3D CFD Simulation of Airflow Re-Distribution and Associated Pressure Drops Inside the Overcast in Underground Coal Mines

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Outline

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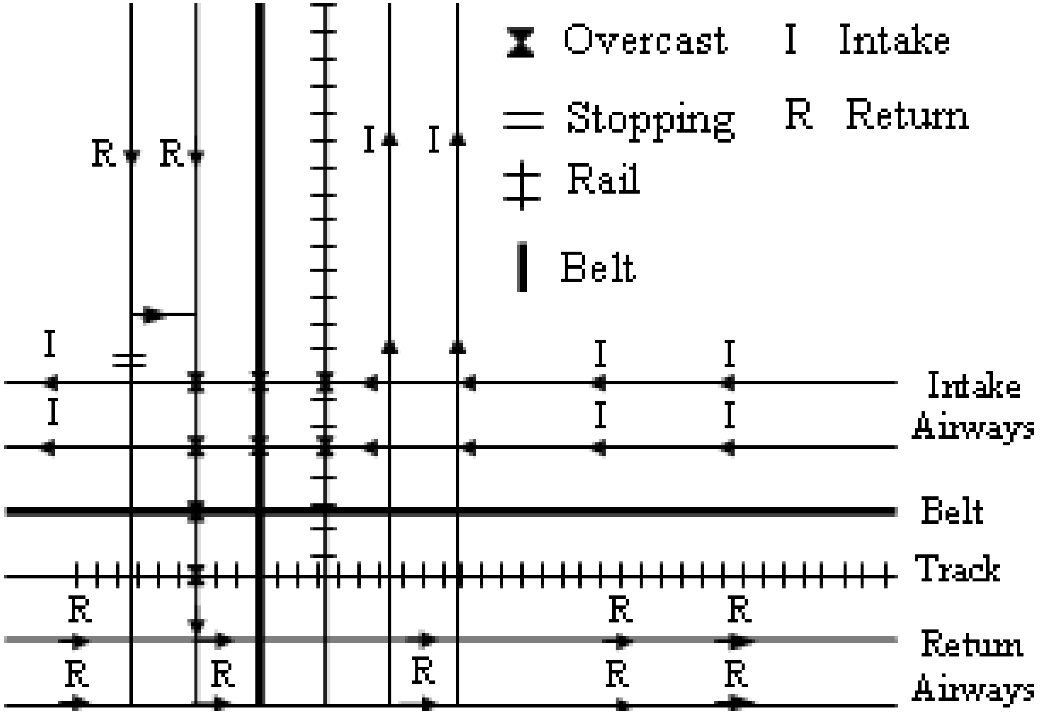
Introduction

- Overcasts are air bridges to permit one airway to pass over another without mixing
- They are more commonly used in coal mines



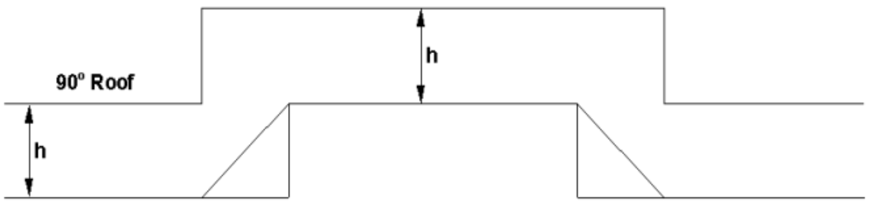
Overcasts in a typical intersection in an underground coal mine

Introduction

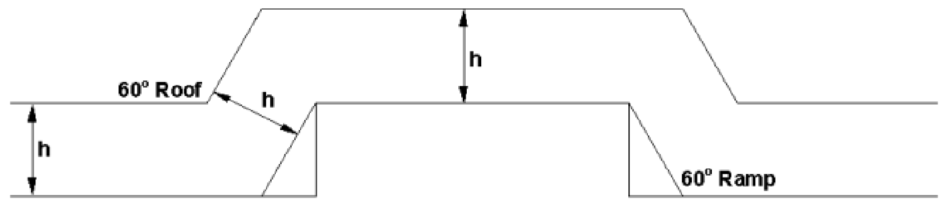
- Measurements of pressure and shock losses are reported by Tien (1988) for seven different overcast configuration
- However no numerical study has been made to predict pressure and shock losses around the underground overcast
- The objective of the study is to determine total pressure loss and shock losses around overcast using CFD study
- The pressure and shock losses are determined for
  - different overcast configuration at a given airflow rate
  - different airflow rates for a given overcast configuration
  - different spacing between two overcast in series for a given overcast configuration and air flow rate

