# FLUID MODELING OF A HEAVY GAS VAPOR DETENTION SYSTEM

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ABSTRACT This paper summarizes wind tunnel simulations of the Falcon Series large scale liquefied natural gas (LNG) spill experiments conducted at the Nevada test site by the Lawrence Livermore National Laboratory (LLNL) in 1987.

## 1. Introduction

Dispersion of liquefied natural gas in the event of an accidental spill is a major concern in LNG storage safety planning, hazard response, and facility siting. Field experiments were supported by the Department of Transportation (DOT) and the Gas Research Institute (GRI) in 1987 [Brown et al., 1988] to evaluate the effectiveness of vapor fences as a mitigation technique for accidental release of LNG. Post-field-spill wind-tunnel experiments were performed by Colorado State University [Shin, 1991] to evaluate the simulation of physical modeling and to assist in the development and verification of analytical models.

## 2. Post-field Experimental Measurements

Sixteen post-field-spill tests were simulated in the Environmental Wind Tunnel (EWT) at Colorado State University at model length scales of 1:50, 1:100, 1:150, and 1:200 to examine the sensitivity of results to various scaling arguments. Each test was repeated 5 times to evaluate the reproducibility. The modeled release site consisted of a 58 x 40 m bermed basin filled with water, a 22 m wide by 14 m tall barrier placed 5 m upwind, and a 58 m long by 44 m wide by 9 m vapor fence which enclosed the release area. Pure Argon was used as a simulant gas for all test sets, and pure Freon-12 gas was used for the simulation of Falcon 4 with model scales of 1:150 and 1:200.

A rack of eight hot-wire aspirating probes were manufactured to obtain the concentration time histories at points downwind of the spill site. The aspirated probes have a 60 Hz frequency response which corresponds for a model scale of 1:100 to 11 Hz at field scale - far above the 1 Hz frequency limit used in field tests.

## 3. Discussion

Field data and wind tunnel experiments were compared through surface pattern and statistical methods. A layer-averaged slab model developed by Meroney et al. [1988] (FENC23) was expanded to predict dense gas dispersion with the effect of fences.

### 3.1 <u>Effect of Different Model Scales and Different Simulant Gases on Plume Similarity</u>

Peak centerline concentrations, concentration time histories, and concentration contours from model data were compared to field data. Figure 1 shows concentration time series observed at (X=150 m, Y=-28 m, Z=5 m) for all model scales and for the Falcon

4 test. The fractional bias (FB) and normalized mean square error (NMSE) defined by;

$$FB = (\bar{C}_m - \bar{C}_f) / [0.5(\bar{C}_m + \bar{C}_f)]$$

$$NMSE = \overline{(C_m - C_f)^2} / (\bar{C}_m \bar{C}_f)$$

were calculated, where an overbar indicates an average over all points in the data set. Data from post-field-spill experiments of Falcon 2, 3, and 4 tests were examined. All downwind data points (X > 0 m) were included, and concentration time histories from both field and model tests were averaged over the same time period (11 sec in field time). Data were analyzed for the magnitude of $\bar{C}_{MAX}$, the arrival time of concentration with a magnitude of 20 percent of $\bar{C}_{MAX}$, and the arrival time of $\bar{C}_{MAX}$.

Figure 2 is a plot of NMSE vs. FB for peak concentration data. This figure shows that all laboratory tests underpredict the peak concentrations. Most laboratory simulations have values of $-0.50 \le FB \le -0.25$ and $0.35 \le NMSE \le 0.70$. Comparing Hanna's [1990] results for numerical hazardous gas model performance to Figure 2 confirms that wind tunnel predictions of peak concentrations are generally better than numerical predictions. Figure 3 shows a plot of NMSE vs. FB for the arrival time of concentrations with a magnitude of 20 percent of $\bar{C}_{MAX}$. NMSE and FB values for arrival time of $\bar{C}_{MAX}$ are within a range of ± 0.30 and $0.0 \le NMSE \le 0.45$. The figures also show that Freon-12 simulant gas predicts the field data better than Argon gas, suggesting that improvement in plume Reynolds number magnitude is desirable.

