*FATIGUE

The keyword *FATIGUE provides a way of defining and solving fatigue and durability analysis problems. The keyword cards in this section are defined in alphabetical order:

FATIGUE_*{OPTION}

Available options include:

<BLANK>

D3PLOT

ELOUT

Purpose: Perform fatigue analysis on parts or structures to get cumulative damage ratio and expected fatigue life. See Remark 3.

Card Summary:

Card 1. This card is only required when the keyword option is unused (<BLANK>).

PID	PTYPE						

Card 2. This card is only required when keyword option is unused (<BLANK>).

DT							

Card 3. This card is required.

STRSN	INDEX	RESTRT	TEXPOS	DMGMIN			

Card 3a. This card is only read when RESTART = 1. It is optional.

FILENAME

Data Card Definitions:

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

Card 2	1	2	3	4	5	6	7	8
Variable	DT							
Type	F							
Default	none							

Card 3	1	2	3	4	5	6	7	8
Variable	STRSN	INDEX	RESTRT	TEXPOS				
Type	I	I	I	F				
Default	0	0	0	0.0				

Stress/Strain Binary Database Card. Card 3a is only read if RESTART = 1. It is optional.

Card 3a	1	2	3	4	5	6	7	8
Variable	FILENAME							
Type	C							

VARIABLE	DESCRIPTION
PID	Part ID, part set ID, or element (solid, shell, beam, thick shell) set ID. EQ.0: fatigue analysis is performed on the whole structure.
PTYPE	Type of PID: EQ.0: part (default) EQ.1: part set EQ.2: SET_SOLID EQ.3: SET_BEAM

VARIABLE	DESCRIPTION
	EQ.4: SET_SHELL EQ.5: SET_TSHELL
DT	Time step for saving the stress/strain data in transient analysis
STRSN	Type of fatigue analysis variable: EQ.0: stress (default) EQ.1: strain
INDEX	Stress/strain index for performing fatigue analysis: EQ.0: von Mises stress/strain EQ.1: maximum principal stress/strain EQ.2: maximum shear stress/strain
RESTRT	Restart options. This flag is used to save an LS-DYNA transient analysis if the binary database for stress/strain time history data has been created in previous runs. See Remark 4. EQ.0: initial run EQ.1: restart with existing stress/strain binary database
TEXPOS	Exposure time. If this is 0, the exposure time is the same as ENDTIM in *CONTROL_TERMINATION.
DMGMIN	Minimum fatigue damage ratio for parts undergoing fatigue analysis: EQ.0: no change on computed fatigue damage ratio LT.0: for each part, the minimum fatigue damage ratio dumped to D3FTG is |DMGMIN| × the computed nonzero minimum fatigue damage ratio computed on the current part. GT.0: for each part, the minimum fatigue damage ratio dumped to D3FTG is DMGMIN.
FILENAME	Path and name of existing stress/strain binary database (such as d3plot or binout)

Remarks:

1. **D3PLOT.** When D3PLOT is used, the stress/strain data are provided by the D3PLOT database.

2. **ELOUT.** When ELOUT is used, the stress/strain data are provided by the ELOUT database. The keyword *DATABASE_ELOUT must be included to define time step for writing the stress/strain data. In addition, BINARY must be set to 2 in *DATABASE_ELOUT so that the data is written to a binary database binout. The keyword(s) *DATABASE_HISTORY_*OPTION* with the element type specified in the option must be included to define the elements where the stress/strain data are needed, and the fatigue analysis is requested.

3. **Current Restrictions.** Currently, the fatigue analysis is performed based on the D3PLOT or ELOUT database. Thus, the option D3PLOT or ELOUT is always needed.

4. **Restarts.** When RESTRT = 1, LS-DYNA reads the existing binary database (by default, d3plot if the option D3PLOT is used, or binout if the option ELOUT is used) to obtain the stress/strain time history data for the fatigue analysis. This binary database should be in the same directory as the current run. Otherwise, the path and name of the binary database should be defined by Card 3a. When running a restart with the ELOUT keyword option, *DATABASE_ELOUT must be removed from the input deck to avoid overwriting the original ELOUT database (which is saved in binout).

