# *FREQUENCY_DOMAIN

Purpose: The keyword *FREQUENCY_DOMAIN provides a way of defining and solving frequency domain vibration and acoustic problems. The keyword cards in this section are defined in alphabetical order:

*FREQUENCY_DOMAIN_ACCELERATION_UNIT

*FREQUENCY_DOMAIN_ACOUSTIC_BEM_*{OPTION}*

*FREQUENCY_DOMAIN_ACOUSTIC_DIRECTIVITY

*FREQUENCY_DOMAIN_ACOUSTIC_FEM

*FREQUENCY_DOMAIN_ACOUSTIC_FREQUENCY

*FREQUENCY_DOMAIN_ACOUSTIC_FRINGE_PLOT_*{OPTION}*

*FREQUENCY_DOMAIN_ACOUSTIC_INCIDENT_WAVE

*FREQUENCY_DOMAIN_ACOUSTIC_SOUND_SPEED

*FREQUENCY_DOMAIN_FRF

*FREQUENCY_DOMAIN_LOCAL_*{OPTION}*

*FREQUENCY_DOMAIN_MODE_*{OPTION}*

*FREQUENCY_DOMAIN_PATH

*FREQUENCY_DOMAIN_RANDOM_VIBRATION_*{OPTION}*

*FREQUENCY_DOMAIN_RESPONSE_SPECTRUM

*FREQUENCY_DOMAIN_SEA_CONNECTION

*FREQUENCY_DOMAIN_SEA_INPUT

*FREQUENCY_DOMAIN_SEA_SUBSYSTEM

*FREQUENCY_DOMAIN_SSD

## *FREQUENCY_DOMAIN_ACCELERATION_UNIT

Purpose: LS-DYNA's default behavior is to *assume* that accelerations are derived:

$$[\text{acceleration unit}] = \frac{[\text{length unit}]}{[\text{time unit}]^2}.$$

This card extends LS-DYNA to support *other* units for acceleration.

| Card 1 | 1 | 2 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | UNIT | UMLT | | | | | | |
| Type | I | F | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| UNIT | Flag for acceleration unit conversion:<br>EQ.0: use [length unit]/[time unit]$^2$ as unit of acceleration.<br>EQ.1: use $g$ as unit for acceleration, and SI units (Newton, kg, meter, second, etc.) elsewhere.<br>EQ.2: use $g$ as unit for acceleration, and Engineering units (lbf, lbf × second$^2$/inch, inch, second, etc.) elsewhere.<br>EQ.3: use $g$ as unit for acceleration, and units (kN, kg, mm, ms, GPa, etc.) elsewhere.<br>EQ.4: use $g$ as unit for acceleration, and units (Newton, ton, mm, second, MPa, etc.) elsewhere.<br>EQ.-1: use $g$ as unit for acceleration and provide the multiplier for converting g to [length unit]/[time unit]$^2$. |
| UMLT | Multiplier for converting $g$ to [length unit]/[time unit]$^2$ (used only for UNIT = -1). |

**Remarks:**

LS-DYNA uses consistent units. With *consistent units* acceleration is defined using:

$$[\text{acceleration unit}] = \frac{[\text{length unit}]}{[\text{time unit}]^2}.$$

However, it is the convention of many industries to use $g$ (gravitational acceleration on the Earth's surface) as the base unit for acceleration. Usually, data from vibration tests, both random and sine sweep, are expressed in systems for which $g$ is the unit of acceleration. With this keyword, LS-DYNA supports such conventions. Internally, LS-DYNA implements this keyword by converting the input deck into consistent units, and then proceeding with the calculation as usual. However, results are output in the unit system specified with this keyword.

***FREQUENCY_DOMAIN_ACOUSTIC_BEM_*{OPTION1}_{OPTION2}***

Available options include:

<BLANK>

ATV (see Remark 17)

MATV (see Remark 18)

HALF_SPACE

PANEL_CONTRIBUTION

POWER (see Remark 19)

Purpose: Activate the boundary element method in the frequency domain for acoustic problems. Unless the BEM=**filename** option is included in the LS-DYNA command line, this keyword is ignored.

## Card Summary:

**Card 1.** This card is required.

| RO | C | FMIN | FMAX | NFREQ | DTOUT | TSTART | PREF |
|---|---|---|---|---|---|---|---|

**Card 2.** This card is required.

| NSIDEXT | TYPEXT | NSIDINT | TYPINT | FFTWIN | TRSLT | IPFILE | IUNITS |
|---|---|---|---|---|---|---|---|

**Card 2.1a.** Include this card if FFTWIN = 5 or 8.

| T_HOLD | DECAY | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 2.1b.** Include this card if FFTWIN = 7.

| ALPHA | | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 3.** This card is required.

| METHOD | MAXIT | TOLITR | NDD | TOLLR | TOLFCT | IBDIM | NPG |
|---|---|---|---|---|---|---|---|

**Card 4.** This card is required.

| | NBC | RESTRT | IEDGE | NOEL | NFRUP | VELOUT | DBA |
|---|---|---|---|---|---|---|---|

**Card 4.1.** Include NBC of this card.

| SSID | SSTYPE | NORM | BEMTYP | LC1 | LC2 | | |
|---|---|---|---|---|---|---|---|

**Card 5.** Include this card if using the PANEL_CONTRIBUTION keyword option.

| NSIDPC | | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 6.** Include this card if using the HALF_SPACE keyword option.

| PID | | | | | | | |
|---|---|---|---|---|---|---|---|

**Data Card Definitions:**

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | RO | C | FMIN | FMAX | NFREQ | DTOUT | TSTART | PREF |
| Type | F | F | F | F | I | F | F | F |
| Default | none | none | none | none | 0 | 0.0 | 0.0 | 0.0 |

| VARIABLE | DESCRIPTION |
|---|---|
| RO | Fluid density |
| C | Sound speed of the fluid:<br>GT.0: Real constant sound speed<br>LT.0: \|C\| is the load curve ID, which defines the frequency-dependent complex sound speed. See *FREQUENCY_DOMAIN_ACOUSTIC_SOUND_SPEED. |
| FMIN | Minimum value of output frequencies |
| FMAX | Maximum value of output frequencies |
| NFREQ | Number of output frequencies |
| DTOUT | Time interval between writing velocity or acceleration, and pressure at boundary elements in the binary file, to be processed at the end of an LS-DYNA transient simulation. |

| VARIABLE | DESCRIPTION |
|---|---|
| TSTART | Start time for recording velocity or acceleration in LS-DYNA simulation. See Remark 1. |
| PREF | Reference pressure used to output pressure in dB to the file Press_dB. If PREF = 0.0, the Press_dB file is not generated. A file called Press_Pa is generated and contains the pressure at the output nodes (see Card 2). See Remark 2. |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NSIDEXT | TYPEXT | NSIDINT | TYPINT | FFTWIN | TRSLT | IPFILE | IUNITS |
| Type | I | I | I | I | I | I | I | I |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| NSIDEXT | Node ID, node set ID, or segment set ID of output exterior field points. |
| TYPEXT | Output exterior field point type:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID |
| NSIDINT | Node ID, node set ID, or segment set ID of output interior field points. |
| TYPINT | Output interior field point type:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID |
| FFTWIN | FFT windows (Default = 0). See Remark 3.<br>EQ.0: Rectangular window<br>EQ.1: Hanning window |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.2: Hamming window<br>EQ.3: Blackman window<br>EQ.4: Raised cosine window<br>EQ.5: Exponential window<br>EQ.6: Triangular window<br>EQ.7: Kaiser window<br>EQ.8: Auto exponential window |
| TRSLT | Flag to output time domain results (see Remark 4):<br>EQ.0: Do not output time domain results.<br>EQ.1: Request time domain results (Press_Pa_t gives absolute value pressure as a function of time).<br>EQ.2: Requiest time domain results (Press_Pa_t gives real value pressure as a function of time). |
| IPFILE | Flag for output files (default = 0):<br>EQ.0: Press_Pa (magnitude of pressure as a function of frequency), Press_dB (sound pressure level or SPL as a function of frequency), and bepres (ASCII database file for LS-Prepost) are provided.<br>EQ.1: Press_Pa_real (the real part of the pressure as a function of frequency) and Press_Pa_imag (the imaginary part of the pressure as a function of frequency) are provided, in addition to Press_Pa, Press_dB, and bepres.<br>EQ.10: Files for IPFILE = 0 and fringe files for acoustic pressure.<br>EQ.11: Files for IPFILE = 1 and fringe files for acoustic pressure.<br>EQ.20: Files for IPFILE = 0 and fringe files for sound pressure level.<br>EQ.21: Files for IPFILE = 1 and fringe files for sound pressure level.<br>EQ.31: Files for IPFILE = 1 and fringe files for acoustic pressure (real part).<br>EQ.41: Files for IPFILE = 1 and fringe files for acoustic pressure (imaginary part). |

| VARIABLE | DESCRIPTION |
|---|---|
| IUNITS | Flag for unit changes (see Remark 5):<br>EQ.0: Do not apply a unit change.<br>EQ.1: Use MKS units; thus, no change is needed.<br>EQ.2: Use units: lbf × $s^2$/in, inch, s, lbf, psi, etc., and change to MKS in the BEM acoustic computation.<br>EQ.3: Use units: kg, mm, ms, kN, GPa, etc., and change to MKS in the BEM acoustic computation.<br>EQ.4: Use units: ton, mm, s, N, MPa, etc., and change to MKS in the BEM acoustic computation. |

**Exponential FFT Window.** Additional card for FFTWIN = 5 or 8.

| Card 2.1a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | T_HOLD | DECAY | | | | | | |
| Type | F | F | | | | | | |
| Default | 0.0 | 0.02 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| T_HOLD | Hold-off period before the exponential window. The length of the hold-off period should coincide with the pre-trigger time to reduce the effects of noise in the captured time domain data. It is only used when FFTWIN = 5. For FFTWIN = 8 (auto exponential window), T_HOLD is ignored.<br>LT.0.0: \|T_HOLD\| is a curve ID defining the specific hold-off period for each panel. The abscissa value is the panel ID, and the ordinate value gives the hold-off period for that panel. This is useful when the system includes multiple panels, and each panel experiences impact at a different time (thus, the hold-off period differs for each panel). |
| DECAY | Decay ratio at the end of capture duration. For example, DECAY = 0.02 means the vibration must decay to 2% of its amplitude within the capture duration. |

**Kaiser FFT Window.** Additional card for FFTWIN = 7.

| Card 2.1b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ALPHA | | | | | | | |
| Type | F | | | | | | | |
| Default | 0.0 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| ALPHA | A non-negative real number that determines the shape of the Kaiser window and, therefore, controls the tradeoff between main-lobe width and side lobe labels of the spectral leakage pattern. |

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | METHOD | MAXIT | TOLITR | NDD | TOLLR | TOLFCT | IBDIM | NPG |
| Type | I | I | F | I | F | F | I | I |
| Default | 0 | 100 | $10^{-4}$ | 1 | $10^{-6}$ | $10^{-6}$ | 200 | 2 |

**VARIABLE** | **DESCRIPTION**

METHOD

Method used in the acoustic analysis:

- EQ.0: Rayleigh method (very fast). See Remark 6.
- EQ.1: Kirchhoff method coupled to FEM for acoustics (*MAT_ACOUSTIC). See Remark 6.
- EQ.2: Variational Indirect BEM
- EQ.3: Collocation BEM
- EQ.4: Collocation BEM with Burton-Miller formulation for exterior problems (no irregular frequency phenomenon)
- EQ.211: Variational Indirect BEM with Fast Matrix Assembly. See Remark 7.

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.311: Collocation Direct BEM with Fast Matrix Assembly. See Remark 8. |
| MAXIT | Maximum number of iterations for the iterative solver (default = 100) if METHOD ≥ 2. |
| TOLITR | Tolerance for the iterative solver. The default value is $10^{-4}$. |
| NDD | Number of domain decompositions. It is used for saving memory. For large problems, the boundary mesh is decomposed into NDD domains for less memory allocation. NDD = 0 invokes using an internally-determined, recommended domain decomposition. NDD is only used if METHOD ≥ 2. See Remark 9. |
| TOLLR | Tolerance for low-rank approximation of a dense matrix (default = $10^{-6}$). |
| TOLFCT | Tolerance in the factorization of the low-rank matrix (default = $10^{-6}$). |
| IBDIM | Inner iteration limit in GMRES iterative solver (default = 1000). |
| NPG | Number of Gauss integration points (default = 2). |

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | | NBC | RESTRT | IEDGE | NOEL | NFRUP | VELOUT | DBA |
| Type | | I | I | I | I | I | I | I |
| Default | | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Remark | | | 10 | 11 | 12 | 13 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| NBC | Number of boundary condition cards (default = 1). See Card 4.1. |
| RESTRT | This flag can save an LS-DYNA transient analysis if the binary output file in the (bem=**filename**) option has not been changed (default = 0). |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.-30: Read in user-provided velocity spectrum saved in a binary file, bevelf.lsda. |
| | EQ.-3: Read in user-provided velocity spectrum saved in an ASCII file, bevelf. |
| | EQ.0: Process the LS-DYNA time domain analysis, generating a new binary file. |
| | EQ.1: Do not process the LS-DYNA time domain analysis. Use the binary files from the previous run. The files include the binary output file filename and the binary file bin_velfreq, which saves the boundary velocity from FFT. |
| | EQ.2: Restart from the d3dump file by using the "R=" command line parameter. This is useful when the last run was interrupted by sense switches such as "sw1". |
| | EQ.3: Read in user-provided velocity history saved in an ASCII file, bevel. |
| | EQ.4: Run acoustic computation on a boundary element mesh with velocity information given with a denser finite element mesh in the last run. This option requires both "bem = filename" and "lbem = filename2" in the command line, where filename2 is the name of the binary file generated in the last run with denser mesh. |
| | EQ.5: Do not process the LS-DYNA time domain analysis. Use the binary file filename from the previous run. An FFT computes the new frequency domain boundary velocity with results saved in bin_velfreq. |
| | EQ.30: Read in user-provided velocity history saved in a binary file, bevel.lsda. |
| IEDGE | Free edge and multi-connection constraints option (default = 0):<br>EQ.0: Free edge and multi-connection constraints not considered.<br>EQ.1: Free edge and multi-connection constraints considered.<br>EQ.2: Only free edge constraints are considered.<br>EQ.3: Only multi-connection constraints are considered. |
| NOEL | Location where normal velocity or acceleration is taken (default = 0): |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.0: Elements or segments<br>EQ.1: Nodes |
| NFRUP | Preconditioner update option:<br>EQ.0: Updated at every frequency.<br>GE.1: Updated every NFRUP frequencies. |
| VELOUT | Flag for writing out nodal or elemental velocity data:<br>EQ.0: Do not write out velocity data.<br>EQ.1: Write out time-domain velocity data (in the $x$, $y$, and $z$ directions).<br>EQ.2: Write out frequency domain velocity data (in the normal direction). |
| DBA | Flag for writing out weighted SPL files with different weighting options:<br>EQ.0: Do not write out weighted SPL files.<br>EQ.1: Write out Press_dB(A) by using A-weighting.<br>EQ.2: Write out Press_dB(B) by using B-weighting.<br>EQ.3: Write out Press_dB(C) by using C-weighting.<br>EQ.4: Write out Press_dB(D) by using D-weighting. |

**Boundary Condition Cards.** The deck must include NBC cards in this format: one for each boundary condition.

| Card 4.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SSID | SSTYPE | NORM | BEMTYP | LC1 | LC2 | | |
| Type | I | I | I | I | I | I | | |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SSID | Part, part set ID, or segment set ID of boundary elements (see Remark 14) |
| SSTYPE | Boundary element type:<br>EQ.0: Part set ID<br>EQ.1: Part ID<br>EQ.2: Segment set ID |
| NORM | NORM should be set such that the normal vectors point away from the fluid.<br>EQ.0: Normal vectors are not inverted (default).<br>EQ.1: Normal vectors are inverted. |
| BEMTYP | Type of input boundary values in BEM analysis.<br>EQ.0: The BEM analysis processes the boundary velocity.<br>EQ.1: The BEM analysis processes the boundary acceleration.<br>EQ.2: LC1 and LC2 prescribe the real and imaginary parts of the pressure.<br>EQ.3: LC1 and LC2 prescribed the real and imaginary parts of the normal velocity.<br>EQ.4: LC1 and LC2 prescribe the real and imaginary parts of the impedance.<br>EQ.5: LC1 gives the acoustic absorption coefficient.<br>EQ.6: Specify a symmetry condition (or rigid wall).<br>LT.0: Set the normal velocity (only the real part) through an amplitude as a function of frequency load curve with curve ID \|BEMTYP\|. |
| LC1 | Load curve ID for defining the real part of the pressure, the real part of the normal velocity, the real part of the impedance, or the acoustic absorption coefficient. See BEMTYP = 2, 3, 4, and 5, respectively. |
| LC2 | Load curve ID for defining the imaginary part of the pressure, normal velocity, or impedance. See BEMTYP = 2, 3, and 4, respectively. |

**Panel Contribution Card.** Additional for PANEL_CONTRIBUTION keyword option.

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NSIDPC | | | | | | | |
| Type | I | | | | | | | |
| Default | 0 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| NSIDPC | Node set ID for the field points where panel contributions to SPL (Sound Pressure Level) are requested. See Remark 15. |

**Half Space Card.** Additional card for HALF_SPACE keyword option.

| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | | | | | | | |
| Type | I | | | | | | | |
| Default | 0 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| PID | Plane ID for defining the half-space problem; see keyword *DEFINE_PLANE. |

**Remarks:**

1. **TSTART field.** TSTART indicates the time at which velocity or acceleration and pressure are stored in the binary file.

2. **PREF field.** This reference pressure is required for the computation of the pressure in dB. Usually, in International Unit System, the reference pressure is 20 $\mu$Pa.

3. **FFT windowing.** The LS-DYNA analysis provides velocity or acceleration (pressure) written to a binary file (bem=**filename**). The boundary element method is

processed after the LS-DYNA trnsient analysis. An FFT algorithm transforms the time domain data into the frequency domain to use the boundary element method for acoustics. We propose several windows to overcome the FFT leakage problem due to the truncation of the temporal response. Windowing creates a periodic velocity, acceleration, and pressure needed for the FFT.

4. **TRSLT field.** If requesting time domain results, FMIN automatically changes to 0.0

5. **IUNITS field.** Units are automatically converted into kg, m, s, N, and Pa so that the reference pressure is not too small. For example, it may be as low as $20.0 \times 10^{-15}$ GPa if using the units kg, mm, ms, kN, and GPa, possibly resulting in a truncation error in the computation, especially for single precision.

6. **Rayleigh and Kirchhoff methods.** The Rayleigh method (METHOD = 0) is an approximation suitable only for external radiation problems. It is very fast since there is no linear system to solve. The Kirchhoff method (METHOD = 1) involves coupling the BEM and FEM for acoustics (*MAT_ACOUSTIC) with a non-reflecting boundary condition; see *BOUNDARY_NON_REFLECTING. In this case, at least one fluid layer with a non-reflecting boundary condition is merged with the vibrating structure. This additional fluid is given in *MAT_ACOUSTIC with the same density and sound speed used in this keyword. Both methods provide a good approximation to a full BEM calculation for external problems when used appropriately.

7. **Variational Indirect BEM with fast matrix assembly method.** The Variational Indirect BEM with fast matrix assembly method (METHOD = 211) uses Skeletonized Interpolation to speed up matrix assembly. It is up to 5 times faster than METHOD = 2 for large problems.

8. **Collocation Direct BEM with fast matrix assembly method.** The Collocation Direct BEM with fast matrix assembly method (METHOD = 311) uses Skeletonized Interpolation to speed up matrix assembly. It is up to 5 times faster than METHOD = 3 for large problems.

9. **NDD field.** The BEM formulation for large and medium size problems (more than 2000 boundary elements) is memory and time consuming. In this case, LS-DYNA may be run using the memory option. To save memory, domain decomposition can be used.

