Modeling of Fuel Sloshing Phenomena Considering Solid-Fluid Interaction

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Abstract

The sloshing phenomenon in partially filled fuel tanks is more pronounced when vehicles experience a sudden start or stop. Sloshing is un-desired because it produces noise, high impact force on the tank walls and the challenge of low fuel handling. Today, the solution for containing sloshing is to incorporate baffles inside the tank. The presence of baffle dissipates the energy that is induced by the fuel motions. Design of baffles is a necessary step during the design of a fuel tank to meet required performance specification in service. A methodology to simulate sloshing phenomenon that incorporates solid-fluid interaction is presented in this paper.

The methodology makes use of both Eulerian and Lagrangian formulation. Eulerian domain includes both air and fuel inside the tank, and the space around the tank. Lagrangian domain includes the tank shell and baffle structure. A concept of coupling surfaces is introduced in Eulerian domain to build the boundary of the inner and the outer of tank structure. The coupling surfaces also act as interactive surfaces between both Eulerian and Lagrangian domains to prevent penetration. A computational method is employed to simulate the sloshing phenomenon in tank when the vehicle is in motion. The simulation results are compared with the sloshing test results.

Introduction

The sloshing phenomenon in partially filled fuel tank is observed when the vehicle experiences sudden acceleration or deceleration. The phenomenon, first of all, may cause noise. During sloshing the fuel hits the tank walls which results in sloshing induced vibration of the tank structure and the fuel, subsequently producing undesired noise. In addition, the pressure from the sloshing waves generates impact forces on tank structure including baffles. Also, sloshing phenomena poses a challenge on the low fuel level management.

One of the fuel tank design objectives is to effectively reduce noise level caused by fluid motion inside the tank by designing baffles and separators to control the sloshing. In addition, alternate materials and manufacturing processes are evaluated for fuel tank design in order to reduce weight and cost, and to provide structural integrity for higher structural performance. Sloshing in the tank may be controlled by incorporating baffles, and the effectiveness highly depends on the shape, the location, and the number of baffles inside a tank. Validation of multiple baffle designs via physical testing is a very tedious and expensive. Also, the visual/digital inspection of the sloshing event inside the tank is not adequate for baffles design validation. Due to the complexities associated with the sloshing phenomenon, the CAE simulation is a desired method to meet the design intent, and shorten the development time.

Several CAE codes were employed to simulate sloshing, such as, MSC-Dytran, Fluent, and LS-DYNA (1,2,3). This paper presents a CAE methodology for simulating fuel sloshing using LS/DYNA.

Computational Model

Problem Formulation:

Solid-fluid interaction can be effectively model using ALE (Arbitrary Lagrangian-Eulerian) formulation available in LS-DYNA, version 970. In ALE formulation, the Lagrangian domain deals with the movement/deformation of the structure part, and Eulerian domain deals with the movement of air or fluid. The ALE capability of LS-DYNA is used to model sloshing phenomenon in the fuel tank.

In general, there exist two phases of fluid inside the tank, namely the fuel and air, and one phase, the air, outside the tank. To capture the 3D sloshing phenomena, a solid elements domain is used to represent the fluid, and a shell elements domain is used to represent tank geometry, Fig.1. The solid-fluid interaction is modeled by introducing coupling surface concept to envelop the portions of Eulerian domain inside and outside of the tank structure. The coupling algorithm resolves the interaction between the fluid and structure. The coupling surface functions as a "contact" surface to prevent the inner and outer portions of fluid from penetration through the structure.

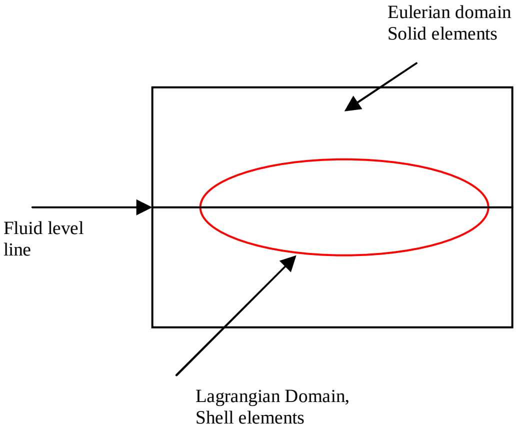


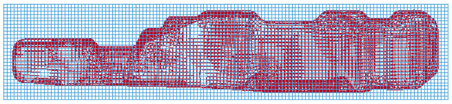
Figure 1. concept

Initially, fuel inside tank is leveled which separates the phases of air and fuel. This step separates the material portions of fuel and air. Later, as the simulation progresses, the solid and fluid particles may move in the Eulerian and Lagrangian domains, respectively.

CAE Model set-up:

Figure 2 shows the set-up of the geometric model. The Eulerian domain, discretizd by solid elements, covers both air and fuel portions. The structure of the tank defines the Larangian domain, discretized by shell elements. The structure boundary is also used as coupling surface between fluid and solid phases shown in Figure 3. The coupling surface is defined by ***constrained_lagrange_in_solid*** card in LS-DYNA.

