A Proposed Physical Model for the Buncefield Gas Cloud Formation

or

Determination of the Reynolds Number Independent Concentration Field in a Continuous, Steady-feed, Planar, 2D Gas Gravity Current Flowing into Still Air

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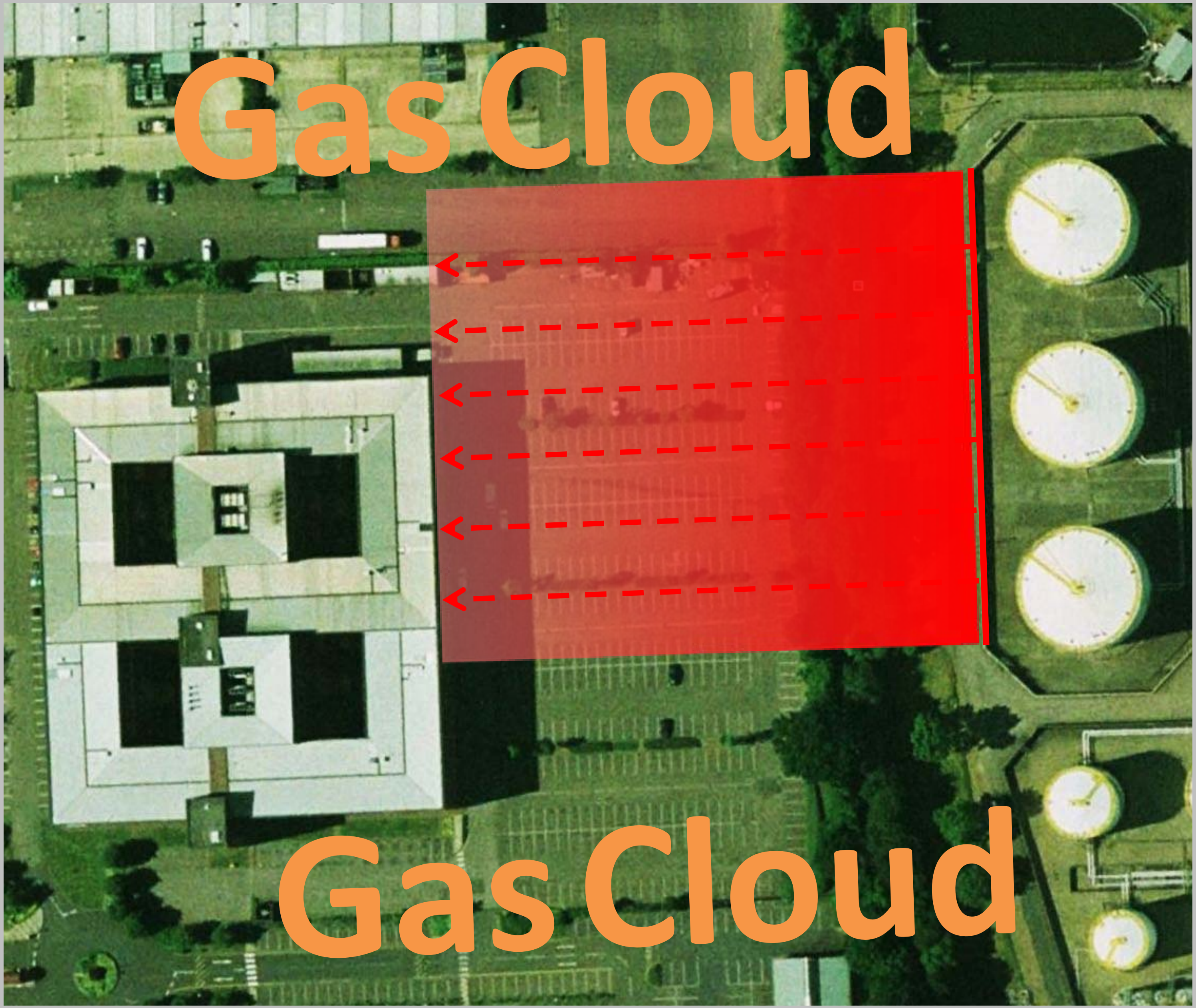
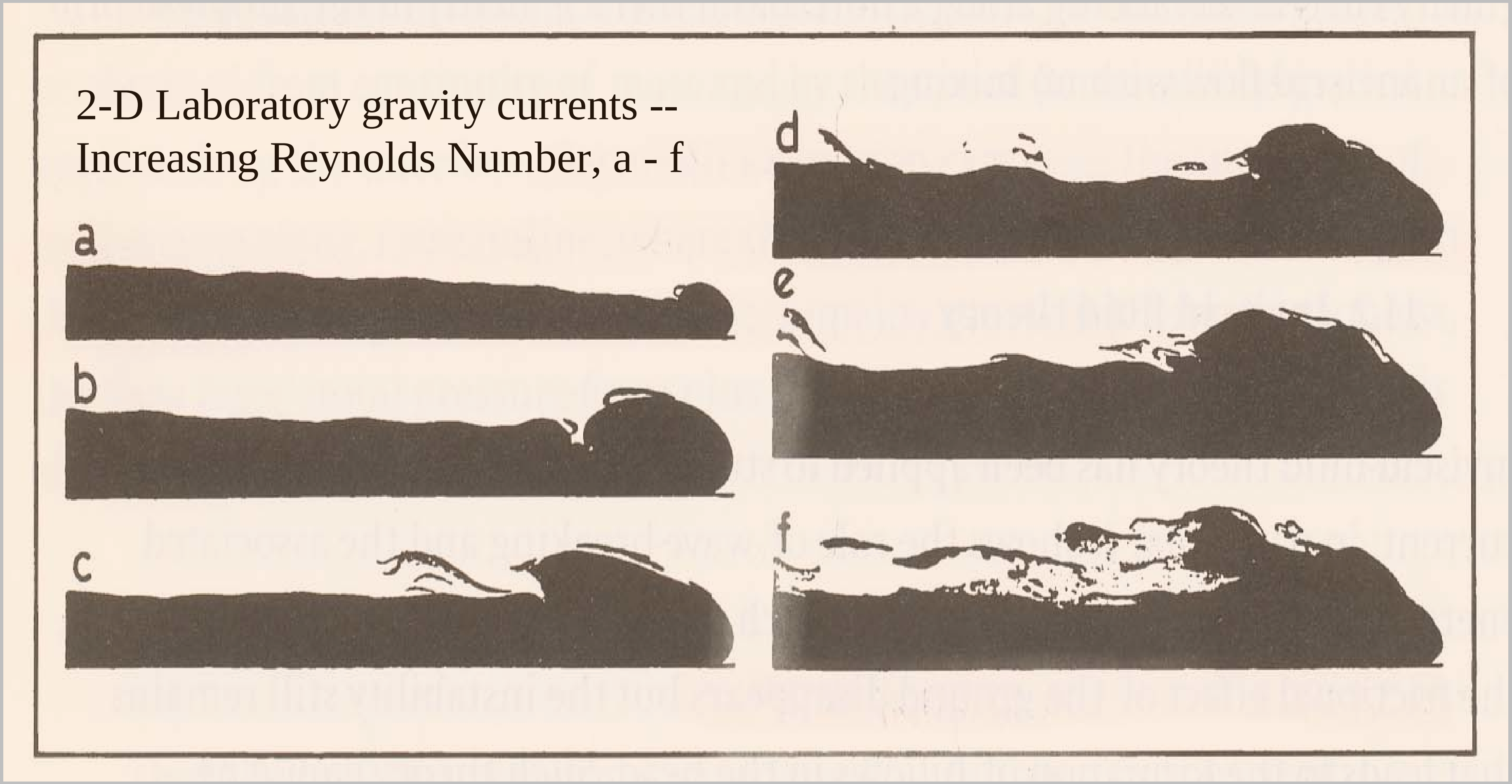
UKELG Workshop
Buxton 3-3-12

