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SURFACE PATTERN COMPARABILITY OF WIND-TUNNEL SIMULATIONS OF THE THORNEY ISLAND DENSE GAS DISPERSION TRIALS

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INTRODUCTION

In 1976 the Health and Safety Executive (HSE) initiated a program of research on the atmospheric dispersion of heavy gases. The principal theme of the experimental part of the program was the study of the dispersion of fixed-volume clouds. The clouds were initially placed at atmospheric pressure and temperature in a ground-level container which was then suddenly removed. The Heavy Gas Dispersion Trials (HGDT) project was the large-scale constituent of their program, and it was the subject of the report by McQuaid and Roebuck (1984).

Subsequently, Davies and Inman (1986) simulated 34 of the 42 field experiments in a meteorological wind tunnel. Davies and Inman provided some comparisons between their laboratory measurements and the Thorney Island field results. This paper examines the data further by the Surface Pattern Comparison technique described by Meroney (1986, 1987). The emphasis here is to analyze the results to establish the level of confidence which can be placed in laboratory simulations.

Field Measurement Program

The HGDT project as originally planned was limited to experiments on clouds dispersing over uniform, unobstructed ground. After these experiments had commenced, a second series of experiments were performed in which the effects of several types of obstruction were studied. The former experimental program was designated Phase I and the later instantaneous spills were designated Phase II and the later continuous spills designated Phase III. Alternative arrangements of solid fences (5 m), porous fences (10 m), buildings (9 m cube), and vapor barrier enclosures (2.4 m x 26 m x 54 m) were placed up and downstream of the release location. Fifteen experiments were performed for instantaneous unobstructed releases; ten experiments were performed for instantaneous releases in the presence of walls, porous walls, and small buildings; four experiments were completed for continuous unobstructed releases; and thirteen experiments were completed for continuous releases within a vapor barrier fence enclosure.

The experiments were performed over an airfield at Thorney Island, West Sussex, U.K., at which gas of various densities was released in both unobstructed and obstructed configurations. The data obtained were very comprehensive, including concentration, turbulence, visual records, and detailed meteorological information. Up to 100 gas sensor records were obtained in individual trials at distances up to 750 m from the release point. The fully developed field of 45 measurement stations carried a total of 215 transducers, 183 being gas sensing devices and 32 environmental sensors. The standard gas sensors used an oxygen depletion concept to cause variations in an electrochemical cell. These sensors had a frequency response of 1 Hz (McQuaid and Roebuck, 1986).

During the Phase I and II tests the field release volume was a twelve-sided polygon tent which was about 14 m diameter and 13 m high containing a total volume of 2000 m^3. During a release a flexible top cover was withdrawn by raising it into a bundle above the gas tent cylinder. During some tests both permeable and impermeable vapor barriers of various heights were placed downwind of the dense gas releases. During the Phase III tests gas from the tent was bled through a pipeline to a point source and released continuously until the volume was depleted. The vapor barrier enclosure surrounded the continuous source and polygon tent during most of these tests.

Model Measurement Program

Meroney (1986, 1987) previously considered model simulation experiments of six of the Thorney Island trials (Hall and Waters, 1985; van Heugten and Duijm, 1984; Duijm et al., 1985; Schatzmann et al., 1985). The details of the trials selected and the model scales used are recorded in Table 1. Scale ratios used varied from 1:90 to 1:164. The collapsing tent source was simulated by a cubical volume with a collapsing bellows (Hall and Waters, 1985) or by a plastic truncated cylinder which was retracted downward by gravity beneath the tunnel floor at the time of release. All laboratory investigators used aspirated hot wire anemometer systems to detect continuous gas concentrations. Model experiments were replicated from 3 to 5 times each. Unfortunately, the model experiments were not reported in enough detail to use the surface pattern comparison test method.

The purpose of the Davies and Inman (1986) wind-tunnel tests was to obtain a large data base of laboratory simulations over a range of model scales typical of those used in hazard studies on prototype installations. Scales ranging from 1:40 to 1:250 were used to simulate 34 trials from the Thorney Island HGDT project. A total of 86 laboratory simulations were produced. Typically, 10 repetitions of each wind tunnel run were required to map the concentration field for each simulation and to provide point to point comparisons with the 10 to 20 "ground level" (0.4 m high) sensors which intercepted the gas cloud during the field trials.

The instantaneous spill cases of the HGDT project were simulated at scales of 1:40, 1:100, and 1:150 using a collapsing wall type container to simulate the prototype collapsing bag. A large grid of sensor locations were used in the laboratory to enable concentration contours to be prepared from the laboratory measurements. Concentration measurements were made in the laboratory with low-volume hot-wire aspirated katherometers. These instruments permitted measurement of concentration time series at each sensor location.

