-2} W_i - (\sum W_i)^2}$$

$$K = \frac{\sum \omega_i^2 W_i \sum \omega_i^{-1} W_i X_i + \sum W_i \sum \omega_i W_i X_i}{\sum \omega_i^2 W_i \sum \omega_i^{-2} W_i - (\sum W_i)^2}$$

where:

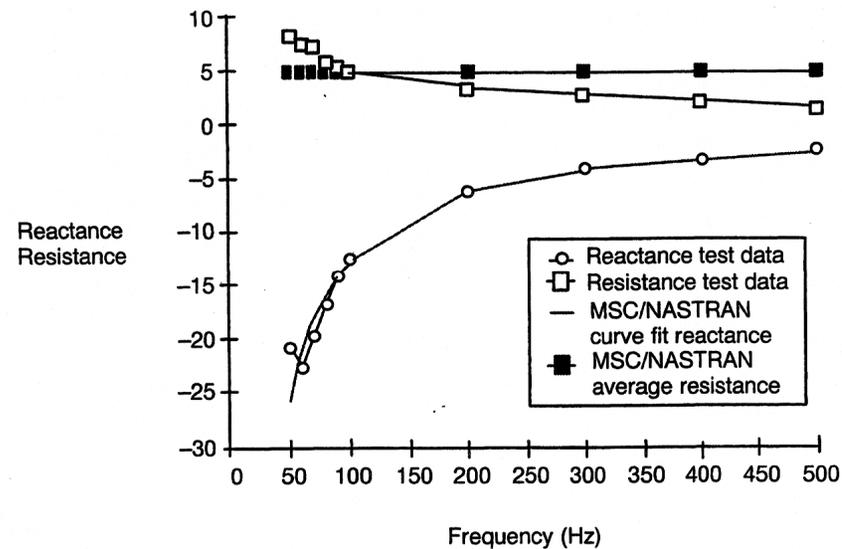
W_i = weighting table value

X_i = reactance table value

ω_i = frequency (rad/sec)

CHACAB (CONT.)

- Example of how CHACAB element fits test data.
- This may vary and must be checked.
- Adjust weighting factor to match test data for reactance



- Only CHEXA is supported.

LIMITATIONS OF THE CHACAB

- **The CHACAB and CHACBR elements are structural elements and all faces must be connect to structural points.**
- **The face on the fluid side should connect to structural grids that have all degrees of freedom constrained (SPC, SPC1) except the DOF that is normal to the fluid.**
- **These grids should coincide with the fluid grids but be separate from them. If the fluid side of the element attaches directly to fluid points a bad solution will result with no warning. This can happen when both the CHACAB or CHACBR element and the fluid points are in the residual.**
- **Residual vectors due to damping should be turned off to avoid large number of residual vectors**
 - RESVEC(NODAMP)=BOTH



WORKSHOP 5

INTERIOR ACOUSTICS WITH ABSORBERS

MODELLING OF ABSORPTION

- **Plane Absorbers can be used if the thickness of the absorbing layer is small compared to the wave length**
 - Locally Reacting Normal Impedance

PLANE ABSORBERS (CONT)

- **Locally Reacting Normal Impedance Boundary Condition is obtained by :**

$$P = Z(\omega)V_n$$

- **The real part of the impedance is called **Resistance**.**
- **The imaginary part of the impedance is called **Reactance**.**
- **Usually this is a good approximation to describe absorbing surfaces.**

ABSORBED ENERGY

- **Acoustic energy flowing through the absorbing surface per area within one period T :**

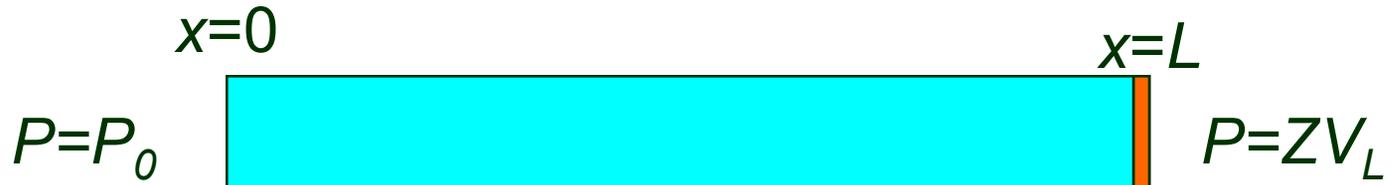
$$W_{abs} = \int_0^T p v_n dt = \int_0^T \Re[P \exp(i\omega t)] \Re[V_n \exp(i\omega t)] dt = \frac{T}{2} \Re(P V_n^*)$$

- **With Impedance Boundary Condition:**

$$W_{abs} = \frac{T}{2} \Re(Z) |V_n|^2$$

- **Absorption is governed by the Resistance only**

IMPEDANCE TUBE



$$P(x) = P_0 \frac{\exp(-ikx) + R \cdot \exp(ik(x - 2L))}{1 + R \cdot \exp(-2ikL)}$$

Reflection Coefficient: $R = P_{\text{reflected}} / P_{\text{incident}} \quad \text{at } x = L$

Wave Number: $k = \omega / c$

IMPEDANCE TUBE (CONT.)

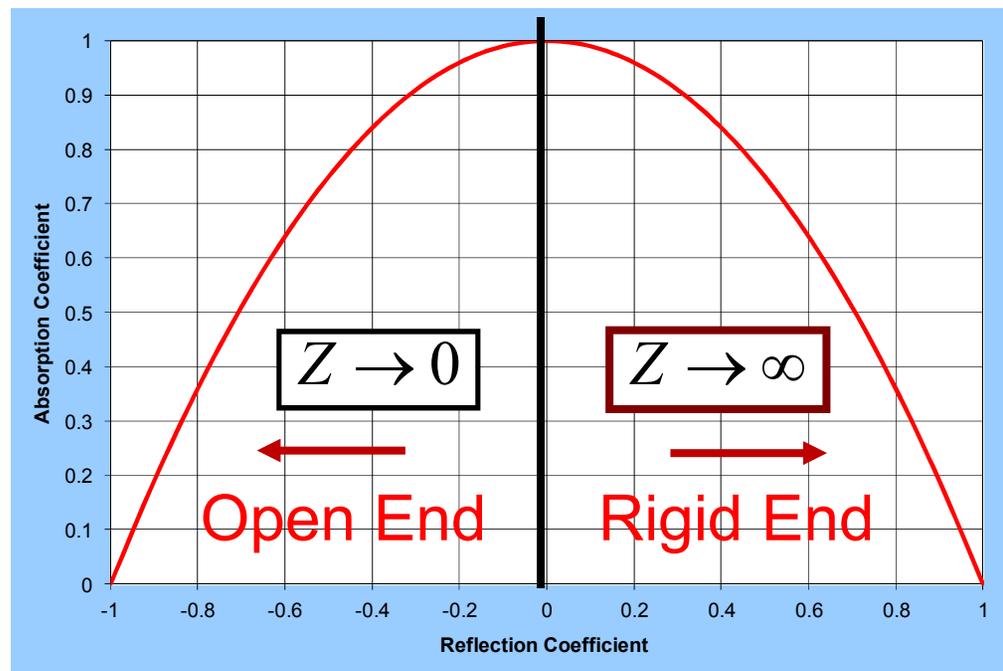
- **At $x=L$:**
$$P(L) = ZV_L \Rightarrow R = \frac{(Z/\rho_0c) - 1}{(Z/\rho_0c) + 1}$$
- **Open End:**
$$Z = 0 \Rightarrow R = -1, P(L) = 0$$
- **Complete Absorption:**
$$Z = \rho_0c \Rightarrow R = 0$$
- **Rigid End:**
$$Z \rightarrow \infty \Rightarrow R \rightarrow 1, V_L \rightarrow 0$$

ABSORPTION COEFFICIENT

- **Definition:**

$$\alpha = \frac{W_{incident} - W_{reflected}}{W_{incident}} = 1 - |R|^2$$

- **Interpretation:**



DISCRETE EQUATION WITH ABSORPTION

- **Direct Frequency Response Analysis:**

$$\left(-\omega^2 \mathbf{Q} + i\omega \mathbf{A} + \mathbf{H}\right) \mathbf{P}(\omega) = i\omega \mathbf{G}(\omega)$$

- Inverse Mass Matrix \mathbf{H} may have frequency dependent contributions from reactance (plane absorbers)
- Admittance Matrix \mathbf{A} has frequency dependent contributions from resistance (plane absorbers)

DISCRETE EQ. WITH ABSORPTION (CONT.)

- **Modal Frequency Response Analysis:**

The substitution $\mathbf{P}(\omega) = \sum_n \varphi_{fn} X_{fn}(\omega) = \Phi_f \mathbf{X}_f(\omega)$

- **gives**

$$(-\omega^2 \hat{\mathbf{Q}} + i\omega \hat{\mathbf{A}} + \hat{\mathbf{H}}) \mathbf{X}_f(\omega) = i\omega \hat{\mathbf{G}}$$

where

$$\begin{aligned} \hat{\mathbf{Q}} &= \Phi_f^t \mathbf{Q} \Phi_f, & \hat{\mathbf{A}} &= \Phi_f^t \mathbf{A} \Phi_f \\ \hat{\mathbf{H}} &= \Phi_f^t \mathbf{H} \Phi_f, & \hat{\mathbf{G}} &= \Phi_f^t \mathbf{G} \end{aligned}$$

PAABSF BULK DATA ENTRY

- **Properties:**

1	2	3	4	5	6	7	8	9
PAABSF	PID	TZREID	TZIMID	S	A	B	K	RHOC

- PID Property Identification Number that matches the PID of the corresponding CAABSF entry
- TZREID Identification Number of a TABLEDi entry that defines the resistance as a function of frequency
- TZIMID Identification Number of a TABLEDi entry that defines the reactance as a function of frequency
- S Impedance Scale Factor (Default = 1.0)
- A Area Factor when less than 3 grids are specified on the CAABSF entry (Default = 1.0)
- B Frequency independent resistance
- K Frequency independent reactance coefficient
- RHOC Constant used to compute absorption coefficient ($=\rho c$)

PAABSF BULK DATA ENTRY (CONT.)

- **Remarks:**

- The resistance used is given by

$$Z_R(f) = (S/A)[TZREID(f) + B]$$

- The reactance used is given by

$$Z_I(f) = (S/A)[TZIMID(f) - K/(2\pi f)]$$

- The absorption coefficient is computed from

$$\alpha = \frac{4(Z_R/\rho c)}{(Z_R/\rho c + 1)^2 + (Z_I/\rho c)^2}$$

- Output of the resistance, reactance and the absorption coefficient is activated by the **STRESS** Case Control command.

CAABSF EXAMPLE

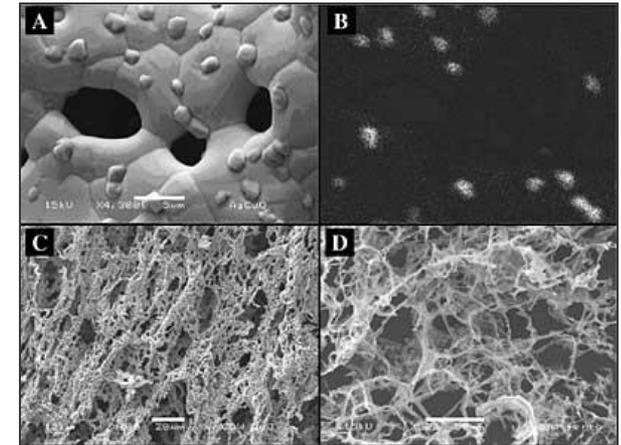
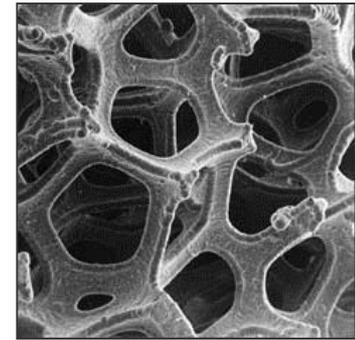
- **Example:**

	1	2	3	4	5	6	7	8	9
CAABSF		101	1000	1	2	3	4		
\$	PID	TZREID	TZIMID	S	A	B	K	RHOC	
PAABSF		1000	1101						411.4
\$	TABLED1	1101							
	0.	4000.	1000.	3500.	ENDT				

- The resistance linearly decreases from $4000 Pa/(m/s)$ at $0 Hz$ to $3500 Pa/(m/s)$ at $1000 Hz$

RIGID POROUS ABSORBER

- **Porous material**
 - Not completely solid
 - Containing voids or air pockets
- **Porosity is the general parameter that defines the degree of openness of the material**
- **The tortuosity coefficient measures the complexity of the path an air particle must follow to proceed from one point to another**
 - In a fluid, the particle follows a straight path, in a porous media, it needs to follow a tortuous path around the solid frame
- **If the porous material is enclosed in a frame which is considered as rigid we talk about rigid porous absorber**



HOW IS IT MODELED?

- **A porous material enclosed in a frame is considered as rigid**
- **It occurs if, for example, one of the following behaviors is present:**
 - ✓ high skeleton density
 - ✓ very large elastic modulus
 - ✓ weak fluid structure coupling
- **In this condition the porous material can be considered as an equivalent fluid with both density and bulk modulus being complex frequency dependent parameters**
- **Documentation**
 - MD Nastran R2 release guide

EQUIVALENT FLUID APPROACH

- In the equivalent fluid approach, the equation of motion reads

$$\frac{1}{\rho_e} \nabla^2 P + \frac{\omega^2}{B_e} P = 0$$

where ρ_e is the equivalent density, B_e the equivalent bulk modulus, P the complex pressure amplitude and ω the circular excitation frequency.

- It can be shown that

$$\frac{1}{\rho_e} = \frac{1}{\rho} (1 + iGE) \quad \text{and} \quad \frac{1}{B_e} = \frac{1}{B} - i \frac{A}{\omega} = \left(1 - \frac{i\alpha}{\omega} \right)$$

Here, ρ , B and GE are the values of RHO, BULK and GE respectively of the MAT10 entry for the porous absorber material while α is the normalized admittance coefficient for which a new input field has been created in it

1	2	3	4	5	6	7	8	9	10
MAT10	MID	BULK	RHO	C	GE	ALPHA			

NORMALIZED ADMITTANCE COEFFICIENT

- The equivalent fluid approach leads to an element damping matrix (**C**) that is proportional to the mass matrix (**M**)

$$C_e(\omega) = \alpha(\omega) M_e$$

- The coefficient of proportionality is the normalized admittance coefficient α that is a function of the excitation frequency
- **The rigid porous absorber properties are described by complex parameters (density and bulk modulus)**
 - In general, MSC Nastran doesn't support complex material properties
 - Following relationships are used in calculating the equivalent fluid properties and entered on the MAT10 entry

- Mass density $\rho_{porous} = \rho_r + i\rho_i \Rightarrow \rho = \frac{\rho_r^2 + \rho_i^2}{\rho_r}$

- Bulk modulus $B_{porous} = B_r + iB_i \Rightarrow B = \frac{B_r^2 + B_i^2}{B_r}$

- Structural damping $GE = -\rho_i / \rho_r$

- **The normalized admittance coefficient α is calculated as** $\alpha = \omega \frac{B_i}{B_r} = 2\pi f \frac{B_i}{B_r}$

RIGID POROUS ABSORBERS

- **Normalized admittance coefficient must be defined on the MAT10 entry using a unit circular excitation frequency ($\omega=1$)**
 - MSC Nastran will internally calculate the value at each excitation frequency, using the current circular excitation frequency as scaling factor.

$$\alpha_{(\omega=1)} = 1 \cdot \frac{B_i}{B_r} = \frac{B_i}{B_r} \quad \Rightarrow \quad \alpha_{(\omega=\bar{\omega})} = \bar{\omega} \cdot \frac{B_i}{B_r} = \bar{\omega} \cdot \alpha_{(\omega=1)} = (2\pi \bar{f}) \cdot \alpha_{(\omega=1)}$$

- It allows calculating the new rigid porous absorber damping matrix (C) for each excitation frequency loop

$$C_e(\bar{\omega}) = \alpha(\bar{\omega}) \cdot M_e$$

- **No additional table is required to define the frequency-dependency nature of the rigid porous absorber**

RIGID POROUS ABSORBERS - USER INPUT

- Bulk Data entries **PSOLID** and **MAT10** are affected by this implementation

- PSOLID entry

- New option FFLUID for the 8th field (FCNT) of the PSOLID card

1	2	3	4	5	6	7	8	9	10
PSOLID	PID	MID	CORDM	IN	STRESS	ISOP	FCTN		

FCNT Fluid element flag. (Character):

- “FFLUID” indicates a frequency dependent rigid porous absorber
- “PFLUID” indicates a standard fluid element or a frequency independent rigid porous absorber
- “SMECH” indicates a structural element

Default = “SMECH.”

- MAT10 entry

- No modification has been done in the format of this card and no new options have been added.
- The only remark that has to be done is relative to the meaning of the 7th field in case of frequency dependent rigid porous absorber.
 - if the MAT10 card is referenced in a PSOLID card where FFLUID option is selected, the value in the 7th field (ALPHA) is considered as the normalized admittance coefficient calculated at unit circular excitation frequency ($\omega = 1$);
 - if the MAT10 card is referenced in a PSOLID card where PFLUID option is selected, the value defined in the 7th field (ALPHA) has no special meaning but it is only the normalized admittance coefficient calculated at the most appropriate excitation frequency (defined in order to have good results in the range of interest)

EXAMPLE – RIGID POROUS MATERIAL DEFINITION

- Given the following example properties

Material	Density (ρ)	Speed of Sound (C)	Bulk Modulus (B)
Porous Absorber	3.8663+14.2204i	92.7076+70.2854i	-171190+102356i

$$\rho_{porous} = \rho_r + i\rho_i \Rightarrow \rho = \frac{\rho_r^2 + \rho_i^2}{\rho_r} \qquad B_{porous} = B_r + iB_i \Rightarrow B = \frac{B_r^2 + B_i^2}{B_r}$$

- The corresponding PSOLID and MAT10 entries would look like

PSOLID	PID	MID	CORDM	IN	STRESS	ISOP	FCTN
PSOLID	10	20					FFLUID

MAT10	MID	BULK	RHO	C	GE	ALPHA
MAT10	20	-232390	56.1695		-3.678	-0.5979

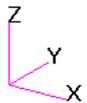
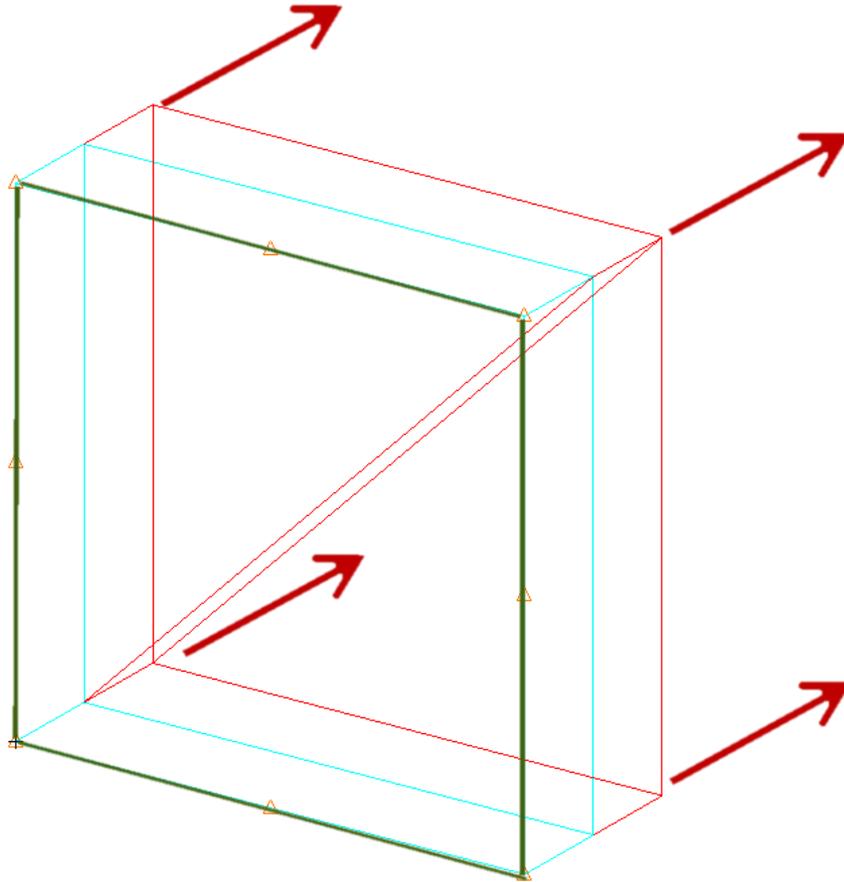
- Note that for rigid porous material, these values may be negative

RIGID POROUS MATERIAL - EXAMPLE

- **Example**

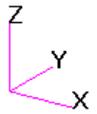
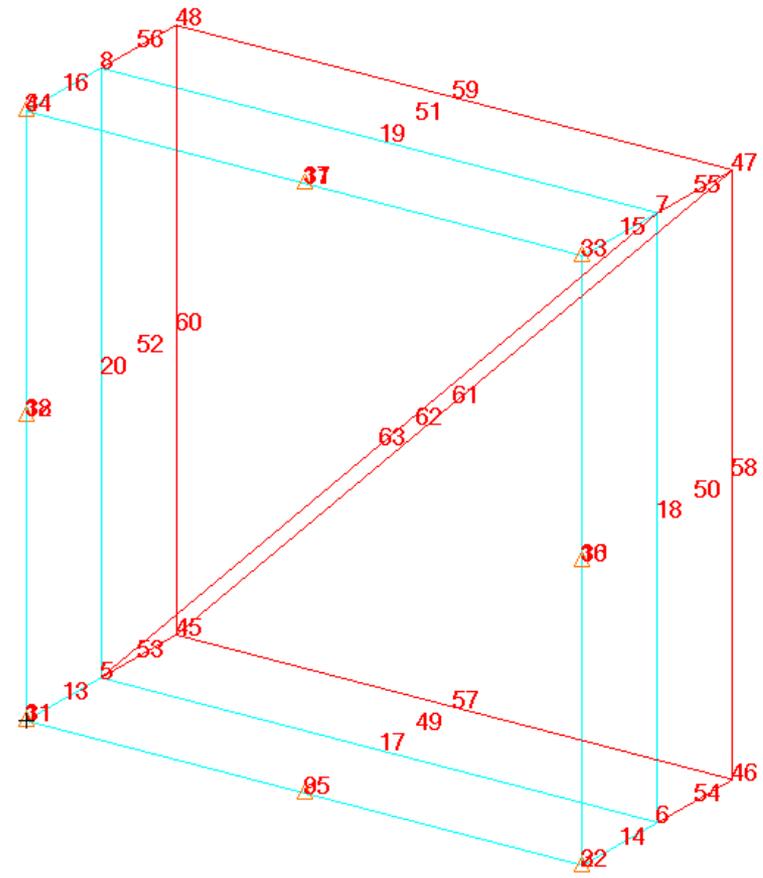
- This example contains:

- Fluid elements
- Rigid Porous Absorber
- Structural QUAD8
- CELASs



RIGID POROUS MATERIAL - EXAMPLE

All Grids IDs

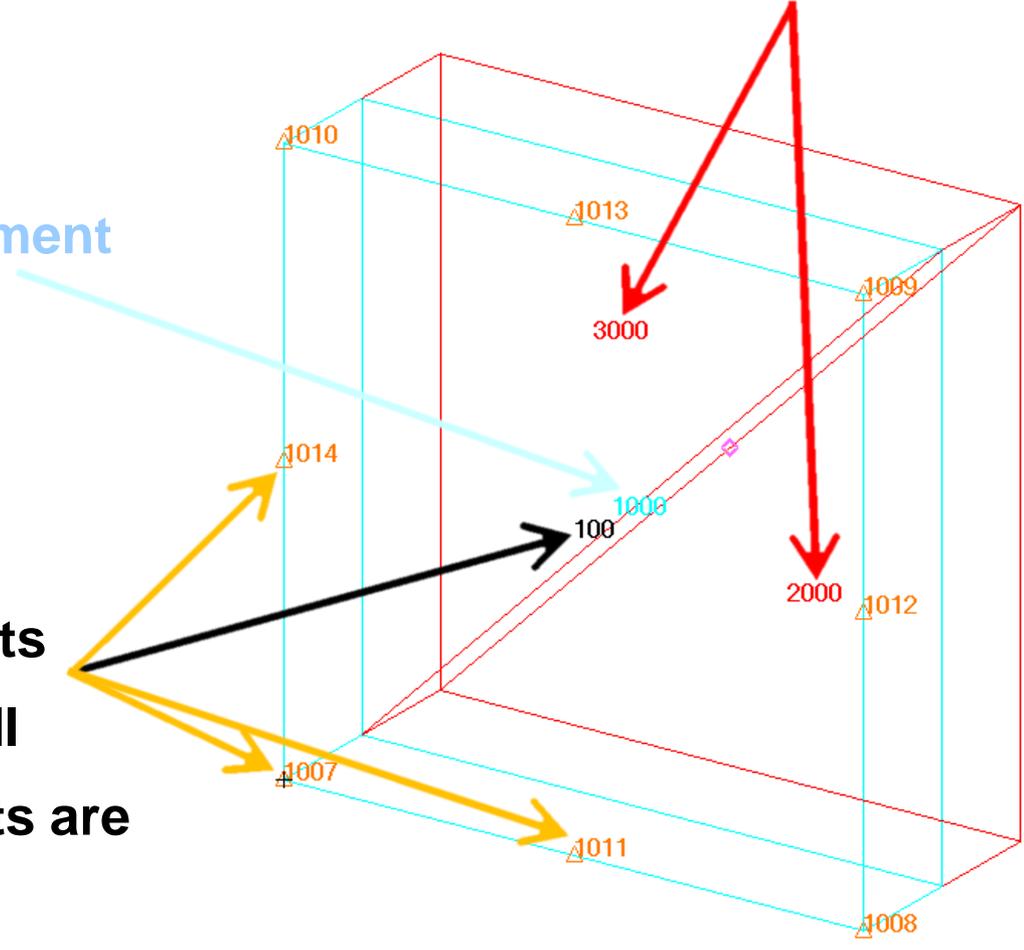


RIGID POROUS MATERIAL - EXAMPLE

All Element IDs

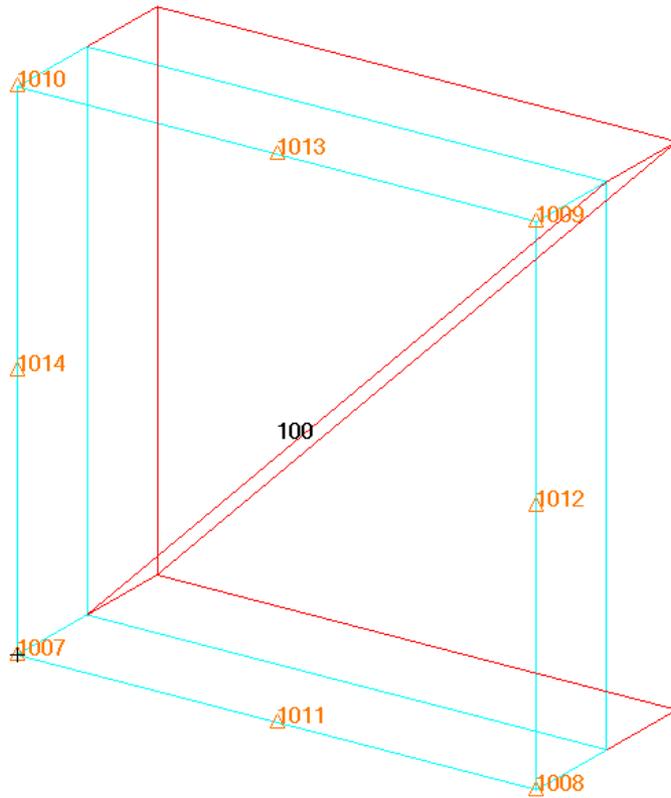
- **Rigid Porous Element**
 - GE = 0.02
 - Alpha = 0.5
- **Structure Elements**
(For clarity, not all structure elements are highlighted)

Fluid Elements

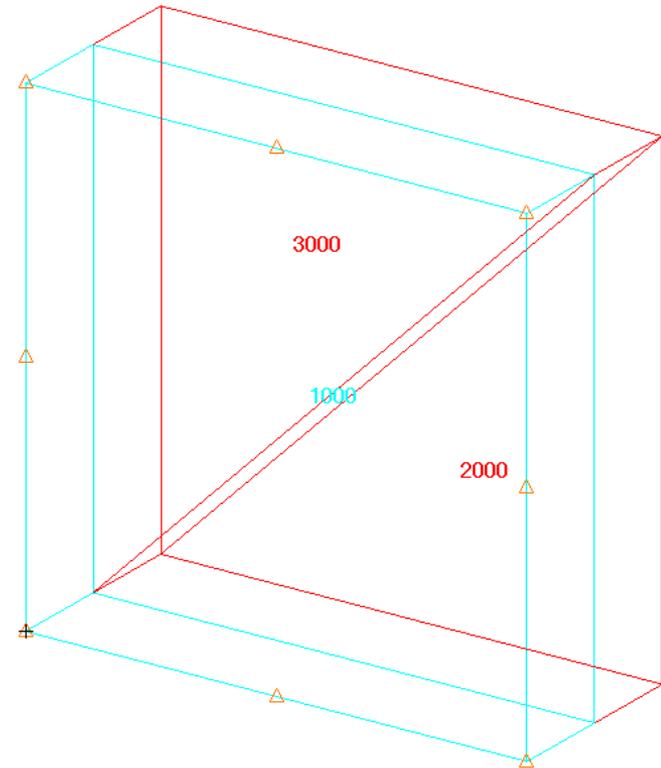


RIGID POROUS MATERIAL - EXAMPLE

- **Structural Element IDs**



- **Acoustics Element IDs**



SAMPLE INPUT – RIGID ABSORBER

```
SOL 111 $ MODAL frequency response
$
CEND
$ dynamic load
TITLE= POROUS ELEMENT TEST.
SUBTITLE= HEXA 20 POROUS ELEMENT ON THE STRUCTURE PANEL
DLOAD=100
FREQ=200
PARAM, PREFDB,1.0
PARAM,ACOUT,RMS
$
oload(phase)=all
DISP(phase)=ALL
force(phase)=all
SPC =1313
METHOD(struct)=30
METHOD(fluid)=20
.
Begin Bulk
$
EIGRL   30      -0.001      50
EIGRL   20      -0.001      20
```

SAMPLE INPUT – RIGID ABSORBER (CONT.)

```

acsrce 100      101              1001  1.    1.
sload  101      45      15625.
sload  101      46      15625.
sload  101      47      15625.
sload  101      48      15625.
$ the load is (2*pi)^2 *f^2 so when Q is calculated it becomes a constant
$ for all frequencies
TABLED4 1001  0.0    1.0    0.0    1.E6
         0.0    0.0    39.478420.0  ENDT
$ FREQUENCY RANGE
FREQ 200  0.1      1.      2.      3.      4.
$THE STRUCTURAL POINTS (AT PLANE Y=0)
GRID   31              0.0    0.0    0.0
.
GRID   38              0.0    0.0    0.5
$
$THE STRUCTURAL ELEMENTS
CQUAD8,100,4444,31,32,33,34,35,36,+
+,37,38
$ STRUCTURAL PROPERTIES
PSHELL 4444  77      .05      77      1.0
MAT1   77      100.      .333    1.000
$
$ FLUID POINTS
GRID   1              0.0    0.0    0.0    -1
.
GRID   63              0.5    0.2    0.5    -1
$

```



Acoustic Source

SAMPLE INPUT – RIGID ABSORBER (CONT.)

```
$ FLUID ELEMENTS
CHEXA,1000,15,1,2,3,4,5,6,+
+,7,8,9,10,11,12,13,14,+
+,15,16,17,18,19,20
CPENTA,2000,25,5,6,7,45,46,47,+
+,17,18,63,53,54,55,57,58,+
+,61
CPENTA,3000,35,5,7,8,45,47,48,+
+,63,19,20,53,55,56,61,59,+
+,60
$ FLUID PROPERTIES
$-----
$ This element is referring to a material card where
$ porocity is defined
PSOLID 15      25      1      PFLUID
$-----
PSOLID 25      35      1      PFLUID
PSOLID 35      45      1      PFLUID
MAT10  25      1.      0.1    .02    0.5
MAT10  35      1.      0.1    .10
MAT10  45      1.      0.1    .20
$
```

GE

Alpha, Normalized
admittance coefficient

- Note that the rest of the input file is similar to what we have covered previously

SAMPLE INPUT – RIGID ABSORBER (CONT.)

```
.  
.
$
CELAS2 1007 .0625 31 2
CELAS2 1008 .0625 32 2
CELAS2 1009 .0625 33 2
CELAS2 1010 .0625 34 2
CELAS2 1011 .0625 35 2
CELAS2 1012 .0625 36 2
CELAS2 1013 .0625 37 2
CELAS2 1014 .0625 38 2
$
$ SPC ALL THE STRUCTRUAL POINTS NOT TO ROTATE ABOUT X OR Z
SPC1 1313 1346 31 THRU 38
$ SPC THE END STRUCT. POINTS NOT TO ROATE ABOUT Y (STATED IN THE PROBLEM)
SPC1,1313,5,31,32,33,34,35,36,+
+,37,38
$
ENDDATA
```



SECTION 5

POROELASTIC MATERIAL (PEM)

INTRODUCTION

- **In Section 4, we talked about rigid porous material**
- **This section we discuss porous material that can also be elastic**
- **Vibroacoustics with poroelastic trim components involves multi-physics in terms of the solid-fluid interaction on a microscopic level**
- **Poroelastic materials are widely used in the automotive NVH applications for noise suppression**
- **Some of the poroelastic trim material technology in Actran are implemented in MSC Nastran 2013**
- **Goal is to include trimmed material in a car body**
 - Supports SOL 111 and MFREQ for SOL 200 (as a analysis model, not as a design model)
- **Examples of some trim material applications include**
 - Carpet and lining in a car or airplane floor
 - Dashboard
 - Roof lining
 - etc.

SOME COMMON TERMINOLOGY USED WITH TRIM MATERIAL

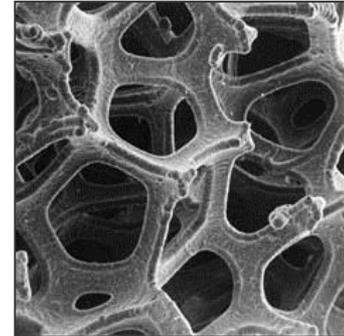
- **Following pages define some of the commonly used constants in defining the trim material**
- **VISC (μ) – fluid dynamic viscosity**
 - It's a measure of resistance due to friction of fluid moving at different velocities
- **GAMMA ($\gamma = \frac{C_p}{C_v}$)**
 - Fluid ratio of specific heat
where C_p is the specific heat at constant pressure
 C_v is the specific heat at constant volume
- **PRANDTL (PR)**
 - Fluid Prandtl number
 - $PR = \mu \frac{C_p}{k}$
where k is thermal conductivity

SOME COMMON TERMINOLOGY USED WITH TRIM MATERIAL (CONT.)

- **Porosity (Ω , POR)**

$$\Omega = \frac{V_f}{V_t} = 1 - \frac{V_s}{V_t}$$

where V_f = volume of fluid
 V_s = volume of solid
 V_t = total volume



- **Tortuosity (α_∞ , TOR)**

- Measures the complexity of the path an air particle must follow to proceed from one point to another



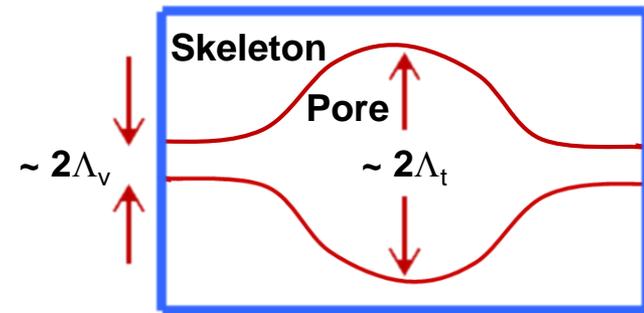
SOME COMMON TERMINOLOGY USED WITH TRIM MATERIAL (CONT.)

- **Resistivity (R , AFR)**

- Resistant encounters by the fluid as it flow through a porous material. This is related to the viscous interaction forces between the fluid and the solid skeleton

- **Viscous Length (Λ_v , VLE)**

- Average macroscopic radius of pores as related to the viscous loss
- For characterizing frequency-dependency of flow resistivity
- Can be evaluated by a Kundt tube measurement (see MSC Nastran 2013 Release Guide for a Kundt tube example)



- **Thermal Length (Λ_t , TLE)**

- Average macroscopic radius of pores as related to the thermal loss
- For characterizing frequency-dependency of bulk modulus
- Can be evaluated by adsorption measurement

- **Biot Number**

- Coupling coefficient between the solid skeleton and the fluid and is equal to 1 for most materials

MODELING TECHNIQUE

- **Two basic ways of modeling trim material**

1. Taped-Over

- Trim component overlap portion of structure and fluid model
- Commonly used with existing fluid/structure model
 - Reduce the requirement of modifying existing fluid/structure mode
- TRMC model may encroach on both the structure and fluid cavity space.
 - Coupling can be handled with the proper tolerance specifications on the ACMODL entry
- Good if TRMCs thickness is much smaller than the dimension of the cavity

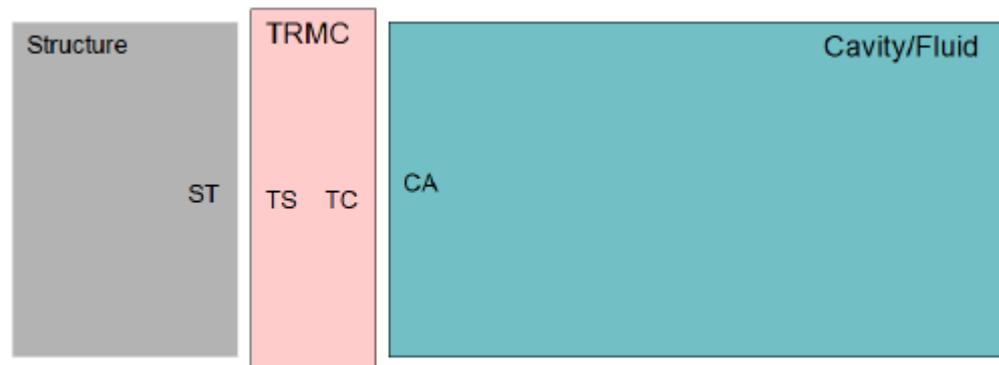


MODELING TECHNIQUE (CONT.)

- **Two basic ways of modeling trim material (cont.)**

- 2. Wedged-In

- Trim component model placed in-between structure and fluid model
 - TRMC model must fit in the space between the structure and cavity
 - Use when fluid/structure model does not exist
 - Recommended method if the thickness of the TRMC is the same order of magnitude as the dimension of the cavity
 - If separation of the structure and fluid is significant, tolerances on the ACMODL may need to increase if TRMC is removed



BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL

- In MSC Nastran, poroelastic material is modeled with solid elements (CHEXA, CTETRA, & CPENTA)
 - Both linear and quadratic elements are supported
- New MATPE1 is used to define the poroelastic material properties
 - Multi-physics materials that invoke MAT1 and MAT10
 - MAT1 For the solid/skeleton phase
 - MAT10 For the fluid phase

1	2	3	4	5	6	7	8	9	10
MATPE1	MID	MAT1	MAT10	BIOT					
	VISC	GAMMA	PRANDTL	POR	TOR	AFR	VLE	TLE	

See previous pages for definitions for the TRIM parameters

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- A new option (**PORO**) is added to the FCNT field (field 8) on the **PSOLID** entry for the poroelastic property
 - The MID on this entry must call out a MATPE1 entry when the PORO option is invoked on the PSOLID entry

PSOLID	PID	MID	CORDM	IN	STRESS	ISOP	FCTN	COROT	
1	2	3	4	5	6	7	8	9	10
MATPE1	MID	MAT1	MAT10	BIOT					
	VISC	GAMMA	PRANDTL	POR	TOR	AFR	VLE	TLE	

- **Example**

- These trim values used in example 1

PSOLID	5	15		TWO		FULL	PORO		
MATPE1	15	16	17						
	1.84-8	1.4	.713	.95	1.4	2.5-5	9.32-2	9.32-2	

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- **Example (cont.)**

1	2	3	4	5	6	7	8	9	10
MATPE1	MID	MAT1	MAT10	BIOT					
	VISC	GAMMA	PRANDTL	POR	TOR	AFR	VLE	TLE	

MATPE1	15	16	17						
	1.84-8	1.4	.713	.95	1.4	2.5-5	9.32-2	9.32-2	

MAT1	16	42.		0.0	6.0-7			.05	
------	----	-----	--	-----	-------	--	--	-----	--

Solid skeleton

MAT10	17		1.21-9	342300.	.01				
-------	----	--	--------	---------	-----	--	--	--	--

Fluid

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- All the trim material specifications are defined in a separate bulk data section separated by the following delimiter (similar to the external acoustics capability)

BEGIN BULK TRMC = x

- Trim components are activated by the TRIMGRP Case Control Command calling out the appropriate TRMC Bulk Data Sections

TRIMGRP = $\left(\begin{array}{c} \text{sid} \\ \text{ALL} \\ \text{NONE} \end{array} \right)$

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- An ACPEMCP entry is required to specify the trim component interface coupling and constraints definition
 - One ACPEMCP entry for each trim component

1	2	3	4	5	6	7	8	9	10
ACPEMCP	TID	SGLUED	SSLIDE	SOPEN	SIMPER				
	SCUX	SCUY	SCUZ	SCRX	SCRY	SCRZ	SCFP		

- Four coupling options are available

SGLUED Identifies the grid points (on the SET1/SET3 entry) of the solid-phase (and/or structure elements) in the trim component which are glued to the structure

SSLIDE Identifies the grid points (on the SET1/SET3 entry) of the solid-phase (and/or structure elements) in the trim component which can slide on the structure

These two are coupling with the structure

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- **Four coupling options are available (cont.)**

SOPEN Identifies the grid points (on the SET1/SET3 entry) of the fluid-phase elements in the trim component which has an open interface with the cavities

SIMPER Identifies the grid points (on the SET1/SET3 entry) of the solid-phase (and/or structure volume elements) in the trim component which has an impervious interface with the cavities

These two are coupling with the fluid

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

- **Seven Constraints Options**

SCUX	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in translational X direction in the CD field
SCUY	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in translational Y direction in the CD field
SCUZ	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in translational Z direction in the CD field
SCRX	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in rotational X direction in the CD field

BASIC REQUIREMENTS FOR DEFINING TRIM MATERIAL (CONT.)

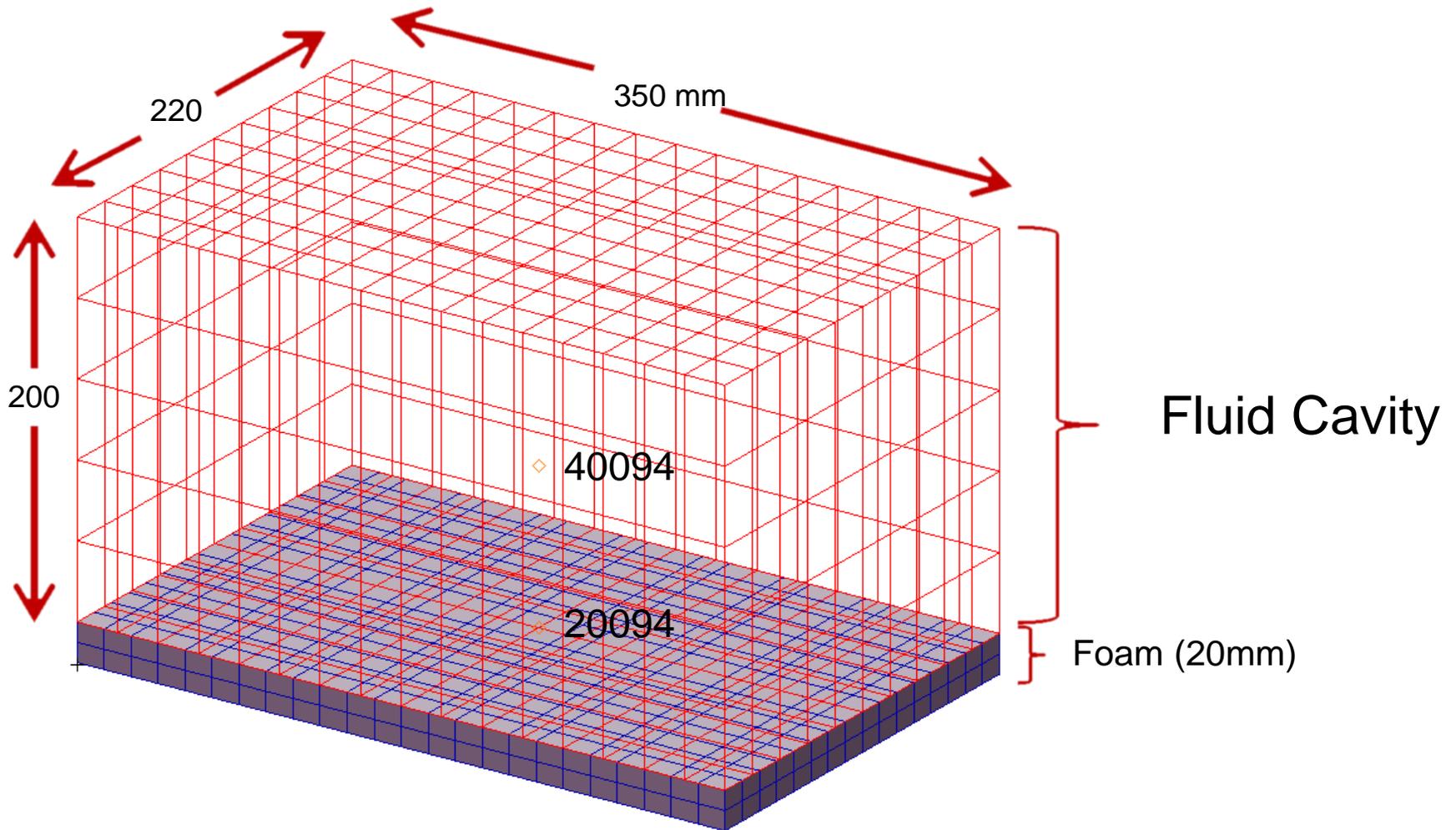
- **Seven Constraints Options (cont.)**

SCRY	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in rotational Y direction in the CD field
SCRZ	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in rotational Z direction in the CD field
SCFP	ID of SET1/SET3 with which grid IDs in the trim component TID has zero constrained in fluid pressure

The first 6 are for structure, and the last one is for fluid

EXAMPLE 1

- **Fluid Cavity Coupled with a Foam Layer**



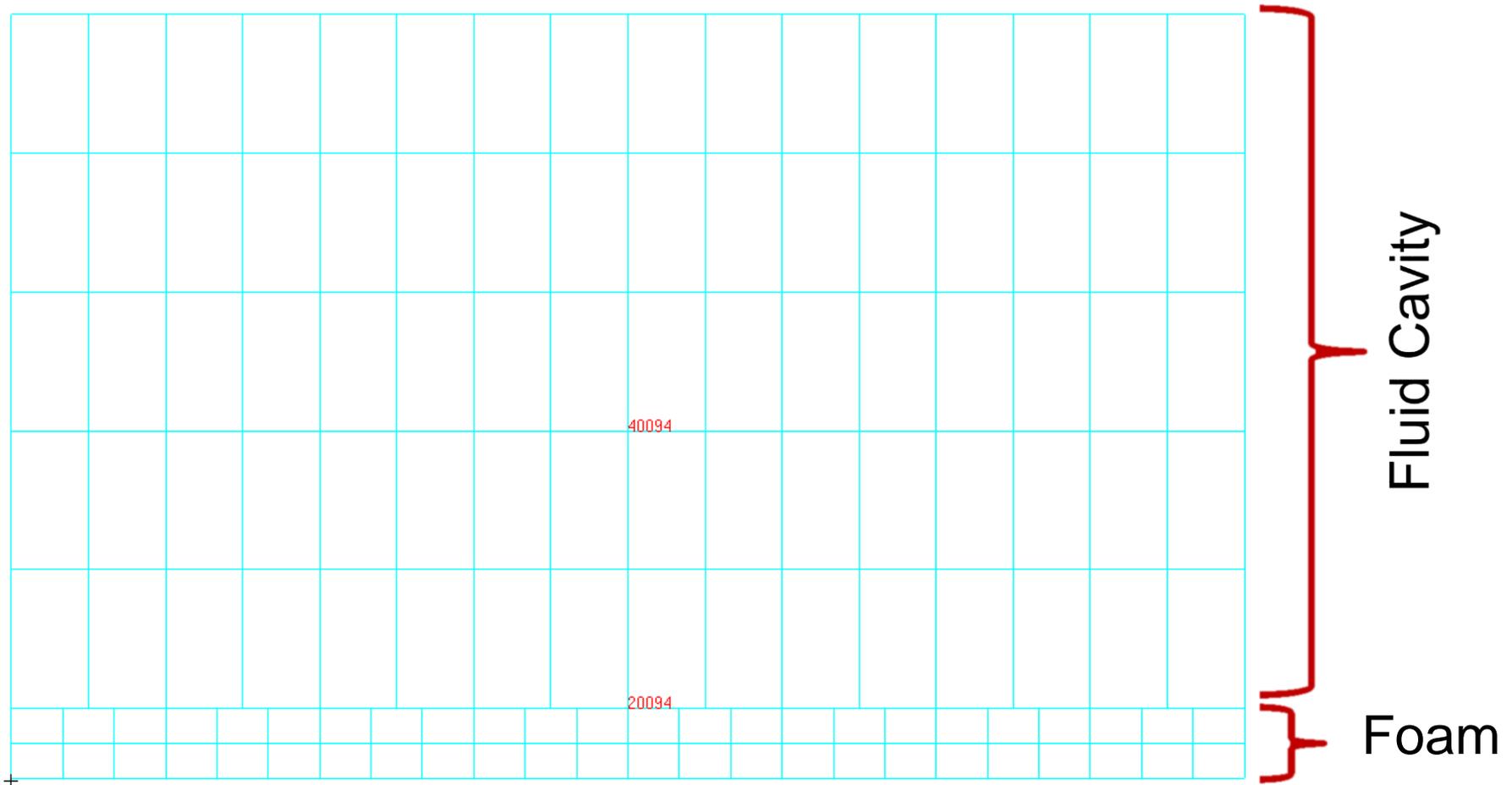
EXAMPLE 1 (CONT.)

- **Unit load applied at grid 20094**
- **Interested in acoustic pressure at grid 40094**
- **Model contains the following trim properties**

Properties	Value
Dynamic Viscosity (μ)	1.84E-8
Gamma (γ)	1.4
Prandtl Number (PR)	0.713
Porosity (Ω , POR)	0.95
Tortuosity (α_{∞} , TOR)	1.40
Resistivity (R , AFR)	2.5E-5
Viscous Length (Λ_v , VLE)	9.32E-2 mm
Thermal Length (Λ_t , TLE)	9.32E-2 mm

EXAMPLE 1 (CONT.)

- **Fluid Cavity Coupled with a Foam Layer**

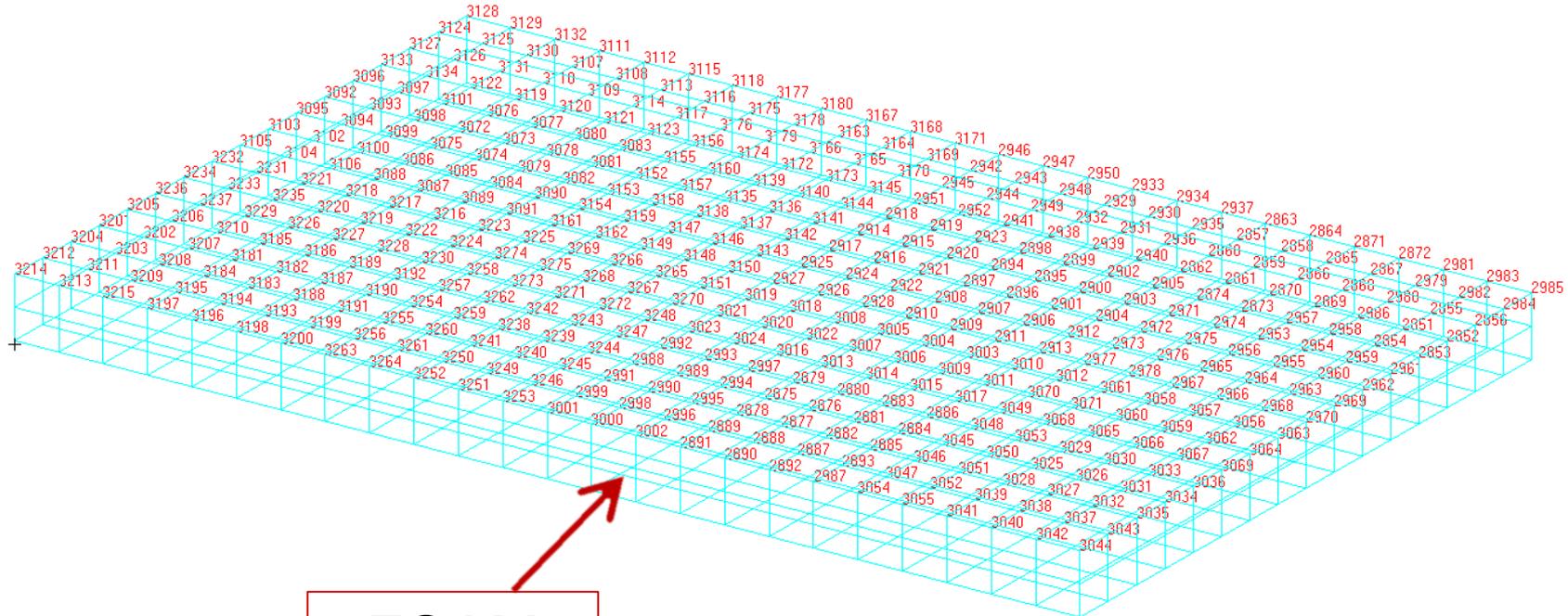


EXAMPLE 1 (CONT.)

