*AIRBAG

Purpose: Define an airbag or control volume.

The keyword *AIRBAG provides a way of defining thermodynamic behavior of the gas flow into the airbag as well as a reference configuration for the fully inflated bag. The keyword cards in this section are defined in alphabetical order:

AIRBAG_*OPTION1_{OPTION2}_{OPTION3}_{OPTION4}

*AIRBAG_ALE

*AIRBAG_CPG

*AIRBAG_INTERACTION

*AIRBAG_PARTICLE

*AIRBAG_REFERENCE_GEOMETRY

*AIRBAG_SALE

*AIRBAG_SHELL_REFERENCE_GEOMETRY

***AIRBAG**_*OPTION1*_*{OPTION2}*_*{OPTION3}*_*{OPTION4}*

OPTION1 specifies one of the following thermodynamic models for modeling airbags using a control volume (CV) approach:

SIMPLE_PRESSURE_VOLUME

SIMPLE_AIRBAG_MODEL

ADIABATIC_GAS_MODEL

WANG_NEFSKE

WANG_NEFSKE_JETTING

WANG_NEFSKE_MULTIPLE_JETTING

LOAD_CURVE

LINEAR_FLUID

HYBRID

HYBRID_JETTING

HYBRID_CHEMKIN

FLUID_AND_GAS

OPTION2 specifies that an additional line of data is read for the WANG_NEFSKE type thermodynamic relationships. The additional data controls the initiation of exit flow from the airbag. *OPTION2* takes the single option:

POP

OPTION3 specifies that a constant momentum formulation is used to calculate the jetting load on the airbag an additional line of data is read in. *OPTION3* takes the single option:

CM

OPTION4, given by:

ID

specifies that an airbag ID and heading information will be the first card of the airbag definition. This ID is a unique number that is necessary for the identification of the airbags in the definition of airbag interaction using *AIRBAG_INTERACTION keyword. The numeric IDs and heading are written into the abstat and d3hsp files.

Core Cards: Common to all airbags

ID Card. Additional card for the ID keyword option. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

Card ID	1	2	3	4	5	6	7	8
Variable	ABID	HEADING						
Type	I	A70						

Card 1	1	2	3	4	5	6	7	8
Variable	SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF
Type	I	I	I	F	F	F	F	F
Default	none	0	0	1.	1.	0.	0.	0.
Remark			optional					

VARIABLE	DESCRIPTION
ABID	Airbag ID. This must be a unique number.
HEADING	Airbag descriptor. It is suggested that unique descriptions be used.
SID	Set ID
SIDTYP	Set type: EQ.0: segment NE.0: part set ID
RBID	Rigid body part ID for user defined activation subroutine: LT.0: -RBID is taken as the rigid body part ID. Built in sensor subroutine initiates the inflator. Load curves are offset by initiation time. EQ.0: the control volume is active from time zero.

VARIABLE	DESCRIPTION
	GT.0: RBID is taken as the rigid body part ID. User sensor subroutine initiates the inflator. Load curves are offset by initiation time. See Appendix D.
VSCA	Volume scale factor (default = 1.0)
PSCA	Pressure scale factor (default = 1.0)
VINI	Initial filled volume
MWD	Mass weighted damping factor, D
SPSF	Stagnation pressure scale factor, $0 \leq \gamma \leq 1$

Remarks:

Card 1 is necessary for all airbag options. The option dependent cards follow.

Lumped parameter control volumes are a mechanism for determining volumes of closed surfaces and applying a pressure based on some thermodynamic relation. The volume is specified by a list of polygons similar to the pressure boundary condition cards or by specifying a material subset which represents shell elements that form the closed boundary. All polygon normal vectors must be oriented to face *outwards* from the control volume; however for *AIRBAG_PARTICLE, which does not rely on control volumes, all polygon normal vectors must be oriented to face *inwards* to get proper volume (see *AIRBAG_PARTICLE). If holes are detected, they are assumed to be covered by planar surfaces.

There are two sets of volume and pressure variables used for each control volume model. First, the finite element model computes a volume V_{femodel} and applies a pressure P_{femodel}. The thermodynamics of a control volume may be computed in a different unit system with its own set of variables: V_{cvolume} and P_{cvolume} which are used for integrating the differential equations for the control volume. The conversion is as follows:

$$V_{\text{cvolume}} = (\text{VSCA} \times V_{\text{femodel}}) - \text{VINI}$$
$$P_{\text{femodel}} = \text{PSCA} \times P_{\text{cvolume}}$$

where VSCA, PSCA, and VINI are input parameters. Damping can be applied to the structure enclosing a control volume by using a mass weighted damping formula:

$$F_i^d = m_i D(v_i - v_{\text{cg}}) \ ,$$

where F_i^d is the damping force, m_i is the nodal mass, v_i is the velocity for a node, v_{cg} is the mass weighted average velocity of the structure enclosing the control volume, and D is the damping factor.

An alternative, separate damping is based on the stagnation pressure. The stagnation pressure is roughly the maximum pressure on a flat plate oriented normal to a steady state flow field. The stagnation pressure is defined as $p = \gamma \rho V^2$, where V is the normal velocity of the control volume relative to the ambient velocity, ρ is the ambient air density, and γ is a factor which varies from 0 to 1 that must be chosen by the user. Small values are recommended to avoid excessive damping.

Sensor Input:

The sensor is mounted on a rigid body which is attached to the structure. *The motion of the sensor is evaluated in the local coordinate system of the rigid body. See *MAT_RIGID.* This local system rotates and translates with the rigid material. The default local system for a rigid body is taken as the principal axes of the inertia tensor.

When the user defined criterion for airbag deployment is satisfied, a flag is set and deployment begins. All load curves relating to the mass flow rate as a function of time are then shifted by the initiation time.

RBID = 0: No Rigid Body

For this case there is no rigid body, and the control volume is active from time zero. There are no additional sensor cards.

RBID > 0: User Supplied Sensor Subroutine

The value of RBID is taken as a rigid body part ID, and a user supplied sensor subroutine will be called to determine the flag that initiates deployment. See Appendix D for details regarding the user supplied subroutine. For RBID > 0 the additional cards are specified below:

User Subroutine Control Card. This card is read in when RBID > 0.

Card 2a	1	2	3	4	5	6	7	8
Variable	N							
Type	I							
Default	none							

User Subroutine Constant Cards. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

Card 2a.1	1	2	3	4	5	6	7	8
Variable	C1	C2	C3	C4	C5			
Type	F	F	F	F	F			
Default	0.	0.	0.	0.	0.			

VARIABLE	DESCRIPTION
N	Number of input parameters (not to exceed 25)
C1, …, CN	Up to 25 constants for the user subroutine

RBID < 0: User supplied sensor subroutine

The value of –RBID is taken as rigid body part ID and a built in sensor subroutine is called. For RBID < 0, there are three additional cards.

Acceleration Sensor Card.

Card 2b.1	1	2	3	4	5	6	7	8
Variable	AX	AY	AZ	AMAG	TDUR			
Type	F	F	F	F	F			
Default	0.	0.	0.	0.	0.			

Velocity Sensor Card.

Card 2b.2	1	2	3	4	5	6	7	8
Variable	DVX	DVY	DVZ	DVMAG				
Type	F	F	F	F				
Default	0.	0.	0.	0.				

Displacement Sensor Card.

Card 2b.3	1	2	3	4	5	6	7	8
Variable	UX	UY	UZ	UMAG				
Type	F	F	F	F				
Default	0.	0.	0.	0.				

VARIABLE	DESCRIPTION
AX	Acceleration level in the local x-direction to activate inflator. The absolute value of the x-acceleration is used. EQ.0: inactive
AY	Acceleration level in local the y-direction to activate inflator. The absolute value of the y-acceleration is used. EQ.0: inactive
AZ	Acceleration level in the local z-direction to activate inflator. The absolute value of the z-acceleration is used. EQ.0: inactive
AMAG	Acceleration magnitude required to activate inflator. EQ.0: inactive
TDUR	Time duration acceleration must be exceeded before the inflator activates. This is the cumulative time from the beginning of the calculation, meaning it is not continuous.

VARIABLE	DESCRIPTION
DVX	Velocity change in the local x-direction to activate the inflator. (The absolute value of the velocity change is used.) EQ.0: inactive
DVY	Velocity change in the local y-direction to activate the inflator. (The absolute value of the velocity change is used.) EQ.0: inactive
DVZ	Velocity change in the local z-direction to activate the inflator. (The absolute value of the velocity change is used.) EQ.0: inactive
DVMAG	Velocity change magnitude required to activate the inflator. EQ.0: inactive
UX	Displacement increment in the local x-direction to activate the inflator. (The absolute value of the x-displacement is used.) EQ.0: inactive
UY	Displacement increment in the local y-direction to activate the inflator. (The absolute value of the y-displacement is used.) EQ.0: inactive
UZ	Displacement increment in the local z-direction to activate the inflator. (The absolute value of the z-displacement is used.) EQ.0: inactive
UMAG	Displacement magnitude required to activate the inflator. EQ.0: inactive

AIRBAG_SIMPLE_PRESSURE_VOLUME_*{OPTION}

Card Summary:

The additional card required for the SIMPLE_PRESSURE_VOLUME keyword is Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

CN	BETA	LCID	LCIDDR				

Data Card Definitions:

Additional card for SIMPLE_PRESSURE_VOLUME option. (For card 1 see the "core cards" section of *AIRBAG.)

Card 3	1	2	3	4	5	6	7	8
Variable	CN	BETA	LCID	LCIDDR				
Type	F	F	I	I				
Default	none	none	none	0				

VARIABLE	DESCRIPTION
CN	Coefficient. Define if the load curve ID, LCID, is unspecified. LT.0.0: |CN| is the load curve ID, which defines the coefficient as a function of time.
BETA	Scale factor, β. Define if a load curve ID is not specified.
LCID	Optional load curve ID defining pressure as a function of relative volume.
LCIDDR	Optional load curve ID defining the coefficient, CN, as a function of time during the dynamic relaxation phase.

Remarks:

Pressure is calculated using the following:

$$\text{Pressure} = \frac{\beta \times \text{CN}}{\text{Relative Volume}}$$

$$\text{Relative Volume} = \frac{\text{Current Volume}}{\text{Initial Volume}}$$

The pressure, therefore, is a function of the ratio of current volume to the initial volume. The constant, CN, is used to establish a relationship known from the literature. The scale factor β is simply used to scale the given values. This simple model can be used when an initial pressure is given and no leakage, no temperature, and no input mass flow is assumed. A typical application is the modeling of air in automobile tires.

The load curve, LCIDDR, can be used to ramp up the pressure during the dynamic relaxation phase to avoid oscillations after the desired gas pressure is reached. In the DE-

FINE_CURVE section this load curve must be flagged for dynamic relaxation. After initialization either the constant or load curve ID, |CN|, is used to determine the pressure.

AIRBAG_SIMPLE_AIRBAG_MODEL_*{OPTION}

Card Summary:

The additional cards required for the SIMPLE_AIRBAG_MODEL option begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

CV	CP	T	LCID	MU	AREA	PE	RO

Card 4a. This card is included if CV = 0.

LOU	T_EXT	A	B	MW	GASC		

Card 4b. This card is included if CV ≠ 0.

LOU							

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	CV	CP	T	LCID	MU	AREA	PE	RO
Type	F	F	F	I	F	F	F	F
Default	none	none	none	none	none	none	none	none

VARIABLE	DESCRIPTION
CV	Heat capacity at constant volume (e.g., Joules/kg/°K). See Remark 3.
CP	Heat capacity at constant pressure (e.g., Joules/kg/°K). See Remark 3.
T	Temperature of input gas
LCID	Load curve ID specifying input mass flow rate. See *DEFINE_CURVE. See Remark 2.
MU	Shape factor for exit hole, μ (see Remark 2): LT.0.0: $\lvert\mu\rvert$ is the load curve number defining the shape factor as a function of absolute pressure.
AREA	Exit area, A (see Remark 2): GE.0.0: A is the exit area and is constant in time. LT.0.0: $\lvert A\rvert$ is the load curve number defining the exit area as a function of absolute pressure.
PE	Ambient pressure, p_e
RO	Ambient density, ρ

Card 4a	1	2	3	4	5	6	7	8
Variable	LOU	T_EXT	A	B	MW	GASC		
Type	I	F	F	F	F	F		
Default	0	0.	0.	0.	0.	0.		

VARIABLE	DESCRIPTION
LOU	Optional load curve ID giving mass flow out as a function of gauge pressure in bag. See *DEFINE_CURVE. See Remark 2.
T_EXT	Ambient temperature
A	First heat capacity coefficient of inflator gas (e.g., Joules/mole/^{o}K)
B	Second heat capacity coefficient of inflator gas, (e.g., Joules/mole/$^{o}K^{2}$)
MW	Molecular weight of inflator gas (e.g., kg/mole)
GASC	Universal gas constant of inflator gas (e.g., 8.314 Joules/mole/^{o}K)

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

VARIABLE	DESCRIPTION
LOU	Optional load curve ID giving mass flow out as a function of gauge pressure in bag. See *DEFINE_CURVE. See Remark 2.

Remarks:

1. **Airbag pressure.** The gamma law equation of state used to determine the pressure in the airbag is given by:

$$p = (\gamma - 1)\rho e \ ,$$

where p is the pressure, ρ is the density, e is the specific internal energy of the gas, and γ is the ratio of the specific heats, such that

$$\gamma = \frac{c_p}{c_v} \ .$$

Here c_v is the specific heat at constant volume, and c_p is the specific heat at constant pressure. See Remark 3. A pressure relation is defined as:

$$Q = \frac{p_e}{p} \ ,$$

where p_e is the external pressure and p is the internal pressure in the bag. A critical pressure relationship is defined as:

$$Q_{\mathrm{crit}} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma - 1}},$$

where γ is the ratio of specific heats as defined above and

$$Q \le Q_{\mathrm{crit}} \Rightarrow Q = Q_{\mathrm{crit}} \ .$$

2. **Leakage.** From conservation of mass, the time rate of change of mass flowing into the bag is given as:

$$\frac{dM}{dt} = \frac{dM_{\mathrm{in}}}{dt} - \frac{dM_{\mathrm{out}}}{dt} \ .$$

The inflow mass flow rate is given by the load curve ID, LCID. Leakage, the mass flow rate out of the bag, can be modeled in two alternative ways. One is to give an exit area with the corresponding shape factor. In this case, the load curve ID, LOU, must be set to zero. The mass flow rate is given by:

$$\frac{dM_{\mathrm{out}}}{dt} = \mu A \sqrt{2p\rho} \sqrt{\frac{\gamma\left(Q^{\frac{2}{\gamma}} - Q^{\frac{\gamma+1}{\gamma}}\right)}{\gamma - 1}}$$

where μ is the shape factor for the exit hole, A is the exit area, p is the pressure, ρ is the density, γ is the ratio of specific heats (see Remark 1), and Q is the ratio of the external pressure to the internal pressure (see Remark 1). The other method is to define a mass flow out by a load curve, LOU. In this case, μ and A must both be set to zero.

3. **Specific heats.** If CV = 0. then the constant-pressure specific heat is given by:

$$c_p = \frac{(a + bT)}{\mathrm{MW}} \ ,$$

and the constant-volume specific heat is then found from:

$$c_v = c_p - \frac{R}{\mathrm{MW}} \ .$$

AIRBAG_ADIABATIC_GAS_MODEL_*{OPTION}

Card Summary:

The additional cards required for the ADIABATIC_GAS_MODEL option begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

PSF	LCID	GAMMA	P0	PE	R0		

Card 3	1	2	3	4	5	6	7	8
Variable	PSF	LCID	GAMMA	P0	PE	RO		
Type	F	I	F	F	F	F		
Default	1.0	none	none	none	none	none		

VARIABLE	DESCRIPTION
PSF	Pressure scale factor
LCID	Optional load curve for preload flag. See *DEFINE_CURVE.
GAMMA	Ratio of specific heats
P0	Initial pressure (gauge)
PE	Ambient pressure
RO	Initial density of gas

Remarks:

The optional load curve ID, LCID, defines a preload flag. During the preload phase the function value of the load curve versus time is zero, and the pressure in the control volume is given as:

$$p = \mathrm{PSF} \times p_0$$

When the *first nonzero* function value is encountered, the preload phase stops and the ideal gas law applies for the rest of the analysis. If LCID is zero, no preload is performed.

The gamma law equation of state for the adiabatic expansion of an ideal gas is used to determine the pressure after preload:

$$p = (\gamma - 1)\rho e \ ,$$

where p is the pressure, ρ is the density, e is the specific internal energy of the gas, and γ is the ratio of the specific heats:

$$\gamma = \frac{c_p}{c_v} \ .$$

The pressure above is the absolute pressure. The resultant pressure acting on the control volume is:

$$p_s = \text{PSF} \times (p - p_e)$$

where PSF is the pressure scale factor. Starting from the initial pressure p_0 an initial internal energy is calculated:

$$e_0 = \frac{p_0 + p_e}{\rho(\gamma - 1)} \ .$$

AIRBAG_WANG_NEFSKE_*{OPTIONS}

Card Summary:

The additional cards required for WANG_NEFSKE, WANG_NEFSKE_JETTING, and WANG_NEFSKE_MULTIPLE_JETTING option begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if the ID keyword option is used. To use the *AIRBAG_-INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

CV	CP	T	LCT	LCMT	TVOL	LCDT	IABT

Card 4. This card is required.

C23	LCC23	A23	LCA23	CP23	LCCP23	AP23	LCAP23

Card 5. This card is required.

PE	RO	GC	LCEFR	POVER	PPOP	OPT	KNKDN

Card 6. If the inflator is modeled (LCMT = 0), fill in the following card. If not, include but leave blank.

IOC	IOA	IVOL	IRO	IT	LCBF		

Card 7. Include this card when CV = 0.

TEXT	A	B	MW	GASC	HCONV		

Card 8. This card is included if and only if the POP keyword option is used.

TDP	AXP	AYP	AZP	AMAGP	TDURP	TDA	RBIDP

Card 9a. This card is included if the WANG_NEFKSE_JETTING keyword option is used.

XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	CA	BETA

Card 9b. This card is included if the WANG_NEFSKE_MULTIPLE_JETTING keyword option is used.

XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	LCJRV	BETA

Card 10. This card is included if either the WANG_NEFKSE_JETTING or the WANG_-NEFKSE_MULTIPLE_JETTING keyword option is used.

XSJFP	YSJFP	ZSJFP	PSID	ANGLE	NODE1	NODE2	NODE3

Card 11. The is card is included if the CM keyword option is used.

NREACT							

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	CV	CP	T	LCT	LCMT	TVOL	LCDT	IABT
Type	F	F	F	I	I	F	I	F
Default	none	none	0.	0	none	0.	0.	not used

VARIABLE	DESCRIPTION
CV	Specific heat at constant volume, e.g., Joules/kg/°K
CP	Specific heat at constant pressure, e.g., Joules/kg/°K
T	Temperature of input gas. For temperature variations a load curve, LCT, may be defined.
LCT	Optional load curve ID defining temperature of input gas as a function of time. This overrides T.
LCMT	Load curve specifying input mass flow rate or tank pressure versus time. If the tank volume, TVOL, is nonzero the curve ID is assumed to be tank pressure as a function of time. If LCMT = 0, then the inflator must be modeled; see Card 6. During the dynamic relaxation phase the airbag is ignored unless the curve is flagged to act during dynamic relaxation.
TVOL	Tank volume which is required only for the tank pressure as a function of time curve, LCMT.
LCDT	Load curve for time rate of change of temperature (dT/dt) as a function of time.
IABT	Initial airbag temperature. (Optional, generally not defined.)

Card 4	1	2	3	4	5	6	7	8
Variable	C23	LCC23	A23	LCA23	CP23	LCCP23	AP23	LCAP23
Type	F	I	F	I	F	I	F	I
Default	none	0	none	0	none	0	0.0	0

VARIABLE	DESCRIPTION
C23	Vent orifice coefficient which applies to exit hole. Set to zero if LC-C23 is defined below.
LCC23	The absolute value, |LCC23|, is a load curve ID. If the ID is positive, the load curve defines the vent orifice coefficient which applies to exit hole as a function of time. If the ID is negative, the vent orifice coefficient is defined as a function of relative pressure, $P_{\text{air}}/P_{\text{bag}}$;

VARIABLE	DESCRIPTION
	see [Anagonye and Wang 1999]. In addition, LCC23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for C23 overrides LCC23.
A23	Vent orifice area: GT.0.0: Vent orifice area which applies to exit hole LT.0.0: The absolute value |A23| is a part ID, see [Anagonye and Wang, 1999]. With LCA23 = -1, |A23| is a part set representing venting holes. The venting leakage through each venting hole represented by a part in part set |A23| is output to abstat. The area of this part/set becomes the vent orifice area. With SIDTYP > 0, airbag pressure will not be applied to part/set |A23| representing venting holes if part/set |A23| is not included in SID, the part set representing the airbag. EQ.0.0: Set A23 to zero if LCA23 is ≠ 0.
LCA23	Load curve defining the vent orifice area which applies to exit hole as a function of *absolute* pressure, or LCA23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for A23 overrides LCA23.
CP23	Orifice coefficient for leakage (fabric porosity). Set to zero if LCCP23 is defined below.
LCCP23	Load curve defining the orifice coefficient for leakage (fabric porosity) as a function of time, or LCCP23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for CP23 overrides LCCP23.
AP23	Area for leakage (fabric porosity)
LCAP23	Load curve defining the area for leakage (fabric porosity) as a function of (absolute) pressure, or LCAP23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for AP23 overrides LCAP23.

