Validation of Phoenics 3.5 for Modelling Tunnel Ventilation Systems Under Fire Conditions

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Introduction

- Fires within tunnels have the potential for catastrophic consequences
- Need to ensure safe evacuation of occupants
- Need tunnel emergency ventilation systems to maintain tenable conditions
- Ventilation systems may be designed to a code or on a performance basis

Purpose

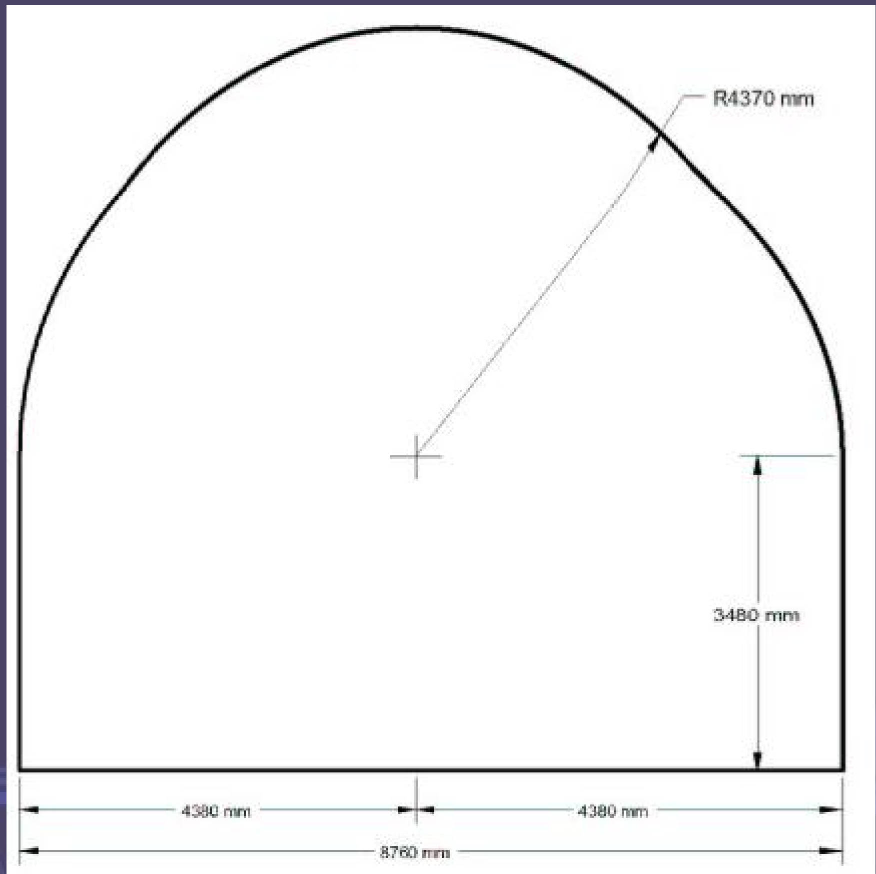
- Increasing demand for performance-based design of ventilation systems
- CFD codes used to assess performance of systems
- Accuracy of codes critical in success of design
- Validation necessary for comparison between numerical prediction and reality
- Reliable and well documented reference data needed
- Previous study on longitudinal ventilation system (forced flow)
- Assess natural ventilation system for further validation

Memorial Tunnel Fire Ventilation Test Program

- Consisted of a comprehensive series of full-scale fire tests
- Natural, longitudinal, transverse ventilation examined
- Fire sizes of 10, 20, 50 and 100 MW
- Conducted in an abandoned road tunnel near Charleston, West Virginia
- Tunnel equipped with instrumentation and recording equipment at various sections
- Comprehensive data available on CD

Description of Memorial Tunnel

- 3.2 percent upgrade from south tunnel portal to the north tunnel portal
- Tunnel length of 854m
- Cross-sectional area of $60m^2$
- Fan rooms located at tunnel portals which reduce the height to 4m



