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# Evolution of Fuel-Air and Contaminant Cloud Resulting from a Cruise Missile Explosion Scenario

Allen S. Grossman, Allen L. Kul

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# **Evolution of Fuel-Air and Contaminant Clouds Resulting from a Cruise Missile Explosion Scenario**

Allen S. Grossman, L103  
Atmospheric Science Division  
grossman1@llnl.gov

Allen L. Kuhl, L030  
DNT Division  
kuhl2@llnl.gov

Lawrence Livermore National Laboratory  
Livermore, Ca., 94551

## **ABSTRACT**

A low-mach-number hydrodynamics model has been used to simulate the evolution of a fuel-air mixture and contaminant cloud resulting from the detonation of a cruise missile. The detonation has been assumed to be non-nuclear. The cloud evolution has been carried out to a time of 5.5 seconds. At this time the contaminant has completely permeated the initial fuel-air mixture cloud.

## **I. INTRODUCTION**

In a recent paper (Grossman, 2005) a state of the art fluid mechanical model (LMC model, Bell, 2003) to predict the cloud motion resulting from a surface or near surface nuclear burst in the time frame 1 – 1000 seconds was applied to several test cases, an idealized 1KT surface burst (Kuhl and Bell, 2004) and a near surface burst (Priscilla type event). This model, developed at Lawrence Berkeley National Laboratory (LBNL), has the potential, after some modification, for simulation of the weapon debris clouds in the required time period. Prior to ~1 second there exist established, weapon hydro codes capable of simulating the burst phenomenology. At times greater than ~1000 sec. the LLNL ARAC meteorological dispersion models (Nasstrom et al, 2000) can accurately predict the debris cloud motion. Currently there are some semi-empirical models (Harvey and Serduke, 1979) that have been employed to predict fallout effects within the 1 – 1000 sec. time range. However, these models are severely limited because they use sparse data sets and/or data from bursts over terrain that may not be applicable to other scenarios. There are no current fluid mechanics codes validated for the time period that connects the weapon outputs to the meteorological dispersion codes. A. Grossman worked with John Bell at LBNL in FY 2004 to provide operational improvements and tracer particle capabilities to the LBNL LMC model. Major results were:

1. Add a vertically structured atmospheric pressure-density profile.
2. Use an improved source model (Priscilla) and a realistic surface structure (raise surface particulates) to drive the LMC.
3. Evaluate computer requirements.
4. Develop formalism for weapon debris and particulate tracer particles.
5. Interface LMC results with NARAC modeling codes.

A scenario has been proposed in which a small aircraft crashes through the roof of a building that contains a cruise missile, with the result that there is ignition of the missile fuel, booster engine fuel, and aircraft fuel. It is assumed that there is no nuclear detonation and the nuclear material in the warhead is vaporized in the ensuing fireball. The main object of this paper is to use the LMC model to calculate the rise of the fireball and vaporized contaminant material clouds for the case described above.

## II. SOURCE

### 1. Fuel-Air Cloud

Table 1 shows the component properties of the missile and the fuel-air mixture that will be ignited.

**TABLE 1. COMPONENT PROPERTIES**

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#### Missile

$D = 52$  cm (missile diameter)

$L = 550$  cm (missile length, without booster)

$l_T = 330$  cm (fuel tank length)

$V = \pi D^2 l_T / 4 = 7 \times 10^5$  cm<sup>3</sup> (fuel volume)

Vehicle mass = 1,300 kg

#### Missile Fuel

kerosene (simulated here by docene):  $C_{12}H_{24}$

$\rho \approx 0.9$  g/cc (density)

$m_K = \rho V = 630$  kg (fuel mass)

molecular weight=168g/g-mole

#### Combustion Cloud

stoichiometric fuel-oxygen cloud:  $C_{12}H_{24} + 18O_2 \rightarrow 12CO_2 + 12H_2O$

stoichiometric fuel-air cloud:



Therefore, one mole of  $C_{12}H_{24}$  requires 18 moles of  $O_2 = 90$  moles of air during combustion.