10. **RESTRT field.** The binary file generated by a previous run can be used for the next run by using the restart option. With the restart option, the BEM calculation uses the binary file generated from a previous calculation. In this case, the frequency range can be changed. However, the time parameters should not be modified between calculations.

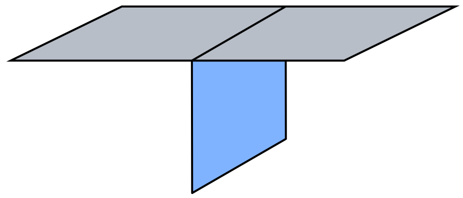

**Figure 23-1.** T-intersection in the Boundary Element Mesh

11. **IEDGE field.** This field only applies to METHOD = 2, the Variational Indirect BEM.

12. **NOEL field.** This field specifies whether the element or nodal velocity (or acceleration) is taken from FEM computation. NOEL should be 0 if Kirchhoff method (METHOD = 1) is used since elemental pressure is processed in FEM. NOEL should be 0 if Burton-Miller collocation method (METHOD = 4) is used since a constant strength element formulation is adopted. In other cases, it is strongly recommended to use element velocity or acceleration (NOEL = 0) if a T-intersection appears in the boundary element mesh. See Figure 23-1.

13. **NFRUP field.** The preconditioner is obtained with the factorization of the influence coefficient matrix. To conserve CPU time, it can be retained for several frequencies. By default (NFRUP = 0), the preconditioner is updated for every frequency. Note that in the MPP version, the preconditioner is updated every NFRUP frequencies on each processor.

14. **Boundary condition cards.** Card 4.1 can be defined if the boundary elements are composed of several panels. It can be defined multiple times if more than 2 panels are used. Each Card 4.1 defines one panel.

15. **NSIDPC field.** The field points where the panel contribution analysis is requested must be one of the field points for acoustic computation (it must be included in the nodes specified by the NSIDEXT or NSIDINT). The panels are defined by Cards 4 and 4.1.

16. **Element sizing.** To obtain accurate results, the element size should not exceed 1/6 of the wavelength $\lambda$ ($\lambda = c/f$ where $c$ is the wave speed and $f$ is the frequency).

17. **Acoustic transfer vector.** Including the ATV keyword option enables obtaining the Acoustic Transfer Vector (ATV). Only METHOD = 2 and 3 are supported for this option. The solver calculates acoustic pressure (and sound pressure level) at field points from a unit normal velocity of each surface node. ATV depends on the structure model, properties of the acoustic fluid, and the location of field points. When the ATV option is included, the structure does not need external excitation, and the curve IDs LC1 and LC2 are ignored. Setting

BINARY = 1 in *DATABASE_FREQUENCY_BINARY_D3ATV causes the output of binary plot database d3atv.

18. **Modal acoustic transfer vector.** Including the MATV keyword option enables calculating the Modal Acoustic Transfer Vector (MATV). The MATV option requires using the implicit eigenvalue solver. *CONTROL_IMPLICIT_GENERAL and *CONTROL_IMPLICIT_EIGENVALUE activate this solver. It calculates acoustic pressure (and sound pressure level) at field points due to vibration in the form of eigenmodes. For each excitation frequency $f$, LS-DYNA generates the pseudo-velocity boundary condition $2\pi if\{\phi\}_j$. Here $i = \sqrt{-1}$ is the imaginary unit. LS-DYNA then runs the acoustic computation for each field point, based on the pseudo-velocity boundary conditions, to obtain the MATV matrices. LS-DYNA saves the MATV matrices to binary file bin_bepressure for future use. Like ATV, MATV depends on the structure model, properties of the acoustic fluids, and the locations of the field points.

19. **Power option.** With the POWER keyword option, acoustic radiated power can be computed with the Rayleigh and Kirchhoff methods.

20. **Output files.** The result files: Press_Pa, Press_dB, Press_Pa_real, Press_Pa_imag, Press_Pa_t, and Press_dB_t have an *xy*-plot format that LS-PrePost can read and plot.

## *FREQUENCY_DOMAIN_ACOUSTIC_DIRECTIVITY

Purpose: Define field point circles for acoustic directivity plot.

Include as many of this card as needed (see Remark 1). This input ends at the next keyword ("*") card.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | CENTER | R | NP | NORM | ANGLE | X | Y | Z |
| Type | I | F | I | I | F | F | F | F |
| Default | none | none | none | none | 0 | 0.0 | 0.0 | 0.0 |

| VARIABLE | DESCRIPTION |
|---|---|
| CENTER | Flag for defining the center point for the circle:<br>EQ.1: Mass center of the original structure<br>EQ.2: Geometry center of the original structure<br>EQ.3: Defined by input variables X, Y, and Z |
| R | Radius of the circle |
| NP | Number of points on the circle |
| NORM | Norm direction of the circle.<br>EQ.1: $x$-direction<br>EQ.2: $y$-direction<br>EQ.3: $z$-direction |
| ANGLE | Angle for the first point on the circle |
| X | $x$-coordinate of the center |
| Y | $y$-coordinate of the center |
| Z | $z$-coordinate of the center |

**Remarks:**

1. **Multiple Directivity Plot.** Card 1 can be repeated if multiple acoustic directivity plot is desired.

2. **Results.** ASCII files Press_Pa_directivity_n and Press_dB_directivity_n are output. Press_Pa_directivity_n provides a list of acoustic pressures (magnitude) for each angle on the $n^{\text{th}}$ circle for a series of frequencies. Press_dB_directivity_n provides a list of SPLs (or decibels) for each angle on the $n^{\text{th}}$ circle for a series of frequencies. The frequencies are defined by FMIN, FMAX and NFREQ in the keyword *FREQUENCY_DOMAIN_ACOUSTIC_BEM.

## *FREQUENCY_DOMAIN_ACOUSTIC_FEM_*{OPTION}*

Available options include:

<BLANK>

EIGENVALUE

MODAL

Purpose: Define an interior acoustic problem and solve the problem with a frequency domain finite element method. When the EIGENVALUE option is used, LS-DYNA computes eigenvalues and eigenvectors of the acoustic system. When the MODAL option is used, LS-DYNA uses a modal superposition method to solve the acoustic problem (see Remark 9).

### Card Summary:

***Card MDL.*** LS-DYNA only reads this card for the MODAL keyword option. It is optional and may be omitted. LS-DYNA assumes that the input contains this card if no data is in the fifth column.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MDMIN | MDMAX | FNMIN | FNMAX | | | | |

**Card 1.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RO | C | FMIN | FMAX | NFREQ | DTOUT | TSTART | PREF |

**Card 2.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | FFTWIN | MTXDMP | RESTRT | | | | |

**Card 3.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PID | PTYP | | | | | | |

**Card 4.** This card can be repeated if multiple boundary conditions are present. For the EIGENVALUE keyword option, this card is optional.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SID | STYP | VAD | DOF | LCID1 | LCID2 | SF | VID |

**Card 5.** Include this card only if the keyword option is *not* EIGENVALUE.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| NID | NTYP | IPFILE | DBA | | | | |

**Data Card Definitions:**

**MODAL Card.** LS-DYNA only reads this optional card for the MODAL keyword option. LS-DYNA assumes that the input contains this card if the fifth column has no data. See Remark 9.

| Card MDL | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MDMIN | MDMAX | FNMIN | FNMAX | | | | |
| Type | I | I | F | F | | | | |
| Default | 1 | optional | 0.0 | optional | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| MDMIN | First mode in modal superposition method (optional) |
| MDMAX | Last mode in modal superposition method (optional) |
| FNMIN | Minimum natural frequency in modal superposition method (optional) |
| FNMAX | Maximum natural frequency in modal superposition method (optional) |

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | RO | C | FMIN | FMAX | NFREQ | DTOUT | TSTART | PREF |
| Type | F | F | F | F | I | F | F | F |
| Default | Rem 2 | none | none | none | 0 | 0.0 | 0.0 | 0.0 |

| VARIABLE | DESCRIPTION |
|---|---|
| RO | Fluid density |
| C | Sound speed of the fluid.<br>GT.0: Real constant sound speed.<br>LT.0: \|C\| is the load curve ID, which defines the frequency- |

| VARIABLE | DESCRIPTION |
|---|---|
| | dependent complex sound speed. See *FREQUENCY_-DOMAIN_ACOUSTIC_SOUND_SPEED. |
| FMIN | Minimum value of output frequencies. |
| FMAX | Maximum value of output frequencies. |
| NFREQ | Number of output frequencies. |
| DTOUT | Time step for writing velocity or acceleration in the binary file. |
| TSTART | Start time for recording velocity or acceleration in transient analysis. |
| PREF | Reference pressure for converting the acoustic pressure to dB. See Remark 3. |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | | FFTWIN | MTXDMP | RESTRT | | | | |
| Type | | I | I | I | | | | |
| Default | | 0 | 0 | 0 | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| FFTWIN | FFT windows (Default = 0):<br>EQ.0: Rectangular window.<br>EQ.1: Hanning window.<br>EQ.2: Hamming window.<br>EQ.3: Blackman window.<br>EQ.4: Raised cosine window. |
| MTXDMP | Acoustic stiffness and mass matrices dumping (when using the option EIGENVALUE):<br>EQ.0: No dumping.<br>EQ.1: Dumping globally assembled acoustic stiffness and mass |

| VARIABLE | DESCRIPTION |
|---|---|
| | matrices in Harwell-Boeing sparse matrix format. |
| RESTRT | This flag is used to save an LS-DYNA time domain analysis if the binary output file (bin_femac) has not been changed (Default = 0):<br>EQ.0: LS-DYNA time domain analysis is processed and generates a new binary file (bin_femac) which saves the boundary velocity history data.<br>EQ.1: LS-DYNA time domain analysis is not processed. The binary file bin_femac from the last run is used. |

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | PTYP | | | | | | |
| Type | I | I | | | | | | |
| Default | none | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| PID | Part ID or part set ID to define the acoustic domain. |
| PTYP | Set type:<br>EQ.0: Part; see *PART.<br>EQ.1: Part set; see *SET_PART. |

**Boundary Condition Definition Card**. It can be repeated if multiple boundary conditions are present. This card is optional when option EIGENVALUE is present.

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SID | STYP | VAD | DOF | LCID1 | LCID2 | SF | VID |
| Type | I | I | I | I | I | I | F | I |
| Default | none | 0 | 0 | none | 0 | 0 | 1.0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| SID | Part ID, part set ID, segment set ID, or node set ID to define where the vibration boundary condition is. |
| STYP | Set type:<br>EQ.0: Part; see *PART.<br>EQ.1: Part set; see *SET_PART.<br>EQ.2: Segment set; see *SET_SEGMENT.<br>EQ.3: Node set; see *SET_NODE. |
| VAD | Boundary condition flag:<br>EQ.0: Velocity by steady state dynamics (SSD).<br>EQ.1: Velocity by transient analysis.<br>EQ.2: Opening (zero pressure).<br>EQ.11: Velocity by LCID1 (amplitude) and LCID2 (phase).<br>EQ.12: Velocity by LCID1 (real) and LCID2 (imaginary).<br>EQ.21: Acceleration by LCID1 (amplitude) and LCID2 (phase).<br>EQ.22: Acceleration by LCID1 (real) and LCID2 (imaginary).<br>EQ.31: Displacement by LCID1 (amplitude) and LCID2 (phase).<br>EQ.32: Displacement by LCID1 (real) and LCID2 (imaginary).<br>EQ.41: Impedance by LCID1 (amplitude) and LCID2 (phase).<br>EQ.42: Impedance by LCID1 (real) and LCID2 (imaginary).<br>EQ.51: Pressure by LCID1 (amplitude) and LCID2 (phase).<br>EQ.52: Pressure by LCID1 (real) and LCID2 (imaginary). |
| DOF | Applicable degrees-of-freedom:<br>EQ.0: Determined by steady state dynamics.<br>EQ.1: $x$-translational degree-of-freedom,<br>EQ.2: $y$-translational degree-of-freedom,<br>EQ.3: $z$-translational degree-of-freedom,<br>EQ.4: Translational motion in direction given by VID,<br>EQ.5: Normal direction of the element or segment. |

| VARIABLE | DESCRIPTION |
|---|---|
| LCID1 | Load curve ID to describe the amplitude (or real part) of velocity; see *DEFINE_CURVE. |
| LCID2 | Load curve ID to describe the phase (or imaginary part) of velocity; see *DEFINE_CURVE. |
| SF | Load curve scale factor. |
| VID | Vector ID for DOF values of 4. |

**Field Points Definition Card**. Not used when option EIGENVALUE is present.

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NID | NTYP | IPFILE | DBA | | | | |
| Type | I | I | I | I | | | | |
| Default | none | 0 | 0 | 0 | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| NID | Node ID, node set ID, or segment set ID for acoustic result output |
| NTYP | Set type:<br>EQ.0: Node; see *NODE.<br>EQ.1: Node set; see *SET_NODE. |
| IPFILE | Flag for output files (default = 0):<br>EQ.0: Press_Pa (magnitude of pressure as function of frequency), Press_dB (sound pressure level or SPL as a function of frequency) are provided.<br>EQ.1: Press_Pa_real (real part of pressure as a function of frequency) and Press_Pa_imag (imaginary part of pressure as a function of frequency) are provided, in addition to Press_Pa, Press_dB. |
| DBA | Flag for writing out weighted SPL files with different weighting options.<br>EQ.0: No writing out weighted SPL files. |

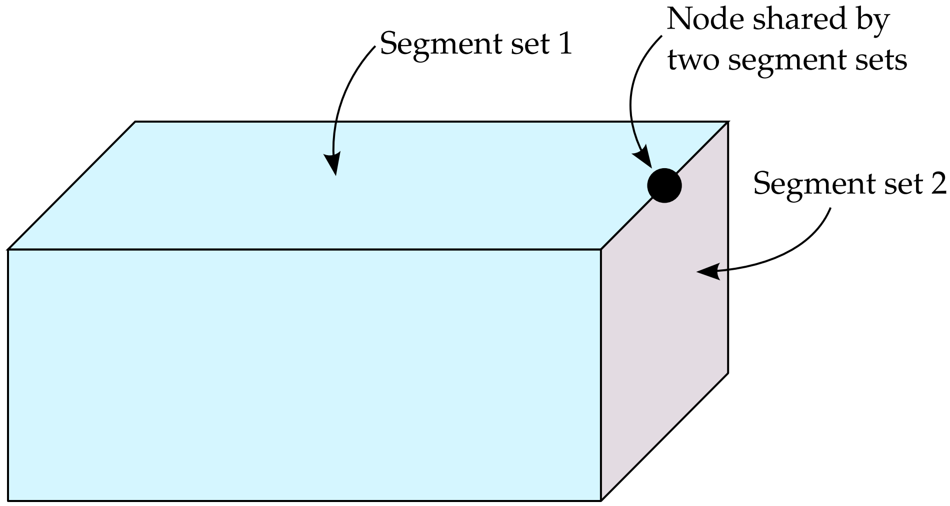


**Figure 23-2.** Nodes with Multiple Boundary Conditions.

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.1: Write out Press_dB(A) by using A-weighting. |
| | EQ.2: Write out Press_dB(B) by using B-weighting. |
| | EQ.3: Write out Press_dB(C) by using C-weighting. |
| | EQ.4: Write out Press_dB(D) by using D-weighting. |

**Remarks:**

1. **Acoustic problem.** This command solves the interior acoustic problems which is governed by Helmholtz equation $\nabla^2 p + k^2 p = 0$ with the boundary condition $\partial p/\partial n = -i\omega\rho v_n$, where $p$ is the acoustic pressure; $k = \omega/c$ is the wave number; $\omega$ is the round frequency; $c$ is the acoustic wave speed (sound speed); $i = \sqrt{-1}$ is the imaginary unit; $\rho$ is the mass density; and $v_n$ is the normal velocity. This command solves the acoustic problem in the frequency domain.

2. **Mass density.** If mass density RO is not given, the mass density of PID (the part which defines the acoustic domain), will be used

3. **Reference pressure.** PREF is the reference pressure to convert the acoustic pressure to dB $L_p = 10\log_{10}(p^2/p_{\mathrm{ref}}^2)$. Note that generally $p_{\mathrm{ref}} = 20\ \mu\mathrm{Pa}$ for air.

4. **Material models for acoustic domain.** If the boundary velocity is obtained from steady state dynamics (VAD = 0) using the keyword *FREQUENCY_DOMAIN_SSD, the part (PID) which defines the acoustic domain should use material model *MAT_ELASTIC_FLUID which enables implicit eigenvalue analysis. If the boundary excitation is given by load curves LCID1 and LCID2 (VAD > 0), the part (PID) which defines the acoustic domain can use any material model

that is compatible with 8-node hexahedron, 6-node pentahedron, or 4-node tetrahedron elements since only the mesh of the PID will be used in the computation. For example, *MAT_ACOUSTIC or *MAT_ELASTIC_FLUID can be used.

5. **Steady state dynamics.** If VAD = 0, the boundary excitation is given as velocity obtained from steady state dynamics. The other parameters in Card 3 (DOF, LCID1, LCID2, SF and VID) are ignored.

6. **Multiple boundary condition definitions.** If a node's vibration boundary condition is defined multiple times, only the last definition is considered. This happens usually when a node is on an edge, is shared by two or more parts, part sets, node sets, or segment sets, and a different vibration condition is defined on each of the node or segment sets. See Figure 23-2.

7. **Output Files.** Results including acoustic pressure and SPL are given in d3acs binary files, which can be accessed by LS-PrePost. Nodal pressure and SPL values for nodes specified by NID and NTYP are given in ASCII file Press_Pa and Press_dB, which can be accessed by LS-PrePost. Press_Pa gives magnitude of the pressure. Press_dB gives the SPL in terms of dB.

8. **Frequencies and Steady State Dynamics.** If the boundary velocity condition is given by Steady State Dynamics (VAD = 0), the range and number of frequencies (FMIN, FMAX and NFREQ) should be compatible with the corresponding parameters in Card 1 of the keyword *FREQUENCY_DOMAIN_SSD.

9. **Modal Acoustics.** When keyword option MODAL is used, LS-DYNA computes the acoustic pressure response by a modal superposition method. An acoustic eigenvalue analysis problem (*FREQUENCY_DOMAIN_ACOUSTIC_-FEM_EIGENVALUE) must be solved first and the binary database d3eigv_ac must be present in the same directory to run modal acoustics. Card MDL is optional, and it defines the eigenmodes to be used in modal superposition if present. Otherwise, all the acoustic eigenmodes saved in d3eigv_ac will be used.

