BOUNDARY_ELEMENT_METHOD_*OPTION

Available options include:

CONTROL

FLOW

NEIGHBOR

SYMMETRY

WAKE

Purpose: Define input parameters for boundary element method analysis of incompressible fluid dynamics or fluid-structure interaction problems.

The boundary element method (BEM) can be used to compute the steady state or transient fluid flow about a rigid or deformable body. The theory which underlies the method (see the LS-DYNA Theory Manual) is restricted to inviscid, incompressible, attached fluid flow. The method should not be used to analyze flows where shocks or cavitation are present.

In practice the method can be successfully applied to a wider class of fluid flow problems than the assumption of inviscid, incompressible, attached flow would imply. Many flows of practical engineering significance have large Reynolds numbers (above 1 million). For these flows the effects of fluid viscosity are small if the flow remains attached, and the assumption of zero viscosity may not be a significant limitation. Flow separation does not necessarily invalidate the analysis. If well-defined separation lines exist on the body, then wakes can be attached to these separation lines and reasonable results can be obtained. The Prandtl-Glauert rule can be used to correct for non-zero Mach numbers in a gas, so the effects of aerodynamic compressibility can be correctly modeled (as long as no shocks are present).

The BOUNDARY_ELEMENT_METHOD_FLOW card turns on the analysis, and is mandatory.

This capability is available only with shared memory parallel (SMP) LS-DYNA executables.

*BOUNDARY_ELEMENT_METHOD_CONTROL

Purpose: Control the execution time of the boundary element method calculation. Using the CONTROL keyword option is highly recommended. The BEM calculations can easily dominate the total execution time of an LS-DYNA run unless the parameters on this card (especially DTBEM and/or IUPBEM) are used appropriately.

The field DTBEM is used to increase the time increment between calls to the BEM routines. This can usually be done with little loss in accuracy since the characteristic times of the structural dynamics and the fluid flow can differ by several orders of magnitude. The characteristic time of the structural dynamics in LS-DYNA is given by the size of the smallest structural element divided by the speed of sound of its material. For a typical problem this characteristic time might be equal to 1 microsecond. Since the fluid in the boundary element method is assumed to be incompressible (infinite speed of sound), the characteristic time of the fluid flow is given by the streamwise length of the smallest surface in the flow divided by the fluid velocity. For a typical problem this characteristic time might be equal to 10 milliseconds. For this example DTBEM might be set to 1 millisecond with little loss of accuracy. Thus, for this example, the boundary element method would be called only once for every 1000 LS-DYNA iterations, saving an enormous amount of computer time.

The field IUPBEM is used to increase the number of times the BEM routines are called before the matrix of influence coefficients is recomputed and factored (these are time-consuming procedures). If the motion of the body is entirely rigid body motion, there is no need to ever recompute and factor the matrix of influence coefficients after initialization, and the execution time of the BEM can be significantly reduced by setting IUPBEM to a very large number. For situations where the structural deformations are modest an intermediate value, such as 10, for IUPBEM can be used.

Card 1	1	2	3	4	5	6	7	8
Variable	LWAKE	DTBEM	IUPBEM	FARBEM				
Type	I	F	I	F				
Default	50	0.	100	2.0				
Remarks	1			2				

VARIABLE	DESCRIPTION
LWAKE	Number of elements in the wake of lifting surfaces. Wakes must be defined for all lifting surfaces.
DTBEM	Time increment between calls to the boundary element method. The fluid pressures computed during the previous call to the BEM will continue to be used for subsequent LS-DYNA iterations until a time increment of DTBEM has elapsed.
IUPBEM	The number of times the BEM routines are called before the matrix of influence coefficients is recomputed and refactored.
FARBEM	Non-dimensional boundary between near-field and far-field calculation of influence coefficients.

Remarks:

1. **Wakes.** Wakes convect with the free-stream velocity. The number of elements in the wake should be set to provide a total wake length equal to 5-10 times the characteristic streamwise length of the lifting surface to which the wake is attached. Note that each wake element has a streamwise length equal to the magnitude of the free stream velocity multiplied by the time increment between calls to the boundary element method routines. This time increment is controlled by DTBEM.