$$\text{Air/Fuel Ratio: } \phi = \frac{m_{\text{air}}}{m_{C_{12}H_{24}}} = \frac{90 \cdot 28.8}{168} = 15.4$$

$$\text{Aircraft fuel: } m_{AC} = 220 \text{ kg (= 80 gal)}$$

$$\text{Booster fuel: } m_B = 272 \text{ kg}$$

Total Fuel:

$$\text{Air: } M_{\text{air}} = \phi \cdot M_F = 17,556 \text{ kg}$$

$$\text{Reactants: } M_R (= M_P) = M_F + M_{\text{air}} = 1,142 + 17,556 = 18,700 \text{ kg}$$

Assume the fuel air mixture is a perfect gas:

$$\frac{p_2 v_2}{p_1 v_1} = \frac{R_2 T_2}{R_1 T_1}, \quad (1)$$

where State 1 represents ambient air:  $v_1 = 1/\rho_1 = 1/(1.2 \cdot 10^{-3}) = 833 \text{ cc/g}$  and  $T_1 = 300 \text{ K}$ . Assuming isobaric combustion ( $p_2 = p_1$ ), and noting  $R_2 \approx R_1$  (the cloud is 94% air), one finds Cloud specific volume:

$$v_2 = v_1 \frac{T_2}{T_1} = 833 \frac{2300}{300} = 833 \cdot 7.67 = 6,386 \text{ cc/g} \quad (2)$$

(i.e., no losses due to radiation heat transfer), the combustion cloud will be at the adiabatic flame temperature. For stoichiometric mixtures of hydrocarbons in air, the adiabatic flame temperature is:  $T_2 \approx 2,300 \text{ K}$  ( $\pm 100 \text{ K}$ ). The resulting specific volume of the cloud is 6,386 cc/g. Then volume of the cloud is:

$$V_c = v_2 \cdot M_P = (6,386 \text{ cc/g}) \times (1.87 \cdot 10^7 \text{ g}) = 1.194 \cdot 10^{11} \text{ cm}^3. \quad (3)$$

Assuming a hemi-spherical cloud shape, where  $\frac{2\pi}{3} R_c^3 = V_c$ , then the cloud radius is:

$$R_c = \left( \frac{3}{2\pi} V_c \right)^{1/3} = \left( 0.477 \times 1.194 \cdot 10^{11} \right)^{1/3} = \left( 5.7 \cdot 10^{10} \right)^{1/3} = 3,849 \text{ cm.} \quad (4)$$

Thus, the hemi-spherical combustion cloud has a radius of 38.5 m (and diameter of  $D_c = 77 \text{ m}$ ). This diameter can be expressed in algebraic form as:

$$D_c (\text{cm}) = 2 \left( \frac{3}{2\pi} v_1 \frac{T_2}{T_1} (1 + \phi) M_F \right)^{1/3} = 73.68 M_F^{1/3}, \quad (5)$$

where  $M_F$  is in units of grams. Hemispheric cloud diameters are listed in Table 2 for different fuel cloud masses. This shows, that neglecting the booster energy results in a combustion-cloud size between 63-70 meters in diameter.

**Table 2. Hemi-spherical Combustion-Cloud Diameter**

CASE	$M_F$ (kg)	$D_c$ (cm)
T-LAM fuel	630	6,316
T-LAM fuel + aircraft fuel	850	6,980
T-LAM fuel + aircraft fuel + booster fuel	1,122	7,656