SURFACE PATTERN COMPARABILITY APPROACH

During the field study there were a large number of uncontrolled or poorly specified variables that have effects on the resultant concentration field. These variables are not completely accounted for by either a physical or numerical model. For example, the full-scale wind field is typically nonstationary, the source conditions are only approximately known, and the modeling method itself introduces errors.

Most model performance measures compare predicted versus observed values directly. Precise pairing in time and space imposes too strong a penalty on small misalignments, while pairing in time alone provides no information on spatial variability. Lewellen and Sykes (1985) have proposed a novel measure of spatial comparison between observed and calculated patterns which compares over increments of decreasing spatial resolution. Essentially it estimates how much the predicted pattern must be shifted in space to cover all of the observed values. The result of such a comparison is knowledge of what percentage of observed concentrations are contained within increased areas of spatial resolution as specified by their angular displacement observed from the release location, delta theta. Ermak and Merry (1988) point out that this approach is equivalent to a conventional ratio method where the space-time correlation restriction is relaxed.

Consider the segment of area $A(x_i, \delta\theta)$ sketched in Figure 1 which is defined by its position in polar coordinates, (r_i, θ_i), centered on the emission point and an angular displacement, $\delta\theta$. The area is bounded as shown by $\theta_i + \delta\theta$, $\theta_i - \delta\theta$, $r_i(1+\delta\theta)$, and $r_i(1-\delta\theta)$. The calculated concentration field within the area A_i is bounded by lower and upper values which we define as $C_c^l(A)$ and $C_c^u(A)$, respectively. Given observed concentrations $C_o(x_i)$ at a number of points $i = 1, 2, 3, \ldots M$, one can assign calculated concentrations at these points as a function of $A(x_i, \delta\theta)$:

$$C_c(x_i, \delta\theta) = \begin{cases} C_c^l(A) & \text{if } C_o(x_i) < C_c^l(A) \\ C_o(x_i) & \text{if } C_c^l(A) < C_o(x_i) < C_c^u(A) \\ C_c^u(A) & \text{if } C_o(x_i) > C_c^u(A) \end{cases} \quad (1)$$

One now calculates the fraction of the test points, f_N, which yield calculated concentrations within a specified ratio N of the observed values within the sector areas defined by $\delta\theta$.

$$f_N(\delta\theta, N) = \frac{1}{M}\sum_{i=1}^{M} H\{N - \exp[\,|\ln(\frac{C_c(x_i, \delta\theta)}{C_o(x_i)})|\,]\} \quad (2)$$

with $H\{f\}$ the Heavyside step function equal to 1 or 0, depending upon whether $f > 0$ or $f < 0$ respectively.

A plot of $f_N(\delta\theta, N)$ gives a direct measure of how the laboratory predicted spatial distribution compares with the observations. As an example, consider Figure 2, from a comparison of the Lawrence Livermore FEM-3 numerical model with field data from the BURRO Trial 8 Liquefied Natural Gas spill. For N = 1, the figure shows that 40% of the observations are covered by a shift of 5^o in the pattern, and that this rises to 90% for a 20^o shift. Most emergency planners should be happy to expand a potentially affected area by only 15^o to 20^o to cover model uncertainty.

Ideally the sum in Equation 2 should include all points where either the calculated or the observed concentrations are greater than background; however, it can only be applied at points where observed values are available. Lewellen and Sykes note it is possible to create artificial patterns of high and low concentrations which would yield high values of f_N; however, such patterns would not be created by any physically consistent modeling technique.

DISCUSSION OF FLUID MODELING VERSUS DATA COMPARISONS

Table 2 lists the prototype and model conditions considered by Davies and Inman. The peak concentration contours at ground level measured at full scale and during the laboratory simulation are plotted together in the Davies and Inman report. Figure 3 displays observed and laboratory simulated ground-level concentration contours for Thorney Island Test 38 modeled at a scale of 1:40. Figure 4 shows a companion plot of f-N, the percentage of field data predicted within a factor of N by the laboratory data, versus angular displacement, a measure of spatial resolution. Table 3 summarizes the values of Theta, θ at which there exists 100% agreement between field and model data at various magnitudes of N ratio. In no case is a Theta value greater than 15^o required to provide agreement within a factor of 2 between field and model results. Figures 5 to 10 provide the same information in a bar chart format that display the percent of measured data predicted exactly for each test in terms of Theta values varying from 0^o to 15^o. All trials were regrouped for comparison as follows:

1. Unobstructed instantaneous releases (Figure 5),
2. Instantaneous releases with wall or building (Figure 6),
3. Continuous releases with fence enclosures (Figures 7 to 9),
4. Unobstructed continuous releases (Figure 10).