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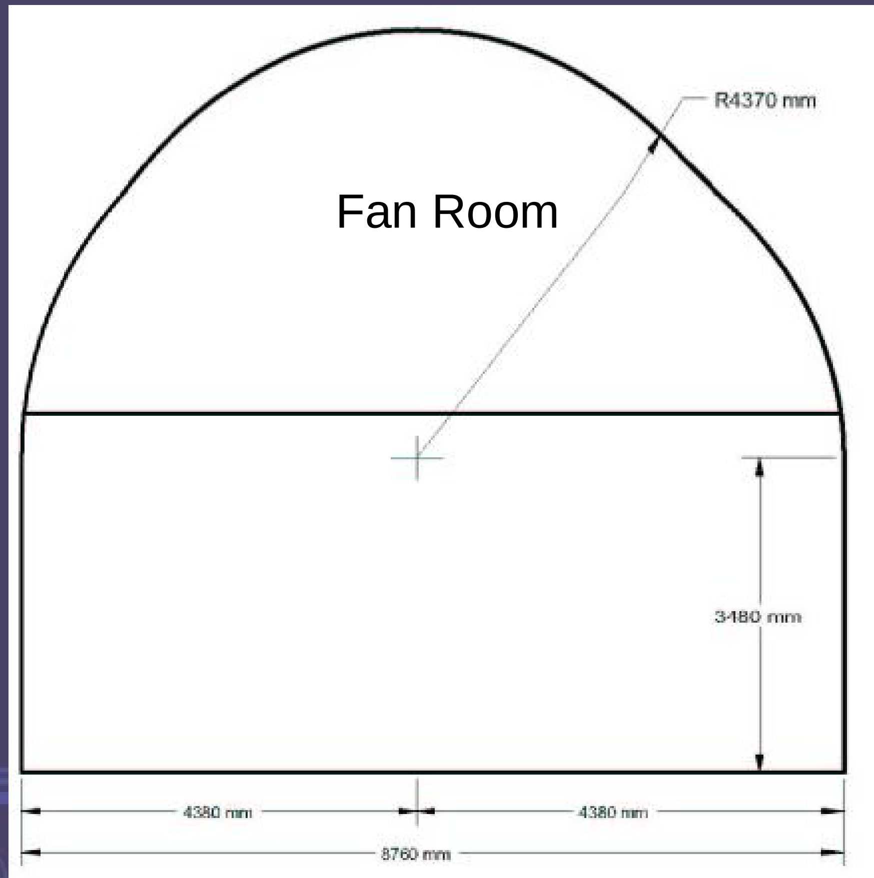
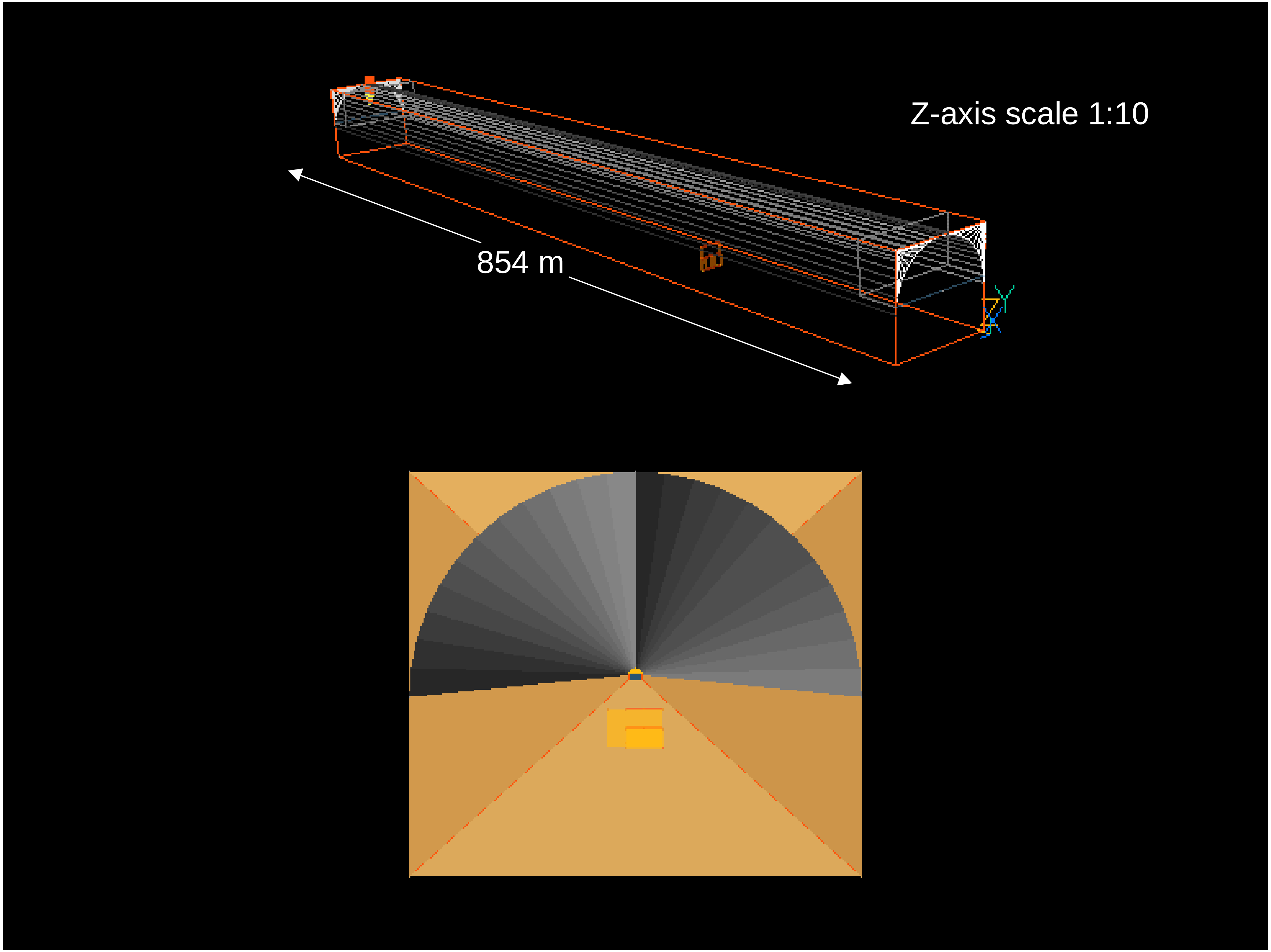