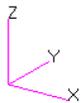
- **Interface Grids**

- Defines by an SET1 or SET3 entry in the BEGIN BULK TRMC section

SET1 104 2851 THRU 3275



FOAM



INPUT FILE

```

$
$ pemt4.dat
$
SOL 111
DIAG 8,15,56
$
CEND
$
TITLE = FOAM (20mm) COUPLED with CAVITY (200mm)
TRIMGRP = 1 $
$
$* CONSTRAINTS
SPC = 1
$
FREQUENCY = 10
DLOAD = 20
$
METHOD (FLUID) = 100
$*
$* SETS FOR OUTPUT REQUESTS
$ G40094 - center, 80mm away from foam
$ G60094 - center, 160mm away from foam
SET 11 = 40094, 60094
$*
SUBCASE 1
$DISPLACEMENT (SORT1,PUNCH) = 11
DISPLACEMENT (SORT2) = 11
$*
BEGIN BULK
param,prefdb,2.-5
$
$ For Trim Component 1
$
$-----2-----3-----4-----5-----6-----7-----8-----9
$ TID SGLUED SSLIDE SOPEN SIMPER
$-----2-----3-----4-----5-----6-----7-----8-----9
ACPEMCP 1 104
$
$
PARAM GRDPNT -1
PARAM AUTOSPC YES
PARAM COUPMASS 2
$
$ AVOID DIRECT COUPLING BETWEEN PLATE AND CAVITY
$
PARAM ASCOUP NO
$

```

```

$
FREQ1 10 20.000 1.000 480
$
RLOAD1 20 5 100
DAREA,5,20094,1,10.2583e9
$*
TABLED1 100 +
+ 1.0 1.0 2000.0 1.0 ENDT
$
EIGRL 100 0.0 1500.0
include 'cavity_350_220_200.bdf' $
$
BEGIN BULK TRMC=1 $ Trim Component 1
$
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
$
PSOLID 5 15 TWO FULL PORO
$
$$$$-----
$$$$ Material Definition Cards
$$$$-----
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
$MATPE1 MID MAT1 MAT10 BIOT
$ VISC GAMMA PRANDTL POR TOR AFR VLE TLE
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
MATPE1 15 16 17 +
+ 1.84-8 1.40 7.13-1 9.5-1 1.40 2.50-5 9.32-2 9.32-2
$
MAT1 16 42.0 0.0 6.0-7 0.05
MAT10 17 1.21-9 342300.00.01
$-----SETS TRIM-----
$
SET1 104 2851 THRU 3275
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
FREQ1 1 20. 1. 480
include 'foam_350_220_20.bdf'
ENDDATA

```

CAVITY

- Rest of the Cavity File

cavity_350_220_200.bdf

```
$
GRID    20001      0.0    0.0    21.0    -1
GRID    20002      21.875 0.0    21.0    -1
GRID    20003      43.75  0.0    21.0    -1
.
.
$
CHEXA   20001    5      20001  20002  20019  20018  30001  30002  +AA1
+AA1    30019  30018
CHEXA   20002    5      20002  20003  20020  20019  30002  30003  +AA2
+AA2    30020  30019
.
.
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
PSOLID      5      3                                PFLUID
$
MAT10      3      1.21E-09342300.0
$
```

TRIM COMPONENT

- Rest of trim component file

foam_350_220_20.bdf

\$-----2-----3-----4-----5-----6-----7-----8-----9-----0--

GRID 2001 218.75 137.5 1.0

GRID 2002 233.3333137.5 1.0

.

.

\$

CHEXA 2001 5 2108 2072 2075 2109 2426 2429+

+ 2428 2427

CHEXA 2002 5 2100 2108 2109 2103 2430 2426+

+ 2427 2431

\$

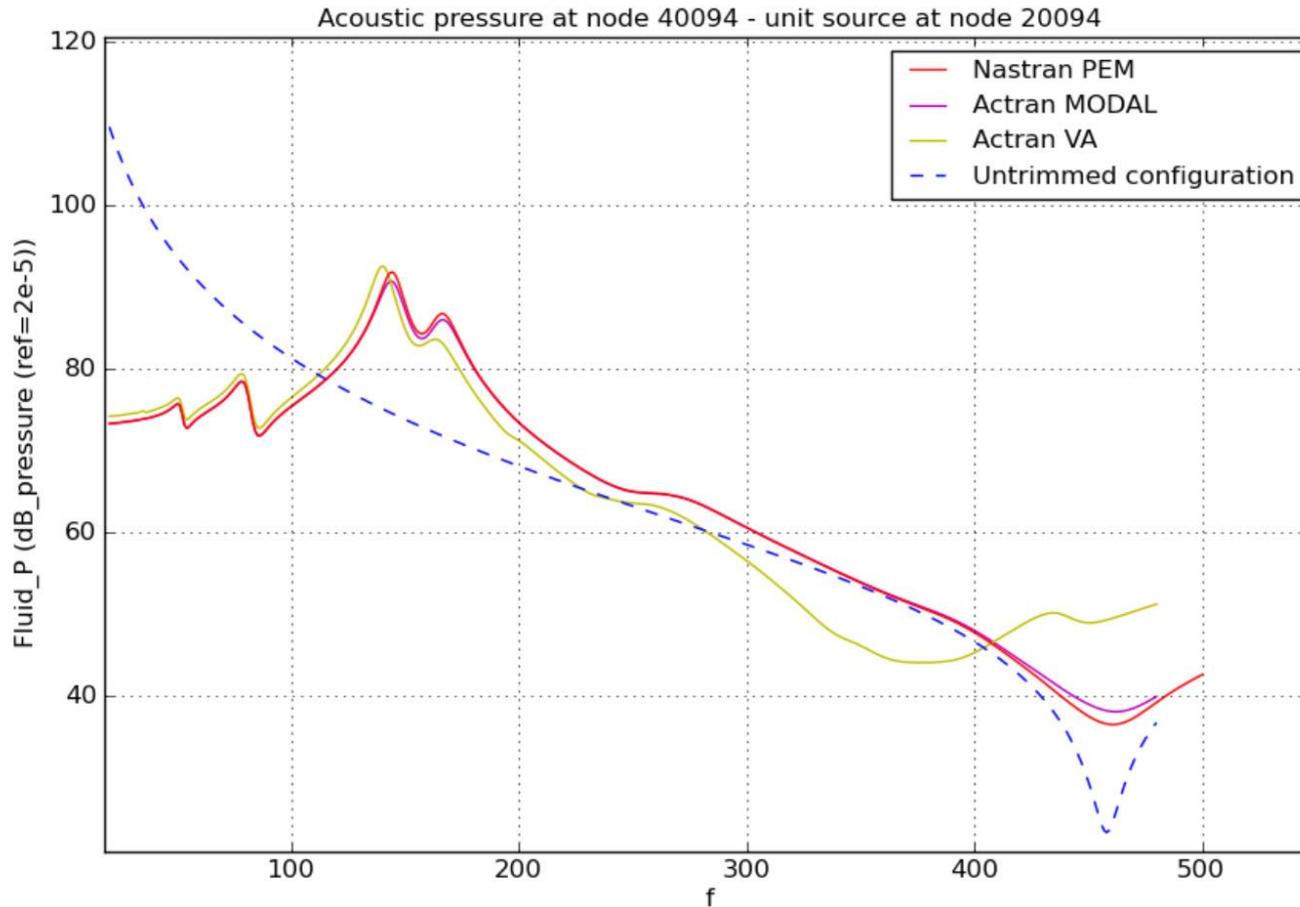
OUTPUT

- Typical Pressure Output

POINT-ID = 40094		COMPLEX ACOUSTIC PRESSURE RESULTS				SUBCASE 1
(MAGNITUDE/PHASE)						
FREQUENCY	TYPE	P	P(RMS)	DB	DB(A)	
0 2.000000E+01	S	9.186047E-02	6.495517E-02	7.324197E+01	2.274197E+01	
		359.9375	359.9375	359.9375	359.9375	
0 2.100000E+01	S	9.212583E-02	6.514280E-02	7.326703E+01	2.392702E+01	
		359.9289	359.9289	359.9289	359.9289	
:						
0 1.420000E+02	S	7.225009E-01	5.108852E-01	9.115617E+01	7.636760E+01	
		314.2096	314.2096	314.2096	314.2096	
0 1.430000E+02	S	7.609262E-01	5.380561E-01	9.160625E+01	7.689482E+01	
		305.3622	305.3622	305.3622	305.3622	
0 1.440000E+02	S	7.769256E-01	5.493693E-01	9.178699E+01	7.715270E+01	
		295.6217	295.6217	295.6217	295.6217	
0 1.450000E+02	S	7.642050E-01	5.403745E-01	9.164359E+01	7.708645E+01	
		285.7084	285.7084	285.7084	285.7084	
:						
0 4.980000E+02	S	2.592315E-03	1.833043E-03	4.225315E+01	3.902115E+01	
		329.8989	329.8989	329.8989	329.8989	
0 4.990000E+02	S	2.636208E-03	1.864080E-03	4.239899E+01	3.918299E+01	
		330.5108	330.5108	330.5108	330.5108	
0 5.000000E+02	S	2.680289E-03	1.895251E-03	4.254303E+01	3.934303E+01	
		331.1078	331.1078	331.1078	331.1078	

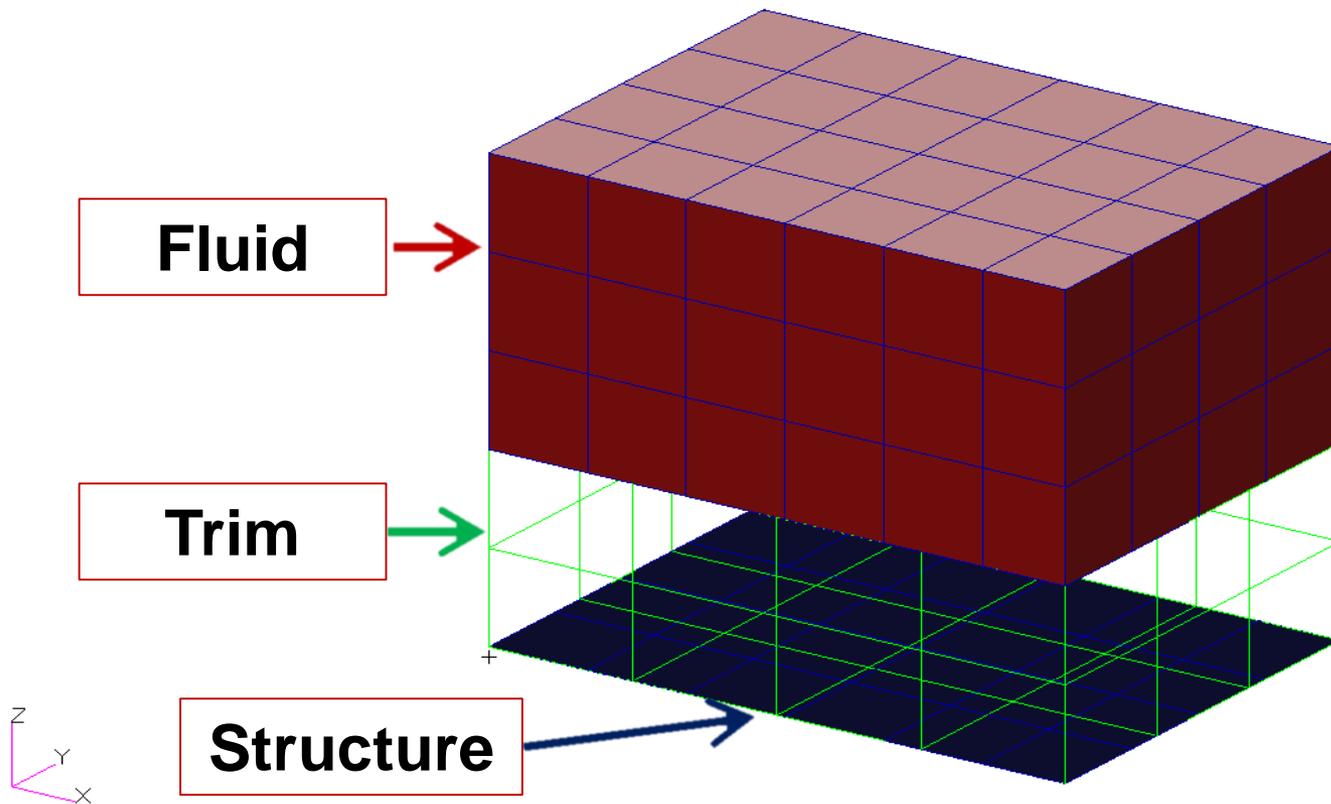
RESULTS FOR EXAMPLE 1

- Results Comparison (graph from MSC Nastran 2013 Release Guide)



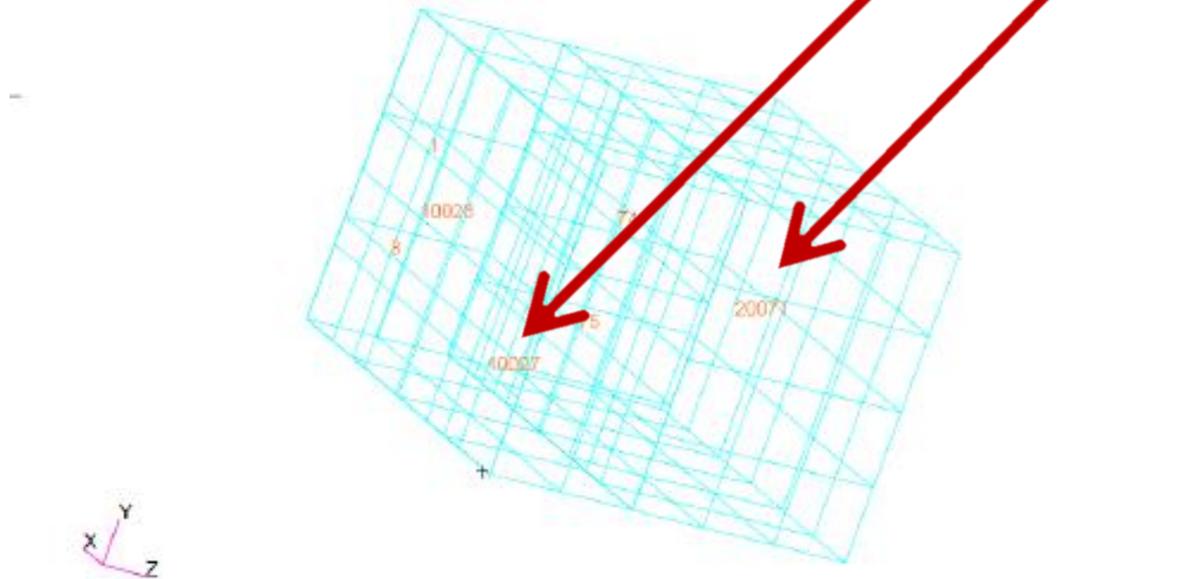
EXAMPLE 2

- In this example, the trim material resides between the structure (plate) and the fluid cavity



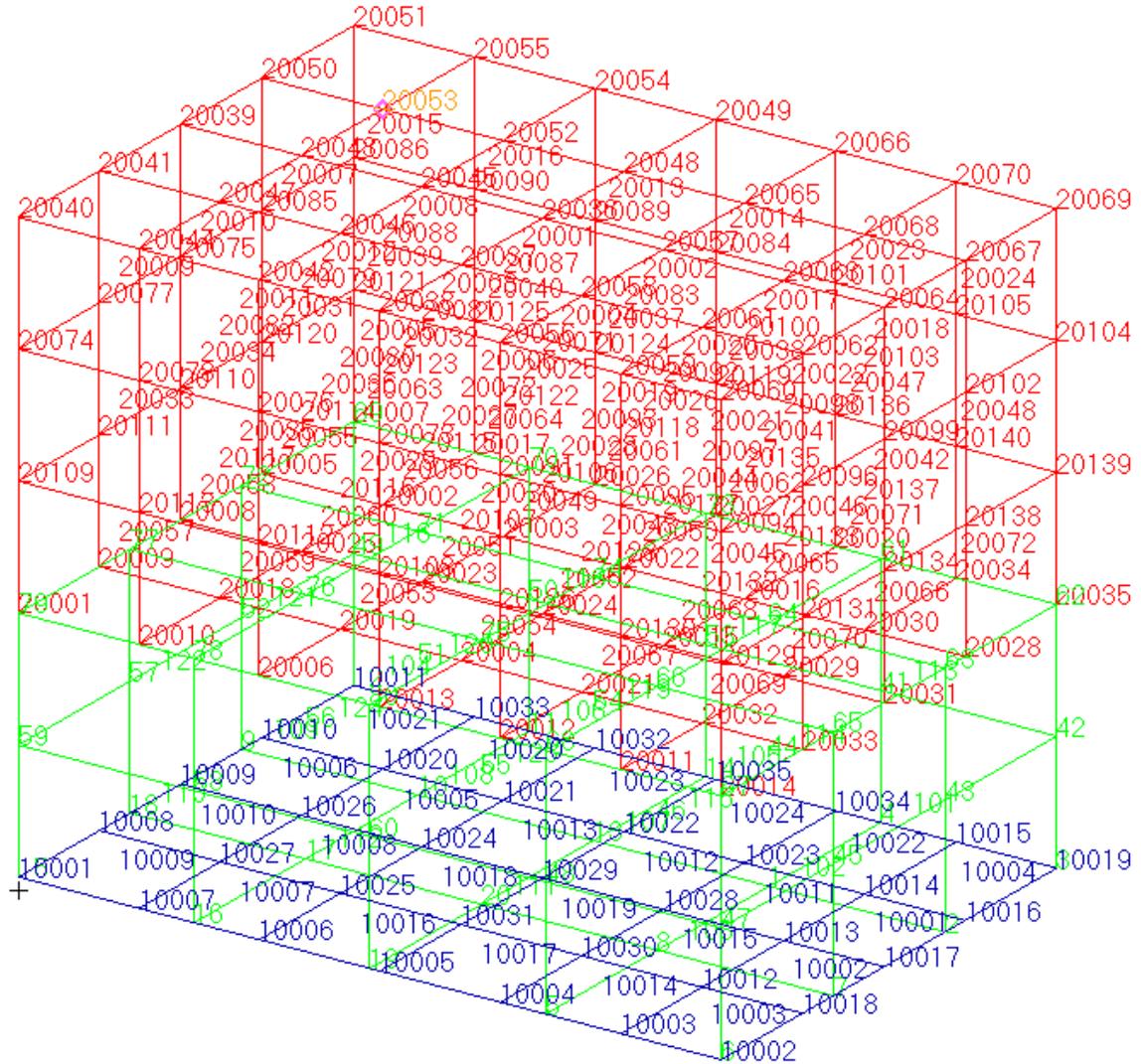
EXAMPLE 2 (CONT.)

- Frequency-dependent material will be used for the trim material
- Load is applied at grid 10027 (structure)
- Monitor pressure at grid 20071 (fluid)



EXAMPLE 2 (CONT.)

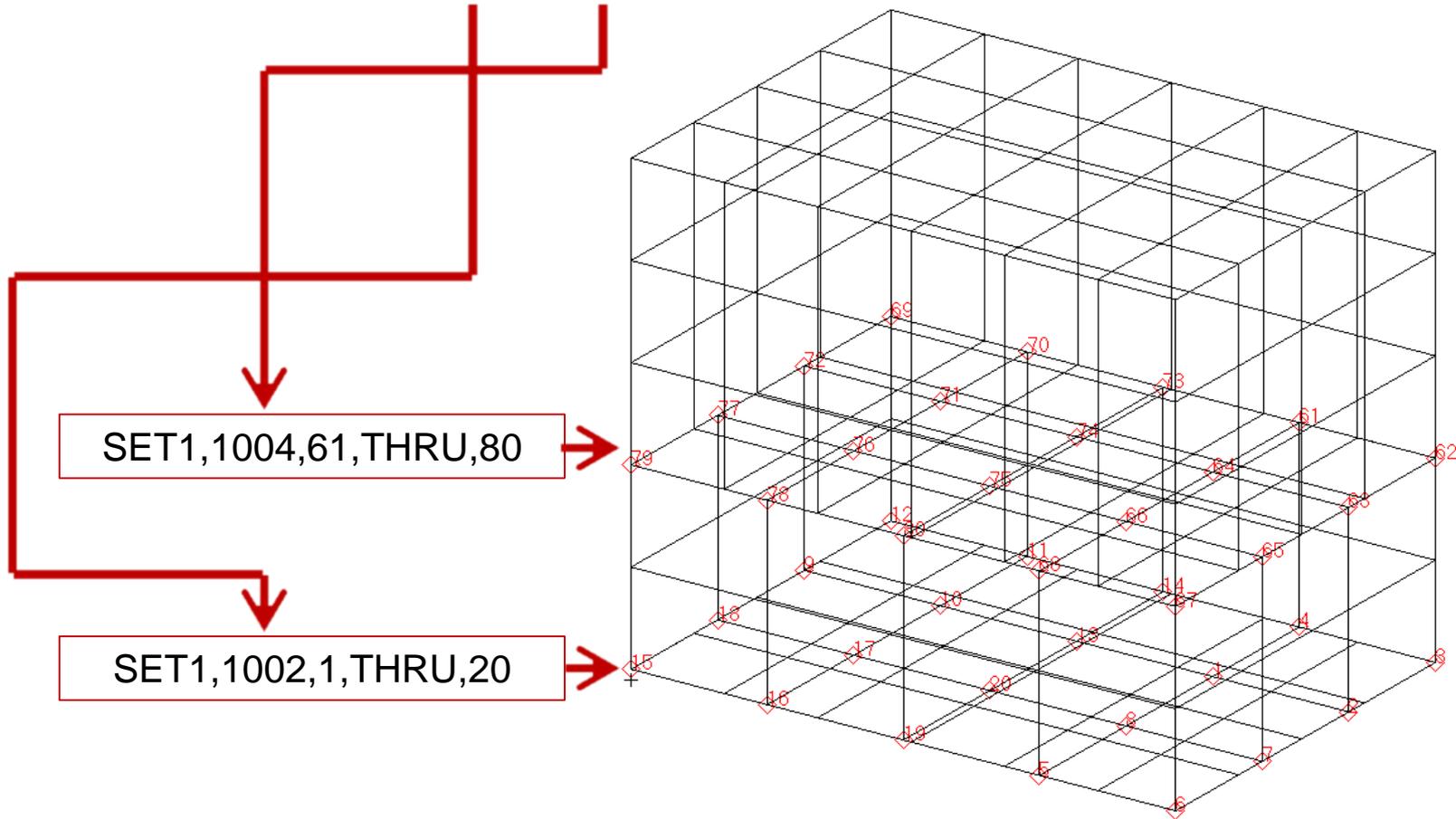
- LABEL IDs**



EXAMPLE 2 (CONT.)

- Define TRIM component interface points

ACPEMCP,9267,,1002,,1004



EXAMPLE 2 (CONT.)

```

$
SOL 111 $
$
CEND $
$
TITLE = PLATE COATED WITH TRIM AND COUPLED WITH CAVITY
SUBTITLE = FOAM AND HEAVY LAYER
ECHO = none
$
SUBCASE 1001 $
$
SET 10 = 9267
TRIMGRP = 10 $ Trim component(s) is selected thru Case SET
SPC = 1
$
FREQUENCY = 10
$*
DLOAD = 20
$*
$* MODES EXTRACTION METHOD
METHOD(STRUCTURE) = 99
METHOD(FUID) = 100
$*
$* SETS FOR OUTPUT REQUESTS
SET 11 = 10027,10028,20071,1,8,74,75
$ gid 1,8 are on str/trmc interface
$ gid 22,23 are on trmc/cavity interface
$*
DISPLACEMENT(trmc=all,sort2,phase) = 11
$
BEGIN BULK $ Main model of structure and cavity
$param,trmbim,modal
$
PARAM GRDPNT -1
PARAM AUTOSPC YES
PARAM COUPEMASS 2
param,prefdb,2.-5
$
ACMODL DIFF GRIDS 1006 3.0
SET1,1006,20001,THRU,20035

```

```

$
$-----2-----3-----4-----5-----6-----7-----8-----9-
$TRMCPL TID CTYPE PLTOL GAPOL1 GAPOL2 GAPOL3 GAPOL4
$-----2-----3-----4-----5-----6-----7-----8-----9-
TRMCPL 9267 SSLIDE 0.03
TRMCPL 9267 SIMPER 0.03
$
$-----2-----3-----4-----5-----6-----7-----8-----9-
$ TID SGLUED SSLIDE SOPEN SIMPER
$ SCUX SCUY SCUZ SCRX SCRY SCRZ SCFP
$-----2-----3-----4-----5-----6-----7-----8-----9-
ACPEMCP 9267 1002 1004
$
$* SOLUTION FREQUENCY RANGE
FREQ1 10 20.000 1.000 480
$*
$* DYNAMIC LOAD DEFINITION
RLOAD1 20 100 100
DAREA 100 10027 3 1.0
TABLED1 100
+ 0.0 1.0 1000.0 1.0 ENDT
$*
EIGRL 99 0.0 800.0
$EIGRL 100 0.0 800.0
EIGRL 100 5
$
$ rest of the noarmal structure and fluid model
.
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
$MATPE1 MID MAT1 MAT10 BIOT
$ VISC GAMMA PRANDTL POR TOR AFR VLE TLE
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-
MATPE1 1 2 3
+ 1.84-8 1.40 7.13-1 9.5-1 1.4 2.5-5 9.32-2 9.32-2
$
SET1 1002 1 THRU 20
SET1 1004 61 THRU 80
$

```

Coupled to the Structure Part

Coupled to the Fluid Part

EXAMPLE 2 (CONT.)

```
$ Poro-elastic material: Foam
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-----
PSOLID      4      1                                PORO
$
$ FOAM: Solid phase
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-----
MAT1       2      42.0      0.0      6.00E-07      0.05
$ Frequency-dependent isotropic material
$
MATF1      2      11
TABLEM1   11
+      20.0      42.0      250.      42.0      500.      45.0      ENDT
$ Foam: Fluid phase
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-----
MAT10      3      1.21E-09342300.00.01
$
$ Master (sampling) frequency range
$ Matching FREQ ID=trimID, otherwise a User FATAL error
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----0-----
FREQ1     9267      20.000      20.000      24
$
$ plus rest of the foam model (grids, CHEXA, etc.)
.
.
$
ENDDATA $
```

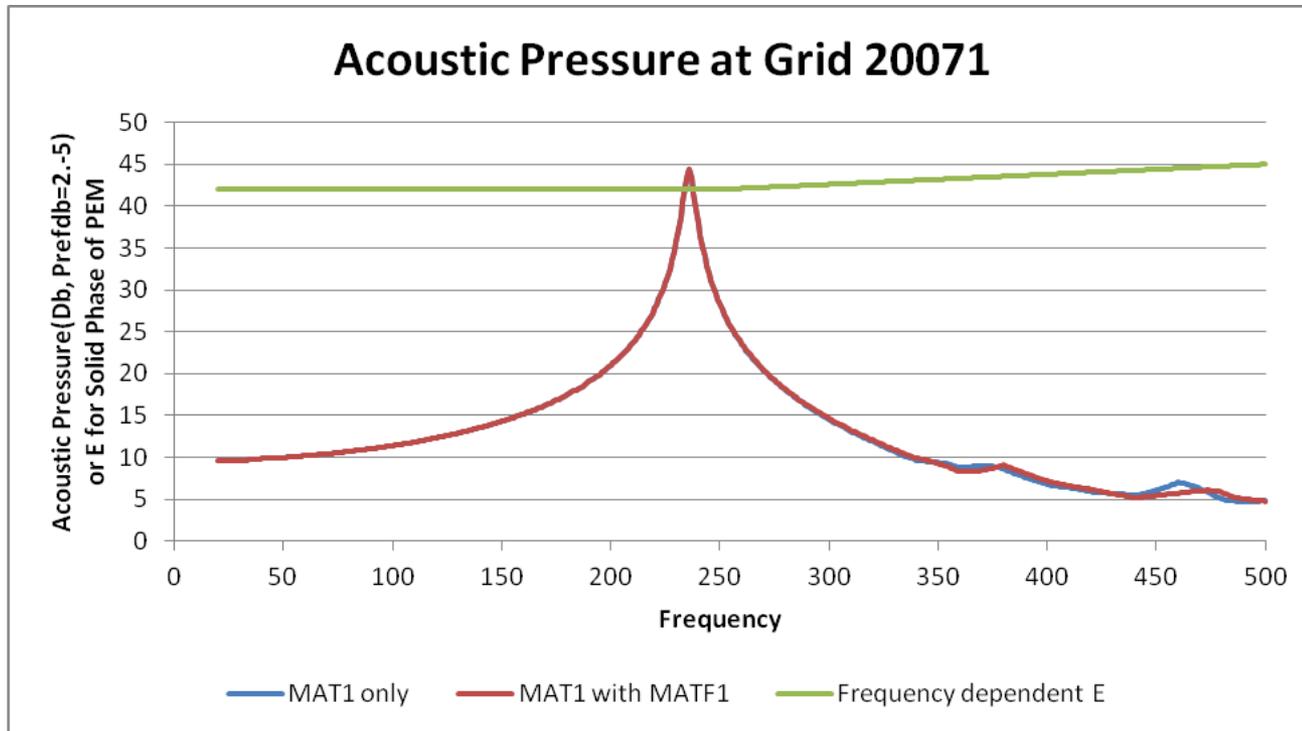


Frequency-dependent Material

EXAMPLE 2 - OUTPUT

- **Acoustic Pressure**

- Material with **Constant E** value vs **Frequency-dependent E** value



Frequency-dependent, E curve

INTERFACE TOLERANCE

- Use TRMCPL entry to override default interface tolerances if default tolerances are insufficient

1	2	3	4	5	6	7	8	9	10
TRMCPL	TID	CTYPE	PLTOL	GAPTOL1	GAPTOL2	GAPTOL3	GAPTOL4		

- **CTYPE** **Coupling type (SGLUED, SSLIDE, SOPEN, or SIMPER)**
- **PLTOL** **In-plane relative tolerance (default=0.1)**
- **GAPTOLi** **Absolute tolerance. Grids on surfaces that are separated further than GAPTOLi will not be coupled. GAPTOL1, GAPTOL2, GAPTOL3, GAPTOL4 will be used in succession for checking tolerance (default=.01)**

GENERAL GUIDELINES AND LIMITATIONS

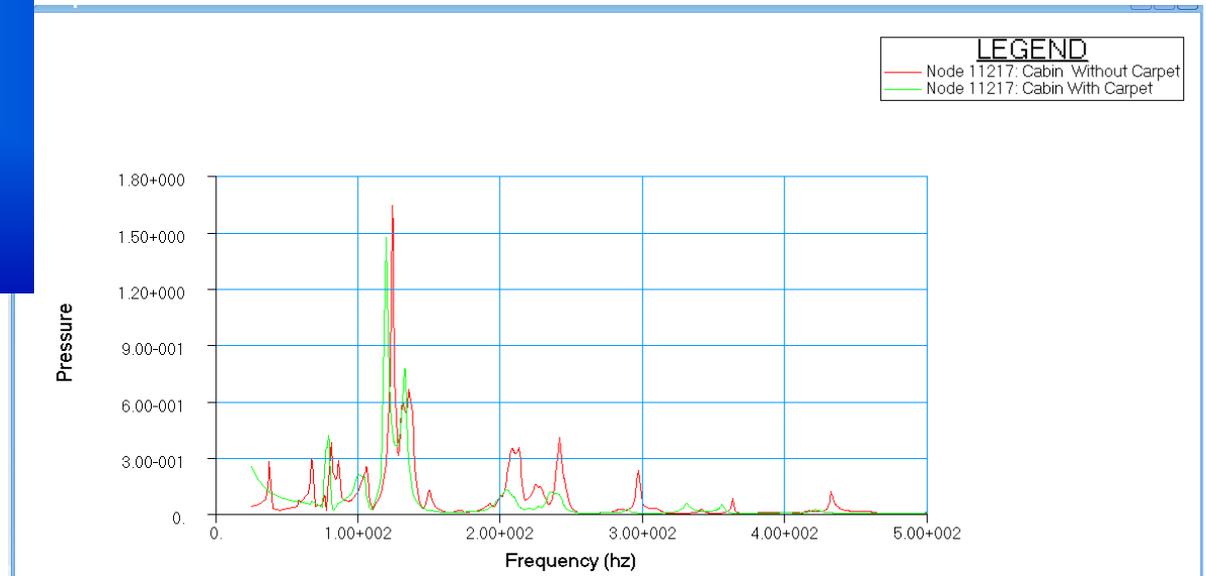
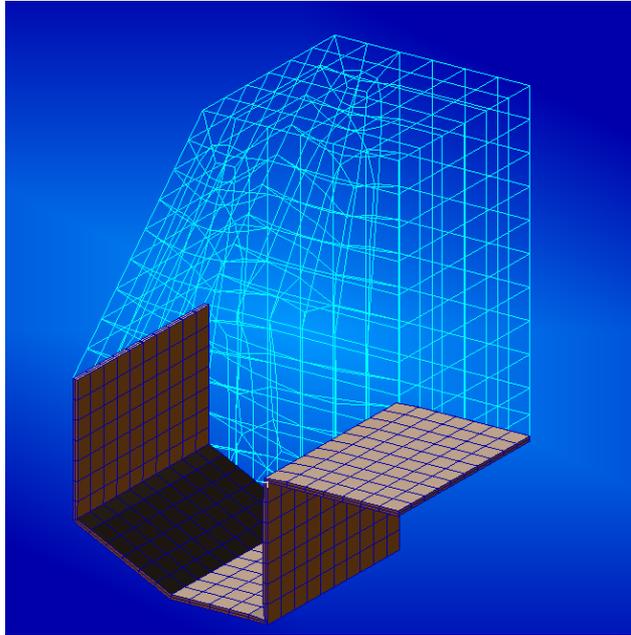
- **The reduced impedance matrix can be calculated in either the direct or modal space**
 - Controlled by “param,trmbim,x”
where x is either physical (default) or modal
 - If data recovery is not needed for the trim material (majority of the case), the modal option is more efficient
 - For SOL 200, only the physical option is supported
 - For SOL 200, the trim component cannot be used as the design model

GENERAL GUIDELINES AND LIMITATIONS (CONT.)

- **FREQ, FREQ1, and/or FREQ2 may be used to specify master frequencies for each trim component**
 - These are frequencies where the impedances are calculated
 - FREQ3, FREQ4, & FREQ5 are not supported for this purpose
 - The ID referenced on the FREQ, FREQ1, and FREQ2 must be the same as the ID specified for the TRMC Bulk Data Section

- **The PEM option creates several sub-directories during the course of the run as it spawns off and execute Actran to calculate the impedance matrices**
 - actran_report, transfer, zred, etc.
 - The above subdirectories should be deleted prior to running the next PEM job

GO TO WORKSHOP 6





SECTION 6

EQUIVALENT RADIATED POWER

EQUIVALENT RADIATED POWER (ERP)

- **What is ERP**
 - ERP stands for Equivalent Radiated Power
 - Simplified method of calculating the radiation due to a collection of panels across a frequency range
- **Why Use ERP?**
 - ERP calculations provide insight into which panels contribute to an acoustic response as a function of frequency
 - Analyzing the interiors/panels of a vehicle body for its vibration and acoustic behavior has become an important aspect in vehicle development. Vibration in the body panels are induced by primary sources of excitation such as engine, power train, wind noise, and road/tire
 - Alternate to performing a full expensive acoustic analysis
 - Automotive laser velocity measurement can be directly correlated to maximum acoustic response
 - Laser velocity measurement is cheap and effective
 - ERP response is similar to panel participation factors (PFPANEL), but without the requirement of an acoustic mesh or acoustic analysis.

EQUIVALENT RADIATED POWER (ERP)

- **Applications**
 - Aircraft
 - Automotive
 - Trains
 - etc.

EQUIVALENT RADIATED POWER (ERP)

$$ERP = C \sum_{surf}^{panel} V_n^2 \Delta S$$

$$C = \alpha * ERPRLF * ERPRHO * ERPC;$$

where	V_n	= normal velocity
	ΔS	= elemental area
	α	= 0.5 for frequency response = 1.0 for transient response
	ERPRLF	= radiation loss factor
	ERPRHO	= fluid density
	ERPC	= speed of sound in fluid

EQUIVALENT RADIATED POWER SOUND PRESSURE LEVEL

$$ERP_{dB} = 10 \text{LOG} \left(\frac{RHOCP}{ERP_{REFDB}} * ERP_{value} \right)$$

- where RHOCP = scale factor used in the computation of ERP in units of dB (default=1.0)
- ERPREFDB = peak reference ERP value in units of dB (default =1.0)

ERP FORMAT- CASE CONTROL

- Requests ERP panel participation factor

Format:

$$\begin{aligned}
 & \text{ERP} \left[\left(\left[\text{SORT2} \right], \left[\text{PRINT}, \text{PUNCH} \right] \left[\text{SOLUTION} = \text{ALL} \right], \right. \right. \\
 & \quad \left. \left[\text{SORT1} \right], \left[\text{PLOT} \right] \right] \left[\text{KEY} = \left\{ \begin{array}{l} \text{frequency} \\ \text{fraction} \end{array} \right\}, \left[\text{FILTER} = \left\{ \begin{array}{l} 0.01 \\ \text{real_value} \end{array} \right\}, \right. \right. \\
 & \quad \left. \left[\text{ERPRHO} = \left\{ \begin{array}{l} 1.0 \\ \text{real_value} \end{array} \right\}, \left[\text{ERPC} = \left\{ \begin{array}{l} 1.0 \\ \text{real_value} \end{array} \right\} \right] \right] \\
 & \quad \left. \left[\text{RHOCF} = \left\{ \begin{array}{l} 1.0 \\ \text{real_value} \end{array} \right\}, \left[\text{ERPRLF} = \left\{ \begin{array}{l} 1.0 \\ \text{real_value} \end{array} \right\} \right] \right] \\
 & \quad \left. \left[\text{ERPREFDB} = \left\{ \begin{array}{l} 1.0 \\ \text{real_value} \end{array} \right\}, \left[\text{CSV} = \text{unit} \right] \right] = \left\{ \begin{array}{l} \text{ALL} \\ \text{setp} \\ \text{NONE} \end{array} \right\}
 \end{aligned}$$

Highlighted items in blue
can also be specified as
PARAMETERS

ERP FORMAT- CASE CONTROL (CONT.)

- **Some useful keywords in the ERP command**
- **Filter** **An ERPMAX value smaller than this filter threshold will not be printed. ERPMAX is the maximum ERP value across all frequencies for a panel.**
- **If output to a .csv file is desired**
 - The unit must be specified with the CSV=unit keyword
 - An assign statement with the logical key USERFILE and FORM=FORMATTED must be used
 - e.g. , to assign a csv file to unit 50, the assign statement will look something like

```
ASSIGN USERFILE = myfile.csv UNIT=50 FORM=FORMATTED STATUS=NEW
```

ERP- BULK DATA INPUT

- The ERPPNL Bulk Data entry specifies the panels for the ERP calculation

ERPPNL

Equivalent Radiated Power Definition

Defines one or more panels by referencing sets of elements or properties.

Format:

1	2	3	4	5	6	7	8	9	10
ERPPNL	NAME1	SETID1	NAME2	SETID2	NAME3	SETID3	NAME4	SETID4	
	NAME5	SETID5							

Example:

ERPPNL	ROOF	1	DOORLF	16					
--------	------	---	--------	----	--	--	--	--	--

Field

Contents

NAME _i	Panel label. (CHAR)
SETID _i	Identification number of a SET3 Bulk Data entry that lists the panel property entries or the panel elements. (Integer > 0)

Remarks:

- The SET3 entries can only refer to CQUAD4, CQUADR, CTRIA3, or CTRIAR structural elements or PSHELL or PCOMP property entries. CQUAD8 and CTRIA6 entries are ignored.
- NAME_i are used in a Case Control SET definition defining *setp* to select the panels in the Case Control command ERP.

SET DEFINITION

- The ERP calculation is typically requested for a group of elements defined on a SET3 Bulk Data entry.

SET3 Labeled Set Definition

Defines a list of grids, elements or points.

Format:

1	2	3	4	5	6	7	8	9	10
SET3	SID	DES	ID1	ID2	ID3	ID4	ID5	ID6	
	ID7	ID8	-etc-						

Example:

SET3	1	POINT	11	12	13	15	18	21	
------	---	-------	----	----	----	----	----	----	--

Field	Contents
SID	Unique identification number. (Integer>0)
DES	Set description (Character). Valid options are "GRID", "ELEM", "POINT" and "PROP".
Idi	Identifiers of grids points, elements, points or properties. (Integer > 0)

ERP CASE CONTROL (CONT.)

Example

SET 17 = 10.,20.,30.,40.,80.,100.

SET 25 = ROOF, DOORLF

ERP (PRINT,PUNCH,SOLUTION=17,KEY=frac) = 25

The above commands will print and punch the ERP output for the panels defined under ROOF and DOORLF, and at 10., 20.,30., 40., 80., and 100. hz. The output will also be sorted in descending order of the fractional ERP value as a function of the total ERP value.

ERP INPUT- AN EXAMPLE

- CASE CONTROL**

ERP(KEY=FREQ,RHOCP=10.0,ERPRHO=10.0,ERPC=10.0,CSV=30) = ALL

- BULK DATA**

ERPPNL	NAME1	SETID1	NAME2	SETID2	NAME3	SETID3	NAME4	SETID4	
	NAME5	SETID5							

BEGIN BULK

cord2r,1000,,0.0,0.0,0.0,0.866025,0.0,0.5,
,-0.5,0.0,0.866025

ERPPNL, ERPX0, 103, ERPX3, 203, erpeid3, 303

set3, 103, prop, 100

set3, 203, prop, 200

set3, 303, element, 114, 124, 134, 214, 224, 234,

, 314, 324, 334

erppnl, nouse1, 100, nouse3, 200

ERP INPUT- AN EXAMPLE (CONT.)

- BULK DATA (Cont.)**

BEGIN BULK

cord2r,1000,,0.0,0.0,0.0,0.866025,0.0,0.5,
 ,-0.5,0.0,0.866025

SET3	SID	DES	ID1	ID2	ID3	
	ID7	ID8	-etc-			

ERPPNL,ERPX0,103,ERPX3,203,erpeid3,303

set3,103,prop,100

set3,203,prop,200

set3,303,element,114,124,134,214,224,234,
 ,314,324,334

erppnl,nouse1,100,nouse3,200

SET3	SID	DES	ID1	ID2	ID3	
	ID7	ID8	-etc-			

REQUEST FOR CSV FILE OUTPUT

- If output to a .csv file is requested, the file must be assigned with logical key USERFILE and FORM=FORMATTED, e.g.,
- ASSIGN USERFILE = myfile.csv UNIT=50 FORM=FORMATTED STATUS=NEW

EXAMPLE:

```
ASSIGN USERFILE='OUTDIR:erp_csv_61.csv',UNIT=61 STATUS=NEW,  
FORM=FORMATTED DELETE  
ASSIGN USERFILE='OUTDIR:erp_csv_62.csv',UNIT=62 STATUS=NEW,  
FORM=FORMATTED DELETE
```

```
set 1000 = erpx0,erpeid3  
ERP(filter=0.01, csv=61, sort2,  
KEY=FREQ,RHOCP=10.0,ERPRHO=10.0,ERPC=10.0) = 1000
```

```
set 2000 = erpx3,erpeid3  
ERP(filter=0.01, csv=62, sort2,  
KEY=FREQ,RHOCP=10.0,ERPRHO=10.0,ERPC=10.0) = 2000
```

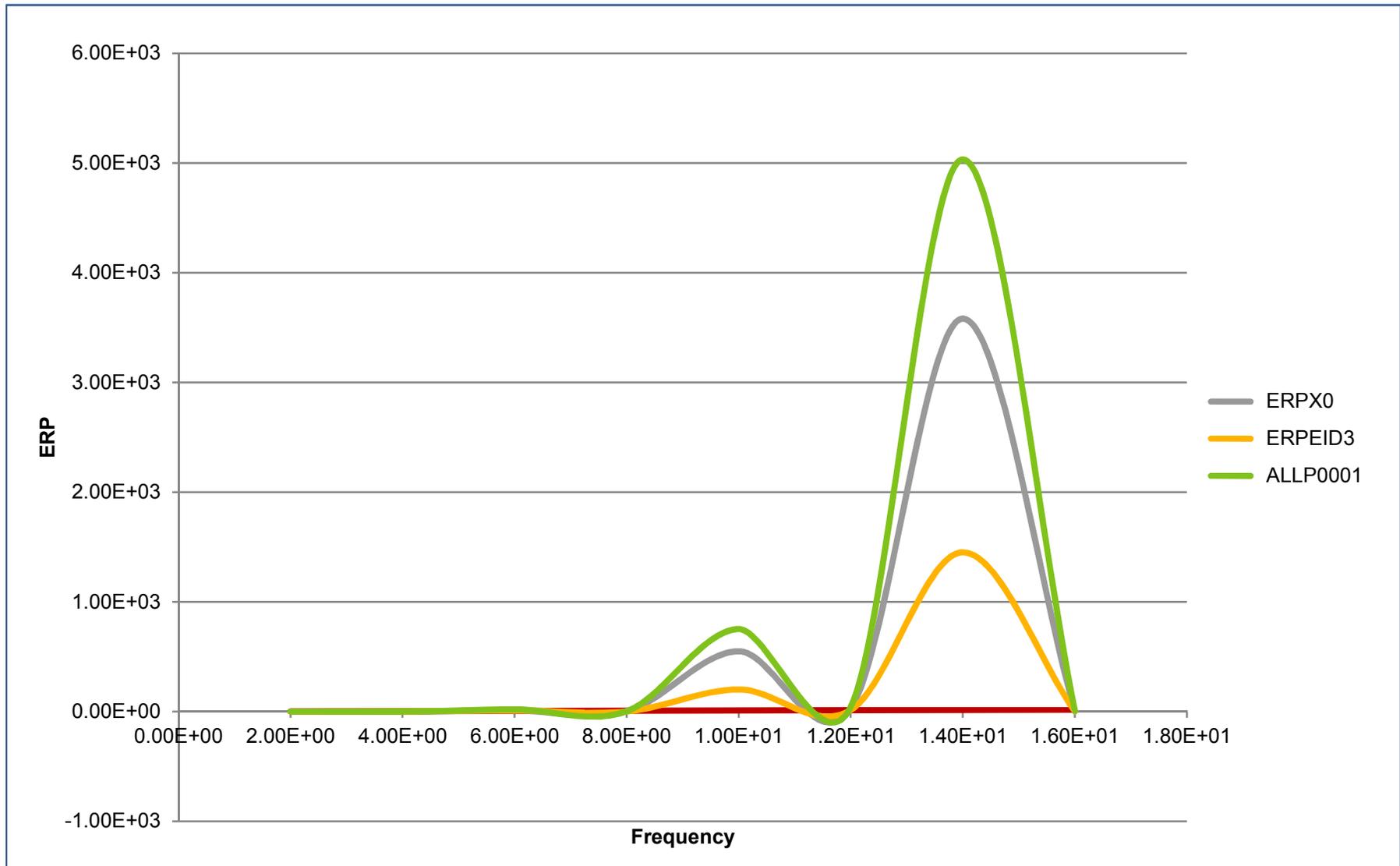
CSV FILE OUTPUT – SUBCASE 1000

Subcase	1000								
EQUIVALENT RADIATED POWER IN PANELS OF QUAD4S									
ALL IN 1 SUBCASE									
FIRST SUBCASE (1000) SUBCASE 1000									
Equivalent Radiated Power									
	ERP	ERP	ERP	Fraction	Fraction	Fraction	ERP(dB)	ERP(dB)	ERP(dB)
Area	1.00E+01	9.00E+00	1.90E+01	1.00E+01	9.00E+00	1.90E+01	1.00E+01	9.00E+00	1.90E+01
Frequency	ERPX0	ERPEID3	ALLP0001	ERPX0	ERPEID3	ALLP0001	ERPX0	ERPEID3	ALLP0001
2.00E+00	3.60E-01	4.22E-01	7.82E-01	1.01E-04	2.91E-04	1.55E-04	5.56E+00	6.25E+00	8.93E+00
4.00E+00	3.67E-02	1.50E-01	1.86E-01	1.02E-05	1.03E-04	3.70E-05	-4.36E+00	1.75E+00	2.71E+00
6.00E+00	9.09E+00	1.10E+01	2.01E+01	2.54E-03	7.58E-03	3.99E-03	1.96E+01	2.04E+01	2.30E+01
8.00E+00	2.70E+00	4.87E-01	3.19E+00	7.54E-04	3.36E-04	6.34E-04	1.43E+01	6.88E+00	1.50E+01
1.00E+01	5.50E+02	2.02E+02	7.52E+02	1.54E-01	1.39E-01	1.49E-01	3.74E+01	3.31E+01	3.88E+01
1.20E+01	2.83E+01	1.47E+01	4.30E+01	7.90E-03	1.01E-02	8.54E-03	2.45E+01	2.17E+01	2.63E+01
1.40E+01	3.58E+03	1.45E+03	5.03E+03	1.00E+00	1.00E+00	1.00E+00	4.55E+01	4.16E+01	4.70E+01
1.60E+01	2.50E+00	2.54E+00	5.04E+00	6.97E-04	1.75E-03	1.00E-03	1.40E+01	1.41E+01	1.70E+01

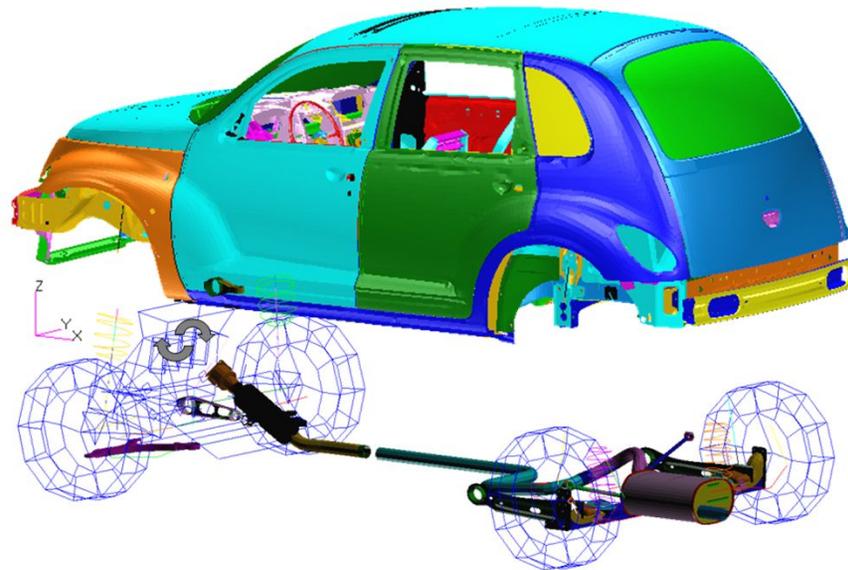
PARTIAL F06 OUTPUT FILE

```
ALL IN 1 SUBCASE
0   FIRST SUBCASE (1000)                                SUBCASE 1000
   PANEL = ERPX0 (AREA = 1.000000E+01)
       E Q U I V A L E N T   R A D I A T E D   P O W E R
       FILTER : 1.000000E-02
       FREQUENCY      ERP      FRACTION      ERP (dB)
       1.000000E+01   5.504193E+02  1.536385E-01  3.740694E+01
       1.400000E+01   3.582562E+03  1.000000E+00  4.554193E+01
       **ERP MAX**    3.582562E+03
1   EQUIVALENT RADIATED POWER IN PANELS OF QUAD4S      PAGE 21
   ALL IN 1 SUBCASE
0   FIRST SUBCASE (1000)                                SUBCASE 1000
   PANEL = ERPEID3 (AREA = 9.000000E+00)
       E Q U I V A L E N T   R A D I A T E D   P O W E R
       FILTER : 1.000000E-02
       FREQUENCY      ERP      FRACTION      ERP (dB)
       1.000000E+01   2.019561E+02  1.391604E-01  3.305257E+01
       1.200000E+01   1.467790E+01  1.011400E-02  2.166664E+01
       1.400000E+01   1.451247E+03  1.000000E+00  4.161741E+01
       **ERP MAX**    1.451247E+03
1   EQUIVALENT RADIATED POWER IN PANELS OF QUAD4S      PAGE 22
   ALL IN 1 SUBCASE
0   FIRST SUBCASE (1000)                                SUBCASE 1000
   PANEL = ALLP0001 (AREA = 1.900000E+01)
       E Q U I V A L E N T   R A D I A T E D   P O W E R
       FILTER : 1.000000E-02
       FREQUENCY      ERP      FRACTION      ERP (dB)
       1.000000E+01   7.523754E+02  1.494645E-01  3.876435E+01
       1.400000E+01   5.033808E+03  1.000000E+00  4.701897E+01
       **ERP MAX**    5.033808E+03
1   EQUIVALENT RADIATED POWER IN PANELS OF QUAD4S      PAGE 23
   ALL IN 1 SUBCASE
0   TEST SECOND SUBCASE (2000) SAME AS FIRST           SUBCASE 2000
   PANEL = ERPX3 (AREA = 9.000000E+00)
       E Q U I V A L E N T   R A D I A T E D   P O W E R
       FILTER : 1.000000E-02
       FREQUENCY      ERP      FRACTION      ERP (dB)
       1.000000E+01   2.019561E+02  1.391604E-01  3.305257E+01
       1.200000E+01   1.467790E+01  1.011400E-02  2.166664E+01
       1.400000E+01   1.451247E+03  1.000000E+00  4.161741E+01
       **ERP MAX**    1.451247E+03
```

ERP FROM CSV FILE – SUBCASE 1000



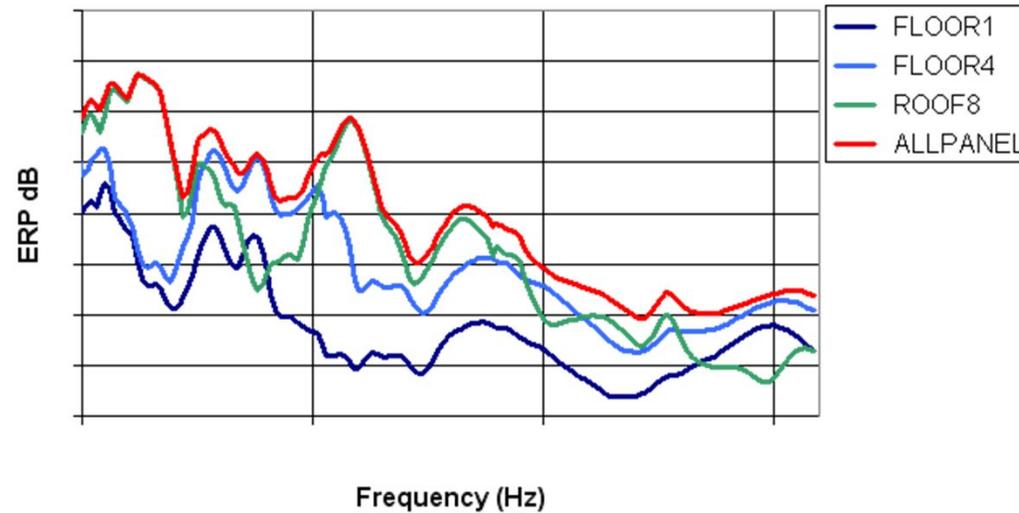
MORE COMPLICATED AUTO EXAMPLE



GRID~350K

SHELL~350K

Equivalent Radiated Power



ERP-LIMITATIONS

- **Supports 3 and 4 node shells only (CQUAD4, CQUADR, CTRIA3, CTRIAR)**
- **Use .csv file for plotting**
- **Superelement-residual only**



WORKSHOP 6

ACOUSTIC RADIATED POWER



SECTION 7

VIRTUAL MASS

INTRODUCTION

- **Virtual mass is used to model the hydrodynamic effects of added mass on a structure when it is in contact with inviscid, incompressible fluids**
- **The fluid domains, which are not explicitly modelled with a fluid mesh (hence the term *virtual* mass), could be**
 - Finite (e.g. fuel in a tank)
 - Infinite (e.g. a ship in the sea)
- **A list of wet, or submerged, finite elements define where the fluid contacts the finite element structure.**
- **Structural surfaces may be wet either on one side only, or on both sides (e.g. baffles).**
- **The entire fluid domain may be composed of several disjoint regions containing different fluids.**

INTRODUCTION (CONT.)