Overcast Configurations

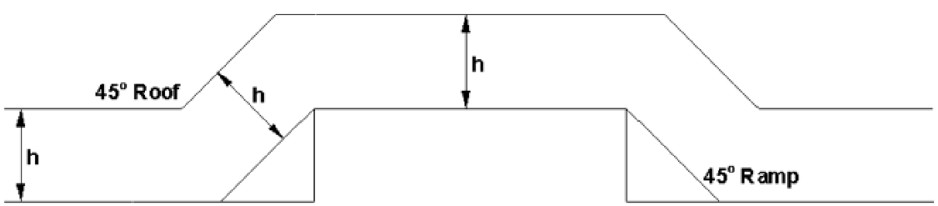
- Seven different configuration used by Tien (1988) will be used for the present study with entry height (*h)* = 6 ft and entry width (*w*) = 20 ft



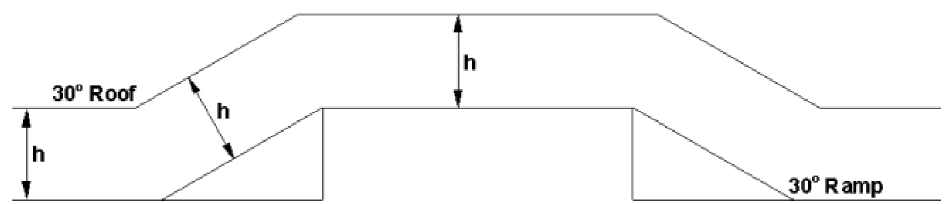
90°roof w/ & w/o ramp



60°roof w/ & w/o ramp

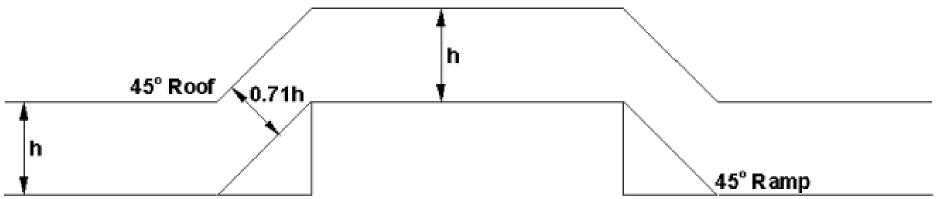


45°roof w/ & w/o ramp

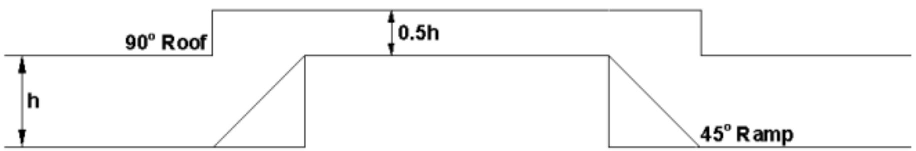


30°roof w/ & w/o ramp

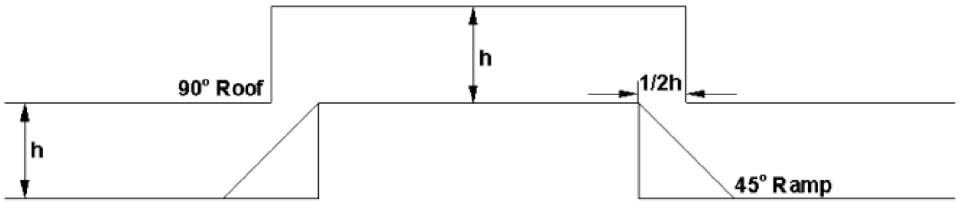
Overcast Configurations



45°roof w/ & w/o ramp (0.71h spacing)