Card 5	1	2	3	4	5	6	7	8
Variable	PE	RO	GC	LCEFR	POVER	PPOP	OPT	KNKDN
Type	F	F	F	I	F	F	F	I
Default	none	none	none	0	0.0	0.0	0.0	0

VARIABLE	DESCRIPTION
PE	Ambient pressure
RO	Ambient density
GC	Gravitational conversion constant (mandatory - no default). If consistent units are being used for all parameters in the airbag definition, then unity should be input.
LCEFR	Optional curve for exit flow rate (mass/time) as a function of (gauge) pressure
POVER	Initial relative overpressure (gauge), P_{over} in control volume
PPOP	Pop Pressure: relative pressure (gauge) for initiating exit flow, P_{pop}
OPT	Fabric venting option. If nonzero, CP23, LCCP23, AP23, and LCAP23 are set to zero. Porosity leakage of each material is output to abstat. EQ.1: Wang-Nefske formulas for venting through an orifice are used. Blockage is not considered. EQ.2: Wang-Nefske formulas for venting through an orifice are used. Blockage of venting area due to contact is considered. EQ.3: Leakage formulas of Graefe, Krummheuer, and Siejak [1990] are used. Blockage is not considered. EQ.4: Leakage formulas of Graefe, Krummheuer, and Siejak [1990] are used. Blockage of venting area due to contact is considered. EQ.5: Leakage formulas based on flow through a porous media are used. Blockage is not considered. EQ.6: Leakage formulas based on flow through a porous media

VARIABLE	DESCRIPTION
	are used. Blockage of venting area due to contact is considered.
	EQ.7: Leakage is based on gas volume outflow as a function of pressure load curve. Blockage of flow area due to contact is not considered. Absolute pressure is used in the porous-velocity-versus-pressure load curve, given as FAC(p) in the *MAT_FABRIC card.
	EQ.8: Leakage is based on gas volume outflow as a function of pressure load curve. Blockage of flow area due to contact is considered. Absolute pressure is used in the porous-velocity-versus-pressure load curve, given as FAC(p) in the *MAT_FABRIC card.
KNKDN	*Optional* load curve ID defining the knock down pressure scale factor as a function of time. This option only applies to jetting. The scale factor defined by this load curve scales the pressure applied to airbag segments which do not have a clear line-of-sight to the jet. Typically, at very early times this scale factor will be less than unity and equal to unity at later times. The full pressure is always applied to segments which can see the jets.

Inflator Card. If the inflator is modeled (LCMT = 0), fill in the following card. *If not, include but leave blank.*

Card 6	1	2	3	4	5	6	7	8
Variable	IOC	IOA	IVOL	IRO	IT	LCBF		
Type	F	F	F	F	F	I		
Default	none	none	none	none	none	none		

VARIABLE	DESCRIPTION
IOC	Inflator orifice coefficient
IOA	Inflator orifice area
IVOL	Inflator volume
IRO	Inflator density

VARIABLE	DESCRIPTION
IT	Inflator temperature
LCBF	Load curve defining burn fraction as a function of time

Temperature Dependent Heat Capacities Card. Include this card when CV = 0.

Card 7	1	2	3	4	5	6	7	8
Variable	TEXT	A	B	MW	GASC	HCONV		
Type	F	F	F	F	F	F		
Default	none	none	none	none	none	none		

VARIABLE	DESCRIPTION
TEXT	Ambient temperature
A	First molar heat capacity coefficient of inflator gas (e.g., Joules/mole/K)
B	Second molar heat capacity coefficient of inflator gas, (e.g., Joules/mole/K^2)
MW	Molecular weight of inflator gas (e.g., Kg/mole).
GASC	Universal gas constant of inflator gas (e.g., 8.314 Joules/mole/K)
HCONV	Effective heat transfer coefficient between the gas in the air bag and the environment at temperature TEXT. If HCONV < 0, then HCONV defines a load curve of data pairs (time, hconv).

Criteria for Initiating Exit Flow Card. Additional card for the POP option to the *AIRBAG_WANG_NEFSKE card.

Card 8	1	2	3	4	5	6	7	8
Variable	TDP	AXP	AYP	AZP	AMAGP	TDURP	TDA	RBIDP
Type	F	F	F	F	F	F	F	I
Default	0.0	0.0	0.0	0.0	0.0	0.0	0.0	none

VARIABLE	DESCRIPTION
TDP	Time delay before initiating exit flow after pop pressure is reached
AXP	Pop acceleration magnitude in the local x-direction. EQ.0.0: Inactive
AYP	Pop acceleration magnitude in the local y-direction. EQ.0.0: Inactive.
AZP	Pop acceleration magnitude in the local z-direction. EQ.0.0: Inactive
AMAGP	Pop acceleration magnitude. EQ.0.0: Inactive
TDURP	Time duration pop acceleration must be exceeded to initiate exit flow. This is a cumulative time from the beginning of the calculation, that is, it is not continuous.
TDA	Time delay before initiating exit flow after pop acceleration is exceeded for the prescribed time duration.
RBIDP	Part ID of the rigid body for checking accelerations against pop accelerations

Remarks:

The gamma law equation of state for the adiabatic expansion of an ideal gas is used to determine the pressure after preload:

$$p = (\gamma - 1)\rho e$$

where p is the pressure, ρ is the density, e is the specific internal energy of the gas, and γ is the ratio of the specific heats:

$$\gamma = \frac{c_p}{c_v} \ .$$

Here c_v is the specific heat at constant volume, and c_p is the specific heat at constant pressure. A pressure relation is defined as:

$$Q = \frac{p_e}{p} \ ,$$

where p_e is the external pressure and p is the internal pressure in the bag. A critical pressure relationship is defined as:

$$Q_{\text{crit}} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma-1}},$$

where γ is the ratio of specific heats as defined above and

$$Q \le Q_{\text{crit}} \Rightarrow Q = Q_{\text{crit}} \ .$$

Wang and Nefske define the mass flow through the vents and leakage by

$$\dot{m}_{23} = C_{23}A_{23}\frac{p}{R\sqrt{T_2}}Q^{\frac{1}{\gamma}}\sqrt{2g_c\left(\frac{\gamma R}{\gamma - 1}\right)\left(1 - Q^{\frac{\gamma-1}{\gamma}}\right)}$$

and

$$\dot{m}'_{23} = C'_{23}A'_{23}\frac{p}{R\sqrt{T_2}}Q^{\frac{1}{\gamma}}\sqrt{2g_c\left(\frac{\gamma R}{\gamma - 1}\right)\left(1 - Q^{\frac{\gamma-1}{\gamma}}\right)} \ .$$

It must be noted that the gravitational conversion constant must be given in consistent units. As an alternative to computing the mass flow out of the bag by the Wang-Nefske model, a curve for the exit flow rate depending on the internal pressure can be taken. Then, no definitions for C23, LCC23, A23, LCA23, CP23, LCCP23, AP23, and LCAP23 are necessary.

The airbag inflator assumes that the control volume of the inflator is constant and that the amount of propellant reacted can be defined by the user as a tabulated curve of fraction reacted versus time. A pressure relation is defined as:

$$Q_{\text{crit}} = \frac{p_c}{p_I} = \left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma}{\gamma-1}} \ ,$$

where p_c is a critical pressure at which sonic flow occurs, and p_I is the inflator pressure. The exhaust pressure is given by

$$p_e = \begin{cases} p_a & \text{if } p_a \ge p_c \\ p_c & \text{if } p_a < p_c \end{cases}$$

where p_a is the pressure in the control volume. The mass flow into the control volume is governed by the equation:

$$\dot{m}_{\text{in}} = C_0 A_0 \sqrt{2 p_I \rho_I} \sqrt{\frac{g_c \gamma \left(Q^{\frac{2}{\gamma}} - Q^{\frac{\gamma+1}{\gamma}} \right)}{\gamma - 1}}$$

where C_0, A_0, and ρ_I are the inflator orifice coefficient, area, and gas density, respectively.

If OPT is defined, then for OPT set to 1 or 2 the mass flow rate out of the bag, $\dot{m}_{out}$ is given by:

$$\dot{m}_{out} = \sqrt{g_c} \left\{ \sum_{n=1}^{\text{nairmats}} [\text{FLC}(t)_n \times \text{FAC}(p)_n \times \text{Area}_n] \right\} \sqrt{2 p \rho} \sqrt{\frac{\gamma \left(Q^{\frac{2}{\gamma}} - Q^{\frac{\gamma+1}{\gamma}} \right)}{\gamma - 1}}$$

where, ρ is the density of airbag gas, “nairmats” is the number of fabrics used in the airbag, and Area_n is the current unblocked area of fabric number n.

If OPT is set to 3 or 4 then:

$$\dot{m}_{\text{out}} = \left\{ \sum_{n=1}^{\text{nairmats}} [\text{FLC}(t)_n \times \text{FAC}(p)_n \times \text{Area}_n] \right\} \sqrt{2 (p - p_{\text{ext}}) \rho}$$

while for OPT set to 5 or 6:

$$\dot{m}_{\text{out}} = \left\{ \sum_{n=1}^{\text{nairmats}} [\text{FLC}(t)_n \times \text{FAC}(p)_n \times \text{Area}_n] \right\} (p - p_{\text{ext}}) \quad .$$

For OPT set to 7 or 8 (may be comparable to an equivalent model ALE model):

$$\dot{m}_{\text{out}} = \sum_{n=1}^{\text{nairmats}} \text{FLC}(t)_n \times \text{FAC}(p)_n \times \text{Area}_n \times \rho_n \quad .$$

Note that for different OPT settings, $\text{FAC}(p)_n$ has different meanings (all units shown just as demonstrations):

1. For OPT of 1, 2, 3 and 4, $\text{FAC}(p)$ is unit-less.

2. For OPT of 5 and 6, $\text{FAC}(p)$ has a unit of (s/m).

3. For OPT of 7 or 8, $\text{FAC}(p)$ is the gas volume outflow through a unit area per unit time thus has the unit of speed,

$$[\text{FAC}(p)] = \frac{[\text{volume}]}{[\text{area}][t]} = \frac{[\text{L}]^3}{[\text{L}]^2 [t]} = \frac{[L]}{[t]} = [\text{velocity}].$$

Multiple airbags may share the same part ID since the area summation is over the airbag segments whose corresponding part IDs are known. Currently, we assume that no more than ten materials are used per bag for purposes of the output. This constraint can be eliminated if necessary.

The total mass flow out will include the portion due to venting, that is, constants C23 and A23 or their load curves above.

If CV = 0. then the constant-pressure specific heat is given by:

$$c_p = \frac{(a + bT)}{MW}$$

and the constant-volume specific heat is then found from:

$$c_v = c_p - \frac{R}{MW}$$

Additional Cards required for JETTING models:

The following additional cards are defined for the WANG_NEFSKE_JETTING and WANG_NEFSKE_MULTIPLE_JETTING options, two further cards are defined for each option. The jet may be defined by specifying either the coordinates of the jet focal point, jet vector head and secondary jet focal point, or by specifying three nodes located at these positions. The nodal point option is recommended when the location of the airbag changes as a function of time.

WANG_NEFSKE_JETTING Card. Include this card if the WANG_NEFSKE_JETTING keyword option is used.

Card 9a	1	2	3	4	5	6	7	8
Variable	XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	CA	BETA
Type	F	F	F	F	F	F	F	F
Default	none	none	none	none	none	none	none	1.0
Remark	1	1	1	1	1	1		

WANG_NEFSKE_MULTIPLE_JETTING Card. Include this card if the WANG_NEFSKE_MULTIPLE_JETTING keyword option is used.

Card 9b	1	2	3	4	5	6	7	8
Variable	XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	LCJRV	BETA
Type	F	F	F	F	F	F	F	F
Default	none	none	none	none	none	none	none	1.0
Remark	1	1	1	1	1	1		

VARIABLE	DESCRIPTION
XJFP	x-coordinate of jet focal point, meaning the virtual origin in Figures 3-1 and 3-2.
YJFP	y-coordinate of jet focal point, meaning the virtual origin in Figures 3-1 and 3-2.
ZJFP	z-coordinate of jet focal point, meaning the virtual origin in Figures 3-1 and 3-2.
XJVH	x-coordinate of jet vector head to defined code centerline
YJVH	y-coordinate of jet vector head to defined code centerline
ZJVH	z-coordinate of jet vector head to defined code centerline
CA	Cone angle, α, defined in radians. LT.0.0: $\lvert\alpha\rvert$ is the load curve ID defining cone angle as a function of time
LCJRV	Load curve ID giving the spatial jet relative velocity distribution; see Figures 3-1, 3-2, and 3-3. The jet velocity is determined from the inflow mass rate and scaled by the load curve function value corresponding to the value of the angle ψ. Typically, the values on the load curve vary between 0 and unity. See *DEFINE_CURVE.
BETA	Efficiency factor, β, which scales the final value of pressure obtained from Bernoulli's equation. LT.0.0: $\lvert\beta\rvert$ is the load curve ID defining the efficiency factor as a

VARIABLE	DESCRIPTION
	function of time

Jetting Card. This card is included if the either the WANG_NEFSKE_JETTING or WANG_NEFSKE_MULTIPLE_JETTING keyword option is used.

Card 10	1	2	3	4	5	6	7	8
Variable	XSJFP	YSJFP	ZSJFP	PSID	ANGLE	NODE1	NODE2	NODE3
Type	F	F	F	I	F	I	I	I
Default	none	none	none	none	none	0	0	0
Remark						1	1	1

VARIABLE	DESCRIPTION
XSJFP	x-coordinate of secondary jet focal point, passenger side bag. If the coordinates of the secondary point are (0,0,0) then a conical jet (driver's side airbag) is assumed.
YSJFP	y-coordinate of secondary jet focal point
ZSJFP	z-coordinate of secondary jet focal point
PSID	Optional part set ID; see *SET_PART. If zero, all elements are included in the airbag.
ANGLE	Cutoff angle in degrees. The relative jet velocity is set to zero for angles greater than the cutoff. See Figure 3-3. This option applies to the MULTIPLE jet only.
NODE1	Node ID located at the jet focal point, that is, the virtual origin in Figures 3-1 and 3-2
NODE2	Node ID for node along the axis of the jet
NODE3	Optional node ID located at secondary jet focal point

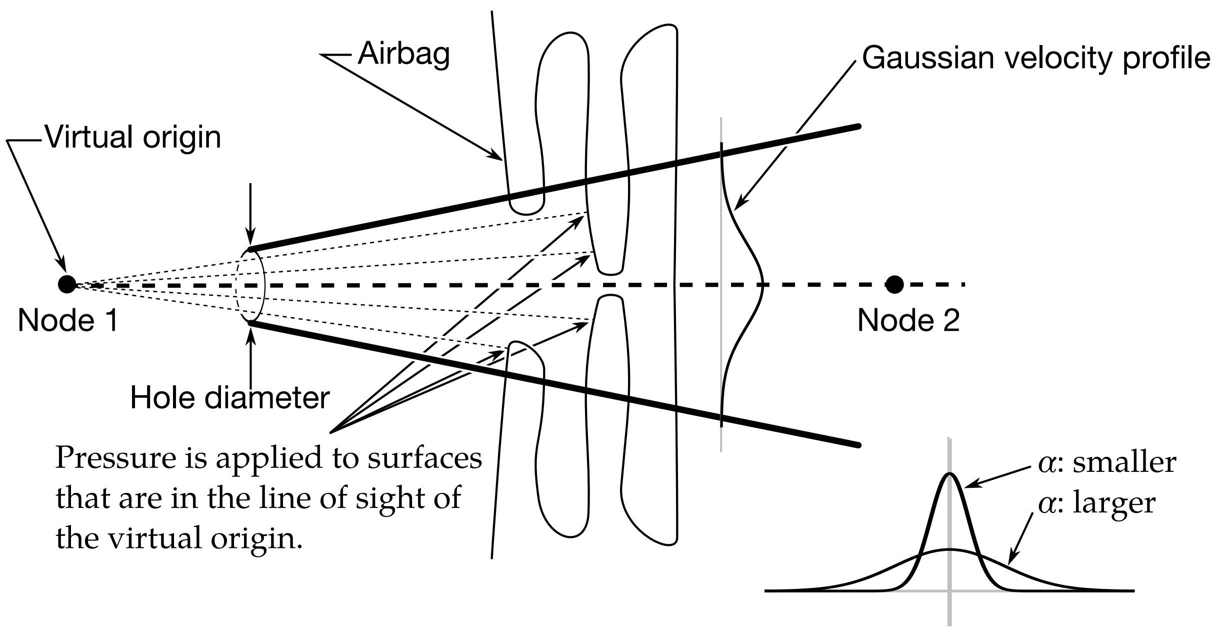

Figure 3-1. Jetting configuration for driver's side airbag (pressure applied only if centroid of surface is in line-of-sight)

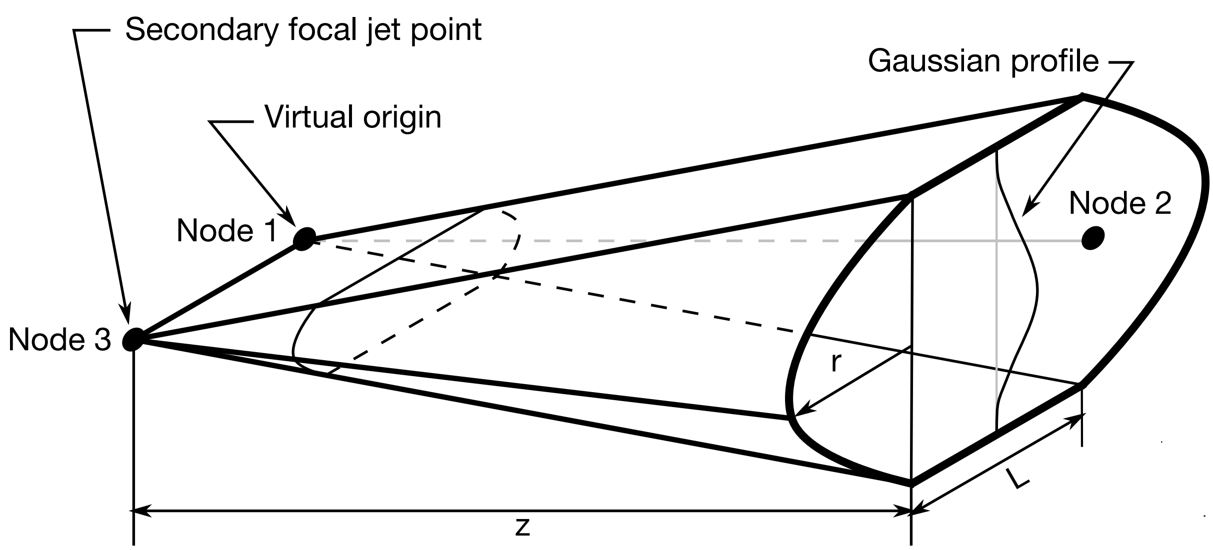

Figure 3-2. Jetting configuration for the passenger's side bag.