## 2. Contaminant Cloud

We assume that the hemi-spherical contaminant cloud created by the “explosion” of the dispersing charge has a final diameter:

$$D_{HDC} = 908 \text{ cm.} \quad (10)$$

## III. RESULTS

As a first simulation we choose as the source, the last case in Table 2, which gives a hemispherical cloud diameter of 77 meters and a density of the fuel-air mixture of  $0.156 \times 10^{-3}$  g/cc. The contaminant cloud has a diameter of 9 meters and an assumed density equal to that of the fuel-air cloud. These sources were used as initial conditions in a vertically stratified atmosphere for the LMC code, and run to a time of 5.5 seconds to explore the cloud behavior. Figure 1 shows the vertical profile of the cloud density at a time of 5.5 seconds. The initial hemispherical cloud has evolved into a toroidal shape with a central stem and a secondary smaller cloud at the top of the stem. The height of the top of the small cloud in the stem is  $\sim 133$  m and has a diameter of  $\sim 21$  m. The height of the top of the toroidal cloud is  $\sim 94$  m, its outer diameter is  $\sim 80$  m, and its thickness is  $\sim 26$  m. Figure 2 shows a horizontal cross section of the combustion cloud density. Figure 3 shows the vertical profile of the contaminant cloud density at a time of 5.5 seconds. The dimensions of the contaminant cloud are similar to the fuel-air combustion cloud indicating that the contaminant has permeated (mixed with) the combustion cloud. Figure 4 shows the horizontal contaminant cloud cross-section.

This simulation was performed in an open atmosphere, no building to constrain cloud motion, as a test of the LMC code capability to model this type of source. It appears that even at 5.5 seconds elapsed time the cloud dimensions are of the same order as that of the overlying building. Building effects must be taken account of in the next level of simulation. This simulation serves as a proof of concept that the LMC code has the capability to provide contaminant tracer distributions for the fuel-air combustion source outlined above.

## IV. REFERENCES

Bell, J. B., 2003, AMR for low Mach Number reacting flows. LBNL Report LBNL-54351, Proceedings of the Chicago Workshop on Adaptive Refinement Methods.

Harvey, T. F., and F. J. D. Serduke, 1979, Fallout model for system studies. LLNL Report UCRL-52858.

Grossman, A. S., 2005, High Fidelity Fluid Mechanical Model for the Early Time Prediction of Atmospheric Contaminant Clouds From Nuclear Explosions. LLNL Report UCRL-PROP-209613 (G1).

Kuhl, A. L., and J. B. Bell, 2004, Low-Mach-Number AMR Code Simulation of Nuclear Cloud Rise: 1-KT Nuclear Surface Burst on an Ideal Surface. (Personal Communication by A. Kuhl.)

Nasstrom, J.S., G. Sugiyama, J.M. Leone, Jr., and D.L. Ermak, 2000: A real-time atmospheric dispersion modeling system, *Eleventh Joint Conference on the Applications of Air Pollution Meteorology*, Long Beach, CA, Jan. 9-14, 2000. American Meteorological Society, Boston, MA, 84-89.

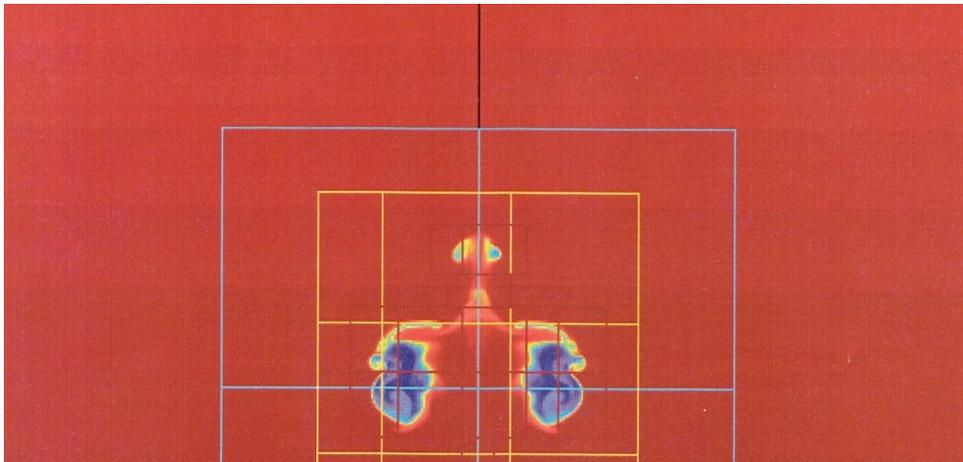


Figure 1. Vertical cross-section of the combustion cloud density at  $t = 5.5$  sec.