Scale ratios of 40, 100, 150, and 250 are denoted by ##/a, ##/b, ##/c, and ##/d, respectively on these figures.

Most laboratory scientists expect that as model scale ratio, LSR, increases the quality of the physical simulation may decrease. This decrease results from mismatch in turbulence size and strength, exaggerated dispersion due to microscopic transport, and mismatach between buoyancy and inertial forces in the model. Thus, one expects some evidence that the quality of simulation decreases as one changes model scale from 1:40 to 1:250 (from cases a to d). It would be valuable if one could quantify the loss of accuracy as a function of model scale.

Unfortunately, close inspection of the data reveals no consistent pattern of error variability with model scale. Tests 42a, b, c, and d; tests 8b and c, tests 38a, b, c, and d show the expected decline in model reliability. Yet tests 49a, b, and c; tests 30a, b, and c; tests 33a, b, and c show the opposite trend! Other tests display an irregular rise and fall of accuracy with scale ratio. At this time it is not known whether this is evidence of normal statistical variability, experimental errors, or fallacies in the similarity theories.

The variation in delta-theta calculated from the surface pattern comparisons were also stratified on the basis of model scale, Reynolds number and Peclet/Richardson number ratio. No systematic dependency of the model reliability could be determined. This result confirms the conclusions found by Davies and Inman (1986), who used conventional statistical scatter diagrams and ratio techniques. On a positive note, most of the data compared within a factor of one for angular displacements of 15 to 20 degrees. Similar comparisons between field data and many numerical models require angular displacements exceeding 45 degrees. Results from continuous spill experiments appear to compare somewhat better than the instantaneous spill experiments.

CONCLUSIONS

Laboratory simulation of dense gas behavior near obstructions appears to be reliable in the sense that predicted concentration contours do not require major modifications to reproduce field data. Based on this Surface Pattern Comparison analysis no limitations could be placed on the largest model scales which might be used to simulate dense cloud behavior. The following additional observations are appropriate:

- Field/fluid model comparisons suggest that most ground level concentrations are predicted exactly for theta increments of less than 20° and within a factor of two (N = 2) for theta increments of less than 15°.

- Strict observance of the roughness Reynolds number criterion ($Re_* > 2.5$) or the source Reynolds number criterion ($Re > 3000$), does not seem to be necessary when simulating flows dominated by the gas release or obstacle configuration. The roughness Reynolds number may indeed be important during simulation experiments when one is concerned with decay of concentration to levels less than 0.1%.

- No difference in physical model performance between unobstructed and obstructed trials could be detected from the Thorney Island field/laboratory comparisons. Apparently cloud dilution during the Thorney Island trials was dominated by source release and obstacle characteristics which were not sensitive to the range of simulation parameters considered.

Acknowledgments

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Figure 1. Schematic of Area Segment

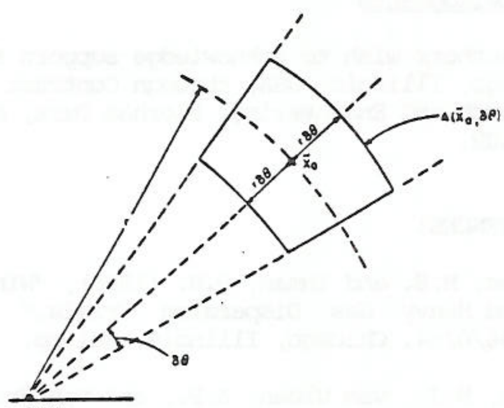

Figure 2. Pattern test results using FEM-3 Numerical Model prediction of BURRO Trial No. 8 LNG field spill data.