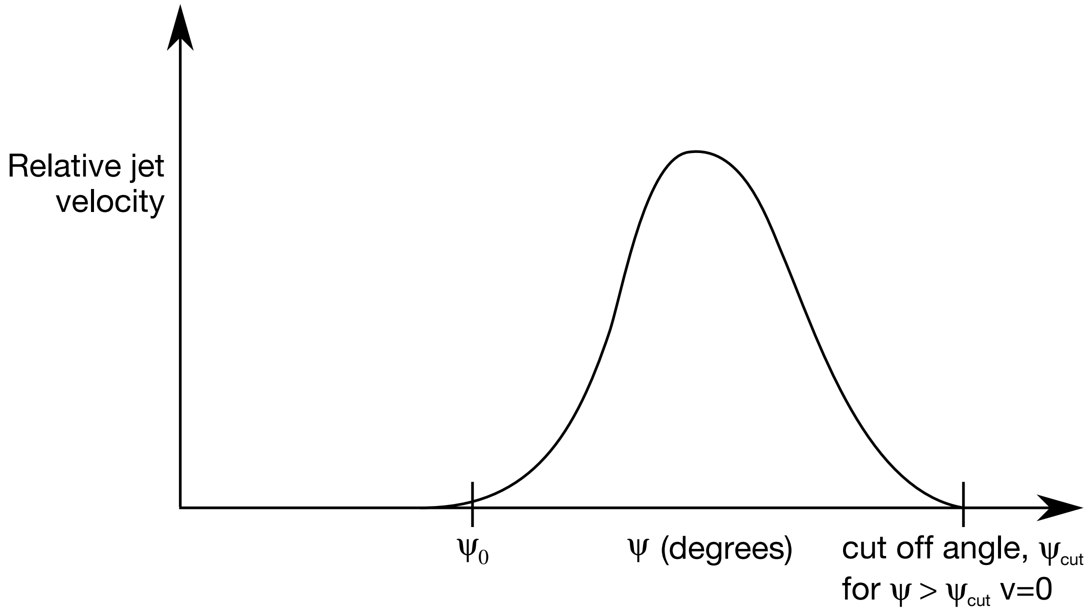

Figure 3-3. Normalized jet velocity versus angle for multiple jet driver's side airbag

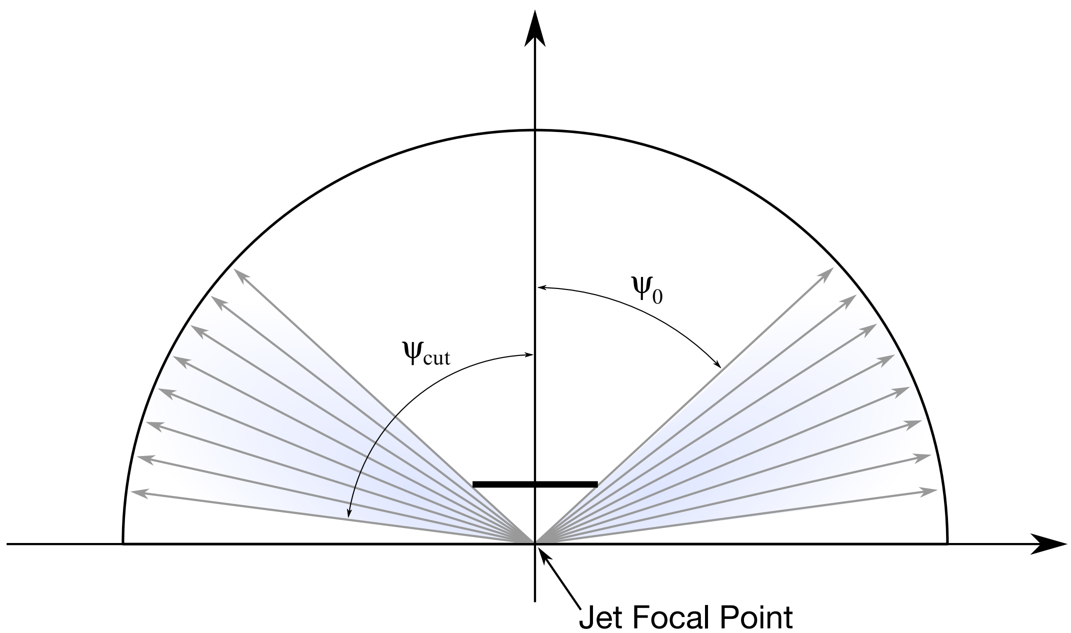

Figure 3-4. Multiple jet model for driver's side airbag. Typically, ψ_{cut} (see input ANGLE) is close to 90°. The angle ψ_0 is included to indicate that there is some angle below which the jet is negligible; see Figure 3-3.

Remarks:

1. **Jet Direction.** It is assumed that the jet direction is defined by the coordinate method (XJFP, YJFP, ZJFP) and (XJVH, YJVH, ZJVH) unless both NODE1 and NODE2 are defined. In which case the coordinates of the nodes give by NODE1, NODE2 and NODE3 will override (XJFP, YJFP, ZJFP) and (XJVH, YJVH, ZJVH). The use of nodes is recommended if the airbag system is undergoing rigid body motion. The nodes should be attached to the vehicle to allow for the coordinates of the jet to be continuously updated with the motion of the vehicle.

2. **Pressure Distribution.** The jetting option provides a simple model to simulate the real pressure distribution in the airbag during the breakout and early unfolding phase. Only the surfaces that are in the line of sight to the virtual origin have an increased pressure applied. With the optional load curve LCRJV, the pressure distribution with the code can be scaled according to the so-called relative jet velocity distribution.

3. **Jetting Configuration.** For passenger side airbags the cone is replaced by a wedge type shape. The first and secondary jet focal points define the corners of the wedge and the angle α then defines the wedge angle.

4. **Surfaces for Applying Pressure.** Instead of applying pressure to all surfaces in the line of sight of the virtual origin(s), a part set can be defined to which the pressure is applied.

5. **Jet Focal Point Placement.** Care must be used to place the jet focal point within the bag. If the focal point is outside the bag, inside surfaces will not be visible so jetting pressure will not be applied correctly.

Additional Card required for CM option:

The following additional card is defined for the WANG_NEFSKE_JETTING_CM and WANG_NEFSKE_MULTIPLE_JETTING_CM options.

CM Card. Additional card required for CM keyword option.

Card 11	1	2	3	4	5	6	7	8
Variable	NREACT							
Type	I							
Default	none							

VARIABLE	DESCRIPTION
NREACT	Node for reacting jet force. If zero, the jet force will not be applied.

Remarks:

Compared with the standard LS-DYNA jetting formulation, the Constant Momentum option has several differences. Overall, the jetting usually has a more significant effect on airbag deployment than the standard LS-DYNA jetting: the total force is often greater and does not reduce with distance from the jet.

The velocity at the jet outlet is assumed to be a choked (sonic) adiabatic flow of a perfect gas. Therefore the velocity at the outlet is given by:

$$v_{\text{outlet}} = \sqrt{\gamma R T} = \sqrt{\frac{(c_p - c_v) T c_p}{c_v}} \ .$$

The density in the nozzle is then calculated from conservation of mass flow.

$$\dot{m} = \rho_0 \nu_{\text{outlet}} A_{\text{outlet}}$$

This is different from the standard LS-DYNA jetting formulation, which assumes that the density of the gas in the jet is the same as atmospheric air, and then calculates the jet velocity from conservation of mass flow.

The velocity distribution at any radius, r, from the jet centerline and distance, z, from the focus, $v_{r,z}$, relates to the velocity of the jet centerline, $v_{r=0,z}$ in the same way as the standard LS-DYNA jetting options:

$$v_{r,z} = v_{r=0,z} e^{-\left(\frac{r}{\alpha z}\right)^2}$$

The velocity at the jet centerline, $v_r = 0$, at the distance, z, from the focus of the jet is calculated such that the momentum in the jet is conserved.

$$\begin{aligned} \text{momentum at nozzle} &= \text{momentum at z} \\ \rho_0 v_{\text{outlet}}^2 A_{\text{outlet}} &= \rho_0 \int v_{\text{jet}}^2 dA_{\text{jet}} \\ &= \rho_0 v_{r=0,Z}^2 \left\{ b + F\sqrt{b} \right\} \end{aligned}$$

where, $b = \frac{\pi(\alpha z)^2}{2}$, and F is the distance between the jet foci (for a passenger jet).

Finally, the pressure exerted on an airbag element in view of the jet is given as:

$$p_{r,z} = \beta \rho_0 v_{r,z}^2$$

By combining the equations above

$$p_{r,z} = \frac{\beta \dot{m} v_{\text{outlet}} \left[e^{-(r/\alpha z)^2} \right]^2}{\left\{ \frac{\pi (\alpha z)^2}{2} + F \sqrt{\frac{\pi (\alpha z)^2}{2}} \right\}}$$

The total force exerted by the jet is given by

$$F_{\text{jet}} = \dot{m} v_{\text{outlet}} \ ,$$

which is independent of the distance from the nozzle. Mass flow in the jet is not necessarily conserved, because gas is entrained into the jet from the surrounding volume. By contrast, the standard LS-DYNA jetting formulation conserves mass flow but not momentum. This has the effect of making the jet force reduce with distance from the nozzle.

The jetting forces can be reacted onto a node (NREACT), to allow the reaction force through the steering column or the support brackets to be modeled. The jetting force is written to the ASCII abstat file and the binary xtf file.

*AIRBAG_LOAD_CURVE_{OPTION}

Card Summary:

The additional card required for the LOAD_CURVE option is Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

STIME	LCID	RO	PE	P0	T	T0	

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	STIME	LCID	RO	PE	P0	T	T0	
Type	F	I	F	F	F	F	F	
Default	0.0	none	none	none	none	none	none	

VARIABLE	DESCRIPTION
STIME	Time at which pressure is applied. LCID is offset by this amount.
LCID	Load curve ID defining pressure as a function of time; see *DEFINE_CURVE.
RO	Initial density of gas (ignored if LCID > 0)
PE	Ambient pressure (ignored if LCID > 0)
P0	Initial gauge pressure (ignored if LCID > 0)
T	Gas Temperature (ignored if LCID > 0)
T0	Absolute zero on temperature scale (ignored if LCID > 0)

Remarks:

Within this simple model the control volume is inflated with a pressure defined as a function of time or calculated using the following equation if LCID = 0.

$$P_{\mathrm{total}} = C\rho(T - T_0)$$

$$P_{gauge} = P_{\mathrm{total}} - P_{\mathrm{ambient}}$$

The pressure is uniform throughout the control volume.

AIRBAG_LINEAR_FLUID_*{OPTION}

Card Summary:

The additional cards required for the LINEAR_FLUID option begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

BULK	RO	LCINT	LCOUTT	LCOUTP	LCFIT	LCBULK	LCID

Card 4. This card is optional.

P_LIMIT	P_LIMLC	NONULL					

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	BULK	RO	LCINT	LCOUTT	LCOUTP	LCFIT	LCBULK	LCID
Type	F	F	I	I	I	I	I	I
Default	none	none	none	optional	optional	optional	optional	none

VARIABLE	DESCRIPTION
BULK	K, bulk modulus of the fluid in the control volume. Constant as a function of time. Define if LCBULK = 0.
RO	ρ, density of the fluid
LCINT	$F(t)$, input flow curve defining mass per unit time as a function of time; see *DEFINE_CURVE.
LCOUTT	$G(t)$, output flow curve defining mass per unit time as a function of time. This load curve is optional.
LCOUTP	$H(p)$, output flow curve defining mass per unit time as a function of pressure. This load curve is optional.
LFIT	$L(t)$, added pressure as a function of time. This load curve is optional.
LCBULK	Curve defining the bulk modulus as a function of time. This load curve is optional, but if defined, the constant, BULK, is not used.
LCID	Load curve ID defining pressure as a function of time; see *DEFINE_CURVE.

Card 4 is optional.

Card 4	1	2	3	4	5	6	7	8
Variable	P_LIMIT	P_LIMLC	NONULL					
Type	F	I	I					
Default	optional	optional	optional					

VARIABLE	DESCRIPTION
P_LIMIT	Limiting value on total pressure (optional)
P_LIMLC	Curve defining the limiting pressure value as a function of time. If nonzero, P_LIMIT is ignored.
NONULL	A flag determining whether pressure is applied on null material parts (see Remark 2): EQ.0: apply pressure everywhere inside the airbag. NE.0: do not apply pressure on null material part of the airbag.

Remarks:

1. **Pressure and Mass Flow Rate.** This model is intended for the simulation of hydroforming processes or similar problems. The pressure is controlled by the mass flowing into the volume and by the current volume. The pressure is uniformly applied to the control volume.

   If LCID = 0 then the pressure is determined from:

$$P(t) = K(t)\ln\left[\frac{V_0(t)}{V(t)}\right] + L(t) \quad ,$$

   where

$$\begin{aligned} P(t) &= \text{Pressure,} \\ V(t) &= \text{Volume of fluid in compressed state,} \\ V_{0(t)} &= V_0(t) \\ &= \frac{M(t)}{\rho} \\ &= \text{Volume of fluid in uncompressed state,} \\ M(t) &= M(0) + \int F(t)dt - \int G(t)dt - \int H(p)dt \\ &= \text{Current fluid mass,} \end{aligned}$$

$$\begin{aligned} M(0) &= V(0)\rho \\ &= \text{Mass of fluid at time zero } P(0) = 0. \end{aligned}$$

By setting LCID ≠ 0 a pressure time history may be specified for the control volume and the mass of fluid within the volume is then calculated from the volume and density.

Note the signs used in the equation for $M(t)$. The mass flow should always be defined as positive since the output flow is subtracted.

2. **NONULL.** The NONULL flag is useful for hydroforming simulations. In this type of simulation, the part set that makes up the airbag will usually include a part ID of null shells, defined by *MAT_NULL. The null shells together with a deformable sheet blank will form an airbag, which upon pressurization, will push the blank into a die cavity. This feature is available in SMP as of Dev 136254.

*AIRBAG_HYBRID_{OPTIONS}

*AIRBAG_HYBRID_JETTING_{OPTIONS}

Card Summary:

The additional cards required for HYBRID and HYBRID_JETTING options begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if the ID keyword option is used. To use the *AIRBAG_-INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

ATMOST	ATMOSP	ATMOSD	GC	CC	HCONV		

Card 4. This card is required.

C23	LCC23	A23	LCA23	CP23	LCP23	AP23	LCAP23

Card 5. This card is required.

OPT	PVENT	NGAS	LCEFR	LCIDM0	VNTOPT		

Card 5.1. Include NGAS pairs of Cards 5.1 and 5.2.

LCIDM	LCIDT		MW	INITM	A	B	C

Card 5.2. Include NGAS pairs of Cards 5.1 and 5.2.

FMASS							

Card 6. This card is included for HYBRID_JETTING only.

XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	CA	BETA

Card 7. This card is included for HYBRID_JETTING only.

XSJFP	YSJFP	ZSJFP	PSID	IDUM	NODE1	NODE2	NODE3

Card 8. This card is included if the CM keyword option is used with HYBRID_JETTING.

NREACT							

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	ATMOST	ATMOSP	ATMOSD	GC	CC	HCONV		
Type	F	F	F	F	F	F		
Default	none	none	none	none	1.0	none		

VARIABLE	DESCRIPTION
ATMOST	Atmospheric temperature
ATMOSP	Atmospheric pressure
ATMOSD	Atmospheric density
GC	Universal molar gas constant

VARIABLE	DESCRIPTION
CC	Conversion constant EQ.0.0: Set to 1.0
HCONV	Effective heat transfer coefficient between the gas in the air bag and the environment at temperature at ATMOST. If HCONV < 0.0, then HCONV defines a load curve of data pairs (time, hconv).

Card 4	1	2	3	4	5	6	7	8
Variable	C23	LCC23	A23	LCA23	CP23	LCP23	AP23	LCAP23
Type	F	I	F	I	F	I	F	I
Default	none	0	none	0	none	0	none	0

VARIABLE	DESCRIPTION
C23	Vent orifice coefficient which applies to exit hole. Set to zero if LC-C23 is defined below.
LCC23	The absolute value, |LCC23|, is a load curve ID. If the LCC23 is positive, the load curve defines the vent orifice coefficient which applies to the exit hole as a function of time. If the LCC23 is negative, the vent orifice coefficient is defined as a function of relative pressure, $P_{\mathrm{air}}/P_{\mathrm{bag}}$; see [Anagonye and Wang 1999]. In addition, LCC23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for C23 overrides LCC23.
A23	If defined as a positive number, A23 is the vent orifice area which applies to the exit hole. If defined as a negative number, with LCA23 ≠ -1, the absolute value |A23| is a part ID; see [Anagonye and Wang 1999]. With LCA23 = -1, a negative A23 represents venting holes by a part set |A23|. The venting leakage through each venting hole represented by a part in part set |A23| is output to abstat. The area of this part/set becomes the vent orifice area. With SIDTYP > 0, airbag pressure will not be applied to part/set |A23| representing venting holes if part/set |A23| is not included in SID, the part set representing the airbag. Set A23 to zero if a positive LCA23 is defined below.
LCA23	Load curve ID defining the vent orifice area which applies to exit

VARIABLE	DESCRIPTION
	hole as a function of *absolute* pressure, or LCA23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for A23 overrides LCA23.
CP23	Orifice coefficient for leakage (fabric porosity). Set to zero if LCCP23 is defined below.
LCCP23	Load curve ID defining the orifice coefficient for leakage (fabric porosity) as a function of time, or LCCP23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for CP23 overrides LCCP23.
AP23	Area for leakage (fabric porosity)
LCAP23	Load curve ID defining the area for leakage (fabric porosity) as a function of (absolute) pressure, or LCAP23 can be defined through *DEFINE_CURVE_FUNCTION. A nonzero value for AP23 overrides LCAP23.

Card 5	1	2	3	4	5	6	7	8
Variable	OPT	PVENT	NGAS	LCEFR	LCIDM0	VNTOPT		
Type	I	F	I	I	I	I		
Default	none	none	none	0	0	0		

VARIABLE	DESCRIPTION
OPT	Fabric venting option; if nonzero CP23, LCCP23, AP23, and LCAP23 are set to zero. Porosity leakage of each material is output to abstat. EQ.1: Wang-Nefske formulas for venting through an orifice are used. Blockage is not considered. EQ.2: Wang-Nefske formulas for venting through an orifice are used. Blockage of venting area due to contact is considered. EQ.3: Leakage formulas of Graefe, Krummheuer, and Siejak [1990] are used. Blockage is not considered. EQ.4: Leakage formulas of Graefe, Krummheuer, and Siejak

VARIABLE	DESCRIPTION
	[1990] are used. Blockage of venting area due to contact is considered. EQ.5: Leakage formulas based on flow through a porous media are used. Blockage due to contact is not considered. EQ.6: Leakage formulas based on flow through a porous media are used. Blockage due to contact is considered. EQ.7: Leakage is based on gas volume outflow versus pressure load curve. Blockage of flow area due to contact is not considered. Absolute pressure is used in the porous-velocity-versus-pressure load curve, given as FAC(P) in the *MAT_FABRIC card. EQ.8: Leakage is based on gas volume outflow versus pressure load curve. Blockage of flow area due to contact is considered.
PVENT	Gauge pressure when venting begins
NGAS	Number of gas inputs to be defined below (including initial air). The maximum number of gases is 17.
LCEFR	Optional curve for exit flow rate (mass/time) versus (gauge) pressure
LCIDM0	Optional curve representing inflator's total mass inflow rate. When defined, LCIDM in the following 2 × NGAS cards defines the molar fraction of each gas component as a function of time and INITM defines the initial molar ratio of each gas component.
VNTOPT	Additional options for venting area definition. <u>For A23 ≥ 0</u> EQ.1: Vent area is equal to A23. EQ.2: Vent area is A23 plus the eroded surface area of the airbag parts. EQ.10: Same as VNTOPT = 2 <u>For A23 < 0</u> EQ.1: Vent area is the increase in surface area of part |A23|. If there is no change in surface area of part |A23| over the initial surface area or if the surface area reduces from the initial area, there is no venting.

VARIABLE	DESCRIPTION
	EQ.2: Vent area is the total (not change in) surface area of part |A23| plus the eroded surface area of all other parts comprising the airbag.
	EQ.10: Vent area is the increase in surface area of part |A23| plus the eroded surface area of all other parts comprising the airbag.

Include NGAS pairs of Cards 5.1 and 5.2

Card 5.1	1	2	3	4	5	6	7	8
Variable	LCIDM	LCIDT		MW	INITM	A	B	C
Type	I	I		F	F	F	F	F
Default	none	none		none	none	none	none	none

Include NGAS pairs of Cards 5.1 and 5.2.

Card 5.2	1	2	3	4	5	6	7	8
Variable	FMASS							
Type	F							
Default	none							

VARIABLE	DESCRIPTION
LCIDM	Load curve ID for inflator mass flow rate (equal to 0 for gas in the bag at time = 0) GT.0: Piecewise linear interpolation LT.0: Cubic spline interpolation
LCIDT	Load curve ID for inflator gas temperature (equal to 0 for gas in the bag at time = 0) GT.0: Piecewise linear interpolation

VARIABLE	DESCRIPTION
	LT.0: Cubic spline interpolation
MW	Molecular weight
INITM	Initial mass fraction of gas component present in the airbag, prior to injection of gas by the inflator. INITM is used to calculate the averaged gas properties and the initial mass of all gas components, assuming that the airbag is initially at ambient temperature and under ambient pressure. The sum of INITM of all gas components should be 1.0.
A	Coefficient for molar heat capacity of inflator gas at constant pressure, (e.g., Joules/mole/°K)
B	Coefficient for molar heat capacity of inflator gas at constant pressure, (e.g., Joules/mole/°K^2)
C	Coefficient for molar heat capacity of inflator gas at constant pressure, (e.g., Joules/mole/°K^3)
FMASS	Fraction of additional aspirated mass

Additional Cards required for HYBRID_JETTING and HYBRID_JETTING_CM:

The following two additional cards are defined for the HYBRID_JETTING options. The jet may be defined by specifying either the coordinates of the jet focal point, jet vector head and secondary jet focal point, or by specifying three nodes located at these positions. The nodal point option is recommended when the location of the airbag changes as a function of time.

Card 6	1	2	3	4	5	6	7	8
Variable	XJFP	YJFP	ZJFP	XJVH	YJVH	ZJVH	CA	BETA
Type	F	F	F	F	F	F	F	F
Default	none	none	none	none	none	none	none	none
Remark	1	1	1	1	1	1		

VARIABLE	DESCRIPTION
XJFP	x-coordinate of jet focal point, that is., the virtual origin in Figures 3-1 and 3-2. See Remark 1 below.
YJFP	y-coordinate of jet focal point, that is, the virtual origin in Figures 3-1 and 3-2.
ZJFP	z-coordinate of jet focal point, that is, the virtual origin in Figures 3-1 and 3-2.
XJVH	x-coordinate of jet vector head to defined cone centerline
YJVH	y-coordinate of jet vector head to defined cone centerline
ZJVH	z-coordinate of jet vector head to defined cone centerline
CA	Cone angle, α, defined in radians. LT.0.0: $\lvert\alpha\rvert$ is the load curve ID defining cone angle as a function of time
BETA	Efficiency factor, β, which scales the final value of pressure obtained from Bernoulli's equation. LT.0.0: $\lvert\beta\rvert$ is the load curve ID defining the efficiency factor as a function of time

Card 7	1	2	3	4	5	6	7	8
Variable	XSJFP	YSJFP	ZSJFP	PSID	IDUM	NODE1	NODE2	NODE3
Type	F	F	F	I	F	I	I	I
Default	none	none	none	none	none	0	0	0
Remark					2	1	1	1

VARIABLE	DESCRIPTION
XSJFP	x-coordinate of secondary jet focal point, passenger side bag. If the coordinate of the secondary point is (0,0,0), then a conical jet (driver's side airbag) is assumed.

