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AN EFFICIENT CSD/CFD FE SCHEME FOR WEAPON FRAGMENTATION

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ABSTRACT

In this work an efficient FE (finite element) scheme to deal with a class of coupled fluid-solid problems is presented. The main ingredients of such methodology are: an accurate Q1/P0 solid element (trilinear in velocities and constant piecewise-discontinuous pressures), a large deformation plasticity model, and a phenomenological model to deal with fragment formation. All the schemes have been fully parallelized and coupled using a loose-embedded procedure with the well-established and validated CFD code, FEFLO98. Several CFD/CSD coupled cases with experimental verification has been computed.

Constitutive model: The implemented plasticity model relies on a hyperelastic characterization of the elastic material response, which avoids the drawbacks of the widely used hypoelastic models, i.e., the material isotropy, the nonzero residual strain in a closed “elastic” cycle, and in general, the lack of a stored-energy function to obtain the elastic stress tensor. It can be demonstrated that the utilization of hypoelastic models based on commonly used objective stress rates like the Jaumann-Zaremba and Green-McInnis-Naghdi, does not result in a straightforward generalization of the classical radial return algorithm when a J_2 plasticity theory for large deformation cases is developed. However, this is a widely used approach. Our experience indicates that the application of such schemes for blast simulation problems on unstructured meshes, violates in an unacceptable manner the isochoric (incompressible) character of the plastic flow. Hence, the elements tend to have negative volume and their edges tend to cross at high explosive loads (pressures). Reference [1] presents a detailed description of the hyperelastic plasticity model that has been used in this work. However, a brief summary is shown below for completeness. The stored-energy function has the form:

$$W = U(J^e) + \overline{W}(\overline{\boldsymbol{b}^e});\;\; U(J^e) = \frac{1}{2}\kappa\Big[\frac{1}{2}(J^{e2}-1) - \ln J^e\Big];\;\; \overline{W}(\overline{\boldsymbol{b}^e}) = \frac{1}{2}\mu\big(\mathrm{tr}[\overline{\boldsymbol{b}^e}] - 3\big) \tag{1}$$

which results in the following stress-strain relationships:

$$\boldsymbol{\tau} = J^e p \boldsymbol{I} + s;\;\; p = \frac{\kappa}{2}(J^{e2}-1)/J^e;\;\; \boldsymbol{s} = \mu\,\mathrm{dev}[\overline{\boldsymbol{b}^e}] \tag{2}$$

Above, $\boldsymbol{\tau}$ is the Kirchhoff stress tensor, p the mechanical pressure and $\boldsymbol{s}$ the deviatoric part of the stress tensor. J^e is the determinant of the elastic part of the deformation gradient tensor $\boldsymbol{F}^e$, κ the material bulk modulus and μ the shear modulus. Finally, $\overline{\boldsymbol{b}^e}$ is the volume-preserving part of $\boldsymbol{b}^e$ (elastic left Cauchy-Green tensor). The yield condition is a classical Mises-Hubert type, but formulated in terms of the Kirchhoff stress tensor:

$$f(\boldsymbol{\tau}, \alpha) := ||\boldsymbol{s}|| - \sqrt{\frac{2}{3}}\,\sigma_Y \leq 0 \tag{3}$$

where σ_Y denotes the flow stress, K denotes the isotropic hardening modulus, and α the hardening parameter. $||\boldsymbol{s}||$ is the norm of $\boldsymbol{s} = \sqrt{s_{ij}s_{ij}}$ (repeated index sum). Non-linear and well known yield stress models (i.e. Johnson-Cook model) have been easily accommodated in the formulation.

Fragmentation algorithm: It is based on experimental data collected for more than 50 years: This is the Mott's theory for break-up of cylindrical "ring-bombs". In [2] a detailed description of the model can be consulted. A brief summary of it is presented as follows: According to Mott, the average circumferential length of the resulting fragment is given by:

$$x_0 = \left(\frac{2\sigma_F}{\rho\gamma'}\right)\frac{r}{V} \tag{4}$$

where ρ and σ_F are the density and strength of the bomb material, respectively, r is the radius of the ring at the moment of fracture, V its radial velocity, and γ' denotes a semi-empirical statistical constant determining the dynamic fracture properties of the material. The value of this last constant has been calibrated using theoretical assumptions and experimental data. Two others important relationship has been used for relatively large fragments: These are the representative values of average aspect ratios of fragment lengths to circumferential breadth l_0/x_0, and the aspect ratios of circumferential breadth to fragment thickness x_0/t_0. The reported values in the literature for such relationships are between $l_0/x_0 \approx x_0/t_0 \approx 2.5$ and $l_0/x_0 \approx x_0/t_0 \approx 5.0$. In this job a value of 4.0 has been used. However, and additional random effect is introduced to the fragment sizes.

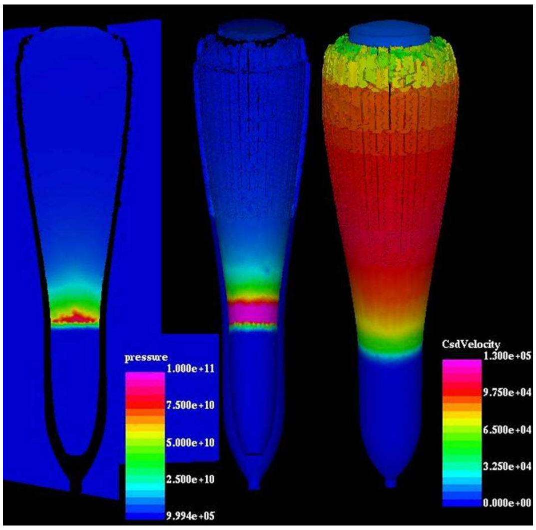

Figure 1: From left to right: CFD pressure and embedded fragments (vertical cut); projected CFD pressure over the solid faces; velocity of the fragments (time=50 milliseconds)

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