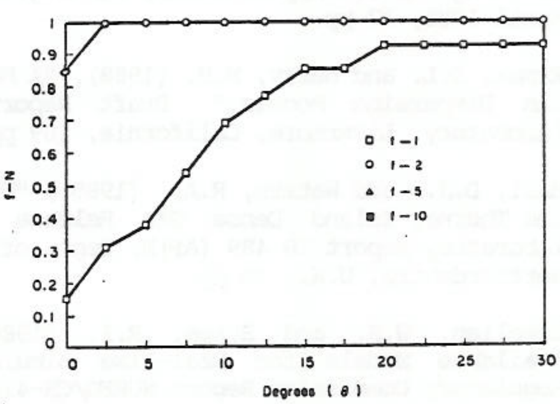

Table 1: INSTANTANEOUS RELEASES: PROTOTYPE

TEST CONFIGURATION	NO.	Specific Gravity	V (cu.m.)	D (m)	u (m/s)	u* (m/s)	Zo(cm)	P.G. Stab.	Humidity %
Thorney Is., U.K.	7	1.78	2000.0	14.0	3.2	0.13	1	E	81
1000 cu.m.	8	1.63	2000.0	14.0	2.4	0.12	0.3	D	88
(Hall & Waters, 1985)	11	2.03	2000.0	14.0	5.1	0.26	1	D	77
(Duijm et al, 1985)	13	1.96	2000.0	14.0	7.5	0.38	1	D	74
(Schatzman et al, 1985)		1.96	2000.0	14.0	7.5	0.38	1	D	74
		1.96	2000.0	14.0	7.5	0.38	1	D	74
	15	1.41	2000.0	14.0	5.4	0.27	1	C-D	88
		1.41	2000.0	14.0	5.4	0.27	1	C-D	88
		1.41	2000.0	14.0	5.4	0.27	1	C-D	88
	18	1.87	2000.0	14.0	7.4	0.30	1	C	

INSTANTANEOUS RELEASES: MODEL

NO.	NO. TEST	SCALE RATIO	SPECIFIC GRAVITY	V(cc)	D(cm)	u(cm/s)	u*(cm/s)	Zo(cm)	P.G Stab.	D (cm*cm/s)
7	T33	90	2.08	2744	16.0	40	3.00	0.40	D	0.09
8	TN08	107	4.18	1633	13.0	53	2.80	0.02	D	0.09
11	T29	90	3.56	2744	16.0	86	4.50	0.02	D	0.09
13	P3	90	2.00	2744	16.0	84	4.40	0.02	D	0.09
	TN013A	107	1.96	1633	13.0	73	3.90	0.01	D	0.09
	TN013B	107	4.18	1633	13.0	132	7.20	0.01	D	0.09
15	P3	90	2.00	2744	16.0	84	4.40	0.02	D	0.09
	UH15A	164	1.41	450	8.5	42	2.10 *	0.01	D	0.09
	UH15B	164	4.18	450	8.5	117	5.87 *	0.01	D	0.09
18	P3	90	2.00	2744	16.0	84	4.40	0.02	D	0.09

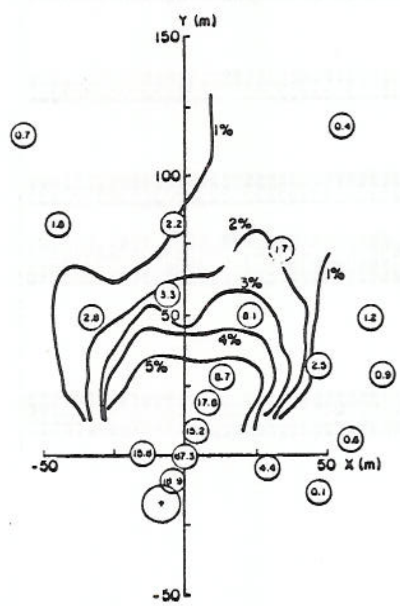

Figure 3. Ground-level peak concentration data for Thorney Island Trial No. 38. Field data show in circles.

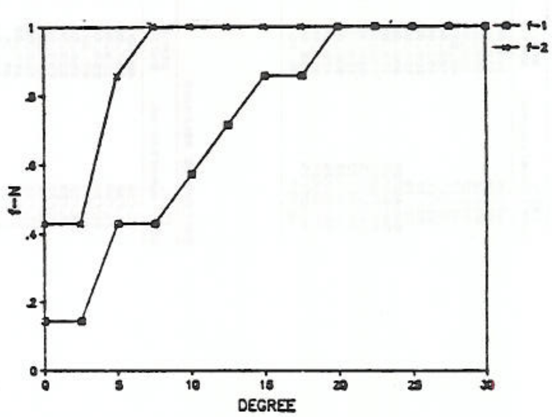

Figure 4. Pattern test result for Thorney Island Trial No. 38.