VARIABLE	DESCRIPTION
YSJFP	y-coordinate of secondary jet focal point
ZSJFP	z-coordinate of secondary jet focal point
PSID	Optional part set ID; see *SET_PART. If zero, all elements are included in the airbag.
IDUM	Dummy field (variable not used)
NODE1	Node ID located at the jet focal point, that is, the virtual origin in Figures 3-1 and 3-2 . See Remark 1 below.
NODE2	Node ID for node along the axis of the jet. See Figures 3-1 and 3-2.
NODE3	Optional node ID located at secondary jet focal point. See Figure 3-2.

Additional card required for HYBRID_JETTING_CM option.

Card 8	1	2	3	4	5	6	7	8
Variable	NREACT							
Type	I							
Default	none							
Remark	4							

VARIABLE	DESCRIPTION
NREACT	Node for reacting jet force. If zero the jet force will not be applied.

Remarks:

1. **Jetting.** It is assumed that the jet direction is defined by the coordinate method (XJFP, YJFP, ZJFP) and (XJVH, YJVH, ZJVH) unless both NODE1 and NODE2 are defined. In which case the coordinates of the nodes given by NODE1, NODE2 and NODE3 will override (XJFP, YJFP, ZJFP) and (XJVH, YJVH, ZJVH). The use of nodes is recommended if the airbag system is undergoing rigid body motion. The nodes should be attached to the vehicle to

allow for the coordinates of the jet to be continuously updated with the motion of the vehicle.

The jetting option provides a simple model to simulate the real pressure distribution in the airbag during the breakout and early unfolding phase. Only the surfaces that are in the line of sight to the virtual origin have an increased pressure applied. With the optional load curve LCRJV, the pressure distribution with the code can be scaled according to the so-called relative jet velocity distribution.

For passenger side airbags the cone is replaced by a wedge type shape. The first and secondary jet focal points define the corners of the wedge and the angle α then defines the wedge angle.

Instead of applying pressure to all surfaces in the line of sight of the virtual origin(s), a part set can be defined to which the pressure is applied.

2. **IDUM.** This variable is not used and has been included to maintain the same format as the WANG_NEFSKE_JETTING options.

3. **Focal Point Placement.** Care must be used to place the jet focal point within the bag. If the focal point is outside the bag, inside surfaces will not be visible so jetting pressure will not be applied correctly.

4. **NREACT.** See the description related to the WANG_NEFSKE_JETTING_CM option. For the hybrid inflator model the heat capacities are compute from the combination of gases which inflate the bag.

AIRBAG_HYBRID_CHEMKIN_*{OPTION}

Card Summary:

The HYBRID_CHEMKIN model includes 3 control cards (Cards 3 – 5). For each gas species an additional set of cards must follow consisting of a control card (Card 6) and several thermodynamic property data cards. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

LCIDM	LCIDT	NGAS	DATA	ATMT	ATMP	RG	

Card 4. This card is required.

HCONV							

Card 5. This card is required.

C23	A23						

Card 6. For each gas species (see NGAS on Card 3), include one of this card followed by several thermo-dynamic property data cards whose format depends on the DATA field on Card 3. The next keyword ("*") card terminates this input.

CHNAME	MW	LCIDN	FMOLE	FMOLET			

Card 7a.1. This card is included if and only if DATA = 1.

TLOW	TMID	THIGH					

Card 7a.2. This card is included if and only if DATA = 1.

ALOW	BLOW	CLOW	DLOW	ELOW	FLOW	HLOW	

Card 7a.3. This card is included if and only if DATA = 1.

AHIGH	BHIGH	CHIGH	DHIGH	EHIGH	FHIGH	HHIGH	

Card 7b. This card is included if and only if DATA = 3.

A	B	C	D	E			

Data Card Definitions:

Card 3	1	2	3	4	5	6	7	8
Variable	LCIDM	LCIDT	NGAS	DATA	ATMT	ATMP	RG	
Type	I	I	I	I	F	F	F	

VARIABLE	DESCRIPTION
LCIDM	Load curve specifying input mass flow rate as a function of time: GT.0: piece wise linear interpolation LT.0: cubic spline interpolation

VARIABLE	DESCRIPTION
LCIDT	Load curve specifying input gas temperature as a function of time: GT.0: piece wise linear interpolation LT.0: cubic spline interpolation
NGAS	Number of gas inputs to be defined below (including initial air)
DATA	Thermodynamic database (see remarks): EQ.1: NIST database (3 additional property cards are required below) EQ.2: CHEMKIN database (no additional property cards are required) EQ.3: Polynomial data (1 additional property card is required below)
ATMT	Atmospheric temperature
ATMP	Atmospheric pressure
RG	Universal gas constant

Card 4	1	2	3	4	5	6	7	8
Variable	HCONV							
Type	F							
Default	0.							

VARIABLE	DESCRIPTION
HCONV	Effective heat transfer coefficient between the gas in the air bag and the environment at temperature ATMT. If HCONV < 0, then HCONV defines a load curve of data pairs (time, hconv).

Card 5	1	2	3	4	5	6	7	8
Variable	C23	A23						
Type	F	F						
Default	0.	0.						

VARIABLE	DESCRIPTION
C23	Vent orifice coefficient
A23	Vent orifice area

Gas Species Control Card. For each gas species include a set of cards consisting of this card followed by several thermo-dynamic property data cards whose format depends on the DATA field on Card 3. The next keyword ("*") card terminates this input.

Card 6	1	2	3	4	5	6	7	8
Variable	CHNAME	MW	LCIDN	FMOLE	FMOLET			
Type	A	F	I	F	F			
Default	none	none	0	none	0.			

VARIABLE	DESCRIPTION
CHNAME	Chemical symbol for this gas species (e.g., N2 for nitrogen, AR for argon). Required for DATA = 2 (CHEMKIN), optional for DATA = 1 or DATA = 3.
MW	Molecular weight of this gas species.
LCIDN	Load curve specifying the input mole fraction versus time for this gas species. If > 0, FMOLE is not used.
FMOLE	Mole fraction of this gas species in the inlet stream.
FMOLET	Initial mole fraction of this gas species in the tank.

NIST Data Cards. Include this card if DATA = 1. The required data can be found on the NIST web site at http://webbook.nist.gov/chemistry/.

Card 7a.1	1	2	3	4	5	6	7	8
Variable	TLOW	TMID	THIGH					
Type	F	F	F					
Default	none	none	none					

NIST Data Cards. Include this card if DATA = 1. The required data can be found on the NIST web site at http://webbook.nist.gov/chemistry/.

Card 7a.2	1	2	3	4	5	6	7	8
Variable	ALOW	BLOW	CLOW	DLOW	ELOW	FLOW	HLOW	
Type	F	F	F	F	F	F	F	
Default	none	none	none	none	none	none	none	

NIST Data Cards. Include this card if DATA = 1. The required data can be found on the NIST web site at http://webbook.nist.gov/chemistry/.

Card 7a.3	1	2	3	4	5	6	7	8
Variable	AHIGH	BHIGH	CHIGH	DHIGH	EHIGH	FHIGH	HHIGH	
Type	F	F	F	F	F	F	F	
Default	none	none	none	none	none	none	none	

VARIABLE	DESCRIPTION
TLOW	Curve fit low temperature limit
TMID	Curve fit low-to-high transition temperature
THIGH	Curve fit high temperature limit

VARIABLE	DESCRIPTION
ALOW, …, HLOW	Low temperature range NIST polynomial curve fit coefficients (see remarks)
AHIGH, …, HIGH	High temperature range NIST polynomial curve fit coefficients (see remarks)

Polynomial Fit Card. This card is included if DATA = 3.

Card 7b	1	2	3	4	5	6	7	8
Variable	A	B	C	D	E			
Type	F	F	F	F	F			
Default	none	0.	0.	0.	0.			

VARIABLE	DESCRIPTION
A	Coefficient; see remarks.
B	Coefficient; see remarks.
C	Coefficient; see remarks.
D	Coefficient; see remarks.
E	Coefficient; see remarks.

Remarks:

Specific heat curve fits:

$$\text{NIST:}\quad c_p = \frac{1}{M}\left(a + bT + cT^2 + dT^3 + \frac{e}{T^2}\right)$$

$$\text{CHEMKIN:}\quad c_p = \frac{\overline{R}}{M}\left(a + bT + cT^2 + dT^3 + eT^4\right)$$

$$\text{POLYNOMIAL:}\quad c_p = \frac{1}{M}\left(a + bT + cT^2 + dT^3 + eT^4\right)$$

where,

$$\overline{R} = \text{universal gas constant } 8.314\,\frac{\text{Nm}}{\text{mole} \times K}$$

$$M = \text{gas molecular weight}$$

AIRBAG_FLUID_AND_GAS_*{OPTION}

Card Summary:

The additional cards required for the AIRBAG_FLUID_AND_GAS option begin with Card 3. See the "core cards" section of *AIRBAG for cards preceding Card 3.

Card ID. This card is included if and only if the ID keyword option is used. To use the *AIRBAG_INTERACTION keyword ID Cards are required.

ABID	HEADING

Card 1. This card is required.

SID	SIDTYP	RBID	VSCA	PSCA	VINI	MWD	SPSF

Card 2a. This card is read when RBID > 0.

N							

Card 2a.1. This card is read when RBID > 0. Define N constants for the user subroutine. Include only the number of cards necessary, that is, for nine constants use 2 cards.

C1	C2	C3	C4	C5			

Card 2b.1. This card is read when RBID < 0.

AX	AY	AZ	AMAG	TDUR			

Card 2b.2. This card is read when RBID < 0.

DVX	DVY	DVZ	DVMAG				

Card 2b.3. This card is read when RBID < 0.

UX	UY	UZ	UMAG				

Card 3. This card is required.

XWINI	XWADD	XW	P	TEND	RHO	LCXW	LCP

Card 4. This card is required.

GDIR	NPROJ	IDIR	IIDIR	KAPPA	KBM		

Data Card Definitions:

Additional cards required for FLUID_AND_GAS option. (For card 1 see the "core cards" section of *AIRBAG.) Currently this option only works in SMP and explicit analysis.

Card 3	1	2	3	4	5	6	7	8
Variable	XWINI	XWADD	XW	P	TEND	RHO	LCXW	LCP
Type	F	F	F	F	F	F	I	I
Default	none	none	none	none	none	none	none	none

Card 4	1	2	3	4	5	6	7	8
Variable	GDIR	NPROJ	IDIR	IIDIR	KAPPA	KBM		
Type	F	I	I	I	F	F		
Default	none	3	none	none	1.0	none		

VARIABLE	DESCRIPTION
XWINI	Fluid level at time $t = 0$ in |GDIR| direction
XWADD	Fluid level filling increment per time step
XW	Final fluid level in filling process
P	Gas pressure at time t = TEND
TEND	Time when gas pressure P is reached
RHO	Density of the fluid (for example, for water, RHO ≈ 1.0 kg/m^3)
LCXW	Load curve ID for fluid level as a function of time. XW, XWADD, and XWINI are ignored with this option.
LCP	Load curve ID for gas pressure as a function of time. P and TEND are ignored with this option.

VARIABLE	DESCRIPTION
GDIR	Global direction of gravity. Use negative numbers for the negative direction, such as -3.0 for the negative global z-axis. EQ.1.0: Global x-direction EQ.2.0: Global y-direction EQ.3.0: Global z-direction
NPROJ	Number of projection directions (only global axis) for volume calculation
IDIR	First direction of projection (if $\lvert NPROJ \rvert \neq 3$), only global axis.
IIDIR	Second direction of projection (if $\lvert NPROJ \rvert = 2$), only global axis.
KAPPA	Adiabatic exponent
KBM	Bulk modulus of the fluid (e.g. for water, BKM ≈ 2080 N/mm^2)

Remarks:

The *AIRBAG_FLUID_AND_GAS option models a quasi-static multi chamber fluid/gas structure interaction in a simplified way including three possible load cases: (i) only gas, (ii) only incompressible fluid, or (iii) the combination of incompressible fluid with additional gas "above." See Figure 3-5.

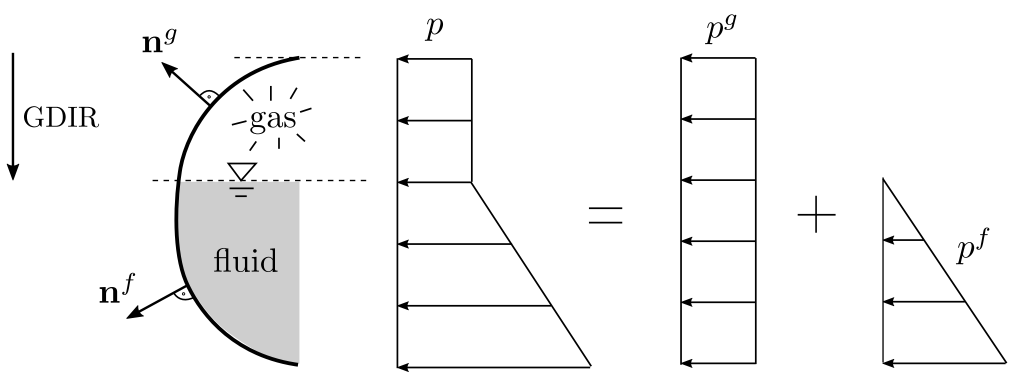

Figure 3-5. Hydrostatic pressure distribution in a chamber filled with gas and incompressible fluid

The theory is based on the description of gases and fluids as energetically equivalent pressure loads. The calculation of the fluid volume is carried out using the directions of projection and a non-normalized normal vector. This model, therefore, requires that the normal of the shell elements belonging to a filled structure must point outwards. Holes are not detected, but can be taken into account as described below.

In case of a pure gas (no fluid), the *AIRBAG_SIMPLE_PRESSURE_VOLUME and *AIRBAG_FLUID_AND_GAS cards give identical results as they are based on the same theory. The update of the gas pressure due to volume change is calculated with the following simple gas law

$$p^g = \left(1 - \mathrm{KAPPA} \times \frac{v^g - v^g_{\mathrm{old}}}{v^g_{\mathrm{old}}}\right) p^g_{\mathrm{old}}$$

with adiabatic exponent KAPPA and gas volume v^g.

The theory of incompressible fluids is based on the variation of the potential energy and an update of the water level due to changes in the volume and the water surface, see Haßler and Schweizerhof [2007], Haßler and Schweizerhof [2008], Rumpel and Schweizerhof [2003], and Rumpel and Schweizerhof [2004].

In case of multiple fluid/gas filled chambers each chamber requires an additional *AIRBAG_FLUID_AND_GAS card. Some of the parameters which are called local parameters only belong to a single chamber (such as gas pressure). In contrast global, parameters belong to all chambers (such as the direction of gravitation).

Because the theory only applies to quasi-static fluid-structure interaction, the load must be applied slowly, so the kinetic energy is almost zero throughout the process.

All parameters input on Card 3 are local parameters describing the filling of the chamber. The water level and the gas pressure can be defined by curves using LCXW and LCP or by using the parameters XWINI, XW, XWADD, P and TEND. When describing the fluid and gas filling using the parameters, the gas pressure at time $t = 0$ is set to 0 and the initial water level is set to XWINI in |GDIR|-direction. At each timestep, XWADD is added to the water level, until XW is reached. The gas pressure will be raised until P is reached at time t = TEND.

In general, global parameters belong to all chambers. To describe the global axis in GDIR, NPROJ, IDIR and IIDIR the following mapping applies: the x-axis is axis 1, the y-axis is axis 2, and the z-axis is axis 3.

The gas and fluid volume is calculated by using contour integrals in the global x-, y- and z-coordinates. If one of the boundaries is discontinuous in one or two global directions, these directions must be ignored in NPROJ, IDIR and IIDIR. At least one direction of projection must be set (NPROJ = 1, IDIR = value), but it is recommended to use as many directions of projection as possible.

In case of a structure filled exclusively with fluid, IDIR and IIDIR should not be set to |GDIR|. In case of holes in a structure (for example, take advantage of symmetry planes), IDIR and IIDIR should not be set to the normal direction of the plane describing the hole or symmetry plane.

An example of a water filled tube structure illustrating how to use NPROJ, IDIR, IIDIR, and GDIR is shown in Figure 3-6. In this example gravity is acting opposite to the global *z*-axis. In this case, then, GDIR = -3. The structure is filled exclusively with water, so the projection direction cannot be set to |GDIR| = 3. To use the symmetry of the tube only half of the structure has been modeled. The normal of the symmetry plane is in the *y*-direction, so the projection direction cannot be set to 2. Because the symmetry axes (2 and 3) are not allowed, the only direction of projection is 1; therefore, NPROJ = 1 and IDIR = 1.

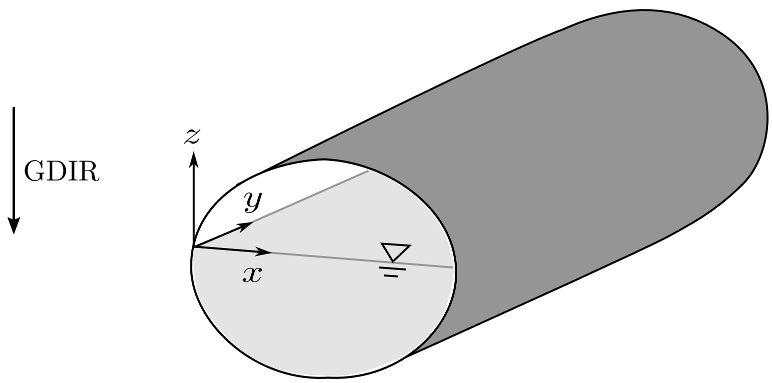

Figure 3-6. Example for water filled tube structure

For further explanations and examples see Haßler and Schweizerhof [2007], Haßler and Schweizerhof [2008], and Maurer, Gebhardt, and Schweizerhof [2010].

The possible entries for NPROJ, IDIR and IIDIR are:

NPROJ	IDIR	IIDIR
3		
2	1	2
2	1	3
2	2	3
1	1	
1	2	
1	3	

*AIRBAG_ALE

Purpose: Provide a simplified approach to defining the deployment of the airbag using the ALE capabilities with an option to switch from the initial ALE method to a control volume (CV) method similar to *AIRBAG_HYBRID at a chosen time. An enclosed airbag (and possibly the airbag canister/compartment and/or a simple representation of the inflator) shell structure interacts with the inflator gas(es). This definition provides a single fluid to structure coupling for the airbag-gas interaction during deployment in which the CV input data may be used directly.

Card Summary:

Card 1. This card is required.

SID	SIDTYP					MWD	SPSF

Card 2. This card is required.

ATMOST	ATMOSP		GC	CC	TNKVOL	TNKFINP	

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

NQUAD	CTYPE	PFAC	FRIC	FRCMIN	NORMTYP	ILEAK	PLEAK

Card 4. This card is required.

IVSETID	IVTYPE	IBLOCK	VNTCOF				

Card 5a. This card is for an ALE mesh defined with a part ID. NZ must not be defined (NZ = 0) to activate this card.

IDA	IDG	NZ	MOVERN	ZOOM			

Card 5b. This card is included to automatically define an ALE mesh. It is activated when NZ ≠ 0.

NX	NY	NZ	MOVERN	ZOOM			

Card 5b.1. This card is included when NZ > 0.

X0	Y0	Z0	X1	Y1	Z1		

Card 5b.2. This card is included when NZ > 0.

X2	Y2	Z2	Z3	Y3	Z3		

Card 6. This card is required.

SWTIME		HG	NAIR	NGAS	NORIF	LCVEL	LCT

Card 7. This card is required.

			MWAIR	INITM	AIRA	AIRB	AIRC

Card 8. Include NGAS of this card.

LCMF			MWGAS		GASA	GASB	GASC

Card 9. Include NORIF of this card.

NODEID	VECID	ORIFARE					

Data Card Definitions:

Card 1	1	2	3	4	5	6	7	8
Variable	SID	SIDTYP					MWD	SPSF
Type	I	I					F	F
Default	none	none					0	0

VARIABLE	DESCRIPTION
SID	Set ID. This set ID contains the Lagrangian elements (segments) which make up the airbag and possibly the airbag canister/compartment and/or a simple representation of the inflator. See Remark 1.
SIDTYP	Set type: EQ.0: Segment set EQ.1: Part set
MWD	Mass weighted damping factor, D, used during the CV phase
SPSF	Stagnation pressure scale factor, $0 \leq \gamma \leq 1$. SPSF is needed during the CV phase.

Ambient Environment Card.

Card 2	1	2	3	4	5	6	7	8
Variable	ATMOST	ATMOSP		GC	CC	TNKVOL	TNKFINP	
Type	F	F		F	F	F	F	
Default	0.	0.		none	1.0	0.0	0.0	

VARIABLE	DESCRIPTION
ATMOST	Atmospheric ambient temperature. See Remark 2.
ATMOSP	Atmospheric ambient pressure. See Remark 2.
GC	Universal molar gas constant.
CC	Conversion constant. EQ.0: Set to 1.0.
TNKVOL	Tank volume from the inflator tank test or inflator canister volume. See Remark 9 and Card 6. **LCVEL = 0 and TNKFINP is defined:** TNKVOL is the defined tank. Inlet gas velocity is estimated by LS-DYNA method (testing). **LCVEL = 0 and TNKFINP is not defined:** TNKVOL is the estimated inflator canister volume inlet gas velocity is estimated automatically by the Lian-Bhalsod-Olovsson method. **LCVEL ≠ 0:** This must be left blank.
TNKFINP	Tank final pressure from the inflator tank test data. Only define this parameter for option 1 of TNKVOL definition above. See Remark 9.

