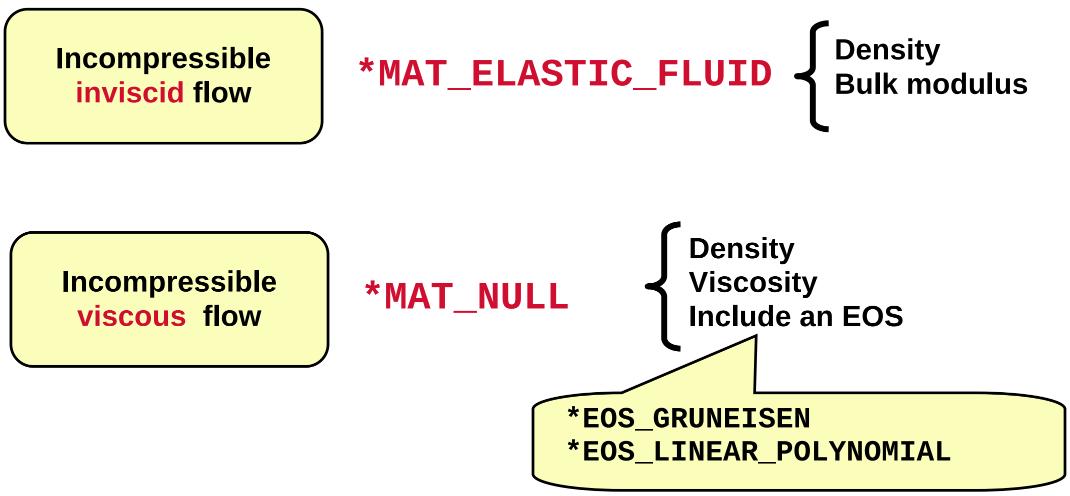
As published in FEA Information Worldwide News
Issue: February 2005

Casting Modeling

The LS-DYNA ALE formulation allows LS-DYNA to model the fluid filling of a casting. The benchmark problem selected comes from the 7th Conference on Modeling of Casting, Welding, and Advanced Solidification Process, London, England, 10-15 September, 1995. The conference proceedings define a benchmark test for analysis codes. The benchmark test fully defines the problem and presents experimental results including X-ray video of the mold filling. Eight different analysis codes were compared in their prediction of the process.

The first step in using LS-DYNA is to select a material model for incompressible liquid metal flow. There are 2 choices:

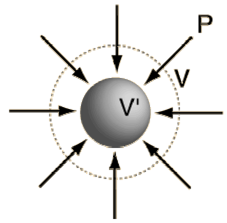


MAT_ELASTIC_FLUID and MAT_NULL only consider the normal (pressure) stresses and neglect the deviatoric (shear) stresses

$$\sigma_{ij} = \mathrlap{\overbrace{\phantom{\sigma^e_{ii} + \sigma^e_{ij}}}^{\text{Elastic}}}\underbrace{\sigma^e_{ii}}_{\text{Dilatation (normal)}} + \underbrace{\sigma^e_{ij} + \overbrace{\sigma^p_{ij}}^{\text{Plastic}}}_{\text{Deviatoric (shear)}}$$

The bulk elastic properties of a material determine how much it will compress under a given amount of external pressure. The ratio of the pressure to the fractional change in volume is called the Bulk Modulus (B) of the material.

Bulk Modulus	
Steel	160.e+09 N/m^2
Aluminum	71.3e+09 N/m^2
Water	2.20e+09 N/m^2



$$B = \frac{P}{-\frac{dV}{V}} = \frac{P}{\mu}$$

The material bulk modulus and density are all that is required to use material model *MAT_ELASTIC_FLUID. An equation of state (EOS) is needed for *MAT_NULL. The EOS requires the speed of sound in the material. The propagation speed of traveling waves is characteristic of the media in which they travel. The speed of sound in liquids and solids is predictable from their density and bulk modulus.

Elastic wave speed	
Steel	4512 m/s
Aluminum	5149 m/s
Water	1483 m/s

$$c = \sqrt{\frac{B}{\rho}}$$

Either *EOS_LINEAR_POLYNOMIAL or *EOS_GRUNEISEN can be used to model an incompressible liquid.

EOS_LINEAR_POLYNOMIAL	**EOS_GRUNEISEN**
$P = C_0 + C_1\mu + C_2\mu^2 + C_3\mu^3 + \left(C_4 + C_5\mu + C_6\mu^2\right)E$ E = internal energy	$P = \dfrac{\rho_0 c^2 \mu\left[1 + \left(1 - \gamma_0/2\right)\mu - \frac{a}{2}\mu^2\right]}{\left[1 - (S_1 - 1)\mu - S_2\frac{\mu^2}{\mu+1} - S_3\frac{\mu^3}{(\mu+1)^2}\right]^2} + (\gamma_0 + a\mu)E$
For a liquid, set C_1 = B (bulk modulus), and $C_0 = C_2 = C_3 = C_4 = C_5 = C_6 = 0$. Then, $P = B\mu = \rho c^2 \mu$	For an incompressible liquid, set $S_1 = S_2 = S_3 = a = \gamma_0 = 0$. Then, $P = \rho c^2 \mu$

The benchmark casting problem was modeled using 8-node solid elements. The elements were defined as ALE with a single material (the flowing aluminum) and void (initial element fill is vacuum) formulation. The inlet mass flow rate is defined in the problem specification. The fill time is 2 seconds. Shown below is the calculated fill pattern at 1 second. Also shown is an X-ray of the experiment from (M. Cross & J. Campbell, Modeling of Casting, Welding, and Advanced Soldification Processes VII, p929, 1995).