- **Virtual fluid volume produces a mass matrix**
- **Fluids coupled directly to structure through the mass matrix.**
- **Generates very dense mass matrix**
- **Incompressible fluid**
- **Full coupling between accelerations and pressures on the flexible structural interfaces.**
- **Represents the fluid coupled to a boundary consisting of:**
 - Structural elements
 - Free surfaces
 - Planes of symmetry
 - Infinite fluids
- **One or two wetted sides.**
- **Supports multiple fluid volumes**

INTRODUCTION (CONT.)

- **Supported in all dynamic solutions except cyclic symmetry.**
- **Only wetted structural elements are defined to have fluid.**
- **Fluids on interior or exterior surfaces.**
- **Infinite exterior fluid allowed.**
- **Free surfaces allowed.**
- **Gravity effects not included**
- **No sloshing effects unless phantom boundaries are used.**
- **Fuel tanks, nuclear fluid containers, drilling platforms, underwater devices, and ships where fluid dynamics can be ignored.**

ASSUMPTIONS AND RESTRICTIONS

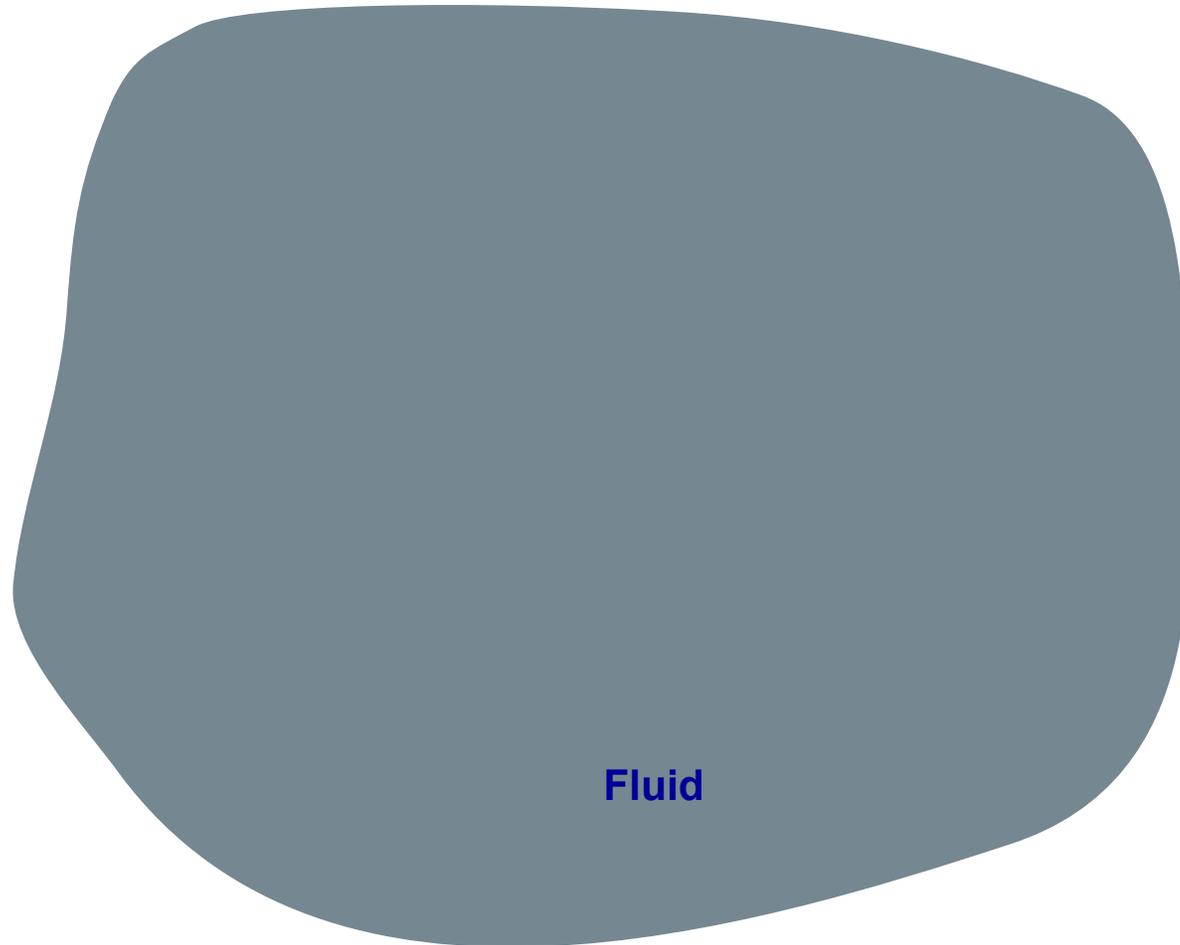
- **The fluid is incompressible**
- **No viscosity effects**
- **The fluid has uniform density, for example, no immiscible layers are allowed**
- **Internal (finite) fluids must have a free surface**
- **External fluids may or may not have a free surface**
- **No surface wave effects**
- **No gravity effects**
- **Irrotational flow**
- **No steady flow**
- **No nonlinear effects**

ASSUMPTIONS AND RESTRICTIONS (CONT.)

- **Important frequency range for structural modes is:**
 - Above the gravity sloshing frequencies
 - Below the compressible acoustic frequencies (speed of sound assumption)
- **Density within a volume is constant**
- **If a free surface is defined, the pressure at the surface is assumed to be zero.**
- **The interface between fluid and structure (the wetted surface) is comprised solely of CQUAD4 or CTRIA3 elements**
 - If for example a tank is meshed with solid elements, it will be necessary to coat the wetted surface with a thin layer of plate elements

SOME LEGAL CONFIGURATIONS

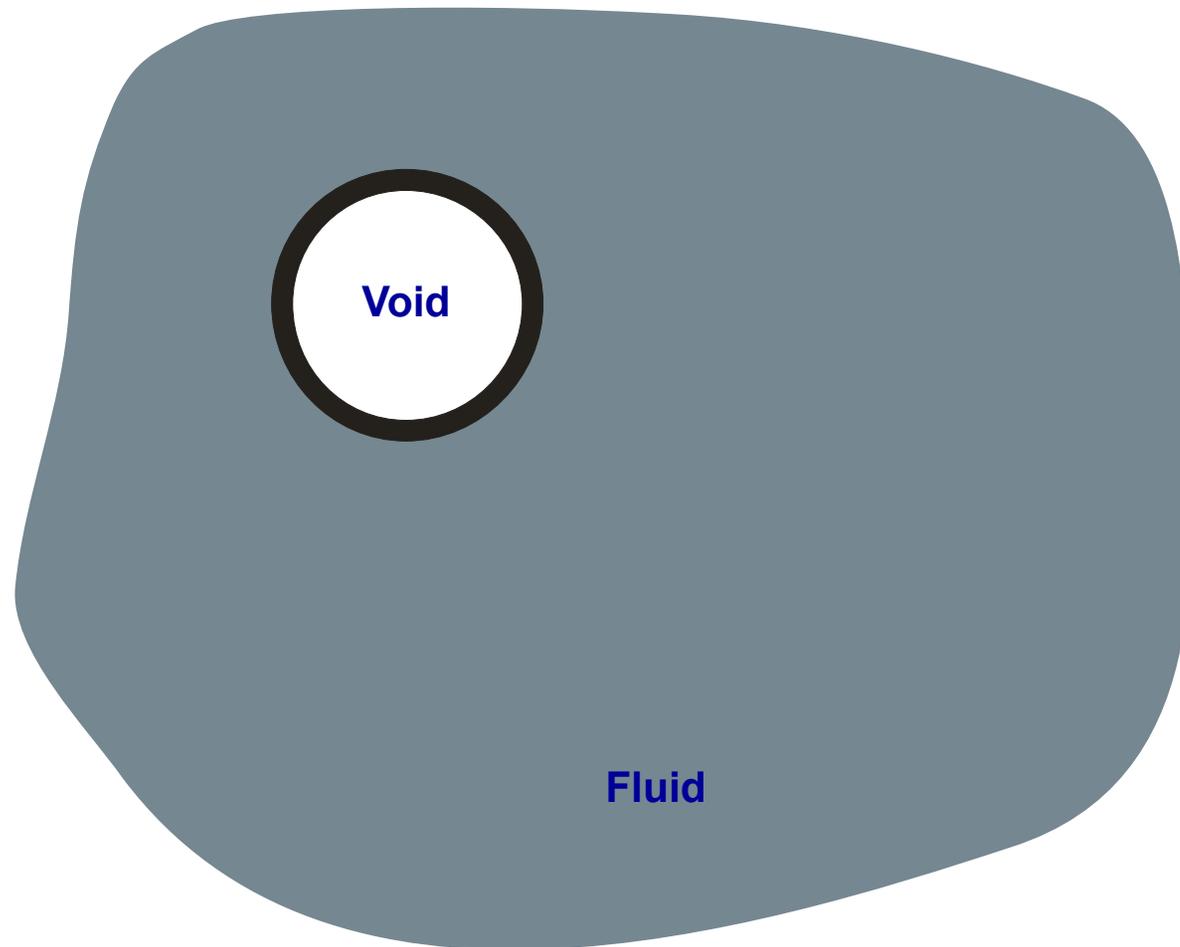
**Consider an
Infinite fluid**



Fluid

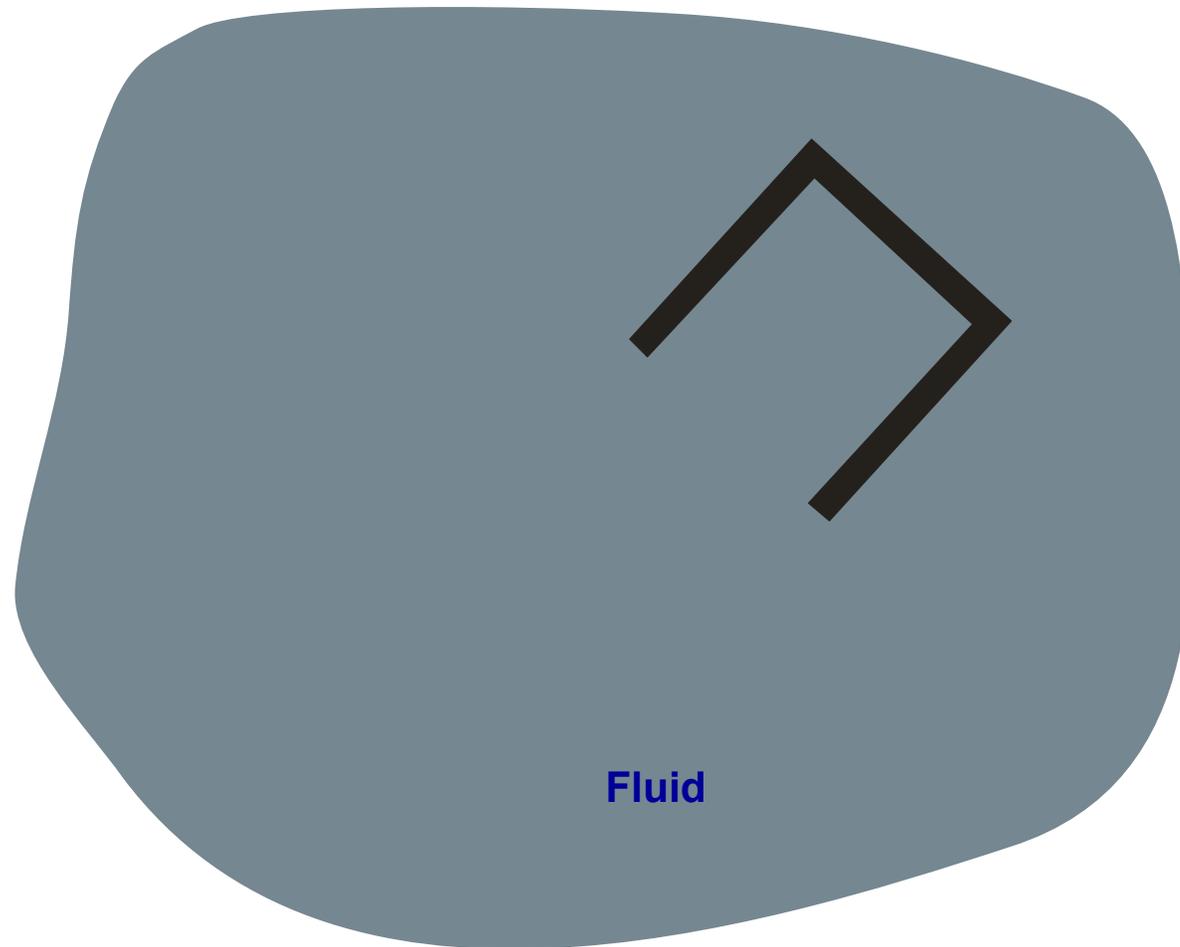
SOME LEGAL CONFIGURATIONS

**Empty closed
vessel in an
infinite fluid**



SOME LEGAL CONFIGURATIONS

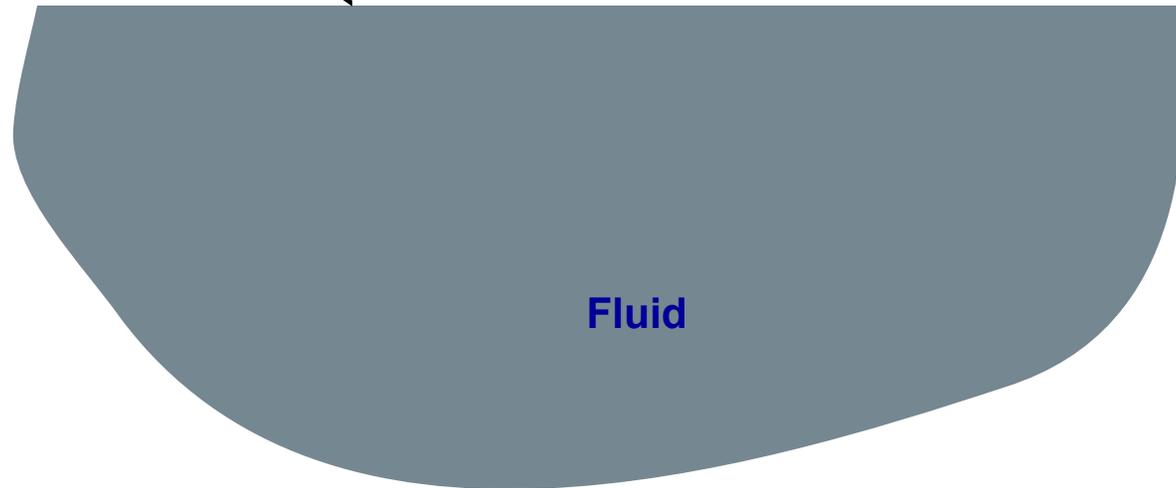
**Open
container in
an infinite
fluid**



SOME LEGAL CONFIGURATIONS

**Consider a
Finite fluid**

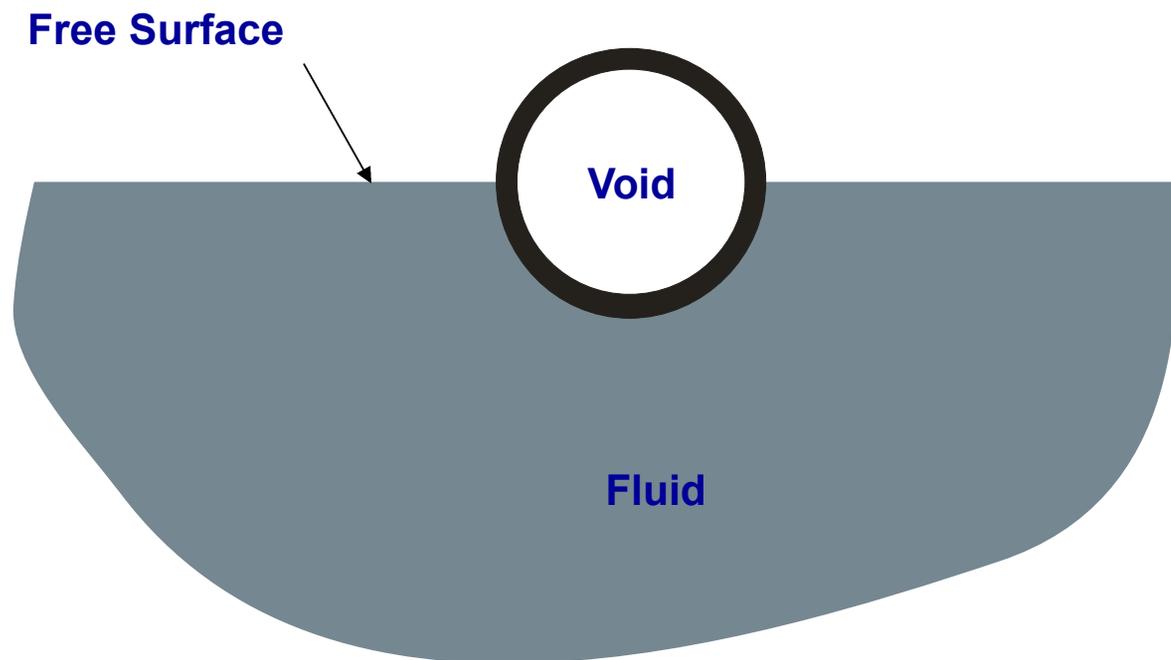
Free Surface



Fluid

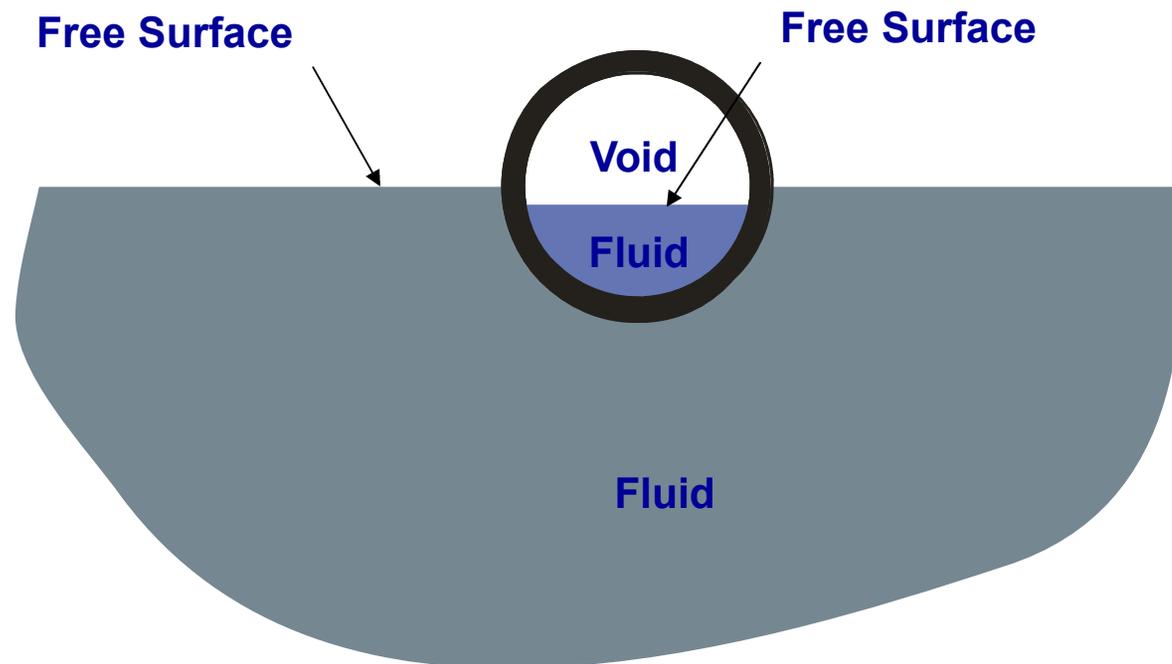
SOME LEGAL CONFIGURATIONS

**Empty closed
vessel in a
finite fluid**



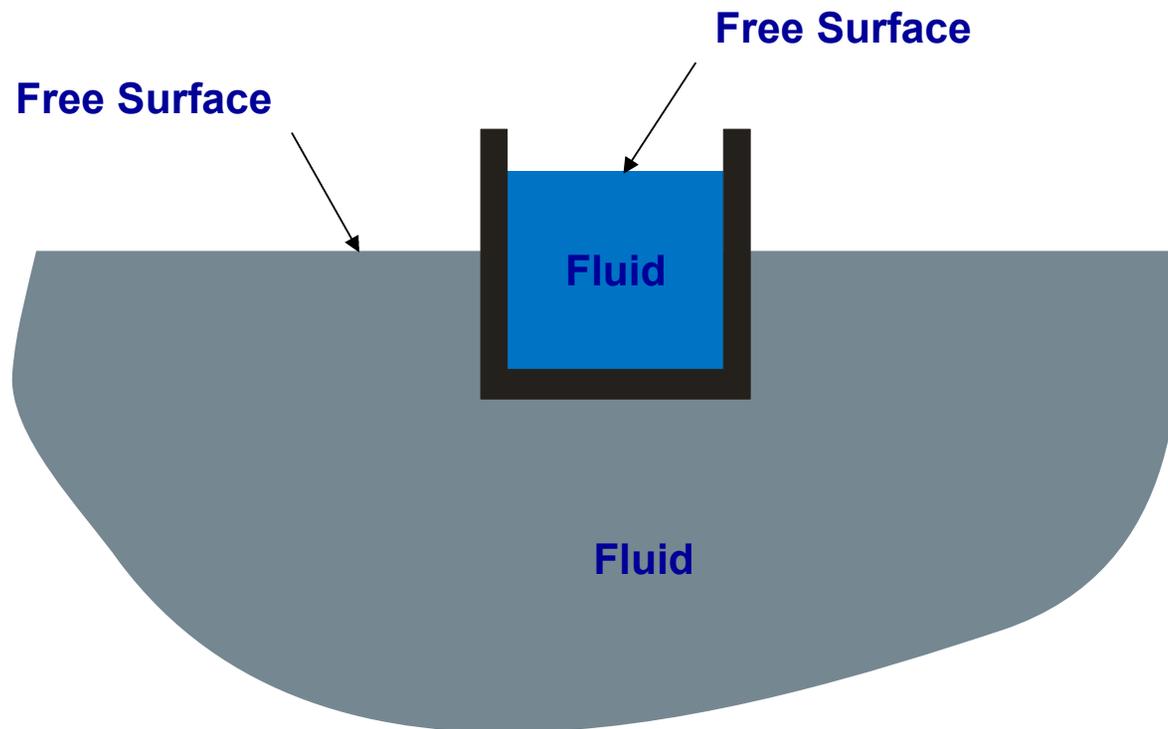
SOME LEGAL CONFIGURATIONS

**Partially filled
closed vessel
in a finite fluid**



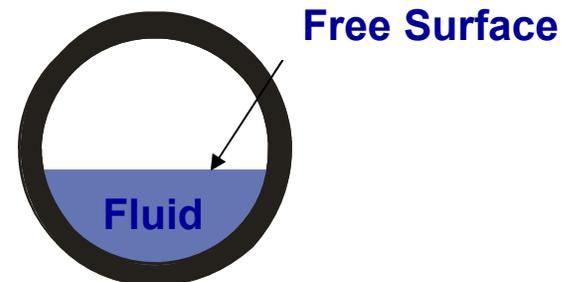
SOME LEGAL CONFIGURATIONS

**Partially filled
open vessel in
a finite fluid**



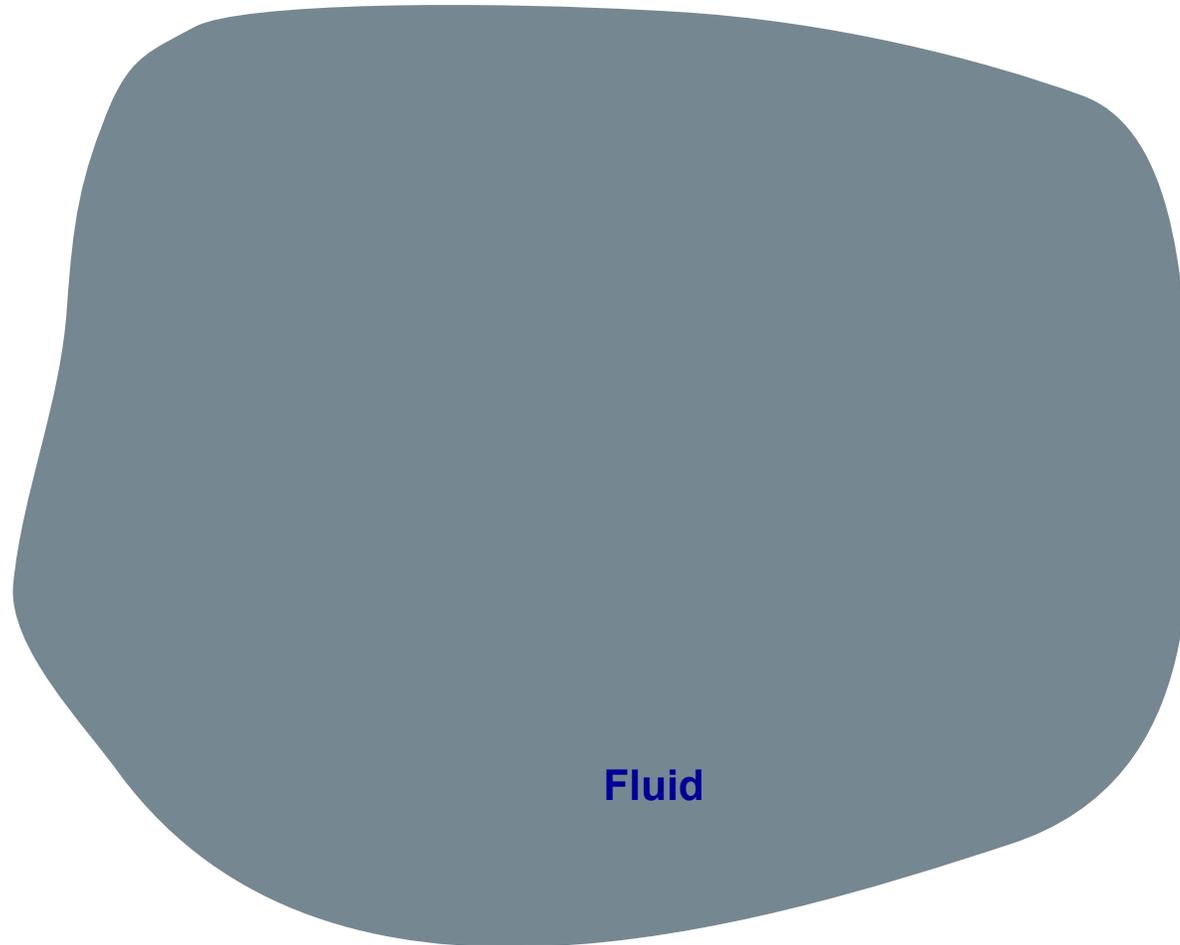
SOME LEGAL CONFIGURATIONS

**Closed vessel
with internal
fluid**



SOME ILLEGAL CONFIGURATIONS

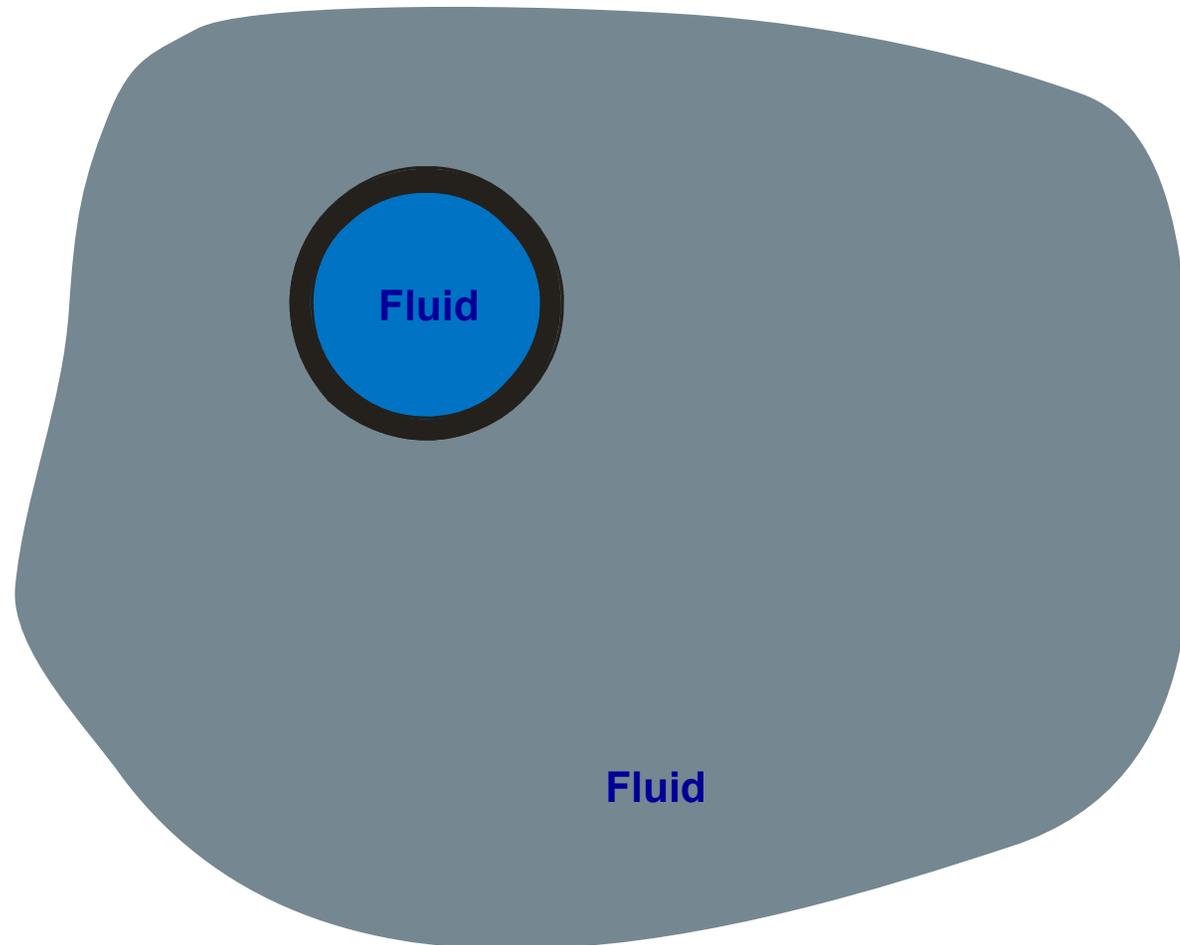
**Consider an
Infinite fluid**



Fluid

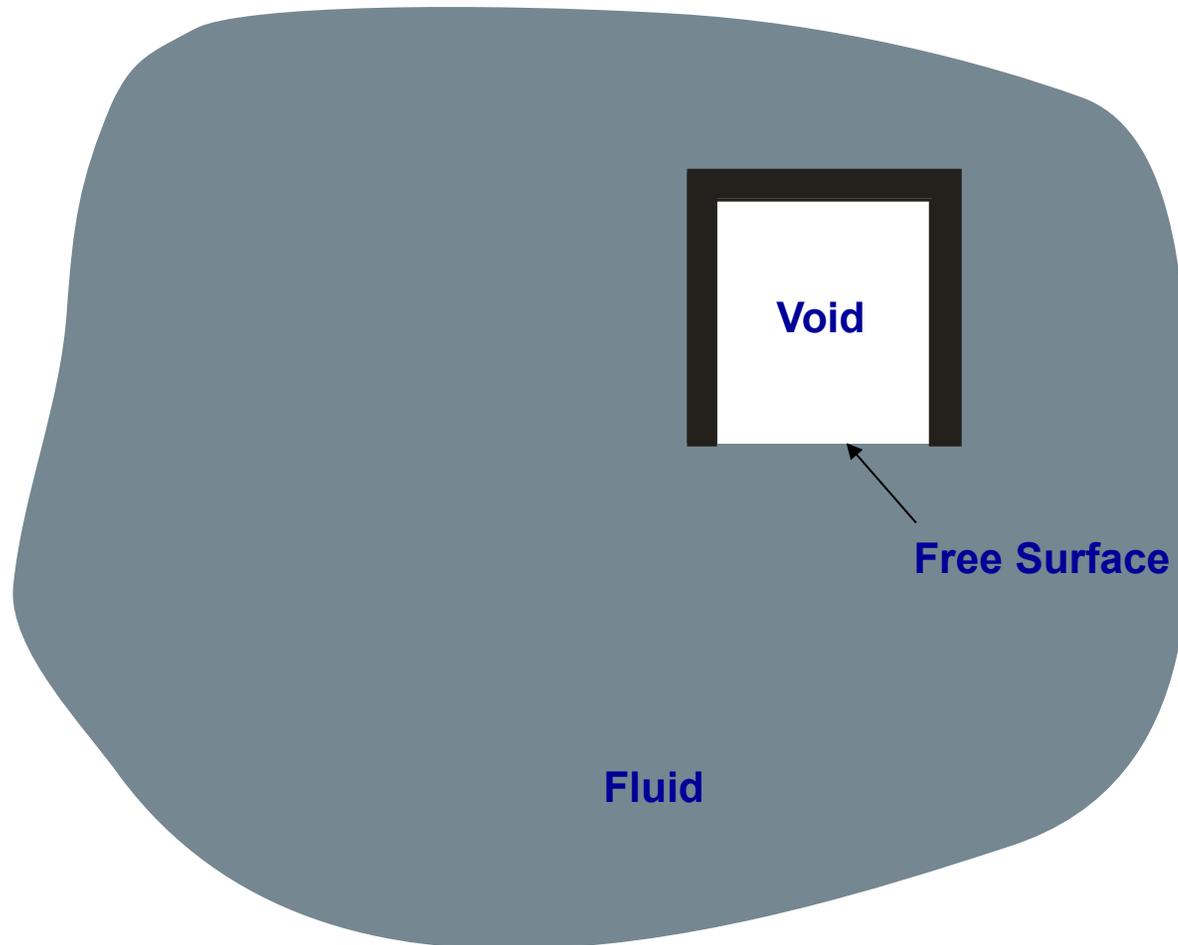
SOME ILLEGAL CONFIGURATIONS

**Completely
filled closed
vessel in an
infinite fluid**



SOME ILLEGAL CONFIGURATIONS

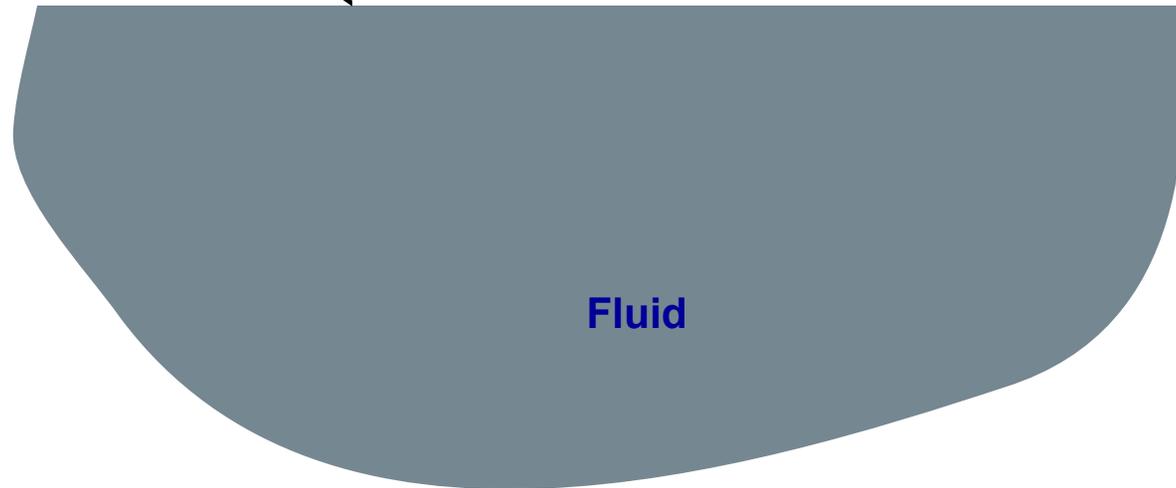
**Open
container with
a free surface
in an infinite
fluid**



SOME ILLEGAL CONFIGURATIONS

**Consider a
Finite fluid**

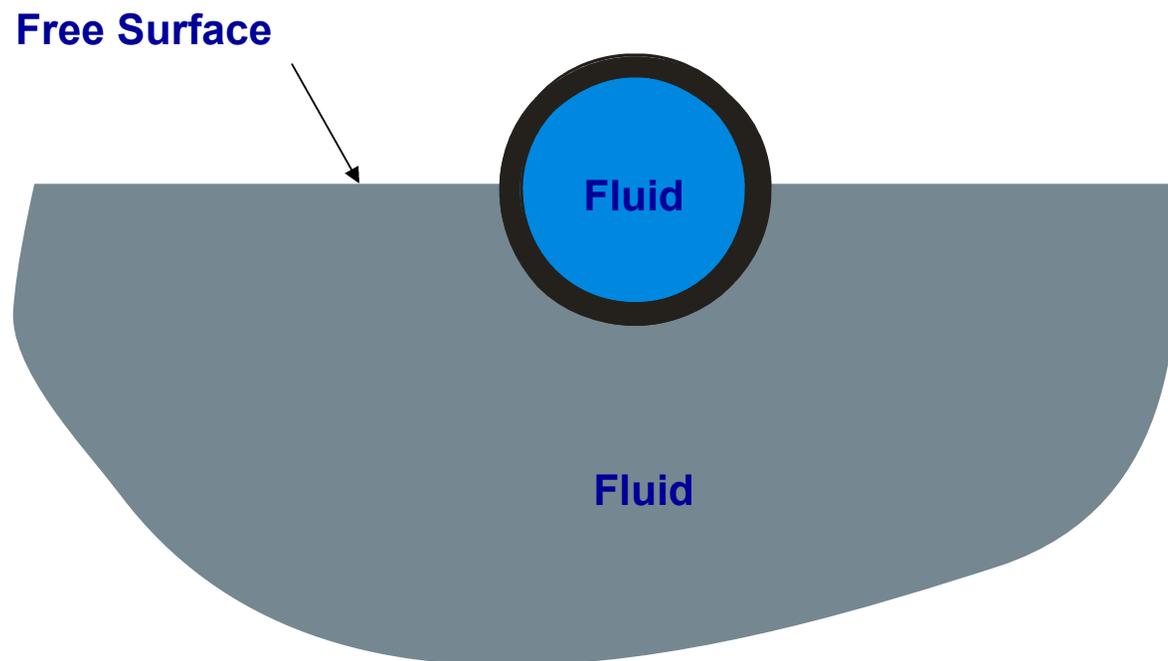
Free Surface



Fluid

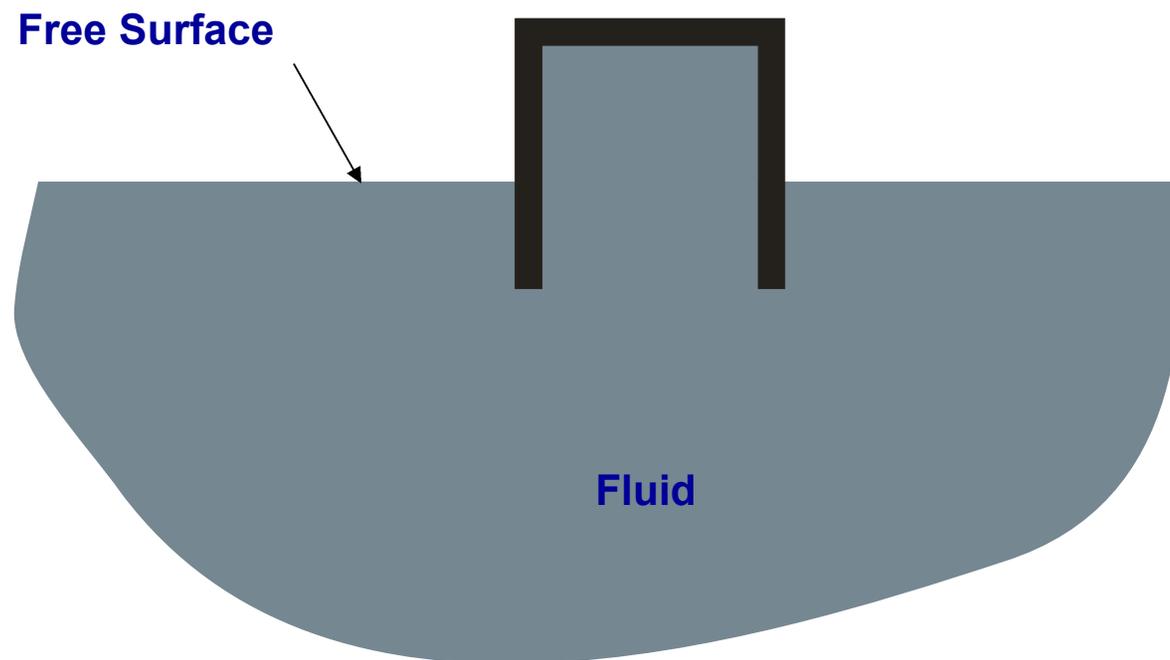
SOME ILLEGAL CONFIGURATIONS

**Completely
filled closed
vessel in a
finite fluid**



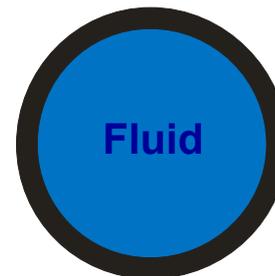
SOME ILLEGAL CONFIGURATIONS

**Open vessel
with no free
surface**



SOME ILLEGAL CONFIGURATIONS

**Completely
filled closed
vessel**



THE MFLUID ENTRY

- The **MFLUID** case control command references the **MFLUID** bulk data entry, which defines the fluid properties

```
SOL 103
CEND
DISP=ALL
MFLUID=17
SUBCASE 1
  METHOD=12
  BEGIN BULK
  GRID, 52, , 5.2, 3.4, 1.22
  ...
  MFLUID, 17, , 15., 1.225, 22, , N, N
  ...
```

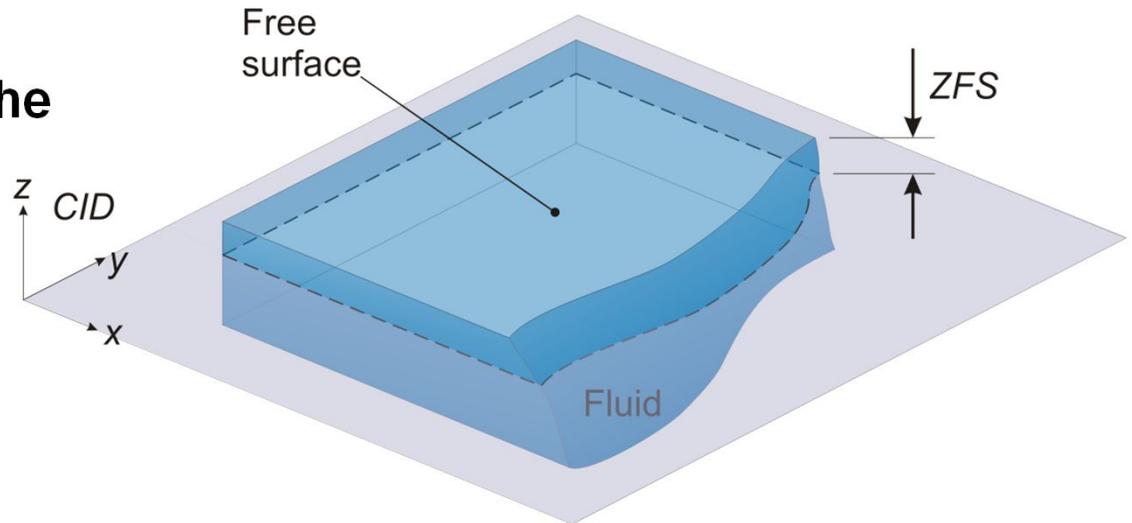
- Only one case control **MFLUID** entry is allowed, above **SUBCASE** level
- If there is no **MFLUID** case control entry present, no virtual mass will be calculated

- There may be one or more **MFLUID** bulk data entries

CID AND ZFS

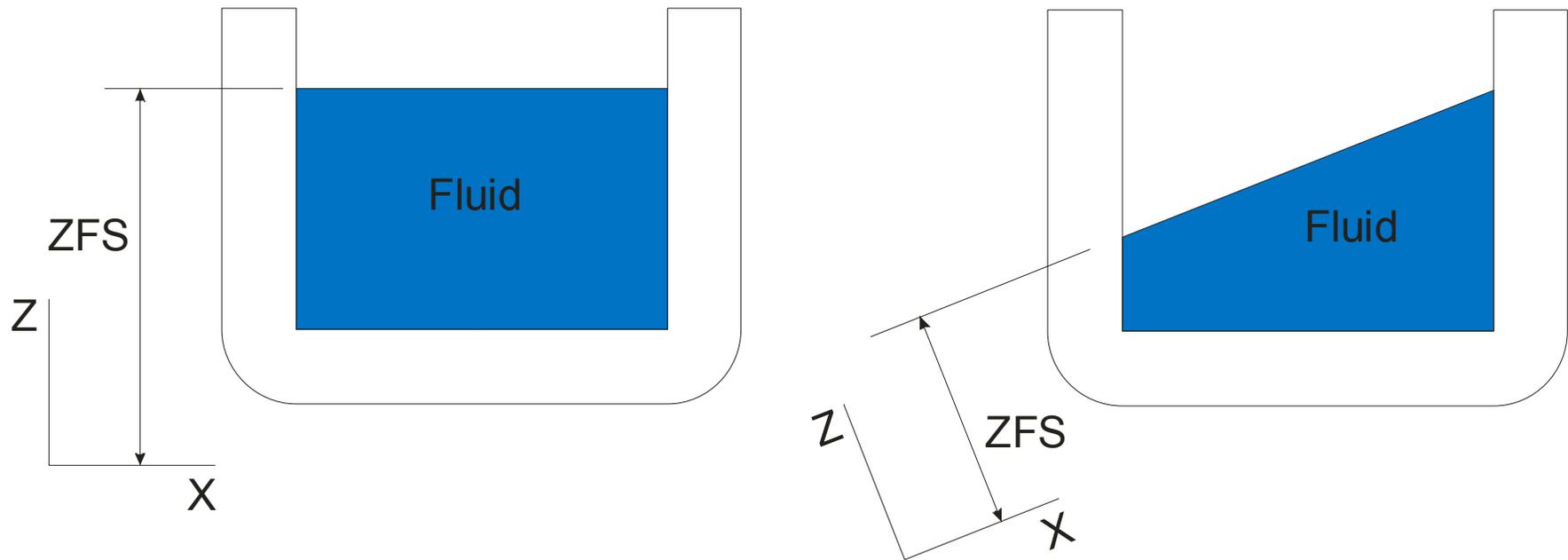
1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- The CID in field 3 allows a coordinate system to be defined, the Z direction of which is used to locate the free surface of the fluid. The value of ZFS in field 4 defines the location of the plane of the free surface which is parallel to the X-Y plane of the coordinate system defined by CID.
- If CID is left blank, the basic coordinate system is used



ZFS

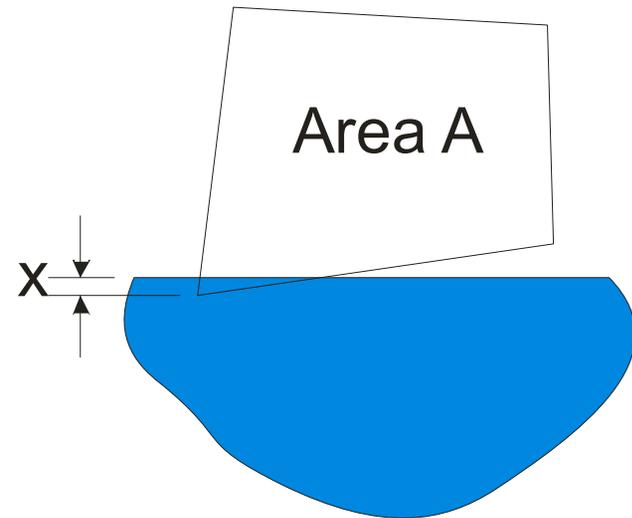
- The orientation of CID and ZFS is arbitrary



- If ZFS is left blank, an infinitely large positive value is assumed

ZFS – TO WET OR NOT

- An element that has all of its GRID points on or above the free surface is not wet (no virtual mass)
- A tolerance is calculated for each wetted element
 - $TOL = 0.01 * SQRT(2 * A)$
 - $A = \text{area of the element}$
- If $X < TOL$ for a GRID point, it is considered to be on the free surface and no virtual mass will be calculated for it



RHO, ELIST1 AND ELIST2

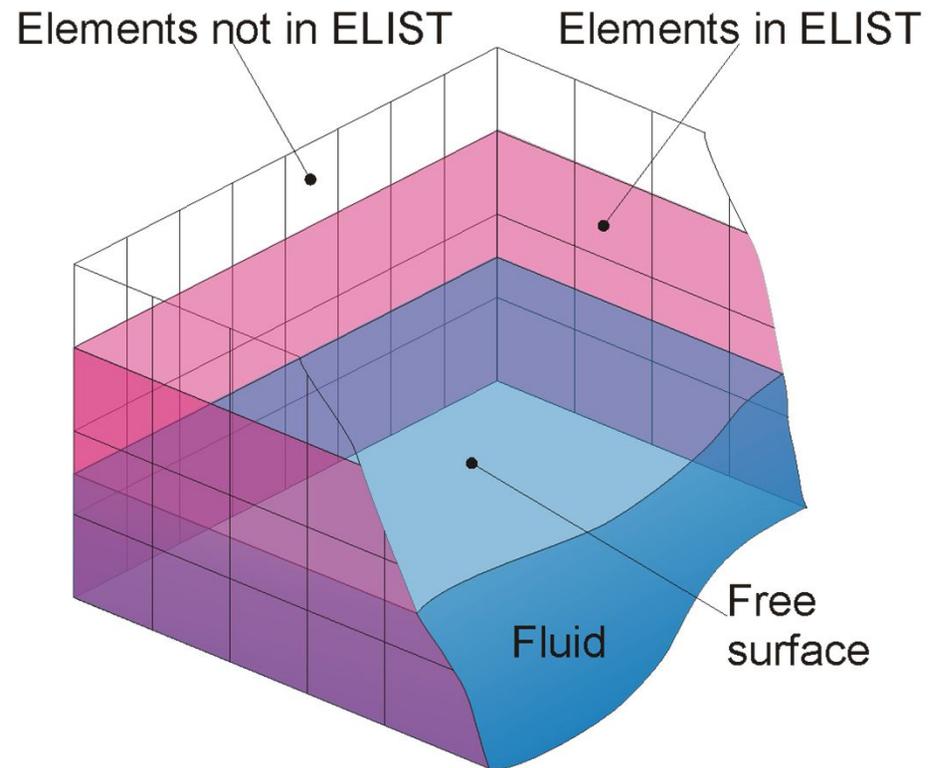
1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- **RHO in field 5 is the fluid density**
- **The MFLUID entry ELIST fields reference the wetted elements on ELIST bulk data entries**

1	2	3	4	5	6	7	8	9	10
ELIST	LID	E1	E2	E3	E4	E5	E6	E7	
	E8	E9	E10	etc.					