Coupling Card. See keyword *CONSTRAINED_LAGRANGE_IN_SOLID.

Card 3	1	2	3	4	5	6	7	8
Variable	NQUAD	CTYPE	PFAC	FRIC	FRCMIN	NORMTYP	ILEAK	PLEAK
Type	I	I	F	F	F	I	I	F
Default	4	4	0.1	0.0	0.3	0	2	0.1

VARIABLE	DESCRIPTION
NQUAD	Number of (quadrature) coupling points for coupling Lagrangian parts to ALE solid parts. If NQUAD = n, then n × n coupling points will be parametrically distributed over the surface of each Lagrangian segment. See Remark 12.
CTYPE	Coupling type (see Remark 12): EQ.4: Penalty coupling with coupling in the normal direction under compression only (default). EQ.6: Penalty coupling in which coupling is under both tension and compression in the normal direction for the unfolded region and under only compression in the normal direction for folded region.
PFAC	Penalty factor. PFAC is a scale factor for scaling the estimated stiffness of the interacting (coupling) system. It is used to compute the coupling forces to be distributed on the Lagrangian and ALE parts. See Remark 13. GT.0: Fraction of estimated critical stiffness. LT.0: -PFAC is a load curve ID. The curve defines the relative coupling pressure (y-axis) as a function of the tolerable fluid penetration distance (x-axis).
FRIC	Coupling coefficient of friction
FRCMIN	Minimum fluid volume fraction in an ALE element to activate coupling.
NORMTYP	Penalty coupling spring direction: EQ.0: Normal vectors are interpolated from nodal normals.

VARIABLE	DESCRIPTION
	EQ.1: Normal vectors are interpolated from segment normals.
ILEAK	Leakage control flag. Default = 2 (with energy compensation).
PLEAK	Leakage control penalty factor (default = 0.1)

Venting Hole Card.

Card 4	1	2	3	4	5	6	7	8
Variable	IVSETID	IVTYPE	IBLOCK	VNTCOF				
Type	I	I	I	F				
Default	0	0	0	0.0				

VARIABLE	DESCRIPTION
IVSETID	Set ID defining the venting hole surface(s). See Remark 4.
IVTYPE	Set type of IVSETID: EQ.0: Part Set (default). EQ.1: Part ID. EQ.2: Segment Set.
IBLOCK	Flag for considering blockage effects for porosity and vents (see Remark 5): EQ.0: no (blockage is NOT considered, default). EQ.1: yes (blockage is considered).
VNTCOF	Vent Coefficient for scaling the flow. See Remark 6.

ALE Mesh from Part ID Card. Parameters for transformation of the ALE mesh specified with part IDs.

Card 5a	1	2	3	4	5	6	7	8
Variable	IDA	IDG	NZ	MOVERN	ZOOM			
Type	I	I	I	I	I			
Default	none	none	↓	0	0			

VARIABLE	DESCRIPTION
IDA	Part ID of the initial air mesh
IDG	Part ID of the initial gas mesh
NZ	Leave blank to activate.
MOVERN	ALE mesh automatic motion option. EQ.0: ALE mesh is fixed in space. GT.0: Node group ID. See *ALE_REFERENCE_SYSTEM_-NODE ALE mesh can be moved with PRTYP = 5, mesh motion follows a coordinate system defined by 3 reference nodes. See Remark 7.
ZOOM	ALE mesh automatic expansion option: EQ.0: Do not expand ALE mesh EQ.1: Expand/contract ALE mesh by keeping all airbag parts contained within the ALE mesh (equivalent to PRTYP = 9). See Remark 8.

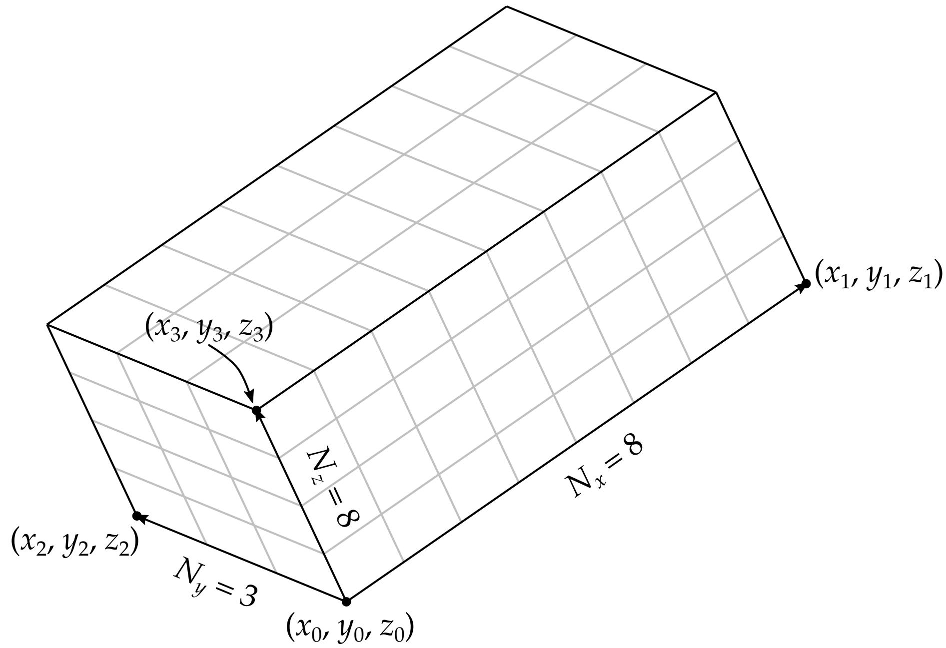

Figure 3-7. Illustration of automatic mesh generation for the ALE mesh in a hexahederal region

Automatic ALE Mesh Card. Parameters for ALE mesh automatic definition and its transformation. See Figure 3-7.

Card 5b	1	2	3	4	5	6	7	8
Variable	NX	NY	NZ	MOVERN	ZOOM			
Type	I	I	I	I	I			
Default	none	none	none	0	0			

VARIABLE	DESCRIPTION
NX	NX is the number of ALE elements to be generated in the *x*-direction.
NY	NY is the number of ALE elements to be generated in the *y*-direction.
NZ	NZ is the number of ALE elements to be generated in the *z*-direction.
MOVERN	ALE mesh automatic motion option.

VARIABLE	DESCRIPTION
	EQ.0: ALE mesh is fixed in space. GT.0: Node group ID. See *ALE_REFERENCE_SYSTEM_-NODE ALE mesh can be moved with PRTYP = 5, mesh motion follows a coordinate system defined by 3 reference nodes. See Remark 7.
ZOOM	ALE mesh automatic expansion option: EQ.0: Do not expand ALE mesh. EQ.1: Expand/contract ALE mesh by keeping all airbag parts contained within the ALE mesh (equivalent to PRTYP = 9). See Remark 8.

Origin for ALE Mesh Card. Include Cards 5b.1 and 5b.2 when NZ > 0.

Card 5b.1	1	2	3	4	5	6	7	8
Variable	X0	Y0	Z0	X1	Y1	Z1		
Type	F	F	F	F	F	F		
Default	none	none	none	none	none	none		

Card 5b.2	1	2	3	4	5	6	7	8
Variable	X2	Y2	Z2	Z3	Y3	Z3		
Type	F	F	F	F	F	F		
Default	none	none	none	none	none	none		

VARIABLE	DESCRIPTION
X0, Y0, Z0	Coordinates of origin for ALE mesh generation (node0).
X1, Y1, Z1	Coordinates of point 1 for ALE mesh generation (node1). x-extent = node1 – node0

VARIABLE	DESCRIPTION
X2, Y2, Z2	Coordinates of point 2 for ALE mesh generation (node2). $y\text{-extent} = \text{node2} - \text{node0}$
X3, Y3, Z3	Coordinates of point 3 for ALE mesh generation (node3). $z\text{-extent} = \text{node3} - \text{node0}$

Miscellaneous Parameters Card.

Card 6	1	2	3	4	5	6	7	8
Variable	SWTIME		HG	NAIR	NGAS	NORIF	LCVEL	LCT
Type	F		F	I	I	I	I	I
Default	10^{16}		0.	0	0	0	0	0
Remarks	3						9	10

VARIABLE	DESCRIPTION
SWTIME	Time to switch from ALE method to control volume (CV) method. Once switched, a method similar to that used by the *AIRBAG_-HYBRID card is used.
HG	Hourglass control for ALE fluid mesh(es).
NAIR	Number of air components. For example, this equals 2 when air contains 80% of N_2 and 20% of O_2. If air is defined as a single gas, then NAIR = 1.
NGAS	Number of inflator gas components.
NORIF	Number of point sources or orifices. This determines the number of point source cards to be read.
LCVEL	Load curve ID for inlet velocity (see also TNKVOL & TNKFINP of Card 2 above). This is the same estimated velocity curve used in *SECTION_POINT_SOURCE_MIXTURE card.
LCT	Load curve ID for inlet gas temperature (see *AIRBAG_HYBRID).

Air Component Card. Include NAIR cards, one for each air component.

Card 7	1	2	3	4	5	6	7	8
Variable				MWAIR	INITM	AIRA	AIRB	AIRC
Type				F	F	F	F	F
Default				0.	0.	0.	0.	0.

VARIABLE	DESCRIPTION
MWAIR	Molecular weight of air component
INITA	Initial Mass Fraction of air component(s)
AIRA	First coefficient of molar heat capacity at constant pressure (e.g., J/mole/K). See Remark 11.
AIRB	Second coefficient of molar heat capacity at constant pressure (e.g., J/mole/K^2). See Remark 11.
AIRC	Third coefficient of molar heat capacity at constant pressure (e.g., J/mole/K^3). See Remark 11.

Gas Component Card. Include NGAS cards, one for each gas component.

Card 8	1	2	3	4	5	6	7	8
Variable	LCMF			MWGAS		GASA	GASB	GASC
Type	I			F		F	F	F
Default	none			0		0	0.	0.

VARIABLE	DESCRIPTION
LCMF	Load curve ID for mass flow rate (see *AIRBAG_HYBRID, e.g., kg/s). See Remark 11.
MWGAS	Molecular weight of inflator gas components.

VARIABLE	DESCRIPTION
GASA	First coefficient of molar heat capacity at constant pressure (e.g., J/mole/K). See Remark 11.
GASB	Second coefficient of molar heat capacity at constant pressure (e.g., J/mole/K^2). See Remark 11.
GASC	Third coefficient of molar heat capacity at constant pressure (e.g., J/mole/K^3). See Remark 11.

Point Source Cards. Include NORIF cards, one for each point source.

Card 9	1	2	3	4	5	6	7	8
Variable	NODEID	VECID	ORIFARE					
Type	I	I	I					
Default	0	0	0					

VARIABLE	DESCRIPTION
NODEID	The node ID defining the point source.
VECID	The vector ID defining the direction of flow at the point source.
ORIFARE	The orifice area at the point source.

Remarks:

1. **Lagrangian Elements for Airbag Components.** This set ID typically contains the Lagrangian segments of the 3 parts that are coupled to the inflator gas: airbag, airbag canister (compartment), and inflator. As in all control-volume, orientation of elements representing bag and canister should point outward. During the ALE phase the segment normal will be reversed automatically for fluid-structure coupling. *However, the orientation of inflator element normal vectors should point to its center.* See Figure 3-8.

2. **Atmospheric Density.** Atmospheric density for the ambient gas (air) can be computed from

$$\rho_{\mathrm{amb}} = \frac{P_{\mathrm{amb}}}{RT_{\mathrm{amb}}}$$

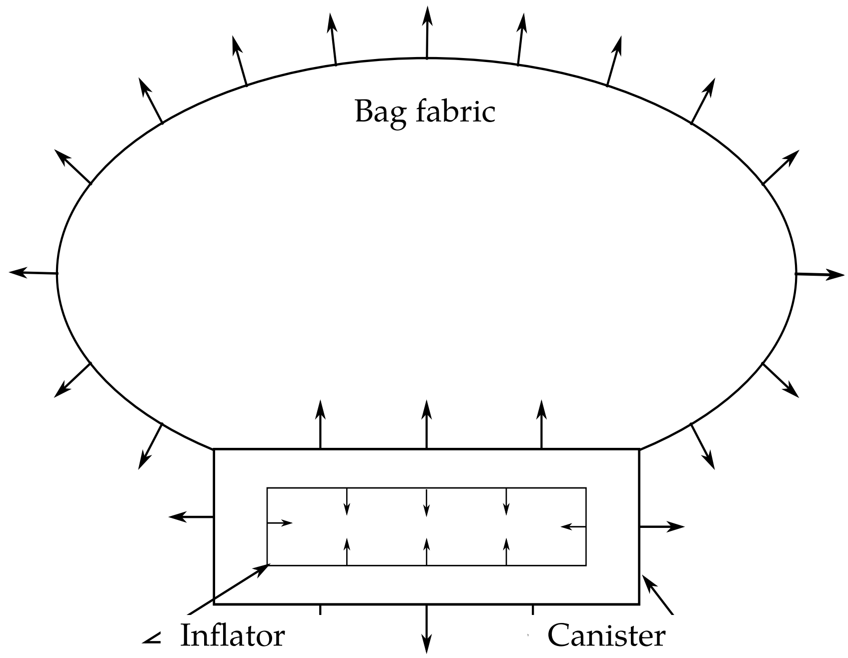

Figure 3-8. Arrows indicate "outward" normal

3. **ALE to Control Volume Switch.** Since *all* ALE related activities will be turned off after the switch from ALE method to control volume method, no other ALE coupling will exist beyond t = SWTIME.

4. **Venting.** Vent definition will be used for ALE venting. Upon switching, area of the segments will be used for venting as a23 in *AIRBAG_HYBRID.

5. **Fabric Porosity.** Fabric porosity for ALE and *AIRBAG_HYBRID can be defined on *MAT_FABRIC. Define FLC and FAC on *MAT_FABRIC. FVOPT 7 and 8 will be used for both ALE and *AIRBAG_HYBRID. IBLOCK = 0 will use FVOPT = 7 and IBLOCK = 1 will use FVOPT=8.

6. **Vent Coefficient.** VCOF will be used to scale the vent area for ALE venting and this coefficient will be used as vent coefficient c23 for *AIRBAG_HYBRID upon switching.

7. **ALE Mesh Motion.** If the airbag moves with the vehicle, set MOVERN = GROUPID; this GROUPID is defined using *ALE_REFERENCE_SYSTEM_NODE. The 3 nodes defined in *ALE_REFERENCE_SYSTEM_NODE will be used to transform the ALE mesh. The point sources will also follow this motion. This simulates PRTYP = 5 in the *ALE_REFERENCE_SYSTEM_GROUP card.

8. **Mesh Expansion.** Automatic expansion/contraction of the ALE mesh to follow the airbag expansion can be turned on by setting zoom = 1. This feature is particularly useful for fully folded airbags requiring very fine ale mesh initially. As

the airbag inflates the ale mesh will be automatically scaled such that the airbag will be contained within the ALE mesh. This simulates PRTYP = 9 in the *ALE_-REFERENCE_SYSTEM_GROUP card.

9. **Inlet Gas Velocity.** There are 3 methods for defining the inlet gas velocity:

   a) Inlet gas velocity is estimated by LS-DYNA method (testing), if

   $$\text{LCVEL} = 0 \Rightarrow \text{TNKVOL} = \text{Tank volume}$$

   and

   $$\text{TNKFINP} = \text{Tank final pressure from tank test data.}$$

   b) Inlet gas velocity is estimated automatically by Lian-Bhalsod-Olovsson method if,

   $$\text{LCVEL} = 0 \Rightarrow \text{TNKVOL} = \text{Tank volume.}$$

   and

   $$\text{TNKFINP} = \text{blank.}$$

   c) Inlet gas velocity is defined by user via a load curve LCVEL if,

   $$\begin{aligned} \text{LCVEL} &= \text{n}, \\ \text{TNKVOL} &= 0, \end{aligned}$$

   and

   $$\text{TNKFINP} = 0$$

10. **Sampling Points.** LCT and LCIDM should have the same number of sampling points.

11. **Heat Capacity at Constant Pressure.** The per-mass-unit, temperature-dependent, constant-pressure heat capacity is

$$C_p(T) = \frac{\left[A + BT + CT^2\right]}{MW}.$$

where,

$$A = \tilde{C}_{p_0}$$

these quantities often have units of,

$C_p(T)$	A	B	C
$\frac{\text{J}}{\text{kg} \times \text{K}}$	$\frac{\text{J}}{\text{mole} \times \text{K}}$	$\frac{\text{J}}{\text{mole} \times \text{K}^2}$	$\frac{\text{J}}{\text{mole} \times \text{K}^3}$

12. **Coupling.** Sometimes CTYPE = 6 may be used for a complex folded airbag. NQUAD = 2 may be used as a starting value and increased as necessary depending on the relative mesh resolutions of the Lagrangian and ALE meshes.

13. **PFAC.** Use a load curve for PFAC whenever possible. It tends to be more robust.

Related Cards:

$$\text{AIR} \longrightarrow \begin{cases} \text{*PART (AMMG2)} \\ \text{*SECTION\_SOLID} \\ \text{*MAT\_GAS\_MIXTURE} \end{cases}$$

$$\text{GAS} \longrightarrow \begin{cases} \text{*PART (AMMG1)} \\ \text{*SECTION\_POINT\_SOURCE\_MIXTURE} \\ \text{*MAT\_GAS\_MIXTURE} \end{cases}$$

Couplings ⟶ *CONSTRAINED_LAGRANGE_IN_SOLID

ALE Mesh Motion ⟶ *ALE_REFERENCE_SYSTEM_GROUP

Control Volume ⟶ *AIRBAG_HYBRID

Vent ⟶ *AIRBAG_ALE/Card4

Example 1:

```
$...|....1....|....2....|....3....|....4....|....5....|....6....|....7....|....8
*AIRBAG_ALE
$#1     SID   SIDTYPE      NONE      NONE      NONE      NONE       MWD      SPSF
        123         1         0         0         0         0       0.0       0.0
$#2 ATMOST    ATMOSP      NONE        GC        CC    TNKVOL     TNKFP
    298.15 1.0132E-4         0     8.314       0.0       0.0       0.0
$#3  NQUAD     CTYPE      PFAC      FRIC    FRCMIN   NRMTYPE     ILEAK     PLEAK
         4         4     -1000       0.0       0.3         0         2       0.1
$#4 VSETID  IVSETTYP    IBLOCK  VENTCOEF
         1         2         0      1.00
$#5NXIDAIR   NYIDGAS        NZ    MOVERN      ZOOM
     50000     50003         0         0         0
$#6 SWTIME      NONE        HG      NAIR      NGAS     NORIF     LCVEL       LCT
   1000.00     0.000    1.e-4         1         1         8      2002      2001
$#7 AIR         NONE      NONE     MWAIR    INITM      AIRA      AIRB      AIRC
         0         0         0   0.02897      1.00    29.100   0.00000   0.00000
$#8 GASLCM      NONE      NONE     MWGAS      NONE      GASA      GASB      GASC
      2003         0         0    0.0235         0    28.000   0.00000   0.00000
$#9 NODEID    VECTID  ORIFAREA
    100019         1 13.500000
    100020         2 13.500000
    100021         3 13.500000
    100022         4 13.500000
    100023         5 13.500000
    100024         6 13.500000
    100017         7 13.500000
    100018         8 13.500000
$ PFAC CURVE = penalty factor curve.
*DEFINE_CURVE
$     lcid      sidr       sfa       sfo      offa      offo    dattyp
```

```
      1000         0       0.0       2.0       0.0       0.0
$                 a1                  o1
                 0.0        0.00000000
           1.0000000      4.013000e-04
*SET_SEGMENT_TITLE
vent segments (defined in IVSETID)
         1       0.0       0.0       0.0       0.0
      1735      1736       661      1697       0.0       0.0       0.0       0.0
      1735      2337      1993      1736       0.0       0.0       0.0       0.0
      1735      1969      1988      2337       0.0       0.0       0.0       0.0
      1735      1697       656      1969       0.0       0.0       0.0       0.0
*DEFINE_VECTOR
$#     vid        xt        yt        zt        xh        yh        zh
         1       0.0       0.0-16.250000 21.213200 21.213200-16.250000
         2       0.0       0.0-16.250000 30.000000-1.000e-06-16.250000
         3       0.0       0.0-16.250000 21.213200-21.213200-16.250000
         4       0.0       0.0-16.250000-1.000e-06-30.000000-16.250000
         5       0.0       0.0-16.250000-21.213200-21.213200-16.250000
         6       0.0       0.0-16.250000-30.0000001.0000e-06-16.250000
         7       0.0       0.0-16.250000-21.213200 21.213200-16.250000
         8       0.0       0.0-16.2500001.0000e-06 30.000000-16.250000
$...|....1....|....2....|....3....|....4....|....5....|....6....|....7....|....8
```

In this example, pre-existing background air mesh with part ID 50000 and gas mesh with part ID 50003 are used. Thus NZ = 0. There is no mesh motion nor expansion allowed. An inlet gas velocity curve is provided.