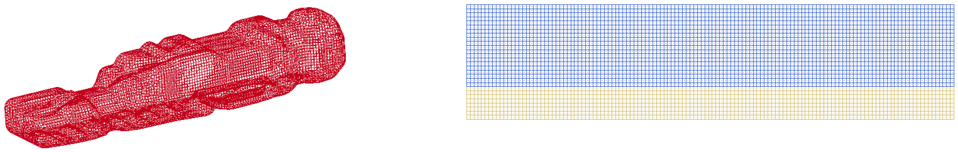
a. Lagrangian Domain **b. Eulerian Domain**



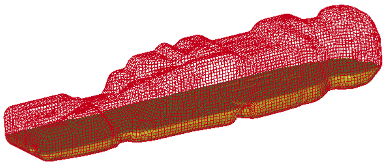
c. Model

Figure 2. CAE Model set up (1)

In the Eulerian domain two material phases, fuel and air, are considered. Materials of both phases are defined by using ***ale_multi-material_group(_part)*** card. The fuel level inside tank is introduced by ***initial_volume_fraction_geometry*** card. Figure 3 shows the final CAE model for the sloshing simulation.



a. Coupling surface **b. Leveling fluid and air**



C. Final model

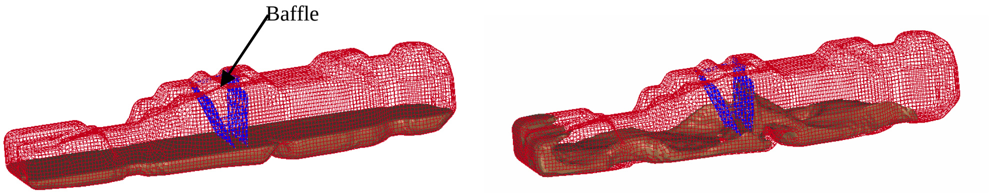
Figure 3. CAE Model set up (2)

Simulation of Fuel Tank Sloshing Phenomena and Test Result

Simulation Example:

The example presented here is a fuel tank with the certain level of fluid. The tank was designed with a baffle inside, Fig. 4(a). It was assumed that the tank was moving at a certain speed and then suddenly stopped, the time vs. speed plot is shown in Fig. 5. For simplicity, the tank structure was assumed to be rigid in the current investigation. In future, this assumption will be removed.

The animation results from the simulation showed that the fluid inside tank moved steadily with tank in the beginning (Fig. 4(a)), but later when the tank suddenly stopped at 20ms, the sloshing phenomena dominated. Fig. 4(b) shows the fluid wave produced due to sloshing.



a. before moving

b. at 100 ms after stopping

Figure 4. Example of fuel tank sloshing simulation

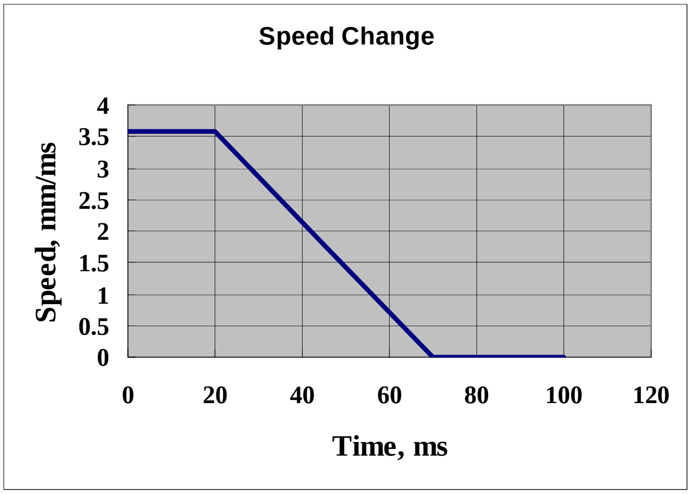


Figure 5. Speed plot of tank

Figure 6 shows the fluid sloshing at a snap shot during physical testing of the same fuel tank. It can be seen that the simulation snap shot presented in Fig. 4(b) matches very closely to the experimental wave profile presented in Fig. 6.

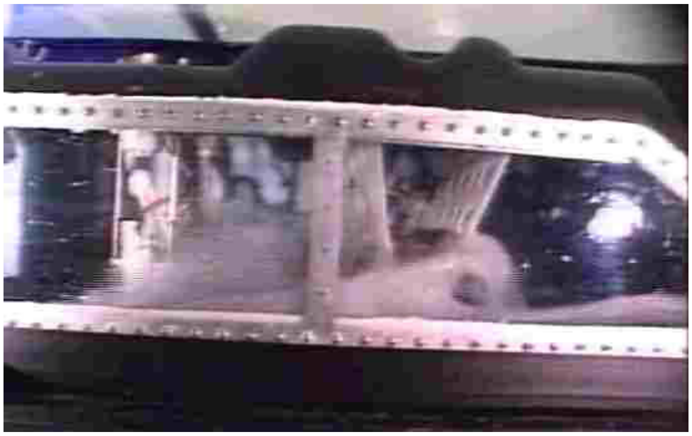


Figure 6.Physical Testing

Conclusion:

This research works show that the recently developed ALE formulation in LS-DYNA can accurately model the coupled solid-fluid interaction problem such as sloshing. Our work shows that ALE method in LS-DYNA successfully mimics sloshing phenomenon when the vehicle experiences sudden acceleration or deceleration. This simulation methodology may help reveal more details of sloshing process inside tank during operation, and support further investigations on the noise control, low fuel handling, and fuel indication issues.

Acknowledgement

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Reference

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