Table 2. PROTOTYPE AND MODEL CONDITIONS
CONFIGURATION: THORNEY ISLAND

INSTANTANEOUS RELEASES

TRIAL CONFIGURATION/NO.	SCALE RATIO	<SPECIFIC GRAVITY>f	<SPECIFIC GRAVITY>m	U10,f m/s	U10,m m/s	VOL. m**3	RATE m**3/min	D cm**2/s	<Ri>B	<Pe/Ri>m	<Re>m	<Re*>m	PASQUILL STABILITY
UI/08	100.00	1.70	1.70	2.40	.24	2000.00	-	.08	15.50	269.00	1679.89	7.73	D
UI/08	150.00	1.70	1.70	2.40	.20	2000.00	-	.08	15.50	146.00	914.42	6.31	D
UI/12	100.00	2.30	2.30	2.60	.26	1950.00	-	.08	24.70	184.00	1804.59	8.37	E
UI/12	150.00	2.30	2.30	2.60	.21	1950.00	-	.08	24.70	100.00	982.50	6.84	E
UI/17	40.00	4.20	4.20	5.30	.84	1700.00	-	.08	12.50	2502.00	13890.88	26.98	D/E
UI/17	100.00	4.20	4.20	5.30	.53	1700.00	-	.08	12.50	633.00	3514.14	17.07	D/E
UI/17	150.00	4.20	4.20	5.30	.43	1700.00	-	.08	12.50	345.00	1912.86	13.93	D/E
UI/19	100.00	2.10	2.10	6.60	.66	2100.00	-	.08	3.50	3556.00	4695.46	21.25	D/E
UI/19	150.00	2.10	2.10	6.60	.54	2100.00	-	.08	3.50	1936.00	2555.88	17.35	D/E
SW-50/20	100.00	1.90	1.9[illegible]	5.60	.56	1920.00	-	.08	3.50	2655.00	3866.78	18.03	C/D
SW-50/20	150.00	1.90	1.[illegible]	5.60	.45	1920.00	-	.08	3.50	1445.00	2104.81	14.72	C/D
SW-50/21	100.00	2.00	2.[illegible]	3.90	.39	2050.00	-	.08	9.00	807.00	2752.39	12.56	D/E
SW-50/21	150.00	2.00	2.[illegible]	3.90	.32	2050.00	-	.08	9.00	439.00	1498.21	10.25	D/E
SW-50/22	150.00	4.20	4.[illegible]	6.00	.49	1400.00	-	.08	7.80	500.00	2029.79	15.77	D/E
98-50/28	100.00	2.00	2.0[illegible]	9.00	.90	1850.00	-	.08	1.50	9918.00	[illegible]138.01	28.98	D
98-50/28	150.00	2.00	2.[illegible]	9.00	.73	1850.00	-	.08	1.50	5399.00	[illegible]341.11	23.66	D
98-27/29	100.00	2.00	2.[illegible]	5.50	.55	1950.00	-	.08	4.10	2264.00	[illegible]17.41	17.71	E
98-27/29	150.00	2.00	2.[illegible]	5.50	.45	1950.00	-	.08	4.10	1232.00	[illegible]077.93	14.46	D
UI/34	40.00	1.80	1.80	1.40	.22	2110.00	-	.08	60.40	184.00	[illegible]43.30	7.13	F