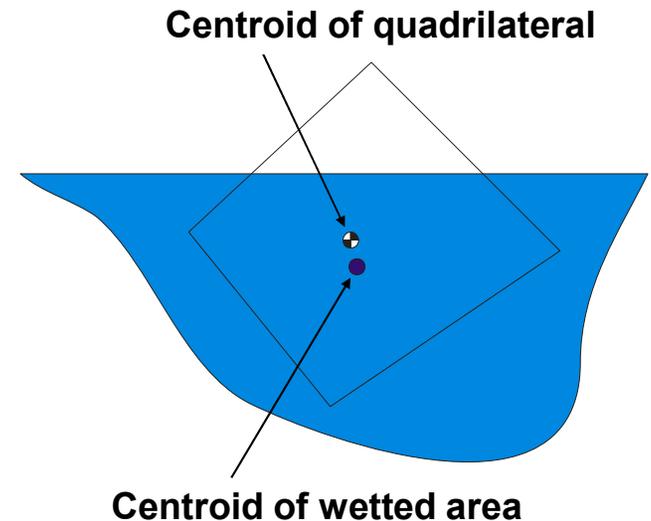
ELIST – CANDIDATES TO BE WET

- Any elements appearing on **ELIST** entries referenced by an active **MFLUID** entry are candidates to be wet by a fluid
- However, only elements below the free surface defined by **ZFS** are actually wetted



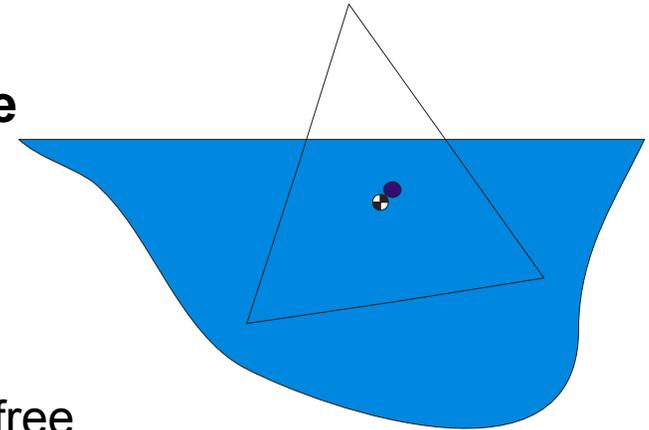
PARTIALLY WETTED ELEMENTS

- Geometrically, elements intersected by the free surface are only partially wetted
- To account for this, the centroids of the wetted areas are established
- Mass distribution for a partially wetted element is calculated using the same principal as static equilibrium among all GRID points of the element for a concentrated load applied at the centroid of the wetted area
- Therefore, virtual mass is calculated for all GRID points attached to the partially wetted element, even those above the free surface



PARTIALLY WETTED ELEMENTS

- **Virtual mass added above the free surface is mitigated by two effects**
- **Appropriate element mesh density**
 - If the finite element mesh in the region of the free surface is not too coarse, virtual mass added above the free surface can be minimized
- **Free surface pressure**
 - The pressure at the free surface is zero. It is therefore immediately obvious that pressures near the free surface are low resulting in lower relative values of mass for the virtual mass effects from elements near the free surface – any value of mass added to a GRID point above the free surface will therefore be of a correspondingly low value



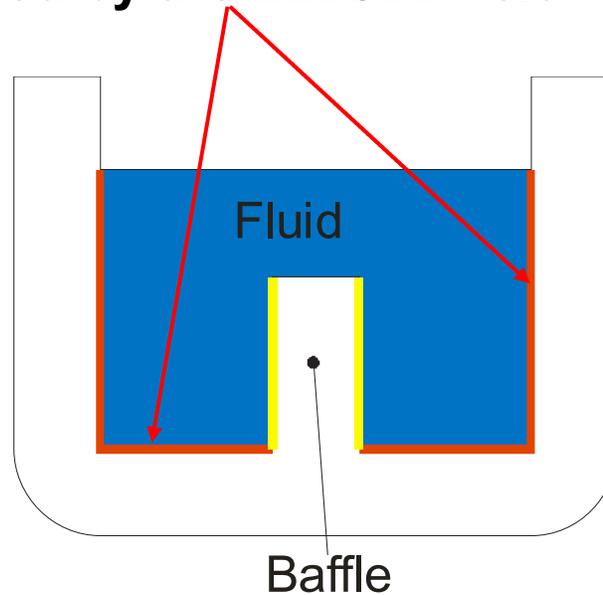
ELIST1 AND ELIST2

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- If elements are to be wet on one side only, they are added to an ELIST entry referenced by the ELIST1 field

```

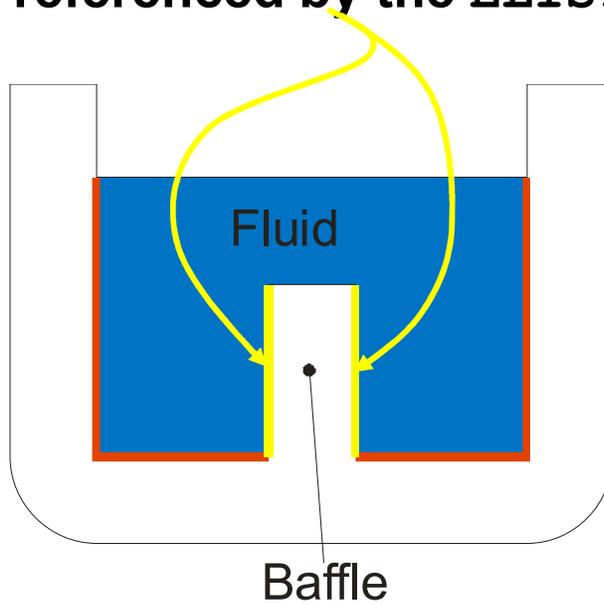
MFLUID=1
...
BEGIN BULK
...
MFLUID,1,,20.,1.,11,,N,N
...
ELIST,11,27,43,46
...
ENDDATA
    
```



ELIST1 AND ELIST2

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- If elements are to be wet on both sides by the same fluid (e.g. a baffle), they are added to an ELIST entry referenced by the ELIST2 field

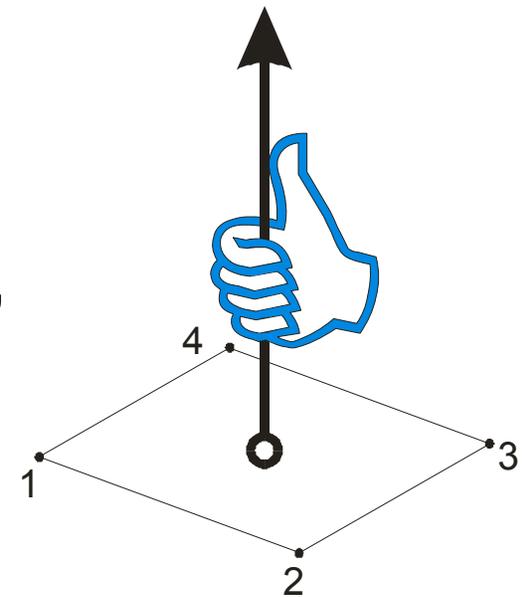


```

MFLUID=1
...
BEGIN BULK
...
MFLUID,1,,20.,1.,,12,N,N
...
ELIST,12,62,88,82
...
ENDDATA
    
```

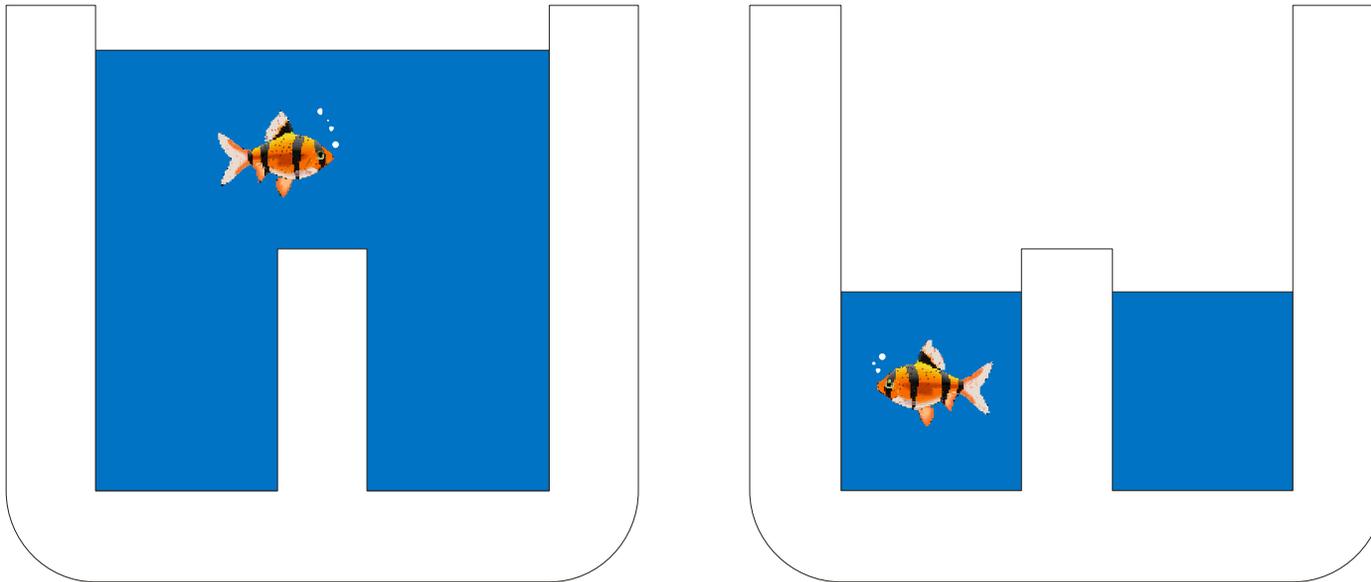
ELIST - WHICH SIDE IS WET?

- The right hand rule is used to determine which side of the elements on an **ELIST** entry, referenced by the **ELIST1** field, is wet
- The **GRID** point order gives the positive normal direction for the element
- If the id on the **ELIST** entry is positive, the element is wet on its positive normal side
- If the id on the **ELIST** entry is negative, the element is wet on the side opposite the positive normal side



ELIST

- A fluid may be represented by a single MFLUID bulk data entry only if a fish can swim from one region of the fluid to another



- If a fish cannot swim from one region to another, multiple MFLUID entries are needed (no jumping fish allowed!)

ELIST

- If elements form a barrier between unconnected fluids, they may appear on two **ELIST** entries each referenced by different **MFLUID** entries

```
MFLUID=1
```

```
...
```

```
BEGIN BULK
```

```
...
```

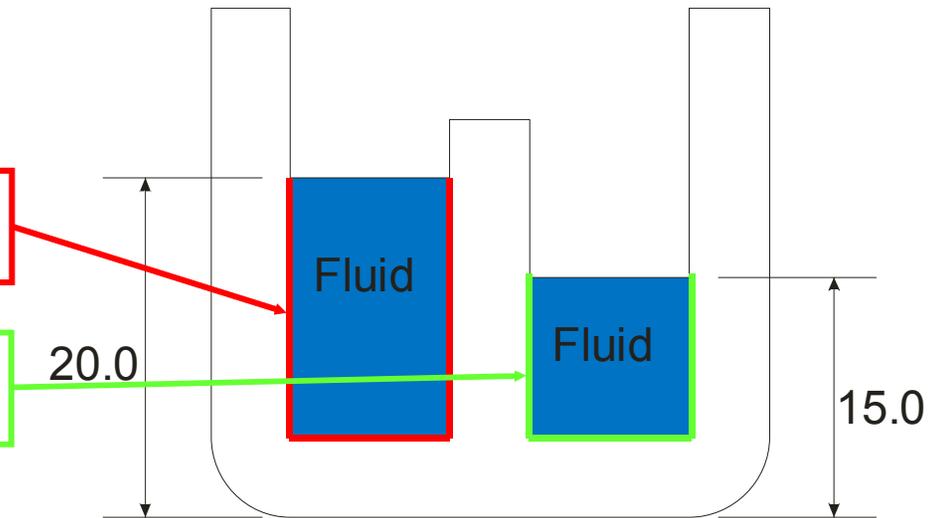
```
MFLUID,1,,20.,1.,11,,N,N  
ELIST,11,27,43,46,-58,-59,...
```

```
...
```

```
MFLUID,1,,15.,1.,12,,N,N  
ELIST,12,62,88,82,58,59,...
```

```
...
```

```
ENDDATA
```

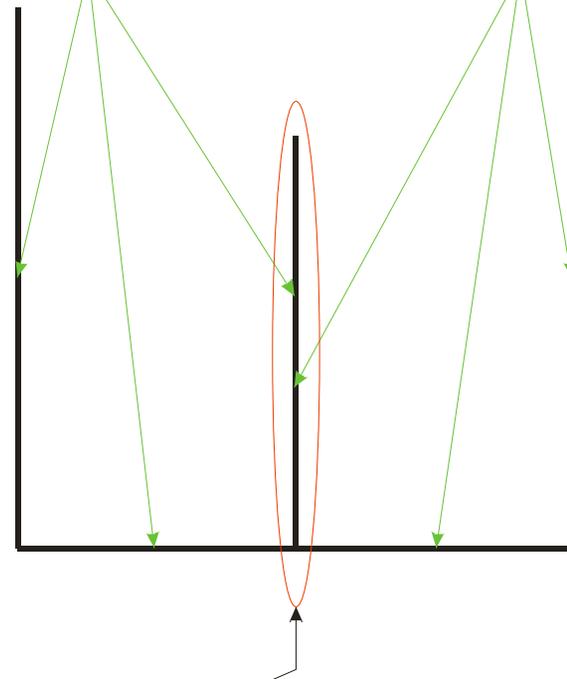


ELIST

```
MFLUID=1
...
BEGIN BULK
...
MFLUID,1,,20.,1.,11,,N,N
ELIST,11,27,43,46,-58,-59,...
...
MFLUID,1,,15.,1.,12,,N,N
ELIST,12,62,88,82,58,59,...
...
ENDDATA
```

ELIST1 for
ELIST 11

ELIST1 for
ELIST 12



These elements appear
on 2 ELIST entries

PLANE1 AND PLANE2

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- **Symmetry and anti-symmetry planes may be defined to reduce model size.**
- **Symmetry planes are planes of zero displacement.**
- **Anti-symmetry planes are planes of zero pressure.**
- **The free surface is treated exactly like a plane of anti-symmetry.**

PLANE1 AND PLANE2

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- **PLANE1** refers to the X-Z plane of the coordinate system defined by CID
- **PLANE2** refers to the Y-Z plane of the coordinate system defined by CID
- **PLANE1** and **PLANE2** may be defined as S, A or N
- **S** means the plane will be treated with a symmetry condition
- **A** means the plane will be treated with an anti-symmetry condition
- **N** means no symmetry treatment is defined

RMAX

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

- **RMAX may be used to limit the distance among elements for which interactions are calculated.**
- **If the elements are further away from each other than RMAX, then no interaction virtual mass terms will be calculated for these elements. This can speed up the calculation of the virtual mass matrix and reduced the density of the final mass matrix.**
- **The default value is 1.0E+10**

FMEXACT

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

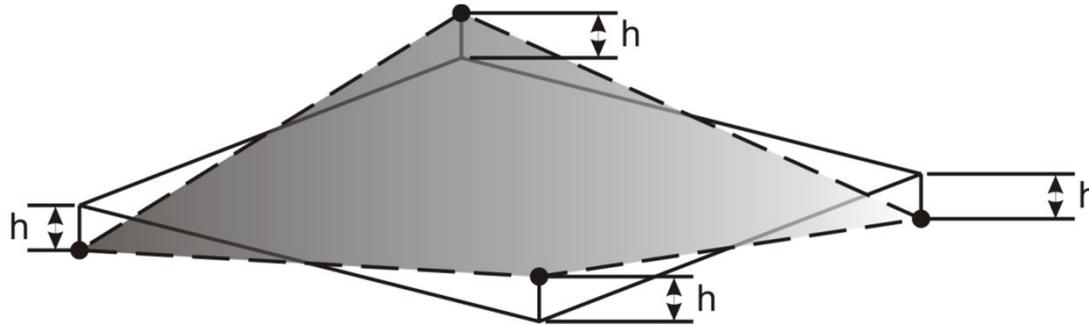
- **FMEXACT** may be used to limit the elements for which virtual mass terms are calculated using exact integration.
- Exact integration takes around 5 times longer than centre point integration to calculate the virtual mass terms, but the pay-off is better accuracy.
- By default a large value is defined (1.0E+15), which essentially means all terms are calculated using exact integration.

FMEXACT

1	2	3	4	5	6	7	8	9	10
MFLUID	SID	CID	ZFS	RHO	ELIST1	ELIST2	PLANE1	PLANE2	
	RMAX	FMEXACT							

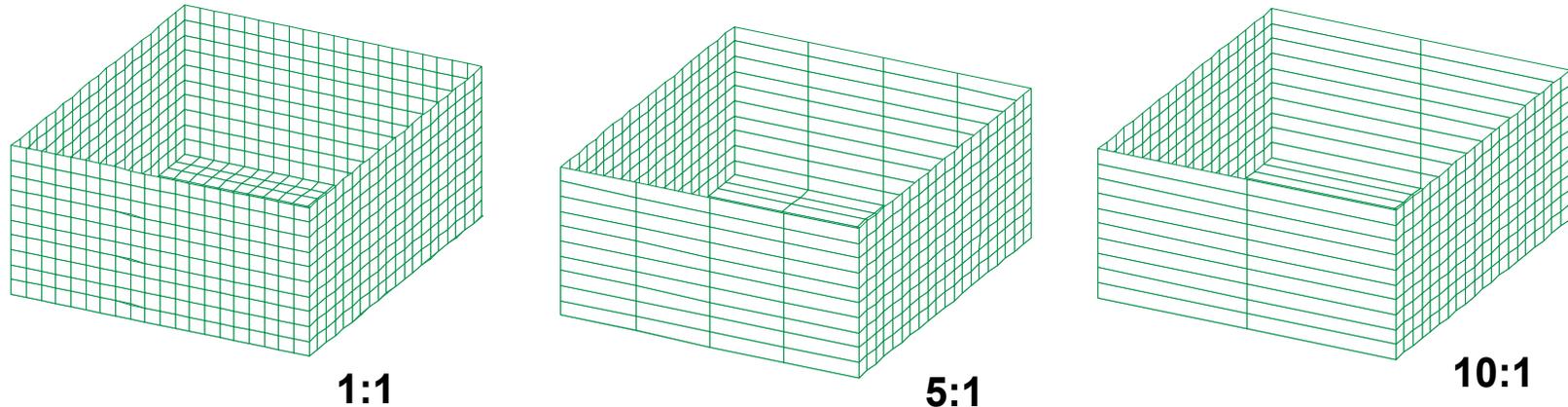
- **As the distance between elements increases relative to the cross sectional area of the elements, the relative magnitude of the virtual mass terms drops off rapidly. This means the virtual mass terms for distant elements are comparatively small, and errors in the virtual mass calculation become decreasingly important.**
- **Studies suggest that if the distance between elements is greater than 2 times the square root of the element with the largest area, errors will be lower than 5%. This corresponds to an FMEXACT value of 2.0, but its use is left to the discretion of the user.**

WARPED QUAD4 ELEMENTS



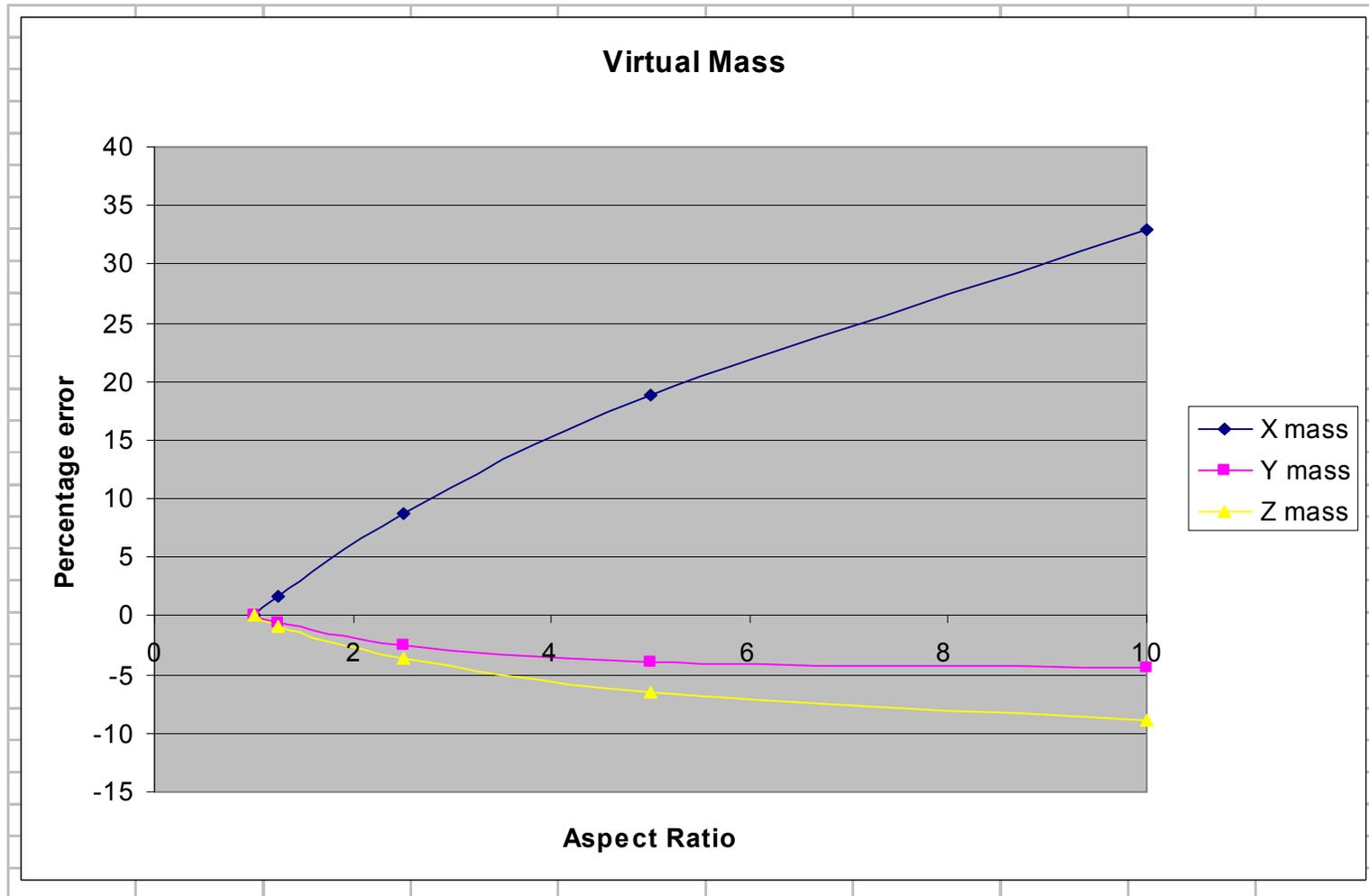
- If any QUAD4 elements are warped, the element is first projected onto a mid-plane which is then used for the virtual mass calculation
- This is a standard procedure for the QUAD4 element

QUAD4 ASPECT RATIO



- **The aspect ratio of QUAD4 elements should be kept below 2:1 to reduce errors in the virtual mass calculation**
- **The following graph compares the values of virtual mass in the X,Y & Z directions with the value obtained from a model using elements with only aspect ratios of 1.0**

QUAD4 ASPECT RATIO



MFLUID REMARKS

- **Several MFLUID entries, each corresponding to a different fluid volume, may be used simultaneously.**
- **If there is an ELIST present, and there is no free surface (ZFS is blank) nor planes of anti-symmetry (PLANE1 & PLANE2 are either S or N), a special external fluid is assumed.**
- **For the special external fluid case, the origin of the coordinate system on the MFLUID entry must be close to the center of the enclosed volume.**

EFFICIENCY OPTIONS FOR VIRTUAL MASS

- **Virtual Mass generates dense mass matrix**
 - Modes runs can be expensive for large model
- **The VMOPT parameter is a method to include or exclude the virtual mass effects during the normal mode calculation for the modal dynamic solutions (i.e., SOLs 103, 110, 108,109,111 and 112)**
- **For large model using frequency response or transient response**
 - May consider using the “direct method” (sol 108/109)
 - Bypasses the more time consuming normal modes calculation, due to dense and coupled mass matrix
- **Three options to perform virtual mass analysis:**
 - PARAM,VMOPT,0 (default)
 - PARAM,VMOPT,1
 - PARAM,VMOPT,2

EFFICIENCY OPTIONS FOR VIRTUAL MASS

- **Param,vmopt,0** (default)

- VM is added before eigenvalue calculation
 - Similar to vmopt,1 when component modes are not requested
- Option to perform component modes by specifying qset points on structure and VM is added afterwards to perform a 2nd eigenvalue calculation
 - Similar to vmopt,2 when component modes are requested
 - Autoqset is not supported
 - Must request more modes than desired. Higher modes are not accurate
- GPWG output does not contain fluid mass

- **Param,vmopt,1**

- VM is added before eigenvalue calculation
- This is the most expensive and accurate option (only practical in testing academic problems)
- Not feasible for any decent size production model
- GPWG output does contain the virtual fluid mass in mass output.

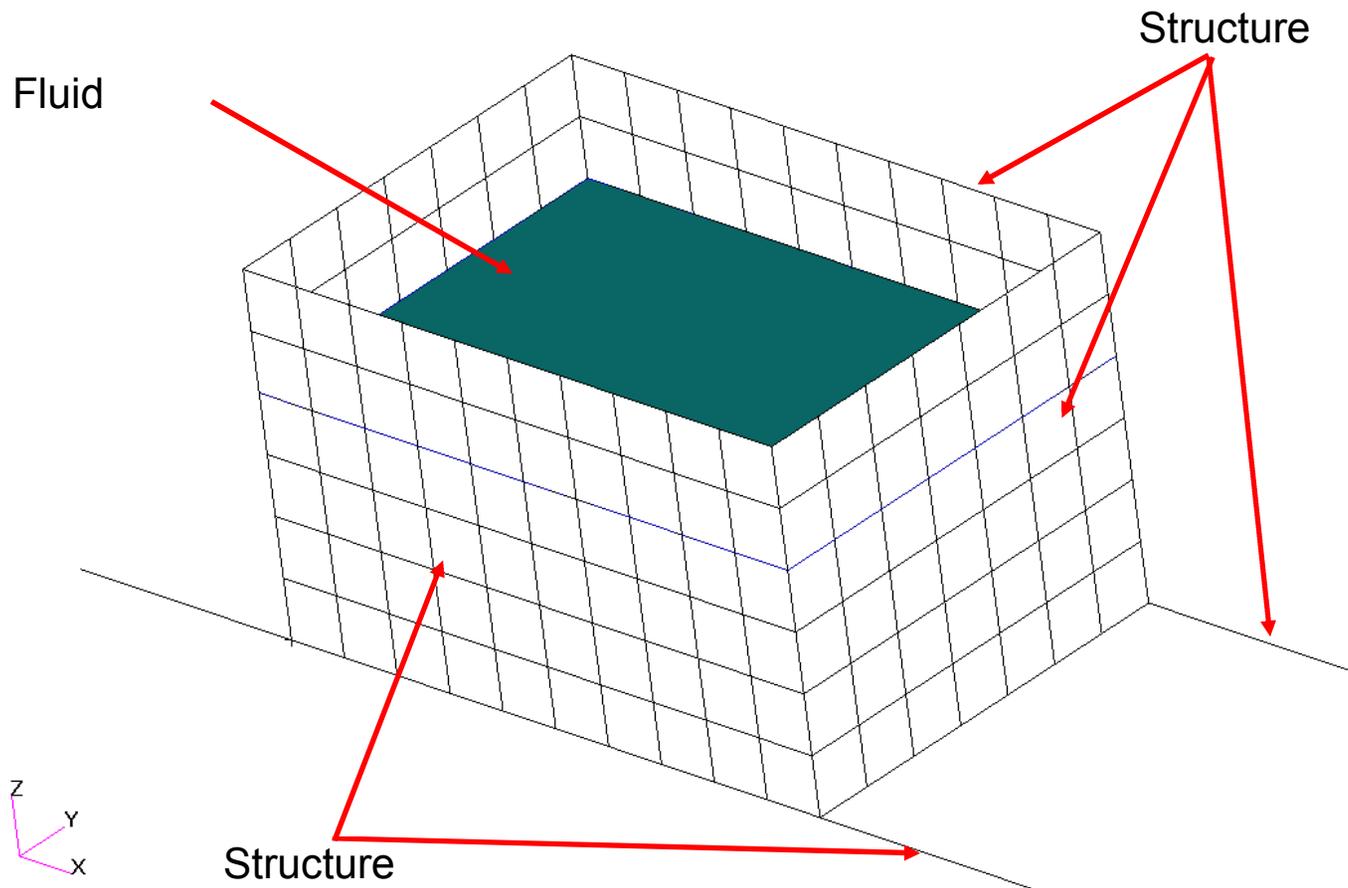
EFFICIENCY OPTIONS FOR VIRTUAL MASS

▪ Param,vmopt,2

- Less expensive, implemented to improve efficiency
- Calculate modes of structure without VM or fluid effects(dry modes)
- Use these modes to form generalized coordinates
- A modal reduction is performed on the structure and the fluid, then combined.
- 2nd eigenvalue calculation with the VM added (wet modes)
- Both eigenvalue tables are printed, allowing comparison of the dry and wet modes.
- Only practical method with high VM density (more than several hundred fluid elements)
- Must request more modes than desired. A general rule-of-thumb is to double the frequency range of interest. Higher modes are not accurate.
- GPWG output does not contain the virtual fluid mass, but the virtual mass of the fluid is printed in a separate table.

EXAMPLE 1

- Tank with fluid and interested in 1st 10 modes



EXAMPLE 1

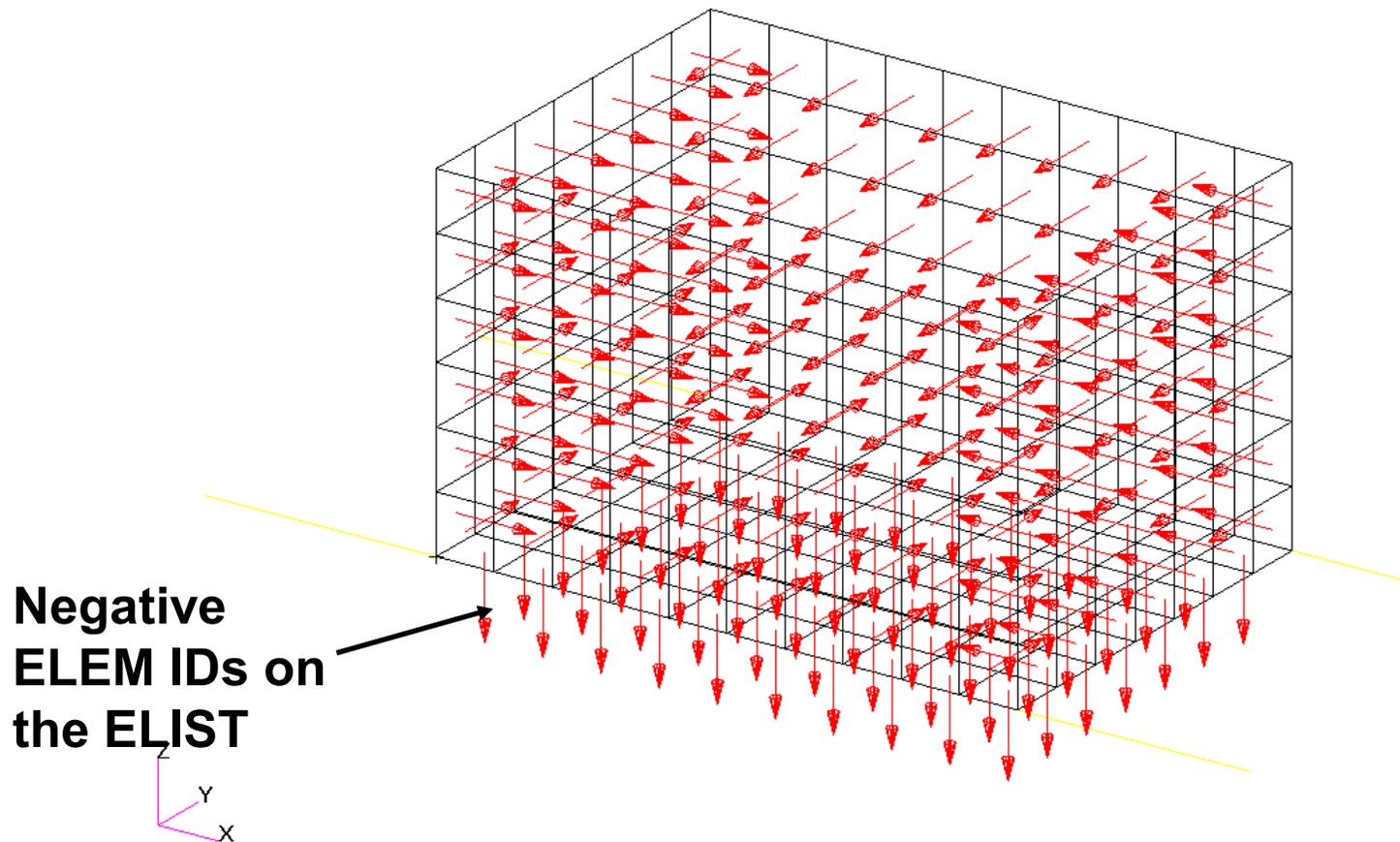
```
SOL 103
CEND
TITLE = tank with virtual mass - vmopt=0 - no qset
  SPC = 1
  DISPLACEMENT=ALL
$
subcase 2
method=10
mfluid=5
$
BEGIN BULK
param,vmopt,0
PARAM POST 0
$
cord2r,1,, 5.0,3.5,0, 5.0,3.5,1.0,+
+, 6.0,3.5,0.0
$
mfluid, 5, 1, 4.0, 9.35e-5, 11,, n, n
elist,11, -33,thru,-102, 103,thru,306
$
eigr1,10,,10
$
SPC1  1  123456 4  8  12  16
$
include 'tank.bdf'
$
ENDDATA
```

Free
Surface

Fluid
Density

EXAMPLE 1

- Element Normal (isometric view)



EXAMPLE 1

- **Example is run 7 different ways**
 1. Without fluid – request 10 modes
 2. With fluid and using vmopt,1 – request 10 modes
 3. With fluid and using default vmopt,0 – request 10 modes
 4. With fluid and using default vmopt,0 – request 10 modes and component modes
 5. With fluid and using default vmopt,0 – request 50 modes and component modes
 6. With fluid and using vmopt,2 – request 10 modes
 7. With fluid and using vmopt,2 – request 50 modes

EXAMPLE 1

1. Without fluid – request 10 modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	1.426740E+04	1.194462E+02	1.901045E+01	1.000000E+00	1.426740E+04
2	2	1.845324E+04	1.358427E+02	2.162004E+01	1.000000E+00	1.845324E+04
3	3	3.864439E+04	1.965818E+02	3.128696E+01	1.000000E+00	3.864439E+04
4	4	5.460051E+04	2.336675E+02	3.718934E+01	1.000000E+00	5.460051E+04
5	5	9.874239E+04	3.142330E+02	5.001174E+01	1.000000E+00	9.874239E+04
6	6	1.006206E+05	3.172075E+02	5.048513E+01	1.000000E+00	1.006206E+05
7	7	1.310010E+05	3.619406E+02	5.760463E+01	1.000000E+00	1.310010E+05
8	8	1.698014E+05	4.120697E+02	6.558292E+01	1.000000E+00	1.698014E+05
9	9	1.754530E+05	4.188711E+02	6.666540E+01	1.000000E+00	1.754530E+05
10	10	1.788128E+05	4.228626E+02	6.730067E+01	1.000000E+00	1.788128E+05

2. With fluid and using vmopt,1 – request 10 modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	8.812992E+02	2.968668E+01	4.724782E+00	1.000000E+00	8.812992E+02
2	2	1.681743E+03	4.100906E+01	6.526794E+00	1.000000E+00	1.681743E+03
3	3	1.767828E+03	4.204555E+01	6.691757E+00	1.000000E+00	1.767828E+03
4	4	2.897365E+03	5.382718E+01	8.566862E+00	1.000000E+00	2.897365E+03
5	5	3.323205E+03	5.764724E+01	9.174844E+00	1.000000E+00	3.323205E+03
6	6	3.872637E+03	6.223051E+01	9.904293E+00	1.000000E+00	3.872637E+03
7	7	7.576898E+03	8.704538E+01	1.385370E+01	1.000000E+00	7.576898E+03
8	8	8.477134E+03	9.207135E+01	1.465361E+01	1.000000E+00	8.477134E+03
9	9	1.371607E+04	1.171156E+02	1.863953E+01	1.000000E+00	1.371607E+04
10	10	1.684915E+04	1.298043E+02	2.065899E+01	1.000000E+00	1.684915E+04

EXAMPLE 1

3. With fluid and using default vmopt,0 – request 10 modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	8.812992E+02	2.968668E+01	4.724782E+00	1.000000E+00	8.812992E+02
2	2	1.681743E+03	4.100906E+01	6.526794E+00	1.000000E+00	1.681743E+03
3	3	1.767828E+03	4.204555E+01	6.691757E+00	1.000000E+00	1.767828E+03
4	4	2.897365E+03	5.382718E+01	8.566862E+00	1.000000E+00	2.897365E+03
5	5	3.323205E+03	5.764724E+01	9.174844E+00	1.000000E+00	3.323205E+03
6	6	3.872637E+03	6.223051E+01	9.904293E+00	1.000000E+00	3.872637E+03
7	7	7.576898E+03	8.704538E+01	1.385370E+01	1.000000E+00	7.576898E+03
8	8	8.477134E+03	9.207135E+01	1.465361E+01	1.000000E+00	8.477134E+03
9	9	1.371607E+04	1.171156E+02	1.863953E+01	1.000000E+00	1.371607E+04
10	10	1.684915E+04	1.298043E+02	2.065899E+01	1.000000E+00	1.684915E+04

4. With fluid and using default vmopt,0 – request 10 modes and component modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	9.431653E+02	3.071100E+01	4.887807E+00	1.000000E+00	9.431653E+02
2	2	1.718486E+03	4.145463E+01	6.597709E+00	1.000000E+00	1.718486E+03
3	3	1.807031E+03	4.250919E+01	6.765547E+00	1.000000E+00	1.807031E+03
4	4	3.049137E+03	5.521899E+01	8.788375E+00	1.000000E+00	3.049137E+03
5	5	4.495334E+03	6.704726E+01	1.067090E+01	1.000000E+00	4.495334E+03
6	6	5.177262E+03	7.195319E+01	1.145171E+01	1.000000E+00	5.177262E+03
7	7	1.057092E+04	1.028150E+02	1.636351E+01	1.000000E+00	1.057092E+04
8	8	1.356802E+04	1.164818E+02	1.853866E+01	1.000000E+00	1.356802E+04
9	9	2.994362E+04	1.730423E+02	2.754053E+01	1.000000E+00	2.994362E+04
10	10	3.347340E+04	1.829574E+02	2.911857E+01	1.000000E+00	3.347340E+04

EXAMPLE 1

5. With fluid and using default vmopt,0 – request 50 modes and component modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	8.833276E+02	2.972083E+01	4.730217E+00	1.000000E+00	8.833276E+02
2	2	1.683238E+03	4.102728E+01	6.529695E+00	1.000000E+00	1.683238E+03
3	3	1.769334E+03	4.206345E+01	6.694606E+00	1.000000E+00	1.769334E+03
4	4	2.904254E+03	5.389114E+01	8.577041E+00	1.000000E+00	2.904254E+03
5	5	3.332036E+03	5.772379E+01	9.187027E+00	1.000000E+00	3.332036E+03
6	6	3.894524E+03	6.240612E+01	9.932242E+00	1.000000E+00	3.894524E+03
7	7	7.604702E+03	8.720494E+01	1.387910E+01	1.000000E+00	7.604702E+03
8	8	8.490837E+03	9.214574E+01	1.466545E+01	1.000000E+00	8.490837E+03
9	9	1.413513E+04	1.188912E+02	1.892213E+01	1.000000E+00	1.413513E+04
10	10	1.726702E+04	1.314040E+02	2.091360E+01	1.000000E+00	1.726702E+04
11	11	2.221150E+04	1.490352E+02	2.371969E+01	1.000000E+00	2.221150E+04
12	12	2.376125E+04	1.541468E+02	2.453323E+01	1.000000E+00	2.376125E+04
13	13	2.684310E+04	1.638386E+02	2.607573E+01	1.000000E+00	2.684310E+04
14	14	2.814782E+04	1.677731E+02	2.670192E+01	1.000000E+00	2.814782E+04
15	15	2.865218E+04	1.692695E+02	2.694008E+01	1.000000E+00	2.865218E+04
16	16	3.046947E+04	1.745551E+02	2.778130E+01	1.000000E+00	3.046947E+04
17	17	3.294541E+04	1.815087E+02	2.888801E+01	1.000000E+00	3.294541E+04
18	18	3.933098E+04	1.983204E+02	3.156367E+01	1.000000E+00	3.933098E+04
19	19	4.376307E+04	2.091962E+02	3.329462E+01	1.000000E+00	4.376307E+04
20	20	6.445804E+04	2.538859E+02	4.040719E+01	1.000000E+00	6.445804E+04
21	21	6.758982E+04	2.599804E+02	4.137717E+01	1.000000E+00	6.758982E+04
22	22	7.890756E+04	2.809049E+02	4.470741E+01	1.000000E+00	7.890756E+04
23	23	8.286220E+04	2.878579E+02	4.581401E+01	1.000000E+00	8.286220E+04
24	24	9.895093E+04	3.145647E+02	5.006452E+01	1.000000E+00	9.895093E+04
25	25	1.010583E+05	3.178967E+02	5.059483E+01	1.000000E+00	1.010583E+05
26	26	1.068547E+05	3.268864E+02	5.202559E+01	1.000000E+00	1.068547E+05
27	27	1.432133E+05	3.784353E+02	6.022985E+01	1.000000E+00	1.432133E+05
28	28	1.455310E+05	3.814852E+02	6.071526E+01	1.000000E+00	1.455310E+05
29	29	1.539298E+05	3.923389E+02	6.244267E+01	1.000000E+00	1.539298E+05
30	30	1.574020E+05	3.967392E+02	6.314300E+01	1.000000E+00	1.574020E+05
31	31	1.756281E+05	4.190800E+02	6.669866E+01	1.000000E+00	1.756281E+05
32	32	1.756312E+05	4.190837E+02	6.669924E+01	1.000000E+00	1.756312E+05
33	33	1.798374E+05	4.240724E+02	6.749321E+01	1.000000E+00	1.798374E+05
34	34	1.885432E+05	4.342156E+02	6.910756E+01	1.000000E+00	1.885432E+05
35	35	1.950661E+05	4.416629E+02	7.029283E+01	1.000000E+00	1.950661E+05
36	36	2.069792E+05	4.549496E+02	7.240749E+01	1.000000E+00	2.069792E+05
37	37	2.198725E+05	4.689056E+02	7.462865E+01	1.000000E+00	2.198725E+05
38	38	2.204072E+05	4.694755E+02	7.471934E+01	1.000000E+00	2.204072E+05
39	39	3.264553E+05	5.713627E+02	9.093520E+01	1.000000E+00	3.264553E+05
40	40	3.455634E+05	5.878464E+02	9.355866E+01	1.000000E+00	3.455634E+05
41	41	3.779384E+05	6.147670E+02	9.784320E+01	1.000000E+00	3.779384E+05
42	42	5.699876E+05	7.549752E+02	1.201580E+02	1.000000E+00	5.699876E+05
43	43	6.158501E+05	7.847612E+02	1.248986E+02	1.000000E+00	6.158501E+05
44	44	6.498905E+05	8.061578E+02	1.283040E+02	1.000000E+00	6.498905E+05
45	45	7.099879E+05	8.426078E+02	1.341052E+02	1.000000E+00	7.099879E+05
46	46	8.370758E+05	9.149185E+02	1.456138E+02	1.000000E+00	8.370758E+05
47	47	9.089189E+05	9.533724E+02	1.517339E+02	1.000000E+00	9.089189E+05
48	48	1.046522E+06	1.022997E+03	1.628150E+02	1.000000E+00	1.046522E+06
49	49	1.273300E+06	1.128406E+03	1.795914E+02	1.000000E+00	1.273300E+06
50	50	1.494629E+06	1.222550E+03	1.945749E+02	1.000000E+00	1.494629E+06

EXAMPLE 1

6. With fluid and using vmopt,2 – request 10 modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	R E A L E I G E N V A L U E S (AFTER VIRTUAL MASS EFFECTS ARE INCLUDED)		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	9.484548E+02	3.079699E+01	4.901494E+00	1.000000E+00	9.484548E+02
2	2	1.724572E+03	4.152797E+01	6.609381E+00	1.000000E+00	1.724572E+03
3	3	1.811064E+03	4.255660E+01	6.773093E+00	1.000000E+00	1.811064E+03
4	4	3.240361E+03	5.692416E+01	9.059762E+00	1.000000E+00	3.240361E+03
5	5	5.362912E+03	7.323190E+01	1.165522E+01	1.000000E+00	5.362912E+03
6	6	1.320032E+04	1.148927E+02	1.828573E+01	1.000000E+00	1.320032E+04
7	7	1.324979E+04	1.151077E+02	1.831997E+01	1.000000E+00	1.324979E+04
8	8	1.444709E+04	1.201961E+02	1.912980E+01	1.000000E+00	1.444709E+04
9	9	3.383205E+04	1.839349E+02	2.927415E+01	1.000000E+00	3.383205E+04
10	10	3.452221E+04	1.858015E+02	2.957123E+01	1.000000E+00	3.452221E+04

EXAMPLE 1

7. With fluid and using vmopt,2 – request 50 modes

MODE NO.	EXTRACTION ORDER	EIGENVALUE	REAL EIGENVALUES (AFTER VIRTUAL MASS EFFECTS ARE INCLUDED)		GENERALIZED MASS	GENERALIZED STIFFNESS
			RADIANS	CYCLES		
1	1	8.833276E+02	2.972083E+01	4.730217E+00	1.000000E+00	8.833276E+02
2	2	1.683238E+03	4.102728E+01	6.529695E+00	1.000000E+00	1.683238E+03
3	3	1.769334E+03	4.206345E+01	6.694606E+00	1.000000E+00	1.769334E+03
4	4	2.904254E+03	5.389114E+01	8.577041E+00	1.000000E+00	2.904254E+03
5	5	3.332036E+03	5.772379E+01	9.187027E+00	1.000000E+00	3.332036E+03
6	6	3.894524E+03	6.240612E+01	9.932242E+00	1.000000E+00	3.894524E+03
7	7	7.604702E+03	8.720494E+01	1.388910E+01	1.000000E+00	7.604702E+03
8	8	8.490837E+03	9.214574E+01	1.466545E+01	1.000000E+00	8.490837E+03
9	9	1.413513E+04	1.188912E+02	1.892213E+01	1.000000E+00	1.413513E+04
10	10	1.726702E+04	1.314040E+02	2.091360E+01	1.000000E+00	1.726702E+04
11	11	2.221150E+04	1.490352E+02	2.371969E+01	1.000000E+00	2.221150E+04
12	12	2.376125E+04	1.541468E+02	2.453323E+01	1.000000E+00	2.376125E+04
13	13	2.684310E+04	1.638386E+02	2.607573E+01	1.000000E+00	2.684310E+04
14	14	2.814782E+04	1.677731E+02	2.670192E+01	1.000000E+00	2.814782E+04
15	15	2.865218E+04	1.692695E+02	2.694008E+01	1.000000E+00	2.865218E+04
16	16	3.046947E+04	1.745551E+02	2.778130E+01	1.000000E+00	3.046947E+04
17	17	3.294541E+04	1.815087E+02	2.888801E+01	1.000000E+00	3.294541E+04
18	18	3.933098E+04	1.983204E+02	3.156367E+01	1.000000E+00	3.933098E+04
19	19	4.376307E+04	2.091962E+02	3.329461E+01	1.000000E+00	4.376307E+04
20	20	6.445804E+04	2.538859E+02	4.040719E+01	1.000000E+00	6.445804E+04
21	21	6.758982E+04	2.599804E+02	4.137717E+01	1.000000E+00	6.758982E+04
22	22	7.890756E+04	2.809049E+02	4.470740E+01	1.000000E+00	7.890756E+04
23	23	8.286220E+04	2.878579E+02	4.581401E+01	1.000000E+00	8.286220E+04
24	24	9.895093E+04	3.145647E+02	5.006452E+01	1.000000E+00	9.895093E+04
25	25	1.010583E+05	3.178967E+02	5.059483E+01	1.000000E+00	1.010583E+05
26	26	1.068547E+05	3.268864E+02	5.202559E+01	1.000000E+00	1.068547E+05
27	27	1.432133E+05	3.784353E+02	6.022985E+01	1.000000E+00	1.432133E+05
28	28	1.455310E+05	3.814852E+02	6.071526E+01	1.000000E+00	1.455310E+05
29	29	1.539298E+05	3.923389E+02	6.244267E+01	1.000000E+00	1.539298E+05
30	30	1.574020E+05	3.967392E+02	6.314301E+01	1.000000E+00	1.574020E+05
31	31	1.756281E+05	4.190800E+02	6.669865E+01	1.000000E+00	1.756281E+05
32	32	1.756311E+05	4.190837E+02	6.669924E+01	1.000000E+00	1.756311E+05
33	33	1.798374E+05	4.240724E+02	6.749321E+01	1.000000E+00	1.798374E+05
34	34	1.885432E+05	4.342156E+02	6.910756E+01	1.000000E+00	1.885432E+05
35	35	1.950661E+05	4.416629E+02	7.029284E+01	1.000000E+00	1.950661E+05
36	36	2.069792E+05	4.549496E+02	7.240748E+01	1.000000E+00	2.069792E+05
37	37	2.198725E+05	4.689056E+02	7.462865E+01	1.000000E+00	2.198725E+05
38	38	2.204072E+05	4.694755E+02	7.471934E+01	1.000000E+00	2.204072E+05
39	39	3.264553E+05	5.713627E+02	9.093520E+01	1.000000E+00	3.264553E+05
40	40	3.455634E+05	5.878464E+02	9.355866E+01	1.000000E+00	3.455634E+05
41	41	3.779384E+05	6.147670E+02	9.784320E+01	1.000000E+00	3.779384E+05
42	42	5.699876E+05	7.549752E+02	1.201580E+02	1.000000E+00	5.699876E+05
43	43	6.158501E+05	7.847612E+02	1.248986E+02	1.000000E+00	6.158501E+05
44	44	6.498904E+05	8.061578E+02	1.283040E+02	1.000000E+00	6.498904E+05
45	45	7.099879E+05	8.426078E+02	1.341052E+02	1.000000E+00	7.099879E+05
46	46	8.370758E+05	9.149185E+02	1.456138E+02	1.000000E+00	8.370758E+05
47	47	9.089189E+05	9.533724E+02	1.517339E+02	1.000000E+00	9.089189E+05
48	48	1.046522E+06	1.022997E+03	1.628150E+02	1.000000E+00	1.046522E+06
49	49	1.273300E+06	1.128406E+03	1.795914E+02	1.000000E+00	1.273300E+06
50	50	1.494629E+06	1.222550E+03	1.945749E+02	1.000000E+00	1.494629E+06

EXAMPLE 1

- **Vmopt=2 is the recommended method (and only practical option) for any decent size model**
- **When using vmopt=2, more modes must be requested to obtain accurate lower modes**
- **When using vmopt=0, more modes must be requested to obtain accurate lower modes if component modes are requested**

MODEL SIZE RESTRICTIONS

- **The use of virtual mass creates very dense mass matrix**
- **Large number of wetted surfaces will require large runtime**
- **For model with more than 5000 wetted elements, use PARAM,VMOPT,2**
- **Even PARAM,VMOPT,2 can have performance issues if the number of wetted elements are too large (> 100,000)**

GPWG OUTPUT

- **The GPWG output is not used in any subsequent calculation, it is used strictly for informational purposes**
- **The mass may be different in different directions for the MFLUID.**
- **The mass differences in the three component directions of the fluid coordinate system is a realistic effect.**
- **It is a function of the geometry.**
- **Example A - flat plate immersed completely in a fluid.**
 - The associated fluid mass is zero for any motion in the plane of the plate.
 - Fluid mass is effective for any motion normal to the plate.
- **Example B- Coffee cup filled with coffee.**
 - If you move the cup up and down, the cup will feel the full effect.
 - However, if you move it sideways, it doesn't feel the full effect.

CAN WE PRINT THE MASS DUE TO THE VIRTUAL MASS?

- Using “param,grdpnt,x” and “param,vmopt,1”, total mass is printed

```
      O U T P U T   F R O M   G R I D   P O I N T   W E I G H T   G E N E R A T O R
                    R E F E R E N C E   P O I N T   =           0
                               M O
*  1.321642E-02  -1.456954E-10  -1.942544E-10  -2.001504E-10  4.558921E-02  -4.625749E-02  *
* -1.456954E-10  1.675021E-02  -5.478461E-10  -4.383210E-02  2.144424E-09  8.375106E-02  *
* -1.942544E-10  -5.478461E-10  2.799581E-02  9.798535E-02  -1.399791E-01  -1.324512E-09  *
* -2.001504E-10  -4.383210E-02  9.798535E-02  5.202820E-01  -4.899267E-01  -2.191605E-01  *
*  4.558921E-02  2.144424E-09  -1.399791E-01  -4.899267E-01  1.000388E+00  -1.595623E-01  *
* -4.625749E-02  8.375106E-02  -1.324512E-09  -2.191605E-01  -1.595623E-01  7.176725E-01  *
```

CAN WE PRINT THE MASS DUE TO THE VIRTUAL MASS?