## 3.2 Surface Pattern Comparisons of Laboratory/Field Data

Spatial distribution of plume concentrations appears to be more critical than the temporal distribution for hazard assessment. Lewellen and Sykes [1985] proposed a measure of the spatial comparison between observed and predicted patterns, which compares data over increments of decreasing spatial resolution. It estimates how much the predicted pattern must be shifted in space to cover all of the observed values. Thus, the comparison is not between the observed and predicted concentration at a point, but rather between the observed concentration at a point and the calculated concentration anywhere in the area $\delta A$. One can calculate the fraction of the test points, $f_N(\delta\theta, N)$, which yield predicted concentrations within a specified ratio N of the observed values within the areas defined by $\delta A$. A plot of $f_N(\delta\theta, N)$ gives a direct measure of how well the laboratory-predicted spatial distribution compares with the observations. Thus, one can plot the sequence of curves $f_N(\delta\theta, N)$ as a function of $\delta\theta$ for a various values of N.

Figure 4 plots f-N vs Degree with specified pattern factors for different run conditions. Figure 4 shows that 100 percent of the observations are covered by a shift of 15° for N = 1, and the shift decreases to 7° for N = 2. Summary bar charts shown in Figure 5 demonstrate that the pattern factor increases as the length scale ratio decreases, suggesting that the model predicts the observations better spatially as the model size increases.

### 3.3 Depth-Averaged Numerical Model

The effect of a fence on plume dispersion located downwind of a source area was included in a model called FENC23 [Meroney et al., 1988]. In this study FENC23 was expanded to include the effects of fences located upwind and downwind of the source area. The $Pe_*/Ri_*$ ratio for laboratory tests ranged from 0.07 to 0.001 implying that the model tests might underpredict peak concentrations. The numerical model demonstrated that plume dispersion was significantly influenced by microscopic diffusion when a fence is not present, however the effect of $Pe_*/Ri_*$ ratio change is not significant when fences are included.

Figure 6 shows a peak concentration decay comparison between different fencing schemes. The peak model and field concentrations were compared to numerical predictions. The figure shows that the numerical model predicts field data and wind-tunnel data fairly well.

## 4. Conclusions

1. The $Pe_*/Ri_*$ ratio is not critical in laboratory simulations when obstacles are present.
2. Peak concentrations of field data and post-field wind-tunnel simulations agreed within a range of $-0.50 \le FB \le -0.25$ and $0.35 \le NMSE \le 0.70$ for most simulations. Arrival times of $0.2\bar{C}_{MAX}$ have FB values within $\pm 0.38$ and $0.0 \le NMSE \le 0.4$. The arrival time of $\bar{C}_{MAX}$ have FB values in a range of $\pm 0.30$ and $0.0 \le NMSE \le 0.45$.

## References


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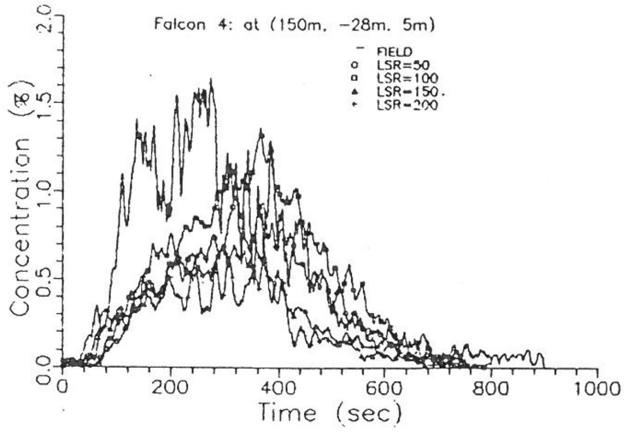


Figure 1 Concentration time history comparison between all model scales for Falcon 4

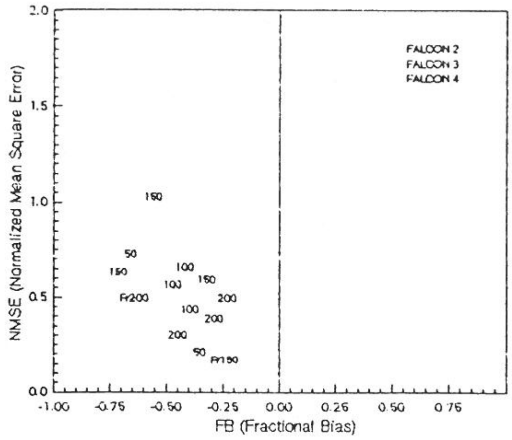


Figure 2 Weighted average Fractional Bias, FB, and Normalized Mean Square Error, NMSE, for peak concentration predictions for all physical model