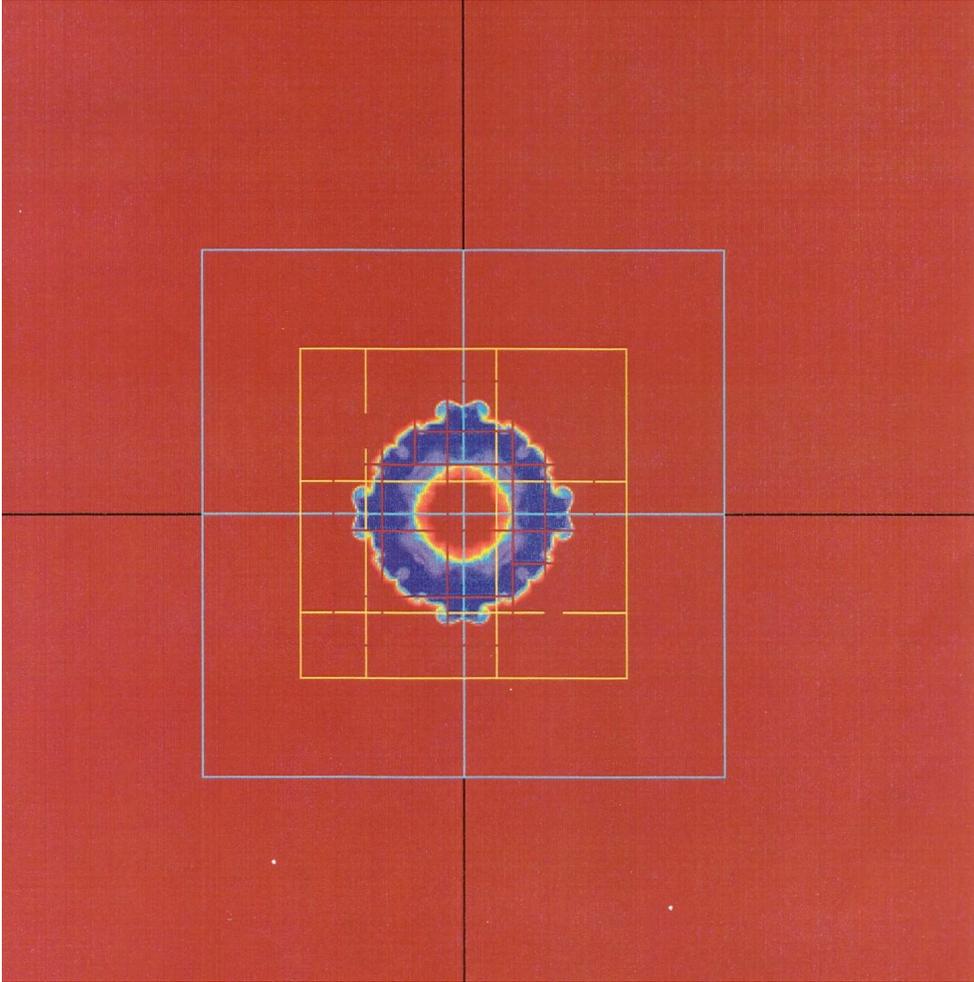


Figure 2. Horizontal cross-section of the main cloud density at  $t = 5.5$  sec.

