Acoustic Cavities in Nastran 95

Excerpts from NASA Nastran Manuals

November 2020

1 User's Guide Information

1.1 2.4.3 Acoustic Cavity Analysis

An acoustic cavity analysis may be performed with Rigid Format 3 to obtain, the stationary waves in the steady-state flow of a gas through an axisym- metric chamber with radial slots. The width and depth of the slots and the diameter of the center volume may vary along the axis of the chamber. The boundaries of the chamber are assumed to be rigid. The output available includes pressures at points in the grid and the velocities in the fluid elements.

1.2 7.2.3 Acoustic Cavity Analysis

The acoustic cavity analysis capability was implemented primarily to obtain the resonant frequencies of a compressible fluid in a solid rocket motor cavity. The enclosed gas is modeled with finite elements. The surrounding propellant is assumed to be rigid and small motion theory is used, i.e., the steady state velocities are small with respect to the wave velocity. Rigid Format 3 is used to obtain these resonant frequencies.

The spape of the cavity may consist of a circular center volume surrounded by equally spaced narrow radial slots. The width and depth of the slots and the diameter of the center volume may vary along the axis of the cav- ity. The finite-element model is defined by a set of two-dimensional ele- ments lying on the center plane of one slot and on the corresponding cross section of the center yolume. The entire cavity is solved by assuming a Fourier Series of pressure and velocity around the circumference. With minor correction terms, the pressure coefficients in the slots couple di- rectly with the Fourier coefficients of pressure in the center volume. The user may request a printout of the pressures at the points and/or the ve- locities in the elements.

Remarks:

- The fluid grid points are defined by GRIDF cards for the central volume and by GRIDS cards for the slot area. One degree of freedom is produced for each point in the model. The width and number of slots are defined on the GRIDS card. If the slot point lies on the opening to the central cavity, the location is specified on a GRIDS card on which is also given a unique GRIDF identifier. This eliminates the need for inputting a separate GRIDF card for the same point. The SLBDY card is used to define a list of GRIDS points which lie on the opening to the central cavity.

- The GRIDF points are connected by the CAXIF2, CAXIF3, and CAXIF4 elements. Each element defines a volume generated by revolving the cross section shape around the center axis. The CAXIF2 element defines a volume which contains the center axis.
- The GRIDS points are connected by the CSLOT3 and CSLOT4 ele- ments. Each element may have a different fluid property.
- The default properties of the model are defined by the re- quired AXSLOT card. The harmonic index N specifies the Fourier Series term to be analysed. N = 0 restricts the mo- tion to axisymmetric radial and longitudinal motion. N = 1 defines the lateral motion where the velocity. is normal to the center axis, etc. Repeated runs with N = 0, 1, ..., M/2 may be necessary to extract all possible modes. M is the number of radial slots specified.
- The default on all boundaries is a fixed surface. If a free surface with zero pressure is desired, the SPC or SPCl data cards may be used to constrain the pressure at selected points.
- The two dimensional wave equation problem may be solved by using only CSLOT elements and GRIDS points, by spec- ifying only one slot (M = 1) and by setting the harmonic index, N, to zero.
- The finite element approximation assumes that the veloc- ity is constant over the cross section of each element and that the pressure distribution does not vary across the width of the slot. In regions where the velocity may ab- ruptly change direction, a finer finite element mark should be chosen.

1.3 7.2.3.1 Example - Acoustic Cavity Problem

The acoustic cavity shown below consists of a central cavity having a radius of four inches and four equally spaced slots. The cavity is open at the right end. 'The slot width varies linearly with radial position. The input data for the simple finite element model chosen is presented in Section Three CSLOT elements and six CAXIF elements are used. The harmonic index is one, which will result in lateral motion. That is, the gas will travel back and forth across the cavity from one slot to the slot on the opposite side.

Notes:

1. The PRESSURE control card requests output pressures at the GRIDF and GRIDS points. the STRESS control card requests the velocities in the finite elements.

2. Required for acoustic cavity analysis and defines the default density, compressibility, harmonic index, slot width, and number of slots for the overall problem.· . These values may be overridden by the individual cards below.

