



**LSTC**  
Livermore Software  
Technology Corp.

# **LS-971 R4-EFG User's Manual**

**January 2009**

**LSTC**



## Card 1

Variable	SECID	<b>ELFORM</b>	
Type	I	I	

**ELFORM** EQ.41: EFG formulation  
EQ.42: for 4-noded adaptive EFG

Card 2 and Card 3 define only for the EFG option

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	IDIM	TOLDEF
Type	F	F	F	I	I	I	I	F
Default	1.01	1.01	1.01	0	0	-1	2	0.01
Variable	IGL	STIME	IKEN	SF	MID	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

\*SECTION\_SOLID\_EFG

5, 41

1.1, 1.1, 1.1, , , 7, -1 ,

, 1.5



Normalized dilation parameters (normalized support size) in X, Y and Z directions

Variable	<b>DX</b>	<b>DY</b>	<b>DZ</b>	ISPLINE	IDILA	IEBT	IDIM	TOLDEF
Type	<b>F</b>	<b>F</b>	<b>F</b>	I	I	I	I	F
Default	<b>1.01</b>	<b>1.01</b>	<b>1.01</b>	0	0	-1	2	0.01

- $1.0 \leq DX, DY, DZ \leq 2.0$  is recommended
- CPU time increases with support size

Some Guidelines for DX, DY and DZ

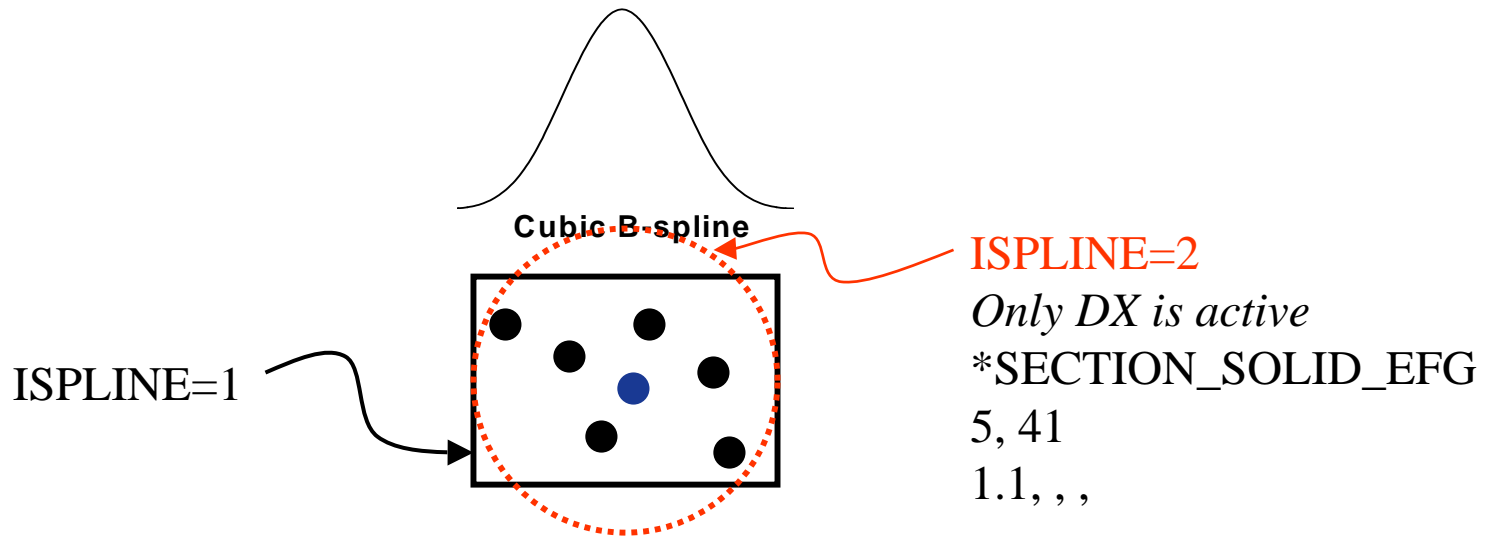
	Regular 'mesh'	Irregular 'mesh'
Foam	1.0~1.2	1.0~1.2
Metal	1.2~1.4	1.0~1.2
Fluid or E.Q.S.	1.4~1.6	1.2~1.4



### EFG kernel function

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	IDIM	TOLDEF
Type	F	F	F	I	I	I	I	F
Default	1.01	1.01	1.01	0	0	-1	2	0.01

- ISPLINE** EQ.0: Cubic spline function (default)
- EQ.1: Quadratic spline function
- EQ.2: Cubic spline function (circular shape)
- EQ.10 Cubic spline function with bilinear bases function





