Plume Rise and Touchdown during Jack Rabbit Trial 8

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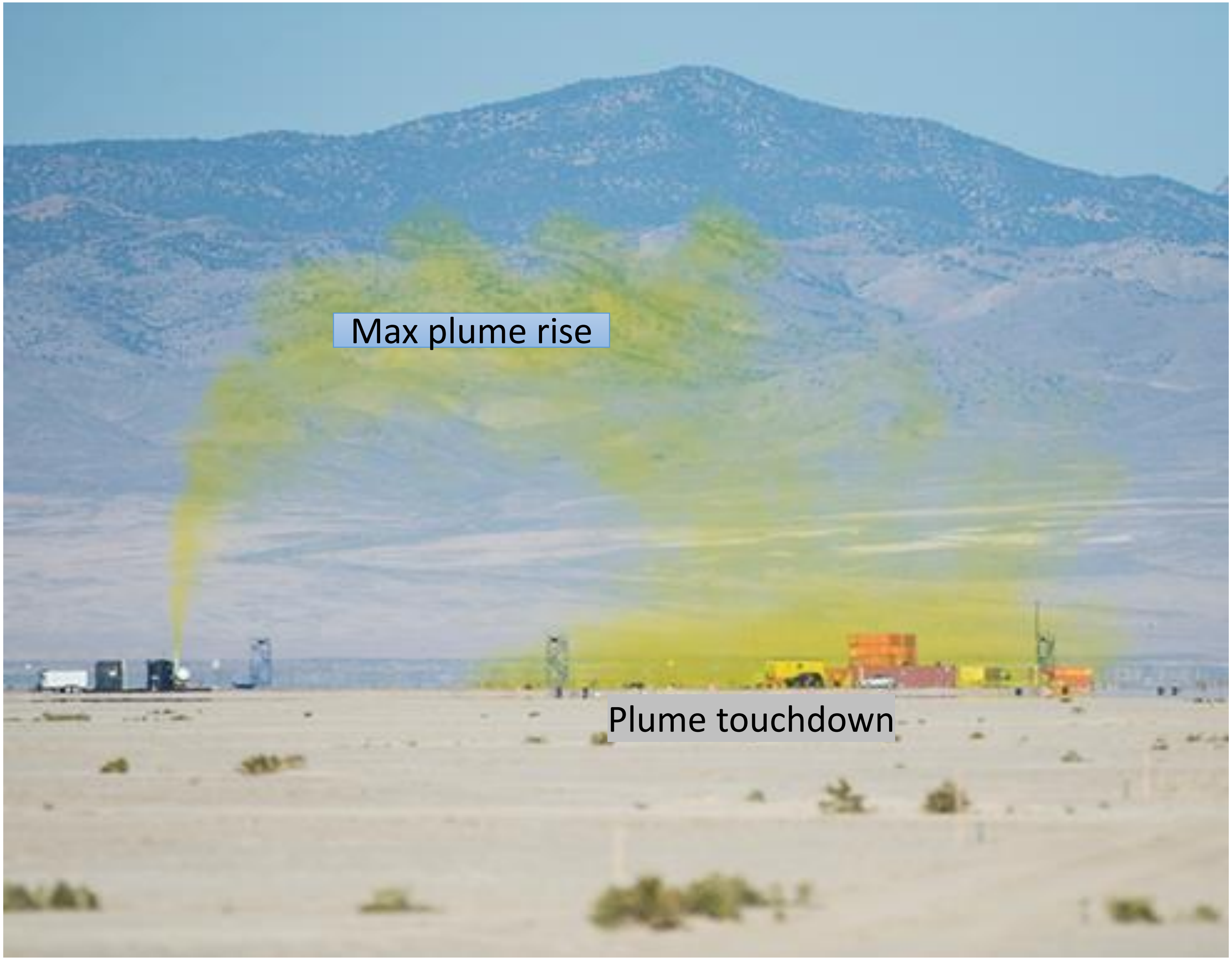
Presented at 25th Annual GMU Conference on Atmospheric Turbulence and Dispersion

Fairfax, VA, November 2-4, 2021

Trial 8 dense plume about 30 s after release. Distance from the source to the low red CONEX obstacle is about 85 m