Z-axis scale 1:10
854 m

Scenario Modelled

- Test 501: examined natural ventilation with a 20MW fire
- Objective: To measure the buoyancy driven airflows, air temperature and stratified smoke layers when no forced flow is provided
- Ambient temperature of 7^{o}C
- Initial draught was observed from North to South

Phoenics Model

- *Phoenics Version 3.5* utilising special purpose version *Flair*
- *Geometry built using VR Editor*
- *Cartesian coordinate system and mesh*
- *40 time steps over 10 minute simulation period (15 seconds per time step)*
- *Gravitational acceleration:*

  $x = 0, \qquad y = -9.8\ m/s^2, \qquad z = -0.31\ m/s^2$

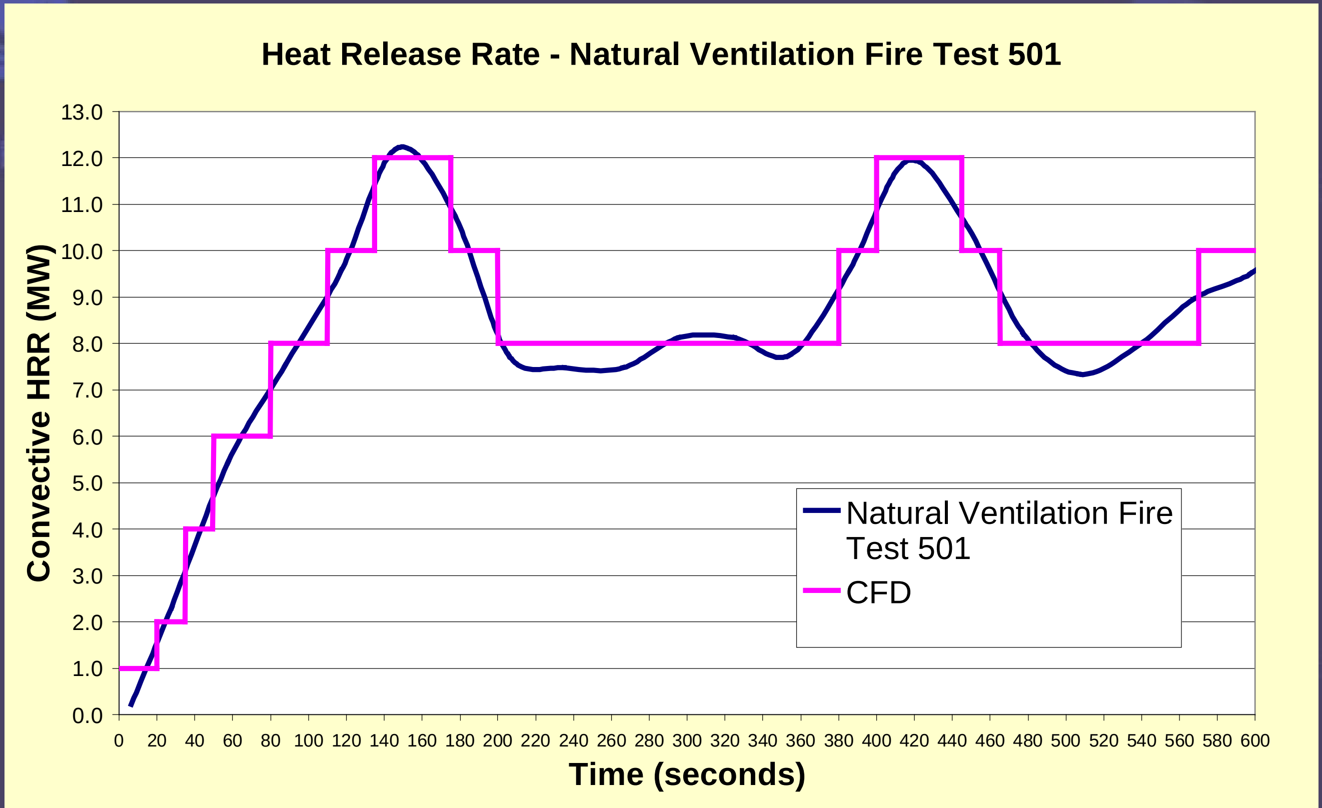
- *Parameters from previous study:*
  - *k-e turbulence model*
  - *Buoyancy effect on turbulence with a coefficient of 0.1*