## ■ $C^2$ B-cubic spline function in 1-D

$$w(z) = \begin{cases} \frac{2}{3} - 4|z|^2 + 4|z|^3 & \text{for } 0 \leq |z| \leq \frac{1}{2} \\ \frac{4}{3} - 4|z| + 4|z|^2 + \frac{4}{3}|z|^3 & \text{for } \frac{1}{2} \leq |z| \leq 1 \\ 0 & \text{otherwise} \end{cases}$$
$$z = \frac{x - s}{a}$$

## ■ Multi-dimension

$$\begin{cases} w_a(d_I) = \frac{1}{a} w\left(\frac{d_I}{a}\right); d_I = \|\mathbf{x} - \mathbf{x}_I\| & \text{ISPLINE}=0, 1 \\ w_a(\mathbf{x} - \mathbf{x}_I) = \prod_{i=1}^{n_{sd}} \frac{1}{a_i} w\left(\frac{x_i - x_{iI}}{a_i}\right) & \text{ISPLINE}=2 \end{cases}$$

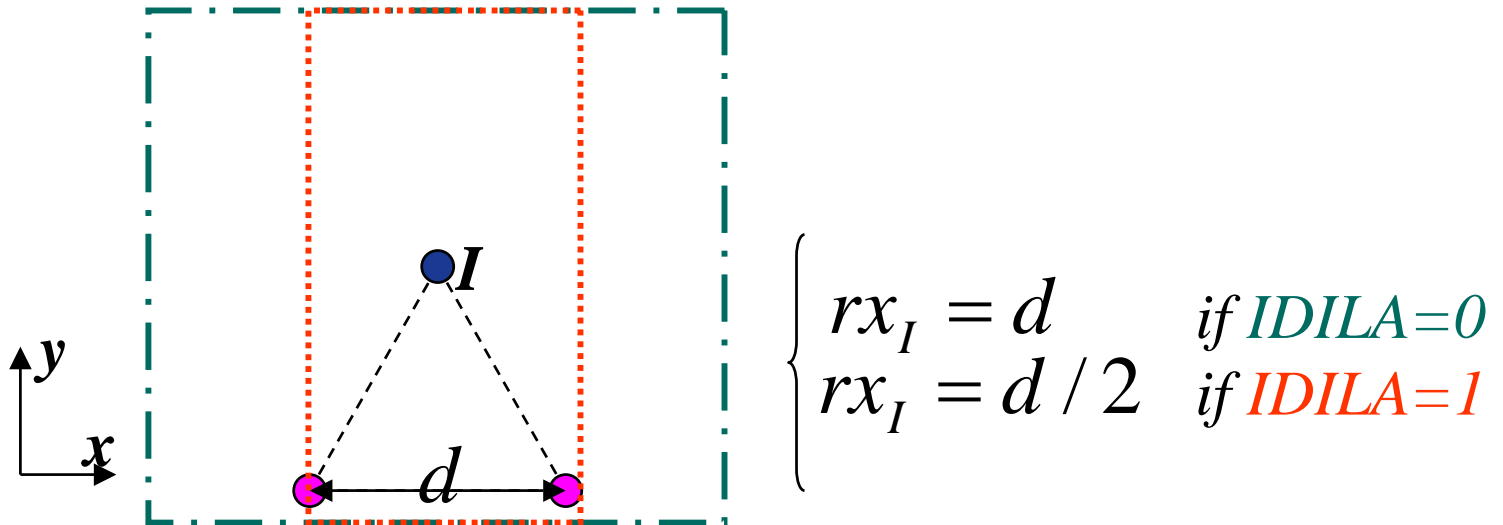


### Choice for the dilation parameter

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	IDIM	TOLDEF
Type	F	F	F	I	I	I	I	F
Default	1.01	1.01	1.01	0	0	-1	2	0.01

**IDILA** EQ.0: Maximum distance based on background elements (default)

EQ.1: Maximum distance based on surrounding nodes



$X\text{-support in computation} = rx_I \cdot DX$



Essential boundary condition treatment

Variable	DX	DY	DZ	ISPLINE	IDILA	<b>IEBT</b>	IDIM	TOLDEF
Type	F	F	F	I	I	<b>I</b>	I	F
Default	1.01	1.01	1.01	0	0	<b>-1</b>	2	0.01

- IEBT** EQ. 1: Full transformation
- EQ.-1: (w/o transformation) (default)
- EQ. 2: Mixed transformation
- EQ. 3: Coupled FEM/EFG
- EQ. 4: Fast transformation
- EQ.-4: (w/o transformation)
- EQ. 5: Fluid particle (trial version)
- EQ. 7: Maximum Entropy approximation

- Mixed transformation is equivalent to Full transformation with improved efficiency.
- Coupled FEM/EFG (IEBT=3) does not work for nearly incompressible materials.
- Fast transformation is suggested for the solid materials.
- Current fluid particle formulation (IEBT=5) only supports for the 4-noded background element.