## *FREQUENCY_DOMAIN_ACOUSTIC_FREQUENCY

Purpose: Specify output frequencies for a frequency domain acoustic computation, especially with different spacing options. The frequencies defined here override those defined in *FREQUENCY_DOMAIN_ACOUSTIC_BEM or *FREQUENCY_DOMAIN_ACOUSTIC_FEM.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FMIN | FMAX | NFREQ | FSPACE | LCFREQ | BIAS | SPREADF | FRACTN |
| Type | F | F | I | I | I | F | F | I |
| Default | none | none | none | 0 | 0 | 3 | 0.1 | 3 |

| VARIABLE | DESCRIPTION |
|---|---|
| FMIN | Minimum frequency for output, $f_{\min}$ |
| FMAX | Maximum frequency for output, $f_{\max}$. Ignored if FSPACE = 6. |
| NFREQ | Total number of frequencies for output:<br>GT.0: NFREQ is the number of frequencies for the whole range.<br>LT.0: \|NFREQ\| is the number of frequencies for each interval. |
| FSPACE | Frequency spacing option for output (see Figure 23-3 and Remark 1):<br>EQ.0: Linear<br>EQ.1: Logarithmic<br>EQ.2: Biased spacing (range)<br>EQ.3: Eigenfrequencies only<br>EQ.4: Biased spacing (eigenfrequency)<br>EQ.5: Biased spacing (eigenfrequency spread)<br>EQ.6: Octave frequencies starting with FMIN |
| LCFREQ | Load curve ID defining the frequencies for output. If defined, all other fields are ignored. |
| BIAS | Bias parameter, $p$ (FSPACE = 2, 4, and 5 only) |

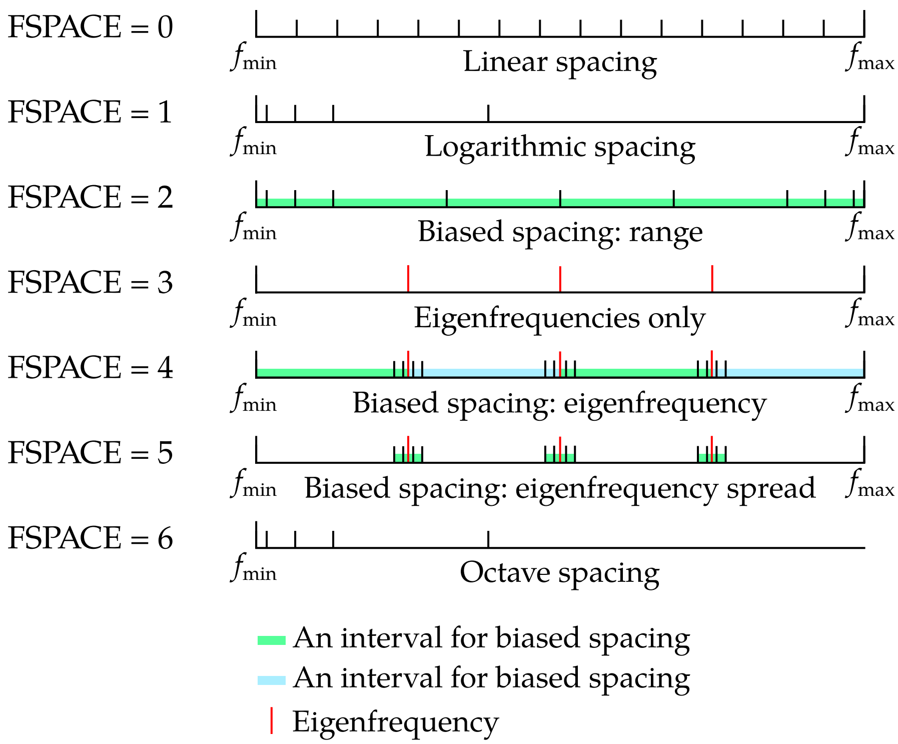


**Figure 23-3.** Frequency spacing depending on the choice of FSPACE

| VARIABLE | DESCRIPTION |
|---|---|
| SPREADF | Spread ratio, $\sigma$ (FSPACE = 5 only) |
| FRACTN | Octave fraction, $\alpha$ (FSPACE = 6 only). For example, FRACTN = 3 means 1/3 octave spacing. FMAX is ignored. |

## Remarks:

1. **Output frequencies.** Unless LCID is defined, the output frequencies depend on the choice of FSPACE as shown in Figure 23-3. Here we will give equations for determining the output frequencies.

   a) *Linear spacing (FSPACE = 0).* For linear spacing, the output frequencies are given by:

   $$f_k = f_{\min} + \frac{k-1}{N-1}(f_{\max} - f_{\min}) \ .$$

   Here, $k$ is the $k^{\text{th}}$ frequency with $k = 1, \dots, N$ where $N$ is the number of frequencies.

   b) *Logarithmic spacing (FSPACE = 1).* For logarithmic spacing, the output frequencies are given by:

$$f_k = f_{\min}\left(\frac{f_{\max}}{f_{\min}}\right)^{\frac{k-1}{N-1}} \quad .$$

Here, $k$ is the $k^{\text{th}}$ frequency with $k = 1, \dots, N$ where $N$ is the number of frequencies.

c) *Biased spacing (FSPACE = 2, 4, and 5).* For biased spacing, the output frequencies in each frequency interval $[\bar{f}_1, \bar{f}_2]$ are given by:

$$f_k = \frac{1}{2}(\bar{f}_1 + \bar{f}_2) + \frac{1}{2}(\bar{f}_2 - \bar{f}_1)|x|^{1/p}\operatorname{sign}(x) \quad ,$$

where

$$x = -1 + \frac{2(k-1)}{n-1}$$

In the above, $k$ is the $k^{\text{th}}$ frequency is the $k^{\text{th}}$ frequency in the interval with $k = 1, \dots, n$ where $n$ is the number of frequency points in the frequency interval, and $p$ is the bias parameter.

The lower and upper limits of the frequency interval, $\bar{f}_1$ and $\bar{f}_2$, depend on the setting of FSPACE. For FSPACE = 2:

$$\bar{f}_1 = f_{\min} \quad , \qquad \bar{f}_2 = f_{\max} \quad .$$

For FSPACE = 4:

$$\bar{f}_1 = F_i \quad , \qquad \bar{f}_2 = F_{i+1}$$

with $\bar{f}_1 = f_{\min}$ in the first interval and $\bar{f}_2 = f_{\max}$ in the last interval. Other than than the endpoints, $F_i$ is the $i^{\text{th}}$ eigenfrequency. For FSPACE = 5:

$$\bar{f}_1 = F_i(1-\sigma) \, , \qquad \bar{f}_2 = F_i(1+\sigma) \quad .$$

Here, $F_i$ is the $i^{\text{th}}$ eigenfrequency, and $\sigma$ is the spread ratio.

d) *Octave spacing (FSPACE = 6).* For octave spacing, the output frequencies are given by:

$$f_k = f_{\min}\left(2^{(1/\alpha)}\right)^{k-1}$$

Here, $k$ is the $k^{\text{th}}$ frequency with $k = 1, \dots, N$ where $N$ is the number of frequencies, and $\alpha$ is the octave fraction.

## *FREQUENCY_DOMAIN_ACOUSTIC_FRINGE_PLOT_*OPTION*

Available options include:

CUBE

NODE_SET

PART

PART_SET

PLATE

SPHERE

Purpose: Define field points for the acoustic pressure computation by the BEM acoustic solver and save the results to D3ACP binary database. The field points can be defined using existing structure components if option NODE_SET, PART, or PART_SET is used. The field points can be created by LS-DYNA if option SPHERE, PLATE, or CUBE is used. SPHERE, PLATE, and CUBE are only available for SMP while PART, PART_SET, and NODE_SET are available for both MPP and SMP.

### Card Summary:

**Card 1a.** This card is included if the keyword option is NODE_SET, PART, or PART_-SET.

| PID/SID | | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 1b.** This card is included if the keyword option is SPHERE.

| CENTER | R | DENSITY | X | Y | Z | HALF1 | HALF2 |
|---|---|---|---|---|---|---|---|

**Card 1c.** This card is included if the keyword option is PLATE.

| NORM | LEN_X | LEN_Y | X | Y | Z | NELM_X | NELM_Y |
|---|---|---|---|---|---|---|---|

**Card 1d.1.** This card is included if the keyword option is CUBE.

| LEN_X | LEN_Y | LEN_Z | X | Y | Z | | |
|---|---|---|---|---|---|---|---|

**Card 1d.2.** This card is included if the keyword option is CUBE.

| NELM_X | NELM_Y | NELM_Z | | | | | |
|---|---|---|---|---|---|---|---|

**Data Card Definitions:**

**PART, PART_SET, and NODE_SET Card.**

| Card 1a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID/SID | | | | | | | |
| Type | I | | | | | | | |
| Default | none | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| PID/SID | Part ID, part set ID, or node set ID |

**SPHERE Card.**

| Card 1b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | CENTER | R | DENSITY | X | Y | Z | HALF1 | HALF2 |
| Type | I | F | I | F | F | F | I | I |
| Default | 1 | none | none | none | none | none | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| CENTER | Flag for defining the center point for the sphere:<br>EQ.1: Mass center of the original structure<br>EQ.2: Geometry center of the original structure<br>EQ.3: Defined by $(x, y, z)$ |
| R | Radius of the sphere. |
| DENSITY | Parameter to define how coarse or dense the created sphere mesh is. It is a number between 3 and 39, where “3” gives you 24 elements while “39” gives you 8664 elements. |
| X | $x$-coordinate of the center |

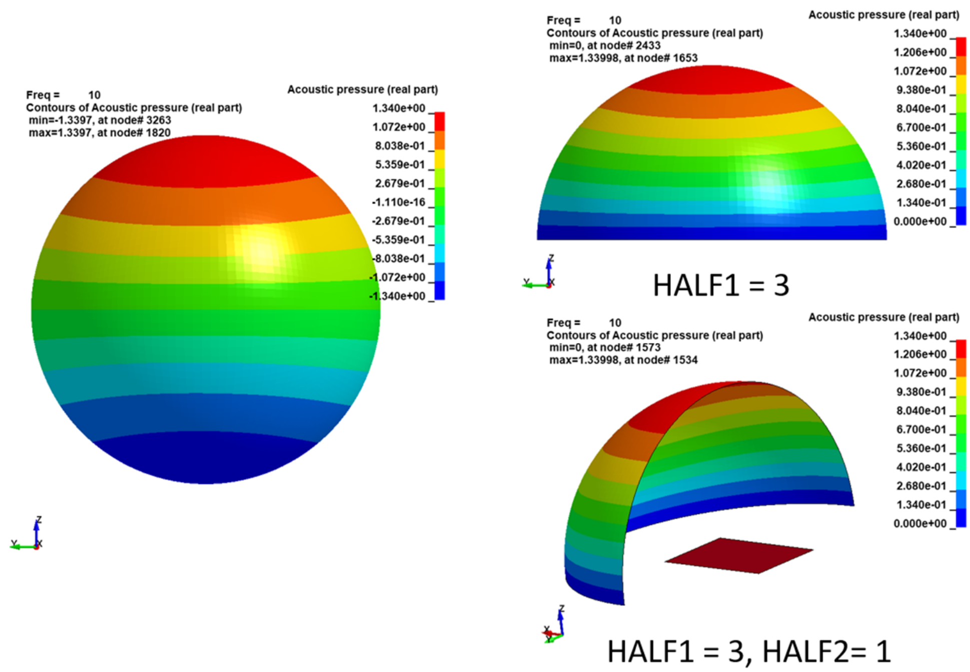


**Figure 23-4.** Defining a half or quarter sphere

| **VARIABLE** | **DESCRIPTION** |
|---|---|
| Y | $y$-coordinate of the center |
| Z | $z$-coordinate of the center |
| HALF1 | Create a half sphere by trimming the defined sphere (see Remark 3 and Figure 23-4). Note that $(x_0, y_0, z_0)$ below is the center of the sphere.<br>EQ.0: A full sphere is created, no trimming<br>EQ.1: Keep $x \geq x_0$<br>EQ.-1: Keep $x \leq x_0$<br>EQ.2: Keep $y \geq y_0$<br>EQ.-2: Keep $y \leq y_0$<br>EQ.3: Keep $z \geq z_0$<br>EQ.-3: Keep $z \leq z_0$ |
| HALF2 | Create a quarter sphere by trimming the half sphere defined with HALF1 (see Remark 3 and Figure 23-4):<br>EQ.0: No second trimming |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.1: Keep $x \geq x_0$ |
| | EQ.-1: Keep $x \leq x_0$ |
| | EQ.2: Keep $y \geq y_0$ |
| | EQ.-2: Keep $y \leq y_0$ |
| | EQ.3: Keep $z \geq z_0$ |
| | EQ.-3: Keep $z \leq z_0$ |

**Plate Card.**

| Card 1c | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NORM | LEN_X | LEN_Y | X | Y | Z | NELM_X | NELM_Y |
| Type | I | F | F | F | F | F | I | I |
| Default | 1 | none | none | none | none | none | 10 | 10 |

| VARIABLE | DESCRIPTION |
|---|---|
| NORM | Norm direction of the plate.<br>EQ.1: $x$-direction<br>EQ.2: $y$-direction<br>EQ.3: $z$-direction |
| LEN_X | Length of longer side of the plate |
| LEN_Y | Length of shorter side of the plate |
| X | $x$-coordinate of the center |
| Y | $y$-coordinate of the center |
| Z | $z$-coordinate of the center |
| NELM_X | Number of elements on longer side of the plate |
| NELM_Y | Number of elements on shorter side of the plate |

**Cube Card 1.**

| Card 1d.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LEN_X | LEN_Y | LEN_Z | X | Y | Z | | |
| Type | F | F | F | F | F | F | | |
| Default | none | none | none | none | none | none | | |

| VARIABLE | DESCRIPTION |
|---|---|
| LEN_X | Length of $x$-side of the cube |
| LEN_Y | Length of $y$-side of the cube |
| LEN_Z | Length of $z$-side of the cube |
| X | $x$-coordinate of the corner of the cube with smallest nodal coordinates |
| Y | $y$-coordinate of the corner of the cube with smallest nodal coordinates |
| Z | $z$-coordinate of the corner of the cube with smallest nodal coordinates |

**Cube Card 2.**

| Card 1d.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NELM_X | NELM_Y | NELM_Z | | | | | |
| Type | I | I | I | | | | | |
| Default | 10 | 10 | 10 | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| NELM_X | Number of elements on $x$-side of the cube |
| NELM_Y | Number of elements on $y$-side of the cube |

| VARIABLE | DESCRIPTION |
|---|---|
| NELM_Z | Number of elements on *z*-side of the cube |

**Remarks:**

1. **LS-PrePost.** The acoustic pressure results at those field points are saved in D3ACP binary database and are accessible by LS-PrePost. With the FCOMP tool in LS-PrePost, the fringe plot of the results (real part acoustic pressure, imaginary part acoustic pressure, magnitude of acoustic pressure and Sound Pressure Level) can be generated.

2. **Field Points.** The field points defined by this keyword are separate from the field points defined in Card 2 of *FREQUENCY_DOMAIN_ACOUSTIC_BEM. The acoustic pressure results for the latter are only saved in ASCII database Press_Pa, Press_dB, etc. (in a tabular format that can be plotted in LS-PrePost by using the XYPlot tool).

3. **Half or Quarter Sphere.** The parameters HALF1 and HALF2 change a full sphere to a half sphere or a quarter sphere. See Figure 23-4 for illustration.

## *FREQUENCY_DOMAIN_ACOUSTIC_INCIDENT_WAVE

Purpose: Define incident sound wave for acoustic scattering problems.

**Wave Definition Cards.** This card may be repeated to define multiple incident waves. Include as many cards as desired. This input ends at the next keyword ("*") card.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | TYPE | MAG | XC | YC | ZC | | | |
| Type | I | F | F | F | F | | | |
| Default | 1 | none | none | none | none | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| TYPE | Type of incident sound wave:<br>EQ.1: plane wave.<br>EQ.2: spherical wave. |
| MAG | Magnitude of the incident sound wave:<br>GT.0: constant magnitude.<br>LT.0: \|MAG\| is a curve ID, which defines the frequency dependent magnitude. See *DEFINE_CURVE. |
| XC, YC, ZC | Direction cosines for the plane wave (TYPE = 1) or coordinates of the point source for the spherical wave (TYPE = 2). |

**Remarks:**

1. **Plane Waves.** For plane waves, the incident wave is defined as

$$p(x,y,z) = Ae^{-ik(\alpha x+\beta y+\gamma z)} ,$$

where $A$ is the magnitude of the incident wave and $\alpha$, $\beta$, and $\gamma$ are the direction cosines along the incident direction. $i = \sqrt{-1}$ is the imaginary unit and $k = \omega/c$ is the wave number. $\omega$ is the round frequency and $c$ is the sound speed.

2. **Spherical Waves.** For spherical waves, the incident wave is defined as

$$p(r) = A\frac{e^{-ikr}}{r} ,$$

where $A$ is the magnitude of the incident wave and $r$ is the distance measured from the position of the point source.

## *FREQUENCY_DOMAIN_ACOUSTIC_SOUND_SPEED

Purpose: Define frequency dependent complex sound speed to be used in frequency domain finite element method or boundary element method acoustic analysis.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ID | | | | | | | |
| Type | I | | | | | | | |
| Default | none | | | | | | | |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LCID1 | LCID2 | | | | | | |
| Type | I | I | | | | | | |
| Default | none | none | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| ID | Complex sound speed ID. |
| LCID1 | Curve ID for real part of frequency dependent complex sound speed. |
| LCID2 | Curve ID for imaginary part of frequency dependent complex sound speed. |

**Remarks:**

1. **Acoustic Mediums and Damping.** The sound speed in an acoustic medium is usually defined as a constant real value. But it can also be defined as a complex value which is dependent on frequency, to introduce damping in the system.

2. **Using Complex Sound Speed.** To use the frequency dependent complex sound speed defined here, set the sound speed C = -ID in *FREQUENCY_DO-

MAIN_ACOUSTIC_FEM or *FREQUENCY_DOMAIN_ACOUSTIC_BEM keywords.

## *FREQUENCY_DOMAIN_FRF_*{OPTION}*

Available options include:

<BLANK>

SUBCASE

Purpose: This keyword computes frequency response functions due to nodal excitations.

> **NOTE:** Natural frequencies and mode shapes are needed for computing the frequency response functions. Thus, *CONTROL_IMPLICIT_EIGENVALUE *must* be included in the input. See Remark 1.

When the SUBCASE option is applied, multiple loading cases can be included in one run (see Remark 9).