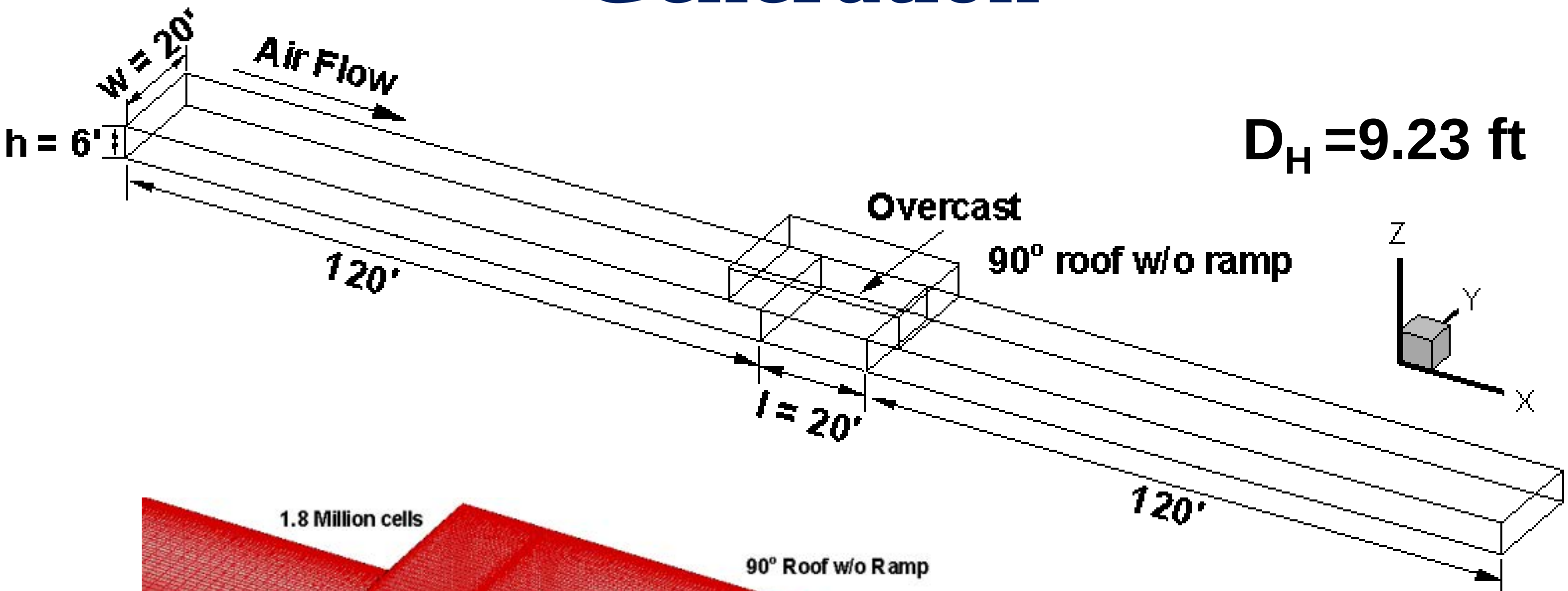
90°roof w/ & w/o ramp (half height)

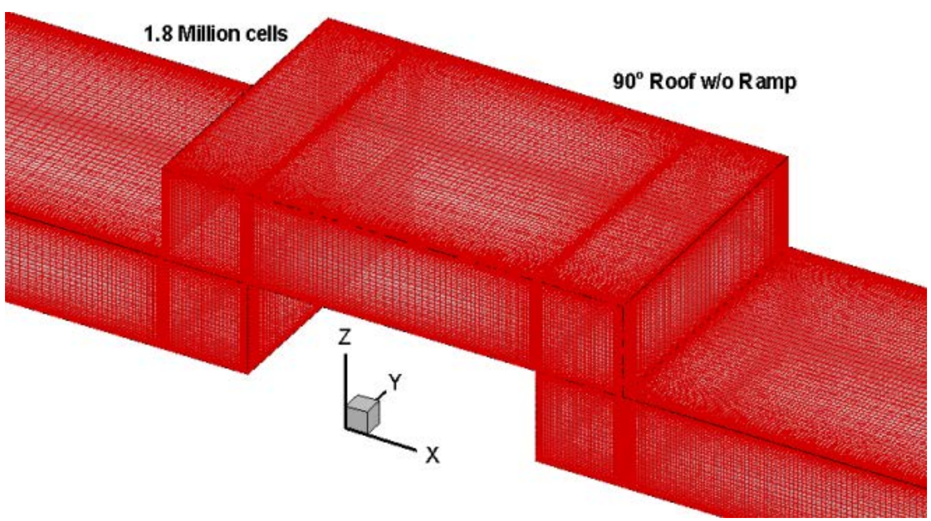


90°roof w/ & w/o ramp (half clearance)