Example 2:

```
$...|....1....|....2....|....3....|....4....|....5....|....6....|....7....|....8
$ SIDTYP: 0=SGSID; 1=PSID
*AIRBAG_ALE
$#1    SID   SIDTYPE      NONE      NONE      NONE      NONE       MWD      SPSF
         1         1         0        0.        0.        0.        0.        0.
$#2 ATMOST    ATMOSP      NONE        GC        CC    TNKVOL     TNKFP
      298.   101325.       0.0     8.314        1.    6.0E-5         0
$#3  NQUAD     CTYPE      PFAC      FRIC    FRCMIN   NRMTYPE     ILEAK     PLEAK
         2         6      -321       0.0       0.3         1         2       0.1
$#4 VSETID  IVSETTYP    IBLOCK  VENTCOEF
         0         0         0         0
$#5NXIDAIR   NYIDGAS        NZ    MOVERN      ZOOM
        11        11         9
$5b     x0        y0        z0        x1        y1        z1  NOT-USED  NOT-USED
      -0.3      -0.3    -0.135       0.3      -0.3    -0.135
$5c     x2        y2        z2        x3        y3        z3  NOT-USED  NOT-USED
      -0.3       0.3    -0.135      -0.3      -0.3      0.39
$#6 SWTIME      NONE        HG      NAIR      NGAS     NORIF     LCVEL       LCT
   0.04000     0.005    1.e-4          2         1         1         0         2
$#7 AIR         NONE      NONE     MWAIR     INITM      AIRA      AIRB      AIRC
                                   0.028      0.80    27.296   0.00523
                                   0.032      0.20    25.723   0.01298
$#8 GASLCM      NONE      NONE     MWGAS      NONE      GASA      GASB      GASC
         1                        0.0249              29.680   0.00880
$#9 NODEID    VECTID  ORIFAREA
      9272         1   1.00e-4
$ Lagrangian shell structure to be coupled to the inflator gas
*SET_PART_LIST
         1       0.0       0.0       0.0       0.0
         1         2         3
*DEFINE_VECTOR
$0.100000E+01,  10.000000000
$      vid        xt        yt        zt        xh        yh        zh
```

```
         1       0.0       0.0       0.0       0.0       0.0  0.100000
$ bag penetration ~ 1 mm  <====>  P_coup ~ 500000 pascal ==> ~ 5 atm
*DEFINE_CURVE
$     lcid      sidr       sfa       sfo      offa      offo    dattyp
       321         0       0.0       0.0       0.0       0.0
$                 a1                  o1
                 0.0                 0.0
          0.00100000       5.0000000e+05
$...|....1....|....2....|....3....|....4....|....5....|....6....|....7....|....8
```

In this example, LS-DYNA automatically creates the background ALE mesh with:

NX = 11 ⇒ 11 elements in the x-direction
NY = 11 ⇒ 11 Elements in the y-direction
NZ = 9 ⇒ 9 Elements in the z-direction

*AIRBAG_CPG_{OPTION}

Available options include:

<BLANK>

ID

TITLE

Use either ID or TITLE to specify an airbag ID and a heading for the airbag.

Purpose: Define an airbag using the Continuum-base Particle Gas (CPG) method. CPG is a particle-based compressible gas solver.

> **NOTE:** This model requires orienting surface normal vectors *inward*, unlike the traditional Control Volume or CV method (also known as Uniform Pressure or UP method) for which they must point *outward*.

Card Summary:

Card ID. Include this card if using the ID or TITLE keyword options.

BAGID	HEADING	

Card 1. This card is required.

SID1	STYPE1	SID2	STYPE2		NPDATA		

Card 2. This card is required.

HLEN	UNIT		TATM	PATM	NVENT		

Card 3. This card is required.

	NGAS	NORIF	NID1	NID2	NID3		

Card 4. Additional cards for NPDATA > 0 (see Card 1). Define NPDATA cards, one for each part or part set providing additional data.

SIDH	STYPEH	HCONV	PFRIC				

Card 5. Include NVENT instantiations of this card (see Card 2).

SID3	STYPE3		LCTC	LCPC			

Card 6. This card is required.

PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR		

Card 7. Include NGAS of this card. See Card 3.

LCM*i*	LCT*i*	XM*i*	A*i*	B*i*	C*i*	INFG*i*	

Card 8. Include NORIF of this card. See Card 3.

SSID*i*				INFO*i*			

Data Card Definitions:

Title Card. Additional card for the ID or TITLE keyword options.

Card ID	1	2	3	4	5	6	7	8
Variable	BAGID	HEADING						
Type	I	A60						

VARIABLE	DESCRIPTION
BAGID	Airbag ID. This must be a unique number.
HEADING	Airbag descriptor. We suggest using unique descriptions.

Card 1	1	2	3	4	5	6	7	8
Variable	SID1	STYPE1	SID2	STYPE2		NPDATA		
Type	I	I	I	I		I		
Default	none	0	0	0		0		

VARIABLE	DESCRIPTION
SID1	Part or part set ID defining the complete airbag

VARIABLE	DESCRIPTION
STYPE1	Set type: EQ.0: Part EQ.1: Part set
SID2	Part or part set ID defining the internal parts of the airbag
STYPE2	Set type: EQ.0: Part EQ.1: Part set
NPDATA	Number of parts or part sets with additional data

Card 2	1	2	3	4	5	6	7	8
Variable	HLEN	UNIT		TATM	PATM	NVENT		
Type	F	I		F	F	I		
Default	0.	0		293 K	1 atm	0		

VARIABLE	DESCRIPTION
HLEN	Average interparticle distance. See Remark 1.
UNIT	Unit system: EQ.0: kg-mm-ms-K EQ.1: SI EQ.2: tonne-mm-s-K
TATM	Atmospheric temperature
PATM	Atmospheric pressure
NVENT	Number of vent hole parts or part sets

Card 3	1	2	3	4	5	6	7	8
Variable		NGAS	NORIF	NID1	NID2	NID3		
Type		I	I	I	I	I		
Default		none	none	0	0	0		.

VARIABLE	DESCRIPTION
NGAS	Number of gas components
NORIF	Number of orifices
NID1 - NID3	Three nodes defining a moving coordinate system. By default, the coordinate system is fixed. See Remark 6.

NPDATA Card. Additional cards for NPDATA > 0. Define NPDATA cards, one for each part or part set with additional data.

Card 4	1	2	3	4	5	6	7	8
Variable	SIDH	STYPEH	HCONV	PFRIC				
Type	I	I	F	F				
Default	none	none	none	0.0				

VARIABLE	DESCRIPTION
SIDH	Part or part set ID defining additional part data
STYPEH	Set type: EQ.0: Part EQ.1: Part set
HCONV	Convective heat transfer coefficient used to calculate heat loss from the airbag's external surface to ambient. See Remark 2.
PFRIC	Friction factor F_r. See Remark 3.

Vent Hole Card. Additional cards for NVENT > 0. Define NVENT cards, one for vent hole.

Card 5	1	2	3	4	5	6	7	8
Variable	SID3	STYPE3		LCT	LCP			
Type	I	I		I	I			
Default	0	none		0	0			

VARIABLE	DESCRIPTION
SID3	Part or part set ID defining vent holes
STYPE3	Set type: EQ.0: Part EQ.1: Part set with each part treated separately
LCT	Optional load curve to impose temperature as a function of time in cases where backflow is detected. Otherwise, TATM is used. See Remark 4.
LCP	Optional load curve to impose pressure as a function of time. Otherwise, PATM is used. See Remark 4.

Air Card. Mandatory card.

Card 6	1	2	3	4	5	6	7	8
Variable	PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR		
Type	F	F	F	F	F	F		
Default	PATM	TATM	none	none	0.0	0.0		

VARIABLE	DESCRIPTION
PAIR	Initial pressure inside bag
TAIR	Initial temperature inside bag

VARIABLE	DESCRIPTION
XMAIR	Molar mass of gas initially inside bag: LT.0.0: -XMAIR references the ID of a *DEFINE_CPG_GAS_-PROPERTIES keyword that defines the gas thermodynamic properties. Note that AAIR, BAIR, and CAIR are ignored.
AAIR – CAIR	Constant, linear, and quadratic heat capacity parameters

Gas Cards. NGAS additional cards, one for each gas (card format for i^{th} gas).

Card 7	1	2	3	4	5	6	7	8
Variable	LCM*i*	LCT*i*	XM*i*	A*i*	B*i*	C*i*	INFG*i*	
Type	I	I	F	F	F	F	I	
Default	none	none	none	none	0.0	0.0	1	

VARIABLE	DESCRIPTION
LCM*i*	Mass flow rate curve for gas component *i*,
LCT*i*	Temperature load curve for gas component *i*
XM*i*	Molar mass of gas component *i*. LT.0.0: The absolute value of XM*i* references the ID of a *DEFINE_CPG_GAS_PROPERTIES keyword that defines the gas thermodynamic properties. Note that A*i*, B*i*, and C*i* are ignored.
A*i* - C*i*	Constant, linear, and quadratic heat capacity parameters for gas component *i*
INFG*i*	Inflator ID for this gas component (defaults to 1)

Orifice Cards. NORIF additional cards, one for each orifice (card format for i^{th} orifice).

Card 8	1	2	3	4	5	6	7	8
Variable	SSID*i*				INFO*i*			
Type	I				I			
Default	none				1			

VARIABLE	DESCRIPTION
SSID*i*	Shell ID defining the location of nozzle *i*. If a negative value is entered, the absolute value refers to a shell set ID. See Remark 5.
INFO*i*	Inflator ID for this orifice (default = 1)

Remarks:

1. **HLEN.** It is recommended to keep this value at around the airbag's surface mesh size or lower.

2. **Thermal coupling.** Using the LS-DYNA implicit thermal solver automatically triggers two-way thermal coupling. The thermal solver imposes the temperature at the fluid particles attached to the wall, and the CPG solver returns a heat flux based on the choice of HCONV, the atmospheric temperature (acts as bulk), and the wall temperature.

3. **Friction.** The friction factor F_r acts as a scaling value on the friction force that is added to the fluid particles close to the wall. The friction force is based on the fluid viscosity (see *DEFINE_CPG_GAS_PROPERTIES) and velocity gradient. For typical airbag applications, effects are expected to be small unless very large values are chosen for F_r .

4. **Backflow.** The velocity direction at a given time automatically determines the state of the vent, meaning whether it is in backflow mode or in outflow mode. If in backflow mode, pressure and temperature are imposed, and the gas fraction of air is set to 1.0 (0.0 to all other gases). If in outflow mode, only the pressure is imposed. In the case of supersonic outflow, user-defined pressure values are ignored and replaced by the upstream pressure.

5. **Selecting an orifice area.** Airbag orifice areas are typically very small. Conversely, traditional CFD recommendations require at least ten elements or points

to properly define any inlet area. Following those guidelines may result in very large models. In practice, a compromise must be found by increasing the numerical surface area of the orifice and keeping enough particles to properly represent the inlet. The use of a *MESH_SIZE_SHAPE close to the inlet may also be useful.

6. **Moving coordinate system.** Defining a moving coordinate system can be used when the entire airbag is attached to a moving part (such as a moving vehicle). The gas velocity is initialized according to the initial velocities of the coordinate system, and the point cloud follows the motion of the coordinate system (translation and rotation).

*AIRBAG_INTERACTION

Purpose: To define two connected airbags which vent into each other.

Card 1	1	2	3	4	5	6	7	8
Variable	AB1	AB2	AREA	SF	PID	LCID	IFLOW	EXCP
Type	I	I	F	F	I	I	I	I
Default	none	none	none	none	0	0	0	0

VARIABLE	DESCRIPTION
AB1	First airbag ID, as defined on *AIRBAG card.
AB2	Second airbag ID, as defined on *AIRBAG card.
AREA	Orifice area between connected bags. LT.0.0: |AREA| is the load curve ID defining the orifice area as a function of absolute pressure. EQ.0.0: AREA is taken as the surface area of the part ID defined below.
SF	Shape factor. LT.0.0: |SF| is the load curve ID defining vent orifice coefficient as a function of relative time.
PID	Optional part ID of the partition between the interacting control volumes. AREA is based on this part ID. If PID is negative, the blockage of the orifice part due to contact is considered,
LCID	Load curve ID defining mass flow rate as a function of pressure difference, see *DEFINE_CURVE. If LCID is defined, AREA, SF and PID are ignored.
IFLOW	Flow direction LT.0: One way flow from AB1 to AB2 only. EQ.0: Two way flow between AB1 and AB2. GT.0: One way flow from AB2 to AB1 only.

VARIABLE	DESCRIPTION
EXCP	Excluding partition part, PID, from bag pressure application. This option applies to *AIRBAG_WANG_NEFSKE and *AIRBAG_HYBRID only. EQ.0: bag pressure will be applied to PID. EQ.1: PID is excluded from bag pressure application.

Remarks:

Mass flow rate and temperature load curves for the secondary chambers must be defined as null curves, for example, in the DEFINE_CURVE definitions give two points (0.0,0.0) and (10000. ,0.0).

All input options are valid for the following airbag types:

*AIRBAG_SIMPLE_AIRBAG_MODEL

*AIRBAG_WANG_NEFSKE

*AIRBAG_WANG_NEFSKE_JETTING

*AIRBAG_WANG_NEFSKE_MULTIPLE_JETTING

*AIRBAG_HYBRID

*AIRBAG_HYBRID_JETTING

The LCID defining mass flow rate as a function of pressure difference may additionally be used with:

*AIRBAG_LOAD_CURVE

*AIRBAG_LINEAR_FLUID

If the AREA, SF, and PID are used to define the interaction, then the airbags must contain the same gas, that is, C_p, C_V and g must be the same. The flow between bags is governed by formulae which are similar to those of Wang-Nefske.

*AIRBAG_PARTICLE_{OPTION1}_..._{OPTION6}

Available options include:

OPTION1 applies to the MPP implementation only.

MPP

OPTION2 also applies to the MPP implementation only. When the DECOMPOSITON option is present, LS-DYNA will automatically insert *CONTROL_MPP_DECOMPOSITION_BAGREF and *CONTROL_MPP_DECOMPOSITION_ARRANGE_PARTS keywords if they are not already present in the input.

DECOMPOSITION

With *OPTION3* you can specify an airbag ID and a heading for the airbag.

ID

TITLE

OPTION4:

MOLEFRACTION (see Remark 10)

INFLATION (see Remark 17)

JET (see Remark 18)

Include *OPTION5* to specify the airbag volume with a segment set:

SEGMENT

OPTION6 allows you to give the birth and death times for the current CPM airbag.

TIME

Purpose: To define an airbag using the particle method. This method is also sometimes referred to as CPM (Corpuscular Particle Method).

NOTE:	This model requires that surface normal vectors be oriented *inward*, unlike the traditional Control Volume or CV method (also known as Uniform Pressure or UP method) for which they must point *outward*. To check bag and chamber integrity, see the CPMERR option on the *CONTROL_CPM card.

Card Summary:

Card MPP. Include this card if using the MPP keyword option.

SX	SY	SZ					

Card ID. Include this card if the using the ID or TITLE keyword options.

BAGID	HEADING	

Card T. Include this card if using the TIME keyword option.

BIRTH	DEATH						

Card 1. This card is required.

SID1	STYPE1	SID2	STYPE2	BLOCK	NPDATA	FRIC	IRPD

Card 2. Include this card if using the SEGMENT keyword option.

SEGSID							

Card 3. This card is required.

NP	UNIT	VISFLG	TATM	PATM	NVENT	TEND	TSW

Card 4. Include this card if using the JET keyword option.

JNODE							

Card 5. When the card after Card 3 or 4, depending on if the JET keyword option is used, begins with a "+" character, the input reader processes it as this card; otherwise, this card is skipped.

TSTOP	TSMTH	OCCUP	REBL	SIDSV	PSID1	TSPLIT	SFFDC

Card 5.1. When Card 5 is included and the card after Card 5 begins with a "+" character, the input reader processes it as this card; otherwise, this card is skipped.

SFIAIR4	IDFRIC	IAIRSTAT	DPWR	VNDAMP	JETLEN	JETEND	

Card 6. Include this card if UNIT = 3. See Card 3.

	MASS		TIME		LENGTH		

Card 7. This card is required.

IAIR	NGAS	NORIF	NID1	NID2	NID3	CHM	CD_EXT

Card 8. Include this card when STYPE2 = 2 (see Card 1). Define SID2 cards, one for each internal part or part set.

SIDUP	STYUP	PFRAC	LINKING				

Card 9. Additional cards for NPDATA > 0 (see Card 1). Define NPDATA cards, one for each heat convection part or part set.

SIDH	STYPEH	HCONV	PFRIC	SDFBLK	KP	INIP	CP

Card 10. Define NVENT of this card (see Card 3).

SID3	STYPE3	C23	LCTC23	LCPC23	ENH_V	PPOP	

Card 11. Include this card when IAIR ≠ 0. See Card 7.

PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR	NPAIR	NPRLX

Card 12. Include this card if using the MOLEFRACTION keyword option.

LCMASS							

Card 13. Include NGAS of this card. See Card 7.

LCMi	LCTi	XMi	Ai	Bi	Ci	INFGi	

Card 14. Include NORIF of this card. See Card 7. Card 14.1 may be required to directly follow an instantion of Card 14 if VD*i* = -3 or -4

NIDi	ANi	VDi	CAi	INFOi	IMOM	IANG	CHM_ID

Card 14.1. Include this card in a set with Card 14 if VD*i* = -3 or -4.

XOFF							

Data Card Definitions:

MPP Card. Additional card for MPP keyword option.

Card MPP	1	2	3	4	5	6	7	8
Variable	SX	SY	SZ					
Type	F	F	F					
Default	none	none	none					

VARIABLE	DESCRIPTION
SX, SY, SZ	Scale factor for each direction used during the MPP decomposition. For instance, increasing SX from 1 to 10 increases the probability that the model is divided along the *x*-direction.

Title Card. Additional card for ID or TITLE keyword options.

Card ID	1	2	3	4	5	6	7	8
Variable	BAGID	HEADING						
Type	I	A60						

VARIABLE	DESCRIPTION
BAGID	Airbag ID. This must be a unique number. The BAGID is referenced in, for example, *INITIAL_AIRBAG_PARTICLE_POSITION.
HEADING	Airbag descriptor. It is suggested that unique descriptions be used.

TIME Card. Additional card for TIME keyword option.

Card T	1	2	3	4	5	6	7	8
Variable	BIRTH	DEATH						
Type	F	F						
Default	none	10^{20}						

VARIABLE	DESCRIPTION
BIRTH, DEATH	Time to activate/deactivate CPM algorithm. CPM particles will be generated after the birth time.

Card 1	1	2	3	4	5	6	7	8
Variable	SID1	STYPE1	SID2	STYPE2	BLOCK	NPDATA	FRIC	IRPD
Type	I	I	I	I	I	I	F	I
Default	none	0	0	0	0	0.0	0.0	0

VARIABLE	DESCRIPTION
SID1	Part or part set ID defining the complete airbag.
STYPE1	Set type: EQ.0: Part EQ.1: Part set
SID2	Part or part set ID defining the internal parts of the airbag
STYPE2	Set type: EQ.0: Part EQ.1: Part set EQ.2: Number of parts to read (not recommended for general use)

VARIABLE	DESCRIPTION
BLOCK	Blocking. Block must be set to a two-digit number:

$$\text{BLOCK} = \text{M} \times 10 + \text{N},$$

The 10's digit controls the treatment of particles that escape due to deleted elements (particles are always tracked and marked).

M.EQ.0: Active particle method which causes particles to be put back into the bag.

M.EQ.1: Particles are leaked through unmeshed vents. See Remark 3.

M.EQ.2: Blockage logic is turned on when the contact pressure is greater than the bag/chamber pressure for the external vents.

The 1's digit controls the treatment of leakage.

N.EQ.0: Always consider porosity leakage without considering blockage due to contact.

N.EQ.1: Check if airbag node is in contact or not. If yes, 1/4 (quad) or 1/3 (tri) of the segment surface will not have porosity leakage due to contact.

N.EQ.2: Same as 1 but no blockage for external vents

N.EQ.3: Same as 1 but no blockage for internal vents

N.EQ.4: Same as 1 but no blockage for all vents.

VARIABLE	DESCRIPTION
NPDATA	Number of parts or part sets data
FRIC	Friction factor F_r if -1.0 < FRIC ≤ 1.0. Otherwise,

LE.-1.0: |FRIC| is the curve ID which defines F_r as a function of the part pressure.

GT.1.0: FRIC is the *DEFINE_FUNCTION ID that defines F_r. See Remark 2.

VARIABLE	DESCRIPTION
IRPD	Dynamic scaling of particle radius flag:

EQ.0: Off

EQ.1: On

SEGMENT Card. This card is included if the SEGMENT keyword option is used.

Card 2	1	2	3	4	5	6	7	8
Variable	SEGSID							
Type	I							

VARIABLE	DESCRIPTION
SEGSID	ID for a segment set. The segments define the volume and should belong to the parts from SID1.