## Domain integration method

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	<b>IDIM</b>	TOLDEF
Type	F	F	F	I	I	I	<b>I</b>	F
Default	1.01	1.01	1.01	0	0	-1	<b>2</b>	0.01

**IDIM** EQ. 1: Local boundary condition method (default)

EQ. 2: Two-points Gauss integration

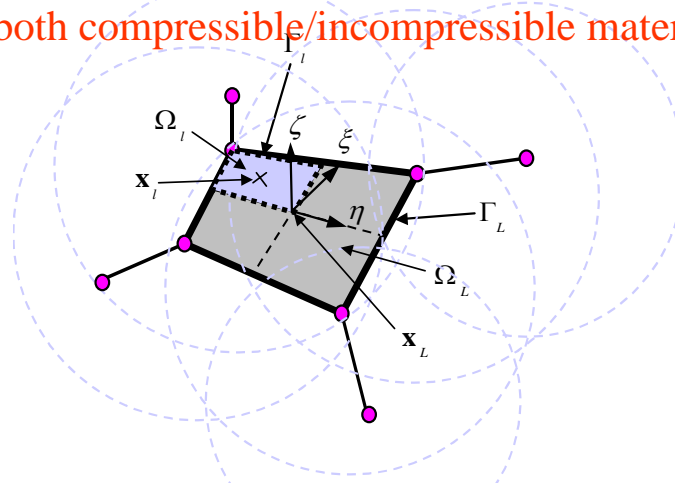
EQ.-1: Stabilized EFG method (apply to 8-noded, 6-noded and combination of them)

EQ.-2: Fractured EFG method (apply to 4-noded & smp only)

■ **IDIM= 1** for compressible materials

■ **IDIM= 2** for nearly incompressible materials

■ **IDIM=-1** applicable for both compressible/incompressible materials (very fast in 8-noded cell)





Deformation tolerance for the activation of Semi-Lagrangian kernel or Eulerian kernel

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	IDIM	<b>TOLDEF</b>
Type	F	F	F	I	I	I	I	<b>F</b>
Default	1.01	1.01	1.01	0	0	-1	2	<b>0.01</b>

**TOLDEF**  $|TODELF| < 1.0$   
= 0.0 : Lagrangian kernel  
> 0.0 : Semi-Lagrangian kernel  
< 0.0 : Eulerian kernel

- The larger number of the  $|TODELF|$ , the earlier activation of Semi-Lagrangian or Eulerian kernel and more CPU time is expected.
- Semi-Lagrangian kernel is suggested in solid.
- Eulerian kernel is suggested in fluid and E.O.S. materials.
- Mass scaling is 'not' supported in Eulerian kernel (SMP only).



Global control for the activation of Semi-Lagrangian kernel or Eulerian kernel

Variable	<b>IGL</b>	STIME	IKEN	SF	MID	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**IGL**

= 0 : local Eulerian kernel or Semi-Lagrangian kernel activation (fast)

= 1 : global Eulerian kernel or Semi-Lagrangian kernel activation (slow)

■ When deformation reaches TOLDEF, the switch of Lagrangian formulation to Eulerian or Semi-Lagrangian kernel formulation is applied locally or globally.



Time control for the activation of Semi-Lagrangian kernel or Eulerian kernel

Variable	IGL	<b>STIME</b>	IKEN	SF	MID	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

■ When time reaches **STIME**, the switch of formulation from stabilized EFG to standard EFG is applied globally.



Kernel approximation in Semi-Lagrangian kernel or Eulerian kernel

Variable	IGL	STIME	<b>IKEN</b>	SF	MID	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**IKEN**

= 0 : Moving-least-square approximation (recommended)

= 1 : Maximum Entropy approximation



Strain filter in fracture analysis

Variable	IGL	STIME	IKEN	SF	MID	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**SF** : For the stress-based cohesive law, a strain filter is recommended as an extra condition for the crack initiation under slow loading. Only when the strain reaches to this value, the crack is allowed to initiate. However, under high dynamic loading, this value should be very small to allow the appearance of “Spall” fracture.