Jack Rabbit II 2016

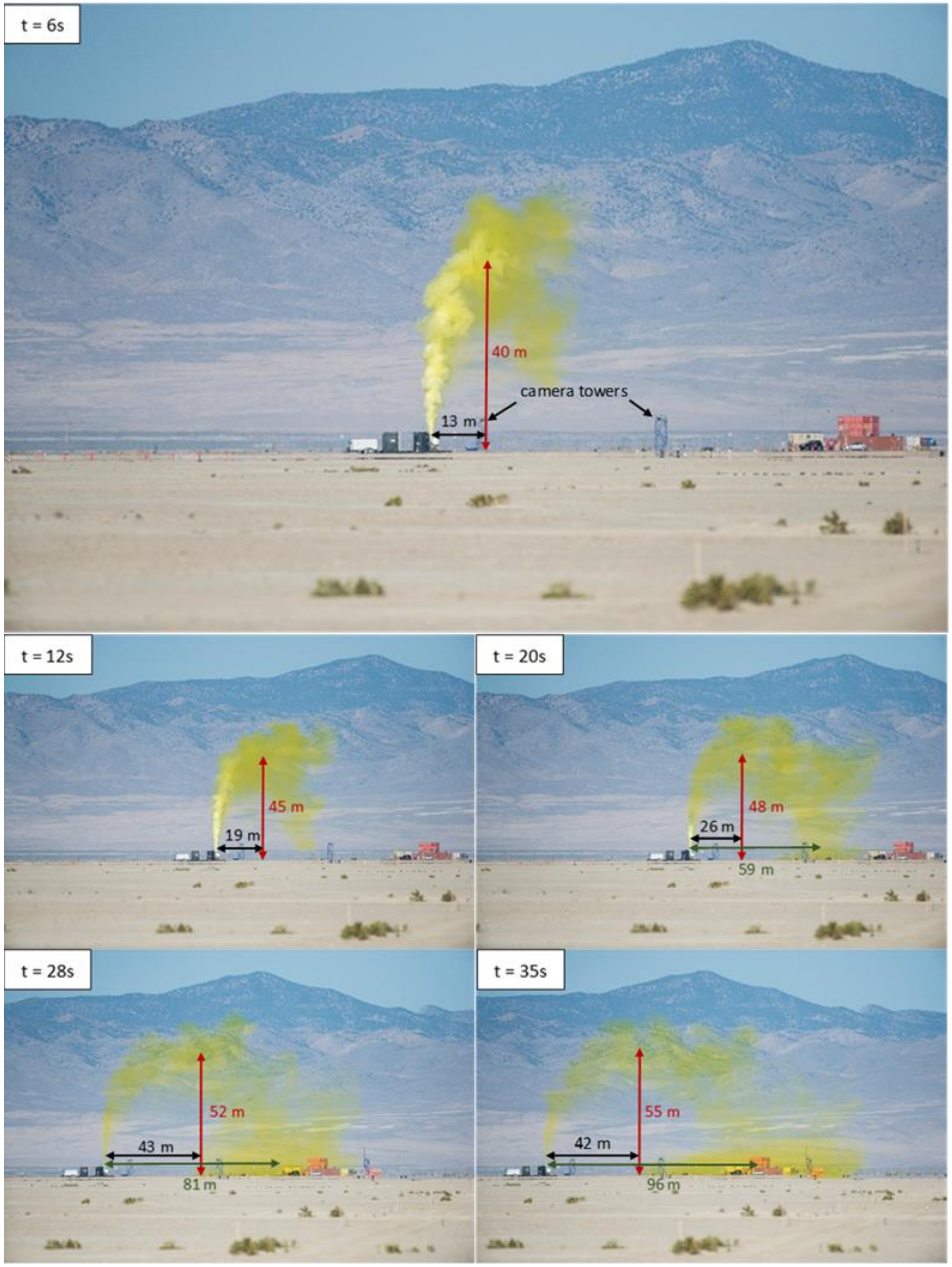
- Sponsored by DHS and DTRA
- 4 trials at DPG, releasing 10 to 20 tons (same set-up as 2015 but with mock urban array removed). Trials 6 and 9 releases were downwards, trial 7 was 45° downwards, trial 8 was vertically up.
- Trial 8 is the only JR(I or II) trial with an upward dense jet release.
- It is also the only vertical dense jet field experiment with releases from a ten ton tank carried out anywhere.
- Can test some models for dense jet: (Briggs, Hoot-Meroney Peterka (HMP) and DRIFT).