Card 3	1	2	3	4	5	6	7	8
Variable	NP	UNIT	VISFLG	TATM	PATM	NVENT	TEND	TSW
Type	I	I	I	F	F	I	F	F
Default	200,000	0	0	293 K	1 atm	0	10^{10}	10^{10}

VARIABLE	DESCRIPTION
NP	Number of particles
UNIT	Unit system: EQ.0: kg-mm-ms-K EQ.1: SI EQ.2: tonne-mm-s-K EQ.3: User defined units (see Remark 11)
VISFLG	Visible particles. This field affects only the CPM database. See Remark 5. EQ.0: Default to 1 EQ.1: Output particle's coordinates, velocities, mass, radius, spin energy, translational energy EQ.2: Output reduced data set with coordinates only EQ.3: Suppress CPM database

VARIABLE	DESCRIPTION
TATM	Atmospheric temperature
PATM	Atmospheric pressure
NVENT	Number of vent hole parts or part sets
TEND	Time when all (NP) particles have entered bag. See Remark 14.
TSW	Time at which algorithm switches to control volumes.

Jet Card. This card is included if the JET keyword option is used.

Card 4	1	2	3	4	5	6	7	8
Variable	JNODE							
Type	I							

VARIABLE	DESCRIPTION
JNODE	Node ID on which to apply the reaction force from the thrust (see Remark 18)

Optional Control Cards. When the card after Card 3 or 4 depending on if the JET keyword option is used begins with a "+" character, the input reader processes it as this card; otherwise this card is skipped.

Card 5	1	2	3	4	5	6	7	8
Variable	TSTOP	TSMTH	OCCUP	REBL	SIDSV	PSID1	TSPLIT	SFFDC
Type	F	F	F	I	I	I	F	F
Default	10^{10}	1.0 ms	0.1	0	none	none	none	1.0

VARIABLE	DESCRIPTION
TSTOP	Time at which front tracking switches from IAIR = 4 to IAIR = 2. See Card 7.
TSMTH	To avoid sudden jumps in the pressure signal during switching,

VARIABLE	DESCRIPTION
	front tracking is tapered during a transition period. If set to zero, the default time of 1.0 millisecond will be applied.
OCCUP	Particles occupy OCCUP percent of the airbag's volume (default = 10%). This field can be used to balance computational cost and signal quality. OCCUP ranges from 0.001 to 0.1.
REBL	If the option is ON, all energy stored from damping will be evenly distributed as vibrational energy to all particles. This improves the pressure calculation in certain applications. EQ.0: Off (Default) EQ.1: On
SIDSV	Part set ID for internal shell part. The volume occupied by this part is excluded from the bag volume. These internal parts must be consistently orientated for the excluded volume to be correctly calculated.
PSID1	Part set ID for external parts which have normals pointed outward. This option is usually used with an airbag integrity check when there are two CPM bags connected with bag interaction. Therefore, one of the bags can have the correct shell orientation but the shared parts for the second bag will have wrong orientation. This option will automatically flip the parts defined in this set in the second bag during integrity checking.
TSPLIT	Start time to activate particle splitting algorithm. See Remark 15.
SFFDC	Scale factor for the force decay constant. SFFDC has a range of [0.01,100.0]. The default value is 1.0. The value given here will replaced the values from *CONTROL_CPM.

Optional Control Cards. When Card 5 is included and the card after Card 5 begins with a "+" character, the input reader processes it as this card; otherwise this card is skipped.

Card 5.1	1	2	3	4	5	6	7	8
Variable	SFIAIR4	IDFRIC	IAIRSTAT	DPWR	VNDAMP	JETLEN	JETEND	
Type	F	I	I	F	F	F	F	
Default	1.0	0	0	1.0	0.0	0.0	0.0	

VARIABLE	DESCRIPTION
SFIAIR4	Scale factor for the ratio of initial air particles to inflator gas particles for IAIR = 4. Smaller values weaken the effect of gas front tracking.
IDFRIC	Direction of particle-to-fabric impact force: EQ.0: No change (default) EQ.1: The force is applied in the segment's normal direction.
IAIRSTAT	By default, initial air particles cannot pass through pores and vents when IAIR = 4. This flag can change the treatment: EQ.0: No change (default) EQ.1: Allow passing through pores and vents
DPWR	Exponent for decaying the partial pressure of ambient air inside the airbag for IAIR = 4. See Remark 19.
VNDAMP	Damping coefficient against the motion in the segment normal direction. 0. $\le$ VNDAMP $\le$ 1.0.
JETLEN	Estimated particle jet distance. Based on this distance, the particle-to-particle contact evaluation frequency reduces to preserve the jetting effect from the inflator orifice.
JETEND	End time for the JETLEN option

Optional unit card. Additional card when UNIT = 3.

Card 6	1	2	3	4	5	6	7	8
Variable		MASS		TIME		LENGTH		
Type		F		F		F		
Default		none		none		none		

VARIABLE	DESCRIPTION
MASS, TIME, LENGTH	Conversion factor from current unit to MKS unit. For example, if the current unit is using kg-mm-ms, the input should be 1.0, 0.001, 0.001.

Card 7	1	2	3	4	5	6	7	8
Variable	IAIR	NGAS	NORIF	NID1	NID2	NID3	CHM	CD_EXT
Type	I	I	I	I	I	I	I	F
Default	0	none	none	0	0	0	None	0.

VARIABLE	DESCRIPTION
IAIR	Initial gas inside bag considered: EQ.0: No EQ.1: Yes, using control volume method. EQ.-1: Yes, using control volume method. In this case ambient air enters the bag when PATM is greater than bag pressure. EQ.2: Yes, using the particle method. EQ.4: Yes, using the particle method. Initial air particles are used for the gas front tracking algorithm, but they do not apply forces when they collide with a segment. Instead, a uniform pressure is applied to the airbag based on the ratio of air and inflator particles. In this case NPRLX must be negative so that forces are not applied by the

VARIABLE	DESCRIPTION
	initial air. EQ.-4: Yes, using the particle method. Similar to 4, except the PV energy created to go against the ambient pressure is removed from the airbag system based on the following equation: $$PV = \sum_{\text{segments}} \frac{\text{Collision}_{\text{air}}}{\text{Collision}_{\text{particle}}} V_{\text{seg}} P_{\text{atm}} A_{\text{seg}} dt$$
NGAS	Number of gas components
NORIF	Number of orifices
NID1 - NID3	Three nodes defining a moving coordinate system for the direction of flow through the gas inlet nozzles (Default = fixed system)
CHM	Chamber ID used in *DEFINE_CPM_CHAMBER. See Remark 7.
CD_EXT	Drag coefficient of the external air. If the value is not zero, the inertial effect from external air will be considered and forces will be applied in the normal direction on the exterior airbag surface. GT.0: Drag coefficient LT.0: Curve ID for time dependent drag coefficient **NOTE:** To model drag, you must define ambient air properties with IAR.

Internal Part Set Cards. Additional Cards for STYPE2 = 2. Define SID2 cards, one for each internal part or part set.

Card 8	1	2	3	4	5	6	7	8
Variable	SIDUP	STYUP	PFRAC	LINKING				
Type	I	I	F	I				
Default	none	none	0.	none				

VARIABLE	DESCRIPTION
SIDUP	Part or part set ID defining the internal parts that pressure will be

VARIABLE	DESCRIPTION
	applied to. This internal structure acts as a valve to control the external vent hole area. Pressure will be applied only after switch to UP (uniform pressure) using TSW.
STYUP	Set type: EQ.0: Part EQ.1: Part set
PFRAC	Fraction of pressure to be applied to the set (0.0 to 1.0). If PFRAC = 0.0, no pressure is applied to internal parts.
LINKING	Part ID of an internal part that is coupled to the external vent definition. The minimum area of this part or the vent hole will be used for actual venting area.

Heat Convection Part Set Cards. Additional cards for NPDATA > 0. Define NPDATA cards, one for each heat convection part or part set.

Card 9	1	2	3	4	5	6	7	8
Variable	SIDH	STYPEH	HCONV	PFRIC	SDFBLK	KP	INIP	CP
Type	I	I	F	F	F	F	I	F
Default	none	none	none	FRIC	1.0	0.	0	none

VARIABLE	DESCRIPTION
SIDH	Part or part set ID defining part data.
STYPEH	Set type: EQ.0: Part EQ.1: Part set EQ.2: Part. HCONV is the *DEFINE_CPM_NPDATA ID. EQ.3: Part set. HCONV is the *DEFINE_CPM_NPDATA ID.
HCONV	Convective heat transfer coefficient used to calculate heat loss from the airbag external surface to ambient. See *AIRBAG_HYBRID developments (Resp. P.O. Marklund).

VARIABLE	DESCRIPTION
	LT.0: |HCONV| is a load curve ID defines heat convection coefficient as a function of time. When STYPEH is greater than 1, HCONV is a *DEFINE_CPM_-NPDATA ID.
PFRIC	Friction factor F_r if -1.0 < PFRIC ≤ 1.0. Defaults to FRIC from Card 1 if undefined. Otherwise, LE.-1.0: |PFRIC| is the curve ID which defines F_r as a function of the part pressure. GT.1.0: PFRIC is the *DEFINE_FUNCTION ID that defines F_r. See Remark 2.
SDFBLK	Scaling down factor for blockage factor (Default = 1.0, no scaling down). The valid factor will be (0.0,1.0]. If 0.0, it will set to 1.0.
KP	Thermal conductivity of the part. See Remark 9.
INIP	Place initial air particles on surface. EQ.0: Yes (default) EQ.1: No This feature excludes surfaces from initial particle placement. This option is useful for preventing particles from being trapped between adjacent fabric layers.
CP	Specific heat (see Remark 16).

Vent Hole Card. Additional cards for NVENT > 0. Define NVENT cards, one for vent hole.

Card 10	1	2	3	4	5	6	7	8
Variable	SID3	STYPE3	C23	LCTC23	LCPC23	ENH_V	PPOP	
Type	I	I	F	I	I	I	F	
Default	0	none	1.0	0	0	0	0.0	

VARIABLE	DESCRIPTION
SID3	Part or part set ID defining vent holes.
STYPE3	Set type: EQ.0: Part EQ.1: Part set which each part being treated separately EQ.2: Part set and all parts are treated as one vent. See Remark 13.
C23	GE.0: Vent hole coefficient, a parameter of Wang-Nefske leakage. A value between 0.0 and 1.0 can be input. See Remark 1. LT.0: ID for *DEFINE_CPM_VENT. Some extended options can only be defined through *DEFINE_CPM_VENT. Please check this keyword for more information.
LCTC23	Load curve defining the vent hole coefficient as a function of time. LCTC23 can be defined through *DEFINE_CURVE_FUNCTION. If omitted, a curve equal to 1.0 used. See Remark 1.
LCPC23	Load curve or function defining the vent hole coefficient as a function of pressure. If omitted a curve equal to 1.0 is used. See Remark 1. GT.0: Load curve ID for *DEFINE_CURVE_FUNCTION or *DEFINE_CURVE LT.0: *DEFINE_FUNCTION ID
ENH_V	Enhanced venting option. See Remark 8. EQ.0: Off (default) EQ.1: On EQ.2: Two-way flow for internal vent; treated as hole for external vent (see Remark 8)
PPOP	Pressure difference between interior and ambient pressure (PATM) to open the vent holes. Once the vents are open, they will stay open.

Air Card. Additional card for IAIR ≠ 0.

Card 11	1	2	3	4	5	6	7	8
Variable	PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR	NPAIR	NPRLX
Type	F	F	F	F	F	F	I	I/F
Default	PATM	TATM	none	none	0.0	0.0	0	0

VARIABLE	DESCRIPTION
PAIR	Initial pressure inside bag
TAIR	Initial temperature inside bag
XMAIR	Molar mass of gas initially inside bag: LT.0: -XMAIR references the ID of a *DEFINE_CPM_GAS_-PROPERTIES keyword that defines the gas thermodynamic properties. Note that AAIR, BAIR, and CAIR are ignored.
AAIR - CAIR	Constant, linear, and quadratic heat capacity parameters
NPAIR	Number of air particles. See Remark 6.
NPRLX	Number of cycles to reach thermal equilibrium. See Remark 6. LT.0: If more than 50% of the collision to fabric is from initial air particles, the contact force will not apply to the fabric segment in order to keep its original shape. If the number contains ".", "e" or "E", NPRLX will treated as an end *time* rather than as a cycle count. When the keyword option INFLATION is used, NPRLX is also the number of cycles for maintaining the initial pressure given by PAIR.

MOLEFRACTION Card. Additional card for the MOLEFRACTION option.

Card 12	1	2	3	4	5	6	7	8
Variable	LCMASS							
Type	I							
Default	none							

VARIABLE	DESCRIPTION
LCMASS	Total mass flow rate curve for the MOLEFRACTION option

Gas Cards. NGAS additional cards, one for each gas (card format for i^{th} gas).

Card 13	1	2	3	4	5	6	7	8
Variable	LCM*i*	LCT*i*	XM*i*	A*i*	B*i*	C*i*	INFG*i*	
Type	I	I	F	F	F	F	I	
Default	none	none	none	none	0.0	0.0	1	

VARIABLE	DESCRIPTION
LCM*i*	Mass flow rate curve for gas component *i*, unless the MOLEFRACTION option is used. If the MOLEFRACTION option is used, then it is the time dependent molar fraction of the total flow for gas component *i*.
LCT*i*	Temperature load curve/DEFINE_FUNCTION for gas component *i*
XM*i*	Molar mass of gas component *i*. LT.0: The absolute value of XM*i* references the ID of a *DEFINE_CPM_GAS_PROPERTIES keyword that defines the gas thermodynamic properties. Note that A*i*, B*i*, and C*i* are ignored.

VARIABLE	DESCRIPTION
A*i* - C*i*	Constant, linear, and quadratic heat capacity parameters for gas component *i*
INFG*i*	Inflator ID for this gas component (defaults to 1). The user inflator routine can only be defined using *DEFINE_CPM_GAS_PROPERTIES. Please check this extra card for the interface I/O.

Orifice Cards. NORIF additional cards, one for each orifice (card format for i^{th} orifice).

Card 14	1	2	3	4	5	6	7	8
Variable	NID*i*	AN*i*	VD*i*	CA*i*	INFO*i*	IMOM	IANG	CHM_ID
Type	I	F	I	F	I	I	I	I
Default	none	↓	none	30°	1	0	0	0

VARIABLE	DESCRIPTION
NID*i*	Node ID/Shell ID defining the location of nozzle *i*. See Remark 12.
AN*i*	GT.0: Area of nozzle *i* (default: all nozzles are assigned the same area). LT.0: Load curve ID. Time dependent area of nozzle *i*.
VD*i*	GT.0: Vector ID. Initial direction of gas inflow at nozzle *i*. LT.0: Values in the NID*i* fields are interpreted as shell IDs. See Remark 12. EQ.-1: Direction of the gas inflow is the shell's normal direction EQ.-2: Direction of the gas inflow is the reverse direction from the shell's normal direction EQ.-3: Direction of the gas inflow is the shell's normal direction. This option requires including an additional card (Card 14.1) for setting the offset from the shell's center point. EQ.-4: Direction of gas inflow is the reverse direction from the shell's normal direction. This option requires including an additional card (Card 14.1) for setting the offset from the shell's center point.

VARIABLE	DESCRIPTION
CA*i*	Cone angle in degrees (defaults to 30°). This option is used only when IANG is equal to 1.
INFO*i*	Inflator ID for this orifice. (default = 1)
IMOM	Inflator reaction force (R5.1.1 release and later): EQ.0: Off EQ.1: On
IANG	Activation for cone angle to use for friction calibration (not normally used; eliminates thermal energy of particles from inflator). EQ.0: Off (default) EQ.1: On
CHM_ID	Chamber ID where the inflator node resides. Chambers are defined using the *DEFINE_CPM_CHAMBER keyword.

Additional Orifice Cards. Include this card in a set with Card 14 if VD*i* = -3 or -4.

Card 14.1	1	2	3	4	5	6	7	8
Variable	XOFF							
Type	F							
Default	0.0							

VARIABLE	DESCRIPTION
XOFF	Offset distance from the shell's center to the inflator position

Remarks:

1. **Formula for total vent hole coefficient.** The value must be between 0.0 and 1.0.

$$\text{Total vent hole coefficient} = \min(\max(\text{C23} \times \text{LCTC23} \times \text{LCPC23}, 0.0), 1.0)$$

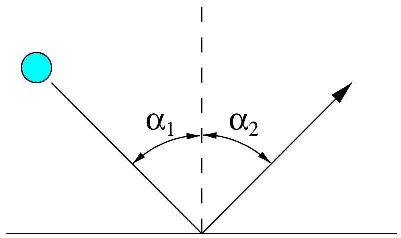

Figure 3-9. Particle Deflection

2. **Surface roughness.** Friction factor to simulate the surface roughness. If the surface is frictionless the particle incoming angle $\alpha_1$is equal to the deflection angle α_2 (see Figure 3-9).

   The surface roughness F_r and the total angle α will have the following relationships:

$$0.0 \le F_\mathrm{r} \le 1.0$$
$$\alpha = \alpha_1 + \alpha_2$$

   For the special case when

$$F_\mathrm{r} = 1.0 \;,$$

   the incoming particle will bounce back from its incoming direction, so

$$\alpha = 0.0 \;.$$

   For $-1.0 < F_r < 0.0$, particles will bounce towards the surface by the following relationship

$$\alpha = 2\left[\alpha_1 - F_r\left(\frac{\pi}{4} - \frac{\alpha_1}{2}\right)\right] \;.$$

   If $F_r \le -1.0$, the absolute value is the curve ID which defines the F_r as a function of the part pressure.

   If $F_r > 1.0$, the value is the *DEFINE_FUNCTION ID. Currently, the code will pass the following 3 values in this function: airbag pressure, airbag volume, and current time. The function will return the value of F_r. A simple example of user provide function with ID 900 is shown below.

```
*DEFINE_FUNCTION
       900
float pfric100(float pressure_bag, float volume_bag, float current_t)
/* function using bag volume to set Fr  */
{
float x = 0., vol1 = 0.5, vol2 = 1.1, vol3 = 1.2;
  if(volume_bag>=0 && volume_bag < vol1 ) {
    x = 1.2;
  } elseif (volume_bag>=vol1 && volume_bag < vol2 ) {
    x = 1;
```

```
    } elseif (volume_bag>=vol2 && volume_bag < vol3) {
      x = 1-(volume_bag-vol2)/vol3;
    } elseif (volume_bag>=vol3 ) {
      x = 0.;
    }
    return -0.06*x;
  }
```

3. **Blocking and BLOCK field.** Setting the 10's digit to 1 allows for physical holes in an airbag. In this case, particles that are far away from the airbag are disabled. In most cases, these are particles that have escaped through unclosed surfaces due to physical holes, failed elements, etc. This reduces the bucket sort search distance.

4. **Convection energy balance.** The change in energy due to convection is given by

$$\frac{\mathrm{d}E}{\mathrm{d}t} = A \times \mathrm{HCONV} \times \left(T_{\mathrm{bag}} - T_{\mathrm{atm}}\right) \ ,$$

where

A = part area
HCONV = user-defined heat convection coefficient
T_{bag} = the weighted average temperature impacting particles
T_{atm} = ambient temperature

5. **Output files.** Particle time history data is output to the d3plot database. LS-PrePost can display and fringe this data. To reduce runtime memory requirements, VISFLG controls the data output. Note that VISFLG only affects version 4 of the CPM output. Version 3 is the default, so you need to change the value of CPMOUT on *CONTROL_CPM for VISFLG to have any effect.

6. **Spatial distribution equilibration for airbag particles.** Total number of particles initialized is NP + NPAIR. Since the initial air particles are placed at the surface of the airbag segments with correct velocity distribution initially, particles are not randomly distributed in space. It requires a finite number of relaxation cycles, NPRLX, to allow particles to move and produce better spatial distribution.

   Since the momentum and energy transfer between particles are based on perfect elastic collisions, the CPM solver would like to keep a similar mole per particle between the inflator and initial air particles. The CPM solver will check the following factor:

$$\text{factor} = \left|1 - \frac{\text{mole per particle of initial air}}{\text{mole per particle of inflator gas}}\right| \ .$$

If the factor is more than 10% apart, the code will issue the warning message with the tag, (SOL+1232), and provide the suggested NPAIR value. The NPAIR value should be adjusted based on the application. For example, this message should be ignored if for certain impact analyses the simulation is setup with only initial air, that is, no inflator gas.

7. **Remark concerning *DEFINE_CPM_CHAMBER.** By default, initial air particles will be evenly placed on airbag segments which cannot sense the local volume. This will create an incorrect pressure field if the bag has several distinct pockets. *DEFINE_CPM_CHAMBER allows the user to initialize air particles by volume ratios of regions of the airbag. The particles will be distributed proportional to the defined chamber volume to achieve better pressure distribution.

   When looking at the airbag statistics in abstat_cpm, plotting the output for the chambers is more meaningful than for the whole bag. The lumped bag data could possibly give wrong pressure and temperature outputs, which can be misleading.

8. **Enhanced venting.** When enhanced venting is on, the vent hole's equivalent radius R_{eq} will be calculated. Particles within R_{eq} on the high pressure side of the vent hole geometry center will be moved toward the hole. This will increase the collision frequency near the vent for particles to detect small structural features and produce better flow through the vent hole.

   When ENH_V equals 1, particles flow from high to low pressure only. When EHN_V equals 2, particles can flow in both directions for internal vent.

   Particles encountering external vents are released. The ambient pressure is not taken into account, and the particle will be released regardless of the value of the pressure in the bag/chamber. Therefore, the vent rate will be sensitive to the vent location.