2. **FARBEM.** The most accurate results will be obtained with FARBEM set to 5 or more, while values as low as 2 will provide slightly reduced accuracy with a 50% reduction in the time required to compute the matrix of influence coefficients.

*BOUNDARY_ELEMENT_METHOD_FLOW

Purpose: Turn on the boundary element method calculation, specify the set of shells which define the surface of the bodies of interest, and specify the onset flow.

The *BOUNDARY_ELEMENT_METHOD_FLOW card turns on the BEM calculation. This card also identifies the shell elements which define the surfaces of the bodies of interest, and the properties of the onset fluid flow. The onset flow can be zero for bodies which move through a fluid which is initially at rest.

Card 1	1	2	3	4	5	6	7	8
Variable	SSID	VX	VY	VZ	RO	PSTATIC	MACH	
Type	I	F	F	F	F	F	F	
Default	none	none	none	none	none	0.	0.	
Remark	1					2	3	

VARIABLE	DESCRIPTION
SSID	Shell set ID for the set of shell elements which define the surface of the bodies of interest (see *SET_SHELL). The nodes of these shells should be ordered so that the shell normal vectors point into the fluid.
VX, VY, VZ	x, y, and z components of the free-stream fluid velocity
RO	Fluid density
PSTATIC	Fluid static pressure
MACH	Free-stream Mach number

Remarks:

1. **Recommended Model Setup.** Using the NULL material (see *MAT_NULL) for the shell segments in the SSID set is recommended. Fluid pressures can then be displayed in the post-processor. For triangular shells the 4th node number should be the same as the 3rd node number. For fluid-structure interaction problems the boundary element shells should use the same nodes and be coincident

with the structural shell elements (or the outer face of solid elements) which define the surface of the body. This approach guarantees that the boundary element segments will move with the surface of the body as it deforms.

2. **Fluid Static Pressure.** A pressure of PSTATIC is applied uniformly to all segments in the segment set. If the body of interest is hollow, then PSTATIC should be set to the free-stream static pressure minus the pressure on the inside of the body.

3. **Subsonic Compressibility.** The effects of subsonic compressibility on gas flows can be included using a non-zero value for MACH. The pressures which arise from the fluid flow are increased using the Prandtl-Glauert compressibility correction. MACH should be set to zero for water or other liquid flows.

*BOUNDARY_ELEMENT_METHOD_NEIGHBOR

Purpose: Define the neighboring elements for a given boundary element segment.

The pressure at the surface of a body is determined by the gradient of the doublet distribution on the surface (see the LS-DYNA Theory Manual). The "Neighbor Array" is used to specify how the gradient is computed for each boundary element segment. Ordinarily, the Neighbor Array is set up automatically by LS-DYNA, and no user input is required. The NEIGHBOR option is provided for those circumstances when the user desires to define this array manually.

Elements Cards. 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	NELEM	NABOR1	NABOR2	NABOR3	NABOR4			
Type	I	I	I	I	I			
Default	none	none	none	none	none			

VARIABLE	DESCRIPTION
NELEM	Element number
NABOR1	Neighbor for side 1 of NELEM.
NABOR2	Neighbor for side 2 of NELEM.
NABOR3	Neighbor for side 3 of NELEM.
NABOR4	Neighbor for side 4 of NELEM.

Remarks:

Each boundary element has 4 sides (Figure 6-1). Side 1 connects the 1st and 2nd nodes, side 2 connects the 2nd and 3rd nodes, etc. The 4th side is null for triangular elements.

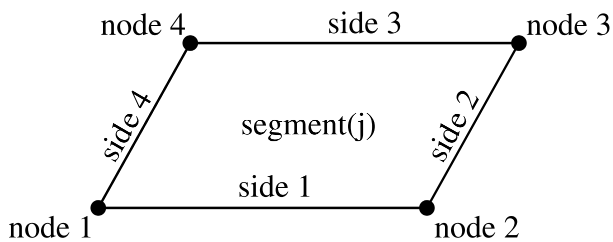

Figure 6-1. Each segment has 4 sides.