Computational Domain & Mesh Generation

D_H =9.23 ft





Governing Equations and Boundary Conditions

Governing Equations and Assumptions

- Numerical simulation is carried out using ANSYS FLUENT 12.0
- Three-dimensional, steady, turbulent, incompressible Navier stokes, continuity, and k-ε equations are solved
- Flow is assumed to be Isothermal
- Walls are assumed to be smooth

Boundary conditions

- **Inlet**: Velocity Boundary conditions (Air Flow rate = 47,000 cfm)
- **Exit**: Fully developed flow conditions
- **Walls**: No-slip.

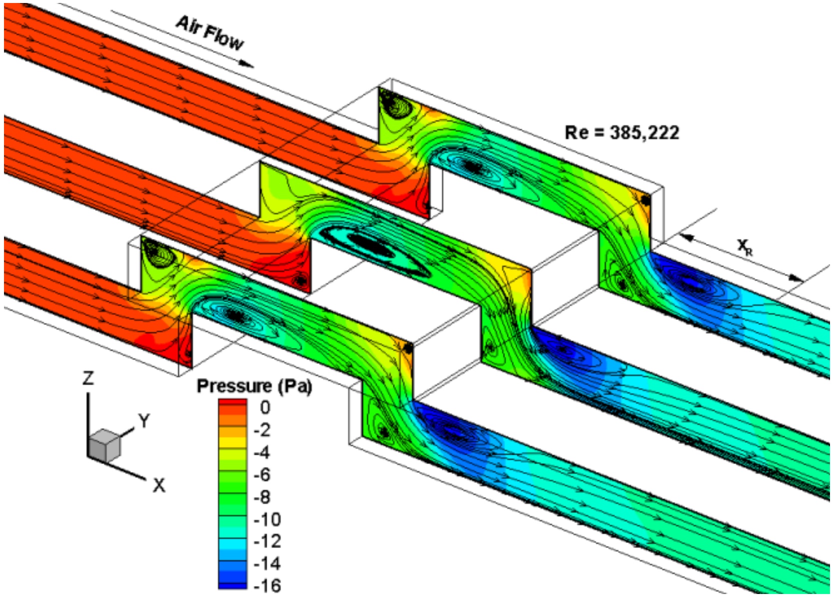
Validation

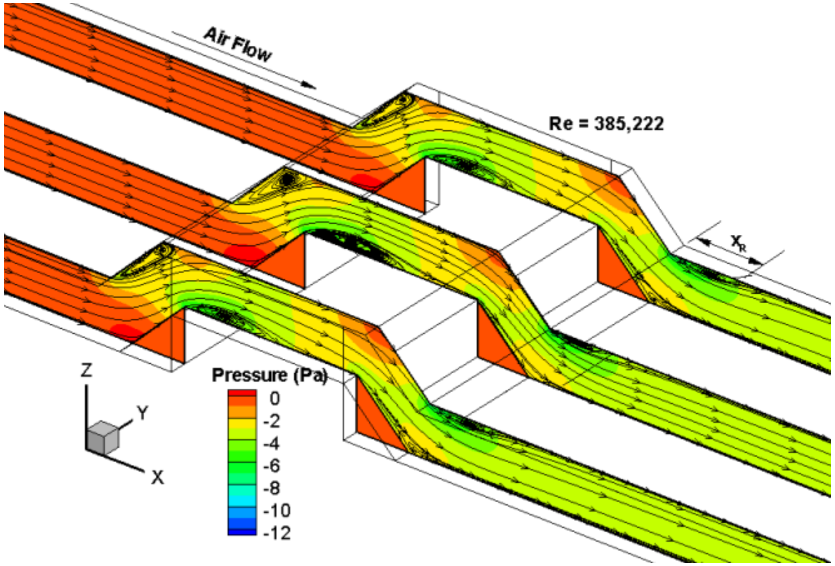
- CFD method is validated by simulating the experimental geometry and flow conditions of Tien (1988)
- The experimental geometry is a 10:1 wooden scale model
- The predicted total pressure loss is compared with the measured results for the overcast with 90° roof w and w/o ramp