Material identification for EFG fracture analysis

Variable	IGL	STIME	IKEN	SF	<b>MID</b>	IBR	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**MID** Material identification used for EFG fracture analysis

\*SECTION\_SOLID\_EFG

5, 41

1.1, 1.1, 1.1, , , , -2,

,,, **100**, 1, 2.0, 0.2

\*MAT\_COHESIVE\_TH

**100**, 1.0e-07, , 1, 330.0, 0.0001, (for MODE-II, not available)

(not available in card two, will be used for mixed mode later)

Currently, only mode-I is considered and only MAT\_COHESIVE\_TH is available. Only 4-noded integration cell (tet. element) is implemented.



Control for branching in fracture analysis

Variable	IGL	STIME	IKEN	SF	MID	<b>IBR</b>	DS	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**IBR**

- = 1: No branching is allowed.
- = 2: Branching is allowed.



Normalized support in fracture analysis

Variable	IGL	STIME	IKEN	SF	MID	IBR	<b>DS</b>	ECUT
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**DS** : Normalized support defined for computing the displacement jump in fracture analysis

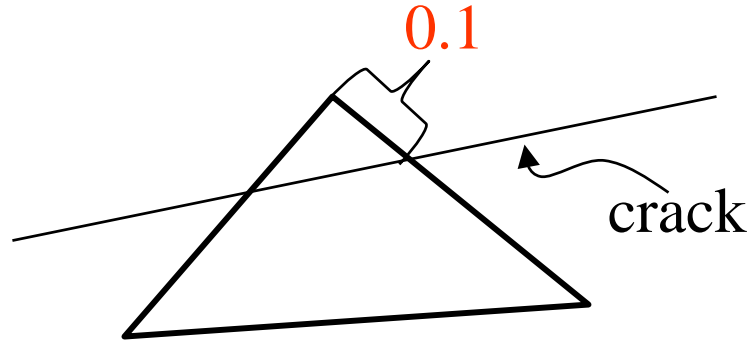


### Minimum edge cut in facture analysis

Variable	IGL	STIME	IKEN	SF	MID	IBR	DS	<b>ECUT</b>
Type	I	F	I	F	I	I	F	F
Default	0	1.e+20	0	0.0		1	1.01	0.1

**ECUT** : 0.0~0.5

Define the minimum edge cut in an integration cell in fracture analysis.





## Some Guidelines for the Parameters

	IEBT	IDIM	TOLDEF
Foam	1,2,3,4,7	1,2,-1	> 0.0
Metal	1,2,4,5,-1,-4,7	2,-1	> 0.0
Fluid or E.Q.S.	5	1=2	< 0.0

- IEBT** EQ. 1: Full transformation  
EQ.-1: (w/o transformation) (default)  
EQ. 2: Mixed transformation  
EQ. 3: Coupled FEM/EFG  
EQ. 4: Fast transformation  
EQ.-4: (w/o transformation)  
EQ. 5: Fluid particles (currently only for 4-noded background element)  
EQ. 7: Maximum Entropy approximation
- IDIM** EQ. 1: Local boundary condition method (default)  
EQ. 2: Two-points Gauss integration  
EQ. -1: Stabilized EFG method  
EQ.-2 : Fracture EFG method
- TOLDEF**  $\geq 0.0$  : Semi-Lagrangian kernel  
 $< 0.0$  : Eulerian kernel



## Card 1

Variable	SECID	<b>ELFORM</b>	SHRF	NIP	PROPT	...		
Type	F	<b>F</b>	F	I	F			
Default								

- ELFORM** EQ. 41: EFG shell (local projection)
- EQ. 42: EFG shell (iso-parametric mapping)
- EQ. 43: EFG 2D plane strain
- EQ. 44: EFG 2D axisymmetric (y-axis of symmetry)

## Card 3 define only for the EFG option

Variable	DX	DY	ISPLINE	IDILA	IEBT	IDIM
Type	F	F	I	I	I	I
Default	1.1	1.1	0	0	1	2

\*SECTION\_SHELL\_EFG

6, 41

1.1, 1.1, , , 4, 1,



**DX, DY, ISPLINE** same as in \*SECTION\_SOLID\_EFG  
IDILA: not available

Essential boundary condition treatment

Variable	DX	DY	ISPLINE	IDILA	<b>IEBT</b>	IDIM
Type	F	F	I	I	<b>I</b>	I
Default	1.01	1.01	0	0	<b>1</b>	2

**IEBT** EQ. 1: Full transformation (default)  
EQ.-1: (w/o transformation)  
EQ. 3: Coupled FEM/EFG



Domain integration method

Variable	DX	DY	DZ	ISPLINE	IDILA	IEBT	<b>IDIM</b>
Type	F	F	F	I	I	I	<b>I</b>
Default	1.01	1.01	1.01	0	0	1	<b>0</b>