3. Defines the points on the slot. GRIDS 2, 5, 8, 9 and 12 also define GRIDF points 1, 4, 7, and 11 at the same location. The slot width is varied on these data cards.

4. Defines remaining GRIDF points directly.

5. Specifies the CSL0T elements, which, in this case use the default fluid properties and number of slots speci- fied on the AXSL0T card.

6. Specifies the CAXIF elements of the central axisym- metric volume. The default fluid properties will be used.

7. Identifies the GRIDS points at the interface between the slots and the central volume

8. Sets the pressure at point 13 to zero.

2 Demonstration Manual - Acoustic Cavity Analysis

2.1 A. Description

This problem illustrates the use of NASTRAN to determine the acoustic modes in a cavity containing both axisymmetric regions and evenly spaced radial slots. The solution is based on an analogy between pressure and displacement, and between fluid particle acceleration and internal structural force described in the Theoretical Manual.

2.2 B. Input

The finite element model for the motor cavity of the Minuteman III, Stage III, is shown in Figure 1 As may be seen, it consists of six slots and a long, slender central cavity of irregular shape. The model consists of AXIF2, AXIF3, and AXIF4 finite elements in the central cavity, and SL0T3 and SL0T4 finite elements in the slotted region

2.3 C. Results

The vibration mode frequencies for harmonic n = 0 as determined with NASTRAN are shown in Table 1. Also shown are the vibration mode frequencies as determined with an acoustic model and reported in Reference 19.

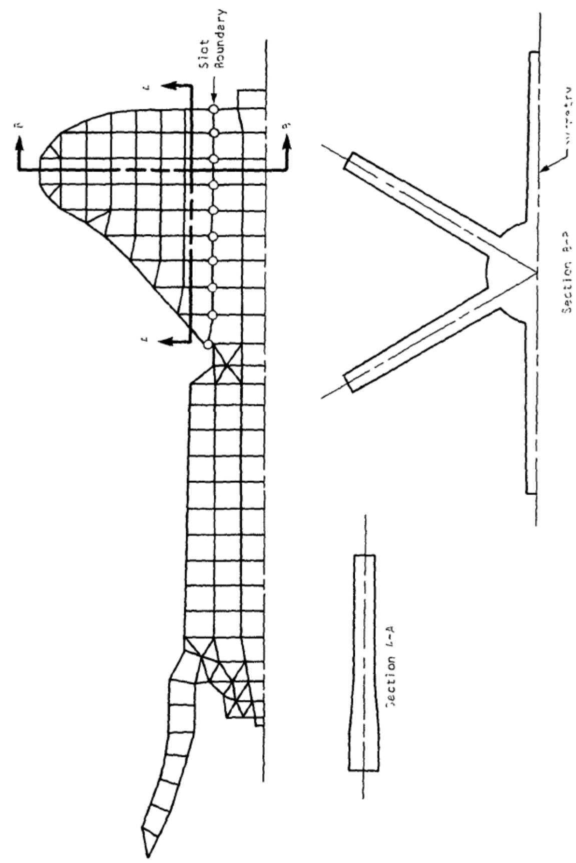

Figure 1. Minuteman III, Stage III, Rocket Motor Cavity

Figure 1: acoustic axisymmetric cavity analysis

3 Acoustic CARDS

- AXSLOT Required to define existence of acoustic slot analysis, includes default parameters
- GRIDF Scalar degree of freedom for acoustic analysis of a fluid
- GRIDS Scalar degree of freedom on acoustic slot boundaries.
- CASIFi Fluid element connection i = 2, 3 or 4 fluid points in an acoustic slot analysis
- CSLOTi Defines an element connecting i = 3 or i = 4 points which solves the wave equation in two dimensions . Used in the acoustic cavity analysis