- Using “param,grdpnt,x” and “param,vmopt,2”
 - Structural mass is printed in the grid point weight generator

```
      OUTPUT FROM GRID POINT WEIGHT GENERATOR
              REFERENCE POINT =      0
                    M O
*  2.109152E-03  0.000000E+00  0.000000E+00  0.000000E+00  1.591200E-03 -7.382034E-03 *
*  0.000000E+00  2.109152E-03  0.000000E+00 -1.591200E-03  0.000000E+00  1.054576E-02 *
*  0.000000E+00  0.000000E+00  2.109152E-03  7.382034E-03 -1.054576E-02  0.000000E+00 *
*  0.000000E+00 -1.591200E-03  7.382034E-03  5.492423E-02 -3.691017E-02 -7.956000E-03 *
*  1.591200E-03  0.000000E+00 -1.054576E-02 -3.691017E-02  1.068666E-01 -5.569200E-03 *
* -7.382034E-03  1.054576E-02  0.000000E+00 -7.956000E-03 -5.569200E-03  1.488844E-01 *
```

- Fluid mass is printed in a separate table

```
      INTERMEDIATE MATRIX ... WVRR

      COLUMN      1
1.110727E-02      -1.456954E-10      -1.942544E-10      -2.001504E-10      4.399801E-02      -3.887546E-02

      COLUMN      2
-1.456954E-10      1.464106E-02      -5.478461E-10      -4.224090E-02      2.144424E-09      7.320530E-02

      COLUMN      3
-1.942544E-10      -5.478461E-10      2.588666E-02      9.060331E-02      -1.294333E-01      -1.324512E-09

      COLUMN      4
-2.001504E-10      -4.224090E-02      9.060331E-02      4.653578E-01      -4.530166E-01      -2.112045E-01

      COLUMN      5
4.399801E-02      2.144424E-09      -1.294333E-01      -4.530166E-01      8.935210E-01      -1.539931E-01

      COLUMN      6
-3.887546E-02      7.320530E-02      -1.324512E-09      -2.112045E-01      -1.539931E-01      5.687881E-01
```

ADDITIONAL REFERENCES

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WORKSHOP 7

VIRTUAL MASS - MFLUID





SECTION 8

EXTERIOR ACOUSTIC ANALYSIS

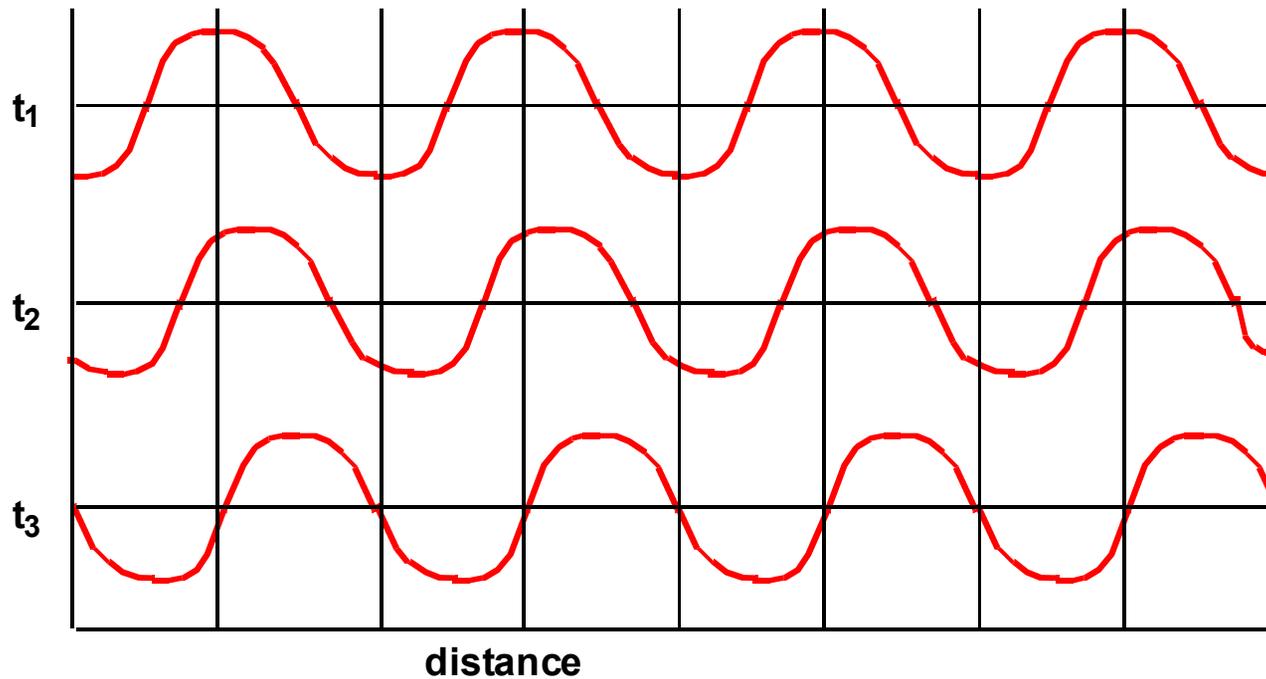


OBJECTIVES

- **Acoustic Analysis of Unbounded Domains**
 - Correct Non-Reflecting Boundary Condition
 - Sound Pressure in the Far Field
 - Radiated Power through Surfaces in the Far Field
 - Radiated Power from the Wetted Surface

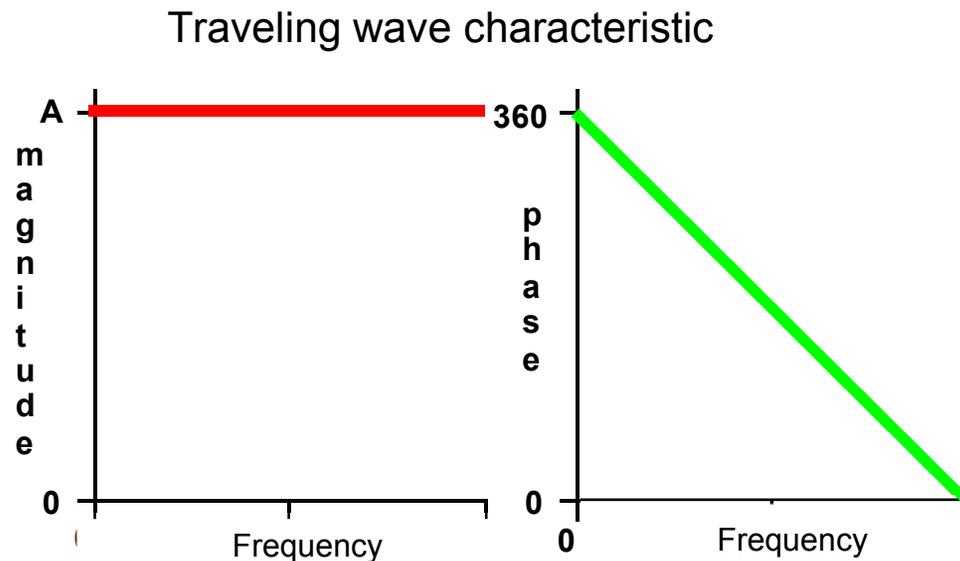
INFINITE BOUNDARIES - TRAVELING WAVES

- An infinite boundary will produce traveling waves



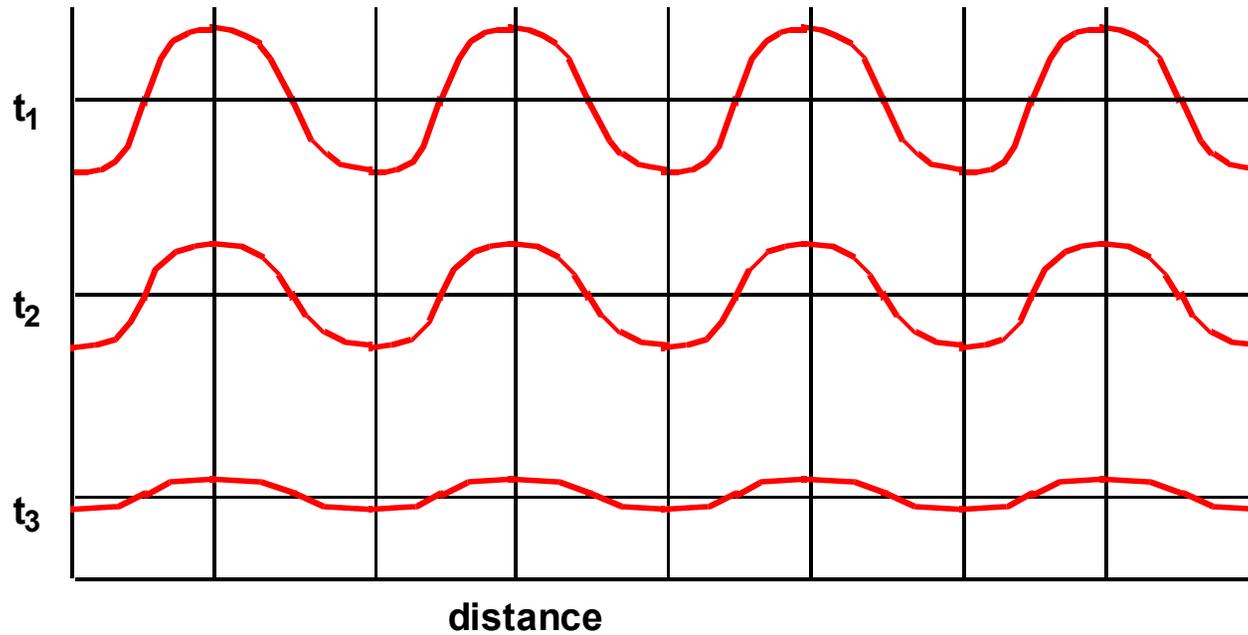
INFINITE BOUNDARIES - TRAVELING WAVES

- **A traveling wave can be identified in the frequency domain when:**
 - The magnitude of the complex pressure at any point is a constant.
 - The observed real pressure varies with time because of the phase change in the wave as it passes by.



FINITE BOUNDARIES - STANDING WAVES

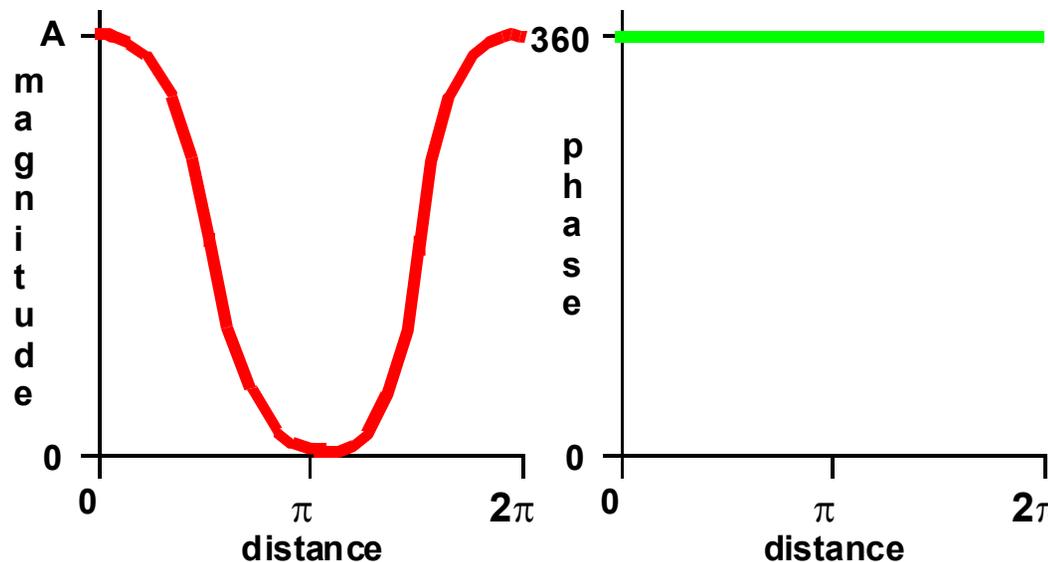
- A finite boundary will create standing waves.



FINITE BOUNDARIES - STANDING WAVES

- **A standing wave can be identified in the frequency domain when:**
 - The magnitude of the complex pressure at any point varies with the mode shape.
 - The phase angle stays constant.

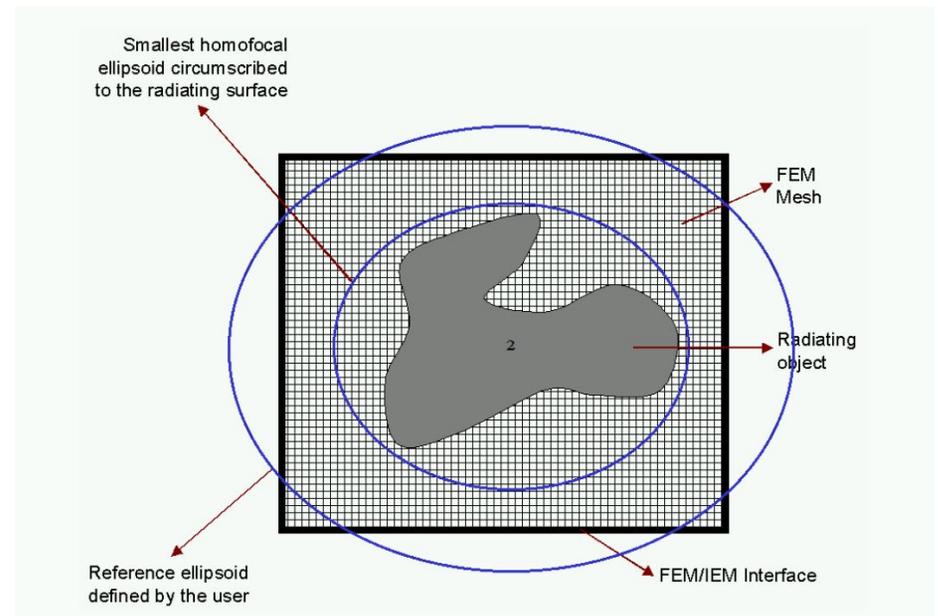
Traveling wave characteristics



- **This can be simulated in a finite element model using an infinite boundary element**
 - Waves must not reflect over the frequency range of interest.

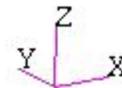
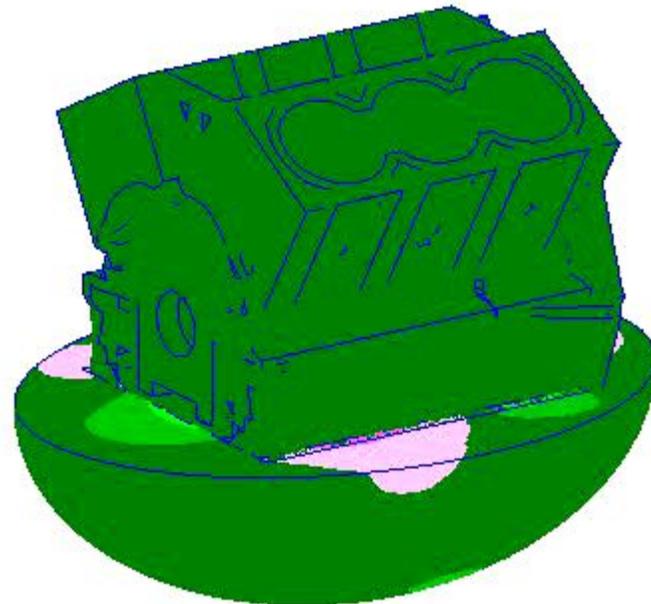
METHOD

- **Integration of Infinite Elements from Actran into MSC Nastran**
- **Vicinity of Radiating Body modeled using standard elements**
- **Infinite Elements provide correct boundary condition**



APPLICATIONS

- **Acoustic radiation from engines, oilpans, exhaust pipe systems, ...**
- **Sound transmission**
- **Not possible is point source in infinite field**
- **Not possible is Scattering – Sound wave hits obstical and returns**



BENEFITS

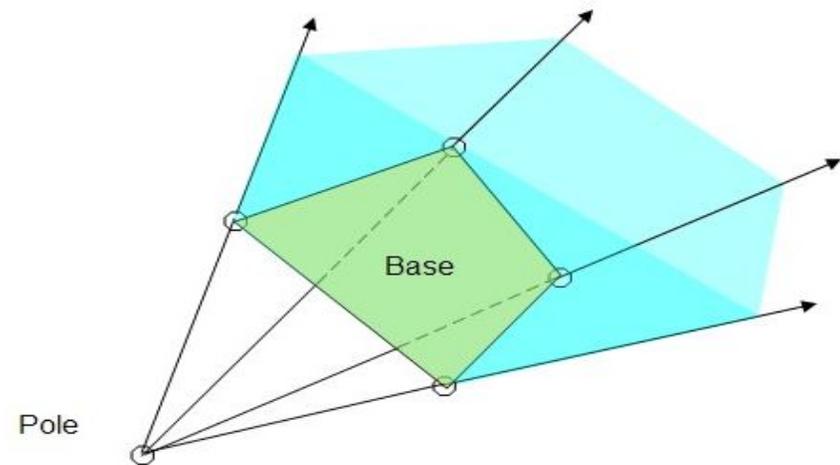
- **Proven Actran technology available within MSC Nastran**
- **Capability to model acoustic radiation, reflection and scattering**

INFINITE ELEMENTS

- **Infinite Element Terminology**
- **Infinite Element Types**
- **Modeling Guidelines**
- **Computational Aspects**
- **Definition of Infinite Elements**

INFINITE ELEMENT TERMINOLOGY

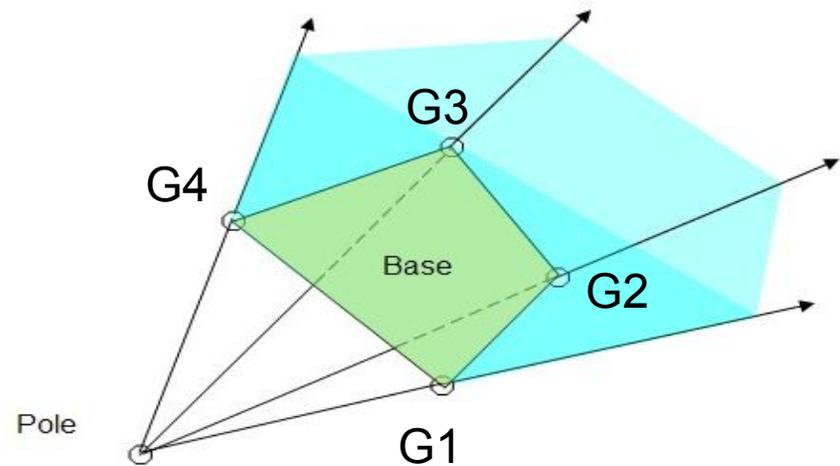
- **Geometry is described by Base and Pole.**
- **Base is attached to the finite fluid domain.**
- **Acoustic pressure is expanded into a power series of $(1/r)$.**
- **Number of terms in series is called radial interpolation order.**



$r =$ distance from pole

INFINITE ELEMENT TYPES

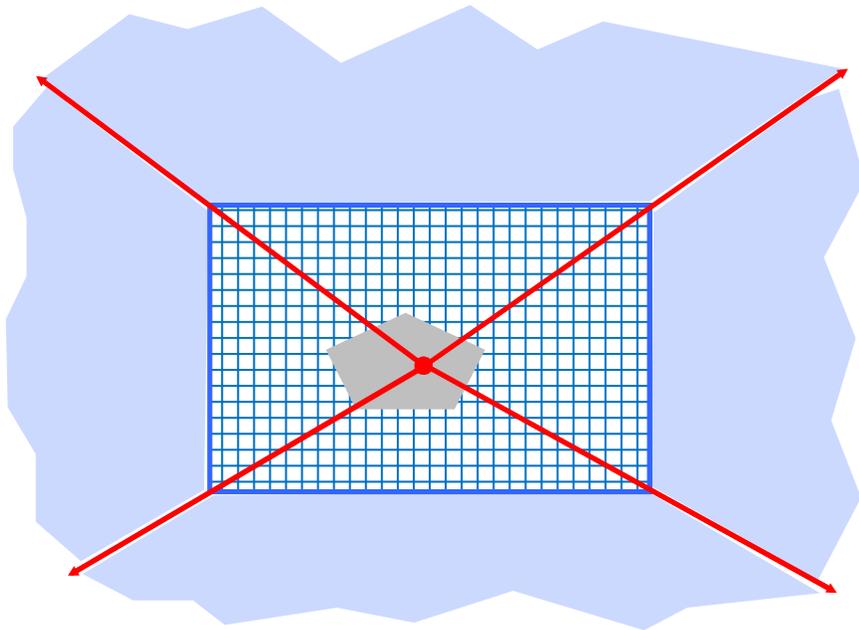
- **CACINF3** is an infinite element with a 3-noded base.
- **CACINF4** is an infinite element with a 4-noded base.
- The element normal should point away from the pole.



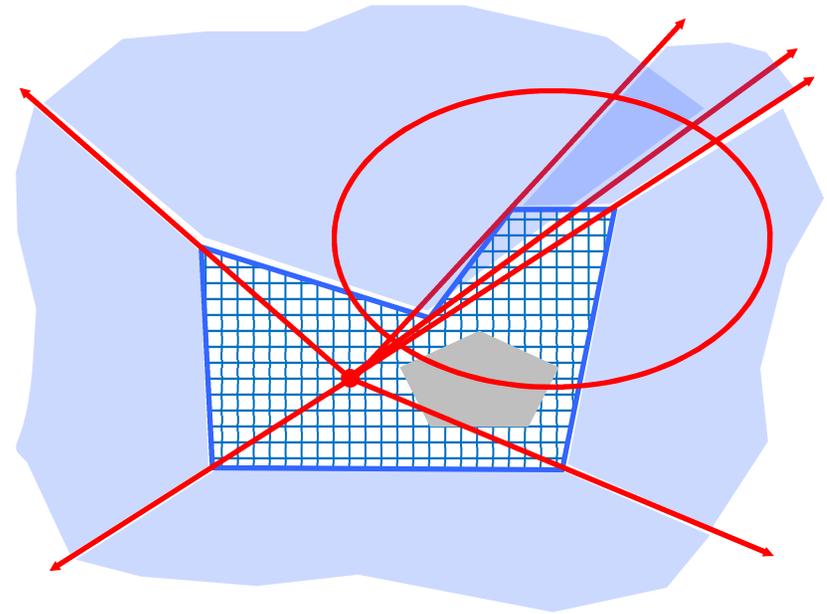
MODELING GUIDELINES

- **The boundary of the infinite domain must be convex.**
- **The boundary of the finite domain need not be smooth.**
- **The pole must be placed such that the infinite domain is covered by the infinite elements.**

MODELING GUIDELINES: CONVEX BOUNDARY



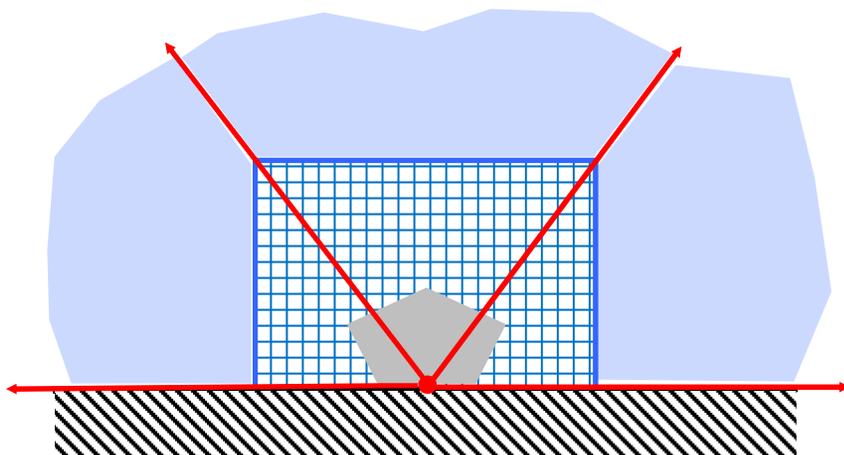
Correct



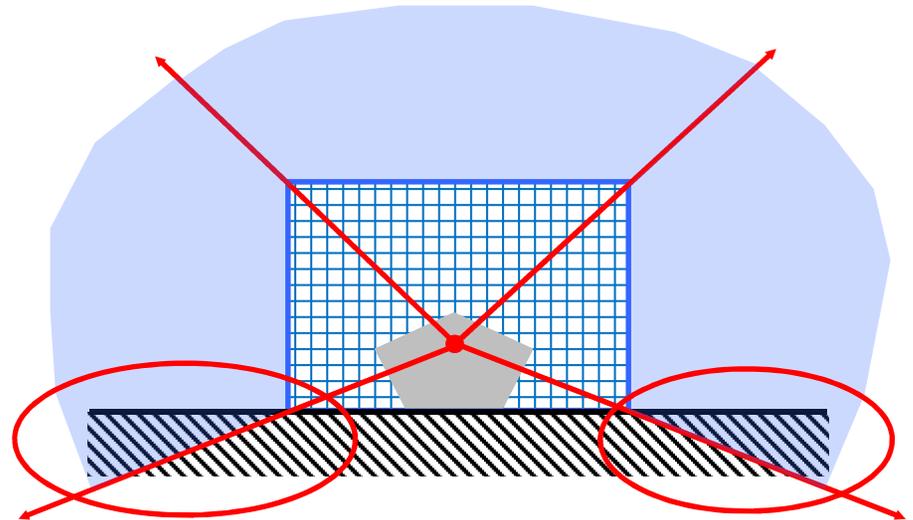
Wrong!

MODELING GUIDELINES: POLE LOCATION

- **With halfspace problems, care has to be taken to correctly position the pole.**



Correct



Incorrect!

COMPUTATIONAL ASPECTS

- **Infinite elements are available in the frequency domain only (SOL 108 and SOL 111).**
- **Matrices of infinite elements are unsymmetric. They are assembled into the p-set.**
- **Modal reduction of the fluid is not recommended.**
METHOD(STRUCT)=n

DEFINITION OF INFINITE ELEMENTS

- **The connectivity of the infinite element base is defined on CACINF3 and CACINF4 bulk data entries.**
- **Properties of infinite elements are defined on PACINF bulk data entries.**
- **Material properties of infinite elements are defined on MAT10 bulk data entries.**

THE CACINF3 AND CACINF4 ENTRIES

1	2	3	4	5	6	7	8	9	10
CACINF3	EID	PID	G1	G2	G3				

1	2	3	4	5	6	7	8	9	10
CACINF4	EID	PID	G1	G2	G3	G4			

Field	Contents
EID	Element Identification Number (Integer > 0)
PID	Property Identification Number of PACINF Entry (Integer > 0)
Gi	Grid Point Identification Numbers of Element Base Connection Points (Integer > 0)

RADIAL INTERPOLATION ORDER

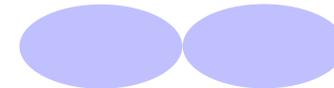
- The radial interpolation order defines the terms kept in the $(1/r)$ series.
- The radial interpolation order needed depends on the directivity of the acoustic field.
- The directivity increases with increasing frequency.

- **Directivity:**

- Monopol proportional to $1/r$

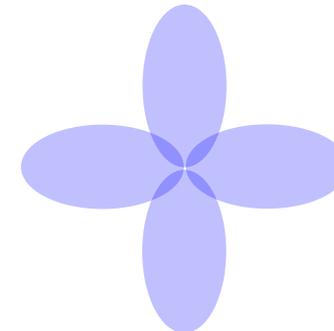


- Dipol proportional to $(1/r)^2$



- Quadrupol proportional to $(1/r)^3$

- ...

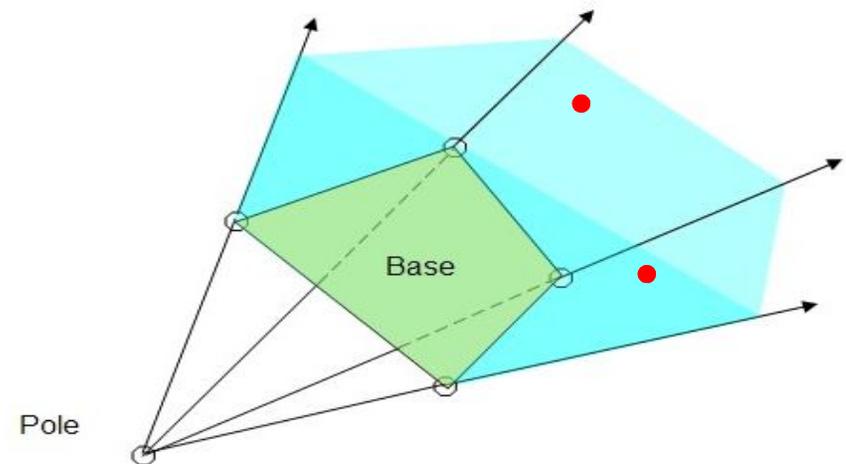


RESULTS

- **Standard acoustic results are available in the finite domain.**
- **Additional results are available at field points inside the infinite domain.**

FIELD POINTS

- **Field points are points inside the infinite elements.**
- **They are used for postprocessing only.**
- **Field points may be connected by elements to form field point meshes.**



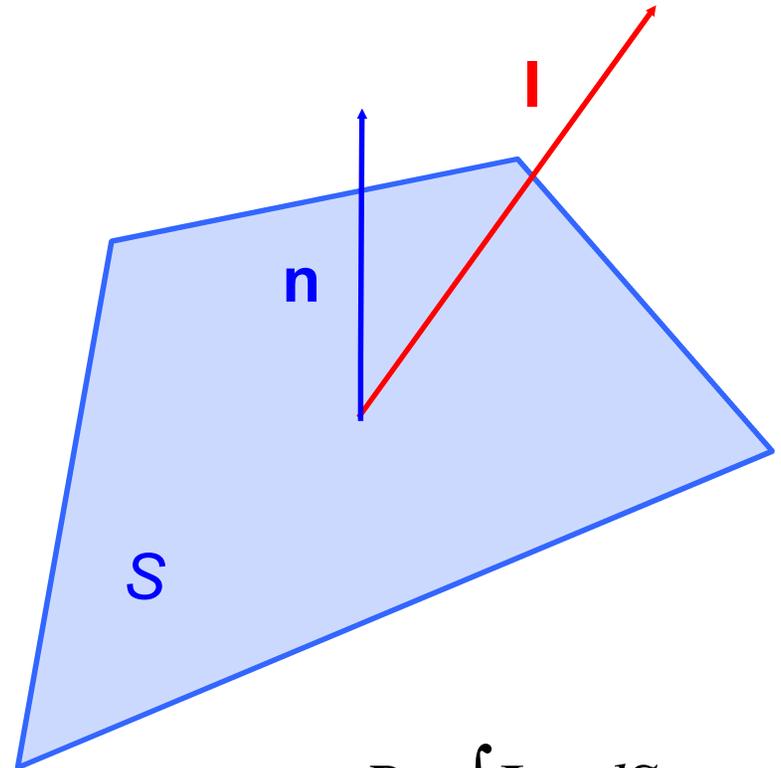
FIELD POINT RESULTS

- **The following results are available at field points:**
 - Acoustic pressure
 - Acoustic velocity
 - Acoustic intensity

- **If a field point mesh is defined, the following additional results are available:**
 - Intensity component normal to field point mesh
 - Acoustic power through the field point mesh

ACOUSTIC INTENSITY

- **Acoustic intensity is a vector.**
- **When integrated over a surface, it gives the mean acoustic power through the surface during one period.**
- **Acoustic intensities are very useful to understand how energy flows through the field.**



$$P = \int_S \mathbf{I} \cdot \mathbf{n} dS$$

DEFINITION OF FIELD POINT MESHES

- Field point meshes are defined in separate sections of the bulk data file.
- These sections follow the main bulk data section.
- Each of the sections begins with

or

where *afpmid* is the acoustic field point mesh identifier (Integer > 0).

```
BEGIN BULK AFPM = afpmid
```

```
BEGIN AFPM = afpmid
```

FIELD POINT MESH BULK DATA ENTRIES

- **Field points are defined using standard GRID bulk data entries.**
- **It is not necessary to place -1 into field 7.**
- **Field points can be connected by any type of elements.**
- **Only CQUAD4 and CTRIA3 elements define a field point mesh.**
- **Property identifiers have to be specified but the referenced PSHELL entries need not be defined.**

FIELD POINT MESH OUTPUT PARAMETERS

- **If output to an .op2 file is requested, parameter POST has to be defined within the section of the acoustic field point mesh.**
- **Output of different field point meshes can be sent to different .op2 files if parameter OUNIT2 is defined within the section of the acoustic field point mesh.**

FIELD POINT MESH EXAMPLE

```
BEGIN AFPM=100
```

```
$  
PARAM, POST, -1  
$  
$ Isolated Field Points along a Line  
$  
GRID      1001      2      5.      0.      0.  
GRID      1002      2      6.      0.      0.  
GRID      1003      2      7.      0.      0.  
GRID      1004      2      8.      0.      0.  
GRID      1005      2      9.      0.      0.  
GRID      1006      2     10.      0.      0.  
CORD2R,   2,, 0., 0., 0., -.5, -.5, .707107  
          , .5, .5, .707107
```

```
$  
BEGIN AFPM = 200
```

```
$  
PARAM, POST, -1  
$  
$ Field Point Mesh  
$  
GRID,   1,, -1., -1., 2.  
GRID,   2,,  0., -1., 2.  
GRID,   3,,  1., -1., 2.  
GRID,   4,, -1.,  0., 2.  
GRID,   5,,  0.,  0., 2.
```

FIELD POINT MESH EXAMPLE

```
GRID, 6,, 1., 0., 2.
GRID, 7,, -1., 1., 2.
GRID, 8,, 0., 1., 2.
GRID, 9,, 1., 1., 2.
GRID, 11,, -1., -1., 2.
GRID, 12,, 0., -1., 3.
GRID, 13,, 1., -1., 2.
GRID, 14,, -1., 0., 3.
GRID, 16,, 1., 0., 3.
GRID, 17,, -1., 1., 2.
GRID, 18,, 0., 1., 3.
GRID, 19,, 1., 1., 2.
$
CQUAD4, 1, 1, 1, 2, 5, 4
CQUAD4, 2, 1, 2, 3, 6, 5
CQUAD4, 3, 1, 4, 5, 8, 7
CQUAD4, 4, 1, 5, 6, 9, 8
$
CQUAD4, 5, 1, 12, 16, 18, 14
CTRIA3, 6, 1, 11, 12, 14
CTRIA3, 7, 1, 12, 13, 16
CTRIA3, 8, 1, 16, 19, 18
CTRIA3, 9, 1, 14, 18, 17
$
ENDDATA
```

CASE CONTROL COMMANDS

- The **ACFPMRESULT** command controls output of acoustic field point mesh results.
- The **ACPOWER** command controls output of the power radiated from the wetted surface.
- The **INTENSITY** command controls output of acoustic intensity on the wetted surface.

THE ACFPMRESULT COMMAND

$$\text{ACFPMRESULT} \left[\left(\left[\text{SORT1} \right], \left[\text{PRINT, PUNCH} \right], \left[\text{VELOCITY} = \begin{Bmatrix} \text{YES} \\ \text{NO} \end{Bmatrix} \right], \right. \right.$$
$$\left. \left[\begin{matrix} \text{REAL or IMAG} \\ \text{PHASE} \end{matrix} \right], \left[\text{POWER} = \begin{Bmatrix} \text{YES} \\ \text{NO} \end{Bmatrix} \right] \right) = \begin{Bmatrix} \text{ALL} \\ \text{n} \\ \text{NONE} \end{Bmatrix}$$

ACFPMRESULT COMMAND: OUTPUT FORMAT

ACFPMRESULT [([**SORT1**] [**PRINT, PUNCH**] [**VELOCITY** = { **YES** }] , [**SORT2**] [**PLOT**]]

[[**REAL or IMAG**] [**POWER** = { **YES** }]] = { **ALL** }
 [**PHASE**] [**NO**]) = { **n** }
 [**NONE**]

Real/Imaginary Part or
Magnitude/Phase

Grid Point (SORT1) or
Frequency (SORT2)
Sorting

ACFPMRESULT COMMAND: RESULTS SELECTION

Acoustic Velocity

ACFPMRESULT ([SORT1] [PRINT, PUNCH] [VELOCITY = { YES }]
[SORT2] [PLOT] [NO])

[REAL or IMAG]
[PHASE]

[POWER = { YES }]
[NO]

{ ALL }
n
{ NONE }

Acoustic Power through
Field Point Mesh

Select Set of Field Point
Mesh Identifiers or all
Field Point Meshes

THE ACPOWER COMMAND

$$\text{ACPOWER} \left[\left(\begin{array}{l} \text{SORT1} \\ \text{SORT2} \end{array} \right), \begin{array}{l} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array}, [\text{CSV} = \text{unit}] \right) = \left\{ \begin{array}{c} \text{ALL} \\ \text{n} \\ \text{NONE} \end{array} \right\}$$

ACPOWER COMMAND: OUTPUT FORMAT

ACPOWER ([[SORT1] [PRINT, PUNCH] , [CSV = unit]) = { ALL
[SORT2] [PLOT] n
NONE }

SORT1: Panel Sorting
SORT2: Frequency Sorting

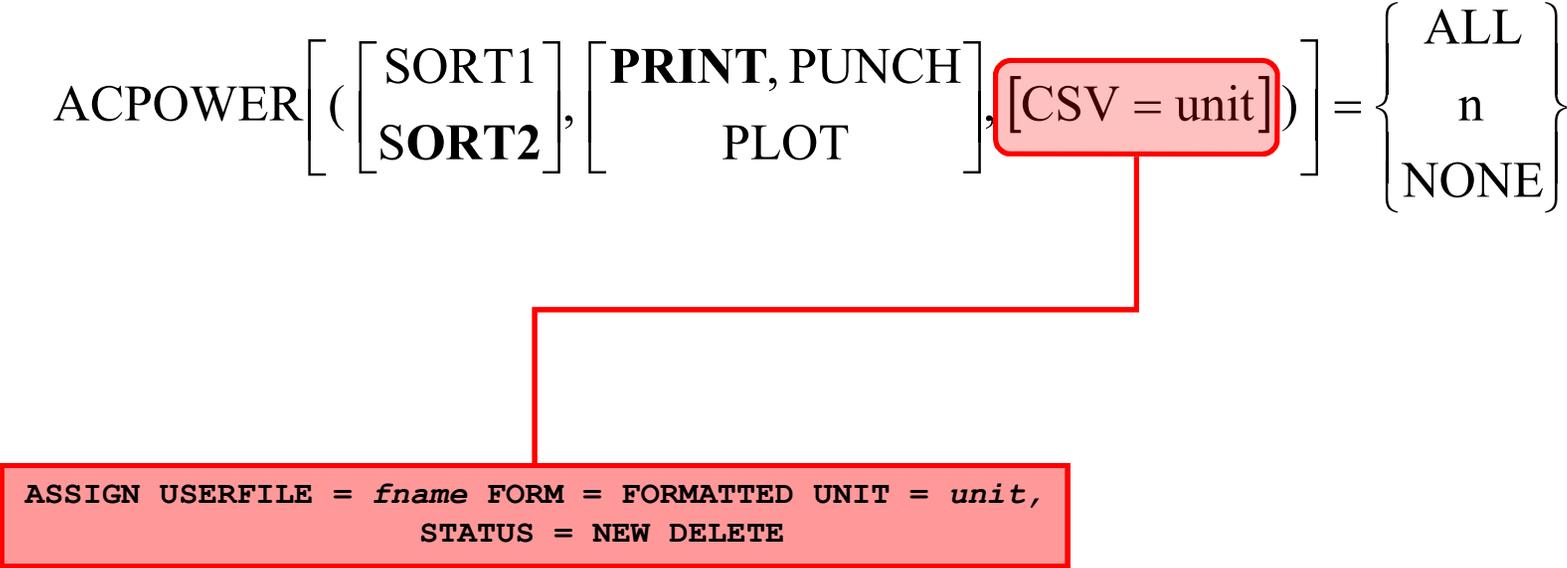
ACPOWER COMMAND: OUTPUT SELECTION

$$\text{ACPOWER} \left(\left(\begin{array}{l} \text{SORT1} \\ \text{SORT2} \end{array} \right), \left(\begin{array}{l} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right), [\text{CSV} = \text{unit}] \right) = \left\{ \begin{array}{l} \text{ALL} \\ n \\ \text{NONE} \end{array} \right\}$$

Select Set of Panels or all
Panels

ACPOWER COMMAND: .CSV FILE (COMMA SEPARATED VALUES)

ACPOWER [([SORT1] [PRINT, PUNCH] [CSV = unit])] = { ALL
n
NONE }



ASSIGN USERFILE = *fname* FORM = FORMATTED UNIT = *unit*,
STATUS = NEW DELETE

CONTENTS OF THE .CSV FILE

Title, Subtitle and Label

Subcase	1							
ACOUSTIC POWER TEST PROBLEM								
NO SETS					SUBCASE 1			
Power Radiated from Wetted Surface								
Frequency	Total	WALL1	WALL2	WALL3	WALL4	WALL5	WALL6	
5.00E+00	1.45E-07	3.69E-10	3.69E-10	5.64E-09	-9.01E-10	1.40E-07	0.00E+00	
1.00E+01	5.74E-06	-5.95E-07	-5.95E-07	-6.27E-08	-6.12E-07	7.61E-06	0.00E+00	
1.50E+01	3.58E-08	5.93E-08	5.93E-08	2.12E-08	5.51E-08	-1.59E-07	0.00E+00	
2.00E+01	6.24E-06	1.68E-06	1.68E-06	-6.51E-07	2.22E-06	1.31E-06	0.00E+00	

Power radiated from total wetted surface

Power radiated from panels

THE INTENSITY COMMAND

$$\text{INTENSITY} \left[\left(\begin{array}{l} \text{SORT1} \\ \text{SORT2} \end{array} \right), \left(\begin{array}{l} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right) \right] = \left\{ \begin{array}{l} \text{ALL} \\ \text{n} \\ \text{NONE} \end{array} \right\}$$

INTENSITY COMMAND: OUTPUT FORMAT

INTENSITY [([SORT1] [PRINT, PUNCH])] = { ALL }
[SORT2] [PLOT] } { n }
{ NONE }

SORT1: Grid Point Sorting
SORT2: Frequency Sorting

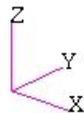
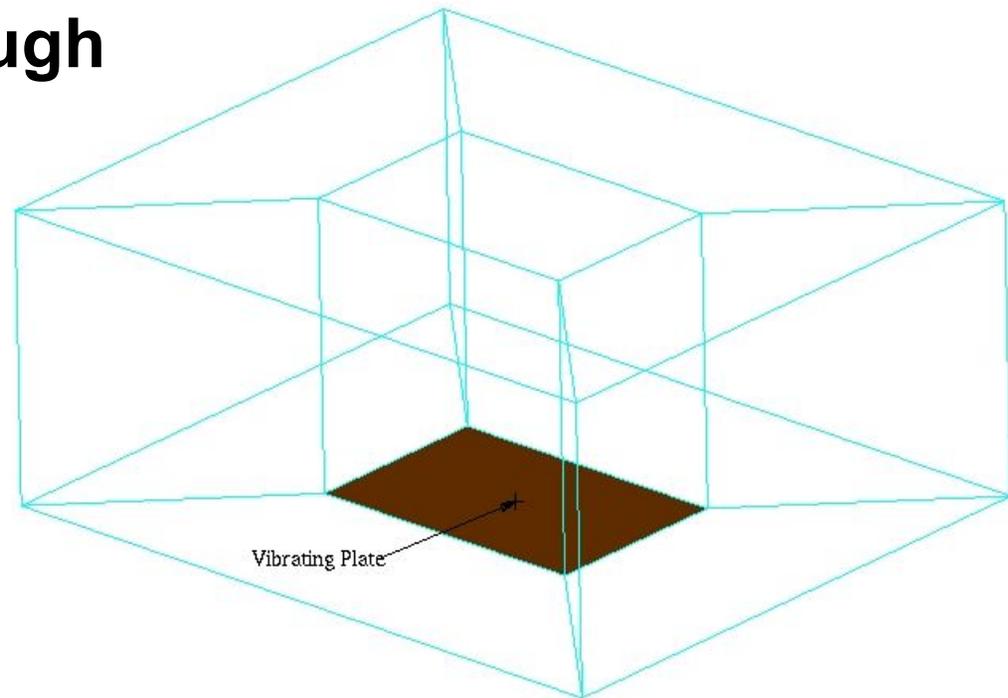
INTENSITY COMMAND: OUTPUT SELECTION

$$\text{INTENSITY} \left[\left(\begin{array}{l} \text{SORT1} \\ \text{SORT2} \end{array} \right), \begin{array}{l} \text{PRINT, PUNCH} \\ \text{PLOT} \end{array} \right) = \left\{ \begin{array}{c} \text{ALL} \\ n \\ \text{NONE} \end{array} \right\}$$

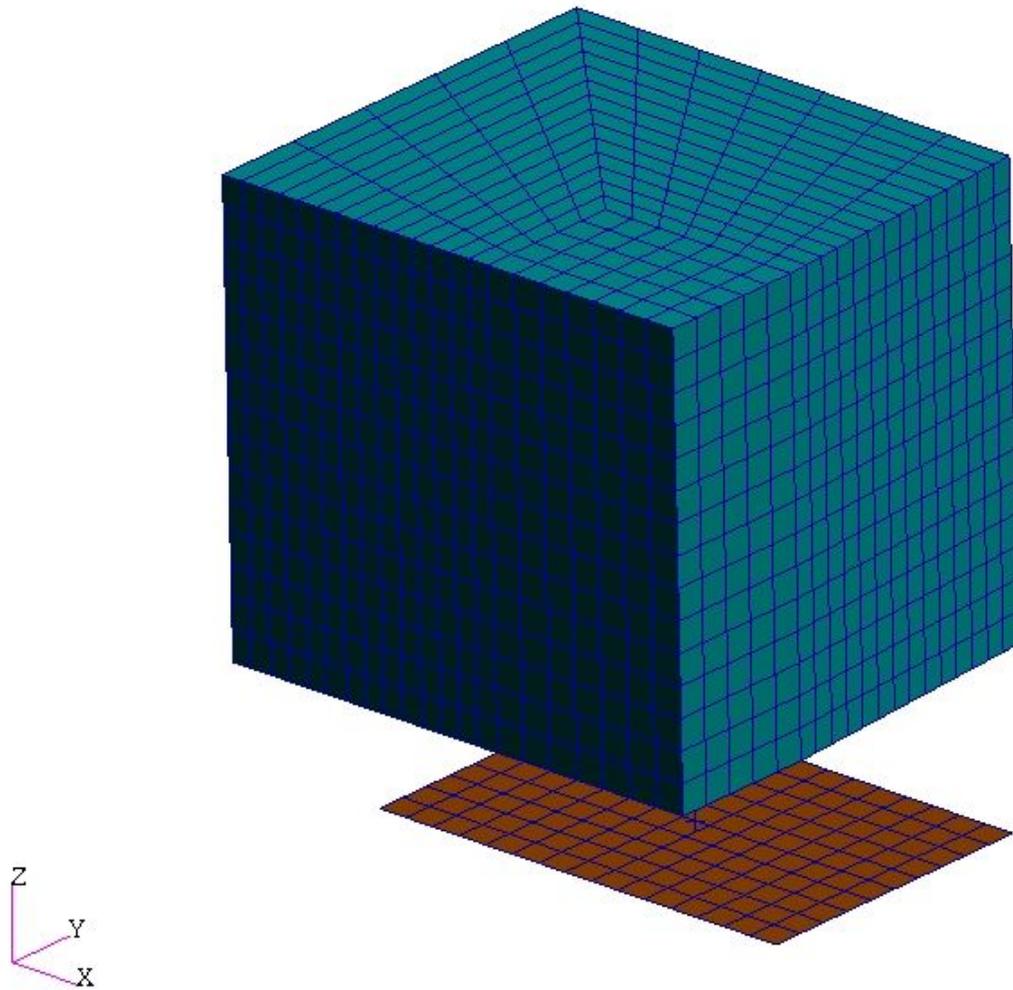
Select Set of Grid Points or
all Grid Points

EXAMPLE

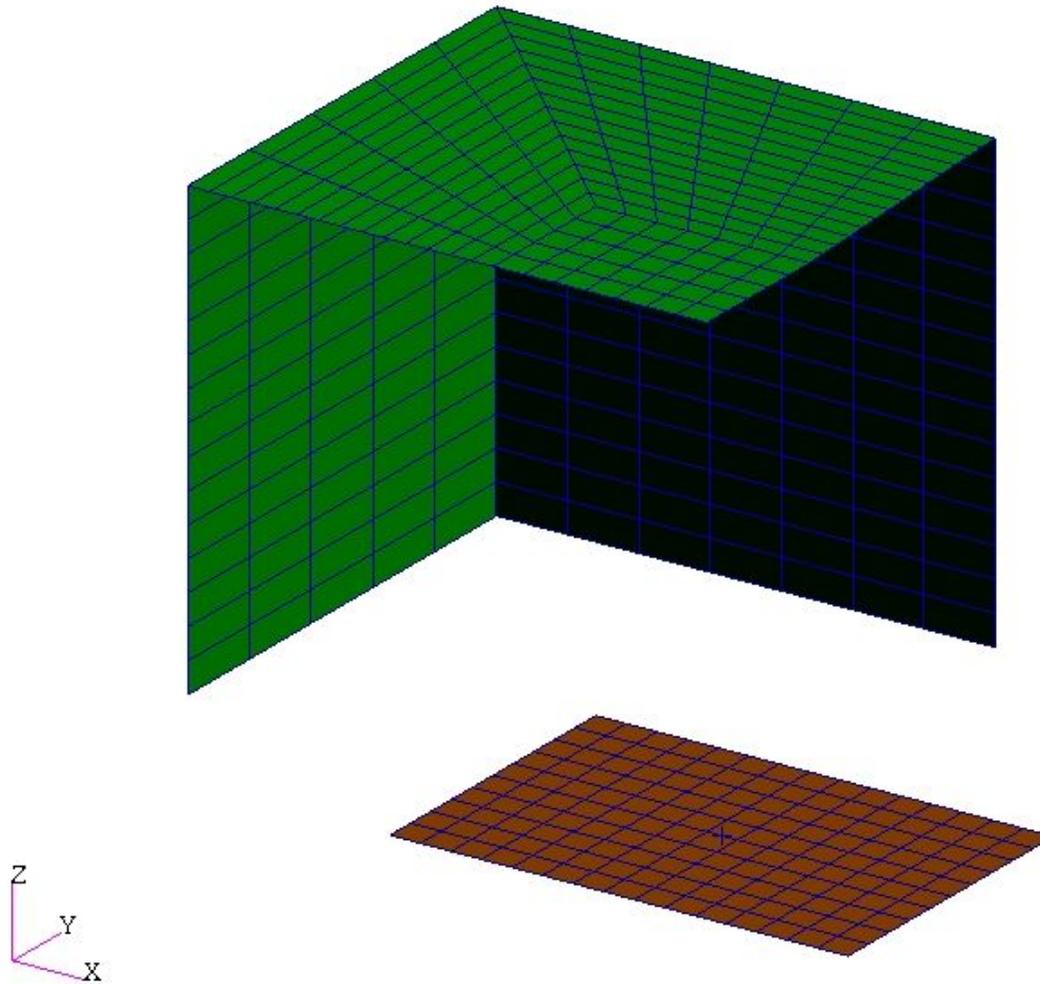
- The example studies the sound transmission through an elastic plate embedded in an infinite rigid wall.