**ELFORM = 41**

**IDIM** EQ.1: first-kind Local boundary condition method  
EQ.2: Gauss integration (default)

**ELFORM = 42**

**IDIM** EQ.1: first-kind Local boundary condition method (default)  
EQ.2: second-kind Local boundary condition method

- **ELFORM = 41** is more suitable for crashworthiness analysis
- **ELFORM = 42** is more suitable for metal forming analysis



## Card 1

Variable	ISPLINE	IDILA	ININT
Type	I	I	I
Default	0	0	12

**ININT**: Factor used in the estimation of maximum workspace (MWSPAC) during Initialization.  $MWSPAC = ININT **3 * NUMNEFG$   
 If IMLM in the second card is used, ININT is not needed.

## Card 2

Variable	IMLM	ETOL	IDEB	HSORT	SSORT
Type	I	F	I	I	I
Default	1	1.0e-4	0	0	0

\*CONTROL\_EFG

,,  
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Card 2

Variable	IMLM	ETOL	IDEB	HSORT	SSORT
Type	I	F	I	I	I
Default	2	1.0e-4	0	0	0

**IMLM:** Optional choice in handling the matrix operation, linear solver and memory.  
EQ. 1 : BCSLIB-EXT solvers  
EQ. 2 : EFGPACK ( ININT is not needed ) (recommended)

**ETOL:** Error tolerance in the IMLM.

IDEB : Output internal debug message  
HSORT: not available

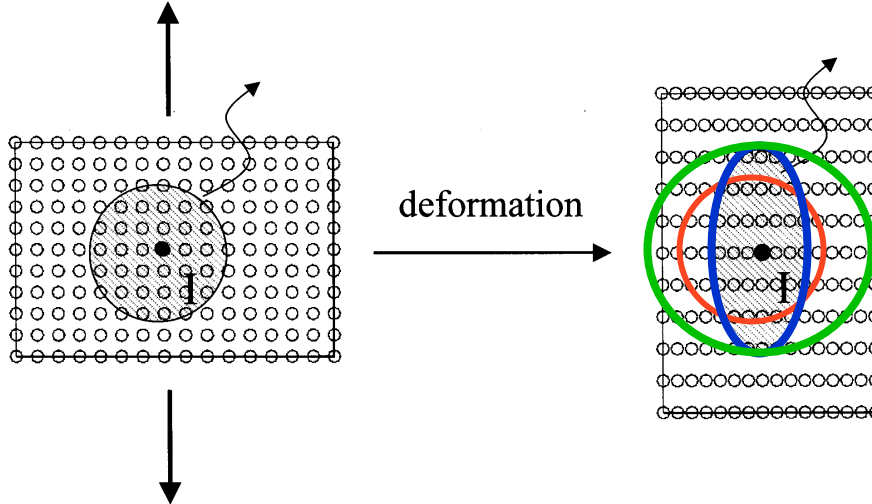
**SSORT:** Automatic sorting of background triangular shell elements to FEM (#2)  
EQ. 0 : no sorting  
EQ. 1 : full sorting



# Appendix



$supp(\Psi_I^{[n]})$  at initial configuration       $supp(\Psi_I^{[n]})$  at current configuration



EFG

⇒ **Lagrangian Kernel:** 1.support is defined in the initial configuration  
2.support covers the same set of material points throughout time

EFG

⇒ **Eulerian Kernel:** 
$$v_i(\mathbf{x}, t) = \frac{\partial u_i(\mathbf{x}, t)}{\partial t} \Big|_{[\mathbf{x}]} + \underbrace{\frac{\partial u_i(\mathbf{x}, t)}{\partial x_j}}_{v_j(\mathbf{x}, t)} v_j(\mathbf{x}, t) = \sum_I \left[ \frac{\partial \Psi_I^x(\mathbf{x}; \mathbf{h}(t))}{\partial t} \Big|_{[\mathbf{x}]} \xi_{il}(t) + \Psi_I^x(\mathbf{x}) \dot{\xi}_{il}(t) + v_j(\mathbf{x}, t) \frac{\partial \Psi_I^x(\mathbf{x}, t)}{\partial x_j} \xi_{il}(t) \right]$$
  
1.support is defined in the current configuration  
2.support covers the different material points throughout time

EFG

⇒ **Semi-Lagrangian Kernel:**  
1.support is defined in the current configuration  
2.support covers same number of material points throughout time