

Numerical Simulation of Airbag Inflation Using a Discrete Membrane Model Toward Prediction of In-Vehicle Pressure Changes

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Barotrauma cases potentially associated with transient in-vehicle pressure changes have been reported in the context of airbag performance enhancements, including increased deployment speed and installation at new locations. A coupled fluid-membrane analysis system that computes the interaction between airbag deployment and in-vehicle airflow is expected to be effective for accurately predicting these pressure-change phenomena. This paper presents an overview of a discrete thin membrane model based on mass-spring systems, developed for predicting in-vehicle pressure changes during airbag deployment.

The proposed method can represent orthotropic material properties that are difficult to represent using conventional mass-spring systems. Airbag geometries are discretized into triangular elements, and the nodes of each element are modeled as mass points p . Node-to-edge springs ξ connecting each p to the midpoint of the edge opposite to p are introduced. Internal forces for p are computed by decomposing ξ deformation into tensile and shear direction components, h and s (Fig. 1(a)). The tensile strain δ and shear strain γ are defined as follows:

$$\delta = \frac{1}{2}(\lambda^2 - 1)$$

$$\gamma = \frac{\Delta s}{h^0}$$

where h^0 denotes the initial state of h , $\lambda = 1 + \frac{\Delta h}{h^0}$ denotes the stretch ratio, and Δ denotes the change of each variable. δ and γ are equivalent to Green-Lagrange and engineering shear strain, respectively. To incorporate orthotropic material properties defined in engineering terms into tensile directions, δ is decomposed into the in-plane fiber direction basis (B_1, B_2) and contributions from each direction are defined as $\delta_1 = \delta \cos^2 \theta$ and $\delta_2 = \delta \sin^2 \theta$, respectively (Fig. 1(b)), where θ denotes the initial angle between the tensile direction and B_1 . Responses corresponding to δ_1 , δ_2 , and γ are defined using k based on Hooke's law assuming in-plane orthotropic materials as follows:

$$f_1^\delta = k_{11}\delta_1 + k_{12}\delta_2$$

$$f_2^\delta = k_{21}\delta_1 + k_{22}\delta_2$$

$$f^\gamma = k_{33}\gamma$$

Inflation behavior of an unfolded airbag model was analyzed by the proposed method. A linear elastic orthotropic material model was used for this calculation, with material parameters equivalent to those of silicone-coated airbag fabrics. For simplicity, the inflation pressure was assumed to increase linearly from 0 kPa to 25 kPa over 30 ms.

The proposed method can represent airbag inflation behavior and output element geometries and velocity distributions (Fig. 2). These results suggest its applicability for providing moving boundary conditions in fluid-membrane interaction simulations.

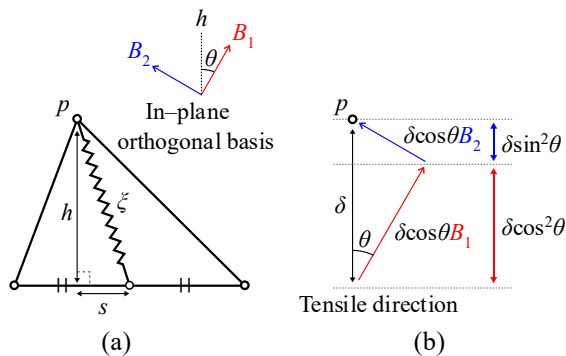


Fig.1 Overview of node-to-edge spring: (a) Definition of parameters, and (b) decomposition of tensile strain

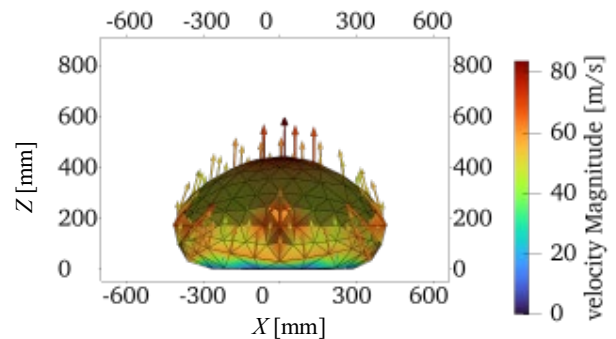


Fig.2 Element geometries and velocity distributions of the airbag model during inflation (10 ms)