10 ton Tank used for JR II Chlorine Releases: Orange arrow depicts location of hole on top of tank (used for Trial 8)

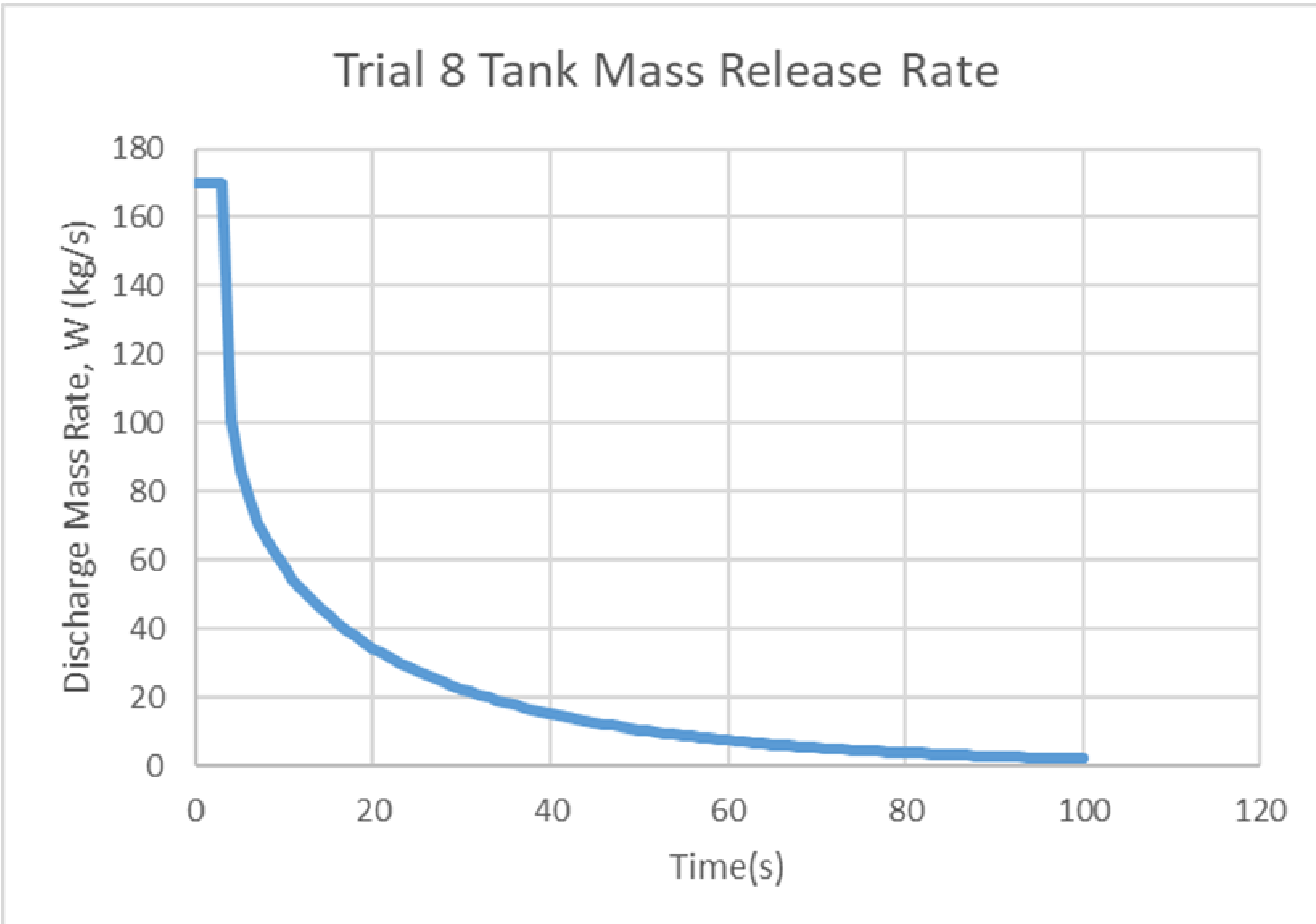
Trial 8 input conditions

- Day and time: 9/11/2016 9:01:45 local time
- Total jet mass released: 2368 kg
- Release duration: 30 s
- Average release rate for 30 s duration: 78.9 kg/s
- Wind speed at 2 m: 2.2 m/s
- Wind direction at 2 m: 175 degrees
- Average ambient T: 14.8 C
- Stability: Shallow (8 m) well-mixed layer, with inversion above (PG class C at z < 8 m and E at z>8 m). The Trial 8 jet is within the inversion layer for most of its trajectory.