For most elements the specification of neighbors is straightforward. For the typical case a quadrilateral element is surrounded by 4 other elements, and the neighbor array is as shown in Figure 6-2.

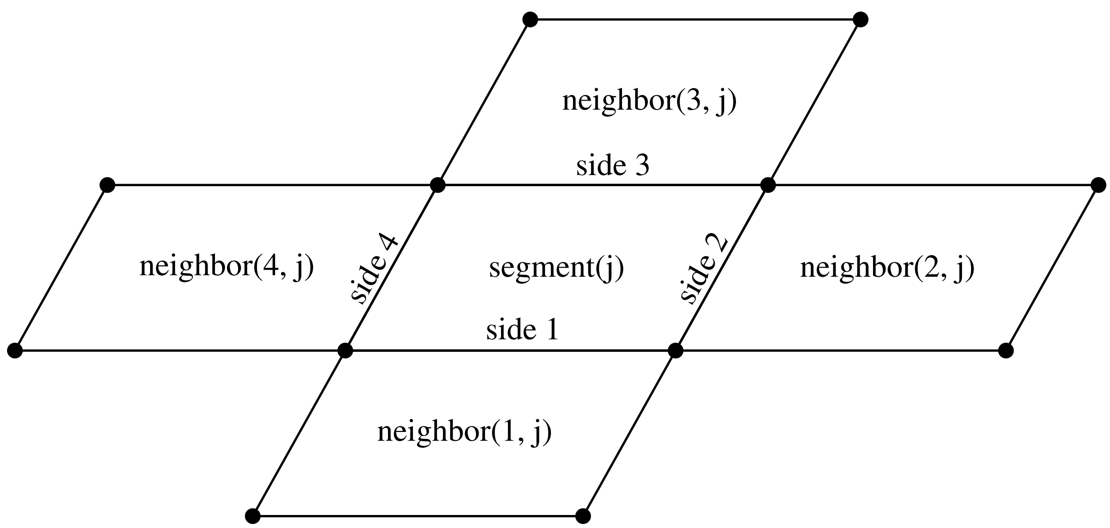

Figure 6-2. Typical neighbor specification.

There are several situations for which the user may desire to directly specify the neighbor array for certain elements. For example, boundary element wakes result in discontinuous doublet distributions, and neighbors which cross a wake should not be used. Figure 6-3 illustrates a situation where a wake is attached to side 2 of segment j. For this situation two options exist. If neighbor(2,j) is set to zero, then a linear computation of the gradient in the side 2 to side 4 direction will be made using the difference between the doublet strengths on segment j and segment neighbor(4,j). This is the default setup used by LS-DYNA when no user input is provided. By specifying neighbor(2,j) as a negative number a more accurate quadratic curve fit will be used to compute the gradient. The curve fit will use segment j, segment neighbor(4,j), and segment -neighbor(2,j); which is located on the opposite side of segment neighbor(4,j) as segment j.

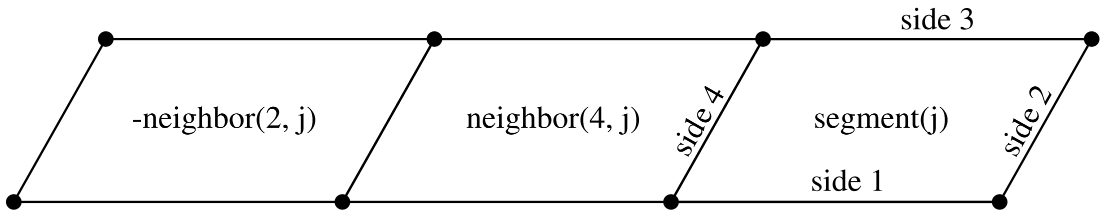

Figure 6-3. If neighbor(2,j) is a negative number, it is assumed to lie on the opposite side of neighbor(4,j) as segment j.

Another possibility is that no neighbors at all are available in the side 2 to side 4 direction. In this case both neighbor(2,j) and neighbor(4,j) can be set to zero, and the gradient in that direction will be assumed to be zero. This option should be used with caution, as the resulting fluid pressures will not be accurate for three-dimensional flows. However, this option is occasionally useful where quasi-two dimensional results are desired. All of the above options apply to the side 1 to side 3 direction in the obvious ways.