Description of Models

Run	Grid (X x Y x Z)	Iterations per time step	Solids, walls properties	Roughness	Heat Release Rate
1	40 x 37 x 461	40	7.22 °C fixed temperature	0.01m	Based upon elapsed time
2	68 x 62 x 606	40	7.22 °C fixed temperature	0.01m	Based upon elapsed time
3	31 x 23 x 348	40	7.22 °C fixed temperature	0.01m	Based upon elapsed time
4	40 x 37 x 461	25	7.22 °C fixed temperature	0.01m	Based upon elapsed time
5	40 x 37 x 461	50	7.22 °C fixed temperature	0.01m	Based upon elapsed time

Fire Modelling

- Blocks of domain material with a heat flux of 1 MW/m^3
- Radiation not modelled – 70% convective component
- Fire located approximately 238m north of the southern portal

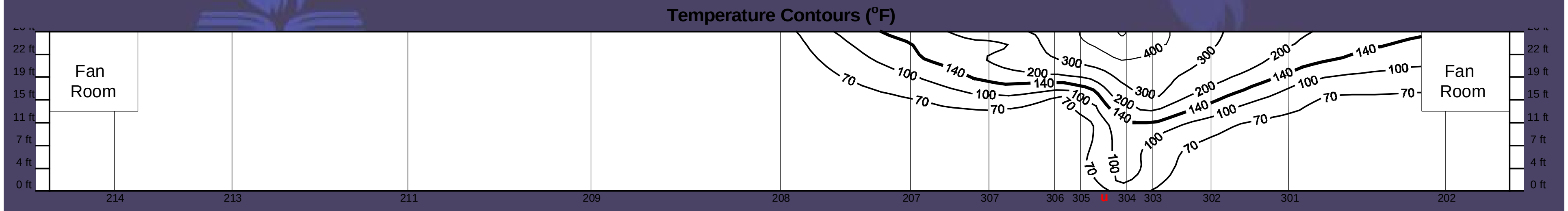


Results – Runs 1 to 5

- Generally temperatures and velocities were over-predicted near the fire in all runs
- At earlier times the hot layer did not spread as far
- At 10 minutes temperatures and velocities were over-predicted throughout (except run 2)
- Run 5 gave closest results to the fire test
  - 50 iterations, intermediate grid
- Require further investigation