Time sequence (from 6 to 35 s) of Trial 8 plume photos



Mass emission rate decreased with time. For input to models, we assumed 11 time periods (from 0 to 100 s) with constant emissions during each period.



Alternate methods for estimating plume conditions after depressurization (expansion)

Expansion Model 1. Velocity increases above the exit value due to acceleration by excess pressure at the exit. This is also referred to as a momentum conservation model (e.g., Britter et al., 2011)

Expansion Model 2. Velocity unchanged from exit velocity (e.g., Ewan and Moodie, 1986)

Next 5 Slides – Brief descriptions of the three models that were tested

1. HMP (analytical equations)
2. Briggs (analytical equations)
3. DRIFT (State-of-the art commercial software)

Hoot, Meroney, and Peterka (1973) Plume Rise

HMP analyzed dense plume observations from many experiments in their wind tunnel. Came up with simple analytical formulas based on fundamental science

Plume rise Δh above source:

$$\Delta h/2R_o = 1.32\,(w_o/u)^{1/3}(\rho_o/\rho_a)^{1/3}[w_o^2/(2R_o g')]^{1/3}$$

where $g' = g(\rho_o-\rho_a)/\rho_o$; g is acceleration of gravity, ρ_a is ambient air density, u is wind speed, and ρ_o, R_o, and w_o are initial plume density, radius and vertical velocity after depressurization.

Hoot, Meroney, and Peterka (1973) Touchdown distance

Plume touchdown distance x_g downwind:

$$x_g/2R_o = w_o u/(2R_o g') + 0.56\{(\Delta h/2R_o)^3 * ((2 + h_s/\Delta h)^3 - 1)u^3/(2R_o w_o g_a')\}^{1/2}$$

where $g_a' = g(\rho_o - \rho_a)/\rho_a$ and h_s is elevation of the stack or vent opening above the ground.

Assumes steady state conditions.

Briggs 1969 model

For the trajectory of a buoyant (or negatively buoyant) plume as a function of distance, x, downwind of the release point:

$$\Delta h = [(19(\rho_o/\rho_a)(M_o/u^2)x - 4.2\ (B_c/u^3)x^2]^{1/3}$$

where $M_o = w_o^2 R_o^2$ is proportional to the initial momentum flux and $B_c = g[(\rho_o - \rho_a)/\rho_a] w_o R_o^2$ is proportional to the initial buoyancy flux (here assumed positive for a dense cloud). Steady state conditions are assumed.

The maximum rise occurs at the distance where $d(\Delta h)/dx = 0$. This equation is most often used for positively buoyant plumes, but is also valid for negatively buoyant clouds.

The plume touchdown distance can be calculated as the distance where $\Delta h = 0$ (i.e., the first term in the equation equals the second term). That is, $x_g = 4.52(\rho_o/\rho_a)uM_o/B_o = 4.52\ w_o u/[g(\rho_o - \rho_a)/\rho_a]$. Briggs does not include a formula for maximum ground level concentration, C_{max}.

How is decrease of source emission rate Q with time handled in steady-state HMP and Briggs models?

- 11 piecewise constant Q's are determined, fitting the Q(t) curve in slide 7
- The model solution is calculated for each of the 11 Q's, assuming steady state conditions

DRIFT model

- This is a commercially-available integral dispersion model that is used by HSE for its regulatory work in the UK (Tickle and Carlisle, 2008).
- A momentum-jet model is used to simulate pressurized releases, which includes both single and two-phase jet models, where the latter assumes homogeneous equilibrium between the gas phase and the dispersed liquid droplet phase.
- The thermodynamic models in DRIFT are able to account for multi-component mixtures and humidity effects (condensation and evaporation of water droplets, and associated latent heat transfer), including their effect on cloud buoyancy (Tickle, 2001).
- Releases can be modelled at different angles to the vertical (including the vertically-upwards case in Trial 8) and also for different lateral cross-wind directions.