### Card Summary:

**Card 1a.** Include this card when the keyword option is unused (<BLANK>).

| N1 | N1TYP | DOF1 | VAD1 | VID1 | FNMAX | MDMIN | MDMAX |
|---|---|---|---|---|---|---|---|

**Card 1a.1.** Include this card when the keyword option is unused (<BLANK>) and VAD1 = 12 on Card 1a.

| N11 | N11TYP | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 1b.** Include this card when the keyword option is SUBCASE.

| NCASES | | | | RELATV | FNMAX | MDMIN | MDMAX |
|---|---|---|---|---|---|---|---|

**Card 2.** This card is required.

| DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | | | |
|---|---|---|---|---|---|---|---|

**Card 3.** Include this card when the keyword option is unused (<BLANK>).

| N2 | N2TYP | DOF2 | VAD2 | VID2 | RELATV | | |
|---|---|---|---|---|---|---|---|

**Card 4.** This card is required.

| FMIN | FMAX | NFREQ | FSPACE | LCFREQ | RESTRT | OUTPUT | |
|---|---|---|---|---|---|---|---|

**Card 5.** Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE. Each repeat defines one subcase for FRF computation, including the title, excitation input, and response output for the subcase.

| TITLE |
|---|

**Card 6.** Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE.

| N1 | N1TYP | DOF1 | VAD1 | VID1 | | | |
|---|---|---|---|---|---|---|---|

**Card 6.1.** Include this card after Card 6 if VAD1 = 12 on Card 6 (SUBCASE keyword option only).

| N11 | N11TYP | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 7.** Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE.

| N2 | N2TYP | DOF2 | VAD2 | VID2 | | | |
|---|---|---|---|---|---|---|---|

**Data Card Definitions:**

Include this card when the keyword option is unused (<BLANK>).

| Card 1a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | N1 | N1TYP | DOF1 | VAD1 | VID1 | FNMAX | MDMIN | MDMAX |
| Type | I | I | I | I | I | F | I | I |
| Default | none | 0 | none | 3 | 0 | 0.0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| N1 | Node / Node set / Segment set ID for excitation input. This field is ignored when VAD1, the excitation type, is set to 0, 1, or 2 (base velocity, base acceleration, or base displacement, respectively). In this case, the excitation is applied through the node(s) under constraints, that is, the node(s) defined in *BOUNDARY_SPC_NODE or *BOUNDARY_SPC_SET. |
| N1TYP | Type of N1: |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID<br>EQ.3: Parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW)<br>EQ.5: Parametric edge ID (see *IGA_EDGE_UVW)<br>EQ.6: Parametric edge set ID (see *SET_IGA_EDGE_UVW)<br>EQ.7: Physical face ID (see *IGA_FACE_XYZ)<br>EQ.8: Physical face set ID (see *SET_IGA_FACE_XYZ)<br>When VAD1, the excitation type, is set to 0, 1, or 2, which is base velocity, base acceleration, or base displacement, this field is ignored. |
| DOF1 | Applicable degrees-of-freedom for excitation input (ignored if VAD1 = 4):<br>EQ.0: Translational movement in the direction given by vector VID1<br>EQ.1: $x$-translational degree-of-freedom, or $x$-rotational degree-of-freedom (for torque excitation, VAD1 = 8)<br>EQ.2: $y$-translational degree-of-freedom, or $y$-rotational degree-of-freedom (for torque excitation, VAD1 = 8)<br>EQ.3: $z$-translational degree-of-freedom, or $z$-rotational degree-of-freedom (for torque excitation, VAD1 = 8) |
| VAD1 | Excitation input type:<br>EQ.0: Base velocity<br>EQ.1: Base acceleration<br>EQ.2: Base displacement<br>EQ.3: Nodal force<br>EQ.4: Pressure<br>EQ.5: Enforced velocity by large mass method<br>EQ.6: Enforced acceleration by large mass method<br>EQ.7: Enforced displacement by large mass method<br>EQ.8: Torque |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.9: Base angular velocity<br>EQ.10: Base angular acceleration<br>EQ.11: Base angular displacement<br>EQ.12: Torsion |
| VID1 | Vector ID for DOF1 = 0 for excitation input. See *DEFINE_VECTOR. |
| FNMAX | Optional maximum natural frequency employed in FRF computation. See Remark 3. |
| MDMIN | The first mode employed in FRF computation (optional). See Remarks 3 and 4. |
| MDMAX | The last mode employed in FRF computation (optional). It should be set as a positive integer in a restart run (RESTRT = 1 or 3) based on the number of eigenmodes available in the existing d3eigv database. See Remarks 3 and 4. |

Include this card when the keyword option is unused (<BLANK>) and VAD1 = 12 on Card 1a.

| Card 1a.1 | 1 | 2 | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variable | N11 | N11TYP | | | | | | |
| Type | I | I | | | | | | |
| Default | none | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| N11 | Node / Node set / Segment set ID for the excitation input for the torque load (VAD1 = 12). This node or set combines with N1 to form a torque load. |
| N11TYP | Type of N11:<br>EQ.0: Node ID<br>EQ.1: Node set ID |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.2: Segment set ID<br>EQ.3: Parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW)<br>EQ.5: Parametric edge ID (see *IGA_EDGE_UVW)<br>EQ.6: Parametric edge set ID (see *SET_IGA_EDGE_UVW)<br>EQ.7: Physical face ID (see *IGA_FACE_XYZ)<br>EQ.8: Physical face set ID (see *SET_IGA_FACE_XYZ) |

Include this card when the keyword option is SUBCASE.

| Card 1b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NCASES | | | | RELATV | FNMAX | MDMIN | MDMAX |
| Type | I | | | | I | F | I | I |
| Default | none | | | | 0 | 0.0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| NCASES | Number of subcases |
| RELATV | Flag for displacement, velocity, and acceleration results:<br>EQ.0: Absolute values are requested.<br>EQ.1: Relative values are requested (for VAD1 = 0, 1, 2 only). |
| FNMAX | Optional maximum natural frequency employed in FRF computation. See Remark 3. |
| MDMIN | The first mode employed in FRF computation (optional). See Remarks 3 and 4. |
| MDMAX | The last mode employed in FRF computation (optional). It should be set as a positive integer in a restart run (RESTRT = 1 or 3) based on the number of eigenmodes available in the existing d3eigv database. See Remarks 3 and 4. |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | | | |
| Type | F | I | I | F | F | | | |
| Default | 0.0 | 0 | 0 | 0.0 | 0.0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPF | Modal damping coefficient, $\zeta$. See Remark 5. |
| LCDAM | Load Curve ID defining mode dependent modal damping coefficient, $\zeta$. See Remark 5. |
| LCTYP | Type of load curve defining modal damping coefficient:<br>EQ.0: Abscissa value represents frequency,<br>EQ.1: Abscissa value gives mode number.<br>See Remark 5. |
| DMPMAS | Mass proportional damping constant, $\alpha$, in Rayleigh damping. See Remark 5. |
| DMPSTF | Stiffness proportional damping constant, $\beta$, in Rayleigh damping. See Remark 5. |

Include this card when the keyword option is unused (<BLANK>).

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | N2 | N2TYP | DOF2 | VAD2 | VID2 | RELATV | | |
| Type | I | I | I | I | I | I | | |
| Default | none | 0 | none | 2 | 0 | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| N2 | Node / Node set / Segment set ID for response output. |

| VARIABLE | DESCRIPTION |
|---|---|
| N2TYP | Type of N2:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID<br>EQ.3: Parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW) |
| DOF2 | Applicable degrees of freedom for response output:<br>EQ.0: Direction given by vector VID2<br>EQ.1: $x$-translational degree of freedom<br>EQ.2: $y$-translational degree of freedom<br>EQ.3: $z$-translational degree of freedom<br>EQ.4: $x$-rotational degree of freedom<br>EQ.5: $y$-rotational degree of freedom<br>EQ.6: $z$-rotational degree of freedom<br>EQ.7: $x$, $y$, and $z$-translational degrees of freedom<br>EQ.8: $x$, $y$, and $z$-rotational degrees of freedom |
| VAD2 | Response output type:<br>EQ.0: Velocity<br>EQ.1: Acceleration<br>EQ.2: Displacement<br>EQ.3: Nodal force (see Remark 8) |
| VID2 | Vector ID for DOF2 = 0 for response direction. See *DEFINE_VECTOR. |
| RELATV | Flag for displacement, velocity, and acceleration results:<br>EQ.0: Absolute values are requested.<br>EQ.1: Relative values are requested (for VAD1 = 0, 1, 2 only). |

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FMIN | FMAX | NFREQ | FSPACE | LCFREQ | RESTRT | OUTPUT | |
| Type | F | F | I | I | I | I | I | |
| Default | none | none | 2 | 0 | none | 0 | 0 | |

| VARIABLE | DESCRIPTION |
|---|---|
| FMIN | Minimum frequency for FRF output (cycles/time). See Remark 6. |
| FMAX | Maximum frequency for FRF output (cycles/time). See Remark 6. |
| NFREQ | Number of frequencies for FRF output. See Remark 6. |
| FSPACE | Frequency spacing option for FRF output:<br>EQ.0: Linear<br>EQ.1: Logarithmic<br>EQ.2: Biased<br>See Remark 6. |
| LCFREQ | Load curve ID defining the frequencies for FRF output. See Remark 6. |
| RESTRT | Restart option:<br>EQ.0: Initial run<br>EQ.1: Restart with d3eigv family files<br>EQ.2: Restart with dumpfrf<br>EQ.3: Restart with d3eigv family files and dumpfrf<br>See Remark 7. |
| OUTPUT | Output option:<br>EQ.0: Write amplitude and phase angle pairs.<br>EQ.1: Write real and imaginary pairs. |

Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE. Each repeat defines one subcase for FRF computation, including the title, excitation input, and response output for the subcase.

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | TITLE | | | | | | | |
| Type | A80 | | | | | | | |
| Default | none | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| TITLE | Title for the subcase |

Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE.

| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | N1 | N1TYP | DOF1 | VAD1 | VID1 | | | |
| Type | I | I | I | I | I | | | |
| Default | none | 0 | none | 3 | 0 | | | |

**VARIABLE** **DESCRIPTION**

N1 — Node / Node set / Segment set ID for excitation input. This field is ignored when VAD1, the excitation type, is set to 0, 1, or 2 (base velocity, base acceleration, or base displacement, respectively). In this case, the excitation is applied through the node(s) under constraints, that is, the node(s) defined in *BOUNDARY_SPC_NODE or *BOUNDARY_SPC_SET.

N1TYP — Type of N1:

EQ.0: Node ID

EQ.1: Node set ID

EQ.2: Segment set ID

EQ.3: Parametric point ID (see *IGA_POINT_UVW)

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW)<br>EQ.5: Parametric edge ID (see *IGA_EDGE_UVW)<br>EQ.6: Parametric edge set ID (see *SET_IGA_EDGE_UVW)<br>EQ.7: Physical face ID (see *IGA_FACE_XYZ)<br>EQ.8: Physical face set ID (see *SET_IGA_FACE_XYZ)<br>When VAD1, the excitation type, is set to 0, 1, or 2, which is base velocity, base acceleration, or base displacement, this field is ignored. |
| DOF1 | Applicable degrees-of-freedom for excitation input (ignored if VAD1 = 4):<br>EQ.0: Translational movement in the direction given by vector VID1<br>EQ.1: *x*-translational degree-of-freedom, or *x*-rotational degree-of-freedom (for torque excitation, VAD1 = 8)<br>EQ.2: *y*-translational degree-of-freedom, or *y*-rotational degree-of-freedom (for torque excitation, VAD1 = 8)<br>EQ.3: *z*-translational degree-of-freedom, or *z*-rotational degree-of-freedom (for torque excitation, VAD1 = 8) |
| VAD1 | Excitation input type:<br>EQ.0: Base velocity<br>EQ.1: Base acceleration<br>EQ.2: Base displacement<br>EQ.3: Nodal force<br>EQ.4: Pressure<br>EQ.5: Enforced velocity by large mass method<br>EQ.6: Enforced acceleration by large mass method<br>EQ.7: Enforced displacement by large mass method<br>EQ.8: Torque<br>EQ.9: Base angular velocity<br>EQ.10: Base angular acceleration<br>EQ.11: Base angular displacement<br>EQ.12: Torsion |

| VARIABLE | DESCRIPTION |
|---|---|
| VID1 | Vector ID for DOF1 = 0 for excitation input. See *DEFINE_VECTOR. |

Include this card after Card 6 if VAD1 = 12 on Card 6 (SUBCASE keyword option only).

| Card 6.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | N11 | N11TYP | | | | | | |
| Type | I | I | | | | | | |
| Default | none | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| N11 | Node / Node set / Segment set ID for the excitation input for the torque load (VAD1 = 12). This node or set combines with N1 to form a torque load. |
| N11TYP | Type of N11:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID<br>EQ.3: Parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW)<br>EQ.5: Parametric edge ID (see *IGA_EDGE_UVW)<br>EQ.6: Parametric edge set ID (see *SET_IGA_EDGE_UVW)<br>EQ.7: Physical face ID (see *IGA_FACE_XYZ)<br>EQ.8: Physical face set ID (see *SET_IGA_FACE_XYZ) |

Include NCASE sets of Cards 5 through 7 when the keyword option is SUBCASE.

| Card 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | N2 | N2TYP | DOF2 | VAD2 | VID2 | | | |
| Type | I | I | I | I | I | | | |
| Default | none | 0 | none | 2 | 0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| N2 | Node / Node set / Segment set ID for response output. |
| N2TYP | Type of N2:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID<br>EQ.3: Parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: Parametric point set ID (see *SET_IGA_POINT_UVW) |
| DOF2 | Applicable degrees of freedom for response output:<br>EQ.0: Direction given by vector VID2<br>EQ.1: $x$-translational degree of freedom<br>EQ.2: $y$-translational degree of freedom<br>EQ.3: $z$-translational degree of freedom<br>EQ.4: $x$-rotational degree of freedom<br>EQ.5: $y$-rotational degree of freedom<br>EQ.6: $z$-rotational degree of freedom<br>EQ.7: $x$, $y$, and $z$-translational degrees of freedom<br>EQ.8: $x$, $y$, and $z$-rotational degrees of freedom |
| VAD2 | Response output type:<br>EQ.0: Velocity<br>EQ.1: Acceleration<br>EQ.2: Displacement |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.3: Nodal force (see Remark 8) |
| VID2 | Vector ID for DOF2 = 0 for response direction. See *DEFINE_VECTOR. |

**Remarks:**

1. **Frequency response functions.** The FRF (frequency response functions) can be given as Displacement/Force (called Admittance, Compliance, or Receptance), Velocity/Force (called Mobility), Acceleration/Force (called Accelerance, Inertance), etc.

2. **Enforced motion.** The excitation input can be given as enforced motion (VAD1 = 5, 6, 7). Large mass method is used for this type of excitation input. The user needs to attach a large mass to the nodes where the enforced motion is applied by using the keyword *ELEMENT_MASS_*{OPTION}* and report the large mass per node (MPN) in the keyword *CONTROL_FREQUENCY_DOMAIN. For more details, please refer to *CONTROL_FREQUENCY_DOMAIN.

3. **Maximum frequency.** FNMAX decides how many natural vibration modes are adopted in FRF computation. LS-DYNA uses only modes with lower or equal frequency than FNMAX in FRF computation. If FNMAX is not given, the number of modes for the FRF computation is the same as the number of modes, NEIG, from the *CONTROL_IMPLICIT_EIGENVALUE keyword card unless MDMIN and MDMAX are prescribed (see Remark 5).

4. **Maximum/minimum mode.** MDMIN and MDMAX decide which mode(s) are adopted in FRF computation. This option helps calculate the contribution from a single mode (MDMIN = MDMAX) or several modes (MDMIN < MDMAX). If only MDMIN is given, LS-DYNA uses the single mode (MDMIN) to compute FRF. In a restart run based on an existing eigenmode database d3eigv (RESTRT = 1 or 3), MDMAX should be a positive integer equal to or less than the number of eigenmodes available in d3eigv.

5. **Damping.** Damping can be prescribed in several ways:

   a) To use a constant modal damping coefficient $\zeta$ for all the modes, define DAMPF only. LCDMP, LCTYP, DMPMAS, and DMPSTF are ignored.

   b) To use mode-dependent modal damping, define a load curve (*DEFINE_CURVE) and specify if the abscissa value represents the frequency or mode number by LCTYP. DMPMAS and DMPSTF are ignored.

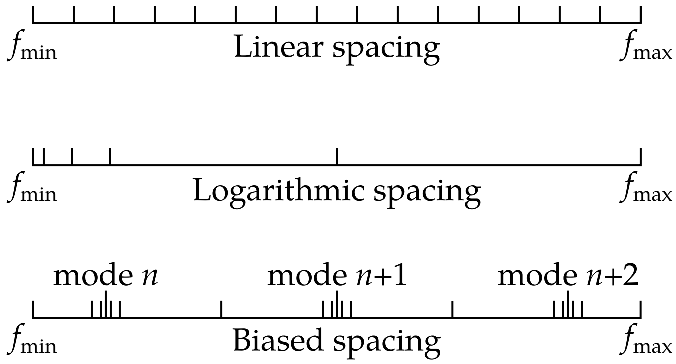


**Figure 23-5.** Spacing options of the frequency points.

c) To use Rayleigh damping, define DMPMAS ($\alpha$) and DMPSTF ($\beta$), keep DAMPF as 0.0, and keep LCDMP and LCTYP as 0. The damping matrix in Rayleigh damping is defined as $\mathbf{C} = \alpha\mathbf{M} + \beta\mathbf{K}$, where, **C**, **M** and **K** are the damping, mass and stiffness matrices respectively.

6. **Frequency points.** There are two methods to define the frequencies.

a) The first method is to define FMIN, FMAX, NFREQ, and FSPACE. FMIN and FMAX specify the frequency range of interest, and NFREQ specifies the number of frequencies at which results are required. FSPACE specifies the type of frequency spacing (linear, logarithmic, or biased) to be used.

These frequency points for which results are required can be spaced equally along the frequency axis (on a linear or logarithmic scale). Or they can be biased toward the eigenfrequencies (the frequency points are placed closer together at eigenfrequencies in the frequency range) to obtain a detailed definition of the response close to resonance frequencies. See Figure 23-5.

b) The second method uses a load curve (LCFREQ) to define the frequencies of interest.

7. **RESTRT field.** To save time in subsequent runs, the modal analysis stored in the d3eigv file during the first run can be reused by setting RESTRT = 1.

RESTRT = 2 or 3 is used when the user wants to add extra vibration modes to the FRF computation. After the initial FRF computation, the number of vibration modes may not be enough. For example, in the initial computation, the only vibration modes used may be up to 500 Hz. However, vibration modes at higher frequencies are needed, so just computing the extra modes (frequencies above 500 Hz) and adding the contribution from these extra modes to the previous FRF results is more efficient.

For RESTRT = 2, LS-DYNA runs a new modal analysis, reads in the previous FRF results (stored in the binary dump file dumpfrf), and adds the contribution from the new modes. For RESTRT = 3, LS-DYNA reads in d3eigv family files generated elsewhere, reads in dumpfrf, and adds the contribution from the new modes.

8. **Nodal force response output.** For nodal force response (VAD2 = 3), the same nodes (or node set) must be defined in *DATABASE_NODAL_FORCE_GROUP. In addition, the MSTRES field for the *CONTROL_IMPLICIT_EIGENVALUE keyword must be set to 1.

9. **SUBCASE option.** The SUBCASE option allows executing multiple FRF subcase computations in one run under one keyword input. Each subcase has its own excitation input (Cards 6 and 6.1) and response output (Card 7). They share the same damping setting and the same set of eigenmodes for modal superposition. The result files have the prefix subcase*_ before the original file name. For example, subcase2_frf_amplitude is the frf_amplitude result for subcase 2 (in the same order as the input deck).

## *FREQUENCY_DOMAIN_LOCAL_*OPTION1*_*{OPTION2}*

Available options for *OPTION1* include:

NODE_SET

PART

PART_SET

For *OPTION2* the available option is:

<BLANK>

EXCLUDE

Purpose: Define local nodes and parts to be included in frequency domain analysis (random vibration, response spectrum analysis and SSD). When the keyword OPTION2 EXCLUDE is used, the nodes and parts defined in this keyword are excluded from participating in the frequency domain analysis. Without this keyword, the frequency domain analysis is always performed on the whole model.

Include as many cards as necessary. This input ends at the next keyword ("*") card.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ID1 | ID2 | ID3 | ID4 | ID5 | ID6 | ID7 | ID8 |
| Type | I | I | I | I | I | I | I | I |

| VARIABLE | DESCRIPTION |
|---|---|
| ID*n* | Node set ID or Part ID or Part set ID *n*. |

### Remarks:

This keyword defines the nodes/parts to be included in frequency domain analysis (random vibration analysis, response spectrum analysis and SSD). The nodes/parts not defined here will be skipped in the analysis (in result databases, the response for those nodes/parts is marked as 0). With this keyword, significant CPU cost saving can be obtained if the user wants only response on a fraction of the nodes/parts of the model. With the option EXCLUDE, this keyword can be used to remove some nodes/parts from the analysis. Without using this keyword, the frequency domain analysis is always performed on the whole model.

# *FREQUENCY_DOMAIN_MODE_*OPTION1_{OPTION2}*

Available options for *OPTION1* include:

LIST

GENERATE

SET

LOAD_PROJECTION

MODAL_COEFFICIENT

For *OPTION2* the available option is:

<BLANK>

EXCLUDE

Purpose: Define vibration modes to be used in modal superposition, modal acceleration or modal combination procedures for mode-based frequency domain analysis (such as frequency response functions, steady state dynamics, random vibration analysis and response spectrum analysis). When the keyword OPTION2 EXCLUDE is used, the modes defined in this keyword are excluded from participating in the modal superposition, modal acceleration, or modal combination procedures.