for the definition of evenly spaced radial slots

4 Supplement - Acoustic cavity modeling

4.1 1.9.1 - Data Card Functions

The NASTRAN structural analysis system is used as the basis for acoustic cavity analysis . Many of the structural analysis options such as selecting boundary conditions, applying loading conditions, and selecting output data are also available for acoustics. The data cards specifically used for acoustic cavity analysis are described below . The card formats are exhibited in Section 2 . 4 . Their purposes are analogous to the use of structural data cards . A gridwork of points is distributed over the longitudinal cross section of an acoustic cavity and finite elements are connected between these points to define the enclosed volume. The points are defined by GRIDF data cards for the axisymmetric central fluid cavity and by GRIDS data cards for the radial slots. The GRIDF points are interconnected by finite elements via the CAXIF2 , CAXIF3, and CAXIF4 data cards to define a cross sectional area of the body of rotation . The CAXIF2 element data card defines the area area of the cross section between the axis and two points ross S off the axis (the GRIDF points may not have a zero radius) . The CAXIF3 and CAXIF4 data cards define triangular or quadrilateral cross sections and connect three or four GRIDF points respectively. The density and/or bulk modulus at each location of the enclosed fluid may also be defined on these cards . The GRIDS points in the slot region are interconnected by finite elements via the CSLØT3 and CSLØT4 data cards . These define finite elements with triangular and quadrilateral cross -sectional shapes respectively. The width of the slot and the number of slots may be defined by default values on the AXSLØT data card . If the width of the slots is a variable , the value is specified on the GRIDS cards at each point . The number of slots , the density, and /or the bulk modulus of the fluid may also be defined individually , for each element on the CSLØT3 and CSLØT4 cards . The AXSLØT data card is used to define the overall parameters for the system . Some of these parameters are called the " default" values and may be selectively changed at particular cross sections of the structure. The values given on the AXSLØT card will be used if a corresponding value on the GRIDS , CAXIFI, or CSLØTi is left blank. The parameters o (density) and B ibulk modulus) are properties of the fluid . If the value given for Bulk Modulus is zero the fluid is considered incompressible to the program . The parameters M (Number of slots) and W (slot width) are properties of the geometry. The parameter M defines the number of equally spaced slots around the circumference with the first slot located at 0 = 0° . The parameter N (harmonic number) is selected by the user to analyze a particular set of acoustic modes. The pressure is assumed to have the following distribution plr,2 ,0) = plr ,z) cos No If N = 0 the breathing and longitudinal modes will result. If N = 1 the pressure at 0 = 180° will be the negative of the pressure at 0 = 0°. If N = 2 , the pressures at 0 = 90° and 0 =

270o will be the negative of that at 0 = 0°. Values of N larger than M / 2 have no significance. The interface between the central cavity and the slots is defined with the SLBDY data cards . The data for each card consists of the density of the fluid at the interface , the number of radial slots around the circumference , and a list of GRIDS points that are listed in the sequence in which they occur as the boundary is traversed . In order to ensure continuity between GRIDF and GRIDS points at the interface , the GRIDF points on the boundary between the cylindrical cavity and the slots are identified on the corresponding GRIDS data cards rather than on GRIDF cards. Thus, the locations of the GRIDF points will be exactly the same as the locations of the corre sponding GRIDS points. Various standard NASTRAN data cards may be used for special purposes in acoustic analysis. The SPCI data card may be used to constrain the pressures to zero at specified points such as at a free boundary . The formats for these cards are included in Section 2 .4 . Dynamic load cards , direct input matrices , and scalar elements may be introduced to account for special effects. The reader is referred to Sections 1 . 4 and 1 . 5 for instruction in the use of these cards