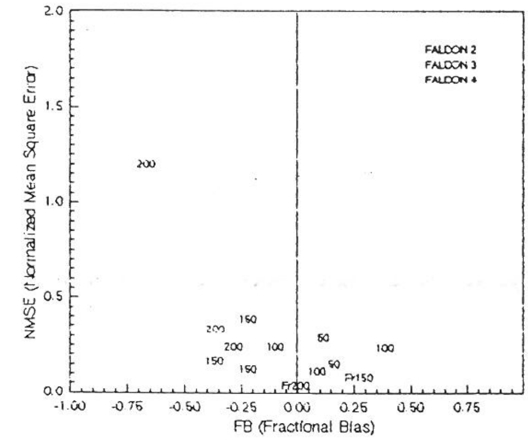


Figure 3 Weighted average Fractional Bias, FB, and Normalized Mean Square Error, NMSE, for arrival time predictions for all physical model

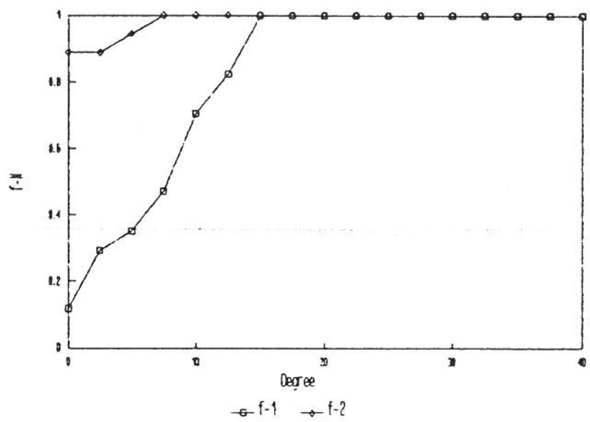


Figure 4 Pattern comparison plot · Falcon 4 (Argon), LSR=100, z=5 m

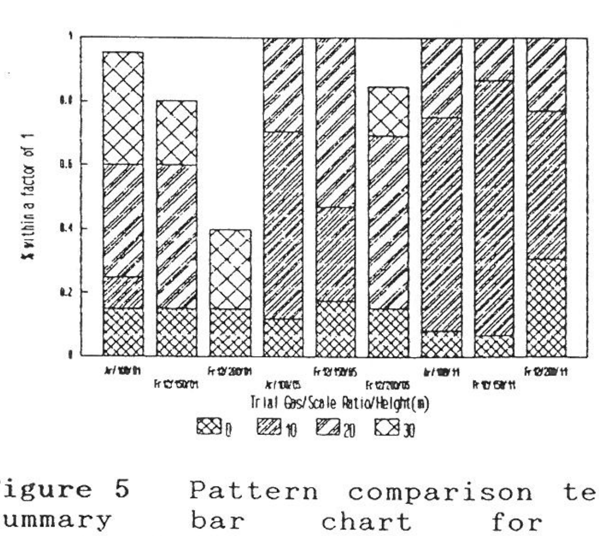


Figure 5 Pattern comparison test summary bar chart for % compatibility of factor 1 at θ angles between 0° and 30°

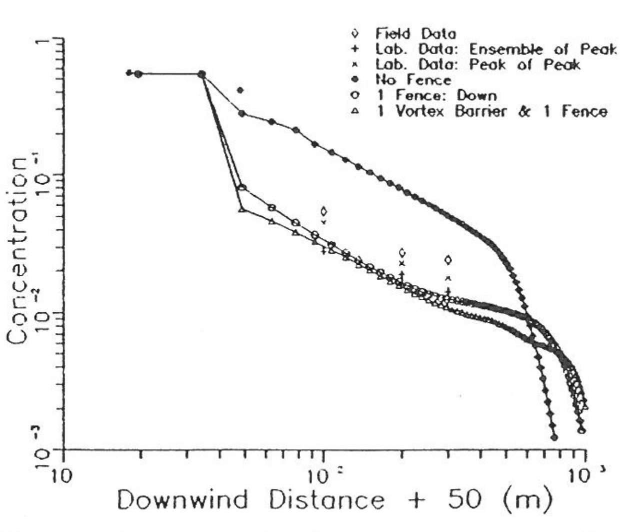


Figure 6 Peak concentration comparison between different fence schemes: $C_D$ = 0.05