## Card Summary:

**Card 1a.** This card is included if and only if OPTION1 is LIST. Include as many cards as necessary. This input ends at the next keyword ("*") card.

| MID1 | MID2 | MID3 | MID4 | MID5 | MID6 | MID7 | MID8 |
|---|---|---|---|---|---|---|---|

**Card 1b.** This card is included if and only if OPTION1 is GENERATE. Include as many cards as necessary. This input ends at the next keyword ("*") card.

| M1BEG | M1END | M2BEG | M2END | M3BEG | M3END | M4BEG | M4END |
|---|---|---|---|---|---|---|---|

**Card 1c.** This card is included if and only if OPTION1 is SET.

| SID | | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 1d.** This card is included if and only if OPTION1 is LOAD_PROJECTION.

| NMSORT | DSKIP | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 1e.** This card is included if and only if OPTION1 is MODAL_COEFFICIENT.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DSKIP | | | | | | | |

**Data Cards:**

**Mode ID Cards.** For LIST keyword option, list the mode IDs. Include as many cards as necessary. This input ends at the next keyword ("*") card.

| Card 1a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MID1 | MID2 | MID3 | MID4 | MID5 | MID6 | MID7 | MID8 |
| Type | I | I | I | I | I | I | I | I |

| VARIABLE | DESCRIPTION |
|---|---|
| MID*n* | Mode ID *n*. |

**Mode Block Cards.** For GENERATE keyword option specify ranges of modes. Include as many cards as necessary. This input ends at the next keyword ("*") card.

| Card 1b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | M1BEG | M1END | M2BEG | M2END | M3BEG | M3END | M4BEG | M4END |
| Type | I | I | I | I | I | I | I | I |

| VARIABLE | DESCRIPTION |
|---|---|
| M*n*BEG | First mode ID in block *n*. |
| M*n*END | Last mode ID in block *n*. All mode ID's between and including M*n*BEG and M*n*END are added to the list. |

**Mode Set Card.** For SET keyword option specify a mode set. Include only one card.

| Card 1c | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SID | | | | | | | |
| Type | I | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SID | Mode set identification (see *SET_MODE). |

**Load Projection Card.** For LOAD_PROJECTION keyword option specify the number of modes to be retained, which have the largest load projection ratios, or specify a threshold load projection ratio for mode truncation.

| Card 1d | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NMSORT | DSKIP | | | | | | |
| Type | I | F | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| NMSORT | Number of modes to be retained which have the largest load projection ratios. |
| DSKIP | The threshold load projection ratio. All modes with load projection ratio less than this value will be skipped. |

**Modal Coefficient Ratio Card.** For MODAL_COEFFICIENT keyword option, specify a threshold modal coefficient ratio (over the largest modal coefficient) for mode truncation.

| Card 1e | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DSKIP | | | | | | | |
| Type | F | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DSKIP | The threshold modal coefficient ratio. All modes with the ratio of its modal coefficient over the largest modal coefficient less than this value will be skipped. |

**Remarks:**

1. **Excluding Modes.** This keyword can be used to remove the modes that add a much smaller contribution to the total structural response than the other modes from the modal superposition, modal acceleration or modal combination procedures of the mode-based frequency domain analysis.

2. **Overriding Mode Lists.** The mode list defined by this keyword overrides the modes specified by MDMIN, MDMAX (or FNMIX, FNMAX) in the keywords *FREQUENCY_DOMAIN_FRF, *FREQUENCY_DOMAIN_SSD, etc.

## *FREQUENCY_DOMAIN_PATH_{OPTION}

Available options include:

<BLANK>

NOJOBID

PARTITION

Purpose: Specify the path and file name of binary databases, such as d3eigv, containing mode information for restarting frequency domain analyses such as FRF, SSD, Random vibration, and Response spectrum analysis.

The PARTITION option supports assigning different binary databases to different frequency ranges. Specifically, each frequency range can be associated with different eigenmodes and modal shape vectors provided by the binary database. This option provides a model for materials that have frequency-dependent properties.

**Partition Cards.** Card 1 for the PARTITION keyword option. Include one card for each frequency range. This input ends at the next keyword ("*") card. See Remark 3.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FBEG | FEND | FILENAME | | | | | |
| Type | F | F | C | | | | | |
| Default | none | none | none | | | | | |

**Filename Card.** Card 1 format used with the keyword option left blank.

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FILENAME | | | | | | | |
| Type | C | | | | | | | |
| Default | none | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| FBEG | Beginning frequency for using this database |

| | |
|---|---|
| FEND | Ending frequency for using this database |
| FILENAME | Path to the database which contains modal information. |

**Remarks:**

1. **Binary File Location.** If the binary database files are in the runtime directory, this card is not needed for the case *without* partitioning.

2. **NOJOBID Option.** When the option NOJOBID is active, LS-DYNA will not add a prefix to the FILENAME on card 1. Even if the user is running LS-DYNA with *CASE or has JOBID in the command line, LS-DYNA will not add a prefix when NOJOBID is active.

   To understand the intent of this feature recall that job ID numbers exist to ensure that filenames are unique so that output files are not overwritten for each calculation in some sequence. When the modal data is being read in as part of a restart calculation from some database already on disk, the default behavior is to replace FILENAME with FILENAME prefixed by the job ID. Consequently, without the NOJOBID option, reusing a single database across multiple modal analyses would involve either renaming or symbolically linking the existing file to the prefixed filename. The NOJOBID option circumvents this difficulty.

   This is useful when the user wants to run multiple load cases for a single frequency domain analysis (FRF, SSD, random vibration, response spectrum analysis), and would like to run each load case with the restart option, RESTRT = 1, in *FREQUENCY_DOMAIN_FRF, or *FREQUENCY_DOMAIN_RANDOM_VIBRATION, or *FREQUENCY_DOMAIN_RESPONSE_SPECTRUM, etc., or RESTMD = 1 in *FREQUENCY_DOMAIN_SSD. In this case, with the option NOJOBID, a single eigenvector database, such as d3eigv, can be used for all the load cases.

3. **Frequency Partition.** When the option PARTITION is active, the binary database designated by FILENAME is used for the frequency range starting from (and including) FBEG and ending at (not including) FEND.

# *FREQUENCY_DOMAIN_RANDOM_VIBRATION_*{OPTION}*

Available options include:

<BLANK>

FATIGUE

Purpose: Set random vibration control options. When the FATIGUE keyword option is used, compute fatigue life of structures or parts under random vibration (see Remark 2).

## Card Summary:

**Card 1.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MDMIN | MDMAX | FNMIN | FNMAX | RESTRT | | | |

**Card 2.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | DMPTYP | | |

**Card 3.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| VAFLAG | METHOD | UNIT | UMLT | VAPSD | VARMS | NAPSD | NCPSD |

***Card 3.1.*** This card is read for VAFLAG = 5, 6 and 7. This card is optional.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PREF | | | | | | | |

**Card 4.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LDTYP | IPANELU | IPANELV | TEMPER | | LDFLAG | ICOARSE | TCOARSE |

**Card 5.** Include NAPSD of this card.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SID | STYPE | DOF | LDPSD | LDVEL | LDFLW | LDSPN | CID |

**Card 6.** Include NCPSD of this card.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LOAD_I | LOAD_J | LCTYP2 | LDPSD1 | LDPSD2 | | | |

**Card 7.** This card is included if the FATIGUE keyword option is used.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| MFTG | NFTG | STRTYP | TEXPOS | STRSF | INFTG | SRANGE | |

**Card 7.1a.** Include NFTG cards that are any combination of this card and Card 7.1b. This card is included when LCID > 0.

| PID | LCID | PTYPE | LTYPE | | | | SNLIMT |
|---|---|---|---|---|---|---|---|

**Card 7.1b.** Include NFTG cards that are any combination of this card and Card 7.1a. This card is included when LCID < 0.

| PID | LCID | PTYPE | | A | B | STHRES | SNLIMT |
|---|---|---|---|---|---|---|---|

**Card 7.2.** Include INFTG of this card when INFTG > 0.

| FILENAME |
|---|

**Data Card Definitions:**

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MDMIN | MDMAX | FNMIN | FNMAX | RESTRT | | | |
| Type | I | I | F | F | I | | | |
| Default | 1 | optional | 0.0 | optional | 0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| MDMIN | First mode in modal superposition method (optional) |
| MDMAX | Last mode in modal superposition method (optional) |
| FNMIN | Minimum natural frequency in modal superposition method (optional) |
| FNMAX | Maximum natural frequency in modal superposition method (optional) |
| RESTRT | Restart option (see Remark 4):<br>EQ.0: A new modal analysis is performed.<br>EQ.1: Restart with d3eigv.<br>EQ.2: Sum up precomputed random vibration PSD and RMS results only. |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | DMPTYP | | |
| Type | F | I | I | F | F | I | | |
| Default | 0.0 | 0 | 0 | 0.0 | 0.0 | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPF | Modal damping coefficient, $\zeta$. |
| LCDAM | Load Curve ID defining mode dependent modal damping coefficient $\zeta$. |
| LCTYP | Type of load curve defining modal damping coefficient:<br>EQ.0: Abscissa value defines frequency.<br>EQ.1: Abscissa value defines mode number. |
| DMPMAS | Mass proportional damping constant $\alpha$, in Rayleigh damping. |
| DMPSTF | Stiffness proportional damping constant $\beta$, in Rayleigh damping. |
| DMPTYP | Type of damping:<br>EQ.0: Modal damping<br>EQ.1: Broadband damping |

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | VAFLAG | METHOD | UNIT | UMLT | VAPSD | VARMS | NAPSD | NCPSD |
| Type | I | I | I | F | I | I | I | I |
| Default | none | 0 | none | ↓ | none | none | 1 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| VAFLAG | Loading type:<br>EQ.0: No random vibration analysis<br>EQ.1: Base acceleration<br>EQ.2: Random pressure<br>EQ.3: Plane wave<br>EQ.4: Shock wave<br>EQ.5: Progressive wave<br>EQ.6: Reverberant wave<br>EQ.7: Turbulent boundary layer wave<br>EQ.8: Nodal force<br>EQ.9: Base velocity<br>EQ.10: Base displacement<br>EQ.11: Enforced acceleration by large mass method (see Remark 15)<br>EQ.12: Enforced velocity by large mass method (see Remark 15)<br>EQ.13: Enforced displacement by large mass method (see Remark 15) |
| METHOD | Method for modal response analysis (see Remark 6):<br>EQ.0: Method set automatically by LS-DYNA (recommended)<br>EQ.1: Modal superposition method<br>EQ.2: Modal acceleration method<br>EQ.3: Modal truncation augmentation method |
| UNIT | Flag for acceleration unit conversion (see Remark 7):<br>EQ.0: Use [length unit]/[time unit]$^2$ as unit of acceleration.<br>EQ.1: Use $g$ as unit for acceleration and SI units (Newton, kg, meter, second, etc.) elsewhere.<br>EQ.2: Use $g$ as unit for acceleration and engineering units (lbf, lbf × second$^2$/inch, inch, second, etc.) elsewhere.<br>EQ.3: Use $g$ as unit for acceleration and units (kN, kg, mm, ms, GPa, etc.) elsewhere.<br>EQ.4: Use $g$ as unit for acceleration and units (Newton, ton, |

| VARIABLE | DESCRIPTION |
|---|---|
| | mm, second, MPa, etc.) elsewhere.<br>EQ.-1: Use *g* as unit for acceleration and provide the multiplier for converting g to [length unit]/[time unit]$^2$. |
| UMLT | Multiplier for converting *g* to [length unit]/[time unit]$^2$ (used only for UNIT = -1). |
| VAPSD | Flag for PSD output:<br>EQ.0: Absolute PSD output is requested.<br>EQ.1: Relative PSD output is requested (used only for VAFLAG = 1). |
| VARMS | Flag for RMS output:<br>EQ.0: Absolute RMS output is requested.<br>EQ.1: Relative RMS output is requested (used only for VAFLAG = 1). |
| NAPSD | Number of auto PSD load definition. Card 5 is repeated NAPSD times; one for each auto PSD load definition. |
| NCPSD | Number of cross PSD load definition. Card 6 is repeated NCPSD times; one for each cross PSD load definition. |

This card is read when VAFLAG = 5, 6, or 7. It is optional.

| Card 3.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PREF | | | | | | | |
| Type | I | | | | | | | |
| Default | 2.e-5 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| PREF | Reference pressure used to convert acoustic pressure to SPL (dB). This reference pressure is only needed if VAFLAG = 5, 6, or 7. For VAFLAG = 5, 6, or 7, if this Card 3.1 is not provided, LS-DYNA will use a default value $2.0 \times 10^{-5}$ as the reference pressure. |

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LDTYP | IPANELU | IPANELV | TEMPER | | LDFLAG | ICOARSE | TCOARSE |
| Type | I | I | I | F | | I | I | F |
| Default | 0 | 0 | 0 | 0.0 | | 0 | 0 | 0.1 |

| VARIABLE | DESCRIPTION |
|---|---|
| LDTYP | Excitation load (LDPSD in Card 5) type:<br>EQ.0: PSD<br>EQ.1: SPL (for plane wave only)<br>EQ.2: Time history load |
| IPANELU | Number of strips in $U$-direction (used only for VAFLAG = 5, 6, 7). See Remark 3. |
| IPANELV | Number of strips in $V$-direction (used only for VAFLAG = 5, 6, 7). See Remark 3. |
| TEMPER | Temperature |
| LDFLAG | Type of loading curves:<br>EQ.0: Log-log interpolation (default)<br>EQ.1: Semi-log interpolation<br>EQ.2: Linear-linear interpolation |
| ICOARSE | Option for PSD curve coarsening:<br>EQ.0: No coarsening; use original data (default).<br>EQ.1: Coarsening by keeping only peaks and troughs<br>EQ.2: Coarsening by removing intermediate points whose slope change percentage is less than prescribed tolerance (TCOARSE) |
| TCOARSE | Tolerance for slope change percentage for removing intermediate points from PSD curve (default is 0.1) for ICOARSE = 2 |

**Auto PSD Cards.** Include NAPSD cards of this format, one per excitation.

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SID | STYPE | DOF | LDPSD | LDVEL | LDFLW | LDSPN | CID/VID |
| Type | I | I | I | I | I | I | I | I |
| Default | ↓ | none | none | none | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| SID | GE.0: Set ID for the panel exposed to acoustic environment, or the nodes subjected to nodal force excitation, or nodal acceleration excitation. For VAFLAG = 1, base acceleration, leave this as blank<br>LT.0: Used to define the cross-PSD. \|SID\| is the ID of the load cases. |
| STYPE | Flag specifying meaning of SID:<br>EQ.0: Node<br>EQ.1: Node set<br>EQ.2: Segment set<br>EQ.3: Part<br>EQ.4: Part set<br>LT.0: Used to define the cross-PSD. \|STYPE\| is the ID of the load cases. |
| DOF | Applicable degrees-of-freedom for nodal force excitation or base acceleration (DOF = 1, 2, and 3), or wave direction:<br>EQ.0: Translational movement in direction given by vector VID<br>EQ.1: $x$-translational degree-of-freedom<br>EQ.2: $y$-translational degree-of-freedom<br>EQ.3: $z$-translational degree-of-freedom |
| LDPSD | Load curve for PSD, SPL, or time history excitation |

| VARIABLE | DESCRIPTION |
|---|---|
| LDVEL | Load curve for phase velocity |
| LDFLW | Load curve for exponential decay for TBL in flow-wise direction |
| LDSPN | Load curve for exponential decay for TBL in span-wise direction |
| CID/VID | Coordinate system ID for defining wave direction, see *DEFINE_-COORDINATE_SYSTEM; or vector ID for defining load direction for nodal force or base excitation, see *DEFINE_VECTOR. |

**Cross PSD Cards.** Include NCPSD cards of this format, one per excitation.

| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LOAD_I | LOAD_J | LCTYP2 | LDPSD1 | LDPSD2 | | | |
| Type | I | I | I | I | I | | | |
| Default | none | none | 0 | none | none | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| LOAD_I | ID of load *i* for cross PSD |
| LOAD_J | ID of load *j* for cross PSD |
| LCTYP2 | Type of load curves (LDPSD1 and LDPSD2) for defining cross PSD:<br>EQ.0: LDPSD1 defines real part and LDPSD2 defines imaginary part.<br>EQ.1: LDPSD1 defines magnitude and LDPSD2 defines phase angle (in degrees).<br>EQ.2: LDPSD1 defines magnitude and LDPSD2 defines phase angle (in radians). |
| LDPSD1 | Load curve for real part or magnitude of cross PSD |
| LDPSD2 | Load curve for imaginary part or phase angle of cross PSD |

**Fatigue Card.** Additional card for FATIGUE keyword option.

| Card 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MFTG | NFTG | STRTYP | TEXPOS | STRSF | INFTG | SRANGE | |
| Type | I | I | I | F | F | I | F | |
| Default | 0 | 1 | 0 | 0.0 | 1.0 | 0 | 3.0 | |

| VARIABLE | DESCRIPTION |
|---|---|
| MFTG | Method for random fatigue analysis:<br>EQ.-1: Steinberg's three-band method using peak-crossing frequency to compute the number of stress cycles<br>EQ.0: No fatigue analysis (default)<br>EQ.1: Steinberg's three-band method using zero-crossing frequency (with positive slope) to compute the number of stress cycles<br>EQ.2: Dirlik method<br>EQ.3: Narrow band method<br>EQ.4: Wirsching method<br>EQ.5: Chaudhury and Dover method<br>EQ.6: Tunna method<br>EQ.7: Hancock method<br>EQ.8: Lalanne method. |
| NFTG | Field specifying the number of S - N curves to be defined:<br>GE.0: Number of S - N curves defined by Cards 7.1a and 7.1b which are included in the required combination to get to "NFTG" number of cards, one for each S - N fatigue curve definition. The default value is 1.<br>EQ.-999: S - N curves are defined through *MAT_ADD_FATIGUE. |
| STRTYP | Stress type of S - N curve in fatigue analysis:<br>EQ.0: von-Mises stress |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.1: Maximum principal stress (not implemented)<br>EQ.2: Maximum shear stress (not implemented)<br>EQ.-n: The n$^{th}$ stress component |
| TEXPOS | Exposure time |
| STRSF | Stress scale factor to accommodate different ordinates in S - N curve (not used if NFTG = -999):<br>EQ.1: Used if the ordinate in S - N curve is stress range (default)<br>EQ.2: Used if the ordinate in S - N curve is stress amplitude |
| INFTG | Flag for including initial damage ratio (see Remark 5):<br>EQ.0: No initial damage ratio,<br>GT.0: Read existing d3ftg files to obtain the initial damage ratio. When INFTG > 1, the initial damage ratio comes from multiple loading cases (correspondingly, multiple binary databases, defined by Card 7.2). The value of INFTG should be ≤ 10. |
| SRANGE | Stress range for fatigue analysis. The default is 3.0, which means 3.0 times the RMS stress) |

**S-N Curve Cards.** NFTG additional cards for FATIGUE keyword option of a combination of Cards 7.1a and 7.1b. Each Card 7.1a or Card 7.1b defines one zone for fatigue analysis and the corresponding S - N fatigue curve for that zone. Card 7.1a is included for LCID > 0.

| Card 7.1a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | LCID | PTYPE | LTYPE | | | | SNLIMT |
| Type | I | I | I | I | | | | I |
| Default | none | none | 0 | 0 | | | | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| PID | Part ID, part set ID, or element (solid, shell, beam, thick shell) set ID |

| VARIABLE | DESCRIPTION |
|---|---|
| LCID | S - N fatigue curve ID for the current part or part set:<br>GT.0: S - N fatigue curve ID<br>EQ.-1: S - N fatigue curve uses equation $NS^b = a$<br>EQ.-2: S - N fatigue curve uses equation $\log(S) = a - b\log(N)$<br>EQ.-3: S - N fatigue curve uses equation $S = a\,N^b$<br>EQ.-4: S - N fatigue curve uses equation $S = a - b\log(N)$ |
| PTYPE | Type of PID.<br>EQ.0: Part (default)<br>EQ.1: Part set<br>EQ.2: SET_SOLID<br>EQ.3: SET_BEAM<br>EQ.4: SET_SHELL<br>EQ.5: SET_TSHELL |
| LTYPE | Type of LCID.<br>EQ.0: Semi-log interpolation (default)<br>EQ.1: Log-log interpolation<br>EQ.2: Linear-linear interpolation |
| SNLIMT | Flag setting algorithm used when stress is lower than the lowest stress on S - N curve (if LCID > 0):<br>EQ.0: Use the life at the last point on S - N curve<br>EQ.1: Extrapolation from the last two points on S - N curve<br>EQ.2: Infinity |

**S-N Curve Cards.** NFTG additional cards for FATIGUE keyword option of a combination of Cards 7.1a and 7.1b. Each Card 7.1a or Card 7.1b defines one zone for fatigue analysis and the corresponding S - N fatigue curve for that zone. Card 7.1b is included for LCID < 0.

| Card 7.1b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | LCID | PTYPE | | A | B | STHRES | SNLIMT |
| Type | I | I | I | | F | F | F | I |
| Default | none | none | 0 | | none | none | 0. | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| PID | Part ID, part set ID, or element (solid, shell, beam, thick shell) set ID |
| LCID | S - N fatigue curve ID for the current part or part set:<br>GT.0: S - N fatigue curve ID<br>EQ.-1: S - N fatigue curve uses equation $NS^b = a$<br>EQ.-2: S - N fatigue curve uses equation $\log(S) = a - b\log(N)$<br>EQ.-3: S - N fatigue curve uses equation $S = a\,N^b$<br>EQ.-4: S - N fatigue curve uses equation $S = a - b\log(N)$ |
| PTYPE | Type of PID.<br>EQ.0: Part (default)<br>EQ.1: Part set<br>EQ.2: SET_SOLID<br>EQ.3: SET_BEAM<br>EQ.4: SET_SHELL<br>EQ.5: SET_TSHELL |
| A | Material parameter $a$ in S - N fatigue equation. |
| B | Material parameter $b$ in S - N fatigue equation. |
| STHRES | Fatigue threshold |

| VARIABLE | DESCRIPTION |
|---|---|
| SNLIMT | Flag setting algorithm used when stress is lower than STHRES:<br>EQ.0: Use the life at STHRES<br>EQ.1: Ignored<br>EQ.2: Infinity |

**Initial Damage Card.** INFTG additional cards for FATIGUE keyword option when INFTG > 0.

| Card 7.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FILENAME | | | | | | | |
| Type | C | | | | | | | |
| Default | d3ftg | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| FILENAME | Path and name of existing binary database for fatigue information. |

**Remarks:**

1. **Historical Background.** This command evaluates the structural random vibration response due to aero acoustic loads, base excitation, or nodal force. This capability originated in Boeing's in-house code N-FEARA, which is a NIKE3D-based Finite Element tool for performing structural analysis with vibro-acoustic loads. The main developer of N-FEARA is Mostafa Rassaian from the Boeing Company.