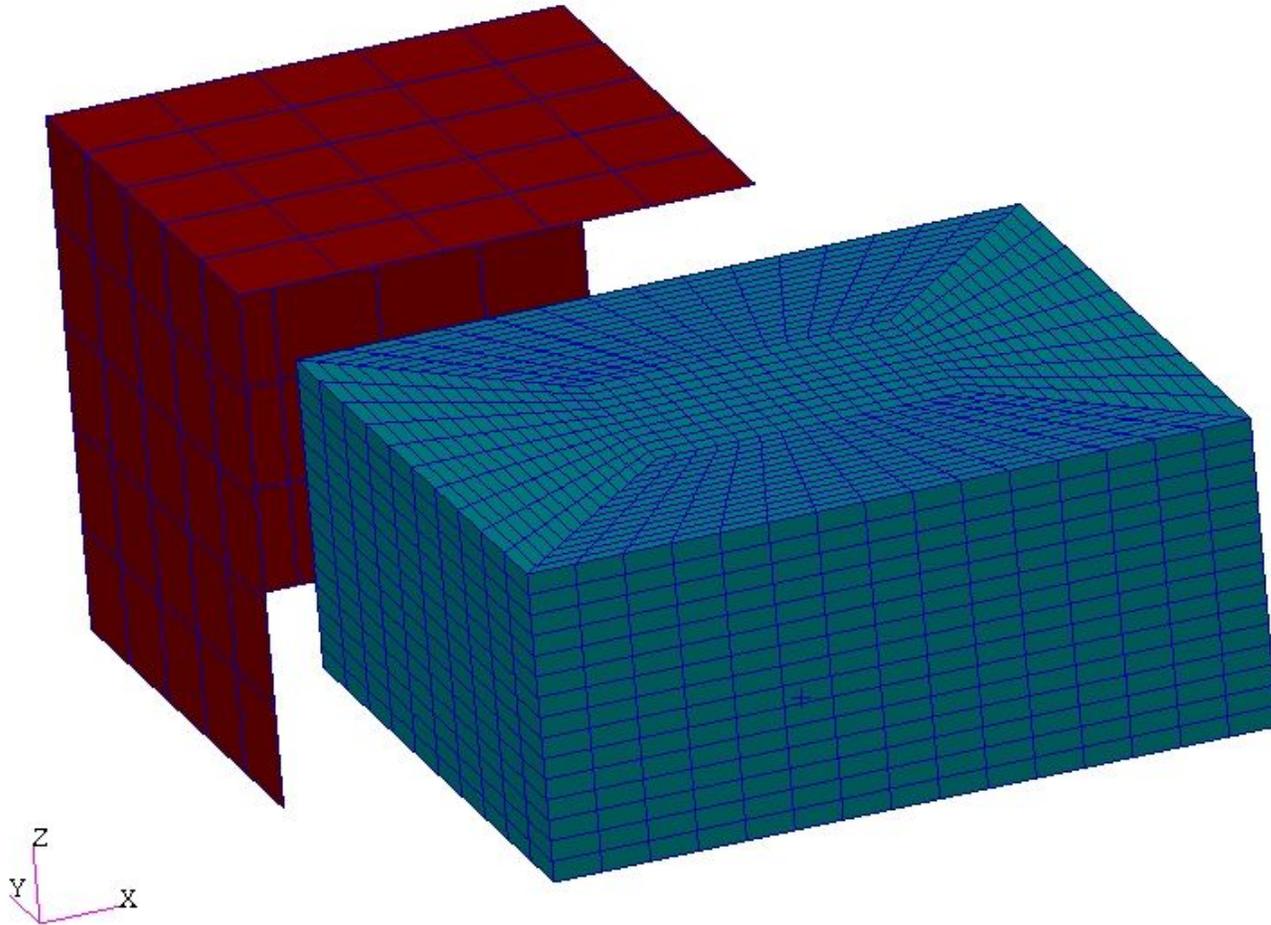
EXAMPLE: MESH OF STRUCTURE AND QUARTER OF FLUID MESH



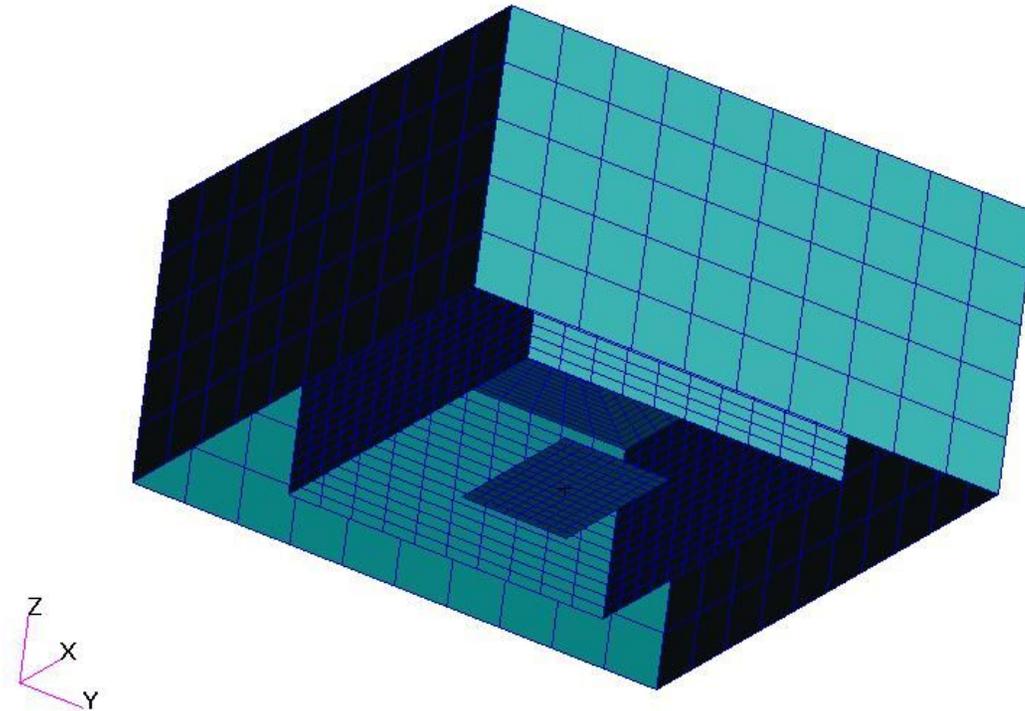
EXAMPLE: MESH OF STRUCTURE AND QUARTER OF INFINITE ELEMENT MESH



EXAMPLE: FLUID MESH AND QUARTER OF FIELD POINT MESH



EXAMPLE: MESH OF STRUCTURE AND INFINITE ELEMENT MESH AND FIELD POINT



EXAMPLE: INPUT FILE- USING UMFPACK

```
NASTRAN SYSTEM(209)=16
```

UMFPACK Sparse Solver

```
SOL 108
CEND
TITLE      = Vibrating Plate Example
SUBTITLE   = Direct Frequency Response
$
ECHO = SORT(EXCEPT, GRID, CHEXA, CQUAD4, CACINF4)
$
DLOAD     = 10
FREQ      = 20
SPC       = 1
$
DISP(PLOT) = ALL
ACFPMRESULT(PHAS) = ALL
$
BEGIN BULK
$
PARAM, POST, -1
ACMODL, IDENT
$
RLOAD1, 10, 200,,, 300
PLOAD2, 200, 1., 1, THRU, 150
TABLED1, 300
        , 0., 1., 1000., 1., ENDT
$
FREQ, 20, 10.
$
```

Field Point Mesh Results for
all Field Point Meshes

EXAMPLE: INPUT FILE

```
$  
$ Fluid  
GRDSET,,,,,, -1  
INCLUDE 'fluid1.bdf'  
$  
$ Structure  
INCLUDE 'structure.bdf'  
$  
BEGIN AFPM=100  
$  
$ Isolated Field Points  
GRID, 10001,, 0., 0., 3.5  
GRID, 10002,, 0., 0., 5.  
GRID, 10003,, 0., 0., 10.  
$  
BEGIN AFPM=200  
$  
$ Field Point Mesh  
INCLUDE 'fpm.bdf'  
$  
ENDDATA
```

EXAMPLE: INPUT FILE– USING ITER SOLV

```
SOL 108
CEND
TITLE      = Vibrating Plate Example
SUBTITLE   = Direct Frequency Response
$
ECHO = SORT(EXCEPT, GRID, CHEXA, CQUAD4, CACINF4)
$
DLOAD      = 10
FREO       = 20
SMETHOD  = 30
SPC        = 1
$
DISP(PLOT) = ALL
ACFPMRESULT(PHAS) = ALL
$
BEGIN BULK
$
PARAM, POST, -1
ACMODL, IDENT
$
RLOAD1, 10, 200,,, 300
PLOAD2, 200, 1., 1, THRU, 150
TABLED1, 300
          , 0., 1., 1000., 1., ENDT
$
FREQ, 20, 10.
$
```

Parameters of Iterative Solver

Field Point Mesh Results for
all Field Point Meshes

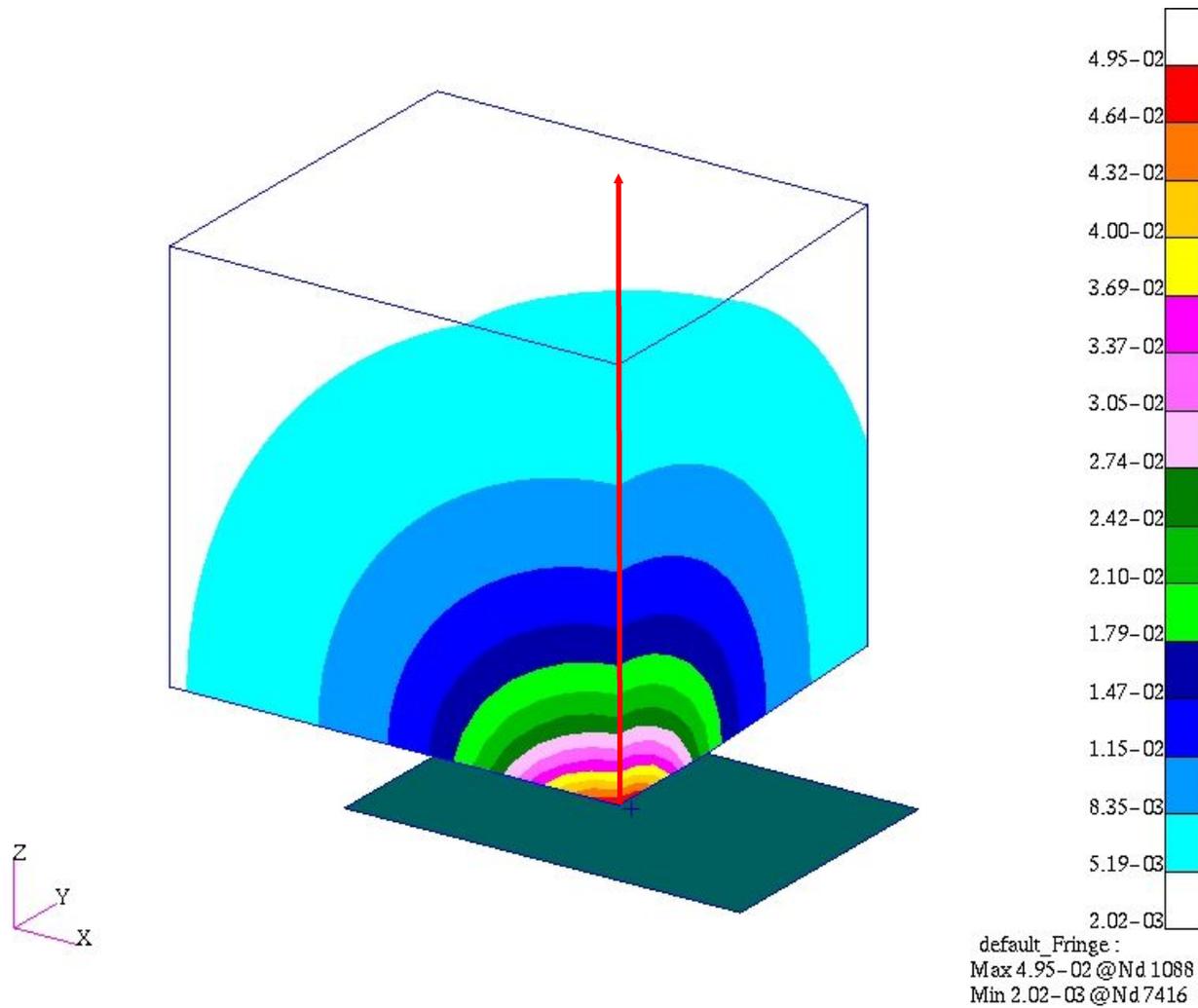
EXAMPLE: PART OF FLUID MESH DEFINITION

```

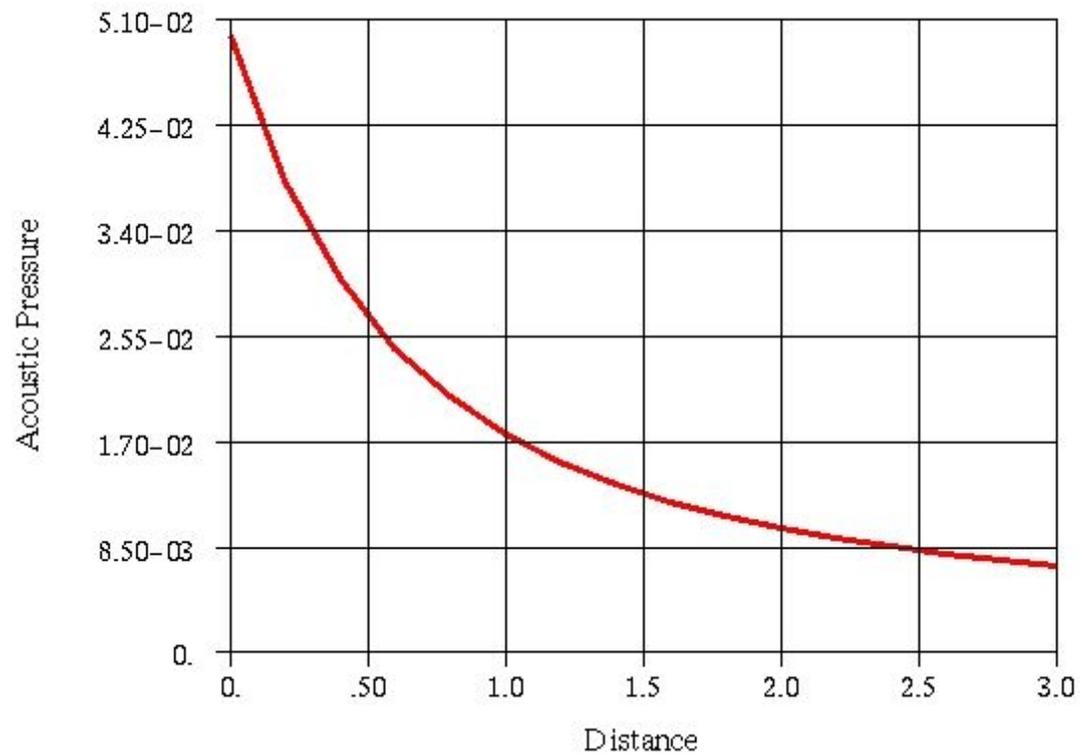
$ Exterior Acoustics - Vibrating Plate Example
$ Fluid Model of Domain 1: Finite and Infinite Elements
$
$ -----
$
$
$      PID      MID      RIO      XP      YP      ZP
PACINF  10       20       10       0.       0.       0.
PSOLID  2        20
MAT10   20              1.21    340.
$
CHEXA   1001     2        1001    1002    1018    1017    1177    1178
        1194     1193
CHEXA   1002     2        1002    1003    1019    1018    1178    1179
        1195     1194
...
$ Infinite Elements
$
CACINF4 13901    10       3641    3642    3658    3657
CACINF4 13902    10       3642    3643    3659    3658
CACINF4 13903    10       3643    3644    3660    3659
CACINF4 13904    10       3644    3645    3661    3660
CACINF4 13905    10       3645    3646    3662    3661
CACINF4 13906    10       3646    3647    3663    3662
...

```

EXAMPLE: ACOUSTIC PRESSURE IN FINITE DOMAIN



EXAMPLE: PRESSURE ALONG Z-AXIS



EXAMPLE: FIELD POINT MESH RESULTS

```

0
FREQUENCY = 1.000000E+01                                ACOUSTIC FIELD POINT MESH = 100
      ACOUSTIC FIELD POINT MESH RESULTS
      ACOUSTIC PRESSURE                                INTENSITY COMP.
POINT ID.  MAGNITUDE  PHASE  NORMAL TO FPM  INTENSITY  INTENSITY  INTENSITY
      10001  5.867592E-03  3.224626E+02  0.0          3.901852E-16  1.102822E-09  4.101243E-08
      10002  4.148942E-03  3.068220E+02  0.0          1.168128E-16  3.946748E-10  2.071128E-08
      10003  2.089879E-03  2.542063E+02  0.0          1.290767E-17  5.147245E-11  5.294778E-09
1 VIBRATING PLATE EXAMPLE                                DECEMBER 6, 2005 MSC.NASTRAN 12/ 5/05 PAGE 16
  DIRECT FREQUENCY RESPONSE
0
*** USER INFORMATION MESSAGE 3119 (AFPINI)
DATA RECOVERY OF ACOUSTIC FIELD POINT MESH 200 INITIATED
1 VIBRATING PLATE EXAMPLE
  DIRECT FREQUENCY RESPONSE
0
FREQUENCY = 1.000000E+01                                ACOUSTIC FIELD POINT MESH = 200
      ACOUSTIC FIELD POINT MESH RESULTS
      ACOUSTIC PRESSURE                                INTENSITY COMP.
POINT ID.  MAGNITUDE  PHASE  NORMAL TO FPM  INTENSITY  INTENSITY  INTENSITY
      46567  2.959861E-03  2.856447E+02  7.442431E-09  -7.647572E-09  7.442431E-09  1.545178E-10
      46568  2.930327E-03  2.848879E+02  7.258169E-09  -7.408595E-09  7.258169E-09  1.340973E-09
      46569  2.846820E-03  2.826632E+02  6.691689E-09  -6.762688E-09  6.691689E-09  2.608988E-09
      46570  2.722373E-03  2.790949E+02  5.876647E-09  -5.877888E-09  5.876647E-09  3.492858E-09
      46571  2.572942E-03  2.743544E+02  4.970530E-09  -4.929979E-09  4.970530E-09  3.970974E-09
      46572  2.412938E-03  2.686276E+02  4.189022E-09  -4.042182E-09  4.189022E-09  4.023463E-09
      46573  3.274509E-03  2.928127E+02  1.022698E-08  -8.121219E-09  1.022698E-08  2.107736E-10
      46574  3.234508E-03  2.919741E+02  9.893179E-09  -7.820792E-09  9.893179E-09  1.809509E-09
      46575  3.122908E-03  2.895207E+02  8.920301E-09  -7.024057E-09  8.920301E-09  3.457678E-09
      46576  2.960447E-03  2.856181E+02  7.592750E-09  -5.968274E-09  7.592750E-09  4.507941E-09
      46577  2.770893E-03  2.804857E+02  6.203833E-09  -4.882053E-09  6.203833E-09  4.973865E-09
      46578  2.573859E-03  2.743491E+02  4.944810E-09  -3.905830E-09  4.944810E-09  5.004789E-09
      46579  3.597602E-03  2.988595E+02  1.353951E-08  -8.067808E-09  1.353951E-08  2.802701E-10
      46580  3.544644E-03  2.979372E+02  1.298966E-08  -7.718223E-09  1.298966E-08  2.386323E-09
      46581  3.399051E-03  2.952536E+02  1.145273E-08  -6.810243E-09  1.145273E-08  4.470247E-09
      46582  3.192353E-03  2.910229E+02  9.454744E-09  -5.649165E-09  9.454744E-09  5.666677E-09
      46583  2.958238E-03  2.855169E+02  7.476965E-09  -4.503807E-09  7.476965E-09  6.064790E-09
      46584  2.721970E-03  2.790005E+02  5.885413E-09  -3.516635E-09  5.885413E-09  5.822169E-09
  
```

Isolated Field Points, No Normal Defined

GUIDELINES

- **The surface the infinite elements are attached to must be convex but need not be smooth.**
- **The radial interpolation order required depends on the directivity of the pressure field.**
- **It is recommended to study the sensitivity of the results with respect to the radial interpolation order.**

GUIDELINES (CONT.)

- **Infinite elements are available in SOL 108 and SOL 111.**
- **Modal reduction can be applied to the structure.**
- **Modal reduction of the fluid is not recommended.**
- **Use of the iterative solver might increase efficiency.**
- **For small-medium size UMFPACK sparse solver gives excellent efficiency over default solver.**

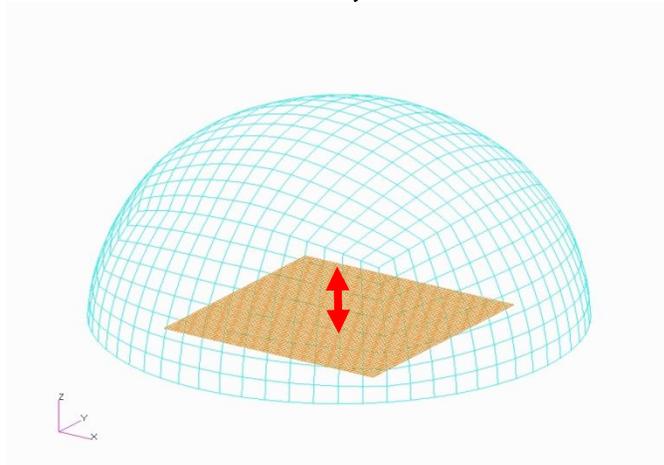


WORKSHOP 8

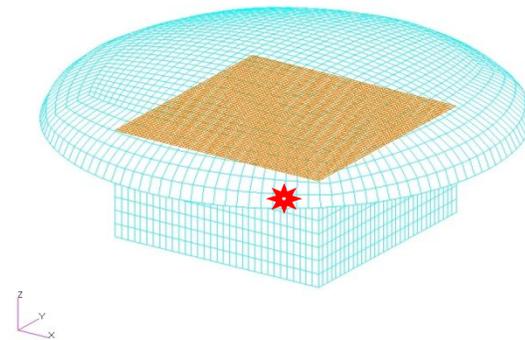
Flat Plate Exterior Acoustics

ACCURACY VALIDATION TEST

- Compare the results of MSC Nastran external acoustic with those from Actran
- Two test models are used
 - Model 1
 - Structure and exterior acoustic
 - Model 2
 - Structure, exterior and interior acoustic



Model 1

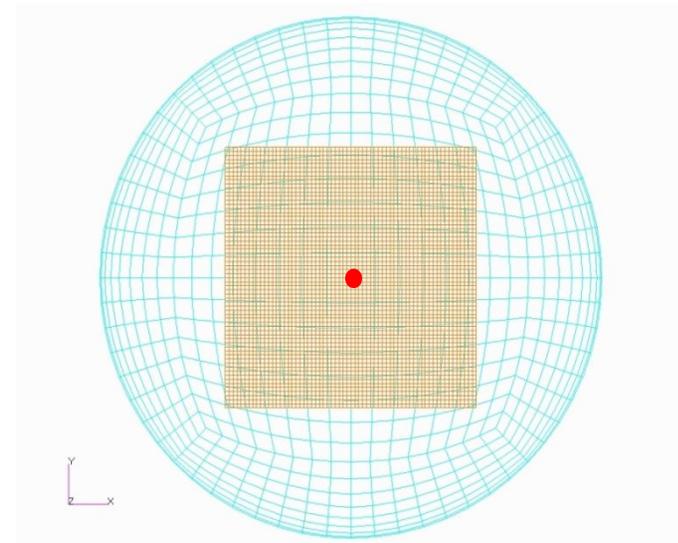
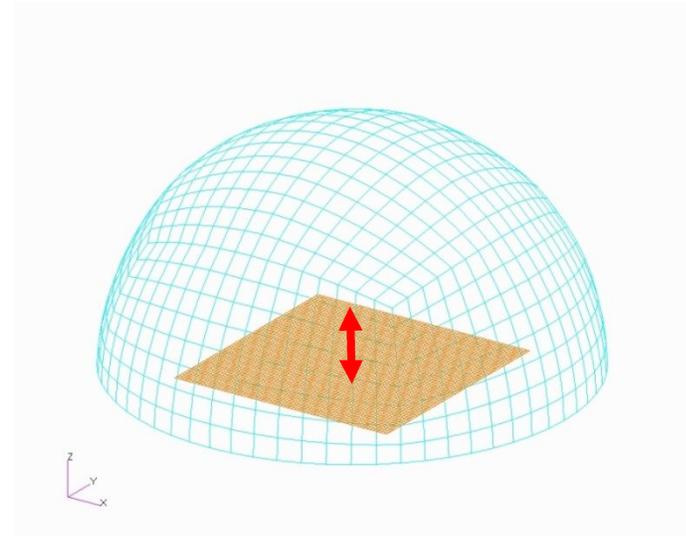


Model 2

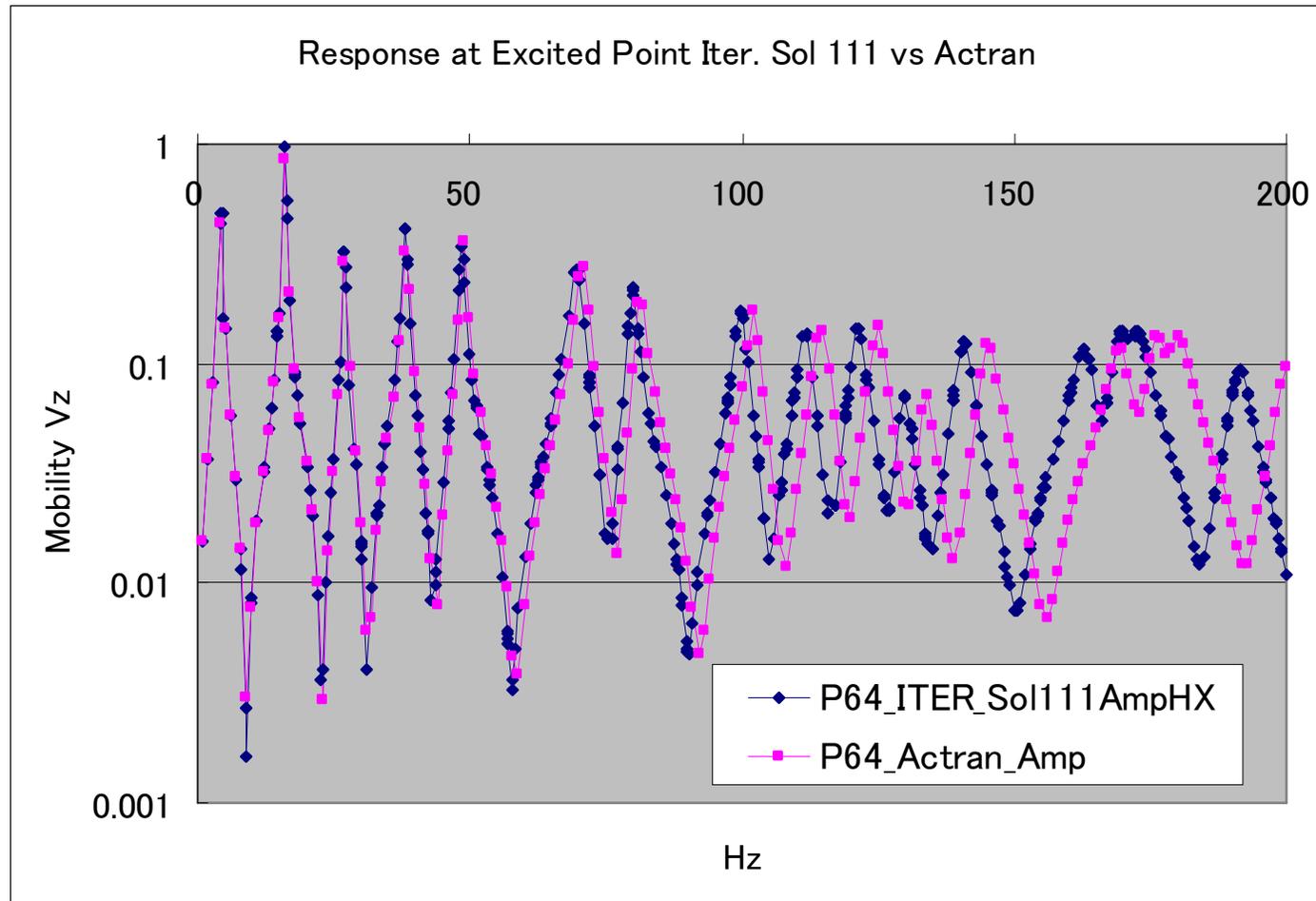
MODEL 1 (EXTERIOR)

- Unit Point Load
- MSC Nastran
 - SOL108/111
- Actran
 - Krylov solver
- Number of Mesh

Plate64	Elm
air	6656
infinite	768
plate	4096
Total	11520



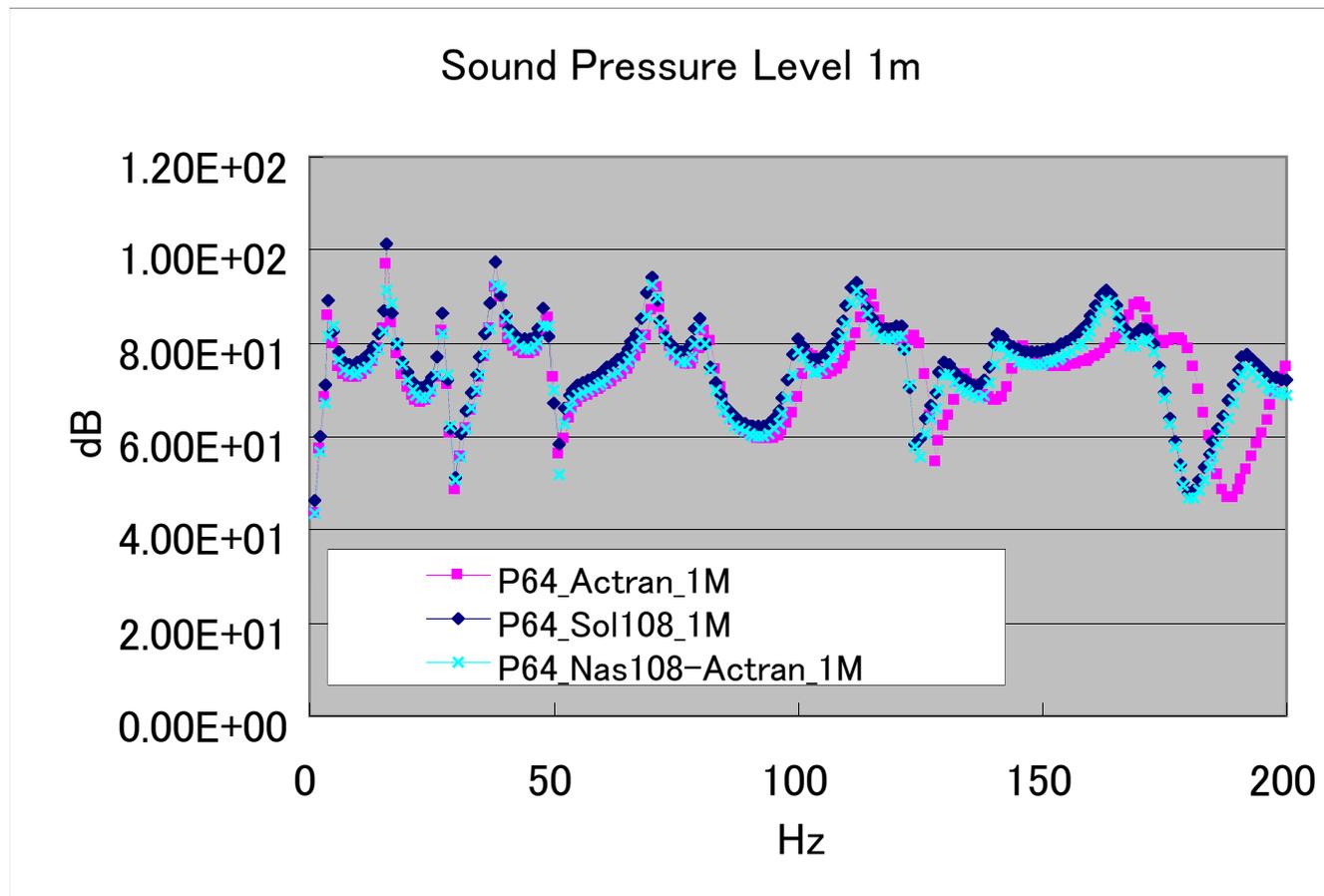
RESULTS: FRF (VELOCITY) OF THE CENTER POINT



In high freq. range, Actran gave “STIFF” results due to using solid shell.

COMPARISON OF RESULTS (COUPLED VS. DECOUPLED)

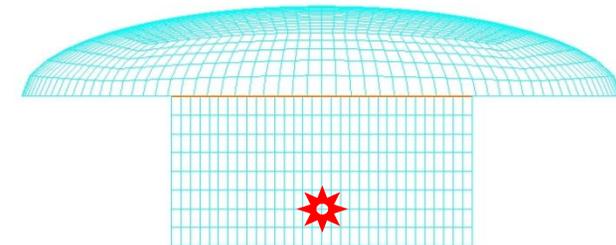
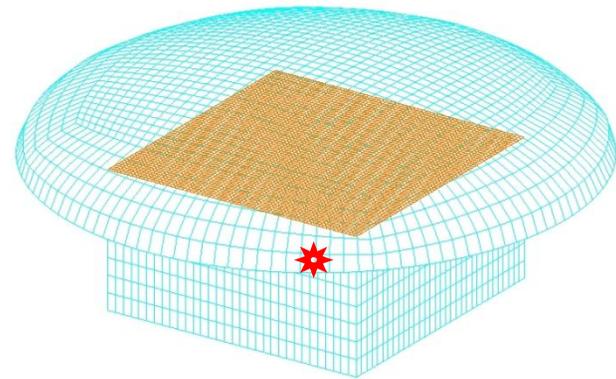
DECOUPLED ANALYSIS: NASTRAN SOL 108 STRUCTURE RESP. -> ACTRAN RADIATION ACOUSTICS



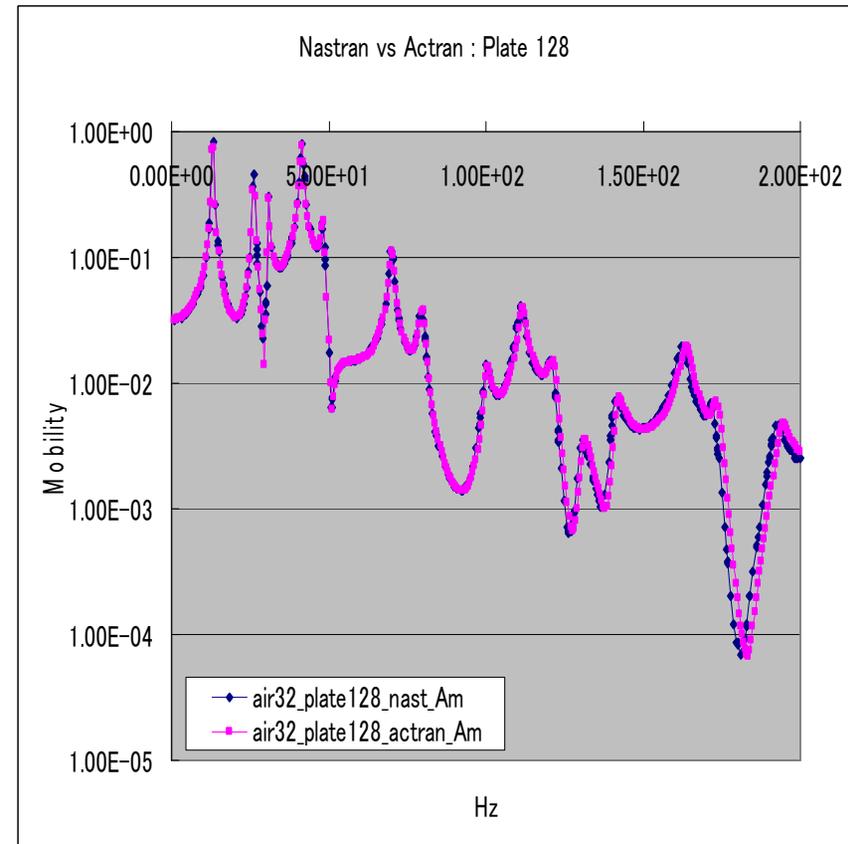
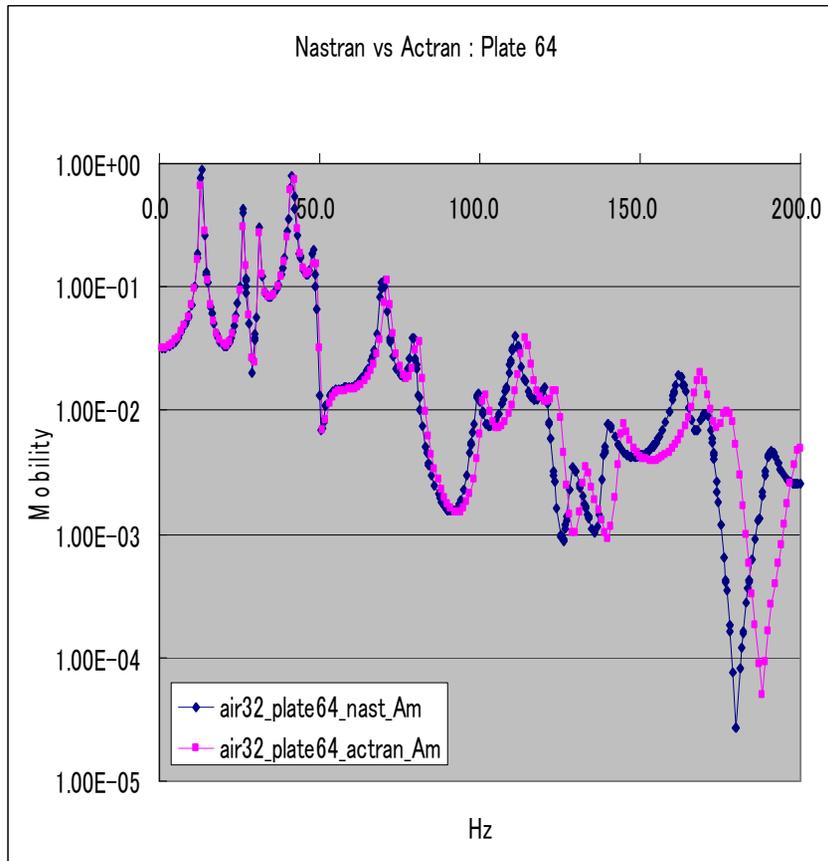
MODEL 2 (INTERIOR + EXTERIOR)

- **Acoustic Source**
 - Source Strength:0.01
- **MSC Nastran**
 - SOL111, Iterative
- **Actran**
 - Krylov solver
- **Number of Mesh**

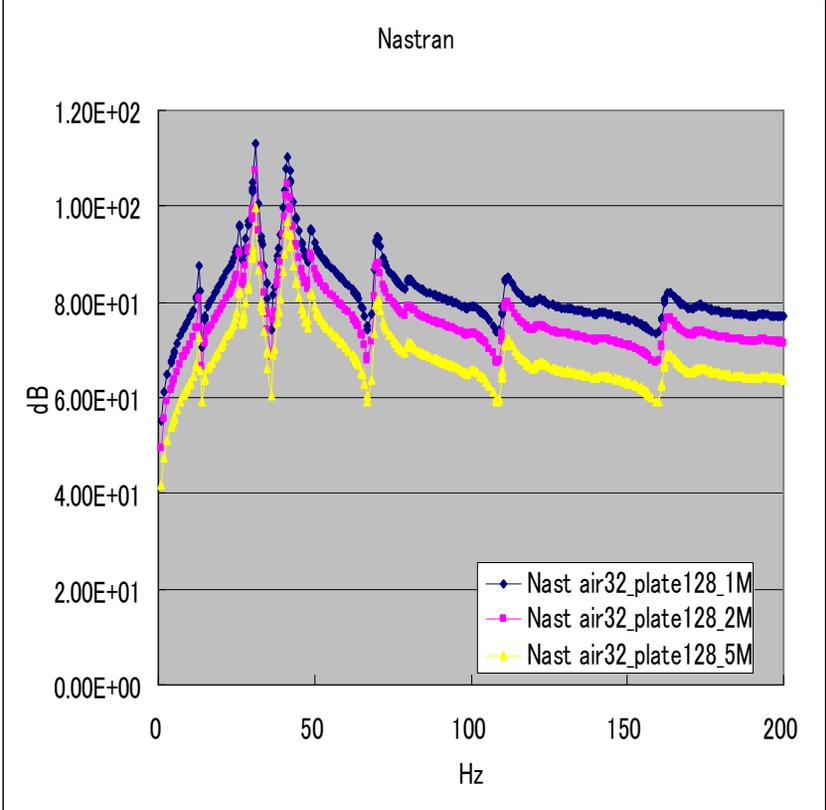
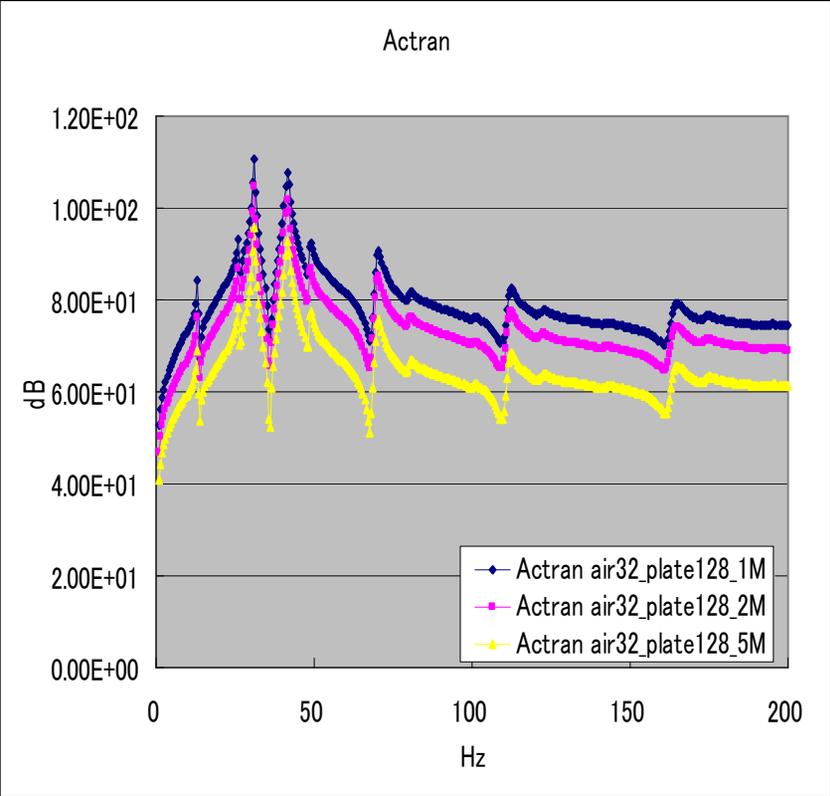
	Plate64	Plate128
air	13440	13440
infinite	1664	1664
air_low	8192	8192
plate	4096	16384
Total	27392	39680



RESULTS: FRF OF THE CENTER POINT



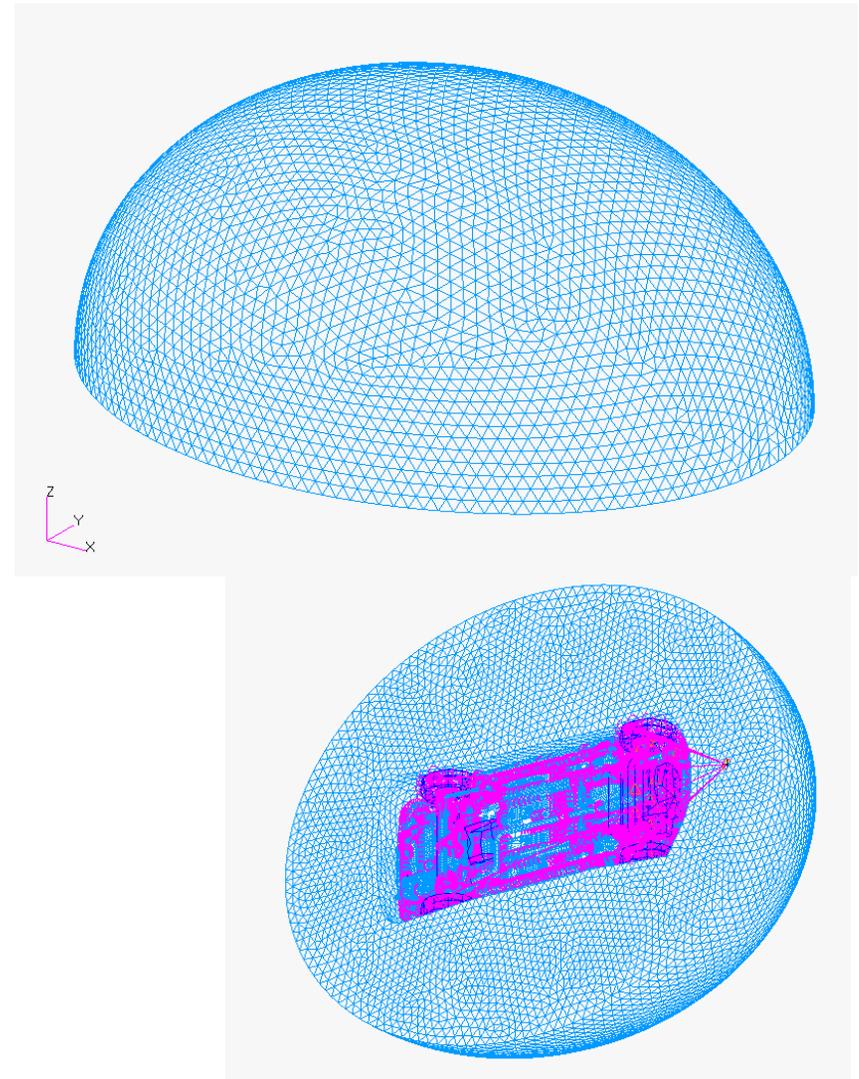
RESULTS: SOUND PRESSURE LEVEL :(PLATE128)



FULL VEHICLE ACOUSTICS (INTERIOR+EXTERIOR)

Model Description

– Node	
Total	421,000
External Acoustic	58,800
Internal Acoustic	3,300
– Element	
Total	702,000
External Acoustic	329,000
Internal Acoustic	2,500
Infinite Element	7,700



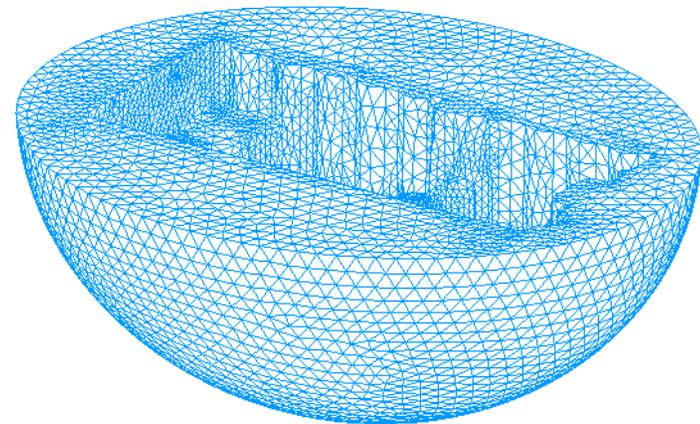
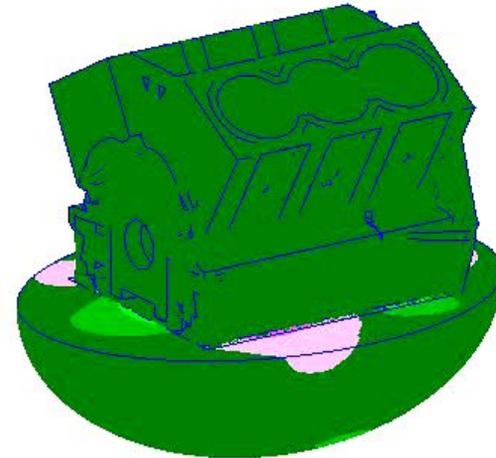
FULL VEHICLE ACOUSTICS (INTERIOR+EXTERIOR)

- **Analysis Condition**
 - Modal Frequency Analysis (SOL 111)
 - DMP=4 (MDACMS)
 - Eigenvalue : 0 ~375Hz, 2640 modes (Structure)
 - Number of Frequencies : 71 Freq.
 - MEM=6GB, SMEM=3GB
 - IBM P630 Power4 1.45GHz
- **Performance Results**
 - Elapsed time = 16.6hr
 - CPU time = 15.7 hr
- **Used Resources (per CPU)**
 - Max. Memory = 4.3GB
 - Max. Disk Space = 9.8GB
 - Total I/O amount = 144.1GB

POWERTRAIN ACOUSTICS (EXTERIOR)

Model Description

- Node
 - Total 473,000
 - External Acoustic 36,200
- Element
 - Total 480,000
 - External Acoustic 194,000
 - Infinite Element 3,800



POWERTRAIN ACOUSTICS (EXTERIOR)

- **Analysis Condition**

- Modal Frequency Analysis (SOL 111)
- Serial run
- Eigenvalue : 0 ~ 3000Hz, 185 modes (Structure)
- Number of Frequencies : 51 Freq.
- MEM=12GB, SMEM=5GB
- IBM Power5 1.85GHz CPU

- **Performance Results**

- Elapsed time = 4.6hr
- CPU time = 2.8 hr

- **Used Resources**

- Max. Memory = 5.6GB
- Max. Disk Space = 23.2GB
- Total I/O amount = 930.4GB

REMARKS ON EXTERIOR ACOUSTICS

- **Results from MSC Nastran agree with those given by Actran**
- **Combined interior/exterior acoustic problem can be solved together**
- **MSC Nastran powerful solver as well as advanced MDACMS/DMP can be used together to greatly reduce the computational time of solving very large scale interior/exterior acoustic problems**
- **Very attractive new feature, huge value**

MDACMS PRELIMINARY RESULTS

- **SOL 111, Iterative Solver**
 - 9:54:31
- **SOL 111, MDACMS, Iterative Solver**
 - 7:00:45
- **SOL 111, MDACMS (DMP=2), Iterative Solver**
 - 4:09:58



WORKSHOP 9

Exterior Acoustics of a Car with Acoustic Pressure Load on Hood



SECTION 9

Special Acoustics Modeling

MODIFYING COUPLING SURFACES

- **In many cases, the default coupling surfaces are sufficient**
- **There are 3 methods available**
 - IDENT (Identical interface points)
 - CP (Closed Pressure, old method)
 - BW (Body in White, default method)
 - Generally, the coupling surface created by the default values is sufficient for most applications
 - Leaving the ACMODL entry out is equivalent to using the default BW method using the default values
- **If not, using the BW method (default method), you can modify the coupling surfaces, if desired**

COUPLING - STRUCTURE/CAVITY INTERACTION

- ***BW search method***
 - **Vast improvement in calculation time over the old CP method**
 - Available since V2004
 - CP method tends to be slower
 - **Better searching methodology**
 - **param,skinout,punch produces .pch file that represent the fluid “skin”**
 - **A utility program is provided for viewing and inspecting the completeness and accuracy of the “skin”**

PARAM,SKINOUT,PUNCH

- **Result is a listing of element and grid ID for the model listed on SET1 BULK DATA entries**
- **These can be used to:**
 - **graphically display fluid and structure interface elements**
 - **in MSC Nastran to limit or expand what elements or grids are used in the fluid/structure interface using the FSET and SSET options on the ACMODL**

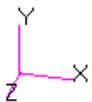
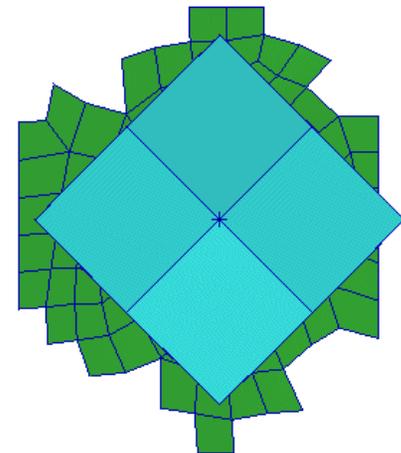
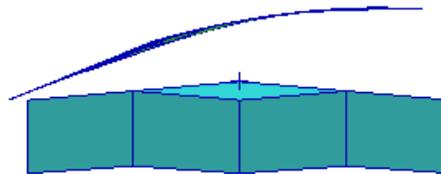
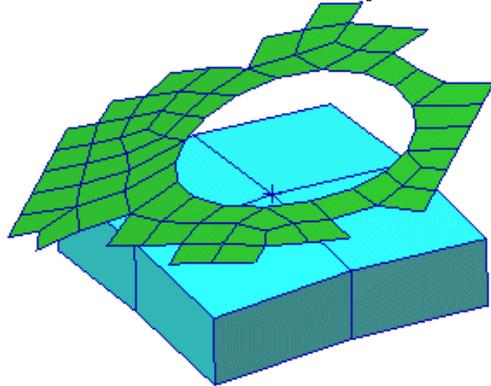
```
$ *****
$ FSI - IDS OF FLUID ELEMENTS AT INTERFACE
$ *****
$ This bulk data entry may be referenced from the FSET field on the
$ ACMODL bulk data entry (with the ELEMENTS option) to remove unwanted
$ fluid faces from the fluid-structure interface.
SET1 1 5001 5001 5001 5002 5002 5003 5003
      5004
$ *****
$ FSI - IDS OF STRUCTURE ELEMENTS AT INTERFACE
$ *****
$ This bulk data entry may be referenced from the SSET field on the
$ ACMODL bulk data entry (with the ELEMENTS option) to remove unwanted
$ structure faces from the fluid-structure interface.
SET1 2 1041 1037 1038 1040 1039 1083 1094
      1092 1091 1090 1082 1095 1093 1063 1081
      1088 1064 1065 1062 1066 1053 1054 1055
      1087 1052 1056 1057 1086 1051 1096 1058
      1019 1028 1085 1073 1050 1072 1076 1084
      1020 1070 1059 1013 1077 1071 1060 1012
      1010 1061 1009 1008 1046 1047 1007 1006
      1044 1045
$ *****
$ FSI - IDS OF FLUID GRIDS AT INTERFACE
$ *****
$ This bulk data entry may be referenced from the FSET field on the
$ ACMODL bulk data entry (with the GRIDS option) to remove unwanted
$ fluid faces from the fluid-structure interface.
SET1 3 5001 5002 5003 5004 5005 5006 5007
      5008 5009 5010 5011 5012 5013 5016
$ *****
$ FSI - IDS OF STRUCTURE GRIDS AT INTERFACE
$ *****
$ This bulk data entry may be referenced from the SSET field on the
$ ACMODL bulk data entry (with the GRIDS option) to remove unwanted
$ structural faces from the fluid-structure interface.
SET1 4 1004 1005 1006 1007 1008 1009 1010
      1017 1018 1027 1028 1029 1030 1031 1032
      1040 1041 1042 1045 1047 1048 1049 1050
      1051 1052 1053 1054 1055 1056 1057 1058
      1059 1060 1061 1062 1063 1064 1065 1066
      1071 1072 1073 1074 1075 1078 1079 1080
      1081 1082 1084 1085 1086 1087 1088 1093
      1094 1095 1096 1097 1098 1099 1101 1102
      1103 1104 1105 1106 1107 1108 1109 1110
      1111 1112 1113 1114 1115 1116 1117 1118
      1119 1120 1121 1122 1123 1125 1126 1127
      1128 1129
```

EXAMPLE OF SKINOUT

- **Problems**

- Initial interface indicates that there are too many structure elements (green)
- Only elements from the inner structural plate are coupled

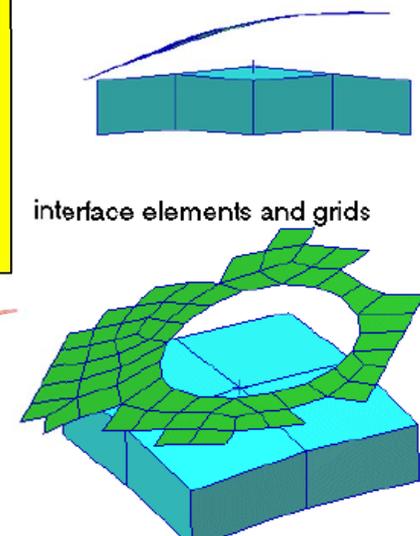
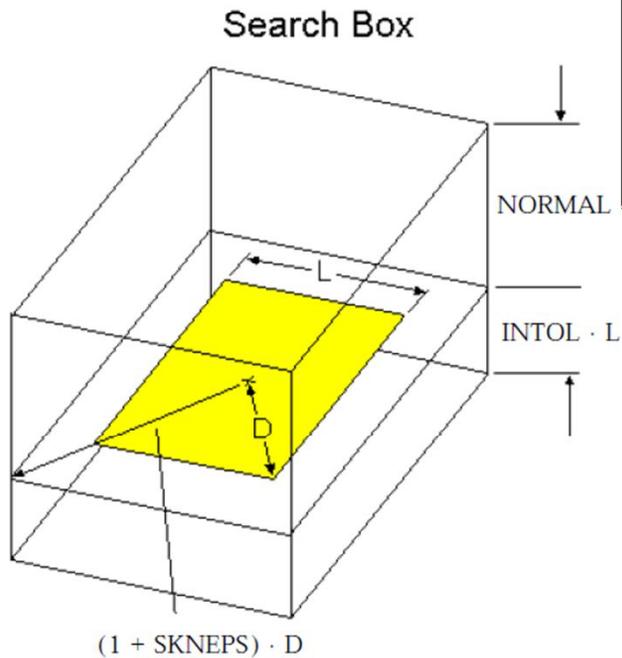
interface elements and grids



CONTROL THE FLUID-STRUCTURE INTERFACE

In example above: SKNEPS = 0.5 default

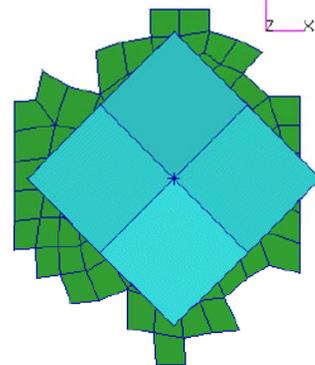
- Extra structure elements were selected that do not project directly onto the fluid faces,
- Only elements from the inner (green) structural plate were selected.



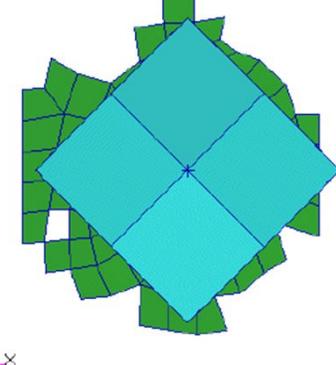
Remove or add elements by adjusting the size of the search box by changing the defaults (NORMAL, INTOL, and SKNEPS fields on the ACMODL entry)

- $NORMAL \cdot L$ - Search box height in positive normal direction from fluid face, where L is smallest fluid face side length,
- $INTOL \cdot L$ - height in negative normal direction,
- $(1 + SKNEPS) \cdot D$ - in-plane width added to fluid face dimensions where D is the distance from the center of the fluid face to the grid point.