Overcast Configuration	Air Quantity (cfm)	Predicted Δp (inches-water)	Experimental Δp (inches-water)	% Error
90° roof w/o ramp	939.5	0.2002	0.32071	37.6
90° roof w/ ramp	1295.5	0.3254	0.45719	28.8

Simulation Results

Re = 385,000



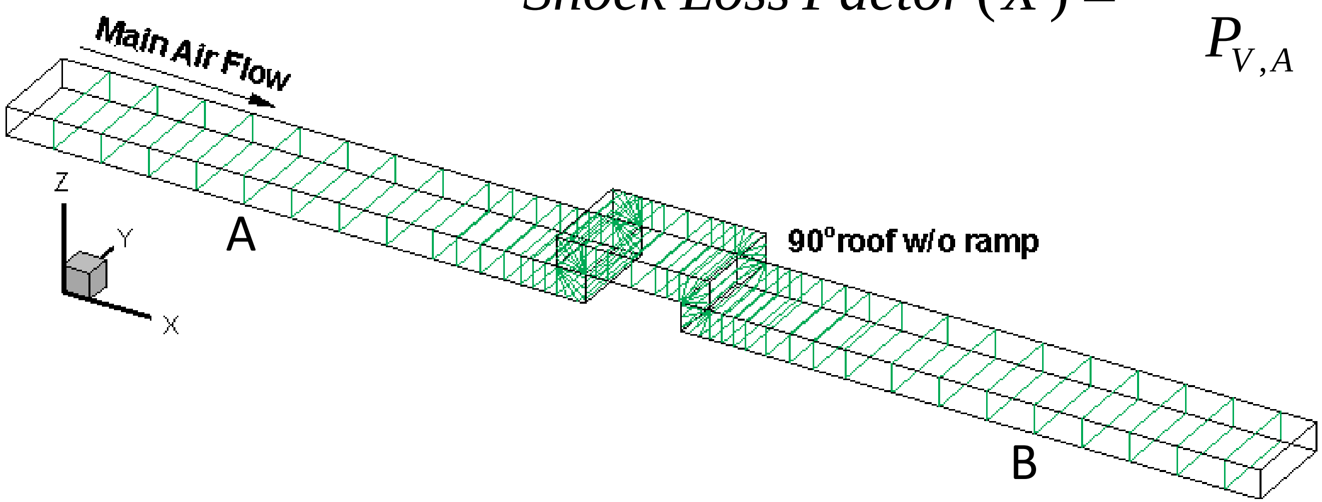


Streamlines demonstrating general flow features (47,000 cfm)