2. **Fatigue.** MSTRES must be set to 1 in the keyword *CONTROL_IMPLICIT_EIGENVALUE for the FATIGUE keyword option because the fatigue analysis is depending on stresses.

3. **IPANELU and IPANELV.** The number of strips the in $U$ and $V$-directions are used to group the elements and thereby reduce the number integration domains reducing computational expense. This option is only available for VAFLAG = 5, 6, and 7.

4. **Restarting.** Restart option RESTRT = 1 is used when mode analysis has been done previously. In this case, LS-DYNA skips modal analysis and reads in the

d3eigv files from the prior execution. For RESTRM = 1, always use MDMIN = 1 and set MDMAX to the number of modes in the previous run (this can be found in the ASCII file eigout, or it can be extracted from the d3eigv files using LS-PrePost). Restart option RESTRT = 2 is used to sum up PSD and RMS results from multiple runs to provide total PSD and RMS response of the same model, subjected to multiple loading resources. The file name and path of the PSD and RMS binary databases (by default, d3psd and d3rms) to be summed, are defined by the keywords *DATABASE_FREQUENCY_BINARY_D3PSD_SUMMATION, and *DATABASE_FREQUENCY_BINARY_D3RMS_SUMMATION. The multiple loading resources can be of different loading type (defined by VAFLAG), and they are applied to the model simultaneously.

5. **Accumulated Fatigue.** The fatigue damage ratio can be accumulated over multiple load cases by setting INFTG = 1. This is useful when a structure is subjected to multiple independent random vibrations. LS-DYNA calculates the total damage ratio by adding the damage ratio from the current calculation to the damage ratio of the previous calculation which are stored in the previous calculation's fatigue database (d3ftg by default). The previous d3ftg file will be overwritten by the new one if it is in the same directory.

6. **Automatic Method Selection.** If METHOD = 0, LS-DYNA uses modal superposition method for cases (VAFLAG) 4, 5, 6, 7. For cases 1, 2, 3 and 8, LS-DYNA uses modal superposition method when preload condition is present and uses modal acceleration method when preload condition is not present.

7. **Units.** In a set of consistent units, the unit for acceleration is defined as

$$1 \ \ (\text{acceleration unit}) = \frac{1(\text{length unit})}{[1(\text{time unit})]^2}$$

Some users in industry prefer to use g (acceleration due to gravity) as the unit for acceleration. For example,

$$1\text{g} = 9.81\frac{\text{m}}{\text{s}^2} = 386.089\frac{\text{inch}}{\text{s}^2}$$

If the input and output use g as the unit for acceleration, select UNIT = 1, 2, or 3.

If UNIT = -1, a multiplier (UMLT) for converting g to [length unit]/[time unit]$^2$ is needed and it is defined by

$$1\text{g} = \text{UMLT} \times \frac{[\text{length unit}]}{[\text{time unit}]^2}$$

For more information about the consistent units, see GS.21 (GETTING STARTED).

8. **Restrictions on Load Curves.** The load curves LDPSD, LDVEL, LDFLW, and LDSPN must all be defined using the same number of points. The number of

points in the load curve LDDAMP can be different from those for LDPSD, LDVEL, LDFLW, and LDSPN.

9. **Wave Direction.** Wave direction is determined by DOF and CID/VID. CID/VID represents a local *U*-*V*-*W* coordinate system for defining acoustic wave direction; only partially correlated waves (VAFLAG=5, 6, 7) need this local coordinate system. For nodal force, base excitation, plane wave or random pressure, CID represents a vector ID defining the load direction (DOF = ±4).

10. **Stress / Strain Computation.** To get stress results (PSD and RMS) from random vibration analysis, the MSTRES field of the *CONTROL_IMPLICIT_EIGENVALUE keyword should be set to 1. To get strain results (PSD and RMS) the STRFLG field of *DATABASE_EXTENT_BINARY should be set to 1. To get stress component results for beam elements (which are not based on resultant formulation), the BEAMIP field of *DATABASE_EXTENT_BINARY should be set greater than 0.

11. **Binary Plot Databases.** PSD and RMS results are given for all nodes and elements. PSD results are written in binary to a file named d3psd. Similarly, RMS results are written in binary to a file named d3rms. See the keyword *DATABASE_FREQUENCY_BINARY_*{OPTION}* for more details.

12. **ASCII Output for Displacement.** Displacement, velocity, and acceleration PSD results are output into ASCII file nodout_psd. The set nodes for which data is written to nodout_psd is specified with the *DATABASE_HISTORY_NODE keyword.

13. **ASCII Output for Stress.** Stress PSD results are output into ASCII file elout_psd. The set of solid, beam, shell, and thick shell elements to be written to the elout_psd file are specified with the following keywords:

    *DATABASE_HISTORY_SOLID

    *DATABASE_HISTORY_BEAM

    *DATABASE_HISTORY_SHELL

    *DATABASE_HISTORY_TSHELL

14. **Cross PSD.** The cross PSD can be defined as complex variables to consider phase difference. In that case, two curves are needed to define the cross PSD (LCPSD1 and LCPSD2). Two load IDs are needed to define the cross PSD (LOAD_I and LOAD_J). They are simply the ordering numbers by which the auto PSDs are defined. For example, the first Card 5 defines load 1 and the second Card 5 defines the load 2. No cross PSD is required if two loads are uncorrelated. Cross PSD for any pair of two correlated loads is defined only once –

from lower load ID to higher load ID (e.g. 1->2, 1->3, 2->3, …). The cross PSD from higher load ID to lower load ID (e.g. 2->1, 3->1, 3->2, …) is added by LS-DYNA automatically by using the relationship

$$G_{ji} = \overline{G_{ij}}$$

where $G_{ij}$ is the cross PSD from load $i$ to load $j$, and $\overline{\phantom{x}}$ represents the complex conjugate.

15. **Large Mass Method.** For the cases with enforced motion excitation, such as nodal velocity, acceleration, or displacement, the large mass method can be used to compute the random vibration response. The excitation input can be given as enforced motion curves (VAFLAG = 11, 12, 13). To use the large mass method, a large mass must be attached to the nodes where the enforced motion is applied by using the keyword *ELEMENT_MASS_*{OPTION}*; MPN must also be set in the keyword *CONTROL_FREQUENCY_DOMAIN. For more details, please refer to *CONTROL_FREQUENCY_DOMAIN.

16. **Cross Correlation.** Cross correlation can be defined only for same type of excitations (e.g. nodal force, random pressure). Correlation between different types of excitations is not allowed.

17. **Output for Fatigue Data.** When the FATIGUE option is used, a binary plot file, d3ftg, is written. Five results are included in d3ftg:

    Result 1. Cumulative damage ratio

    Result 2. Expected fatigue life

    Result 3. Zero-crossing frequency

    Result 4. Peak-crossing frequency

    Result 5. Irregularity factor

    These results are given as element variables. Irregularity factor is a real number from 0 to 1. A sine wave has an irregularity factor of 1, while white noise has an irregularity factor of 0. The lower the irregularity factor, the closer the process is to the broad band case.

18. **Stress Threshold for Fatigue.** In some materials, the S – N curve flattens out eventually, so that below a certain threshold stress STHRES failure does not occur no matter how long the loads are cycled. SNLIMT can be set to 2 in this case. For other materials, such as aluminum, no threshold stress exists and SNLIMT should be set to 0 or 1 for added level of safety.

19. **Restriction on Fatigue Cards.** When the FATIGUE option is used, all fatigue cards (Card 7) *must* be of the same PTYPE (PART or SET of ELEMENTS).

20. **Format for S - N Curves.** S - N curves can be defined by *DEFINE_CURVE or by using a predefined equation by setting LCID < 0. When specified with curves using *DEFINE_CURVE, the abscissa values (first column) represent N (number of cycles to failure) and the ordinate values represent S (stress). The predefined equations are listed as follows:

    a) *LCID = -1.*

    $$NS^b = a$$

    b) *LCID = -2.*

    $$\log(S) = a - b\log(N)$$

    c) *LCID = -3.*

    $$S = a\,N^b$$

    d) *LCID = -4.*

    $$S = a - b\log(N)$$

    Here $N$ is the number of cycles for fatigue failure and $S$ is the stress amplitude. Please note that the first three equations can be converted to each other with some minor manipulations on the constants $a$ and $b$.

**References:**

Mostafa Rassaian, Jung-Chuan Lee, N-FEARA – NIKE3D-based FE tool for structural analysis of vibro-acoustic loads, Boeing report, 9350N-GKY-02-036, December 5, 2003.

## *FREQUENCY_DOMAIN_RESPONSE_SPECTRUM_*{OPTION1}*_*{OPTION2}*

Available options for *OPTION1* include:

<BLANK>

DDAM

Available options for *OPTION2* include:

<BLANK>

MISSING_MASS_CORRECTION (see Remark 13)

Purpose: Obtain the peak response of a structure by performing a response spectrum computation. The structure is subjected to an input response spectrum load, such as the acceleration spectrum load in earthquake engineering. The maximum response is, then, evaluated using the modal superposition method. With the DDAM option, LS-DYNA performs a Dynamic Design Analysis Method (DDAM) shock spectrum analysis. DDAM is a U.S. Navy methodology for qualifying shipboard equipment and supporting structures subject to dynamic loading caused by underwater explosions (UNDEX).

### Card Summary:

**Card 1.** This card is required.

| MDMIN | MDMAX | FNMIN | FNMAX | RESTRT | MCOMB | RELATV | MPRS |
|---|---|---|---|---|---|---|---|

**Card 2.1.** Include this card if MCOMB = 99 in Card 1.

| MCOMB1 | MCOMB2 | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 2.2.** Include this card if MCOMB = 99 in Card 1.

| W1 | W2 | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 3.** Include this card if MPRS = 2 in Card 1.

| R40 | | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 4.** Include this card if *OPTION2* is MISSING_MASS_CORRECTION.

| ZPA | FILENAME |
|---|---|

**Card 5.** This card is required.

| DAMPF | LCDAMP | LDTYP | DMPMAS | DMPSTF | | | |
|---|---|---|---|---|---|---|---|

**Card 6a.** Include this card if *OPTION1* is unset (<BLANK>). This card can be repeated if 2 or more input spectra exist (multiple-point response spectrum).

| LCTYP | DOF | LC/TBID | SF | VID | LNID | LNTYP | INFLAG |
|---|---|---|---|---|---|---|---|

**Card** 6b. Include this card if using the DDAM keyword option.

| STD | UNIT | AMIN | VID | XC | YC | ZC | EFFMAS |
|---|---|---|---|---|---|---|---|

**Card 7a.** Include this card if using the DDAM keyword option when STD > 0 in Card 6b.

| SHPTYP | MOUNT | MOVEMT | MATTYP | | | | |
|---|---|---|---|---|---|---|---|

**Card 7b.1.** Include this card if using the DDAM keyword option when STD = -1 in Card 6b.

| AF | AA | AB | AC | AD | | | |
|---|---|---|---|---|---|---|---|

**Card 7b.2.** Include this card if using the DDAM keyword option when STD = -1 in Card 6b.

| VF | VA | VB | VC | | | | |
|---|---|---|---|---|---|---|---|

**Card 8.** Include this card if using the DDAM keyword option with MCOMB = -14.

| SID | | | | | | | |
|---|---|---|---|---|---|---|---|

**Data Card Definitions:**

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MDMIN | MDMAX | FNMIN | FNMAX | RESTRT | MCOMB | RELATV | MPRS |
| Type | I | I | F | F | I | I | I | I |
| Default | 1 | optional | 0.0 | optional | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| MDMIN | First mode in modal superposition method (optional) |
| MDMAX | Last mode in modal superposition method (optional) |

| VARIABLE | DESCRIPTION |
|---|---|
| FNMIN | Minimum natural frequency in modal superposition method (optional) |
| FNMAX | Maximum natural frequency in modal superposition method (optional) |
| RESTRT | Restart option:<br>EQ.0: A new run including modal analysis,<br>EQ.1: Restart with d3eigv family files created elsewhere. |
| MCOMB | Method for combination of modes:<br>EQ.-14: NRL-SUM method with CSM (Closely Spaced Modes) treatment, where the CSM pairs are defined by SID (Mode set ID, see *SET_MODE) in Card 5<br>EQ.-4: NRL-SUM method with CSM (Closely Spaced Modes) treatment. The CSM pairs are automatically identified.<br>EQ.0: SRSS method<br>EQ.1: NRC Grouping method<br>EQ.2: Complete Quadratic Combination method (CQC)<br>EQ.3: Double Sum method based on Rosenblueth-Elorduy coefficient<br>EQ.4: NRL-SUM method<br>EQ.5: Double Sum method based on Gupta-Cordero coefficient<br>EQ.6: Double Sum method based on modified Gupta-Cordero coefficient<br>EQ.7: Rosenblueth method<br>EQ.8: Absolute value method (ABS)<br>EQ.99: Combining results provided by two mode combination methods defined in Card 2.1 with corresponding weights defined in Card 2.2 |
| RELATV | Type of nodal displacement, velocity and acceleration results:<br>EQ.0: Relative values (with respect to the ground)<br>EQ.1: Absolute values |

| VARIABLE | DESCRIPTION |
|---|---|
| MPRS | Multi-point or multidirectional response combination method:<br>EQ.0: SRSS<br>EQ.1: 100-40-40 rule (Newmark method) (see Remark 7)<br>EQ.2: 100-40-40 rule (Newmark method) with coefficient 0.4 replaced by R40 in Card 3. |

Additional card included when MCOMB = 99 on Card 1.

| Card 2.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MCOMB1 | MCOMB2 | | | | | | |
| Type | I | I | | | | | | |
| Default | 0 | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| MCOMB*i* | *i*th mode combination method for which results will be combined to the other combination method. It can have any value from the MCOMB description other than 99. |

Additional card included when MCOMB = 99 on Card 1.

| Card 2.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | W1 | W2 | | | | | | |
| Type | F | F | | | | | | |
| Default | 0.5 | 0.5 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| W*i* | Weight for the results given by the MCOMB*i* combination |

Included when MPRS = 2 on Card 1.

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | R40 | | | | | | | |
| Type | F | | | | | | | |
| Default | 0.4 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| R40 | Coefficient to replace 0.4 in 100-40-40 rule (see Remark 7) |

Included when OPTION2 = MISSING_MASS_CORRECTION.

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ZPA | FILENAME | | | | | | |
| Type | F | C | | | | | | |
| Default | none | none | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| ZPA | Zero period acceleration |
| FILENAME | Path and name of a file that contains the static response due to a unit gravity loading |

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPF | LCDAMP | LDTYP | DMPMAS | DMPSTF | | | |
| Type | F | I | I | F | F | | | |
| Default | none | 0 | 0 | 0.0 | 0.0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPF | Modal damping ratio, $\zeta$. Ignore if LCDAMP is defined. |
| LCDAMP | Load Curve ID for defining frequency-dependent modal damping ratio $\zeta$ |
| LDTYP | Type of load curve for LCDAMP:<br>EQ.0: Abscissa value defines frequency,<br>EQ.1: Abscissa value defines mode number. |
| DMPMAS | Mass proportional damping constant $\alpha$ in Rayleigh damping |
| DMPSTF | Stiffness proportional damping constant $\beta$ in Rayleigh damping |

**Standard Spectrum Analysis Card.** Include if *OPTION1* is unset. This card can be repeated if 2 or more input spectra exist (multiple-point response spectrum).

| Card 6a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LCTYP | DOF | LC/TBID | SF | VID | LNID | LNTYP | INFLAG |
| Type | I | I | I | F | I | I | I | I |
| Default | none | none | 0 | 1.0 | 0 | none | none | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| LCTYP | Load curve type for defining the input spectrum:<br>EQ.0: Base velocity (as a function of natural frequency),<br>EQ.1: Base acceleration (as a function of natural frequency),<br>EQ.2: Base displacement (as a function of natural frequency),<br>EQ.3: Nodal force (as a function of natural frequency),<br>EQ.4: Pressure (as a function of natural frequency),<br>EQ.5: Base velocity (as a function of natural period),<br>EQ.6: Base acceleration (as a function of natural period),<br>EQ.7: Base displacement (as a function of natural period),<br>EQ.8: Nodal force (as a function of natural period),<br>EQ.9: Pressure (as a function of natural period), |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.10: Base velocity time history,<br>EQ.11: Base acceleration time history,<br>EQ.12: Base displacement time history. |
| DOF | Applicable degrees-of-freedom for excitation input:<br>EQ.1: $x$-translational degree-of-freedom,<br>EQ.2: $y$-translational degree-of-freedom,<br>EQ.3: $z$-translational degree-of-freedom,<br>EQ.4: Translational movement in direction given by VID. |
| LC/TBID | Load curve or table ID (see *DEFINE_TABLE) defining the response spectrum for frequencies. If the table definition is used, a family of curves are defined for discrete critical damping ratios. |
| SF | Scale factor for the input load spectrum |
| VID | Vector ID for DOF values of 4 |
| LNID | Node ID, node set ID, or segment set ID where the excitation is applied. If the input load is given as a base excitation spectrum, LNID = 0. |
| LNTYP | Set type for LNID:<br>EQ.1: Node, see *NODE,<br>EQ.2: Node set, see *SET_NODE,<br>EQ.3: Segment set, see *SET_SEGMENT,<br>EQ.4: Part, see *PART,<br>EQ.5: Part set, see *SET_PART. |
| INFLAG | Frequency interpolation option:<br>EQ.0: Logarithmic interpolation,<br>EQ.1: Semi-logarithmic interpolation,<br>EQ.2: Linear interpolation. |

