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A Study on Fluid Dispersion after Liquid Filled Missile Impact

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1. Introduction

The fire from fuel after accidents as well as direct damage by the liquid filled transportation accidents such as car, helicopter and aircraft crash may cause severe damage to structures. An example is that of the world trade center tower collapse by aircraft impact in the year 2001, which results in spreading fuel and a subsequent fire and blast.

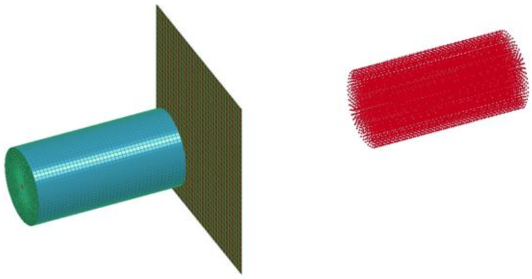
If fuel vapor or fuel droplets etc. of fuel pooling area on the ground come into contact with an various ignition sources (high-temperature, sparks etc.), then ignition can occur and fire can spread. Thus, in order to fire damage evaluations by fuel included transportation crash, the fire duration should be analyzed that consider the fuel spread range, amount of leaked fuel, and various ignition sources.

The water slug impact test performed in Sandia National Laboratory (SNL) in 2002 was representative [1]. The cloud of mist dispersion range of the dyed red water and ejection velocity of water after impact were analyzed using Particle Image Velocimetry (PIV) method and numerical simulation.

In this study, the included fluid was modeled by using smooth particle hydrodynamics (SPH) technique. The fluid dispersion range following impact was analyzed by considering the particle velocity and flying distance. The result values obtained through this study were compared to the water slug (WS) test results. And the applicability of an analysis method was verified by comparing the WS test results. The results and methodology obtained through this study can be utilized to damage assessment, fuel spread and fire risk for large infrastructures such as nuclear power plants following an aircraft impact.

2. Liquid Filled Missile FE Model

The used missile model in this paper is water slug test model [1]. A 1.2m diameter and 2.4m long aluminum tank was filled with approximately 2830L of water (Fig. 1(a)). The shell elements were employed in the missile. The approximately 15000 particles which are used smooth particle hydrodynamics (SPH) technique were employed in liquid (Fig. 1(b)). The mean dimension of particles is 0.05m. The initial impact velocity of missile is 100m/s.



(a) (b)

Fig. 1. Liquid Filled Missile FE Model

The material properties of missile are shown in Table 1. And the properties for liquid used in the SPH are shown in Table 2. The Gruneisen equation of state (EOS) correlated the material volumetric strength and pressure to density ratio as [2, 3]

$$P_H = \frac{\rho_0 C^2 \cdot \mu(\mu+1)}{\left[1-(s-1)\mu\right]^2}$$

Where

$$\mu = \frac{\rho}{\rho_0} - 1$$

Where ρ and ρ_0 are the initial and instantaneous densities of material, C is the intercept, and s is linear Hugoniot slop of shock velocity (v_s) and particle velocity (v_p) relationship.

It like hydrodynamic response by using Gruneisen EOS with negligible strength effects was implemented to liquid model. Thus, the liquid behaves as a fluid on the target wall and base.

Table 1.Aluminum Material Properties

Plastic Kinematic Model for Missile	
Density (kg/m^3)	2700
Elastic Modulus(Pa)	7.3e10
Poisson Ratio	0.3
Yield Stress(Pa)	2.4e8
Tangent Modulus(Pa)	7.0e8

Table 2.Liquid Properties

Null Model for Liquid	
Density (kg/m^3)	1000
Pressure Cutoff	-1
Viscosity Coefficient	100
EOS_Gruneisen Constants for Liquid	
C	1483
S1	1.75
Gamma	1.1

The normalized force and impulse time history for WS are shown in Fig. 2 and 3. The normalized values in Fig. 2 and 3 are compared by impact simulation and theoretical method. As shown in Fig. 2, the initial peak value in a very short time about 4~5micro second was occurred, because of shock wave by the first contact of water.