Effects of different overcast configurations

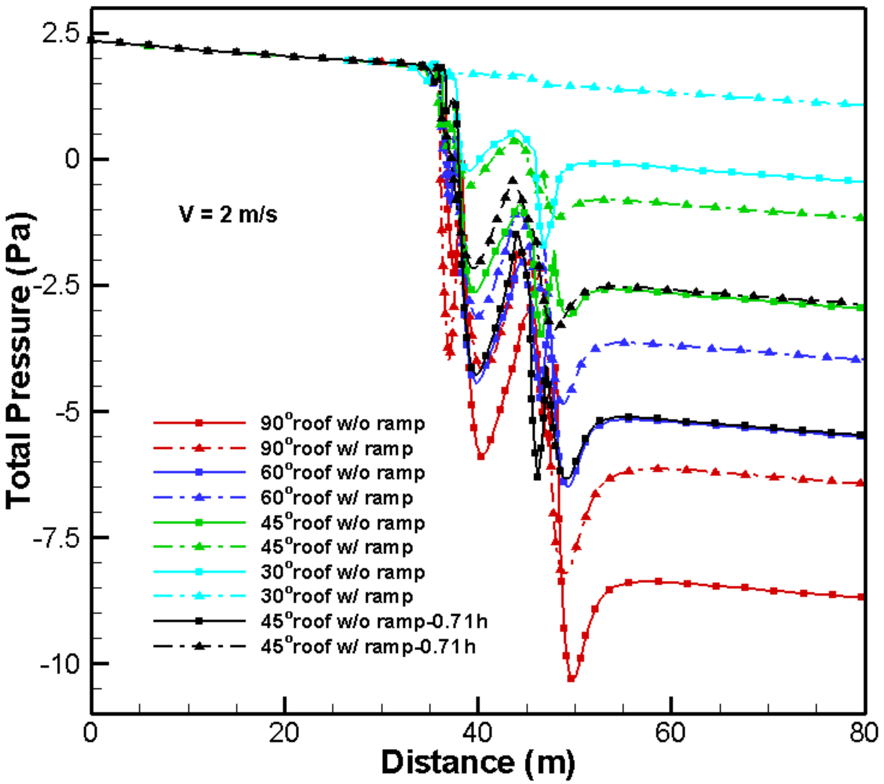
- Air flow rate is fixed at 47,000 cfm
- Cross-sectional planes are created for each overcast structure
- Variation of area weighted average of total pressure and velocity pressure for each cross-sectional plane is evaluated and plotted

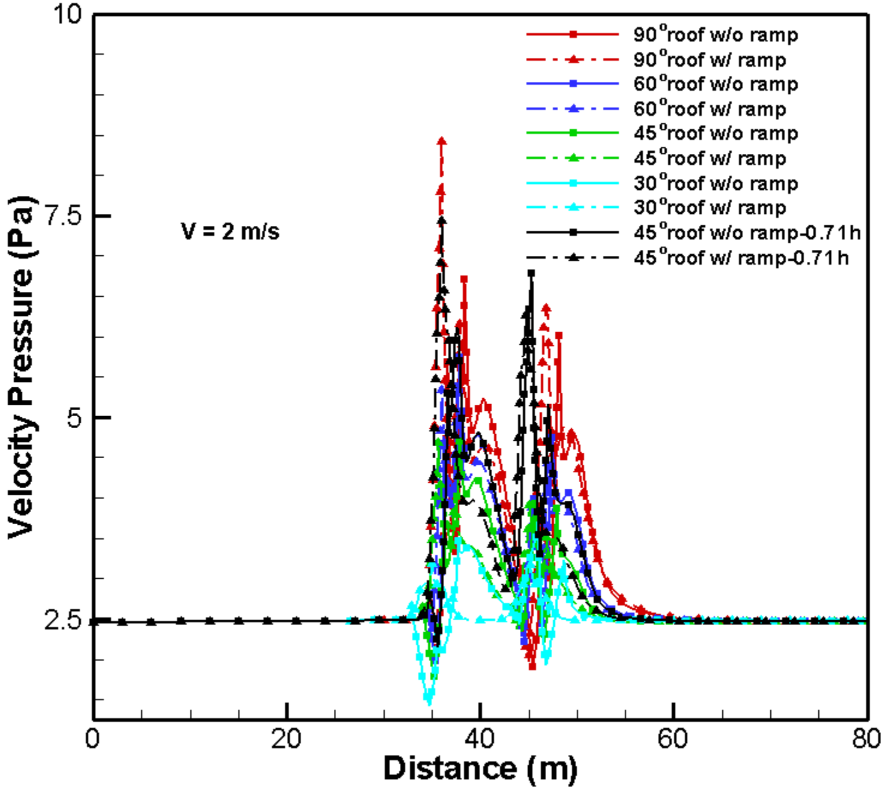
$$\text{Shock Loss Factor}\,(X) = \frac{P_{T,A} - P_{T,B}}{P_{V,A}}$$