Approximate 2D Flow Area – Concentration Decreasing Right to Left



- We are studying a steady-feed 2-D Gas Gravity Current with zero wind - flow driven laterally by a density difference – to quantify air entrainment and characterize the resulting gas concentration field
- Our purpose is to model Buncefield cloud development in zero wind as a 2-D gas gravity current driven by a gas/air density difference



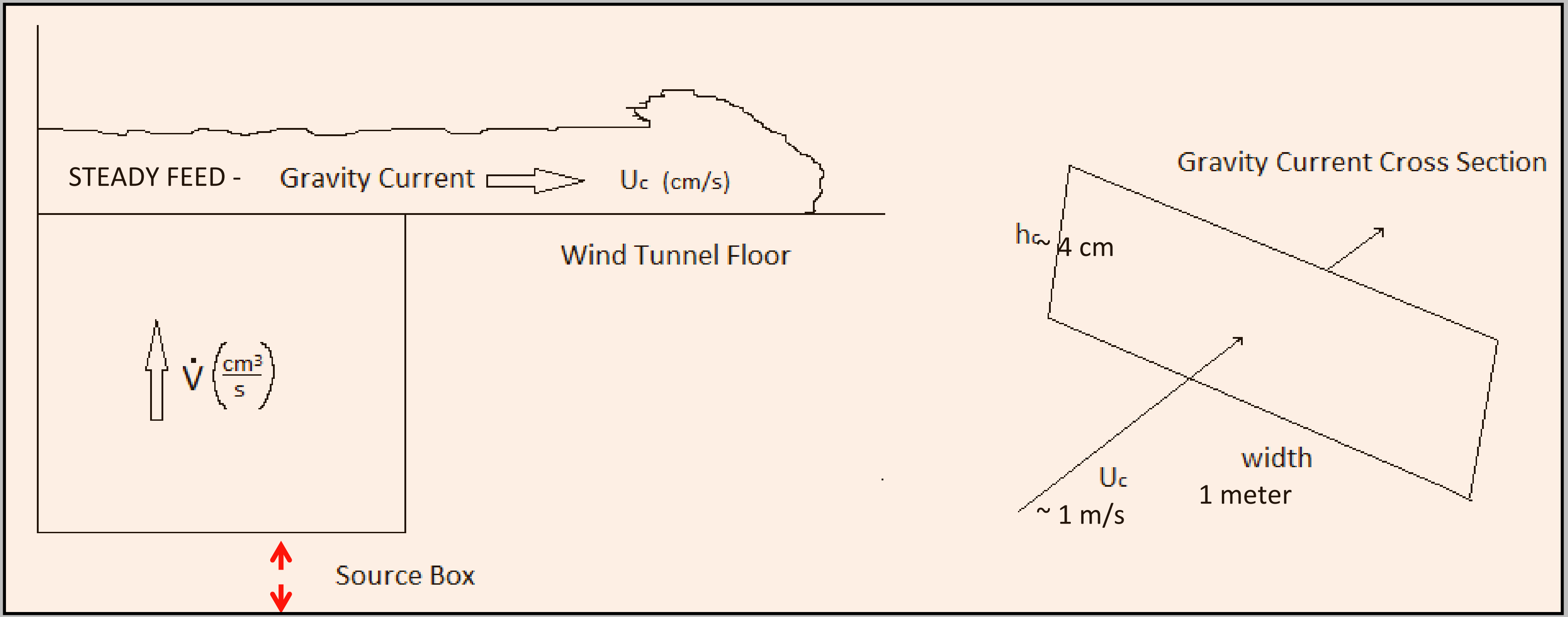
Main Purpose

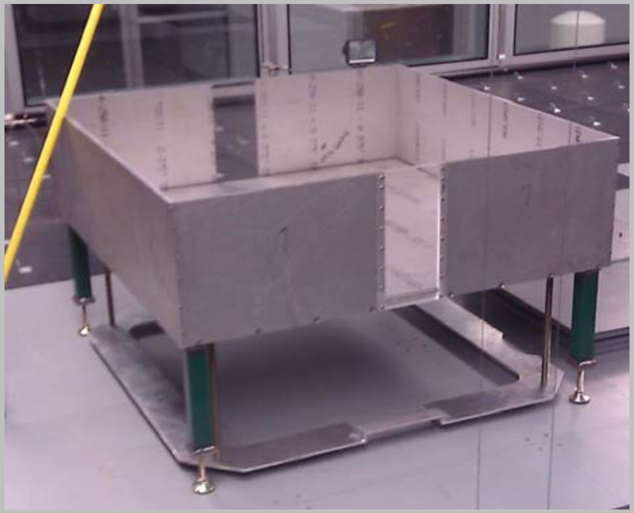
- Determine the magnitude and uniqueness (constancy) of the Froude number for a steady-feed 2D gas gravity current – Reported N_{Fr} range ~ 1.0 to $2^{1/2}$
- Determine the Reynolds number required for N_{Re} independence and verify independence with concentration measurements
- Characterize the resulting (unique) non-dimensional concentration distribution of a continuous, steady 2D (planar) dense gas – a steady-feed 2D CO_2 gravity current (density ~1.5 times air density) into still air

Literature

- N_{Re} independence
  - Schmidt : 1911
  - Keulegan: 1957, 1958
  - Simpson and Britter: 1979
  - Marino, Thomas, and Linden: 2005
- N_{Fr} value (and constancy)
  - von Karman: 1940
  - Benjamin: 1968
  - Huppert and Simpson: 1980
  - Marino, Thomas, and Linden: 2005