For triangular boundary elements side 4 is null. Gradients in the side 2 to side 4 direction can be computed as described above by setting neighbor(4,j) to zero for a linear derivative computation (this is the default setup used by LS-DYNA when no user input is provided) or to a negative number to use the segment on the other side of neighbor(2,j) and a quadratic curve fit. There may also be another triangular segment which can be used as neighbor(4,j) (see Figure 6-4).

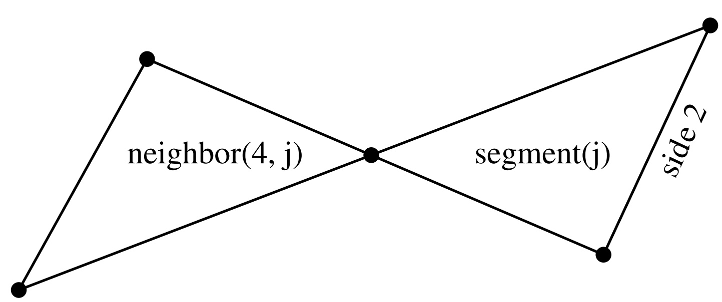

Figure 6-4. Sometimes another triangular boundary element segment can be used as neighbor (4,j).

The rules for computing the doublet gradient in the side 2 to side 4 direction can be summarized as follows (the side 1 to side 3 case is similar):

NABOR2	NABOR4	Doublet Gradient Computation
GT.0	GT.0	Quadratic fit using elements j, NABOR2, and NABOR4.
LT.0	GT.0	Quadratic fit using elements j, -NABOR2, and NABOR4. -NABOR2 is assumed to lie on the opposite side of NABOR4 as segment j (see Fig. 6-3).
GT.0	LT.0	Quadratic fit using elements j, NABOR2, and -NABOR4. -NABOR4 is assumed to lie on the opposite side of NABOR2 as segment j.
EQ.0	GT.0	Linear fit using elements j and NABOR4.
GT.0	EQ.0	Linear fit using elements j and NABOR2.
EQ.0	EQ.0	Zero gradient.

Table 6-5. Surface pressure computation for element j.

*BOUNDARY_ELEMENT_METHOD_SYMMETRY

Purpose: To define a plane of symmetry for the boundary element method. The SYMMETRY option can be used to reduce the time and memory required for symmetric configurations. For these configurations the reduction in the number of boundary elements by a factor of 2 will reduce the memory used by the boundary element method by a factor of 4 and will reduce the compute time required to factor the matrix of influence coefficients by a factor of 8. Only 1 plane of symmetry can be defined.

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

VARIABLE	DESCRIPTION
BEMSYM	Defines symmetry plane for boundary element method. EQ.0: no symmetry plane is defined EQ.1: $x = 0$ is a symmetry plane EQ.2: $y = 0$ is a symmetry plane EQ.3: $z = 0$ is a symmetry plane

*BOUNDARY_ELEMENT_METHOD_WAKE

Purpose: To attach wakes to the trailing edges of lifting surfaces. Wakes should be attached to boundary elements at the trailing edge of a lifting surface (such as a wing, propeller blade, rudder, or diving plane). Wakes should also be attached to known separation lines when detached flow is known to exist (such as the sharp leading edge of a delta wing at high angles of attack). Wakes are required for the correct computation of surface pressures for these situations. As described above, two segments on opposite sides of a wake should never be used as neighbors.

Element Cards. (The next "*" card terminates the input.)

Card 1	1	2	3	4	5	6	7	8
Variable	NELEM	NSIDE						
Type	I	I						
Default	none	none						
Remarks	1							

VARIABLE	DESCRIPTION
NELEM	Element number to which a wake is attached.
NSIDE	The side of NELEM to which the wake is attached (see Figure 6-1). This should be the "downstream" side of NELEM.

Remarks:

1. **Elements and Wake.** Normally two elements meet at a trailing edge (one on the "upper" surface and one on the "lower" surface). The wake can be attached to either element, but not to both.