9. **Effective convection heat transfer coefficient.** If the thermal conductivity, KP, is given, then the effective convection heat transfer coefficient is given by

$$H_{\mathrm{eff}} = \left(\frac{1.0}{\mathrm{HCONV}} + \frac{\text{shell thickness}}{\mathrm{KP}}\right)^{-1} ,$$

   where the part thickness comes from the SECTION database. If KP is not given, H_{eff} defaults to HCONV.

10. **MOLEFRACTION option.** Without the MOLEFRACTION option, a flow rate is specified for each species on the LCM*i* fields of Card 13. With the MOLEFRACTION option the total mass flow rate is specified in the LCMASS field on Card 12 and the molar fractions are specified in the LCM*i* fields of Card 13.

11. **User-defined units.** If UNIT = 3 is used, there is no default value for TATM and PATM, and proper values must be provided. Unit conversion factors must also be provided so that the code sets the correct universal gas constant as well as some other variables.

12. **Shell-based nozzle.** Node ID and shell ID based nozzle should not be used in the same airbag definition. The nozzle location is taken to be at the center of the shell and the initial nozzle direction can be defined by the shell's normal vector or by its reversed normal vector. The shell must include in the airbag definition. This vector transforms with the moving coordinate system defined by NID1 - NID3. The nozzle area is set on the AN*i* fields and shell area is not taken into account; therefore, the mass flowrate distribution with shells is determined in the same way as it is with nozzles defined by nodes.

13. **Merge part set for vent.** When STYPE3 = 2, the first part in the set is designated as the master. All remaining parts are merged into the master so that enhanced venting is treated correctly. ABSTAT_CPM output will be associated with the master part. This option has the same effect as manually merging elements into the master part.

14. **TEND.** If TEND is not defined, particle mass and release rate will be calculated using the whole of the mass-flow curves LCM*i*, regardless of termination time. TEND can be used to limit the curve data but must be equal to or greater than the analysis termination time.

15. **TSPLIT.** Particles that exit by porosity leakage or a vent are removed from the system. If TSPLIT is set, the code keeps track of the number of removed particles (A) and active particles (B) every 200 cycles after time TSPLIT. Once A is greater than B, each active particle will be split into A/B + 1 particles for a better particle density in the volume.

16. **CP.** If the specific heat of the structure part is given, the initial temperature of this part has the initial air temperature, and the part mass (M) is automatically calculated. Heat transfer between gas and structure is based on the convection equation. The time history of the part temperature is stored in the abstat_cpm database under the field of *part_temp*

$$E = \mathrm{AREA} \times H_{\mathrm{eff}} \times \left(T_{\mathrm{gas}} - T_{\mathrm{part}}(t-1)\right)$$

$$T_{\mathrm{part}}(t) = T_{\mathrm{part}}(t-1) + E/(M \times CP)$$

17. **INFLATION keyword option.** The pressure in the closed volume may gradually deviate from the initial value due to volume changes caused by the pressure difference, such as during the process of tire inflation. INFLATION is designed to maintain this initial pressure by adding mass to the initial gas in the closed volume during the NPRLX time steps.

18. **JET keyword option.** For CPM vent, the flow equation is used to construct the probability density function to release or reflect the particle. The algorithm does not create the thrusting effect. To get correct thrust force created from the discharge, the thrust force is evaluated from the following equation and the reaction force is applied to the JNODE input from user.

$$F_{\text{thrust}} = \dot{m}(v_{\text{sound}} - v_{\text{exit}}) + A_{\text{vent}}(P_{\text{bag}} - P_{\text{ambient}})$$
$$F_{\text{JNODE}} = -F_{\text{thrust}}$$

19. **DPWR.** For IAIR = 4, a fraction of the ambient air pressure is applied to the segment from inside the airbag against ambient pressure external to the airbag based on the following equation:

$$\mu = \left(\frac{N_{\text{air}}}{N_{\text{air}} + N_{\text{infl}}}\right)^{\text{DPWR}} .$$

Here,

μ = fraction of ambient pressure applied inside the airbag
N_{air} = number of collisions from initial air particles
N_{infl} = number of collisions from inflator gas particles

This internal air pressure prevents the fabric layers from pressing against each other prior to inflation. This equation models the partial pressure from the air becoming negligible as the inflator gas builds up inside the airbag. Since the ratio is less than 1, the larger the DPWR, the faster this internal air pressure is removed. If this air pressure decreases too quickly, the gap between fabric layers will close due to ambient pressure because the inflator gas does not increase quickly enough.

***AIRBAG_REFERENCE_GEOMETRY**_{OPTION}_{OPTION}_{OPTION}_

Available options include:

<BLANK>

BIRTH

RDT

ID

Purpose: If the reference configuration of the airbag is taken as the folded configuration, the geometrical accuracy of the deployed bag will be affected by both the stretching and the compression of elements during the folding process. Such element distortions are very difficult to avoid in a folded bag. By reading in a reference configuration such as the final unstretched configuration of a deployed bag, any distortions in the initial geometry of the folded bag will have no effect on the final geometry of the inflated bag. This is because the stresses depend only on the deformation gradient matrix:

$$F_{ij} = \frac{\partial x_i}{\partial X_j}$$

where the choice of X_j may coincide with the folded or unfold configurations. It is this unfolded configuration which may be specified here.

When the BIRTH option is specified an additional card setting the BIRTH parameter is activated. The BIRTH parameter specifies a critical time value before which the reference geometry is *not used*. Until the BIRTH time is reached the input geometry is used for (1) inflating the airbag and for (2) determining the time step size, even when the RDT option is set.

NOTE:	This card does not support multiple birth times. The last BIRTH value read will be used for *all* preceding *AIRBAG_REFERENCE_GEOMETRY_BIRTH definitions. RGBRTH in *MAT_FABRIC supports a material dependent birth time.

When the RDT option is active the time step size will be based on the reference geometry once the solution time exceeds the birth time. This option is useful for shrunken bags where the bag does not carry compressive loads and the elements can freely expand before stresses develop. If this option is not specified, the time step size will be based on the current configuration and will increase as the area of the elements increase. The default may be much more expensive but possibly more stable.

ID card. Additional card for keyword option ID.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	SX	SY	SZ	NIDO	IOUT		
Type	I	F	F	F	I	I		
Default	none	1.0	1.0	1.0	1st NID	0		

Birth Card. Additional card for keyword option BIRTH.

Card 1	1	2	3	4	5	6	7	8
Variable	BIRTH							
Type	F							
Default	0.0							

Node Cards. For each node ID having an associated reference position include an additional card in format 2. The next keyword ("*") card terminates this input.

Card 2	1	2	3	4	5	6	7	8	9	10
Variable	NID	X		Y		Z				
Type	I	F		F		F				
Default	none	0.		0.		0.				

VARIABLE	DESCRIPTION
ID	Card ID
SX, SY, SZ	Scale factor in each direction
NIDO	Node ID for origin. Default is the first node ID defined in this keyword.

VARIABLE	DESCRIPTION
IOUT	Flag for outputting the current reference node coordinates EQ.0: Do not output the current reference node coordinates. EQ.1: Store the current reference node coordinates for output to a keyword file. See Remark 4.
BIRTH	Time at which the reference geometry activates
NID	Node ID for which a reference configuration is defined. Nodes defined in this section must also appear under the *NODE input. It is only necessary to define the reference coordinates of nodal points, if their coordinates are different than those defined in the *NODE section.
X	x coordinate
Y	y coordinate
Z	z coordinate

Remarks:

1. **Smaller reference geometry.** Note that a reference geometry which is smaller than the initial airbag geometry will not induce initial tensile stresses.

2. **Liner.** If a liner is included and the parameter LNRC is set to 1 in *MAT_FABRIC, compression is disabled in the liner until the reference geometry is reached, i.e., the fabric element becomes tensile.

3. **Nodes shared by foam and fabric.** Some shell and solid elements modeling the fabric and foam, respectively, share nodes. The reference geometry specified by either *INITIAL_FOAM_REFERENCE_GEOMETRY or *AIRBAG_REFERENCE_GEOMETRY will be applied to both the shell and solid elements that share these nodes. However, having different reference geometry for shell and solid elements sharing common nodes can be achieved by using *INITIAL_FOAM_REFERENCE_GEOMETRY for solid elements and *AIRBAG_SHELL_REFERENCE_GEOMETRY for shell elements.

4. **IOUT file.** When IOUT = 1, the current reference coordinates are output to the following keyword file:

   [JOBID].AIRBAG_REFERENCE_GEOMETRY.TRANSFORMED

   The [JOBID] indicate that this is replaced with the Job ID.

AIRBAG_SALE_*{OPTION1}_{OPTION2}

Available settings of *OPTION1* are:

<BLANK>

EXTRA

With *OPTION1* set to EXTRA, an extra line containing advanced options is included in the input. These advanced options enable changing certain default S-ALE airbag parameters.

Available settings of *OPTION2* are:

<BLANK>

ID

TITLE

To specify an airbag ID and a heading for the airbag, set *OPTION2* to either ID or TITLE.

Purpose: Define an airbag using the S-ALE method. This keyword serves as a wrapper that is translated into several S-ALE keywords during the keyword read-in phase. See Remark 1.

> **NOTE:** This model assumes that surface normal vectors be oriented *inward*, unlike the traditional Control Volume or CV method (also known as Uniform Pressure or UP method) for which they must point *outward*. If the assumption of *inward* orientation is *not* valid, IFLIP = 1 needs to be set. See Remark 2 for a detailed explanation.

Card Summary:

Card ID. Include this card when *OPTION2* is either ID or TITLE.

ID	HEADING	

Card 1. This card is required.

SID1	STYPE1	SID2	STYPE2				

Card 2. This card is required.

	UNIT		TATM	PATM	NVENT		TSW

Card 3. This card is required.

	NGAS	NORIF					

Card 4. Define NVENT of this card. See Card 2.

SID3	STYPE3	C23					

Card 5. This card is required. Define air material properties.

PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR		

Card 6. Include NGAS of this card. See Card 3.

LCM*i*	LCT*i*	XM*i*	A*i*	B*i*	C*i*		

Card 7. Include NORIF of this card. See Card 3.

NID*i*	AN*i*	VD*i*					

Card 8. Include this card if *OPTION1* is set to EXTRA.

IFLIP	LCVEL	PMAX			ILOCK	ILVL	DECAY

Data Card Definitions:

Title Card. Additional card for ID or TITLE keyword options.

Card ID	1	2	3	4	5	6	7	8
Variable	ID	HEADING						
Type	I	A60						

VARIABLE	DESCRIPTION
ID	Airbag ID
HEADING	Airbag heading

Card 1	1	2	3	4	5	6	7	8
Variable	SID1	STYPE1	SID2	STYPE2				
Type	I	I	I	I				
Default	none	0	0	0				

VARIABLE	DESCRIPTION
SID1	Part or part set ID defining the complete airbag
STYPE1	Set type: EQ.0: Part EQ.1: Part set
SID2	Part or part set ID defining the internal parts of the airbag
STYPE2	Set type: EQ.0: Part EQ.1: Part set

Card 2	1	2	3	4	5	6	7	8
Variable		UNIT		TATM	PATM	NVENT		TSW
Type		I		F	F	I		F
Default		0		293 K	1 atm	0		10^{10}

VARIABLE	DESCRIPTION
UNIT	Unit system: EQ.0: kg-mm-ms-K EQ.1: SI EQ.2: tonne-mm-s-K

VARIABLE	DESCRIPTION
TATM	Atmospheric temperature
PATM	Atmospheric pressure
NVENT	Number of vent hole parts or part sets. See Remark 5.
TSW	Time at which the algorithm switches to control volumes

Card 3	1	2	3	4	5	6	7	8
Variable		NGAS	NORIF					
Type		I	I					
Default		none	none					

VARIABLE	DESCRIPTION
NGAS	Number of gas components
NORIF	Number of orifices

Vent Hole Card. Additional cards for NVENT > 0. Define NVENT cards, one for each vent hole.

Card 4	1	2	3	4	5	6	7	8
Variable	SID3	STYPE3	C23					
Type	I	I	F					
Default	0	none	1.0					

VARIABLE	DESCRIPTION
SID3	Part or part set ID defining vent holes
STYPE3	Set type: EQ.0: Part

VARIABLE	DESCRIPTION
	EQ.1: Part set EQ.2: Segment set
C23	Vent hole coefficient, a parameter of Wang-Nefske leakage

Air Card. Mandatory card to define air properties.

Card 5	1	2	3	4	5	6	7	8
Variable	PAIR	TAIR	XMAIR	AAIR	BAIR	CAIR		
Type	F	F	F	F	F	F		
Default	PATM	TATM	none	none	0.0	0.0		

VARIABLE	DESCRIPTION
PAIR	Initial pressure inside the bag (optional if PATM is set)
TAIR	Initial temperature inside the bag (optional if TATM is set)
XMAIR	Molar mass of the gas initially inside the bag
AAIR - CAIR	Constant, linear, and quadratic heat capacity parameters

Gas Cards. NGAS additional cards, one for each gas (card format for i^{th} gas).

Card 6	1	2	3	4	5	6	7	8
Variable	LCM*i*	LCT*i*	XM*i*	A*i*	B*i*	C*i*		
Type	I	I	F	F	F	F		
Default	none	none	none	none	0.0	0.0		

VARIABLE	DESCRIPTION
LCM*i*	Mass flow rate curve for gas component *i*
LCT*i*	Temperature load curve for gas component *i*

VARIABLE	DESCRIPTION
XM*i*	Molar mass of gas component *i*.
A*i* – C*i*	Constant, linear, and quadratic heat capacity parameters for gas component *i*

Orifice Cards. NORIF additional cards, one for each orifice (card format for *i*th orifice).

Card 7	1	2	3	4	5	6	7	8
Variable	NID*i*	AN*i*	VD*i*					
Type	I	F	I					
Default	none	none	none					

VARIABLE	DESCRIPTION
NID*i*	Node ID defining the location of nozzle *i*
AN*i*	Area of nozzle *i*. See Remark 6.
VD*i*	Vector ID defining of gas inflow direction at nozzle *i*

EXTRA Card. Include this card is *OPTION1* is set to EXTRA. This card facilitates changing certain pre-determined parameters in S-ALE simulations.

Card 8	1	2	3	4	5	6	7	8
Variable	IFLIP	LCVEL	PMAX			ILOCK	ILVL	DECAY
Type	I	I	F			I	I	F
Default	0	0	PATM			0	0	0.0

VARIABLE	DESCRIPTION
IFLIP	Flag to flip the normal vectors for airbag shell parts. *ALE_STRUCTURED_FSI expects shell segment normal vectors to point inward, toward the inflator gas to which it couples. See Remark 2.

VARIABLE	DESCRIPTION
LCVEL	Load curve ID for a curve giving the gas inlet velocity as a function of time. See Remark 3.
PMAX	Maximum impact pressure. This is used to set penalty stiffness. See Remark 4.
ILOCK	Load curve ID for specifying offset distance. This offset distance is used to avoid "contact locking" between airbag fabric from different chambers. See Remark 7.
ILVL	Number of airbag segments to look downstream from the gas front. ILVL and DECAY are the two flags needed to activate a mechanism to pre-open the closed airbag tube in front of the gas front to allow more gas flow. See Remark 8.
DECAY	Decaying factor. See Remark 8.

Remarks:

1. **Conversion of this keyword.** During the keyword reader phase, this keyword translates to a combination of several different keywords, namely:

   - *ALE_STRUCTURED_MULTI-MATERIAL_GROUP
   - *MAT_ALE_GAS_MIXTURE_ADV
   - *INITIAL_GAS_MIXTURE
   - *ALE_STRUCTURED_POINT_SOURCE
   - *ALE_STRUCTURED_FSI
   - *SET_MULTI-MATERIAL_GROUP_LIST
   - *DEFINE_SALEAB_PARAMETERS

   The converted keywords are output in saleabcvrt.inc.

2. **IFLIP.** *ALE_STRUCTURED_FSI requires the structure's segment normal vectors to point toward the ALE fluids to which the segments are coupled. If the airbag shell parts' normal vectors point outward, use this flag to reverse the segment normal vectors in the FSI coupling segment set without changing the shell elements' connectivity. This flag provides an easy conversion from CV (control volume) airbags to S-ALE airbags because CV bag definitions require airbag segment normal vectors to point outwards.

3. **LCVEL.** The inlet velocity load curve is optional. If zero, a virtual tank test is performed at the initialization phase using the gas inflow data.

4. **PMAX.** PMAX is an estimated value of the maximum impact pressure applied by the gas onto the airbags. This value is used to set up the stiffness in the FSI between the airbag and inflator gas. The bulk modulus of a gas depends largely on its current pressure. For example, γp for isentropic ideal gas.

   Setting up the "right" penalty stiffness is the most important factor in constructing FSI successfully. From prior experience, we apply the maximum impact pressure at 1/10 of the ALE element size. Because it is impossible to obtain this maximum impact pressure, PMAX gives this estimate. It does not need to be exact. One-half to two times different is good enough. If left blank, the maximum impact pressure is taken as 1 atm.

5. **VENT.** The Wang-Nefske leakage algorithm is used. It is the same approach used by OPT = 2 in *AIRBAG_WANG_NEFSKE. Blockage is always on.

6. **AN*i*.** The orifice area is a mandatory input as its value is used in the following calculations:

   a) Making an estimate of the inflator volume. A virtual tank test is performed before the simulation to obtain an estimated gas velocity curve if LCVEL is not prescribed.

   b) Calculating the injected gas volume in a given time cycle. The gas injected in a cycle pushes the gases away and creates a volume for itself. That volume is calculated as the inlet velocity times orifice area times time step.

   c) Distributing the inflow gas between different nozzles. AN*i* divided by the sum of all nozzle areas scales the inflow gas flow rate to calculate the amount of gas flowing through nozzle *i*.

7. **ILOCK.** This option helps solve so-called "contact locking". When gases from two different chambers enter the same S-ALE cell, airbag fabric segments from different chambers can interlock. With ILOCK enabled, a separate FSI card is added to keep gas from other chambers at an offset distance away. ILOCK specifies how this offset distance varies with time. A constant offset equal to 1.5 to 3 times the S-ALE cell size is a good starting point.

8. **Gas front tracking and pre-opening.** A narrow opening in airbag structures is a challenge for continuum methods like S-ALE. If the distance between the two airbag layers is smaller than the S-ALE cell size, the gas flow chokes simply because the gas sees no way to go through. Refining the S-ALE mesh is not a solution here as the opening could be prohibitively small.

   Setting ILVL and DECAY invokes a method that prevents this issue. The method tracks the gas front and forces open a few layers of airbag segments downstream to create a space inlet where the gas can flow. Then, it applies an artificial force on those fabric segments to pop them up slightly This artificial force is obtained from the gas front FSI pressure. The first flag, ILVL, specifies the number of segments the method looks downstream from the gas front for pre-opening. The second flag, DECAY, serves two purposes:

a) It scales the FSI pressure at the gas front.

b) It fades away this artificial force by capping the new artificial pressure each cycle with DECAY times the last cycle's artificial pressure.

***AIRBAG_SHELL_REFERENCE_GEOMETRY**_*{OPTION}_{OPTION}*

Available options include:

<BLANK>

RDT

ID

Purpose: Usually, the input in this section is not needed; however, sometimes it is convenient to use disjoint pre-cut airbag parts to define the reference geometries. If the reference geometry is based only on nodal input, this is not possible since in the assembled airbag the boundary nodes are merged between parts. By including the shell connectivity with the reference geometry, the reference geometry can be based on the pre-cut airbag parts instead of the assembled airbag. The elements, that are defined in this section, must have identical element IDs as those defined in the *ELEMENT_SHELL input, but the nodal IDs, which may be unique, are only used for the reference geometry. These nodes are defined in the *NODE section but can be additionally defined in *AIRBAG_REFERENCE_GEOMETRY. The element orientation and n1-n4 ordering must be identical to the *ELEMENT_SHELL input.

When the RDT option is active the time step size will be based on the reference geometry once the solution time exceeds the birth time which can be defined by RGBRTH of *MAT_FABRIC.

ID card. Additional card for keyword option ID.

Card 1	1	2	3	4	5	6	7	8
Variable	ID	SX	SY	SZ	NID	IOUT		
Type	I	F	F	F	I	I		
Default	none	1.0	1.0	1.0	↓	0		

Card 2	1	2	3	4	5	6	7	8	9	10
Variable	EID	PID	N1	N2	N3	N4				
Type	I	I	I	I	I	I				
Default	none	none	none	none	none	none				

VARIABLE	DESCRIPTION
ID	Card ID
SX, SY, SZ	Scale factor in each direction
NID	Node ID for origin. The default is the first node ID defined in this keyword.
IOUT	Flag for outputting the current reference node coordinates EQ.0: Do not output the current reference node coordinates. EQ.1: Store the current reference node coordinates for output to a keyword file. See Remark 1.
EID	Element ID
PID	Optional part ID, see *PART, the part ID is not used in this section.
N1	Nodal point 1
N2	Nodal point 2
N3	Nodal point 3
N4	Nodal point 4

Remarks:

1. **IOUT file.** When IOUT = 1, the current reference coordinates are output to the following keyword file:

   [JOBID].AIRBAG_REFERENCE_GEOMETRY.TRANSFORMED

   The [JOBID] indicate that this is replaced with the Job ID.