Experimental Design

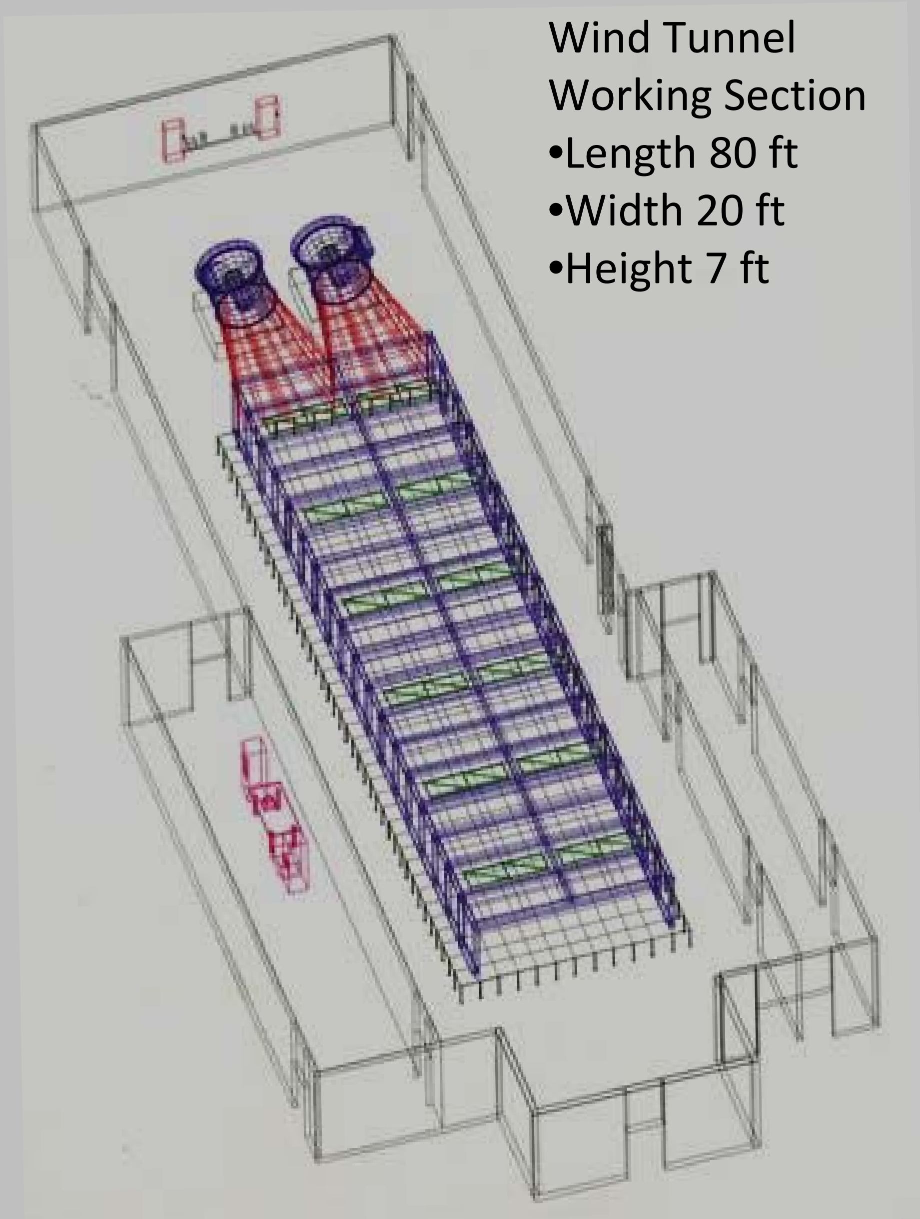




- Reynolds Number $\frac{U_c h_c}{\nu}$
- Froude Number $\frac{U_c^2}{g' h_c}$