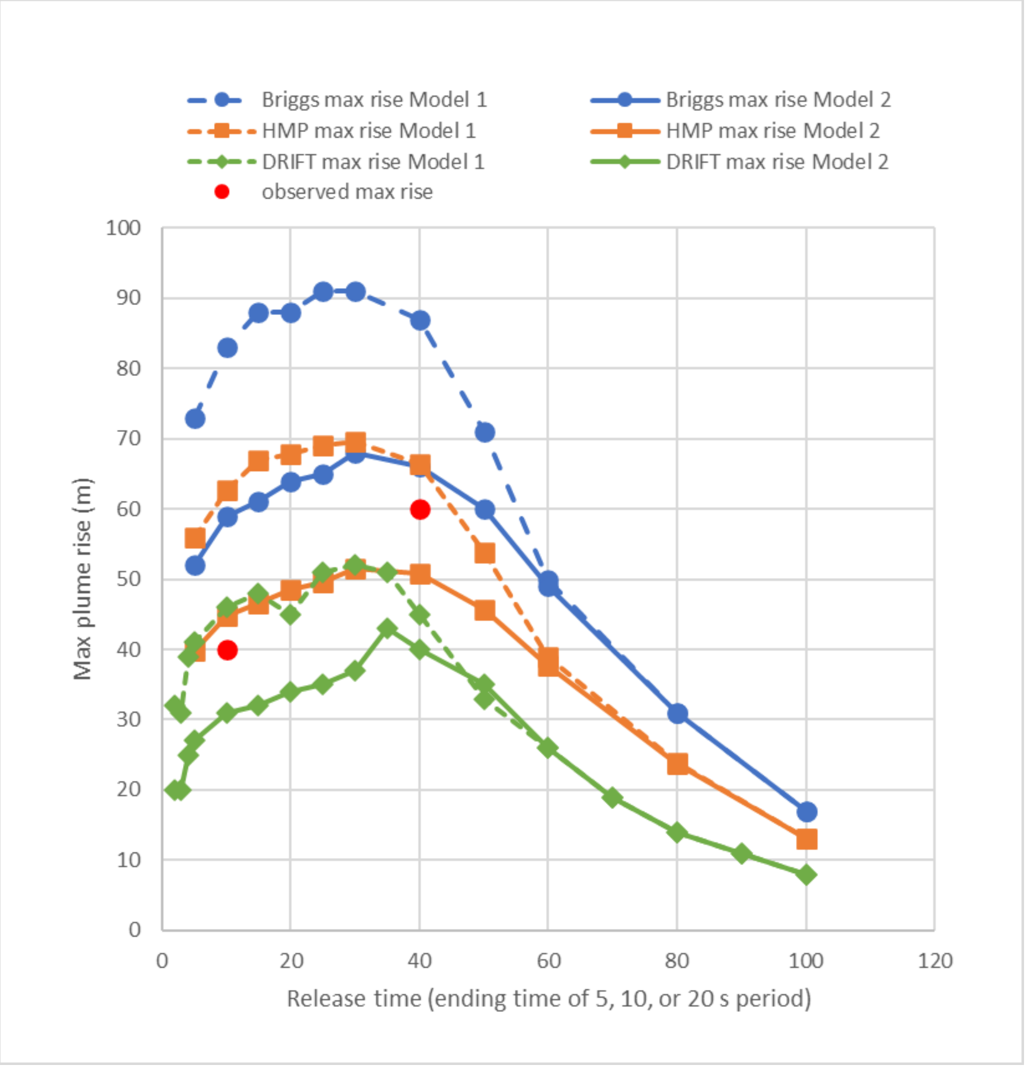
Results of comparisons of the three models are given below

- Maximum plume rise
- Touchdown distance
- Ground level concentration at touchdown

- Calculations are made for 11 piecewise emission periods that match the decrease of Q with time in slide 7