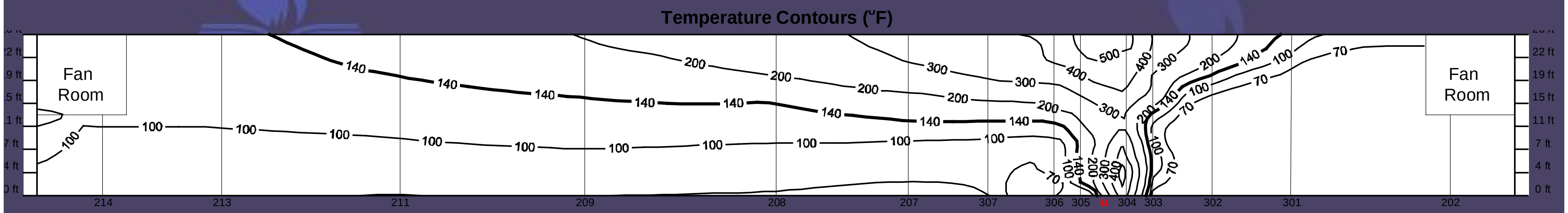
Comparison of Run 5 and Fire Test

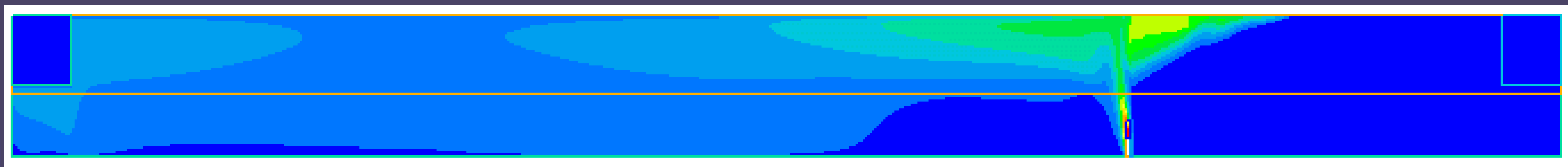
Time of 1 minute



Comparison of Run 5 and Fire Test

Time of 10 minutes





MTFVTP "Elapsed Time"

- Times given in data and output based upon an elapsed time

Test Events Sequence

	Real Time (hr:min:sec)	Elapsed Time (min:sec)
Ignitor Ignition:	11:28:25	
Fuel Oil Ignition:	11:28:50	
Full Pan Engulfment:	11:29:46	0:00
Fuel Oil Shut-Off	11:54:46	25:00
Pan Fuel Oil Burnout:	No visual observation of this event.	

Test was concluded at 11:57:45 when the Central Fans were initiated.

MTFVTP "Elapsed Time"

- Peak Heat Release Rate (HRR) considered to be achieved upon full pan engulfment
- Potentially 1 minute prior to start of Phoenics run where there is a rapidly growing fire within the tunnel
- Significant delay in the fire reaching its peak HRR