5. **Exposure Time.** The exposure time is ENDTIM in *CONTROL_TERMINATION, unless it is defined by a nonzero TEXPOS in Card 3. The exposure time is needed for computing the expected fatigue life, which is given as "exposure time" / "cumulative damage ratio". The expected fatigue life is only computed for the case without initial fatigue damage ratio. This is because for the case with initial fatigue damage ratio (see *INITIAL_FATIGUE_DAMAGE_RATIO), the cumulative damage ratio includes the damage ratio from preceding loads. For structures subjected to long term periodic fatigue loading, the computation can be run for this small fraction of the exposure time using a small ENDTIM in *CONTROL_TERMINATION (if the stress / strain response in this period is a good representation for the whole exposure time). The computed cumulative damage ratio is scaled accordingly to provide the cumulative damage ratio for the whole exposure time.

6. **Minimum Damage Ratio.** The minimum damage ratio dumped to d3ftg can be defined and adjusted by DMGMIN. For some parts, some elements may have 0 damage ratio from computation if they are rigid bodies or they have minimum stress (e.g. the stress is lower than the fatigue limit on the SN curve). The 0 damage ratio may cause a mathematical problem if you want to calculate the fatigue life of the element, or take log scale on the damage ratio for better visualization

of the fatigue damage distribution. DMGMIN can define a nonzero minimum damage ratio for the parts undergoing fatigue analysis to avoid this problem.

7. **Results.** The results (fatigue life, cumulative damage ratio, etc.) are saved in binary plot database d3ftg.

*FATIGUE_FAILURE

Purpose: Determine the treatment of elements that failed due to fatigue in subsequent analysis.

Card 1	1	2	3	4	5	6	7	8
Variable	IFAILURE	DRATIO						
Type	I	F						
Default	0	1.0						

VARIABLE	DESCRIPTION
IFAILURE	Treatment of elements failed due to fatigue: EQ.0: keep the elements in the model. EQ.1: delete the elements from the model.
DRATIO	Threshold value of cumulative damage ratio for an element to be considered failed

Remarks:

1. **Cumulative Damage Ratio.** This keyword controls the treatment of elements which fail during fatigue loading. Usually an element fails if the cumulative damage ratio is ≥ 1. For shell elements and thick shell elements, it is assumed that the elements fail if the cumulative damage ratio from one of the integration points through thickness is ≥ 1. For added safety, a smaller DRATIO may be used, such as DRATIO = 0.5.

2. **Deleted Elements.** If IFAILURE = 1, all the elements with cumulative damage ratio ≥ DRATIO, will be deleted from the model. They will not participate in subsequent computations.

3. **Applicability.** This keyword is only applicable to time domain fatigue analysis.

*FATIGUE_LOADSTEP

Purpose: Define load steps for fatigue analysis.

Load Step Card. This card may be repeated if multiple load steps are present.

Card 1	1	2	3	4	5	6	7	8
Variable	TSTART	TEND	TEXPOS					
Type	F	F	F					
Default	none	none	0.0					

VARIABLE	DESCRIPTION
TSTART	Start time of current load step
TEND	End time of current load step
TEXPOS	Exposure time of current load step EQ.0.0: set to TEND – TSTART (default).

Remarks:

1. **Fatigue Calculation and Exposure Time.** This keyword is applicable to time domain fatigue analysis. For each fatigue load step, LS-DYNA performs a fatigue calculation only for the stress / strain history extracted between TSTART and TEND. The calculated cumulative damage ratio is multiplied by a scale factor (= TEXPOS / (TEND – TSTART)) to provide a cumulative damage ratio for the real load step (for exposure time of TEXPOS). It is assumed that the stress / strain cycles between TSTART and TEND are a good representative of the stress / strain response for the whole exposure time TEXPOS. TEXPOS defined in this Card overrides the same variable defined in Card 3 in the keyword *FATIGUE_*{OPTION}*.

2. **Multiple Load Steps.** Card 1 can be repeated if there are multiple fatigue load steps. The cumulative damage ratios from each load step are summed up to provide the final cumulative damage ratio to be saved in the binary plot database d3ftg. If initial fatigue damage ratios are defined (by the keyword *INITIAL_FATIGUE_DAMAGE_RATIO), they are also added to the final cumulative damage ratio.