SKNEPS=0.5



SKNEPS=0.25



CONTROL THE FLUID-STRUCTURE INTERFACE

- Yet another method to control coupling is to use the INFOR field on the ACMODL entry and manually define structure / fluid elements or grids allowed to participate in coupling
- Modify the SET1 entries generated by the PARAM,SKINOUT, or generate a new SET1 with a pre-processor.

```
SET1  1  5004  5001  5001  5001  5002  5002  5003  5003
SET1  2  1092  1041  1037  1038  1040  1039  1083  1094
      1088  1091  1090  1082  1095  1093  1063  1081
      1087  1064  1065  1062  1066  1053  1054  1055
      1019  1052  1056  1057  1086  1051  1096  1058
      1020  1028  1085  1073  1050  1072  1076  1084
      1010  1070  1059  1013  1077  1071  1060  1012
      1044  1061  1009  1008  1046  1047  1007  1006
      1045  1045
```

ACMODL,DIFF,ELEMENTS,1,2, 1.0, BW

```
acmodl,,elements,1,2
```

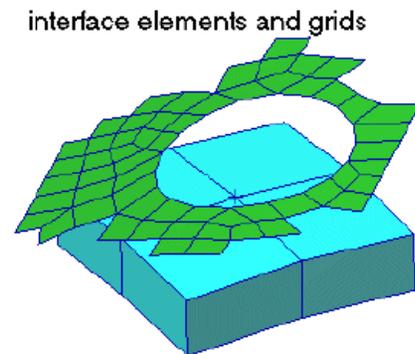
CONTROL THE FLUID-STRUCTURE INTERFACE

- Parallel Structural Element Meshes in the Search Box
- For previous example, none of the outer plate elements were considered in the coupling
 - This is default and expected results (but may not be the desired results)

- To override default behavior, use the ALLSET="YES" on the ACMODL field

Following fields are required as well

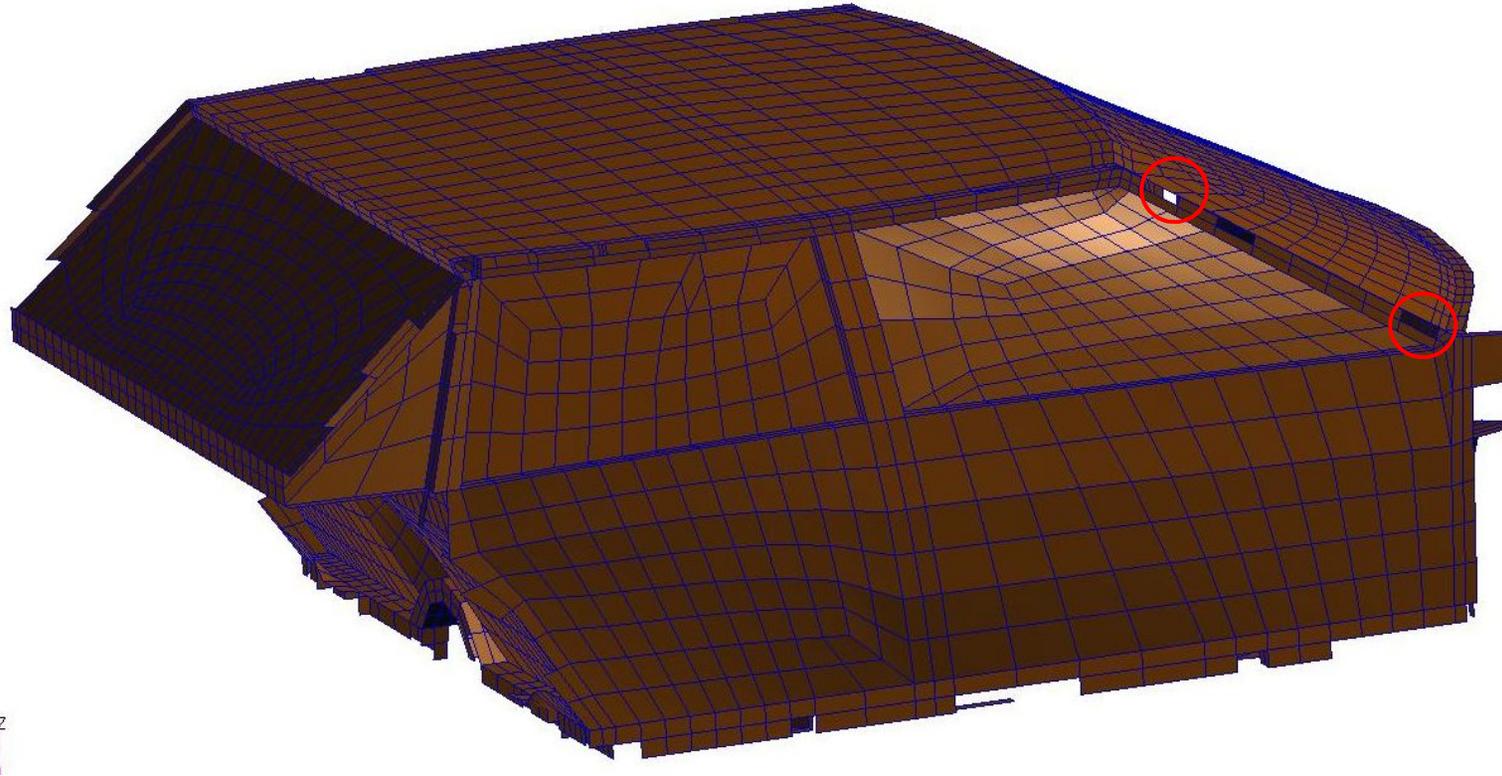
- INTER="DIFF"
- INFOR="ELEMENTS" or "GRIDS"
- SSET



ACMODL	INTER	INFOR	FSET	SSET	NORMAL	METHOD	SKNEPS	DSKNEPS	
	INTOL	ALLSSET	SRCHUNIT						

SKINOUT DISPLAY TEST MODEL

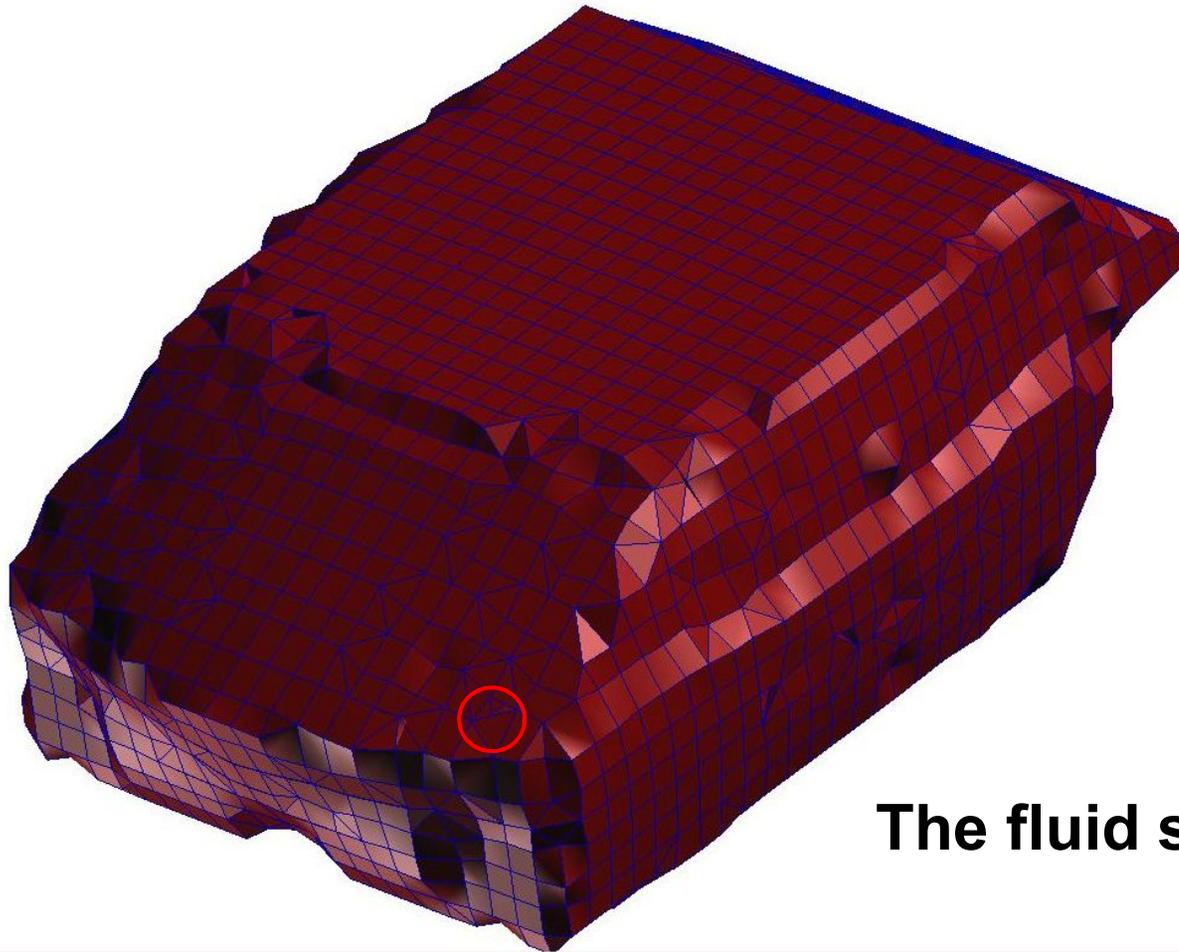
- *Structural coupled elements*



Several 'holes' in the coupling

SKINOUT DISPLAY TEST MODEL

- *Fluid coupled elements*



The fluid skin has 'holes'

SEARCH BOX CONTROLS

- *Three variables under user control*

- **NORMAL***L

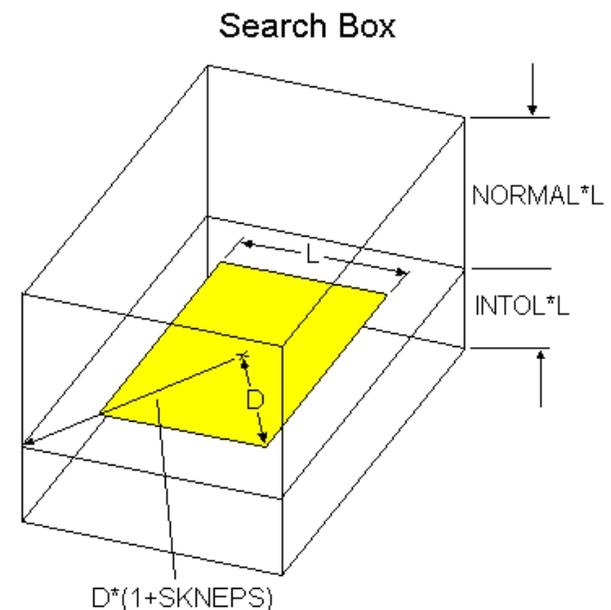
- search box height in positive normal direction from **fluid face**
- L is smallest fluid face side length

- **INTOL***L

- height in negative normal direction (fluid outside cavity)

- **SKNEPS***D

- in-plane width added to **fluid face** dimensions
- D is the fluid face diagonal



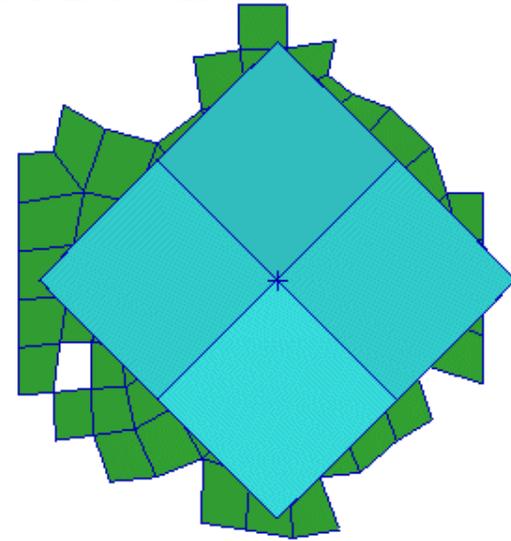
SEARCH BOX CONTROLS

- ***Rules and limitations***
- **Structural element centroid must fall within the search box**
- **Fluid/structure interface matrix is weighed based on the following relationship between the structure and fluid face:**
 - areas
 - angles
 - distances

COUPLING CONTROL - ACOUSTIC1.DAT

- **Modify *ACMODL SKNEPS***
 - 0.5 to 0.25
 - Result
 - Less structural elements are included
 - The revised interface shows that there are still too many structural elements

SKNEPS=0.25

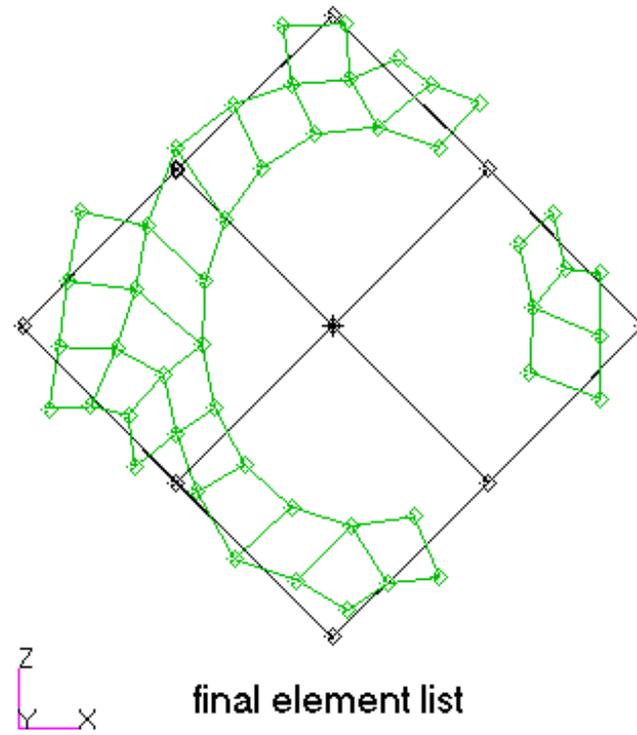


COUPLING CONTROL - ACOUSTIC1.DAT (CONT.)

- ***Modify ACMODL SSET***

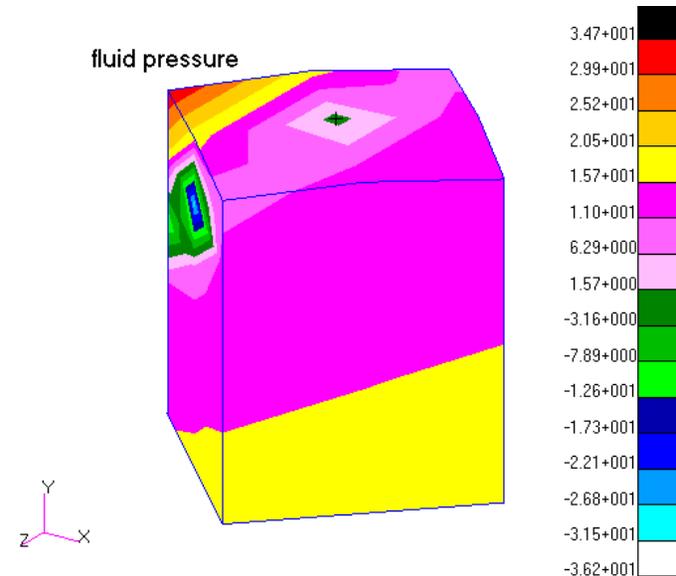
- **Manually remove structural elements from the SET1 entry in the punch file**

- **Results**

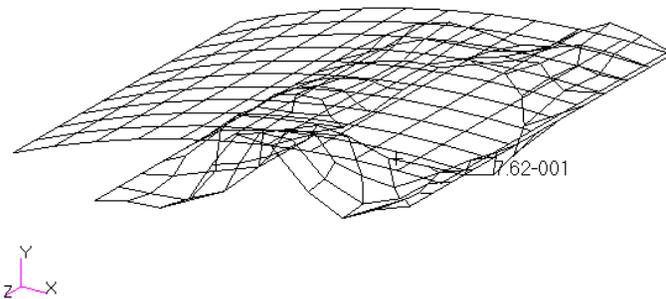


FINAL SOLUTION

- The model is loaded with acoustic power on the upper left hand corner of the fluid, thus the high pressures in that area.
- The effect of the hole in the inner structure can be seen a slight reduction in fluid pressure at the hole.



structural deformation



- The structural deformation shows the outer structure is unaffected by the pressure as expected as there is no coupling

PARALLEL STRUCTURAL ELEMENT MESHES

- ***Multiple sheet metal structures***
 - Outer parallel structural surface not selected even though it falls within the search box
 - Parallel surfaces are ignored using a connectivity technique
 - Structural element **closest** to the fluid face starts connectivity
 - Only elements related through connectivity are used
 - Outside elements not used for connectivity

FLUID-STRUCTURE INTERFACE

- **Identical Fluid-Structural Interface**
 - IDENT on the INTER field of the ACMODL Bulk Data entry.
 - Each of the fluid boundary element surfaces is in full contact with one structural surface.
 - Structure grids and fluid grids coincident at the interface.
 - Use FSET and SSET on ACMODL bulk data entry to decrease search.
 - If used, both sets must be present; otherwise, the interface is not calculated
 - Both set must lie at the fluid-structure interface
 - If no structural elements are found, a warning message will be issued
- **Non-Identical Fluid-Structural Interface**
 - Two different methods are available
 - BW (default, recommended)
 - CP (Old method, prior to version 2004)
 - Non-Identical is the default using the BW method by leaving out the ACMODL

FLUID-STRUCTURE INTERFACE

- **If no ACMODL specified**
 - MSC Nastran will assume non coincident mesh
 - BW method will be used
 - An information message is printed in f06 (just after model summary)

```
0
      M O D E L   S U M M A R Y           BULK = 0
      ENTRY NAME   NUMBER OF ENTRIES
      -----
      CACINF3             1732
      CQUAD4             1126
      CTETRA            12396
      DLOAD              1
      FORCE                1
      FREQ                1
      FREQ1              1
      GRID               4135
      LSEQ                1
      MAT1                1
      MAT10              1
      PACINF             1
      PARAM              3
      PSHELL             1
      PSOLID             1
      RLOAD1             1
      SPC1                1
      SPCADD             1
      TABLED1          1

      M O D E L   S U M M A R Y           AFPM = 4
      ENTRY NAME   NUMBER OF ENTRIES
      -----
      CQUAD4             5
      GRID              20
      PARAM              1
```

```
^^^
^^^ >>> IFP OPERATIONS COMPLETE <<<
^^^
*** USER INFORMATION MESSAGE 6207 (GP5)
    AN ACMODL ENTRY WAS NOT FOUND. A NONMATCHING MESH IS ASSUMED.
    METHOD: BW
```

NON-MATCHING INTERFACE NEW BW METHOD

- **Better for irregular not perfect matching fluid structure meshes**
- 1. **Use the current search algorithm to locate the fluid free faces and the corresponding structural element faces.**
- 2. **For a fluid free face and its list of structural element faces (that were determined by boxing normal to the fluid element) do as follows:**

- a) For each fluid free face establish a face coordinate system.
- b) Determine the resultant pressure force for each grid on the fluid element by the relationship

$$R_i = \int_S [N_f] dS \{p_i = 1; p_j = 0\} \quad i = 1, N \text{ grid/elem}$$

- c) Resolve this resultant pressure force for a unit grid pressure to the grids of the fluid element by the expression (determined by virtual work)

$$\{F_i\} = \int_S \{N_f\}^T [N_f] dS \{p_i\}$$

NON-MATCHING INTERFACE NEW BW METHOD

- d) Using the origin of the free fluid face, determine the center of pressure. (X_{P_i}, Y_{P_i}) .
The relationship will be of the form

$$X_{P_i} = \sum_j^{\text{grids}} \frac{F_j^i}{R_i} (X_j - X_0)$$

$$Y_{P_i} = \sum_j^{\text{grids}} \frac{F_j^i}{R_i} (Y_j - X_0)$$

- e) Using rigid relations to consider only a unit motion normal to the fluid face with the appropriate moment relationships, determine the resulting load distribution at the grids of each of the structural elements. The area of each structural element projected normal to the fluid element will be used as a weighting function. The expression is of the form:

$$\{F_j\} = [W][R]([R]^T[W][R])^{-1} \begin{Bmatrix} R_i \\ 0 \\ 0 \end{Bmatrix}$$

$\{F_j\}$ is the vector of resulting load distribution at the grids of each of the j structural elements.

$[W]$ is a diagonal weighting matrix.

$[R_i]$ is the rigid transformation matrix.

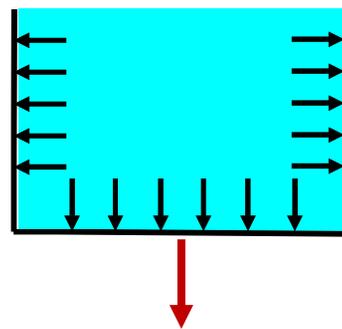
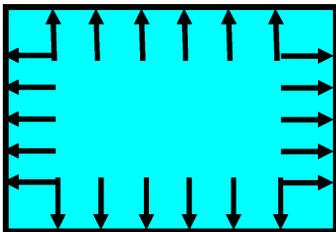
NON-MATCHING INTERFACE NEW BW METHOD

- f) Loop over each grid of the fluid element and accumulate the forces at the structural grids.
- g) Note, with this algorithm, we do not worry if a structural element is only partially wetted by the fluid. We always require rigid body equilibrium.

3. Repeat for the next fluid element and its associated group of structural elements

CHECK OF THE FLUID-STRUCTURE INTERFACE

- **MSC Nastran computes the force resultant on the structure due to a uniform unit pressure in the fluid.**
- **If the fluid is completely enclosed by the structure, this resultant should be zero.**
- **If there are openings, the components of the force resultant are proportional to the projection of the area of the openings on the corresponding coordinate planes.**



ACOUSTIC MODELING TECHNIQUES

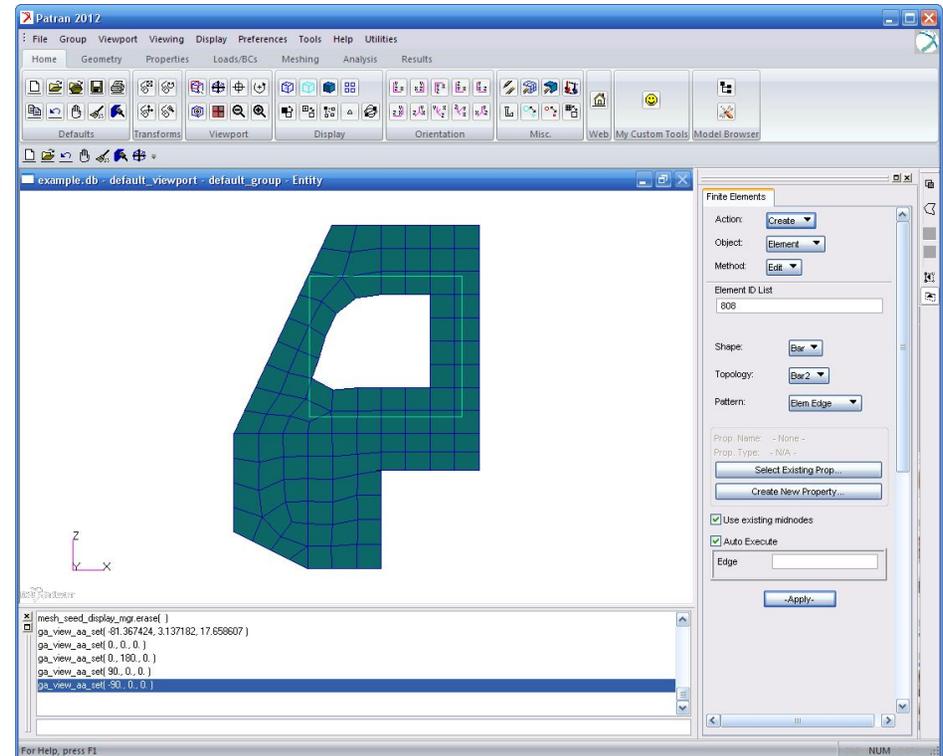
- **Several methods exist to create the acoustic model.**
- **The method used depends upon type of geometry and what modeling tools are available.**
- **Tetra mesh:**
 - If the fluid volume to be meshed can be described by a closed surface or tet-mesh, a general tet-mesh technique can be used.
 - A wrap mesher can generate a closed TRIA mesh from a surface mesh that is initially not closed. Wrap meshers are often available through CFD pre-processor. There is currently no wrap mesher available in MSC pre-processors.
 - For acoustic models, use linear tetra elements.
- **An example is shown on the following pages to fill a "car cabin" that has an initial opening (example, window) using Patran**
- **Some familiarity of Patran is assumed**
 - (Reference PAT301, PAT302, or NAS120)

CREATING A TET MESH FROM AN OPEN WINDOW DESIGN USING PATRAN

- The following is an example outlining the steps
 - Fill an open window design with elements and
 - Create a final tet mesh from it.

Steps

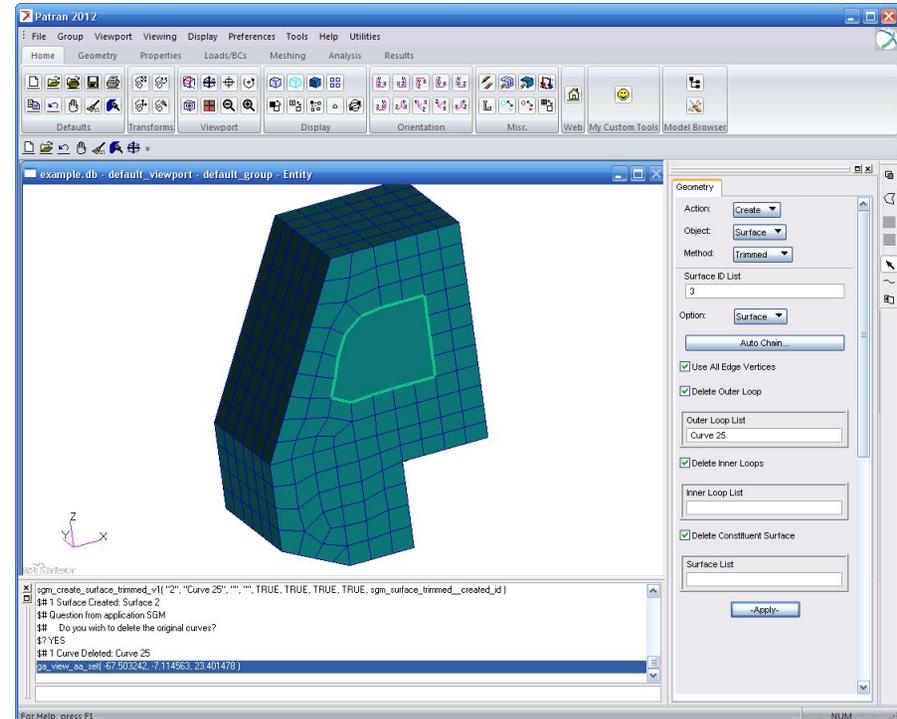
1. From the Mesh menu (*Create/Element/Edit*), create the 1D bar elements around the free edges of the hole.
2. Then use “*Utilities/Geometry/Create Curves From 1D Elements*” to create geometry curves on top of the 1D bars.



CREATING A TET MESH FROM AN OPEN WINDOW DESIGN

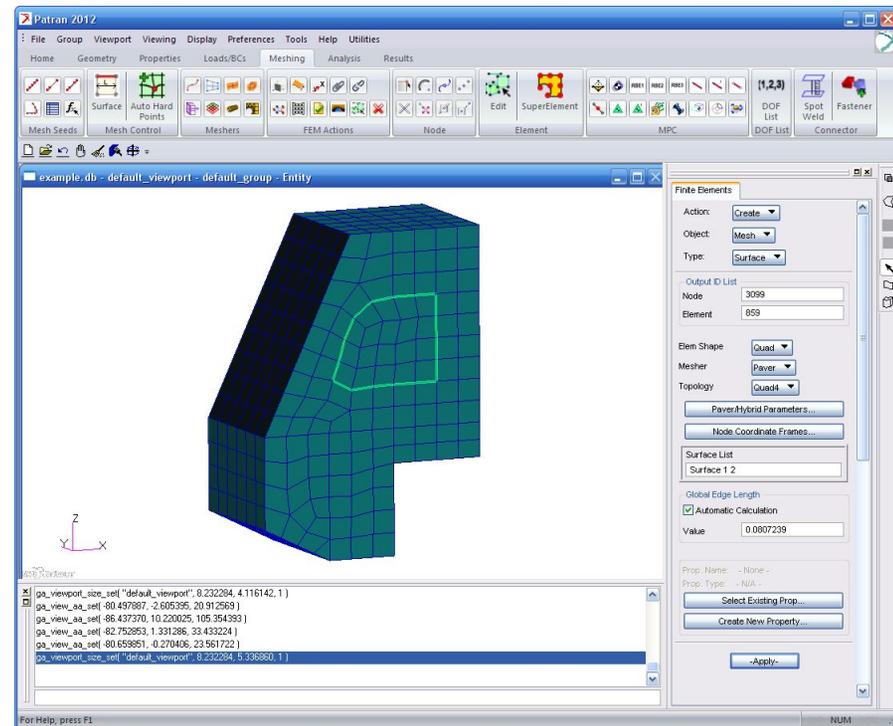
3. Create a chain curve of each curve loop that represents the hole using *Create/Curve/Chain*. (Using Auto Chain is fastest)
4. Then, use the previously created chain curves to create a surface with *Create/Surface/Trimmed*.
 - *Note that the properties can be (probably is)*
5. Mesh the surfaces with Paver mesh with *Create/Mesh/Surface**.

* If you want a finer mesh, you need to mesh seed the edges first using Tabular Seeding.



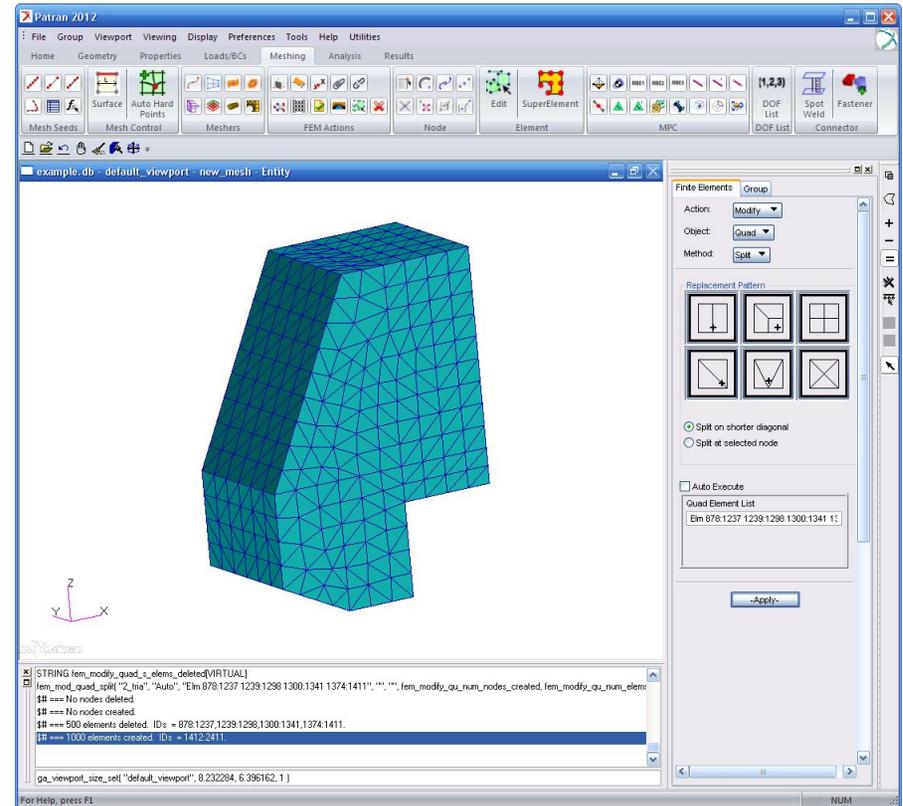
CREATING A TETMESH FROM AN OPEN WINDOW DESIGN

6. Equivalence your mesh
7. For construction purposes, create a Group (*Group/Create*) and make it current. You will create a copy of this mesh into the Group, then modify the QUADs into TRIAs using.
8. Use *Transform/Element/Translate* with a vector of $\langle 0 \ 0 \ 0 \rangle$ to make a copy of the QUADs into the new Group.



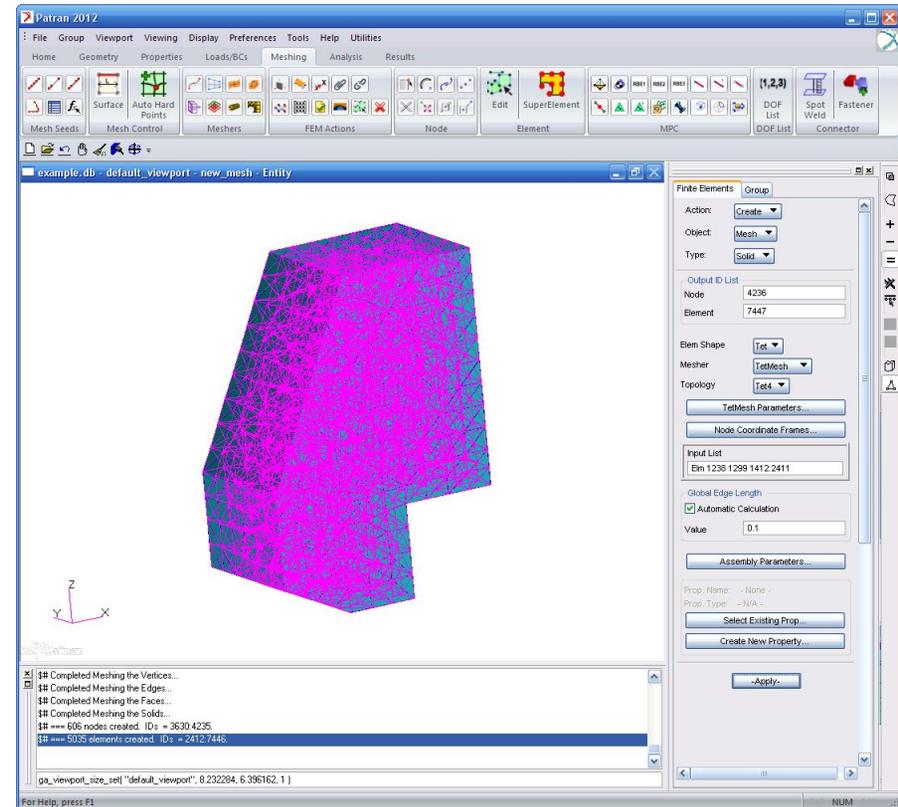
CREATING A TETMESH FROM AN OPEN WINDOW DESIGN

9. Post only the new Group.
10. Then, split the QUADs into TRIAs using *Modify/Quad/Split*. Pick the replacement pattern on the lower left.
11. Once you've obtained the TRIA elements, you can create the TET mesh from them.



CREATING A TETMESH FROM AN OPEN WINDOW DESIGN

12. To create the tetmesh, use *Create/Mesh/Solid, Tet/Tetmesh/Tet4*.
13. Select the TRIA element icon to allow only TRIA elements to be picked from the screen as the Input List.
14. You should now have a TET mesh that fills the volume.
15. The TRIA mesh used to generate the TET mesh can be deleted, if desired.
16. The original QUAD mesh remains in the original group.



WEAKLY COUPLED ACOUSTICS

- **As discussed in previous sections, FSI is supported for both interior and exterior acoustics in MSC Nastran**
- **For modal frequency response analysis, convergence for FSI can be slow for large models that contain both interior and exterior acoustics**
- **To improve efficiency, a 2 steps approach can be used**
 1. FSI with interior acoustic only in modal formulation, followed by
 2. Exterior acoustic job with loading derived from the results of step 1
- **The above approach is typically known as weakly coupled acoustic analysis**

WEAKLY COUPLED ACOUSTICS

- Typical equation that contains both interior and exterior acoustics can be solved in one step

$$(-\omega^2 \begin{bmatrix} M_s & 0 & 0 \\ -A_i^t & M_{fi} & 0 \\ -A_e^t & 0 & M_{fe} \end{bmatrix} + i\omega \begin{bmatrix} B_s & A_i & A_e \\ 0 & B_{fi} & 0 \\ 0 & 0 & B_{fe} \end{bmatrix} + \begin{bmatrix} K_s & 0 & 0 \\ 0 & K_{fi} & 0 \\ 0 & 0 & K_{fe} \end{bmatrix}) \begin{Bmatrix} u_s \\ q_i \\ q_e \end{Bmatrix} = \begin{Bmatrix} P_s \\ G_i \\ G_e \end{Bmatrix} \quad \dots\dots\dots \text{Eqn. 8-1}$$

Structure quantities

M_s = structure mass

B_s = structure damping

K_s = structure stiffness

u_s = structure displacement

P_s = structure loads

WEAKLY COUPLED ACOUSTICS

Interior Acoustics quantities

A_i = interior acoustic coupling matrix

M_{fi} = interior fluid mass

B_{fi} = interior fluid damping

K_{fi} = interior fluid stiffness

q_i = pressure

G_i = source

Exterior Acoustics quantities

A_e = exterior acoustic coupling matrix

M_{fe} = exterior fluid mass

B_{fe} = exterior fluid damping

K_{fe} = exterior fluid stiffness

q_e = pressure

G_e = source

WEAKLY COUPLED ACOUSTICS (CONT.)

- **Step 1 (equation 8-2) is solved with either the direct (SOL 108) or modal (SOL 111) approach**
- **Step 2 (equation 8-3) is solved using the direct approach (SOL 108)**
- **Note that the results using the weakly coupled approach will be different than the default fully coupled approach**
- **Weakly coupled approach is only a good approximation if it is truly weakly coupled**
- **Activated with “param,acoweak,yes”**
- **Only supports SOL 111 and MFREQ for SOL 200**

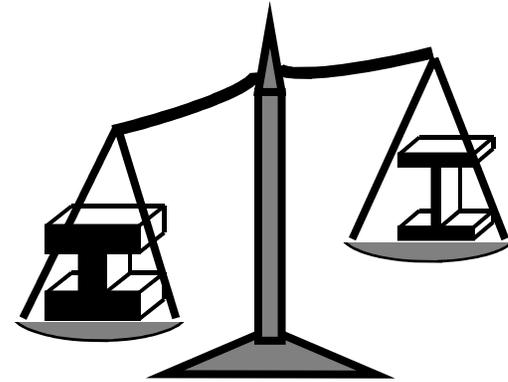


SECTION 10

ACOUSTIC USING OPTIMIZATION

WHAT IS “DESIGN OPTIMIZATION”?

- **Automated modifications of the analysis model parameters to achieve a desired objective while satisfying specified design requirements.**
- **Objective**
 - Minimize weight
 - Maximize payload
 - Minimize Error Function (test/analysis)
- **Design Variables**
 - Element properties (I, J, Area, t, etc.)
 - Grid locations (shape optimization)
 - Topology (remove structure)
- **Design Constraints**
 - Direct Response
 - Stress Limit, Freq, Disp.
 - Derived Response
 - Equation
 - DESVAR range ($.04 < t < .25$)

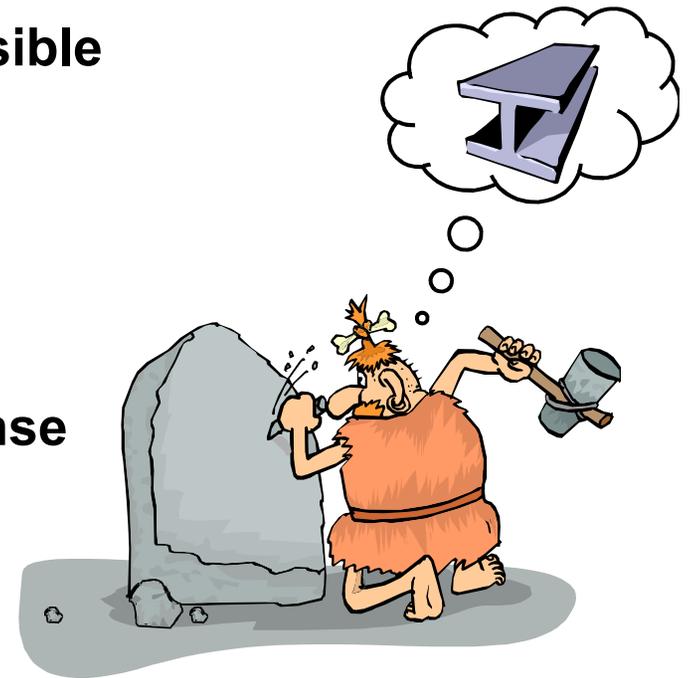


OPTIMIZATION STUDY

- **Optimization is a 3 day class and it covers a wide varieties of topics**
- **In this class, we will just cover a very small area**
 - Attend the optimization class for in-depth coverage of optimization
- **Why are we interested in using optimization for acoustic analysis?**
 - Many times, not only will the peak shifts up and down with design changes, but so will the frequency
 - We will simply look at a case of minimization the pressure response at a particular location across the whole frequency range

OPTIMIZATION APPLICATIONS

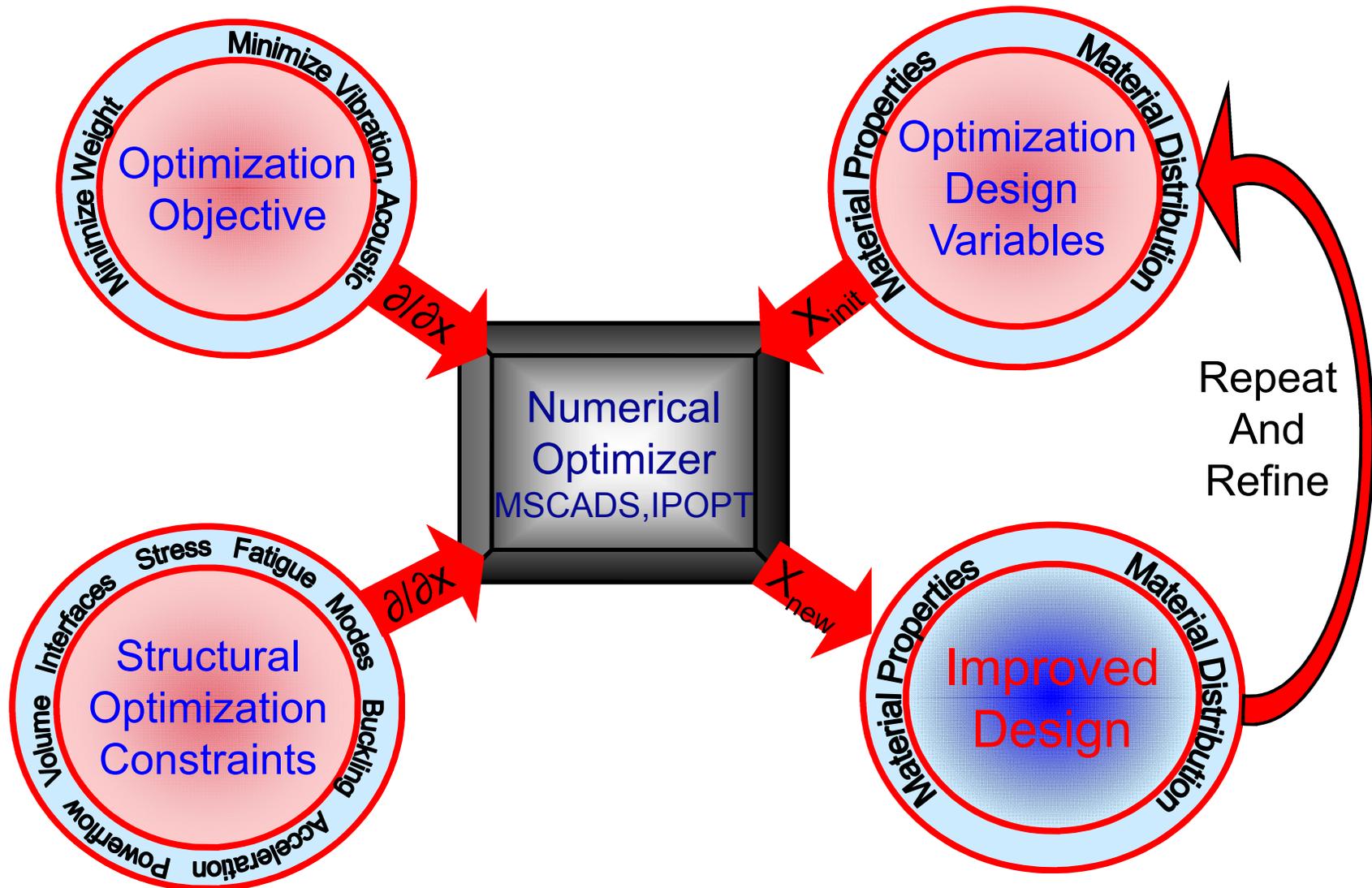
- **Structural design improvements**
 - Minimize thickness, hence weight
- **Generation of feasible designs from infeasible designs**
 - original model violates stress levels
- **Preliminary Design**
 - Candidate designs from topology optimization
- **Model matching to produce similar response**
 - frequency response, modal test
- **Sensitivity evaluation**
 - Identify which regions of the model are most “sensitive” to design changes or imperfections
- **Others**
 - Depends on the designer’s creativities



BASIC FEATURES IMPLEMENTED IN MSC NASTRAN

- **Easy access to design synthesis capabilities**
 - Concept of design model
- **Flexibility for design model representation**
 - User-supplied equation interpretation capability
- **Efficient solution for problems of “any” size**
 - Number of finite element analyses as the measure of efficiency

GRADIENT BASED NUMERICAL OPTIMIZATION



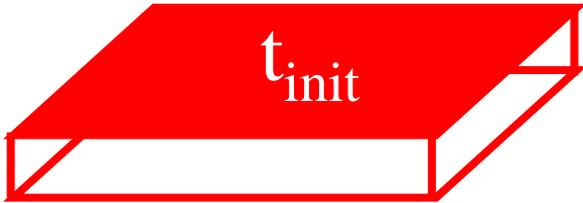
STRENGTHS OF MSC NASTRAN STRUCTURAL OPTIMIZATION

- **Efficient performance for small- to large-scale problems**
- **Reliable convergence characteristics**
- **Flexible user interface and user-defined equations**
- **Full implementation of approximation concepts**
- **Continuous enhancements**
- **Results dependent on the proven reliability of MSC Nastran analysis**
- **High-level support as a part of MSC Nastran**
- **Access to the familiar analysis tools in MSC Nastran**
- **Activated with SOL 200**

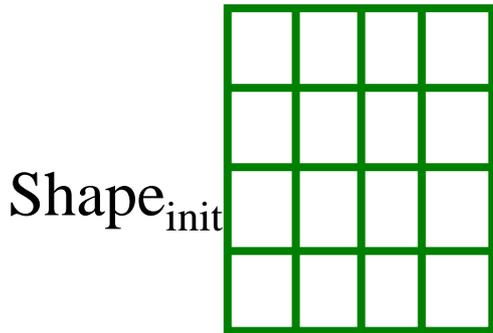
OPTIMIZATION CAPABILITIES SUPPORTED

- **Multi-Disciplinary Optimization**
- **Static Response Optimization**
- **Buckling Response Optimization**
- **Dynamic Response Optimization**
 - Direct Frequency
 - Modal Frequency
 - Modal Transient
 - Acoustics
- **Superelement Optimization**
 - Allows the design model to span superelement boundaries.
- **Aeroelastic Optimization**
 - Static Aeroelastic
 - Flutter

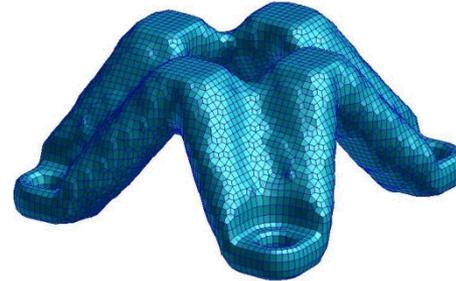
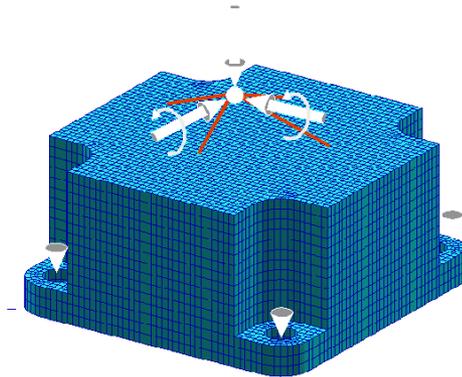
TYPES OF OPTIMIZATION IN MSC.NASTRAN



- Sizing
 - Change in property (t, I, J, theta, etc.)



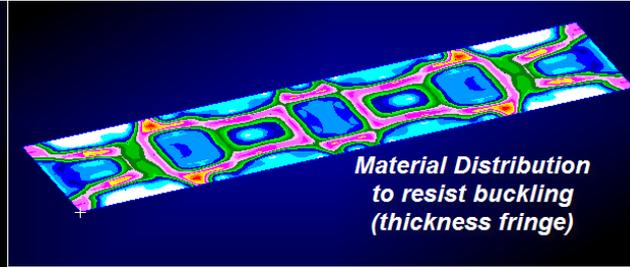
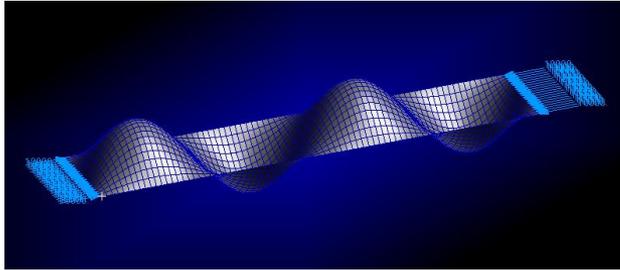
- Shape
 - Change in GRID locations



- Topology
 - “Remove” unneeded structure

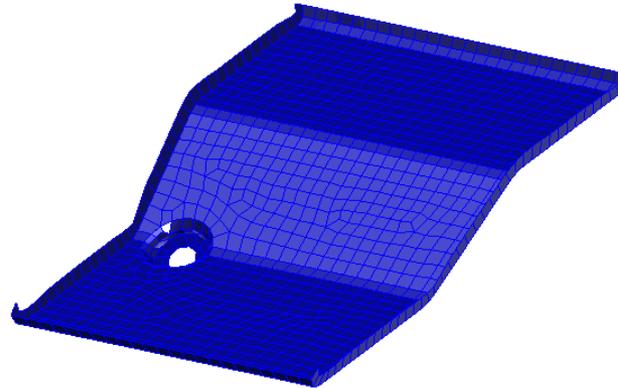
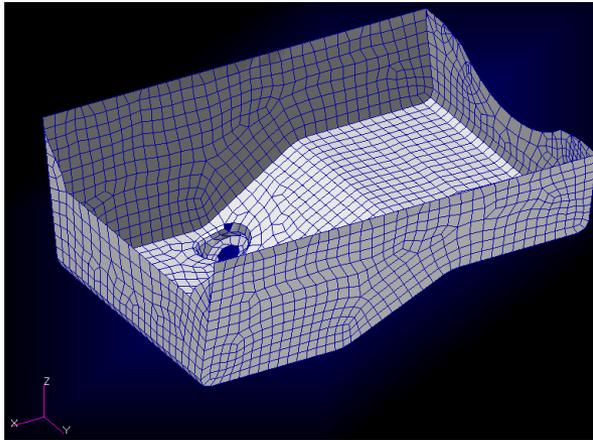
$$\begin{aligned} \rho &= \rho_o \times \\ E &= E_o \times P \end{aligned}$$

TYPES OF OPTIMIZATION IN MSC NASTRAN



• Topometry

- Modify each thickness
- Special form of sizing optimization



- Topography
- Modify flat to dimpled
- Special form of shape optimization

DESIGN OPTIMIZATION IN MSC NASTRAN

- **The ANALYSIS Case Control request allows you to specify the type of optimization analysis discipline that you want to perform for each subcase.**
- **Multi-Disciplinary**
- **The following analysis types are allowed in the ANALYSIS Case Control request:**
 - STATICS Statics
 - MODES Normal Modes
 - BUCK Buckling
 - DFREQ Direct Frequency
 - MFREQ Modal Frequency
 - MTRAN Modal Transient
 - SAERO Static Aeroelasticity
 - FLUTTER Flutter

DESIGN OPTIMIZATION IN MSC NASTRAN (CONT.)

- In the example below you optimize two static load cases in subcases 1 and 2, a modal response in subcase 3, and a transient response in subcase 4.

```
SOL 200
CEND
SPC = 100
DESOBJ(MIN) = 15
ANALYSIS = STATICS
SUBCASE 1
  SUBTITLE = STATIC LOAD CASE 1
  DESSUB = 10
  DISP = ALL
  LOAD = 1
SUBCASE 2
  SUBTITLE = STATIC LOAD CASE 2
  DESSUB = 20
  DISP = ALL
  LOAD = 2
SUBCASE 3
  SUBTITLE = NORMAL MODES
  ANALYSIS = MODES
  DESSUB = 30
  METHOD = 3
SUBCASE 4
  SUBTITLE = MODAL TRANSIENT ANALYSIS
  DESSUB = 40
  ANALYSIS = MTRAN
  METHOD = 4
  DLOAD = 4
  TSTEP = 10
BEGIN BULK
```

COMMONLY USED OPTIMIZATION BULK DATA ENTRIES

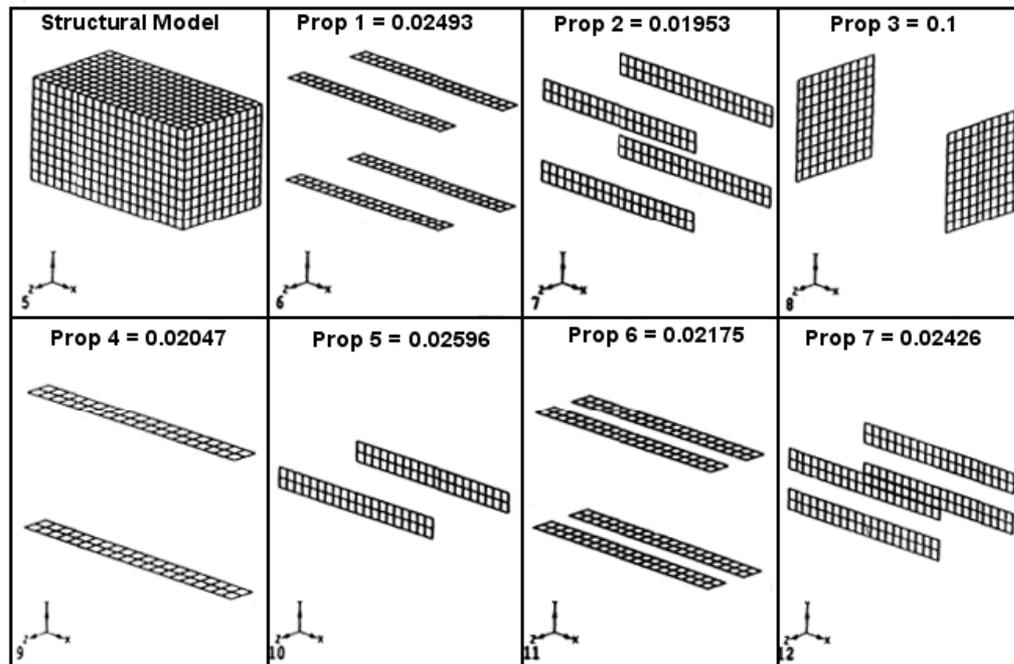
- **DESVAR** Defines a design variable.
- **DVPREL1** Defines the relation between an analysis model property and design variables.
- **DLINK** Relates one design variable to one or more other design variables.
- **DRESP1** Defines a set of direct structural responses that is used in the design either as constraints (referenced by the DCONSTR Bulk Data entry) or as an objective (referenced by the DESOBJ Case Control Command).
- **DCONSTR** Defines a design constraint (referenced by the DESSUB Case Control Command).
- **DCONADD** Defines the design constraints for a subcase as a union of DCONSTR entries.
- **DRESP2** Defines a synthesized response that are used in the design. This response can be either a constraint or an objective.
- **DEQATN** Defines equation(s) for use in design sensitivity.
- **DVCREL1** Defines the relation between a connectivity property and design variables.
- **DVCREL2** Defines the relation between a connectivity property and design variables using a user-supplied equation.
- **DVMREL1** Defines the relation between a material property and design variables.
- **DVMREL2** Defines the relation between a material property and design variables with a user-supplied equation.

ACOUSTIC OPTIMIZATION EXAMPLE

- **This example considers a closed box with fluid elements on the interior.**
- **An acoustic source is located at one end of the box.**
- **A transducer is located at the opposite end.**
- **The design goal is to modify the thicknesses of the box walls such that the peak acoustic pressure at the transducer is minimized.**
 - The challenge is the ability to minimize this pressure across the whole frequency range
- **This is to be done while minimizing the weight of the box as the objective function.**

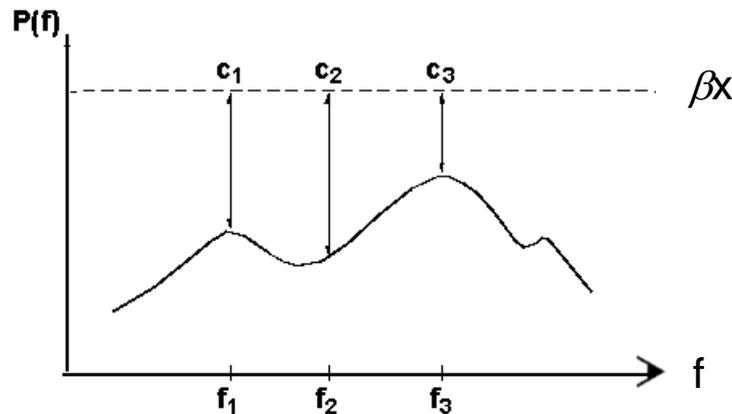
ACOUSTIC OPTIMIZATION (CONT.)