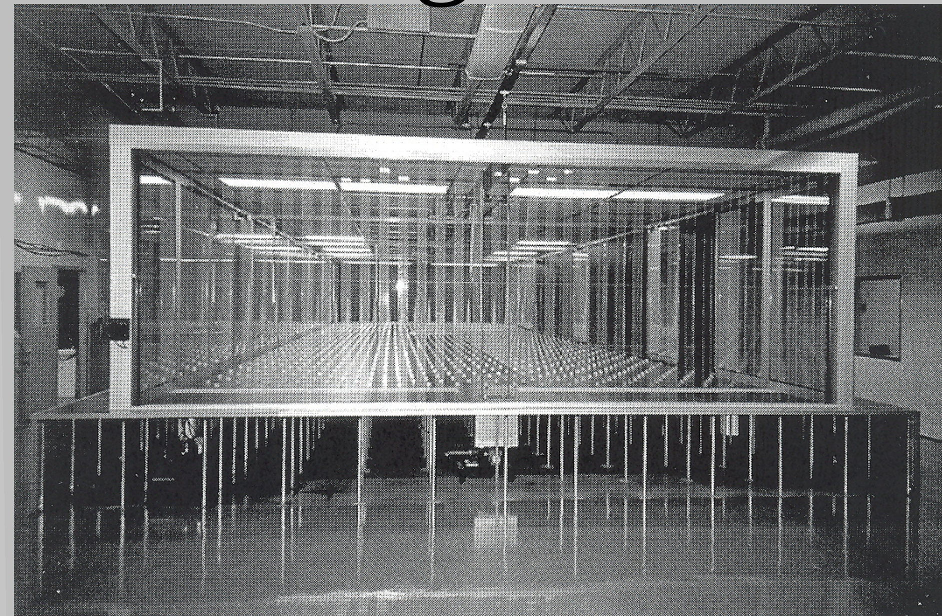
ν = kinematic viscosity, m^2/s
$g' = g((\rho - \rho_{air})/\rho_{air})$, m/s^2