4.2 1.9.2 - Assumptions and limitations

The accuracy of the acoustic model will be dependent on the selection of the mesh of finite elements. The assumption for each element is that the pressure field has a linear variation over the cross section and a sinusoidal variation around the axis in the circumferential direction . In areas where the pressure gradient changes are large, such as near a sharp corner , the points in the mesh should be placed closer together so that large changes in flow may be defined accurately by the finite elements. The shape of the finite elements play an important part in the accuracy of the results . It has been observed that long narrow elements produce disproportionate errors. Cutting a large square into two rectangles will not improve the results whereas dividing the square into four smaller squares may decrease the local error by as much as a factor of ten . The slot portion of the cavity is limited to certain shapes because of basic assumptions in the algorithms. The cross section of the cavity normal to the axis must have a shape that is reasonably well defined by a central circular cavity having equally spaced, narrow slots . Various shapes are shown in Figure 1 in the order of increasing expected error. It is recommended that shapes such as the cloverleaf and square cross section be analyzed with a full three dimensional technique . The assumption of negligible pressure gradient in the circumferential direction within a slot is not valid in these cases. The harmonic orders of the solutions are also limited by the width of the slots. The harmonic number, N , should be no greater than the number of slots divided by two . The response of the higher harmonics is approximated by the slot width correction terms discussed in the NASTRAN Theoretical Manual, Section 17 .1. The output data for the acoustic analysis consists of the values of pressure in the displace ment vector selected via the case control card " PRESSURE = j" . The velocity vector components corresponding to each mode may be optionally requested by the case control card "STRESS = i" , where i is the set number indicating the element numbers to be used for output , or by the words " STRESS = ALL" . The " SET =" card lists the element or point numbers to be output. Plots of the finite element model and /or of the pressure field may be requested with the NASTRAN plot request data cards. The central cavity cross section will be positioned in the XY plane of the Basic Coordinate System of NASTRAN. The slot elements are offset from the XY plane by the width of the slot in the + z direction . The radial direction corresponds to X and the axial direction corresponds to the y direction . Pressures will be plotted in the Z direction for both the slot points and the central cavity points . The case control data cards for plotting are documented in the User 's Manual. The PLOTEL elements are used for plotting the acoustic cavity shape. The plot request card "SET n INCLUDE PLØTEL" must be used where n is a set number

4.3 1.9.3 Acoustic Cavity Example Problem

Table 1 contains a listing of the data cards used as a simple example of acoustic cavity analysis. The problem to be solved is illustrated in Figure 2. The model was subdivided into only ten finite elements in order to limit the number of data cards . For reasonable engineering accuracy , this model should be subdivided into at least four times that number of elements . Each data card in Table 1 is given a number on the left side . The format for each type of bulk data card is given in parentheses above the group of that type . The following is a brief description of each card:

- 1- 5 Each data card in the Executive Control deck has the format of a request word and a selection separated by blanks or a comma . The ID card is first, the CEND card is last , but the intermediate cards may appear in any order . The user may put any pair of words on the ID card for identification purposes. In this particular case Rigid Format number 3 (SØL 3 ,0) was chosen which is Normal Modes analysis. A limit of 2 minutes CPU time was set (TIME 2)

- 6 -7: The TITLE = and SUBTITLE = cards may contain any list of letters and numbers following the (=) sign . This list will appear on the first two lines of each output page

- 8: The method of eigenvalue extraction is selected with the METHØD = data card . The number 11 refers to the identification number of an EIGR bulk data card which appears below as card 32 and 33.

- 9 -11 A simple output request is illustrated with these cards. PRES= ALL will result in print out of all pressures at the GRIDF and GRIDS points . STRESS =ALL will result in the print out of all velocities in the elements . This printout will occur for all extracted eigen vectors. Selected points or elements can be printed via the SET card described in the User ' s Manual .

- 12: The BEGIN BULK card denotes the beginning of the bulk data deck. The Bulk Data Deck cards may occur in any order. Putting these cards in alphabetic sort will save NASTRAN sorting time in large problems, however
- 13: In this problem all the parameters except slot width Wy are constant throughout the volume. The data values on the AXSLØT card will be used whenever a corresponding entry in the following cards is blank
- 21, 22: The location of points within the axisymmetric fluid cavity are described by the GRIDF card. No points are allowed to have a zero or negative radius .
- 23-31: These cards describe the elements shown in Figure 2 . Each element is given a unique identification number and a list of the connected GRIDS or GRIDF points . Since the parameters p and B are constants, these fields are left blank so the values on the AXSLØT card will be used
- 32 , 33 : The EIGR card is used to define parameters for eigenvalue extraction (resonant frequen cies) . More than one of these cards may appear. The method to be used is selected with the METHOD= data card in the Case Control Deck (card 8). With this particular card we selected the Givens Tridiagonalization method (GIV) with a desired number of three (Nd = 3) output mode shapes . The modes will be normalized such that the maximum pressure is 1 .0 (NØRM =MAX) .These two cards illustrate a continuation card
- 34: The SLBDY card defines the boundary between the slot and the central cavity . Both the density (P) and the number of radial slots (M) are blank so the AXSLØT defaults are used, i. e. 0 = 1.2x10 ' and M = 4 . Only four GRIDS points are on the boundary so a continua tion card is not necessary . Field 8 being blank signifies the last entry
- 35: The ENDDATA card is required to denote the end of the bulk data. Any following cards will be ignored by NASTRAN
-