- The box geometry and property groups of thicknesses to be modified are shown below:
- Six design variables are to be related to six of these property groups (the third property group remains fixed).



ACOUSTIC OPTIMIZATION (CONT.)

- To decrease response, many times we manually change the thickness of what we think would be the most affective areas
- **Must take into account the following:**
 - A number of response peaks may exist
 - These peaks may not only increase or decrease, but may shift in frequencies as well.
- **The objective is to minimize the maximum pressure response over peak frequencies f_1 , f_2 , and f_3 .**



ACOUSTIC OPTIMIZATION (CONT.)

- Choose a design variable to represent a peak threshold, here shown in the figure as βx (α is just a constant of proportionality to facilitate scaling the threshold). The difference between βx and the pressure distribution must be a positive quantity at all frequencies of interest.
- Thus, constraints can be written which require c_1 , c_2 , and c_3 to be positive distances.
- The design objective can then be to minimize βx , or

$$\text{Minimize} \quad \beta x \quad (10-1)$$

$$\text{Subject to:} \quad P(f1) - \beta x \leq 0 \quad (10-2)$$

$$P(f2) - \beta x \leq 0$$

$$P(f3) - \beta x \leq 0$$

- As the optimizer decreases the threshold, the constraints ensure that the peaks are reduced as well.
- Any number of these constraints can be written to cover all frequency ranges of interest (or, in the case of transient analysis, time steps).

ACOUSTIC OPTIMIZATION (CONT.)

- **The weight budget is established as a global constraint.**
 - The weight response is defined on DRESP1 number 2;
 - Bounds are placed on this response with DCONSTR number 5, which is referenced in Case Control by the DESGLB command.
- **The objective function is defined as a constant times design variable number 8 using the DRESP2 number 100 entry. This refers to DEQATN 100 which defines:**

$$F = 10000 * x_8 \quad (10-3)$$

- **This is defined as the objective function by the DESOBJ = 100 Case Control command.**

ACOUSTIC OPTIMIZATION (CONT.)

- **The constraints on response peaks are defined by first identifying the pressure responses themselves with DRESP1 entry number 1.**
 - This designates the "1" component of displacement at grid 11280 as the response.
 - Since the ATTB field is blank on this DRESP1 entry, the response is computed for all output frequencies.
- **These pressure responses are used as input to DEQATN 10 via DRESP2 number 11.**
- **These entries, in combination with DCONSTR number 10, identify constraints on pressure response of the form:**

$$k_1 * x_8 - P(f) + k_2 \geq k_2 \quad (10-4)$$

- **Note that the constant k_2 is added to avoid a bound of zero on the constraint.**
- **The constants have been chosen to scale the objective and responses to values that would minimize numerical difficulties.**

ACOUSTIC OPTIMIZATION (CONT.)

- The design cycle history below shows the objective function has decreased from 10000 to 1536 in fifteen iterations

OBJECTIVE AND MAXIMUM CONSTRAINT HISTORY				
CYCLE NUMBER	OBJECTIVE FROM APPROXIMATE OPTIMIZATION	OBJECTIVE FROM EXACT ANALYSIS	FRACTIONAL ERROR OF APPROXIMATION	MAXIMUM VALUE OF CONSTRAINT
INITIAL		1.000000E+04		1.047196E-01
1	5.000000E+03	5.000000E+03	0.000000E+00	1.329407E-03
2	3.790412E+03	3.790412E+03	0.000000E+00	1.216992E-01
3	2.842809E+03	2.842809E+03	0.000000E+00	1.966888E-01
4	2.487458E+03	2.487458E+03	0.000000E+00	3.421387E-03
5	2.271508E+03	2.271508E+03	0.000000E+00	6.903382E-03
6	2.428547E+03	2.428547E+03	0.000000E+00	-5.205078E-04
7	2.329629E+03	2.329629E+03	0.000000E+00	-8.820801E-04
8	2.262553E+03	2.262553E+03	0.000000E+00	-5.514526E-04
9	2.121144E+03	2.121144E+03	0.000000E+00	-1.893822E-03
10	1.988572E+03	1.988572E+03	0.000000E+00	-1.894075E-03
11	1.864286E+03	1.864286E+03	0.000000E+00	-1.894897E-03
12	1.747768E+03	1.747768E+03	0.000000E+00	-1.893230E-03
13	1.638533E+03	1.638533E+03	0.000000E+00	-1.890949E-03
14	1.536125E+03	1.536125E+03	0.000000E+00	-1.891456E-03
15	1.536125E+03	1.536125E+03	0.000000E+00	-1.891456E-03

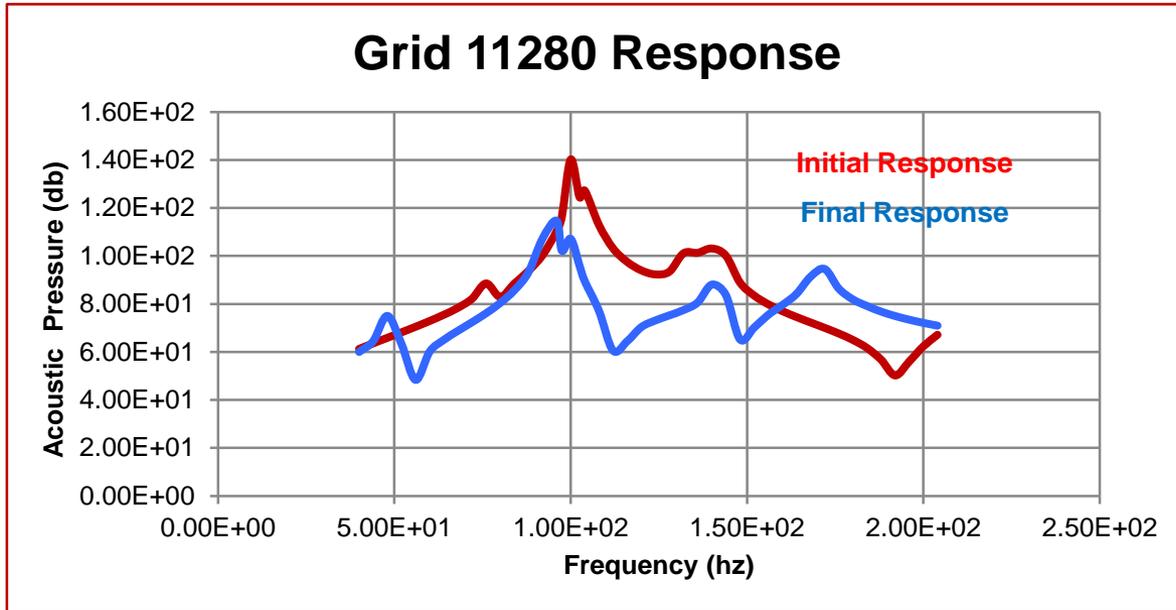
ACOUSTIC OPTIMIZATION (CONT.)

- Design Variables History

DESIGN VARIABLE HISTORY										
INTERNAL DV. ID.	EXTERNAL DV. ID.	LABEL	INITIAL	1	2	3	4	5		
1	1	P1	2.4930E-02	2.0373E-02	1.0373E-02	1.1695E-02	9.9879E-03	1.0316E-02		
2	2	P2	1.9530E-02	2.5744E-02	3.4460E-02	3.1633E-02	3.6139E-02	3.3639E-02		
3	4	P4	2.0470E-02	2.5425E-02	1.8286E-02	2.5047E-02	2.1605E-02	2.4105E-02		
4	5	P5	2.5960E-02	3.2827E-02	4.2827E-02	4.7898E-02	5.0398E-02	5.2918E-02		
5	6	P6	2.1750E-02	2.3042E-02	1.3042E-02	1.1748E-02	1.3238E-02	1.0786E-02		
6	7	P7	2.4260E-02	1.5392E-02	2.5247E-02	2.2126E-02	1.8310E-02	2.0049E-02		
7	8	BETA	1.0000E+00	5.0000E-01	3.7904E-01	2.8428E-01	2.4875E-01	2.2715E-01		
INTERNAL DV. ID.	EXTERNAL DV. ID.	LABEL	6	7	8	9	10	11		
1	1	P1	1.1271E-02	1.1084E-02	1.1755E-02	1.1972E-02	1.1640E-02	1.1323E-02		
2	2	P2	3.3105E-02	3.2162E-02	3.1137E-02	3.0392E-02	3.0014E-02	2.9638E-02		
3	4	P4	2.6605E-02	2.7930E-02	2.9180E-02	2.9266E-02	2.9453E-02	2.9630E-02		
4	5	P5	5.5564E-02	5.7088E-02	5.8653E-02	6.0119E-02	6.1703E-02	6.3245E-02		
5	6	P6	8.2857E-03	7.0357E-03	5.7857E-03	4.6438E-03	4.4216E-03	4.2106E-03		
6	7	P7	1.9367E-02	2.0325E-02	2.0520E-02	2.1414E-02	2.1460E-02	2.1505E-02		
7	8	BETA	2.4285E-01	2.3296E-01	2.2626E-01	2.1211E-01	1.9886E-01	1.8643E-01		
INTERNAL DV. ID.	EXTERNAL DV. ID.	LABEL	12	13	14	15	16	17		
1	1	P1	1.2421E-02	1.3525E-02	1.4265E-02	1.4265E-02				
2	2	P2	2.8433E-02	2.7210E-02	2.6511E-02	2.6511E-02				
3	4	P4	2.8483E-02	2.7289E-02	2.6078E-02	2.6078E-02				
4	5	P5	6.4979E-02	6.6602E-02	6.8415E-02	6.8415E-02				
5	6	P6	4.0050E-03	3.8892E-03	3.8314E-03	3.8314E-03				
6	7	P7	2.1524E-02	2.1545E-02	2.1260E-02	2.1260E-02				
7	8	BETA	1.7478E-01	1.6385E-01	1.5361E-01	1.5361E-01				

ACOUSTIC OPTIMIZATION (CONT.)

- The figure below shows the magnitude of the frequency dependent pressure at the initial and final designs.



- The reduction in the peak pressures is from 140.2 dB to 114.7 dB.
- The frequency where the peak occurs also shifted from 100 hz to 96 hz

ACOUSTIC OPTIMIZATION (CONT.)

- The table below lists the first eight initial and final structural eigenvalues as well as the first nine invariant fluid eigenvalues.

Structural and Fluid Eigenfrequencies in Hz.

Mode No.	Structural Eigenfrequencies		Fluid Eigenfrequencies
	Initial	Final	
1	75.98	49.20	50.05
2	95.27	49.78	100.41
3	104.15	93.96	100.41
4	130.75	95.80	100.41
5	133.57	98.61	112.19
6	143.69	98.65	112.19
7	153.12	163.53	142.00
8	173.63	170.48	142.00
9	212.73	176.07	142.00

- Note that the fluid has three repeated roots at 100.4 Hz and it is the coupling between these fluid resonances and the nearby structural resonances that creates the peak response.

ACOUSTIC OPTIMIZATION EXAMPLE INPUT FILE (DSOUG10B.DAT)

```

$ SOL 200 $ MODAL FREQUENCY RESPONSE
CEND
TITLE = DESIGN OPTIMIZATION WITH ACOUSTICS
SUBTITLE = ACOUSTIC AND STRUCTURAL ELEMENTS
LABEL = BOXAE1.DAT
SET 20 = 11280
$-----2-----3-----4-----5-----6-----7-----8-----9-----10-----
ECHO = SORT(PARAM,EIGC,EIGRL,FREQ,DESVAR,DCONSTR,DRESP1,DRESP2,DEQATN,
            DVPREL1)
SPC = 1
DEGLB = 5
DISP(sort2,PHASE) = 20
METHOD(STRUCTURE) = 20
METHOD(FLUID) = 30
$
FREQUENCY = 200
DLOAD = 100
DESSUB = 10
DESOBJ = 100
ANALYSIS = MFREQ
$
BEGIN BULK
$
$-----2-----3-----4-----5-----6-----7-----8-----9-----10-----
EIGRL 20 300.
EIGRL 30 15. 200. 0 105.
$
$ SOUND PRESSURE LEVEL
PARAM,RMS,YES
$ REFERENCE PRESSURE FOR DB AND DBA
PARAM,PREFDB,2.-5
$
PARAM AUTOSPC NO
$
$ FLUID/STRUCTURE INTERFACE
ACMODL,DIFF , , , ,0.01
$
$ STRUCTURAL DAMPING
PARAM,G,0.02
$

```

```

$
PARAM POST -1
$-----2-----3-----4-----5-----6-----
RLOAD1,100,101,,,102
DAREA,101,1288,3,100.
TABLED1,102
,0.,1.,1000.,1.,ENDT
$-----2-----3-----4-----5-----6-----
FREQ1 200 40. 4.0 41
FREQ 200 97.5 102.5

```

ACOUSTIC OPTIMIZATION EXAMPLE INPUT FILE (CONT.)

- Rest of the Analysis Model

```
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$  REST of ANALYSIS MODEL
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
PSHELL 1      1      .02493  1
PSHELL 2      1      .01953  1
PSHELL 3      1      .100    1
PSHELL 4      1      .02047  1
PSHELL 5      1      .02596  1
PSHELL 6      1      .02175  1
PSHELL 7      1      .02426  1
$
GRID 1      0.0    0.0    0.0
$
GRID 12541  2.    1.    .1      -1
$
CHEXA 10001100 10004 10126 10127 10009 10018 10137 +
+ 10138 10019
$
CHEXA 12000100 12412 12531 12532 12413 12423 12541 +
+ 10006 12424
$
PSOLID,100,100,,,,,1,PFLUID
$
MAT10,100,,1.293,200.
$
```


STANDARD OPTIMIZATION FUNCTION

- **Note that MSC Nastran optimization has several standard optimization functions as shown below**

Function	Description
SUM	Sum of the arguments
AVG	Average of the arguments
SSQ	Sum of the squares of the arguments
RSS	Square root of the sum of the squares of the arguments
MAX	The maximum value of the argument list
MIN	The minimum value of the argument list
BETA	Minimize the maximum response.
MATCH	Match analysis results with user specified values.

- **The previous example could have used the BETA function directly**
 - The equation writing feature is shown here to highlight the flexibility of MSC Nastran optimization
 - Similar technique can be used to represent more generic responses that are not listed in the above table
 - As long as you can write an equation using the MSC Nastran available items such as response, design variables, etc., you can do it

ACOUSTIC EXAMPLE USING BETA FUNCTION

- Revisiting previous problem, the BETA function can be defined as

- Minimize

$$F(X_\beta) = C_1 * X_\beta$$

- Subject to:

$$g = \frac{r_j - \gamma X_\beta}{C_3} < 0$$

- The g (constraint) is computed so that the maximum constraint (g_{\max}) for all response = C_2 (user input on the DRESP2 entry)

$$g_{\max} = (r_{j\max} - \gamma X_\beta) / C_3 = C_2$$

γ is calculated

ACOUSTIC EXAMPLE USING BETA FUNCTION

- To get results similar to the equation previously created manually, the C1, C2, and C3 are defined as follows:

$$C1 = 10000.$$

$$C2 = 1.047$$

$$C3 = 100.$$

ACOUSTIC EXAMPLE USING BETA FUNCTION

```

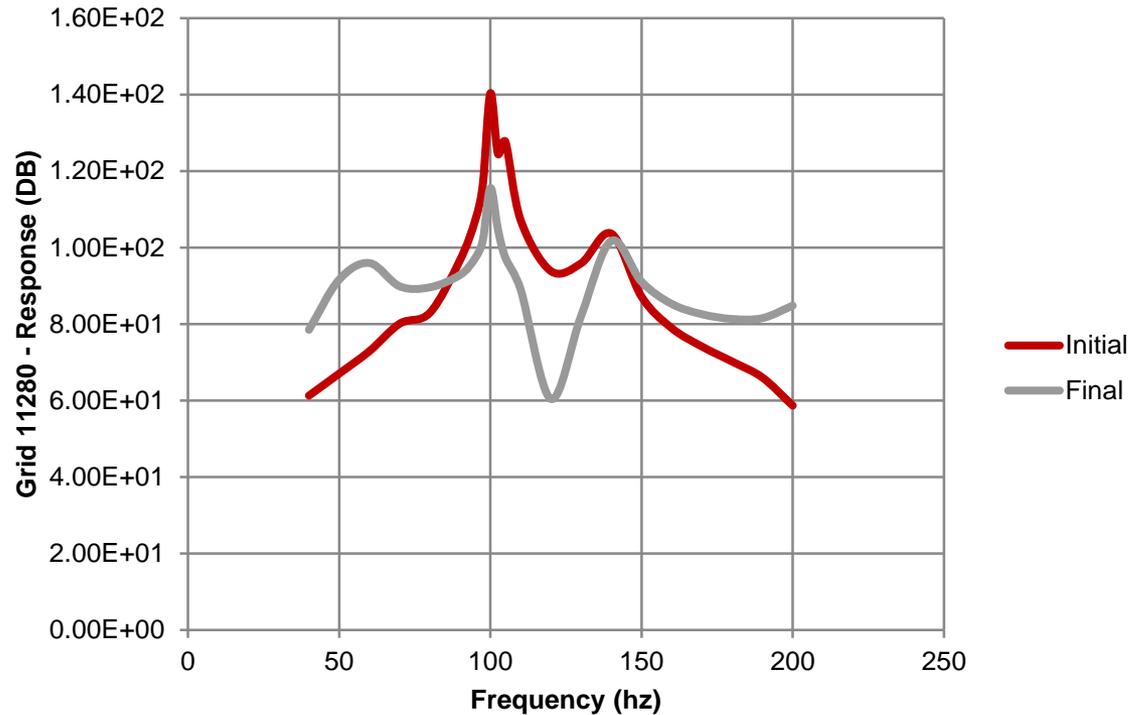
$
$
desvar,1,p1,0.02493,0.0001,1.
desvar,2,p2,0.01953,0.0001,1.
desvar,4,p4,0.02047,0.0001,1.
desvar,5,p5,0.02596,0.0001,1.
desvar,6,p6,0.02175,0.0001,1.
desvar,7,p7,0.02426,0.0001,1.
$
$desvar 8      beta  1.0      0.001
$
dvpres1,1,pshe1,1,4,0.0001
,1,1.
dvpres1,2,pshe1,2,4,0.0001
,2,1.
dvpres1,4,pshe1,4,4,0.0001
,4,1.
dvpres1,5,pshe1,5,4,0.0001
,5,1.
dvpres1,6,pshe1,6,4,0.0001
,6,1.
dvpres1,7,pshe1,7,4,0.0001
,7,1.
$
DRESP2  2      3      4      5      6      7      8
min      10000.  1.047  100.
DRESP1  1
druck   frdisp  1      11280
weight  weight
dconstr 5      2      2890.  2910.

```

C1 C2 C3

ACOUSTIC EXAMPLE USING BETA FUNCTION

- Initial and Final Response



ACOUSTIC EXAMPLE USING BETA FUNCTION

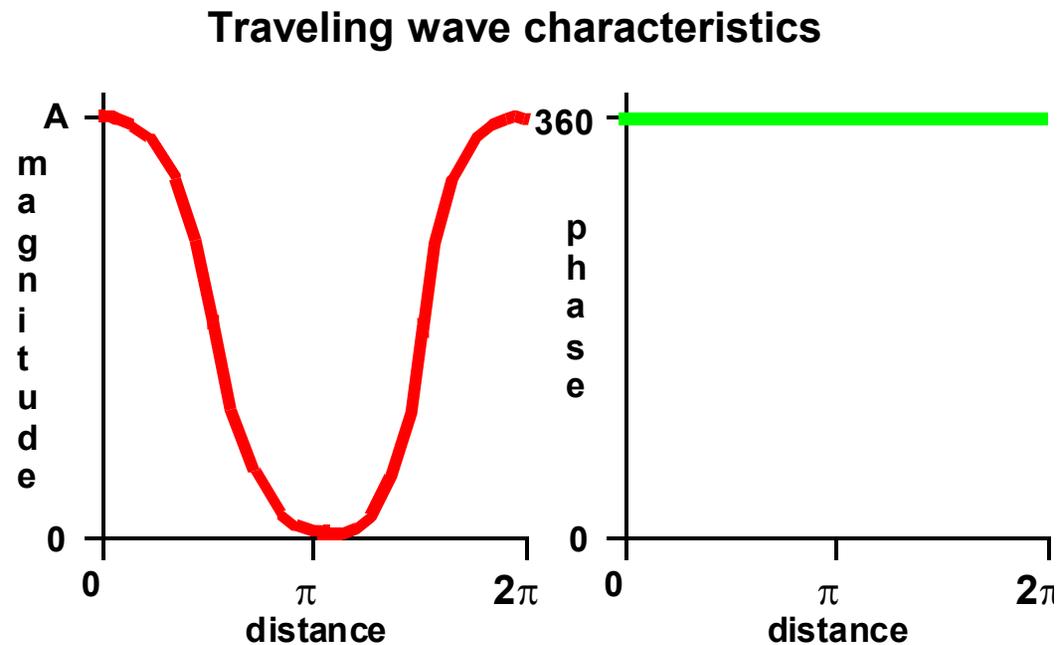
- **The optimization is normally a 3 day class. Some of these materials are bit beyond the scope of this class**
- **See the MSC Nastran Design Sensitivity and Optimization User's Guide for further details**

INFINITE BOUNDARY – APPROXIMATE TECHNIQUE

- **Exterior Acoustic is covered in Section 9**
- **This section offers an approximation technique to model infinite boundary**
- **This is an old technique and is kept here for historical purposes**
 - This section will no longer be updated
- **The exterior acoustic method described in Section 9 is the recommended method**

FINITE BOUNDARIES - STANDING WAVES

- **A standing wave can be identified in the frequency domain when:**
 - The magnitude of the complex pressure at any point varies with the mode shape.
 - The phase angle stays constant.



FINITE ELEMENT INFINITE BOUNDARIES

- **This can be simulated in a finite element model using a boundary absorber**
 - Waves must not reflect over the frequency range of interest.
- **To do this the boundary must be critically damped:**

$$Z(f) = \rho * c$$

where: f is the frequency

c is the speed of sound

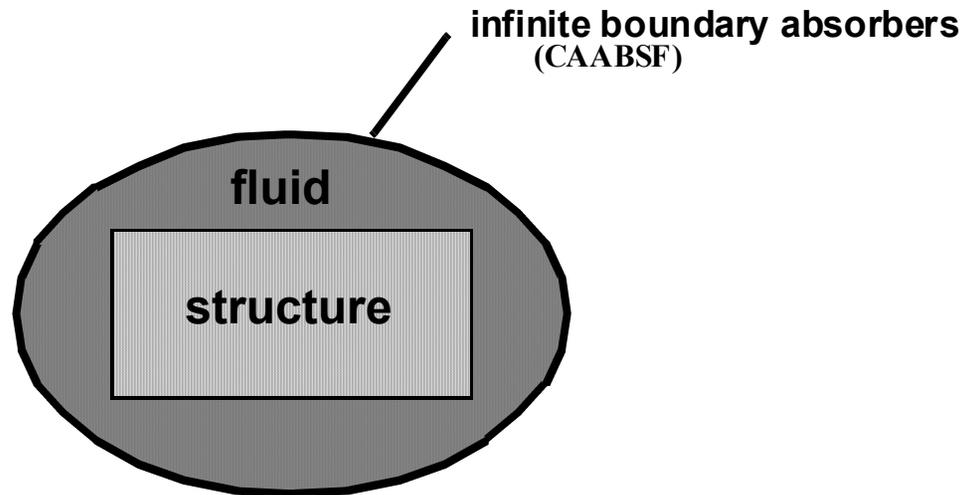
ρ is the fluid density

Z(f) is the user-specified absorber impedance

- **Reference 1: Everstein, G. "A NASTRAN Implementation of the Doubly Asymptotic Approximation for Underwater Shock Response", NASA 3428, pgs. 207-228, 1976. (<http://www.geverstine.com/reprints/Everstine1976.pdf>)**
- **Reference 2: DNH-68, Dave Herting, "Open Acoustic Boundaries Using Absorber Elements" (MSC Internal Document)**

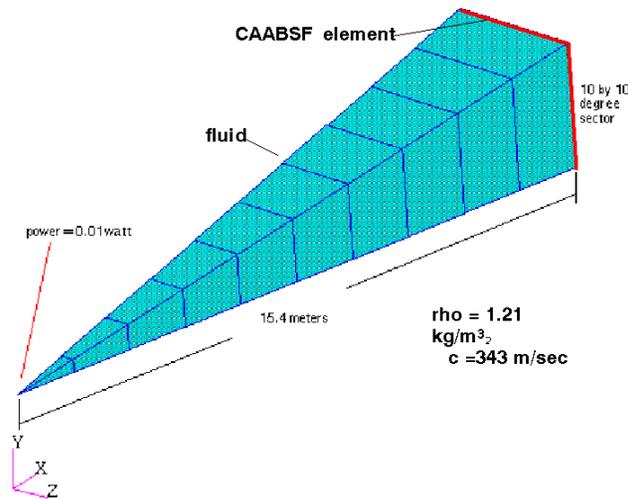
FINITE ELEMENT INFINITE BOUNDARIES

- $Z(f)$ is input as the coefficient B on the PAABSF bulk data entry.
- Good approximation for 3-dimensional problems if the boundary is a smooth shape.



INFINITE BOUNDARY EXAMPLE

- The model shown below is a small sector of a spherical fluid volume.



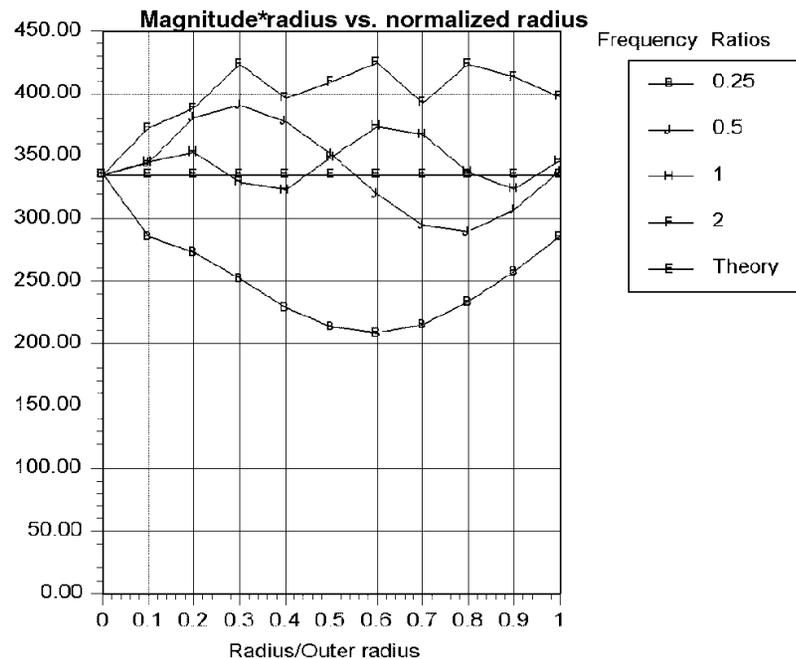
- It is excited by a source of fluid at the center that varies sinusoidally with time.
- Because the sides represent symmetric boundaries the problem actually represent a complete sphere.
- The open end is assumed to be connected to an infinite fluid.
- PAABSF input, $B=415.03$

INFINITE BOUNDARY EXAMPLE

- **Excited at frequencies $n \cdot f$**
 - Where $f = c/R$ is the frequency for a wavelength of length R .
 - The values chosen for n are $1/4$, $1/2$, 1 , and 2 .
 - These are natural mode frequencies

INFINITE BOUNDARY EXAMPLE RESULTS

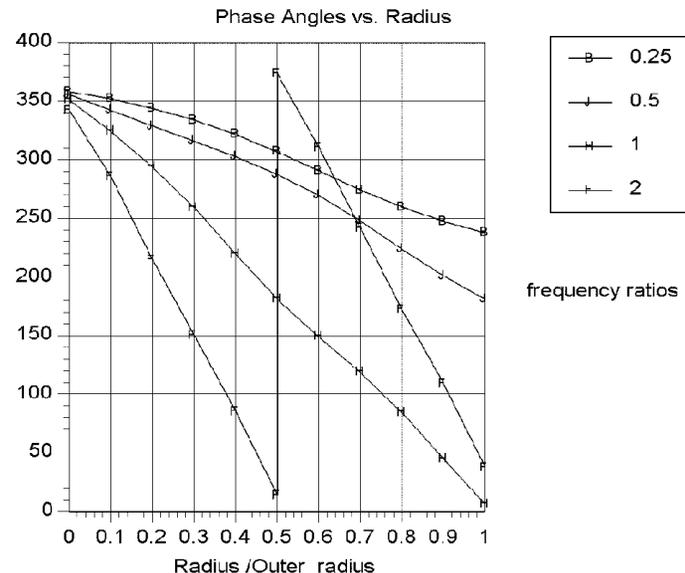
- The calculated results for the infinite fluid should show outward traveling waves.
 - Of magnitude approximately proportional to $1/r$, where r is radius of sphere.



- The calculated theoretical result is a constant value of 335.278. Although the results are not constant, they show only small sinusoidal components. (The deviations are probably caused by the finite element errors near the singularity at the center.)

INFINITE BOUNDARY EXAMPLE RESULTS

- The next figure shows the pressure phase angles vs. scaled radius for the four wavelengths.
- The calculated theoretical results are straight lines starting at 360 degrees at the center and ending at 270, 180, 0, and -360 degrees, depending on the frequency.



- The largest errors appear to occur for the low frequency, quarter-wave case. This is due to the lack of a virtual mass term.
- The error in high frequency case is due to the crude mesh size.

INFINITE BOUNDARY – COMPLETE DAA METHOD

- Previous example did not include all of the terms of the DAA method (Doubly Asymptotic Approximation).

- DAA boundary conditions.

$$\{\dot{P}\} + \rho \cdot c [M_v]^{-1} [A] \{P\} = \rho \cdot c \{\bar{u}_n\}$$

where: **P** = pressure

ρ = fluid density

c = speed of sound in the fluid

M_v = virtual mass matrix

A = area mass

u_n = normal displacement of structure at boundary

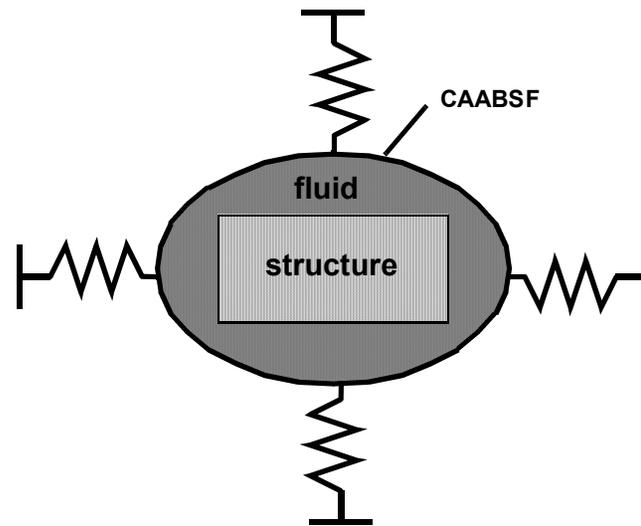
- Multiplying by $[A]^T / (\rho \cdot c)$:

$$\frac{1}{\rho \cdot c} [A^T] \{\dot{P}\} + [A^T] [M_v^{-1}] [A] \{P\} = \{\dot{Q}\}$$

- First term is absorber term used in previous example.
- Second term is a "residual flexibility" term that allows the analysis to converge to correct results at low frequencies.

COMPLETE DAA METHOD IN A FINITE ELEMENT MODEL

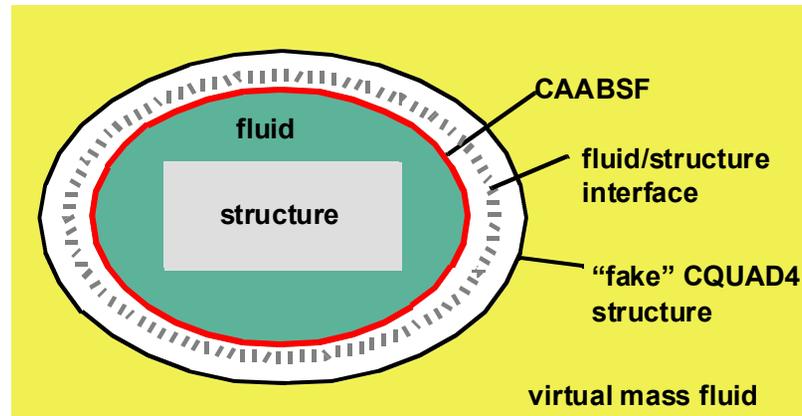
- The virtual mass term representing an infinite fluid using a spherical fluid boundary is equal to the fluid mass inside a sphere of the same diameter as the boundary sphere.
- This virtual mass term can be entered as a fluid stiffness and applied to the fluid boundary:



- The value of K is one over the virtual mass value.

COMPLETE DAA METHOD

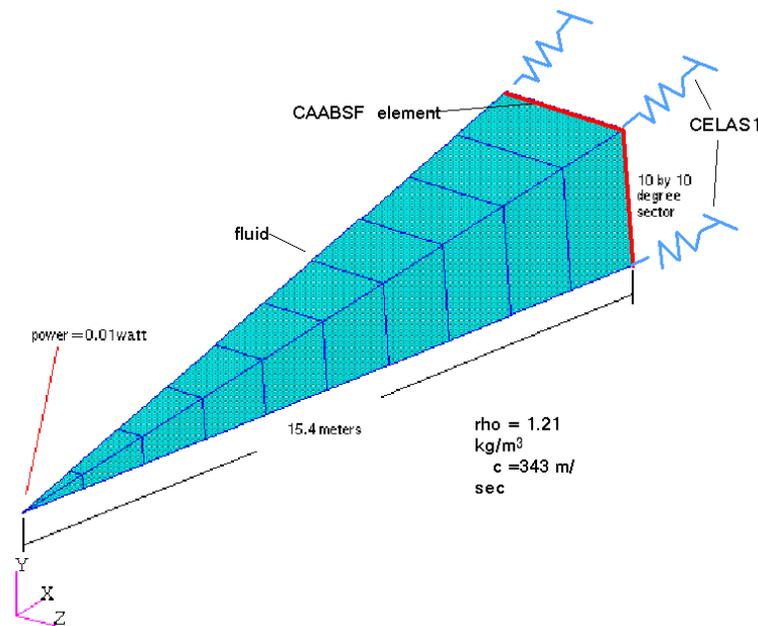
- Or it can be a virtual mass applied to structure on the fluid boundary across the fluid/structure interface.



- See Section 6 for details on the virtual mass method in MSC NASTRAN.

COMPLETE DAA METHOD EXAMPLE

- Improve example problem by adding the virtual mass term.
- Use the virtual mass term transformed to a fluid stiffness approach.



COMPLETE DAA METHOD EXAMPLE

- **Calculate K for the fluid CELAS1s as follows:**

- Mass of fluid inside infinite fluid boundaries is:

$$M_f = \rho \cdot \text{volume} = \frac{4}{3} \pi r^3 \rho$$

For a 10 degree sector divided between 4 grids:

$$M_f = 41 \text{ kg}$$

where: ρ = density

r = radius

- K for fluid is analogous to the inverse of structure mass, so:

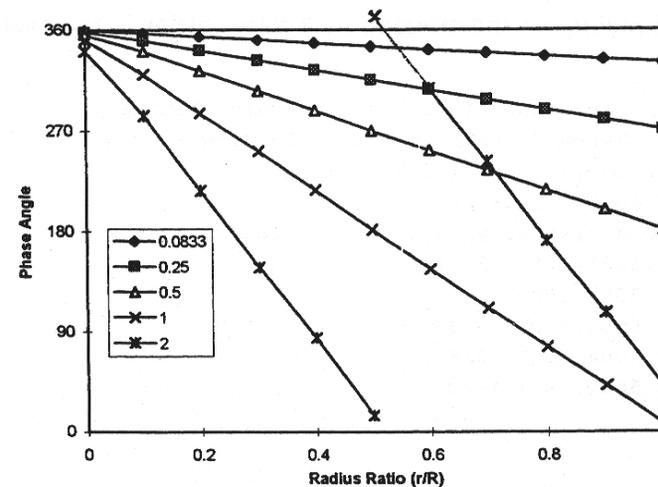
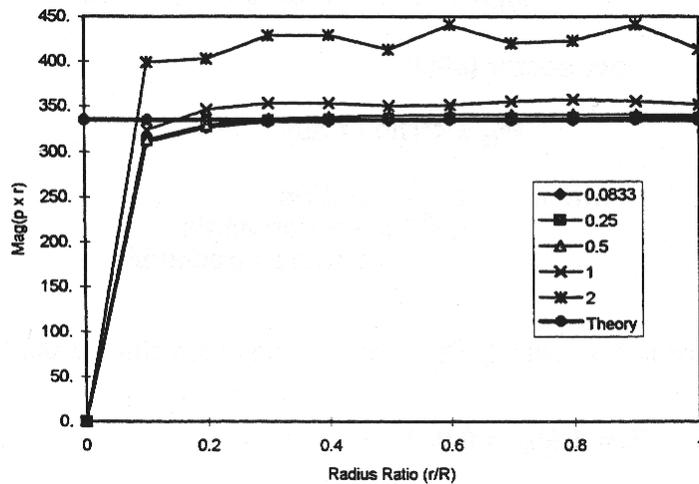
$$K = 1/M_f = 0.097$$

- **The following are the affected bulk data entries in the example.**

```
$ Put an absorber element at the outer boundary
$ REAL IMPEDANCE/AREA = 415.03 Damping -FOR NO REFLECTIONS
CAABSF, 4000, 4000, 2, 21, 3181, 3180
PAABSF,4000,,,,415.03
$ Add DAA virtual mass terms to fluid K matrix
CELAS1, 5001, 5000, 2, 1
CELAS1, 5002, 5000, 21, 1
CELAS1, 5003, 5000, 3180, 1
CELAS1, 5004, 5000, 3181, 1
PELAS, 5000, 9.7144-2
```

COMPLETE DAA METHOD EXAMPLE

- Below are plots similar to the previous plots, but now have the virtual mass added.
- The low frequency analyses are now much closer to theoretical results.

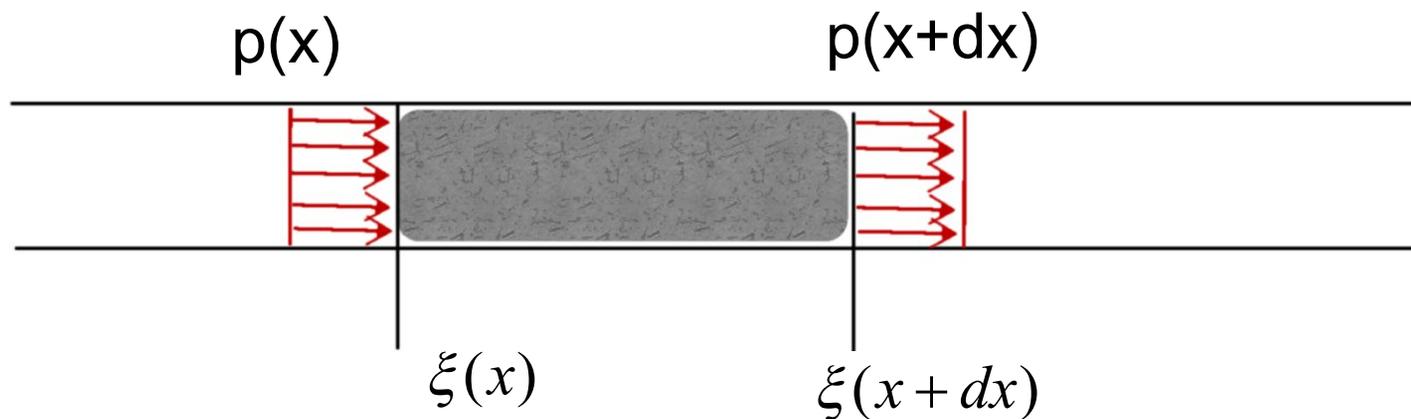


SOME NOTATIONS

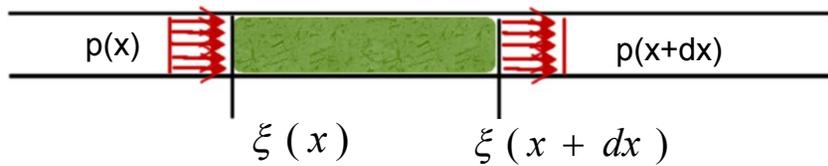
- **Acoustic Medium: Fluid**
- **State of Equilibrium:**
 - p_0, ρ_0 independent of time
 - $\mathbf{v}_0 = \mathbf{0}$
- **Acoustic Variables : p, ρ, \mathbf{v} small**
- **Total Variables**
 - $p_t = p_0 + p$
 - $\rho_t = \rho_0 + \rho$
 - $\mathbf{v}_t = \mathbf{v}$

WAVE EQUATION - 1 DIMENSION

- Need to find a relationship of $p(x,t)$ such that pressure fluctuates over time and space.
- Three variables p, ρ, \mathbf{v}
- Need three equations:
 1. Continuity (Mass conservation) (Pressure and density I)
 2. Newtons 2nd Law ($F=Ma$) (Pressure and velocity)
 3. Gas Law (Pressure and density II)



1. CONTINUITY



Mass is conserved within the volume

$$\frac{d\rho}{dt} = -\rho_0 \frac{du_x}{dx}$$

- **u_x is particle velocity**

2. NEWTON'S 2ND LAW - F=MA



Relationship between pressure and particle velocity

$$p(x+dx) = p(x) + \frac{\partial p}{\partial x} dx$$

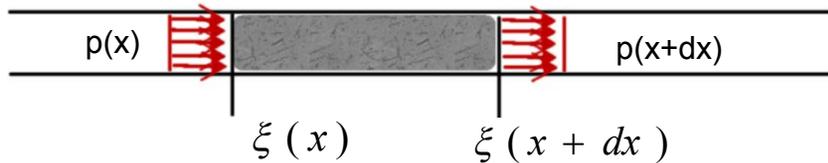
- The pressure difference will accelerate the gas particles

$$\rho_0 dx \frac{d\xi^2}{dt^2} = p(x) - \left(p(x) + \frac{\partial p}{\partial x} dx \right)$$

$$\rho_0 \frac{d\xi^2}{dt^2} = - \frac{\partial p}{\partial x}$$

$$\rho_0 \frac{\partial u}{\partial t} = - \frac{\partial p}{\partial x}$$

3. THE GAS LAW



Relationship between density changes and pressure changes

$$(p_0 + p) \cdot V^\kappa = \text{const}$$

$$V \cdot (\rho_0 + \rho) = \text{const}$$

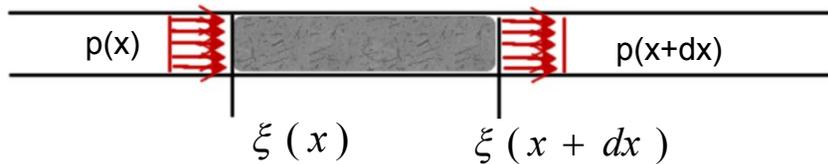
- **From expressions above...**

$$\frac{\partial p}{\partial \rho} = \kappa \frac{p_0}{\rho_0} \quad \begin{array}{l} p \ll p_0 \\ \rho \ll \rho_0 \end{array}$$

$$\frac{p_0}{\rho_0} = \kappa \frac{RT}{M}$$

$$\frac{\partial^2 p}{\partial x^2} - \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = 0 \quad c = \sqrt{\frac{\kappa RT}{M}}$$

THE WAVE EQUATION



Relationship between density changes and pressure changes

- Combining the three, we get the wave equation in one dimension

$$\frac{\partial^2 p}{\partial x^2} - \frac{1}{c^2} \frac{\partial^2 p}{\partial t^2} = 0 \quad c = \sqrt{\frac{\kappa RT}{M}}$$

- Assuming a harmonic solution

$$p(x, t) = p(x) \cdot e^{-j\omega t}$$

$$\frac{\omega}{c} = k$$

$$k = \frac{2\pi}{\lambda}$$

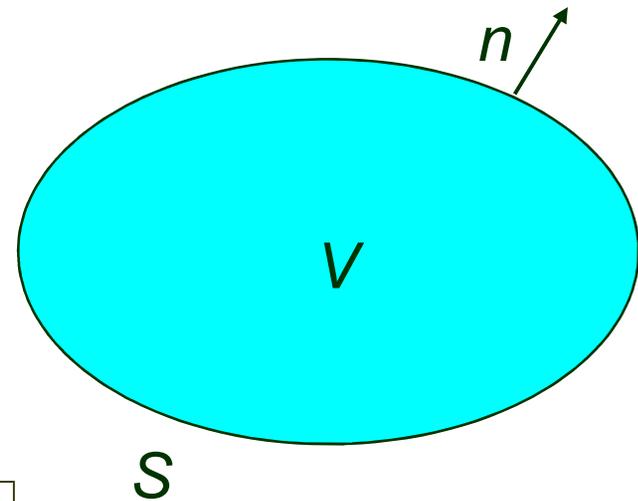
$$\omega = \frac{2\pi}{T}$$

- There are 2 solutions, one wave traveling in positive and one in negative direction

$$p(x, t) = p_+ \cdot e^{-jkx} \cdot e^{-j\omega t} \quad \text{and} \quad p(x, t) = p_- \cdot e^{jkx} \cdot e^{-j\omega t}$$

CONSERVATION OF MOMENTUM

Arbitrary Volume V with
Boundary S moving with V



$$\frac{d}{dt} \int_V (\rho_0 + \rho) \mathbf{v} dV = - \int_S p \mathbf{n} dF$$

Change of Momentum = External Force

CONSERVATION OF MOMENTUM

- **Theorem of Gauss:**
$$\int_S p \mathbf{n} dF = \int_V \nabla p dV$$

- p, ρ, \mathbf{v} **small:**
$$\int_V \left(\rho_0 \frac{\partial \mathbf{v}}{\partial t} + \nabla p \right) dV = \mathbf{0}$$

- **Because V is arbitrary:**
$$\nabla p = -\rho_0 \frac{\partial \mathbf{v}}{\partial t}$$

CONSERVATION OF MASS

- **Constant Mass in $V(t)$:**

$$\frac{d}{dt} \int_V (\rho_0 + \rho) dV = 0$$

- ρ, \mathbf{v} small:

$$\int_V \left(\frac{\partial \rho}{\partial t} + \rho_0 \nabla \cdot \mathbf{v} \right) dV = 0$$

- **Because V is arbitrary:**

$$\frac{\partial \rho}{\partial t} + \rho_0 \nabla \cdot \mathbf{v} = 0$$

CONSERVATION OF ENERGY

- **Change of Energy = External Power:**

$$\frac{d}{dt} \int_V \rho_t \left(e_t + \frac{1}{2} \mathbf{v} \cdot \mathbf{v} \right) dV = - \int_S p_t \mathbf{v} \cdot \mathbf{n} dS$$

- **p, ρ, \mathbf{v}, e small:**
$$\int_V \left(\rho_0 \frac{\partial e}{\partial t} + p_0 \nabla \cdot \mathbf{v} \right) dV = 0$$

- **Thermodynamics:**
$$\frac{\partial e}{\partial t} = T \frac{\partial s}{\partial t} + \frac{p_0}{\rho_0^2} \frac{\partial \rho}{\partial t}$$

- **with Conservation of Mass:**

$$\frac{\partial s}{\partial t} = 0$$

CONSTITUTIVE EQUATION

- **Generally:** $\rho = \rho(p, s)$
- **Because Entropy s is constant:**

$$\frac{\partial \rho}{\partial t} = \left(\frac{\partial \rho}{\partial p} \right)_s \frac{\partial p}{\partial t} = \frac{1}{c^2} \frac{\partial p}{\partial t}$$

with

$$c^2 = \left(\frac{\partial p}{\partial \rho} \right)_s$$

- **Conservation of Mass now reads:**

$$\frac{\partial p}{\partial t} = -\rho_0 c^2 \nabla \cdot \mathbf{v}$$

BULK MODULUS

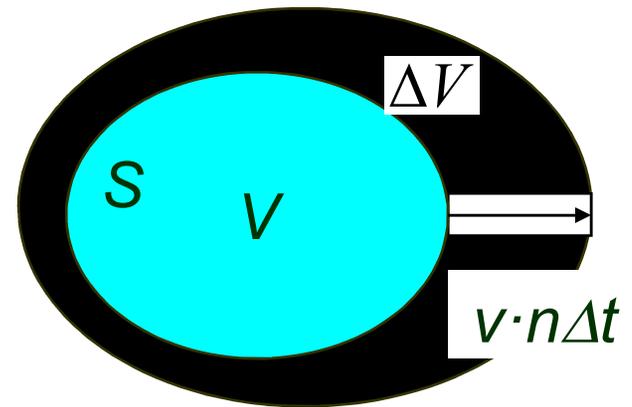
- **Definition:** $B = \rho_0 c^2$

- **Then:**
$$\frac{\partial p}{\partial t} = -B \nabla \cdot \mathbf{v}$$

- **Interpretation:**

$$\nabla \cdot \mathbf{v} = \lim_{V \rightarrow 0} \frac{1}{V} \int_S \mathbf{v} \cdot \mathbf{n} dF = \frac{1}{V} \frac{\partial V}{\partial t}$$

$$\frac{\partial p}{\partial t} = -B \frac{1}{V} \frac{\partial V}{\partial t}$$



WAVE EQUATION

- **Mass:**

$$\frac{1}{B} \frac{\partial p}{\partial t} = -\nabla \cdot \mathbf{v}$$

- **Momentum:**

$$\frac{1}{\rho_0} \nabla p = -\frac{\partial \mathbf{v}}{\partial t}$$

- **Wave Equation:**

$$\frac{\partial}{\partial t}(\text{Mass}) - \nabla \cdot (\text{Momentum})$$

$$\frac{1}{B} \frac{\partial^2 p}{\partial t^2} - \frac{1}{\rho_0} \nabla^2 p = 0$$

PERIODIC WAVES

- For fixed x , let $p(x, t) = p(x, t + T)$. T is the **period**.
- Within T , the wave travels a distance $\lambda = cT$. Thus

$$p(x, t) = p(x + \lambda, t + T) = p(x + \lambda, t)$$

λ is the **wavelength**.

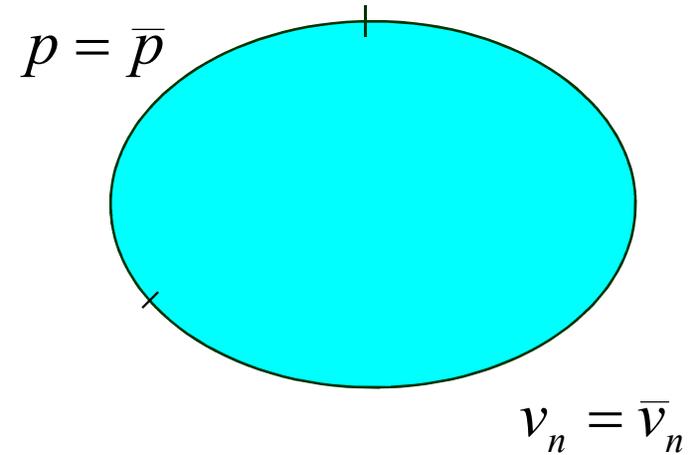
- With the **frequency** $f=1/T$, the

$$c = \lambda f$$

relationship is obtained.

BOUNDARY CONDITIONS

- **Boundary:** $S = S_p \cup S_v$
- **On S_p :** $p = \bar{p}$
- **On S_v :** $\mathbf{v} \cdot \mathbf{n} = v_n = \bar{v}_n$



WEAK FORM OF WAVE EQUATION

- For all \tilde{p} vanishing on S_p :

$$\int_V \tilde{p} \left(\frac{1}{B} \frac{\partial^2 p}{\partial t^2} - \frac{1}{\rho_0} \nabla^2 p \right) dV = 0$$

- Integration by Parts:

$$\int_V \frac{1}{B} \tilde{p} \frac{\partial^2 p}{\partial t^2} dV + \int_V \frac{1}{\rho_0} \nabla \tilde{p} \cdot \nabla p dV = - \int_{S_v} \tilde{p} \frac{\partial v_n}{\partial t} dS$$

FINITE ELEMENT DISCRETIZATION

- **Shape Functions:** $p(\mathbf{x}, t) = \mathbf{N}_p(\mathbf{x})\mathbf{p}(t)$

- **Discrete Wave Equation:**

$$\mathbf{Q}\ddot{\mathbf{p}} + \mathbf{H}\dot{\mathbf{p}} = \dot{\mathbf{g}}$$

- **Matrices:**

- Compressibility Matrix:

$$\mathbf{Q} = \int_V (1/B) \mathbf{N}_p^t \mathbf{N}_p dV$$

- Inverse Mass Matrix:

$$\mathbf{H} = \int_V (1/\rho_0) (\nabla \mathbf{N}_p)^t (\nabla \mathbf{N}_p) dV$$

- Acoustic Load Matrix:

$$\dot{\mathbf{g}} = - \int_{S_v} \mathbf{N}_p^t \dot{v}_n dF$$

HARMONIC WAVES

- **Definition:**

$$p(\mathbf{x}, t) = \hat{p}(\mathbf{x}) \cos(\omega t + \phi) = \hat{p}(\mathbf{x}) (\cos \omega t \cos \phi - \sin \omega t \sin \phi)$$

- **Complex Notation:**

$$p(\mathbf{x}, t) = \Re[P(\mathbf{x}) \exp(i\omega t)] = \Re[P(\mathbf{x})] \cos \omega t - \Im[P(\mathbf{x})] \sin \omega t$$

- **Thus:** $P(\mathbf{x}) = \hat{p}(\mathbf{x}) \exp(i\phi)$

TIME AND FREQUENCY DOMAIN

	Time	Frequency
Momentum	$\nabla p = -\rho_0 \frac{\partial \mathbf{v}}{\partial t}$	$\nabla P = -i\omega\rho_0 \mathbf{V}$
Constitutive	$\frac{\partial p}{\partial t} = -B\nabla \cdot \mathbf{v}$	$P = \frac{iB}{\omega} \nabla \cdot \mathbf{V}$
Wave	$\frac{1}{B} \frac{\partial^2 p}{\partial t^2} - \frac{1}{\rho_0} \nabla^2 p = 0$	$\frac{\omega^2}{B} P + \frac{1}{\rho_0} \nabla^2 P = 0$
FEM	$\mathbf{Q}\ddot{\mathbf{p}} + \mathbf{H}\dot{\mathbf{p}} = \dot{\mathbf{g}}$	$-\omega^2 \mathbf{Q}\mathbf{P} + \mathbf{H}\mathbf{P} = i\omega \mathbf{G}$