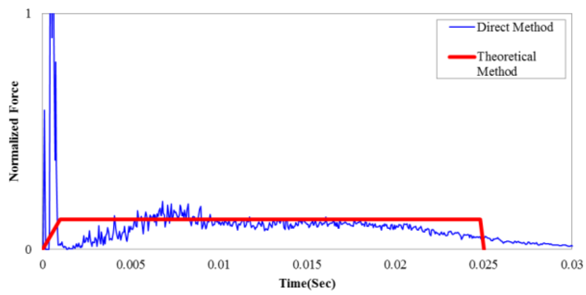


Fig. 2. Normalized Force-Time History

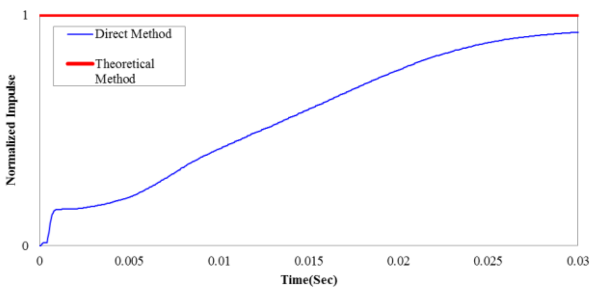


Fig. 3. Normalized Impulse-Time History

3. Numerical Results

A photograph and a simulation still from comparable times illustrating the similarities in predicted shape of the liquid cloud are shown in Fig. 4. The cloud dispersion shape of the experiment and simulation are reasonably similar. However, the radius of cloud dispersion at simulation result is larger than an experimental result since the ejection velocity of some of the particles is excessively occurred. The particle deposition and ratio plot is shown in Fig.5. Most of the particles were distributed within 6m from the rigid wall.

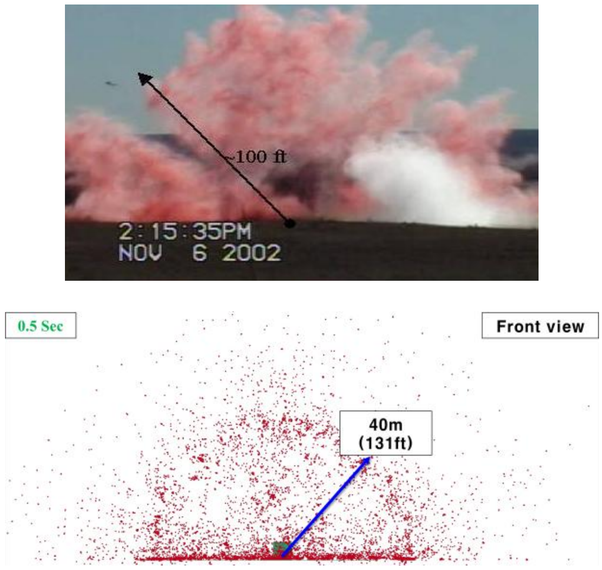


Fig. 4. Experimental[1] and numerical simulation liquid dispersion

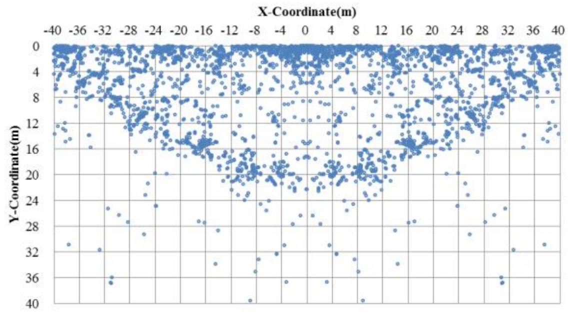


Fig. 5. Particle deposition plot at 0.5sec

4. Summary

In this study, the included fluid was modeled by using smooth particle hydrodynamics (SPH) technique; the fluid spread range following an impact was analyzed. The radius of fluid spread on the numerical analysis became conservative than the WS test results. However, the shape of the cloud is similar to the WS test results. And, the results show that most of the fuel in the vicinity of the wall in microsecond.

Acknowledgement

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