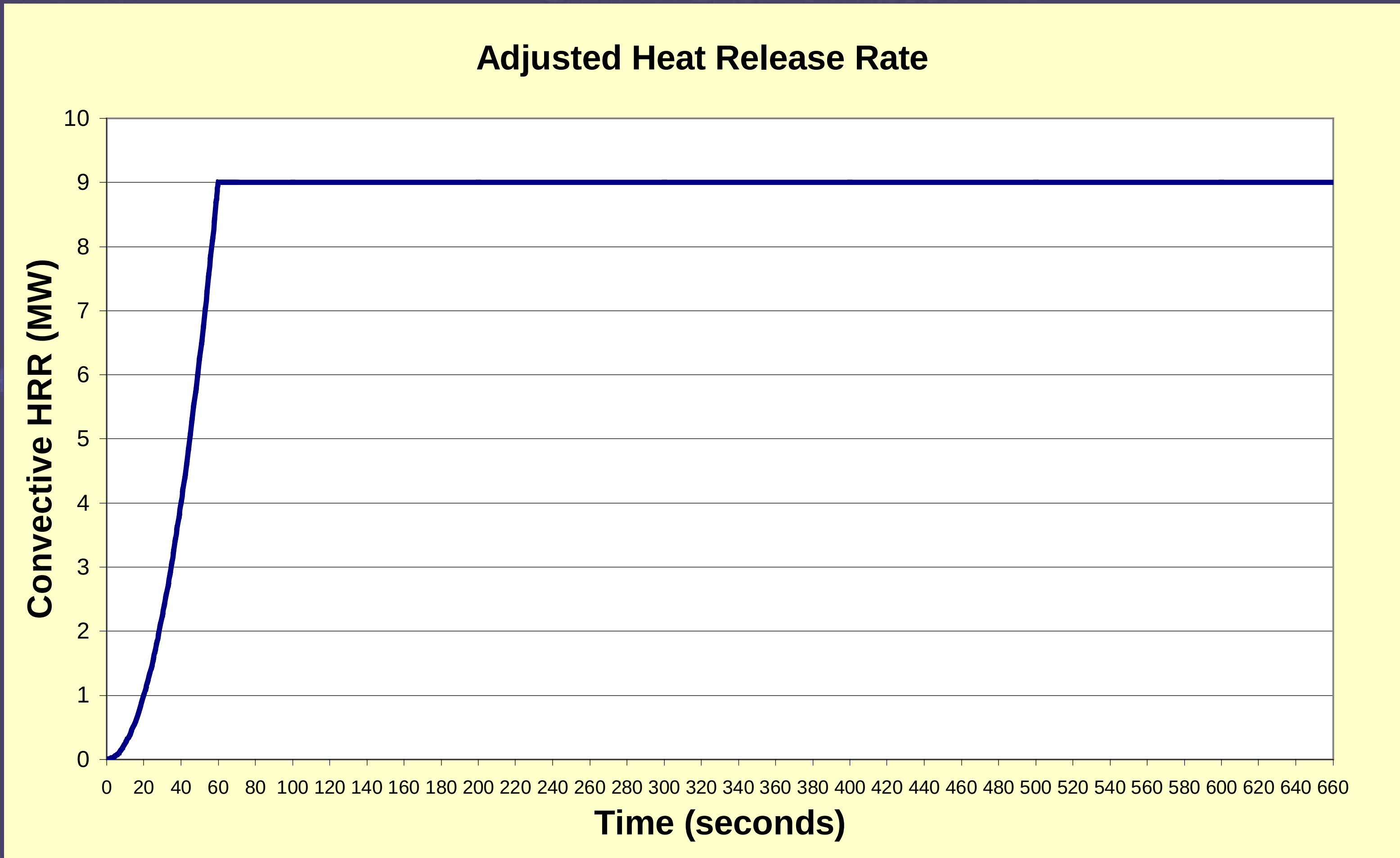
Calculation of Heat Release Rate

- Fire generated by pans of fuel
- Fuel was constantly pumped into pans to maintain constant level
- Weigh cells beneath pan gave feedback to controller, which determined the rate that fuel was pumped into the pan
- HRR determined by fuel consumption
- Fire plume produces turbulent flows and may produce forces on pan
- Fluctuations observed in weight measurements
- Feedback control system results in calculated HRR lagging actual HRR

Adjustments to Phoenics Model

- Time of run extended by 1 minute to allow for burning before elapsed time
- Fire grown to maximum HRR during this 1 minute of extra time before the elapsed time
- Maximum HRR was averaged out to compensate for uncertainties in measured HRR

Adjusted HRR



Description of Models

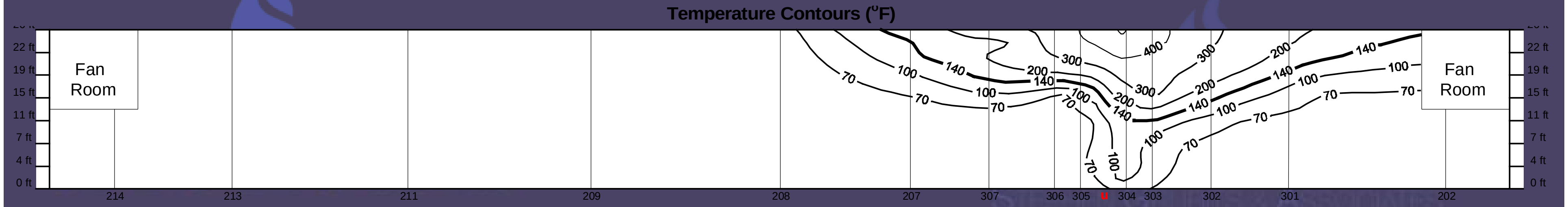
Run	Grid (X x Y x Z)	Iterations per time step	Solids, walls properties	Roughness	Heat Release Rate
6	40 x 37 x 461	50	7.22 ^{o}C fixed temperature	0.01m	Adjusted to take into account burning before elapsed time
7	40 x 37 x 461	50	7.22 ^{o}C fixed temperature	0.001m	Adjusted to take into account burning before elapsed time
8	40 x 37 x 461	50	Adiabatic	0.001m	Adjusted to take into account burning before elapsed time

Results – Runs 6 to 8

- Adjustments to HRR improved results in the earlier times
- At 10 minutes, run 6 gave results that were in good agreement with the fire test data
- A smaller wall roughness resulted in the hot layer spreading further, however flow patterns and characteristics of the hot layer were different at 10 minutes
- Adiabatic walls and solids increased spread of the hot layer, however this came with gross over-predictions