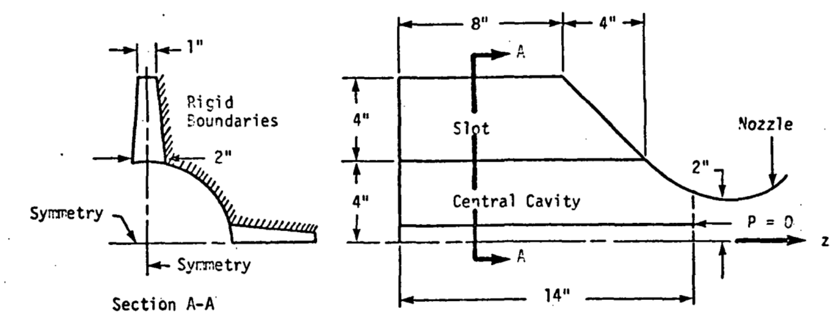

Figure 2: acoustic axisymmetric cavity analysis

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 6      TITLE = ACØUSTIC CAVITY EXAMPLE PRØBLEM
 7      SUBTITLE = FIRST HARMØNIC, LATERAL MØDES
 8      METHØD
 9          SPC = 1
10              PRES = ALL
11              STRESS = ALL
12      BEGIN BULK
```

BULK DATA FIELD

Card No.	1	2	3	4	5	6	7	8	9	10
13	AXSLØT	1.2-7	21.0	1		4				
14	GRIDS	2	4.0	0.0	0.2E 01	1				
15	GRIDS	3	8.0	0.0	1.0					
16	GRIDS	5	4.0	4.0	2.0	4				
17	GRIDS	6	8.0	4.0	1.0					
18	GRIDS	8	4.0	8.0	2.0	7				
19	GRIDS	9	8.0	8.0	1.0					
20	GRIDS	12	4.0	1.2+1	2.0	11				
21	GRIDF	10	2.0	12.0						
22	GRIDF	13	2.0	1.4E1						
23	CSLØT4	1	2	3	6	5				
24	CSLØT4	2	5	6	9	8				
25	CSLØT3	3	8	9	12					
26	CAXIF2	4	1	4						
27	CAXIF2	5	4	7						
28	CAXIF2	6	7	10						
29	CAXIF2	9	10	13						
30	CAXIF3	7	7	10	11					
31	CAXIF3	8	10	11	13					
32	EIGR	11	GIV				3			+AB
33	+AB	MAX								
34	SLBDY			12	8	5	2			
35	SPC	1	13							
36	ENDDATA									

Figure 3: acoustic axisymmetric cavity analysis

Table 1. Example problem data cards.

Card No.		
1	ID ACØUS, MSC	Executive Control Cards
2	APP DISP	
3	SØL 3,0	
4	TIME 2	
5	CEND	
6	TITLE = ACØUSTIC CAVITY EXAMPLE PRØBLEM	Case Control Data Cards
7	SUBTITLE = FIRST HARMØNIC	
8	METHØD = 11	
9	ØUTPUT	
10	PRES = ALL	
11	STRESS = ALL	
12	BEGIN BULK	

Card No.	1	2	3	4	5	6	7	8	9	10
	(AXSLØT	ρ_d	B_d	N	w_d	M_d)				
13	AXSLØT	1.2-7	21.0	1		4				
	(GRIDS	Id	r	z	w	Id_f)				
14	GRIDS	2	4.0	0.0	0.2E 01	1				
15	GRIDS	3	8.0	.0	1.0					
16	GRIDS	5	4.0	4.0	2.0	4				
17	GRIDS	6	8.0	4.0	1.0					
18	GRIDS	8	4.0	8.0	2.0	7				
19	GRIDS	9	8.0	8.0	1.0					
20	GRIDS	12	4.0	1.2+1	2.0	11				
	(GRIDF	Id	r	z)						
21	GRIDF	10	2.0	12.0						
22	GRIDF	13	2.0	1.4E1						
	(CSLØT4	Id	P_1	P_2	P_3	P_4	ρ	B	M)	
23	CSLØT4	1	2	3	6	5				
24	CSLØT4	2	5	6	9	8				
	(CSLØT3	Id	P_1	P_2	P_3		ρ	B	M)	
25	CSLØT3	3	8	9	12					
	(CAXIF2	ID	P_1	P_2			ρ	B)		
26	CAXIF2	4	1	4						
27	CAXIF2	5	4	7						
28	CAXIF2	6	7	10						
29	CAXIF2	9	10	13						

Figure 4: acoustic axisymmetric cavity analysis

Card No.		1	2	3	4	5	6	7	8	9	10
	(	CAXIF3	Id	P_1	P_2	P_3		ρ	B)		
30		CAXIF3	7	7	10	11					
31		CAXIF3	8	10	11	13					
	(	EIGR	Id	Method	f_1	f_2	Ne	Nd	Nz		+XYZ
	(	+XYZ	NØRM)								
32		EIGR	11	GIV				3			+AB
33		+AB	MAX								
	(	SLBDY	ρ	M	ID1	ID2	ID3	ID4	etc.)		
34		SLBDY			12	8	5	2			
35		ENDDATA									

Figure 5: acoustic axisymmetric cavity analysis