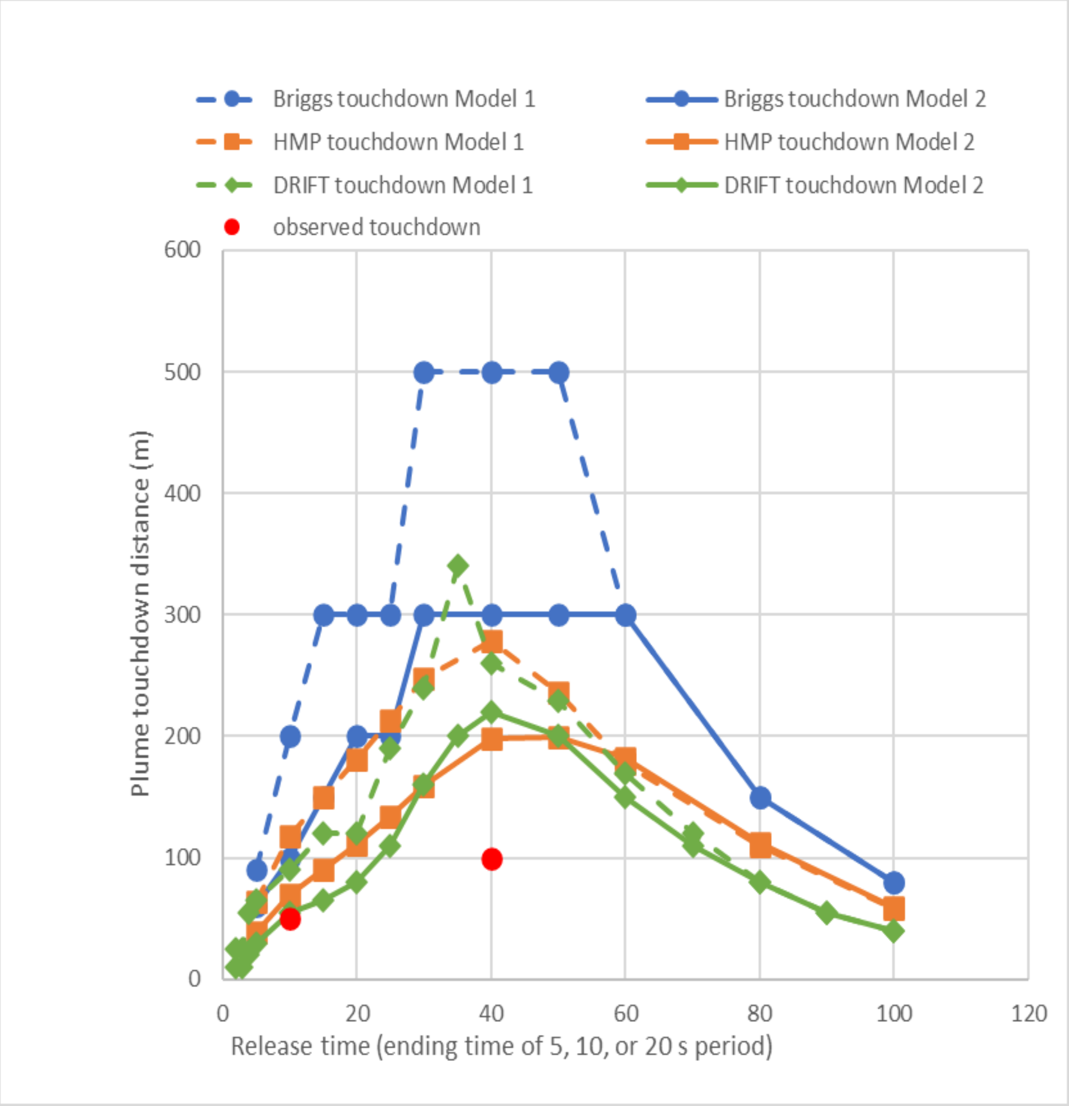
Observed and modeled maximum vertical plume rise, calculated using emissions rates for 11 time segments after release was initiated.

The two red dots are observations



Observed and modeled distance to plume touchdown, calculated using emissions rates for 11 time segments after release was initiated.

The two red dots are observations



Comparison of observed and modeled maximum concentration. Model predictions are at touchdown distance

	Observed at 85 m	HMP Model 1	HMP Model 2	DRIFT Model 1	DRIFT Model 2
Maximum C (ppm)	12080	9570	17660	6600	14000

Conclusions

- The predictions of three dense jet models (HMP, Briggs, and DRIFT) were compared to the observed initial plume rise, touchdown distance, and maximum ground level concentrations during Trial 8 of JR II.
- Predictions of the three models were shown to usually agree with the observed heights and distances within about a factor of two.
- The Briggs model predictions of the distance to maximum plume rise and touchdown were about a factor of two to five too large.
- Additionally, the HMP and DRIFT models predicted chlorine concentrations near the plume touchdown position within a factor of two of the observations.

Acknowledgements

Steven Hanna and Thomas Mazzola's research has been sponsored primarily by the U.S. Defense Threat Reduction Agency (DTRA). Graham Tickle and Simon Gant's contributions were funded by the U.K. Health and Safety Executive (HSE). The contents of is presentation, including any opinions and/or conclusions expressed or recommendations made, are those of the authors alone and do not necessarily reflect DTRA or HSE policy.