Comparison of Run 5, Run 6 and Fire Test

Time of 1 minute



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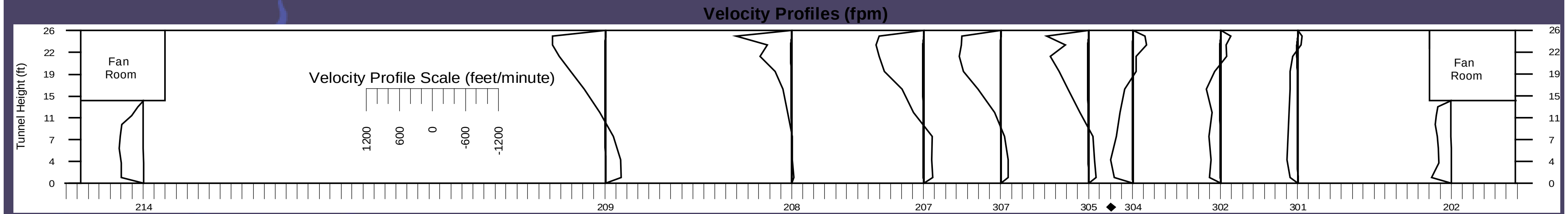
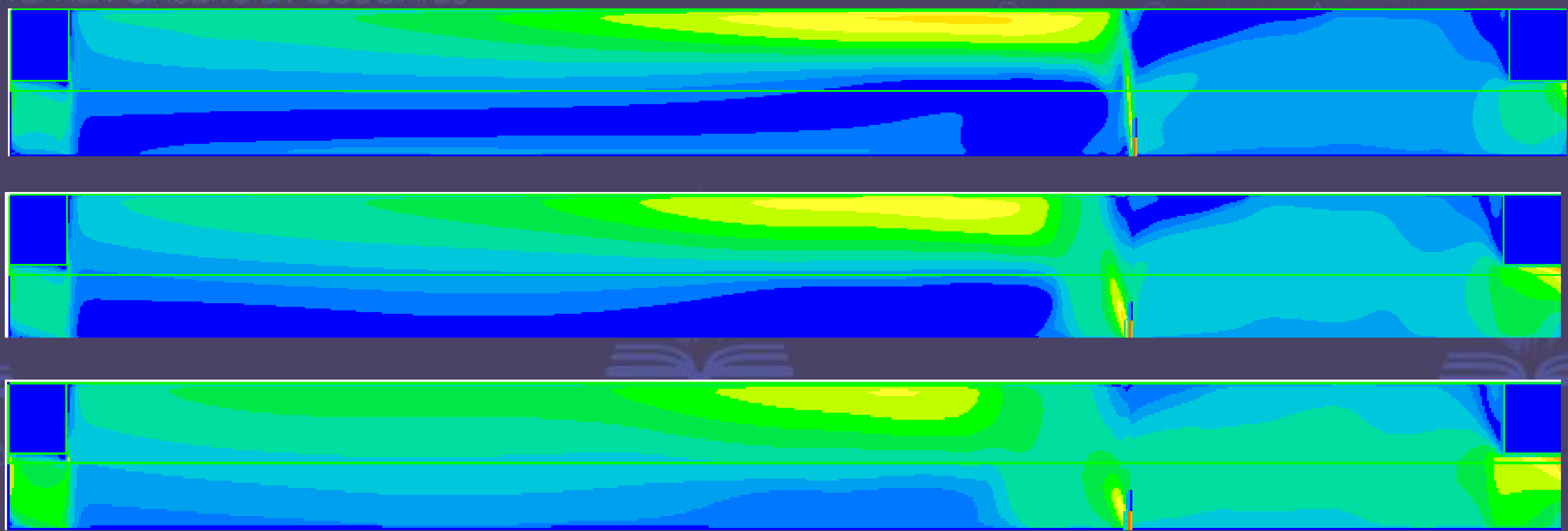
Comparison of Run 6, Run 7, Run 8 and Fire Test