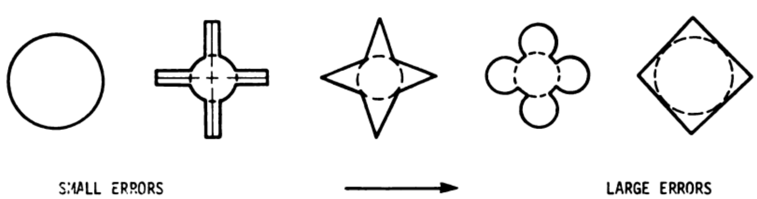
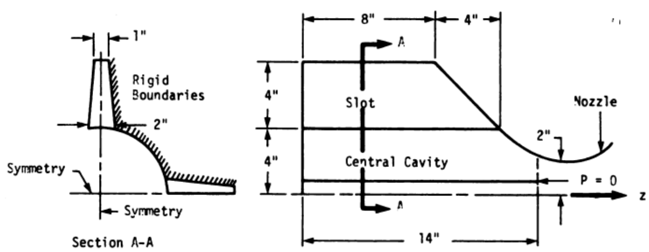


Figure 6: acoustic axisymmetric cavity analysis

ACOUSTIC CAVITY MODELING



__Parameters__:

Density:	$\rho = 1.1463 \times 10^{-7}$ lb-sec^2/in^4
Bulk Modulus:	$B = \rho a^2 = \gamma RT = 20.59$ lb/in^2
Harmonic:	$N = 1$
Number of slots:	$M = 4$

Note: Consistent Dimensional Units must be used.

__FINITE ELEMENT MODEL__:

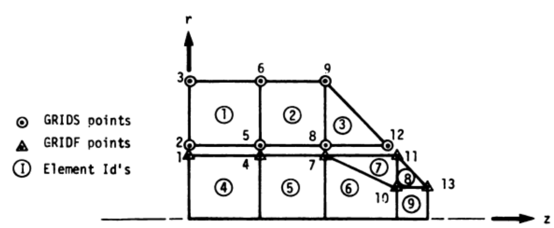


Figure 2. Description of example problem.

Figure 7: acoustic axisymmetric cavity analysis

BULK DATA DECK

Input Data Card CSLØTi Slot Element Connections

Description: Defines an element connecting i = 3 or i = 4 points which solves the wave equation in two dimensions. Used in the acoustic cavity analysis for the definition of evenly spaced radial slots.

Formats and Examples:

1	2	3	4	5	6	7	8	9	10
CSLØT3	EID	IDS1	IDS2	IDS3		RHØ	B	M	
CSLØT3	100	1	3	2		3.E-3		6	
CSLØT4	EID	IDS1	IDS2	IDS3	IDS4	RHØ	B	M	
CSLØT4	101	1	3	2	4		6.2+4	3	

Field	Contents
EID	Element identification number (Integer > 0)
IDSj	Identification number of connected GRIDS points, j = 1,2,...J (Integer > 0)
RHØ	Fluid density in mass units (Real > 0.0 or "blank")
B	Fluid bulk modulus (Real ≥ 0.0 or blank)
M	Number of slots in circumferential direction (Integer ≥ 0, or "blank")

Remarks:

1. This card is allowed only if an AXSLØT card is also present.
2. The element identification number (IDF) must be unique with respect to all other fluid or structural elements.
3. If RHØ, B, or M are blank, the corresponding values on the AXSLØT data card are used, in which case the default value must not be blank (undefined).
4. Plot elements connecting two points at a time are generated for these elements. The CSLØT3 element generates 3 plot elements. The CSLØT4 element generates four plot elements, connecting points 1-2, 2-3, 3-4, and 4-1.
5. If B = 0.0, the slot is considered to be an incompressible fluid.
6. If M = 0 no matrices for CSLØTi elements are generated.

Figure 8: acoustic axisymmetric cavity analysis

BULK DATA DECK

Input Data Card GRIDS Slot Surface Point

Description: Defines a scalar degree of freedom with a two dimensional location. Used in defining pressure in slotted acoustic cavities.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRIDS	ID	R	Z	W	IDF				
GRIDS	25	2.5	-7.3	0.5					

Field	Contents
ID	Identification number of slot point (Integer > 0)
R	Radial location of point in basic coordinate system (Real ≠ 0.0)