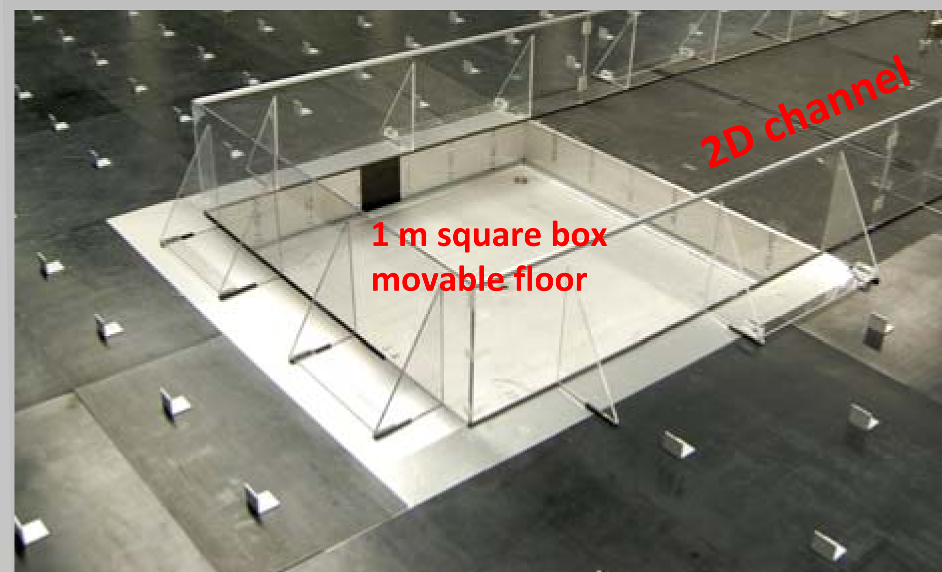
Experimental Design



Wind Tunnel
Working Section

- Length 80 ft
- Width 20 ft
- Height 7 ft





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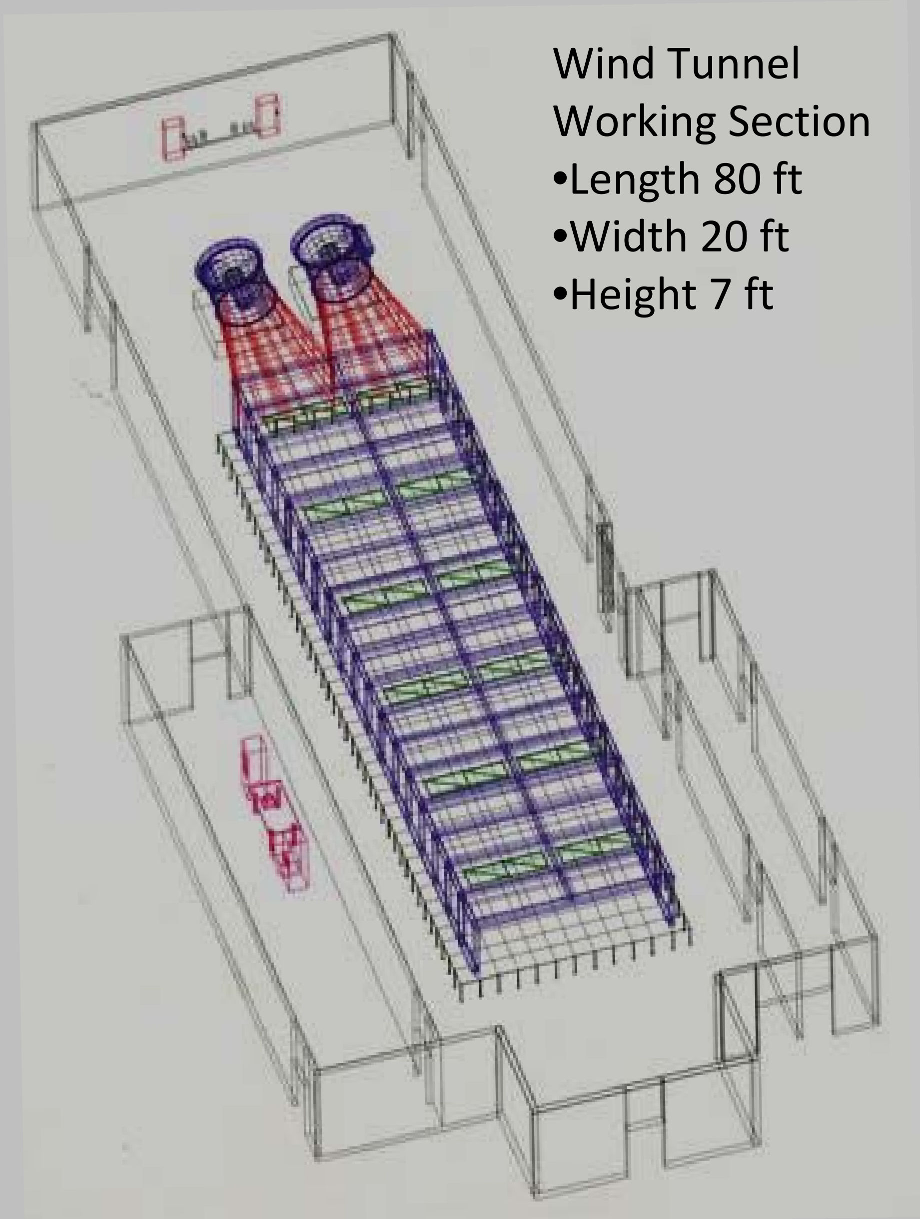