*FATIGUE_MEAN_STRESS_CORRECTION

Purpose: Define mean stress correction method for fatigue analysis.

Card 1	1	2	3	4	5	6	7	8
Variable	METHOD							
Type	I							
Default	0							

Card 2	1	2	3	4	5	6	7	8
Variable	MID	SIGMA						
Type	I	F						
Default	none	none						

VARIABLE	DESCRIPTION
METHOD	Mean stress correction method: EQ.-1: Interpolation on multiple SN curves EQ.0: Goodman equation EQ.1: Soderberg equation EQ.2: Gerber equation EQ.3: Goodman tension only EQ.4: Gerber tension only EQ.5: Morrow equation (for correction on SN curve) EQ.11: Morrow equation (for correction on EN curve) EQ.12: Smith-Watson-Topper equation
MID	Material ID for which the current mean stress correction method is applied.
SIGMA	Ultimate tensile strength, σ_u, to be used in the Goodman equation

VARIABLE	DESCRIPTION
	(METHOD = 0, 3) or the Gerber equation (METHOD = 2, 4), yield strength, σ_y, to be used in the Soderberg equation (METHOD = 1), or true fracture strength, σ_f, to be used in the Morrow equation (METHOD = 5)

Remarks:

1. **Fatigue analysis types.** This keyword can be applied in both time domain and frequency domain fatigue analysis. The method options 0, 1, 2, 3, and 4 are used for stress-based fatigue analysis; the method options 11 and 12 are used for strain-based fatigue analysis.

2. **Multiple material models.** Card 2 can be repeated if there are multiple material models in the input deck and they have different SIGMA values.

*FATIGUE_MULTIAXIAL

Purpose: Define criterion for multiaxial fatigue analysis. Many mechanical components experience multiaxial cyclic loadings during their service life. Compared with the uniaxial fatigue problem, the multiaxial fatigue problem is more complex due to the complex stress / strain states and loading histories. Fatigue cracks initiate and grow on certain critical planes in the material.

Card 1	1	2	3	4	5	6	7	8
Variable	MAXIAL	NPLANE						
Type	I	I						
Default	0	18						

VARIABLE	DESCRIPTION
MAXIAL	Multiaxial fatigue analysis criterion: EQ.0: Fatigue analysis using equivalent stress or strain index (defined by INDEX in *FATIGUE) EQ.1: Fatigue analysis on multiple planes EQ.2: Fatigue analysis on critical plane which is determined by the highest 1st principal stress or strain
NPLANE	Number of planes for fatigue analysis (for MAXIAL = 1 only)

Remarks:

1. **Multiaxial Fatigue Models.** Several criteria have been implemented in LS-DYNA to run multiaxial fatigue problems.

   a) With MAXIAL = 0, the multiaxial fatigue problem can be simplified to uniaxial fatigue problem using an equivalent scalar stress or strain index, such as Von-Mises stress / strain and maximum principal stress / strain. The equivalent scalar stress or strain index is defined by INDEX in *FATIGUE.

   b) With MAXIAL = 1, fatigue analysis can be performed on multiple predefined planes. The highest fatigue damage value from the planes is taken as the fatigue damage value on that element. The number of planes is defined by NPLANE, with the default value of 18. The inclination angles of the planes range from 0 to NPLANE × $\delta\theta$ where $\delta\theta = 180°/\text{NPLANE}$. This criterion is only valid for shell elements with plane stress condition (and this is true for shell elements on the surface of the structure components).

c) With MAXIAL = 2, fatigue analysis can be performed on a critical plane. LS-DYNA goes through whole time history of stress / strain states and computes the principal stress / strain at each time point. At the time point which gives the highest 1st principal stress / strain, orientation of the principal plane is computed, and this defines the critical plane for fatigue damage computation for the whole time history.

*FATIGUE_SUMMATION

Purpose: Cause LS-DYNA to read in existing fatigue databases defined by *INITIAL_-FATIGUE_DAMAGE_RATIO and sum up the damage ratio results from them to obtain the final cumulative damage ratio. The final cumulative damage ratio results are dumped to a new d3ftg database if BINARY in *DATABASE_FREQUENCY_BINARY_D3FTG is set to 1.