Z	Axial location of point in basic coordinate system (Real)
W	Slot width or thickness at the GRIDS point (Real ≥ 0.0, or blank)
IDF	Identification number to define a GRIDF point (Integer > 0, or blank)

Remarks:

1. This card is allowed only if an AXSLØT card is also present.
2. The identification numbers (ID and IDF if present) must be unique with respect to all other scalar, structural and fluid points.
3. If W is "blank", the default value on the AXSLØT card will be used.
4. The IDF number is referenced on the CAXIFi card for central cavity fluid elements next to the interface. The IDF number is entered only if the grid point is on an interface. In this case it should not also be defined on a GRIDF card.
5. If IDF is nonzero then R must be greater than zero.
6. For plotting purposes the R location corresponds to the basic X coordinate. The Z location corresponds to the basic Y coordinate. The slot width, W, corresponds to the basic Z coordinate. The pressure will be plotted in the basic Z direction.
7. Load and constraint conditions are applied as if the GRIDS is a scalar point. Positive loads correspond to inward flow and a single point constraint causes zero pressure at the point.

Figure 9: acoustic axisymmetric cavity analysis

BULK DATA DECK

Input Data Card AXSLØT   Axisymmetric slot analysis parameter

Description: Defines the harmonic index and the default values for acoustic analysis cards.

Format and Example:

11	2	3	4	5	6	7	8	9	10
AXSLØT	RHØD	BD	N	WD	MD				
AXSLØT	0.003	1.5+2	3	0.75	6				

Field	Contents
RHØD	Default density of fluid-mass/volume (Real ≠ 0.0 or blank)
BD	Default bulk modulus of fluid = (force/volume ratio change) (Real ≥ 0.0 or blank)
N	Harmonic index number (Integer ≥ 0)
WD	Default slot width (Real ≥ 0.0 or blank)
MD	Default number of slots (Integer ≥ 0 or blank)

Remarks:

1. No more than one AXSLØT card is permitted.
2. The default values are used on the GRIDS, SLBDY, CAXIFi, and CSLØTi data cards and must be nonzero as noted if these cards use the default.
3. The harmonic index number N must be entered on this card.
4. If the number of slots, M, is different in different regions or the cavity, this fact may be indicated on the CSLØTi and SLBDY cards. If the number of slots is zero, no matrices for CSLØTi elements are generated.
5. A zero entry for bulk modulus is treated as if the fluid was incompressible.

Figure 10: acoustic axisymmetric cavity analysis