**DDAM Spectrum Analysis Card.** Include this card for the DDAM keyword option.

| Card 6b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | STD | UNIT | AMIN | VID | XC | YC | ZC | EFFMAS |
| Type | I | I | F | I | F | F | F | F |
| Default | 1 | 1 | 6 | 0 | none | none | none | 80 |

| VARIABLE | DESCRIPTION |
|---|---|
| STD | Design spectrum standard for shock load:<br>EQ.1: NRL-1396,<br>EQ.-1: Spectrum constants defined through Cards 4b.1 and 4b.2. |
| UNIT | Unit system:<br>EQ.1: MKS (kg, m, s, N, Pa)<br>EQ.2: GPA (kg, mm, ms, kN, GPa)<br>EQ.3: MPA (ton, mm, s, N, MPa)<br>EQ.4: BIN (lbf-$s^2$/in, in, s, lbf, psi)<br>EQ.5 miu_MKS (gm, mm, ms, N, N/mm2)<br>EQ.6: CGS (gm, cm, s, dyne, dyne/cm2) |
| AMIN | Minimum acceleration (in g - gravity acceleration) |
| VID | Direction of shock load<br>EQ.1: $x$-direction<br>EQ.2: $y$-direction<br>EQ.3: $z$-direction<br>LT.0: Direction is given by vector \|VID\| |
| XC | $X$-directional cosine of shock load (if VID is undefined) |
| YC | $Y$-directional cosine of shock load (if VID is undefined) |
| ZC | $Z$-directional cosine of shock load (if VID is undefined) |
| EFFMAS | Minimum percentage requirement of total modal mass |

**NRL-1396 Design Spectrum Standard Card.** Include when STD > 0 for the DDAM option.

| Card 7a | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SHPTYP | MOUNT | MOVEMT | MATTYP | | | | |
| Type | I | I | I | I | | | | |
| Default | 1 | 1 | 1 | 1 | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SHPTYP | Ship type:<br>EQ.1: Submarine<br>EQ.2: Surface ship |
| MOUNT | Mount type:<br>EQ.1: Hull Mounted System<br>EQ.2: Deck Mounted System<br>EQ.3: Shell Plating Mounted System |
| MOVEMT | Movement type:<br>EQ.1: Vertical<br>EQ.2: Athwartship<br>EQ.3: Fore and Aft |
| MATTYP | Material type:<br>EQ.1: Elastic<br>EQ.2: Elasto-plastic |

**Acceleration Spectrum Coefficients Card.** Include this card for the DDAM keyword option if STD = -1.

| Card 7b.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | AF | AA | AB | AC | AD | | | |
| Type | F | F | F | F | F | | | |
| Default | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| AF, AA-AD | Coefficients to define the acceleration spectrum (see Remark 11) |

**Velocity Spectrum Coefficients Card.** Include this card for the DDAM keyword option if STD = -1.

| Card 7b.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | VF | VA | VB | VC | | | | |
| Type | F | F | F | F | | | | |
| Default | 0.0 | 0.0 | 0.0 | 0.0 | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| VF, VA-VC | Coefficients to define the velocity spectrum (see Remark 11) |

**Mode Set Card.** Include this card for the DDAM option with MCOMB = -14.

| Card 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SID | | | | | | | |
| Type | I | | | | | | | |
| Default | none | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SID | Mode set ID (see *SET_MODE) |

**Remarks:**

1. **Modal analysis.** Modal analysis must be performed preceding the response spectrum analysis. Thus, the keywords *CONTROL_IMPLICIT_GENERAL and *CONTROL_IMPLICIT_EIGENVALUE are expected in the input file.

2. **Input spectrum.** MDMIN, MDMAX, FNMIN, and FNMAX should be set appropriately to cover all the natural modes inside the input spectrum.

3. **Stress results.** To include stress results, modal stress computation has to be requested in *CONTROL_IMPLICIT_EIGENVALUE (set MSTRES = 1).

4. **Base excitation output.** For base excitation cases, relative values or absolute values for displacement, velocity, and acceleration results can be output.

5. **Restarts.** RESTRT = 1 enables a fast restart run based on d3eigv family files generated in the last run or elsewhere. LS-DYNA reads d3eigv family files to get the natural vibration frequencies and mode shapes. If the d3eigv family files are located in a directory other than the working directory, the directory must be specified in *FREQUENCY_DOMAIN_PATH.

6. **Double Sum method and earthquake duration.** For the Double Sum method (MCOMB = 3), earthquake duration time is given by ENDTIM in the keyword *CONTROL_TERMINATION.

7. **100-40-40 rule.** The 100-40-40 gives a way of evaluating the maximum response for multi-directional / multi-point loading. As described by Nie et al, the 100-40-40 rule (ASCE 4-98) determines the maximum response, $R$, of a three-dimensional seismic input by taking all the possible permutations of the maxima directional responses:

$$R = \pm\left[R_\mathrm{x}\pm 0.4R_\mathrm{y}\pm 0.4R_\mathrm{z}\right],\text{or } \pm\left[R_\mathrm{y}\pm 0.4R_\mathrm{z}\pm 0.4R_\mathrm{x}\right],\text{or } \pm\left[R_\mathrm{z}\pm 0.4R_\mathrm{x}\pm 0.4R_\mathrm{y}\right]$$

   $R_x$, $R_y$, and $R_z$ are found by looking at the response from each of the loadings that make up the multi-directional / multi-point loading. For instance, $R_x$ may be the response due to the acceleration in the $x$-direction of a node. This rule assumes that when one direction of loading occurs, the responses in the other directions are 40% of their maxima. The field R40 allows the user to adjust this 40% value.

8. **Frequency interpolation.** Three interpolation options are available for frequency interpolation when reading response spectrum values.

a) When INFLAG = 0 (default), logarithmic interpolation is used, that is,

$$\frac{\log y - \log y_1}{\log x - \log x_1} = \frac{\log y_2 - \log y_1}{\log x_2 - \log x_1} \ .$$

b) When INFLAG = 1, semi-logarithmic interpolation is used, that is,

$$\frac{\log y - \log y_1}{x - x_1} = \frac{\log y_2 - \log y_1}{x_2 - x_1} \ .$$

c) When INFLAG = 2, linear interpolation is used, that is,

$$\frac{y - y_1}{x - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \ .$$

9. **Interpolation and damping ratios.** Linear interpolation is used for interpolation with respect to damping ratios.

10. **Base Velocity, acceleration, and displacement time history.** If the load curve is defined as base velocity, base acceleration, or base displacement time history (LCTYP = 10, 11, or 12), an ASCII xyplot database spectrum_curve_printID is generated. It shows the intermediate base acceleration spectrum converted from the time history data. ID is the ordering of the input spectra (defined in Card 3a). For single point response spectrum, ID is 1.

11. **User-defined velocity and acceleration spectra for DDAM.** The user-defined acceleration input spectrum is defined as:

$$A = \begin{cases} A_f \times A_a \dfrac{(A_b + W) \times (A_c + W)}{(A_d + W)^2} & \text{if } A_d \neq 0 \\ A_f \times A_a \dfrac{(A_b + W)}{A_c + W} & \text{if } A_d = 0 \end{cases}$$

where $W$ is the modal weight in thousands of pounds (Kips).

The user-defined velocity input spectrum is defined as

$$V = V_f \times V_a \frac{(V_b + W)}{(V_c + W)} \ .$$

12. **NODFOR_SPCM.** The file nodfor_spcm contains nodal force and group force output for response spectrum analysis. To output this file, include *DATABASE_NODAL_FORCE_GROUP in the input deck.

13. **MISSING_MASS_CORRECTION.** The standard response spectrum method may miss some mass due to the truncation of eigenmodes in modal combination. The MISSING_MASS_CORRECTION option permits inclusion of the missing mass effect in response spectrum analysis. ZPA enables computing the inertia force due to ground acceleration, using the static response from a unit loading specified in FILENAME on Card 4. After that, the difference between the total inertia force and the sum of the modal inertia forces gives the missing inertia

force, and the static response due to the missing inertia force gives the missing mass response. Finally, the following equation gives the total response including the missing mass effect as:

$$R = \sqrt{\left(\sum_{i=1}^{N} \sum_{j=1}^{N} \varepsilon_{ij} R_i R_j\right) + (R_M)^2}$$

where $R_i$ and $R_j$ are the modal responses at modes $i$ and $j$, respectively, and $R_M$ is the missing mass response.

## *FREQUENCY_DOMAIN_SEA_CONNECTION

Purpose: Define connection of subsystems in a SEA model.

### Card Summary:

**Card 1.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CONID | CTYPE | NSUB | IBEAM | | | | |

**Card 2.** This card is required.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SUB1 | SUB2 | SUB3 | SUB4 | SUB4 | SUB6 | SUB7 | SUB8 |

**Card 3a.1.** This card is required for CTYPE = 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ANGLE1 | ANGLE2 | ANGLE3 | ANGLE4 | ANGLE5 | ANGLE6 | ANGLE7 | ANGLE8 |

**Card 3a.2.** This card is required for CTYPE = 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LENGTH | | | | | | | |

**Card 3b.** This card is required for CTYPE = 2.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| ABSORB | THICK | | | | | | |

### Data Card Definitions:

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | CONID | CTYPE | NSUB | IBEAM | | | | |
| Type | I | I | F | F | | | | |
| Default | none | 1 | none | 0 | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| CONID | Connection ID |
| CTYPE | Type of connection:<br>EQ.1: Plate-plate |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.2: Plate-cavity<br>EQ.3: Plate-cavity-cavity<br>EQ.4: Plate-beam |
| NSUB | Number of subsystems in this connection |
| IBEAM | Flag for plate connected to plate:<br>EQ.0: Plate-plate connection<br>EQ.1: Plate-plate-beam connection |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SUB1 | SUB2 | SUB3 | SUB4 | SUB5 | SUB6 | SUB7 | SUB8 |
| Type | I | I | I | I | I | I | I | I |
| Default | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| SUB$i$ | ID of the $i^{th}$ subsystem |

| Card 3a.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ANGLE1 | ANGLE2 | ANGLE3 | ANGLE4 | ANGLE5 | ANGLE6 | ANGLE7 | ANGLE8 |
| Type | F | F | F | F | F | F | F | F |
| Default | none | none | none | none | none | none | none | none |

| VARIABLE | DESCRIPTION |
|---|---|
| ANGLE$i$ | Connection angle of the plate $i$ |

| Card 3a.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LENGTH | | | | | | | |
| Type | F | | | | | | | |
| Default | 0 | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| LENGTH | Length of the edge in connection |

| Card 3b | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | ABSORB | THICK | | | | | | |
| Type | F | F | | | | | | |
| Default | none | none | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| ABSORB | Absorption coefficient |
| THICK | Thickness of the plate |

**Remarks:**

1. **Number of subsystems in connection.** At this time, up to 8 subsystems can be included in one connection.

## *FREQUENCY_DOMAIN_SEA_INPUT

Purpose: Define input power for a subsystem in SEA model.

### Card Summary:

**Card 1.** This card is required.

| SUBID | SUBTYP | LOADTYP | | | | | |
|---|---|---|---|---|---|---|---|

**Card 2.** This card is required

| BWAVE | LWAVE | SWAVE | TWAVE | | | | |
|---|---|---|---|---|---|---|---|

### Data Card Definitions:

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SUBID | SUBTYP | LOADTYP | | | | | |
| Type | I | I | I | | | | | |
| Default | none | 1 | 1 | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SUBID | ID of subsystem |
| SUBTYP | Type of subsystem:<br>EQ.1: plate<br>EQ.2: cavity<br>EQ.3: beam |
| LOADTYP | Input power type:<br>EQ.1: power<br>EQ.2: force<br>EQ.3: velocity<br>EQ.4: bending wave power for plate<br>EQ.5: shear wave power for plate. |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | BWAVE | LWAVE | SWAVE | TWAVE | | | | |
| Type | F | F | F | F | | | | |
| Default | none | none | none | none | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| BWAVE | Bending wave |
| LWAVE | Longitudinal wave |
| SWAVE | Shear wave |
| TWAVE | Torsional wave (required only for beams, SUBTYP = 3) |

**Remarks:**

1. **Input power in torsional wave.** TWAVE (input power in torsional wave) is not required for plate and cavity subsystems (SUBTYP = 1 or 2).

## *FREQUENCY_DOMAIN_SEA_SUBSYSTEM

Purpose: Define input power for a subsystem in an SEA model.

### Card Summary:

**Card 1.** This card is required.

| FMIN | FMAX | NFREQ | NFSPACE | LCFREQ | IREAD | PREF | |
|---|---|---|---|---|---|---|---|

**Card 2.** This card is required.

| SUBID | SUBTYP | DENSITY | E | PR | OUTPUT | | |
|---|---|---|---|---|---|---|---|

**Card 3a.1.** This card is required for plate (SUBTYP = 1).

| A | PERIM | THICK | WIDTH | LENGTH | | | |
|---|---|---|---|---|---|---|---|

**Card 3a.2.** This card is required for plate (SUBTYP = 1).

| DAMPB | DAMPL | DAMPS | LC1 | LC2 | LC3 | | |
|---|---|---|---|---|---|---|---|

**Card 3b.1.** This card is required for cavity (SUBTYP = 2).

| A | PERIM | VOLUME | WIDTH | LENGTH | HEIGHT | | |
|---|---|---|---|---|---|---|---|

**Card 3b.2.** This card is required for cavity (SUBTYP = 2).

| DAMPB | LC1 | | | | | | |
|---|---|---|---|---|---|---|---|

**Card 3c.1.** This card is required for beam (SUBTYP = 3).

| A | ISS | ITT | J | LENGTH | | | |
|---|---|---|---|---|---|---|---|

**Card 3c.2.** This card is required for beam (SUBTYP = 3).

| DAMPB | DAMPL | DAMPS | DAMPT | LC1 | LC2 | LC3 | LC4 |
|---|---|---|---|---|---|---|---|

**Data Card Definitions:**

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | FMIN | FMAX | NFREQ | NFSPACE | LCFREQ | IREAD | PREF | |
| Type | I | I | I | F | I | I | F | |
| Default | none | 1 | 1 | 0 | 0 | 0 | 2.0e-5 | |

| VARIABLE | DESCRIPTION |
|---|---|
| FMIN | Minimum frequency for SEA output (cycles/time) |
| FMAX | Maximum frequency for SEA output (cycles/time) |
| NFREQ | Number of frequencies for SEA output (cycles/time) |
| FSPACE | Frequency spacing option for SEA output:<br>EQ.0: Linear<br>EQ.1: Logarithmic<br>EQ.2: Biased |
| LCFREQ | Load curve ID defining the frequencies for SEA output |
| IREAD | Type of SEA run:<br>EQ.0: Run the SEA analysis.<br>EQ.1: Read the FEM keyword input deck and create the SEA model. |
| PREF | Reference pressure used to convert acoustic pressure to SPL (dB) |

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | SUBID | SUBTYP | DENSITY | E | PR | OUTPUT | | |
| Type | I | I | F | F | F | I | | |
| Default | none | none | none | none | none | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| SUBID | ID of subsystem |
| SUBTYP | Type of subsystem:<br>EQ.1: Plate<br>EQ.2: Cavity<br>EQ.3: Beam |
| DENSITY | Mass density of subsystem |
| E | Young's modulus of subsystem |
| PR | Poisson's ratio of subsystem |
| OUTPUT | Include this subsystem in output:<br>EQ.0: No<br>EQ.1: Yes |

| Card 3a.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | A | PERIM | THICK | WIDTH | LENGTH | | | |
| Type | F | F | F | F | F | | | |
| Default | none | none | none | none | none | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| A | Plate area |

| VARIABLE | DESCRIPTION |
|---|---|
| PERIM | Plate perimeter |
| THICK | Plate thickness |
| WIDTH | Plate width |
| LENGTH | Plate length |

| Card 3a.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPB | DAMPL | DAMPS | LC1 | LC2 | LC3 | | |
| Type | F | F | F | I | I | I | | |
| Default | none | none | none | 0 | 0 | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPB | Damping factor for bending wave |
| DAMPL | Damping factor for longitudinal wave |
| DAMPS | Damping factor for shear wave |
| LC1 | Load curve for damping factor for bending wave |
| LC2 | Load curve for damping factor for longitudinal wave |
| LC3 | Load curve for damping factor for shear wave |

| Card 3b.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | A | PERIM | VOLUME | WIDTH | LENGTH | HEIGHT | | |
| Type | F | F | F | F | F | F | | |
| Default | none | none | none | none | none | none | | |

| VARIABLE | DESCRIPTION |
|---|---|
| A | Cavity area |
| PERIM | Cavity perimeter |
| VOLUME | Cavity volume |
| WIDTH | Cavity width |
| LENGTH | Cavity length |
| HEIGHT | Cavity height |

| Card 3b.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPB | LC1 | | | | | | |
| Type | F | I | | | | | | |
| Default | none | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPB | Damping factor for bending wave |
| LC1 | Load curve for damping factor for bending wave |

| Card 3c.1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | A | ISS | ITT | J | LENGTH | | | |
| Type | F | F | F | F | F | | | |
| Default | none | none | none | none | none | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| AREA | Beam area |
| ISS | $I_{ss}$, area moment of inertia about local $s$-axis |

| VARIABLE | DESCRIPTION |
|---|---|
| ITT | $I_{tt}$, area moment of inertia about local $t$-axis |
| J | $J$, torsional constant |
| LENGTH | Beam length |

| Card 3c.2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPB | DAMPL | DAMPS | DAMPT | LC1 | LC2 | LC3 | LC4 |
| Type | F | F | F | F | I | I | I | I |
| Default | none | none | none | none | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPB | Damping factor for bending wave |
| DAMPL | Damping factor for longitudinal wave |
| DAMPS | Damping factor for shear wave |
| DAMPT | Damping factor for torsional wave |
| LC1 | Load curve for damping factor for bending wave |
| LC2 | Load curve for damping factor for longitudinal wave |
| LC3 | Load curve for damping factor for shear wave |
| LC4 | Load curve for damping factor for torsional wave |

**Remarks:**

1. **Damping factor load curves.** When LC1, LC2, etc., are defined, the damping factors for the corresponding waves are frequency-dependent, and the values defined in these curves override the constant damping factor values defined by DAMPB, DAMPL, etc.

## *FREQUENCY_DOMAIN_SSD_{OPTION}

Available options include:

DIRECT

DIRECT_FREQUENCY_DEPENDENT

FATIGUE

FRF

ERP

SUBCASE

Purpose: Compute steady-state dynamic response due to a given spectrum of harmonic excitations.

When the FATIGUE option is applied, LS-DYNA also calculates the cumulative fatigue damage ratio. When the FRF option is applied, LS-DYNA calculates the steady-state dynamic response due to unit load, which is equivalent to Frequency Response Function (FRF). When the ERP option is used, LS-DYNA also calculates the Equivalent Radiated Power (ERP) due to vibration.

When the DIRECT or DIRECT_FREQUENCY_DEPENDENT option is applied, LS-DYNA performs the steady state dynamic analysis using a direct method, instead of the mode-based method. This method is only available for SMP.

When the SUBCASE option is applied, multiple loading cases can be included in one run (see Remark 16).

