*HOURGLASS

Purpose: Define hourglass and bulk viscosity properties which are referenced using HGID in the *PART command. Properties specified here, when invoked for a particular part, override those in *CONTROL_HOURGLASS and *CONTROL_BULK_VISCOSITY.

An additional option **TITLE** may be appended to *HOURGLASS keywords. If this option is used, then an additional line is read for each section in 80a format which can be used to describe the section. At present, the title serves no purpose other than to perhaps lend clarity to input decks.

Card 1	1	2	3	4	5	6	7	8
Variable	HGID	IHQ	QM	IBQ	Q1	Q2	QB, VDC	QW
Type	I/A	I	F	I	F	F	F	F
Default	0	Rem 9	.10	not used	1.5	0.06	QM, 0.	QM

VARIABLE	DESCRIPTION
HGID	Hourglass ID. A unique number or label must be specified. This ID is referenced by HGID in the *PART command.
IHQ	Hourglass control type. For solid elements six options are available. For quadrilateral shell and membrane elements the hourglass control is based on the formulation of Belytschko and Tsay, that is, options 1-3 are identical, and options 4-5 are identical. See Remark 1. EQ.0: See Remark 9. EQ.1: Standard LS-DYNA viscous form EQ.2: Flanagan-Belytschko viscous form EQ.3: Flanagan-Belytschko viscous form with exact volume integration for solid elements EQ.4: Flanagan-Belytschko stiffness form EQ.5: Flanagan-Belytschko stiffness form with exact volume integration for solid elements.

VARIABLE	DESCRIPTION
	EQ.6: Belytschko-Bindeman [1993] assumed strain co-rotational stiffness form for 2D and 3D solid elements only. See Remark 4.
	EQ.7: Linear total strain form of type 6 hourglass control. (See Remark 6 below).
	EQ.8: Activates the full projection warping stiffness for shell formulations 9, 16 and -16. A speed penalty of 25% is common for this option.
	EQ.9: Puso [2000] enhanced assumed strain stiffness form for 3D hexahedral elements. See Remark 8.
	EQ.10: Cosserat Point Element (CPE) developed by Jabareen and Rubin [2008] and Jabareen et.al. [2013]; see *CONTROL_HOURGLASS.
	A discussion of the viscous and stiffness hourglass control for shell elements follows at the end of this section.
QM	Hourglass coefficient. See Remark 7. Values of QM that exceed 0.15 may cause instabilities for brick elements used with forms IHQ = 0 to 5 and all the IHQ forms applicable to shell elements. The stiffness forms can stiffen the response especially if deformations are large and therefore should be used with care. For the shell and membrane elements QM is taken as the membrane hourglass coefficient, the bending as QB, and warping as QW. These coefficients can be specified independently, but generally, QM = QB = QW is adequate. For type 6 solid element hourglass control, see Remark 4 below. For hourglass type 9, see Remark 8.
IBQ	Not used. Bulk viscosity is always on for solids. Bulk viscosity for beams and shells can only be turned on using the variable TYPE in *CONTROL_BULK_VISCOSITY; however, the coefficients can be set using Q1 and Q2 below.
Q1	Quadratic bulk viscosity coefficient. See Remark 3.
Q2	Linear bulk viscosity coefficient. See Remark 3.
QB	Hourglass coefficient for shell bending. By default, QB = QM. See Remark 5.
VDC	Viscous damping coefficient to help suppress hourglass modes. VDC only applies to type 1 solids with type 6 or 7 hourglass control and to tshell formulations 5 and 6. VDC is a unitless coefficient in

VARIABLE	DESCRIPTION
	which VDC = 1.0 corresponds to critical damping.
QW	Hourglass coefficient for shell warping. By default, QB = QW. See Remark 5.

Remarks:

1. **Viscous versus stiffness control.** Viscous hourglass control is recommended for problems deforming with high velocities. Stiffness control is often preferable for lower velocities, especially if the number of time steps is large. For solid elements the exact volume integration provides some advantage for highly distorted elements.

2. **Automotive crash hourglass control.** For automotive crash, the stiffness form of the hourglass control with a coefficient (QM) of 0.05 is preferred by many users.

3. **Bulk viscosity.** Bulk viscosity is necessary to propagate shock waves in solid materials. Generally, the default values are okay except in problems where pressures are very high, larger values may be desirable. In low-density foams, it may be necessary to reduce the viscosity values since the viscous stress can be significant. It is not advisable to reduce it by more than an order of magnitude.

4. **Belytschko-Bindeman hourglass control.** Type 6 hourglass control is for 2D and 3D solid elements only. Based on elastic constants and an assumed strain field, it produces accurate coarse mesh bending results for elastic material when QM = 1.0. For plasticity models with a yield stress tangent modulus that is much smaller than the elastic modulus, a smaller value of QM (0.001 to 0.1) may produce better results. For foam or rubber models, larger values (0.5 to 1.0) may work better. For any material, keep in mind that the stiffness is based on the elastic constants, so if the material softens, a QM value smaller than 1.0 may work better. For anisotropic materials, an average of the elastic constants is used. For fluids modeled with null material, type 6 hourglass control is viscous and is scaled to the viscosity coefficient of the material (see *MAT_NULL).