CONTINUOUS RELEASES

TRIAL CONFIGURATION/NO.	SCALE RATIO	<SPECIFIC GRAVITY>f	<SPECIFIC GRAVITY>m	U10,f m/s	U10,m m/s	VOL. m**3	RATE m**3/min	D cm**2/s	<Ri>B	<Pe/Ri>m	<Re>m	<Re*>m	PASQUILL STABILITY
FL/30	40.00	1.40	1.40	4.30	.60	1603.00	260.00	.08	.20	10700	947.94	21.09	E
FL/30	100.00	1.40	1.40	4.30	.43	1603.00	260.00	.08	.20	2700	239.81	13.05	E
FL/30	150.00	1.40	1.40	4.30	.35	1603.00	260.00	.08	.20	1500	130.54	11.31	E
FL/30	250.00	1.40	1.40	4.30	.27	1603.00	260.00	.08	.20	700	60.67	8.76	E
FL/33	40.00	1.60	2.50	2.80	.70	1870.00	340.00	.08	1.20	3100	1383.09	22.54	D/E
FL/33	100.00	1.60	2.50	2.80	.44	1870.00	340.00	.08	1.20	800	349.90	14.26	D/E
FL/33	150.00	1.60	2.50	2.80	.36	1870.00	340.00	.08	1.20	400	190.46	11.64	D/E
FL/33	250.00	1.60	2.50	2.80	.28	1870.00	340.00	.08	1.20	200	88.52	9.02	D/E
FL/36	40.00	1.60	2.00	2.40	.49	1963.00	310.00	.08	1.60	1600	998.33	15.77	F/G
FL/36	100.00	1.60	2.00	2.40	.31	1963.00	310.00	.08	1.60	400	252.56	9.98	F/G
FL/36	150.00	1.60	2.00	2.40	.25	1963.00	310.00	.08	1.60	200	137.48	8.15	F/G
FL/37	40.00	1.60	1.60	3.20	.51	1891.00	255.00	.08	.70	2900	809.05	16.29	E
FL/37	100.00	1.60	1.60	3.20	.32	1891.00	255.00	.08	.70	700	204.88	10.30	E
FL/37	150.00	1.60	1.60	3.20	.26	1891.00	255.00	.08	.70	400	111.52	8.41	E
FL/37	250.00	1.60	1.60	3.20	.20	1891.00	255.00	.08	.70	200	51.83	6.52	E
UC/38	40.00	1.60	1.60	3.80	.60	1867.00	280.00	.08	.50	4900	924.77	19.35	F
UC/38	100.00	1.60	1.60	3.80	.38	1867.00	280.00	.08	.50	1200	233.95	12.24	F
UC/38	150.00	1.60	1.60	3.80	.31	1867.00	280.00	.08	.50	700	127.35	9.99	F
UC/38	250.00	1.60	1.60	3.80	.24	1867.00	280.00	.08	.50	300	59.19	7.74	F
FL/39	40.00	1.40	1.40	5.80	.92	1808.00	350.00	.08	.10	26200	1277.35	29.53	D
FL/39	100.00	1.40	1.40	5.80	.58	1808.00	350.00	.08	.10	6600	323.15	18.68	D
FL/39	150.00	1.40	1.40	5.80	.47	1808.00	350.00	.08	.10	3600	175.90	15.25	D
FL/39	250.00	1.40	1.40	5.80	.37	1808.00	350.00	.08	.10	1700	81.75	11.81	D
FL/40	40.00	1.20	1.20	3.10	.49	1860.00	310.00	.18	.20	3400	878.07	15.78	D
FL/40	100.00	1.20	1.20	3.10	.31	1860.00	310.00	.18	.20	900	222.34	9.98	D
FL/40	150.00	1.20	1.20	3.10	.25	1860.00	310.00	.18	.20	500	121.03	8.15	D
FL/40	250.00	1.20	1.20	3.10	.20	1860.00	310.00	.18	.20	200	56.25	6.31	D
FL/42	40.00	1.60	1.60	3.40	.54	1973.00	185.00	.08	.50	3500	711.03	17.31	D
FL/42	100.00	1.60	1.60	3.40	.34	1973.00	185.00	.08	.50	900	179.88	10.95	D
FL/42	150.00	1.60	1.60	3.40	.28	1973.00	185.00	.08	.50	500	97.91	8.94	D
FL/42	250.00	1.60	1.60	3.40	.22	1973.00	185.00	.08	.50	200	45.51	6.92	D
FL/43	40.00	1.30	2.00	1.50	.43	1899.00	265.00	.08	2.50	1100	1031.98	13.94	F
FL/43	100.00	1.30	2.00	1.50	.27	1899.00	265.00	.08	2.50	300	261.07	8.82	F
FL/43	150.00	1.30	2.00	1.50	.22	1899.00	265.00	.08	2.50	200	142.11	7.20	F
UC/45	40.00	2.00	2.00	2.30	.36	1972.00	260.00	.08	2.60	700	693.29	11.71	E/F
UC/45	100.00	2.00	2.00	2.30	.23	1972.00	260.00	.08	2.60	200	175.39	7.41	E/F
UC/46	40.00	2.00	2.00	3.30	.52	1490.00	260.00	.08	1.00	1900	830.43	16.00	D
UC/46	100.00	2.00	2.00	3.30	.33	1490.00	260.00	.08	1.00	500	210.09	10.63	D
UC/46	150.00	2.00	2.00	3.30	.27	1490.00	260.00	.08	1.00	300	114.56	8.68	D
UC/46	250.00	2.00	2.00	3.30	.21	1490.00	260.00	.08	1.00	100	53.15	6.72	D
UC/47	40.00	2.00	2.00	1.50	.24	1936.00	250.00	.08	7.90	200	549.01	7.64	F
FT/49	40.00	1.60	2.50	2.50	.63	1907.00	260.00	.08	1.30	2200	1142.85	20.13	F
FT/49	100.00	1.60	2.50	2.50	.40	1907.00	260.00	.08	1.30	600	289.12	12.73	F
FT/49	150.00	1.60	2.50	2.50	.32	1907.00	260.00	.08	1.30	300	157.38	10.39	F
FT/49	250.00	1.60	2.50	2.50	.25	1907.00	260.00	.08	1.30	100	73.14	8.05	F
FT/50	40.00	1.40	2.00	1.74	.44	1800.00	270.00	.08	2.10	1100	971.60	14.01	F
FT/50	100.00	1.40	2.00	1.74	.28	1800.00	270.00	.08	2.10	300	245.80	8.86	F
FT/50	150.00	1.40	2.00	1.74	.22	1800.00	270.00	.08	2.10	200	133.80	7.23	F