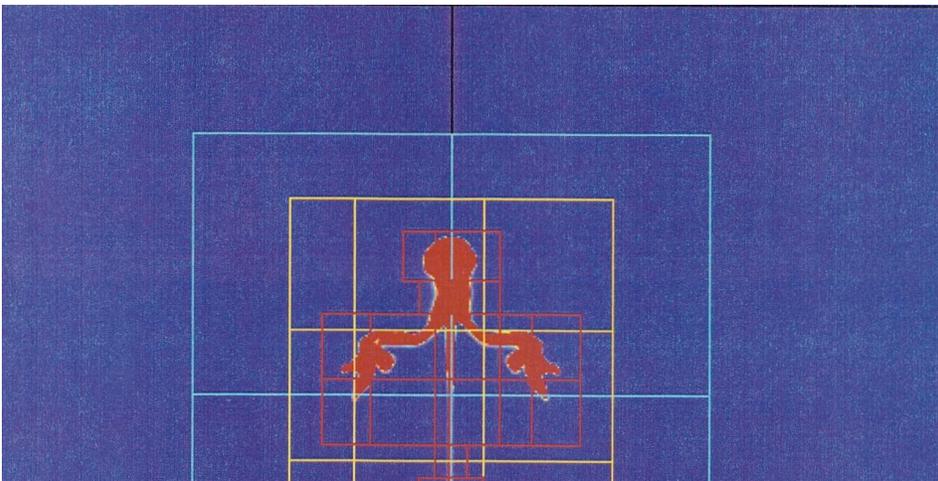


Figure 3. Vertical cross-section of the contaminant cloud density at a  $t = 5.5$  sec.

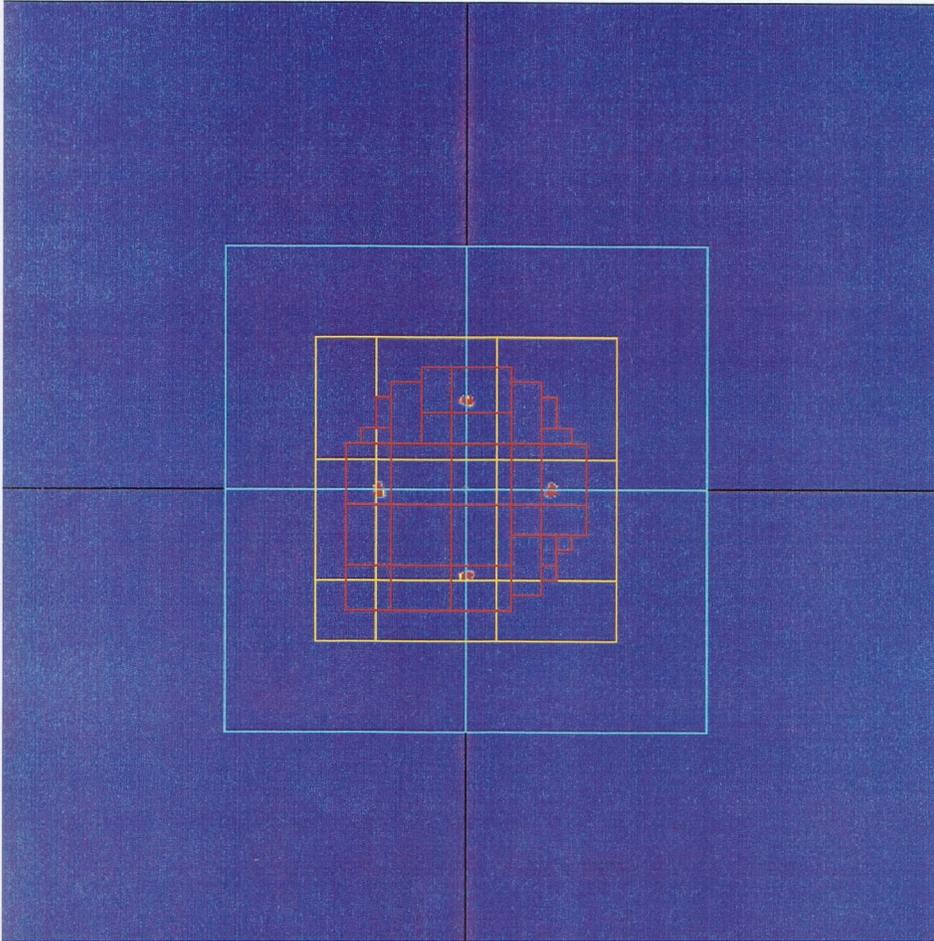


Figure 4. Horizontal cross-section of contaminant cloud at  $t = 5.5$  sec.