5. **One-point quadrature and hourglass deformation modes.** In part, the computational efficiency of the Belytschko-Lin-Tsay and the under-integrated Hughes-Liu shell elements are derived from their use of one-point quadrature in the plane of the element. To suppress the hourglass deformation modes that accompany one-point quadrature, hourglass viscous or stiffness-based stresses are added to the physical stresses at the local element level. The discussion of the hourglass control that follows pertains to all one-point quadrilateral shell and membrane elements in LS-DYNA.

The hourglass shape vector τ_I is defined as

$$\tau_I = h_I - (h_J \hat{x}_{\alpha J}) B_{\alpha I} \ ,$$

where $\hat{x}_{\alpha J}$ are the element coordinates in the local system at the I^{th} element node and $B_{\alpha I}$ is the strain displacement matrix. The hourglass basis vector is:

$$h = \begin{bmatrix} +1 \\ -1 \\ +1 \\ -1 \end{bmatrix} \ ,$$

the basis vector that generates the deformation mode that is neglected by one-point quadrature. In the above equations and the remainder of this subsection, the Greek subscripts have a range of 2, that is, $\hat{x}_{\alpha I} = (\hat{x}_{1I}, \hat{x}_{2I}) = (\hat{x}_I, \hat{y}_I)$.

The hourglass shape vector then operates on the generalized displacements to produce the generalized hourglass strain rates

$$\begin{aligned} \dot{q}_\alpha^M &= \tau_I \hat{v}_{\alpha I} \\ \dot{q}_\alpha^B &= \tau_I \hat{\theta}_{\alpha I} \\ \dot{q}_3^W &= \tau_I \hat{v}_{zI} \end{aligned}$$

where the superscripts M, B, and W denote membrane, bending, and warping modes, respectively. The corresponding hourglass stress rates are then given by

$$\begin{aligned} \dot{Q}_\alpha^M &= \frac{\mathrm{QM} \times EtA}{8} B_{\beta I} B_{\beta I} \dot{q}_\alpha^M \\ \dot{Q}_\alpha^B &= \frac{\mathrm{QB} \times Et^3 A}{192} B_{\beta I} B_{\beta I} \dot{q}_\alpha^B \\ \dot{Q}_3^W &= \frac{\mathrm{QW} \times \kappa G t^3 A}{12} B_{\beta I} B_{\beta I} \dot{q}_3^B \end{aligned}$$

where t is the shell thickness. The hourglass coefficients: QM, QB, and QW are generally assigned values between 0.05 and 0.10.

Finally, the hourglass stresses which are updated using the time step, Δt, from the stress rates in the usual way, that is,

$$\mathbf{Q}^{n+1} = \mathbf{Q}^n + \Delta t \dot{\mathbf{Q}} \ ,$$

and the hourglass resultant forces are then

$$\begin{aligned} \hat{f}_{\alpha I}^H &= \tau_I Q_\alpha^M \\ \hat{m}_{\alpha I}^H &= \tau_I Q_\alpha^B \\ \hat{f}_{3I}^H &= \tau_I Q_3^W \end{aligned}$$

where the superscript H emphasizes that these are internal force contributions from the hourglass deformations.

6. **Linear total strain formulation.** IHQ=7 is a linear total strain formulation of the Belytschko-Bindeman [1993] stiffness form for 2D and 3D solid elements.

This linear form was developed for visco-elastic material and guarantees that an element will spring back to its initial shape regardless of the severity of deformation.

7. **QM default value.** The default value for QM is 0.1 unless superseded by a nonzero value of QH in *CONTROL_HOURGLASS. A nonzero value of QM supersedes QH.

8. **Puso hourglass control.** Hourglass type 9 is available for hexahedral elements and is based on physical stabilization using an enhanced assumed strain method. In performance it is similar to the Belytschko-Bindeman hourglass formulation (type 6) but gives more accurate results for distorted meshes, such as for skewed elements. If QM = 1.0, it produces accurate coarse bending results for elastic materials. The hourglass stiffness is by default based on elastic properties, hence the QM parameter should be reduced to about 0.1 for plastic materials in order not to stiffen the structure during plastic deformation. For materials 3, 18 and 24 a negative value of QM may be used. With this option, the hourglass stiffness is based on the current material properties, that is, the plastic tangent modulus, and is scaled by |QM|.

9. **IHQ default values.** The default value for IHQ, if not defined on *CONTROL_-HOUGRGLASS is as follows:

   a) *Shells.* Viscous type (1 = 2 = 3) for explicit; stiffness type (4=5) for implicit.

   b) *Solids.* Type 2 for explicit; type 6 for implicit.

   c) *Tshell Formulation 1.* Type 2.

10. **IHQ for implict analysis.** For implicit analysis, hourglass forms 6, 7, 9, and 10 are available for solid elements, and the stiffness form (4 = 5) is available for shells.

11. **Tshells and hourglass control.** Hourglass control applicability for tshells depends on the formulation.

   a) Tshell formulations 2 and 3 have 2 × 2 in-plane integration and therefore do not use hourglass control.

   b) In the case of tshell formulation 1, there are two viscous hourglass types (IHQ = 1,2) and one stiffness type (IHQ > 2).

   c) The hourglass type IHQ has no bearing on tshell formulations 5 and 6 as these formulations are based on an assumed strain field, similar to formulation 1 solids with hourglass type 6. The hourglass coefficient QM does affect the behavior of tshell formulations 5 and 6.