Table 3: Pattern Comparison Plot Results

Trial Configuration/No.	:	Scale Ratio	(Density Ratio)F	(Density Ratio)M	Points Compared	Intercept of Theta f-1	f-2	f-5
UI/08	:	100	1.7	1.7	6	10	7.5	
UI/08	:	150	1.7	1.7	7	27.5	7.5	
UI/12	:	100	2.3	2.3	9	25	15	
UI/12	:	150	2.3	2.3	8	15	12.5	
UI/17	:	40	4.2	4.2	7	50	30	
UI/17	:	100	4.2	4.2	8	32.5	15	
UI/17	:	150	4.2	4.2	8	27.5	7.5	
UI/19	:	100	2.1	2.1	10	20	7.5	
UI/19	:	150	2.1	2.1	10	20	10	
5W-50/20	:	100	1.9	1.9	6	15	5	
5W-50/20	:	150	1.9	1.9	5	10	5	
5W-50/21	:	100	2	2	5	20		
5W-50/21	:	150	2	2	12	22.5	12.5	
5W-50/22	:	150	4.2	4.2	6	25	17.5	
9B-50/28	:	100	2	2	7	15	7.5	
9B-50/28	:	150	2	2	6	15	10	
9B-27/29	:	100	2	2	9	20	12.5	
9B-27/29	:	150	2	2	8	27.5	12.5	
FL/30	:	40	1.4	1.4	6	22.5	12.5	
FL/30	:	100	1.4	1.4	6	40		
FL/30	:	150	1.4	1.4	4	12.5	5	
FL/30	:	250	1.4	1.4	4	17.5		
FL/33	:	40	1.6	2.5	6	25		
FL/33	:	100	1.6	2.5	6	17.5	12.5	
FL/33	:	150	1.6	2.5	6	15	10	
FL/33	:	250	1.6	2.5	6	25	12.5	
UI/34	:	40	1.8	1.8	8	22.5		
FL/36	:	40	1.6	2	9	30	7.5	
FL/36	:	100	1.6	2	11	15	7.5	
FL/36	:	150	1.6	2	10	30		
FL/37	:	40	1.6	1.6	4	7.5	7.5	
FL/37	:	100	1.6	1.6	4	22.5	0	
FL/37	:	150	1.6	1.6	4	17.5	2.5	
FL/37	:	250	1.6	1.6	4	15	0	
UC/38	:	40	1.6	1.6	7	20	7.5	
UC/38	:	100	1.6	1.6	8	25	10	
UC/38	:	150	1.6	1.6	11	30	22.5	
UC/38	:	250	1.6	1.6	10	27.5	15	
FL/39	:	40	1.4	1.4	6	22.5	7.5	
FL/39	:	100	1.4	1.4	6	20	10	
FL/39	:	150	1.4	1.4	6	22.5	10	
FL/39	:	250	1.4	1.4	6	17.5	5	
FL/40	:	40	1.2	1.2	5	7.5	7.5	
FL/40	:	100	1.2	1.2	7	15	0	
FL/40	:	150	1.2	1.2	7	7.5	2.5	
FL/40	:	250	1.2	1.2	6	10	10	
FL/42	:	[illegible]	1.6	1.6	5	5	0	
FL/42	:	100	1.6	1.6	5	7.5	0	
FL/42	:	150	1.6	1.6	5	15	15	
FL/42	:	250	1.6	1.6	5	12.5	7.5	
FL/43	:	40	1.3	2	8		5	5
FL/43	:	100	1.3	2	12		20	7.5
FL/43	:	150	1.3	2	12		20	10
UC/45	:	40	2	2	7	15	12.5	
UC/45	:	100	2	2	14	22.5	15	10
UC/46	:	40	2	2	5	22.5	5	
UC/46	:	100	2	2	6	10	10	
UC/46	:	150	2	2	6	17.5	10	
UC/46	:	250	2	2	6	27.5	10	
UC/47	:	40	2	2	15		15	2.5
FT/49	:	40	1.6	2.5	14	20	2.5	2.5
FT/49	:	100	1.6	2.5	14	27.5	10	
FT/49	:	150	1.6	2.5	14	25	10	
FT/49	:	250	1.6	2.5	15	27.5	10	
FT/50	:	40	1.4	2	32.5	30	15	
FT/50	:	100	1.4	2	17	32.5	20	
FT/50	:	150	1.4	2	18	35	10	

UI = Unobstructed instantaneous release
5W-50 = 5m wall at 50m
9B-50 = 9m square bldg, 50m at 45 degree down range
9B-27 = 9m square bldg, 27m at 30 degree up range
FL = Fence longitudinal
UC = Unobstructed continuous release
FT = Fence traverse

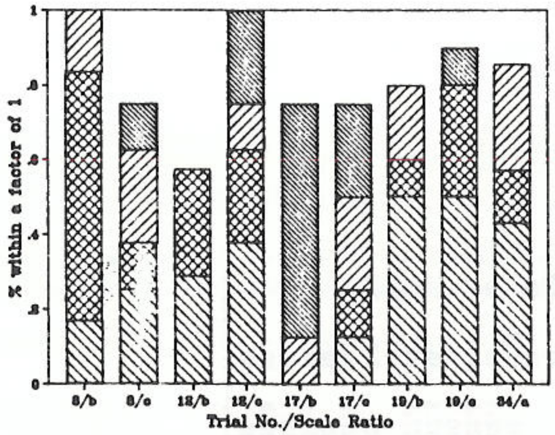

Figure 5.