Time of 10 minutes

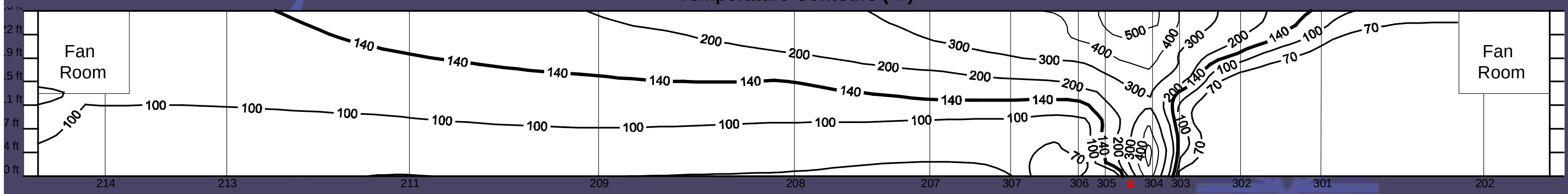


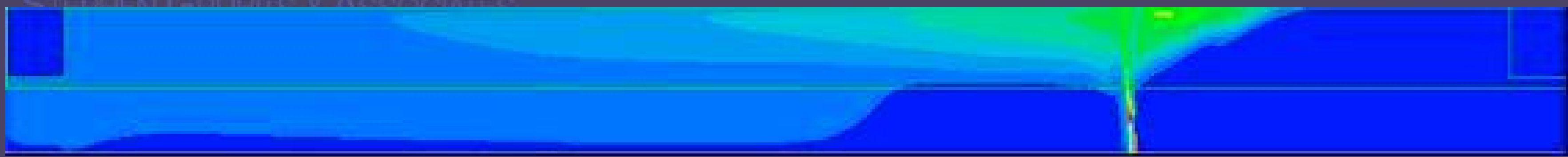


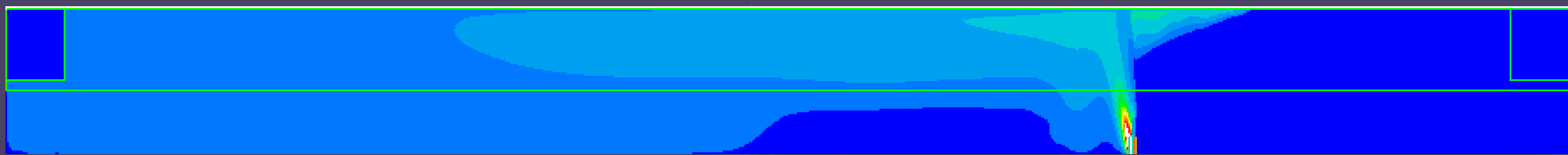
Comparison of Run 6, Run 7, Run 8 and Fire Test

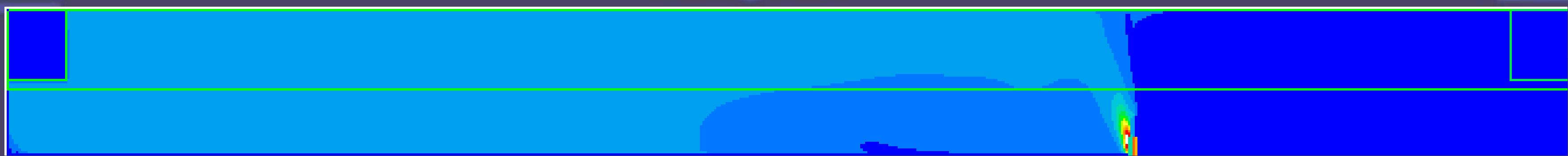
Time of 10 minutes

Temperature Contours (^oF)









Conclusions

- Phoenics run 6 gave results which best represented results from the fire test
  - Grid size of 40 x 37 x 461 cells;
  - 50 iterations per time step;
  - Solids and walls set to 7.22^{o}C fixed temperature
  - Global wall roughness of 0.01m
  - HRR adjusted to take into account burning before elapsed time

Conclusions

- Conditions at 10 minutes in good agreement with the test data
- Under-prediction at earlier time steps, however not necessarily due to Phoenics CFD code as uncertainty in HRR
- Based upon observations made in the assessments:
  - Defining parameters and assumptions for natural ventilation is more critical than for forced flow problems

Conclusions

- Fire growth in initial stages has significant impact on conditions within the tunnel
- Upon reaching 10 minutes, steady state conditions were approached
- Adiabatic conditions resulted in gross-over-predictions
- When using data obtained from a fire test it is important to understand:
  - The procedures used, including the fire source
  - Nomenclature such as “elapsed time”

Conclusions

- Phoenics 3.5 may be used to predict the conditions within a tunnel under fire conditions utilising natural ventilation
  - Particularly once buoyant driven airflows become well established
- Recommend further research on validation of naturally ventilated scenarios using data from other fire tests

Thank You