### Card Summary:

**Card 1.** This card is required.

| MDMIN | MDMAX | FNMIN | FNMAX | RESTMD | RESTDP | LCFLAG | RELATV |
|---|---|---|---|---|---|---|---|

**Card 2.** This card is required.

| DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | DMPFLG | | |
|---|---|---|---|---|---|---|---|

**Card 3.** This card is required.

| | ISTRESS | MEMORY | NERP | STRTYP | NOUT | NOTYP | NOVA |
|---|---|---|---|---|---|---|---|

**Card 4.** Include this card if the ERP keyword option is used.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| RO | C | ERPRLF | ERPREF | RADEFF | | | |

**Card 5.** Include this card if the ERP keyword option is used and NERP > 0.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PID | PTYP | | | | | | |

**Card 6.** If the SUBCASE keyword option is used, include this card. For each case, a set of this keyword and NLOAD copies of Card 7 are included. See Remark 16.

| | | |
|---|---|---|
| CASEID | TITLE | NLOAD |

**Card 7.** When the SUBCASE option is used, for each case include NLOAD of this card following the Card 6 for that case (see Remark 16). Otherwise, include as many definitions of this card as needed.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| NID | NTYP | DOF | VAD | LC1 | LC2 | SF | VID |

**Card 8.** Include this card if the FATIGUE keyword option is used.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LCFTG | | | | | | | |

**Data Card Definitions:**

| Card 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | MDMIN | MDMAX | FNMIN | FNMAX | RESTMD | RESTDP | LCFLAG | RELATV |
| Type | I | I | F | F | I | I | I | I |
| Default | 1 | optional | 0.0 | optional | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| MDMIN | The first mode in modal superposition method (optional). |
| MDMAX | The last mode in modal superposition method (optional). See Remark 3. MDMAX should not be 0 for a restart run based on existing modal analysis results (RESTMD = 1 or 2); see Remark 4. |
| FNMIN | The minimum natural frequency in modal superposition method (optional). |

| VARIABLE | DESCRIPTION |
|---|---|
| FNMAX | The maximum natural frequency in modal superposition method (optional). See Remark 3. |
| RESTMD | Restart option:<br>EQ.0: A new modal analysis is performed,<br>EQ.1: Restart with d3eigv,<br>EQ.2: Restart with modeshp binary scratch file. |
| RESTDP | Restart option:<br>EQ.-1: A new run with writing dumpssd for future restart,<br>EQ.0: A new run without writing dumpssd,<br>EQ.1: Restart with dumpssd with writing new dumpssd for future restart,<br>EQ.2: Restart with dumpssd without writing new dumpssd. |
| LCFLAG | Load curve definition flag:<br>EQ.0: Load curves are given as amplitude / phase angle (defined in degrees in the range (-180°, 180°]).<br>EQ.1: Load curves are given as real / imaginary components. |
| RELATV | Flag for displacement, velocity and acceleration results:<br>EQ.0: Absolute values are requested.<br>EQ.1: Relative values are requested (for VAD = 2, 3 and 4 only; see Card 7). |

**Damping Card.** See Remark 5.

| Card 2 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | DAMPF | LCDAM | LCTYP | DMPMAS | DMPSTF | DMPFLG | | |
| Type | F | I | I | F | F | I | | |
| Default | 0.0 | 0 | 0 | 0.0 | 0.0 | 0 | | |

| VARIABLE | DESCRIPTION |
|---|---|
| DAMPF | Modal damping coefficient, $\zeta$. |
| LCDAM | Load Curve ID defining mode dependent modal damping coefficient $\zeta$. |
| LCTYP | Type of load curve defining modal damping coefficient:<br>EQ.0: Abscissa value defines frequency.<br>EQ.1: Abscissa value defines mode number. |
| DMPMAS | Mass proportional damping constant $\alpha$, in Rayleigh damping. |
| DMPSTF | Stiffness proportional damping constant $\beta$, in Rayleigh damping |
| DMPFLG | Damping flag:<br>EQ.0: Use modal damping coefficient $\zeta$ defined by DAMPF or LCDAM or Rayleigh damping defined by DMPMAS and DMPSTF in this card.<br>EQ.1: Use damping defined by *DAMPING_PART_MASS and *DAMPING_PART_STIFFNESS. |

| Card 3 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | | ISTRESS | MEMORY | NERP | STRTYP | NOUT | NOTYP | NOVA |
| Type | | I | I | I | I | I | I | I |
| Default | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| ISTRESS | Stress computation flag (for keyword option DIRECT only):<br>EQ.0: Stress results are not requested.<br>EQ.1: Stress results are requested. |
| MEMORY | Memory flag:<br>EQ.0: Modal superposition will be performed in-core. This option runs faster.<br>EQ.1: Modal superposition will be performed out-of-core. This |

| VARIABLE | DESCRIPTION |
|---|---|
| | is needed for some large scale problems that cannot fit in main memory. This method incurs a performance penalty associated with disk speed. |
| NERP | Number of ERP panels. |
| STRTYP | Stress used in fatigue analysis:<br>EQ.0: Von Mises stress,<br>EQ.1: Maximum principal stress,<br>EQ.2: Maximum shear stress. |
| NOUT | Part, part set, segment set, or node set ID for response output (use with acoustic computation). See NOTYP below. See Remark 6. |
| NOTYP | Type of NOUT:<br>EQ.0: Part set ID (not implemented)<br>EQ.1: Part ID (not implemented)<br>EQ.2: Segment set ID<br>EQ.3: Node set ID<br>EQ.-2: Segment set ID which mismatches with acoustic boundary nodes. Mapping of velocity or acceleration to the acoustic boundary nodes is performed. |
| NOVA | Response output type:<br>EQ.0: Velocity<br>EQ.1: Acceleration |

**ERP Card.** This card is read only when the ERP keyword option is used.

| Card 4 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | R0 | C | ERPRLF | ERPREF | RADEFF | | | |
| Type | F | F | F | F | I | | | |
| Default | none | none | 1.0 | 0.0 | 0 | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| RO | Fluid density |
| C | Sound speed of the fluid |
| ERPRLF | ERP radiation loss factor.<br>LT.0: Curve ID = (-ERPRLF) specifies frequency-dependent radiation loss factor. |
| ERPREF | ERP reference value. This is used to convert the absolute ERP value to ERP in decibels (dB). |
| RADEFF | Radiation efficiency computation flag:<br>EQ.0: Radiation efficiency computation is not requested, and a classic ERP computation is performed.<br>EQ.1: Radiation efficiency computation is requested, and an enhanced ERP computation using Rayleigh integrals is performed.<br>EQ.2: Radiation efficiency computation is not requested, and a corrected ERP computation is performed. |

**ERP Part Cards.** This card is read NERP times if the ERP keyword option is used.

| Card 5 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | PID | PTYP | | | | | | |
| Type | I | I | | | | | | |
| Default | none | 0 | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| PID | Part, part set, or segment set ID for ERP computation. See PTYP below. Note that the ERP computation works only on a part or part set of shell elements or a set of segments (2D surfaces). |
| PTYP | Type of PID:<br>EQ.0: Part ID<br>EQ.1: Part set ID |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.2: Segment set ID |

**SUBCASE Cards.** This card is read if the SUBCASE keyword option is used. A set of this card with NLOAD instantiations of Card 7 specifies a case. Include as many cases as needed.

| Card 6 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | CASEID | TITLE | | | | | | NLOAD |
| Type | C | C | | | | | | I |
| Default | none | none | | | | | | 1 |

| VARIABLE | DESCRIPTION |
|---|---|
| CASEID | Identification string to be used as the case ID (must include at least one letter). |
| TITLE | A description of the current loading case (can be blank) |
| NLOAD | Number of loads for this loading case |

**Excitation Loads.** When the SUBCASE option is used, for each case include NLOAD of this card following the Card 6 for that case (see Remark 16). Otherwise repeat this card as many times as needed if multiple excitation loads are present.

| Card 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | NID | NTYP | DOF | VAD | LC1 | LC2 | SF | VID |
| Type | I | I | I | I | I | I | F | I |
| Default | none | 0 | none | none | none | none | 1.0 | 0 |

| VARIABLE | DESCRIPTION |
|---|---|
| NID | ID of the entity to which the excitation input is applied. See NTYP below for the types. See Remark 7. |

| VARIABLE | DESCRIPTION |
|---|---|
| NTYP | Type of NID:<br>EQ.0: Node ID<br>EQ.1: Node set ID<br>EQ.2: Segment set ID<br>EQ.3: IGA parametric point ID (see *IGA_POINT_UVW)<br>EQ.4: IGA parametric point set ID (see *SET_IGA_POINT_UVW)<br>EQ.7: IGA physical face ID (see *IGA_FACE_XYZ)<br>EQ.8: IGA physical face set ID (see *SET_IGA_FACE_XYZ) |
| DOF | Applicable degrees-of-freedom for excitation input (ignored if VAD = 1):<br>EQ.1: $x$-translational degree-of-freedom or $x$-rotational degree-of-freedom (for torque excitation, VAD = 8)<br>EQ.2: $y$-translational degree-of-freedom, or $y$-rotational degree-of-freedom (for torque excitation, VAD = 8)<br>EQ.3: $z$-translational degree-of-freedom, or $z$-rotational degree-of-freedom (for torque excitation, VAD = 8)<br>EQ.4: Translational movement in direction given by vector VID, or rotational movement with axis given by vector VID (for torque excitation, VAD = 8) |
| VAD | Excitation input type:<br>EQ.0: Nodal force<br>EQ.1: Pressure<br>EQ.2: Base velocity<br>EQ.3: Base acceleration<br>EQ.4: Base displacement<br>EQ.5: Enforced velocity by large mass method (see Remark 8)<br>EQ.6: Enforced acceleration by large mass method (see Remark 8)<br>EQ.7: Enforced displacement by large mass method (see Remark 8)<br>EQ.8: Torque |

| VARIABLE | DESCRIPTION |
|---|---|
| | EQ.9: Base angular velocity<br>EQ.10: Base angular acceleration<br>EQ.11: Base angular displacement<br>EQ.12: Enforced velocity (for DIRECT type keyword options only)<br>EQ.13: Enforced acceleration (for DIRECT type keyword options only)<br>EQ.14: Enforced displacement (for DIRECT type keyword options only) |
| LC1 | Load Curve ID defining amplitude (LCFLAG = 0) or real (in-phase) part (LCFLAG = 1) of load as a function of frequency. It is not used if the keyword option FRF is active. |
| LC2 | Load Curve ID defining phase angle (LCFLAG = 0) or imaginary (out-phase) part (LCFLAG = 1) of load as a function of frequency. It is not used if the keyword option FRF is active. |
| SF | Scale factor for the load. This scale factor applies to the amplitude of load (LCFLAG = 0) or real and imaginary parts of load (LCFLAG = 1). |
| VID | Vector ID for DOF = 4 for excitation input; see *DEFINE_VECTOR. |

**Load Duration Card.** This card is read only when the FATIGUE keyword option is used.

| Card 8 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Variable | LCFTG | | | | | | | |
| Type | I | | | | | | | |
| Default | none | | | | | | | |

| VARIABLE | DESCRIPTION |
|---|---|
| LCFTG | Load Curve ID defining duration of excitation for each frequency |

**Remarks:**

1. **Direct methods.** When the option DIRECT or DIRECT_FREQUENCY_DEPENDENT is not used, this feature computes the steady-state dynamic response due to a harmonic excitation spectrum by the modal superposition method. When the keyword option DIRECT or DIRECT_FREQUENCY_DEPENDENT is used, a direct method is used. For the direct method, the unknown primary variables are the nodal displacements. A system of dynamic equations is formed in the frequency domain and solved directly without projecting the displacement variables into the modal space.

2. **Modal superposition method and required keywords.** The modal superposition method requires natural frequencies and mode shapes. Thus, the keyword *CONTROL_IMPLICIT_EIGENVALUE *must* be included in the input.

3. **Modes.** MDMIN/MDMAX and FNMIN/FNMAX together determine which modes are used in the modal superposition method. The first mode must have a mode number ≥ MDMIN and frequency ≥ FNMIN; the last mode must have a mode number ≤ MDMAX and frequency ≤ FNMAX. When MDMAX or FNMAX is not given, the last mode in modal superposition method is the last mode available in FILENM.

4. **Restarts.** Restart option RESTMD = 1 is used if mode analysis has been done previously. In this case, LS-DYNA skips modal analysis and reads in d3eigv family files generated previously. Restart option RESTMD = 2 is used if a SSD analysis has been done for the same model previously and the binary scratch file modeshp exists. The modeshp file saves the condensed modal shape (and modal stress if there is any) data. Therefore, the SSD analysis can be restarted with the existing modeshap file if no changes have been made to the modal structure, boundary conditions, and material models. Restarting SSD with RESTMD = 2 is faster than restarting SSD with RESTMD = 1 because of the saved modal shapes. For RESTMD = 1 or 2, always use MDMIN = 1 and MDMAX = number of modes given by modal analysis (can be found from ASCII file eigout or from d3eigv files using LS-PREPOST).

   To add the contribution of additional modes to previous SSD results, restart option RESTDP = 1 is used. In this case, LS-DYNA reads in the binary dump file dumpssd which contains previous SSD results and adds the contribution from new modes. For RESTDP = 1, the new modal analysis (RESTMD = 0) or the d3eigv family files created elsewhere (RESTMD = 1) should exclude the modes used in previous SSD computation. To do this, set LFLAG (and RFLAG, if necessary) and a nonzero LFTEND (and RHTEND) in *CONTROL_IMPLICIT_EIGENVALUE. The RESTDP option can also be used if the frequency range for modal analysis is divided into segments and modal analysis is performed for each frequency range separately.

To add some acoustic field nodes and run BEM/FEM acoustic computation after SSD, the RESTMD and RESTDP options still work even if the number of nodes may be changed after a previous modal analysis, provided that the IDs of the old nodes are not changed.

5. **Damping.** Damping can be prescribed in several ways:

   a) To use a constant modal damping coefficient $\zeta$ for all the modes, define DAMPF only. LCDMP, LCTYP, DMPMAS and DMPSTF are ignored.

   b) To use mode-dependent modal damping, define a load curve (*DEFINE_CURVE) and specify if the abscissa value defines the frequency or mode number with LCTYP. DMPMAS and DMPSTF are ignored.

   c) To use Rayleigh damping, define DMPMAS ($\alpha$) and DMPSTF ($\beta$). Keep DAMPF as its default (0.0) and keep LCDMP and LCTYP as 0. The damping matrix in Rayleigh damping is defined as $\mathbf{C} = \alpha\mathbf{M} + \beta\mathbf{K}$, where, $\mathbf{C}$, $\mathbf{M}$ and $\mathbf{K}$ are the damping, mass, and stiffness matrices, respectively.

6. **Nodal output and acoustic analysis.** NOUT and NOTYP are used to define the nodes where velocity or acceleration are requested to be written to a binary file bin_ssd or other filename defined by "bem=filename" (see keyword *FREQUENCY_DOMAIN_ACOUSTIC_BEM) on the command line. The velocity or acceleration data in this file can be used by the BEM or FEM acoustic solver to perform a vibro-acoustic analysis. If structure nodes and acoustic boundary nodes are mismatched, the option NOTYP = -2 can be used. The velocity or acceleration data given at a structure segment set NOUT is mapped to acoustic boundary nodes.

7. **Base velocity, acceleration, and displacement.** For base velocity, base acceleration, or base displacement (VAD = 2, 3, or 4) excitations, the parameters NID and NTYP are not used and can be blank. The loads are applied through the nodes constrained to the ground or to the shaker table (defined by the keyword *BOUNDARY_SPC or the variables TC or RC in *NODE). The base velocity, base acceleration, and base displacement cases are treated by applying an inertia force to the structure. In each direction, only one base excitation (velocity, acceleration, or displacement) is allowed. Duplicate definitions of base excitation in one direction cause an error termination. These comments apply to base angular cases (VAD = 9, 10, or 11) too.

8. **Large mass method.** For the cases with enforced motion excitation such as nodal velocity, acceleration, or displacement, the large mass method can be used to compute the SSD results. The excitation input can be given as enforced motion curves (VAD = 5, 6, 7). To use the large mass method, a large mass must be attached to the nodes where the enforced motion is applied by using the keyword *ELEMENT_MASS_*{OPTION}*, and the large mass per node (MPN) must

be reported in the keyword *CONTROL_FREQUENCY_DOMAIN. For more details, please refer to *CONTROL_FREQUENCY_DOMAIN.

9. **Displacement, velocity, and acceleration results.** Displacement, velocity, and acceleration results are output into ASCII file NODOUT_SSD. The nodes to be output to NODOUT_SSD are specified by card *DATABASE_HISTORY_NODE. The frequencies for the nodal results in NODOUT_SSD are specified by card *DATABASE_FREQUENCY_ASCII_NODOUT_SSD. If the card *DATABASE_FREQUENCY_ASCII_NODOUT_SSD is not defined, the frequencies for the nodal results in NODOUT_SSD are the same as those in D3SSD binary database, which is defined by card *DATABASE_FREQUENCY_BINARY_D3SSD.

10. **Stress and strain results.** Stress (and strain) results are output into ASCII file ELOUT_SSD. The solid, beam, shell, and thick shell elements to be output to ELOUT_SSD are specified by the following cards:

    - *DATABASE_HISTORY_SOLID_*{OPTION}*
    - *DATABASE_HISTORY_BEAM_*{OPTION}*
    - *DATABASE_HISTORY_SHELL_*{OPTION}*
    - *DATABASE_HISTORY_TSHELL_*{OPTION}*

    The frequencies for the element stress / strain results in ELOUT_SSD are specified by card *DATABASE_FREQUENCY_ASCII_ELOUT_SSD. If the card *DATABASE_FREQUENCY_ASCII_ELOUT_SSD is not defined, the frequencies for the element stress / strain results in ELOUT_SSD are same as those in D3SSD binary database, which is defined by card *DATABASE_FREQUENCY_BINARY_D3SSD.

11. **Phase angle units.** The phase angle is given in degrees in the range (-180°, 180°], for both the input decks and output databases (e.g. D3SSD, NODOUT_SSD, and ELOUT_SSD).

12. **Fatigue.** When the FATIGUE keyword option is used, the cumulative fatigue damage ratio due to the harmonic vibration is computed and saved in binary plot database d3ftg. The *MATERIAL_ADD_FATIGUE keyword is needed to define the S-N fatigue curve for each material.

13. **FRF.** When the FRF keyword option is present, LS-DYNA calculates the steady-state dynamic response due to unit load spectrum. Numerically it is equivalent to Frequency Response Function (FRF). In this case, LC1 and LC2 are not used and can be blank. LS-DYNA generates a unit load spectrum according to the excitation location, the excitation degree of freedom, and the excitation type defined by NID, NTYP, DOF, and VAD in Card 7. This is useful if the user is interested in obtaining FRF fringe plots at some frequencies or would like to get the stress (and strain) FRF results. The name of the binary database is changed to D3FRF.

14. **Frequency-dependent material properties.** For the option DIRECT_FREQUENCY_DEPENDENT, the damping and stiffness matrices can change with frequency, as can the material properties. The keyword *MAT_ADD_PROPERTY_DEPENDENCE can be used to define the properties of a material model that change with frequency.

15. **Radiation efficiency.** For the keyword option ERP and RADEFF = 1, radiated acoustic power can be computed using the Rayleigh integral. Radiation efficiency is computed as the ratio between the radiated acoustic power and the absolute ERP values. The radiated acoustic power results are saved in an ASCII xyplot database radiated_power. The radiation efficiency results are saved in an ASCII xyplot database radiation_efficiency. The computation is suitable for a baffled plate vibrating in out-of-plane motion and placed in light fluid, such as air.

16. **SUBCASE.** With the keyword option SUBCASE, multiple loading cases can be included with one keyword. Each loading case includes one set of Card 6 and Card 7. Card 7 can be repeated for each case if the current loading case has multiple excitation loads. CASEID defined in Card 6 is used as a prefix for the output databases (such as D3SSD and binout). An automatic case ID is assigned (meaning CASE1.D3SSD, CASE2.D3SSD, …) if CASEID is defined as "case" or "CASE". The TITLE field, when defined, is used as the title for the output databases (D3SSD, NODOUT_SSD, ELOUT_SSD, and NODFOR_SSD). Otherwise, the output databases use the global title, defined by the keyword *TITLE. The multiple loading cases may share the same output frequencies (defined by *DATABASE_FREQUENCY_BINARY_D3SSD, *DATABASE_FREQUENCY_ASCII_NODOUT_SSD, *DATABASE_FREQUENCY_ASCII_ELOUT_SSD, and *DATABASE_FREQUENCY_ASCII_NODFOR_SSD). They can also have different output frequencies by appending the option SUBCASE to the corresponding database keywords. With this option, you can set FMIN, FMAX, NFREQ, FSPACE, and LCFREQ for each loading case sequentially.