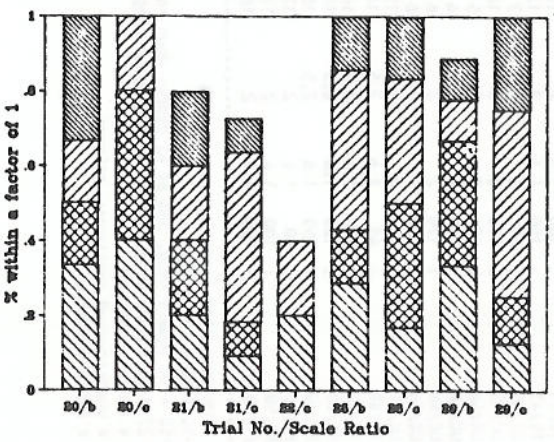

Figure 6.

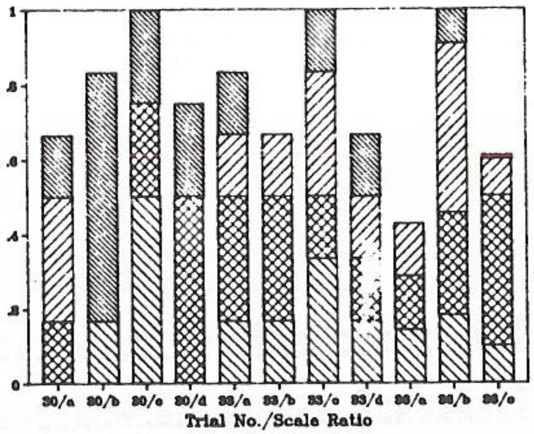

Figure 7.

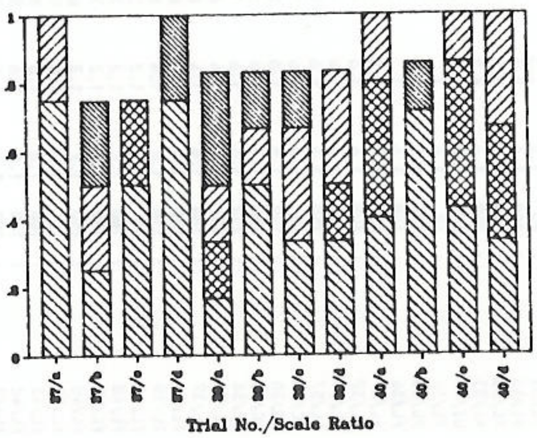

Figure 8.

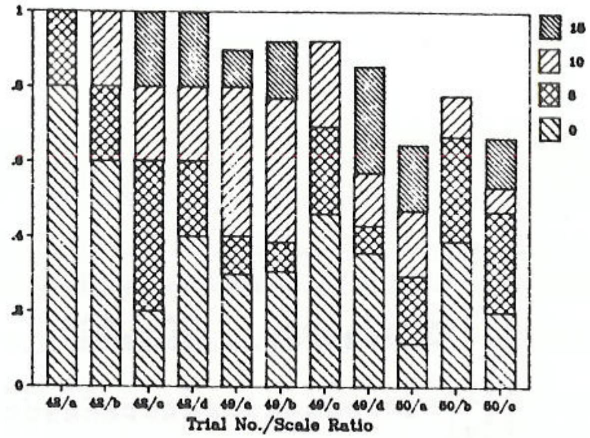

Figure 9.

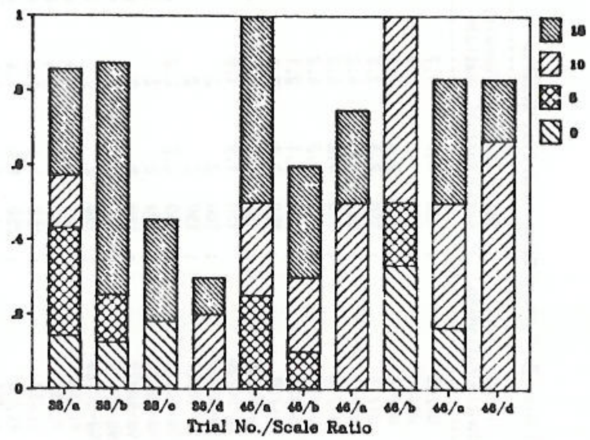

Figure 10.