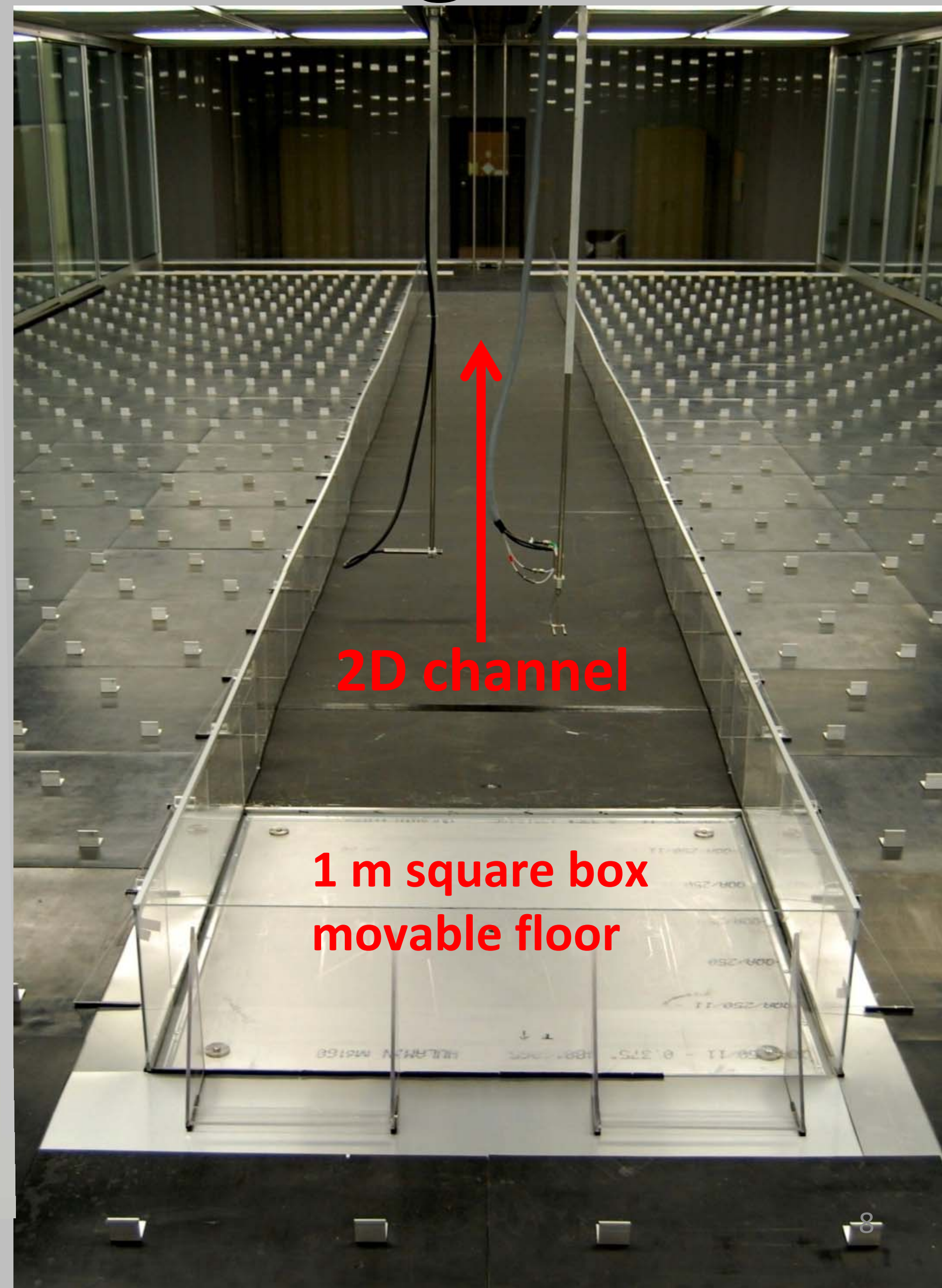

Video Recording

- Synchronized digital video capture of about 2 feet-wide side-on views of flow (visualized with smoke) at 5 stations,1 meter apart, starting from release edge
- Use timed video to measure gravity current height and velocity as function of down-current position and time
- Test Fr = 1 (and constancy) assumption
- Use video to determine rough measurements of entrainment from cloud height measurements as function of distance traveled – these measurements used to estimate approach to N_{Re} independence

Effect of Reynolds Number

Desired Reynolds Number	Flow Rate (liters/min)	Avg. Velocity of Cloud at Source Edge (cm/s)	Height of Cloud at Source Edge (cm)	Duration of Experiment (s)	Distance Traveled by Gravity Current (m)
500	237.6	27.3	1.45	82.1	22.4
1000	475.2	34.4	2.30	41.0	14.1
1500	712.8	39.4	3.01	27.4	10.8
2000	950.5	43.4	3.65	20.5	8.9
2500	1188.1	46.7	4.24	16.4	7.7
3000	1425.7	49.7	4.78	13.7	6.8
4000	1900.9	54.7	5.80	10.3	5.6
5000	2376.2	58.9	6.73	8.2	4.8

Determine N_{Re} Independence

- Measure CO_2 concentration w/FID (propane seeded, no flow visualization)
- Start with largest release rate - N_{Re} (3000) – 1426 liters/min
  - Measure concentration at specific heights and down-channel locations
- Change to lower release rate - N_{Re} (2500) – 1188 liters/min
  - Measure concentration at identical dimensionless times and locations, <u>emphasis on "steady" part of the flow</u>
- If flows are N_{Re} independent, the concentrations at identical scaled values will approach equality

Conclusions/Goals

- If N_{Re} independence can be demonstrated, it should be possible to determine a dimensionless concentration field for such a flow
- Such a correlation would be useful for:
  - consideration of passive or active mitigation systems to prevent or mitigate fire and explosion damage, and
  - calculation of the developing concentration field in a flammable dense gas release in calm (no-wind) incidents as input to quantitative risk assessments