Schematic of the cross-sectional planes inside the airway

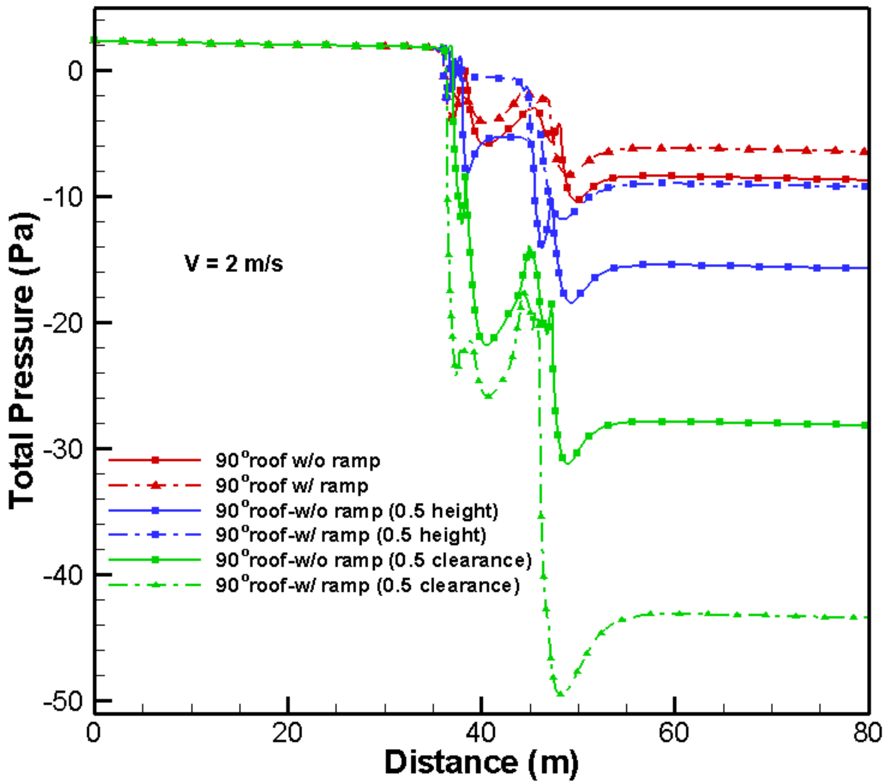
Effects of different overcast configurations

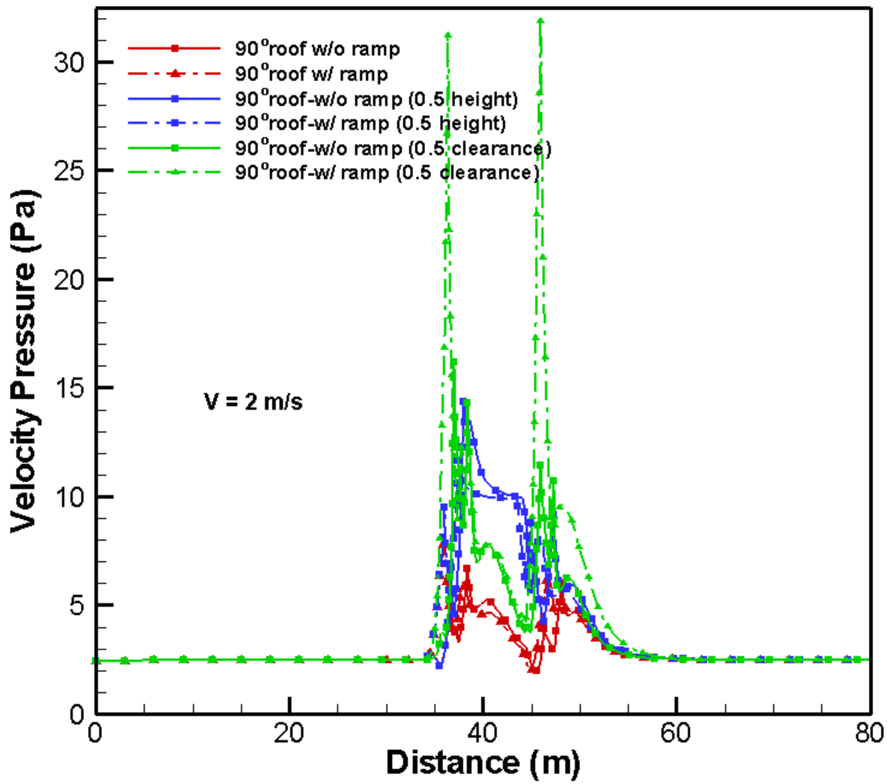




Total and Velocity pressure distributions for different overcast geometries

Effects of different overcast configurations





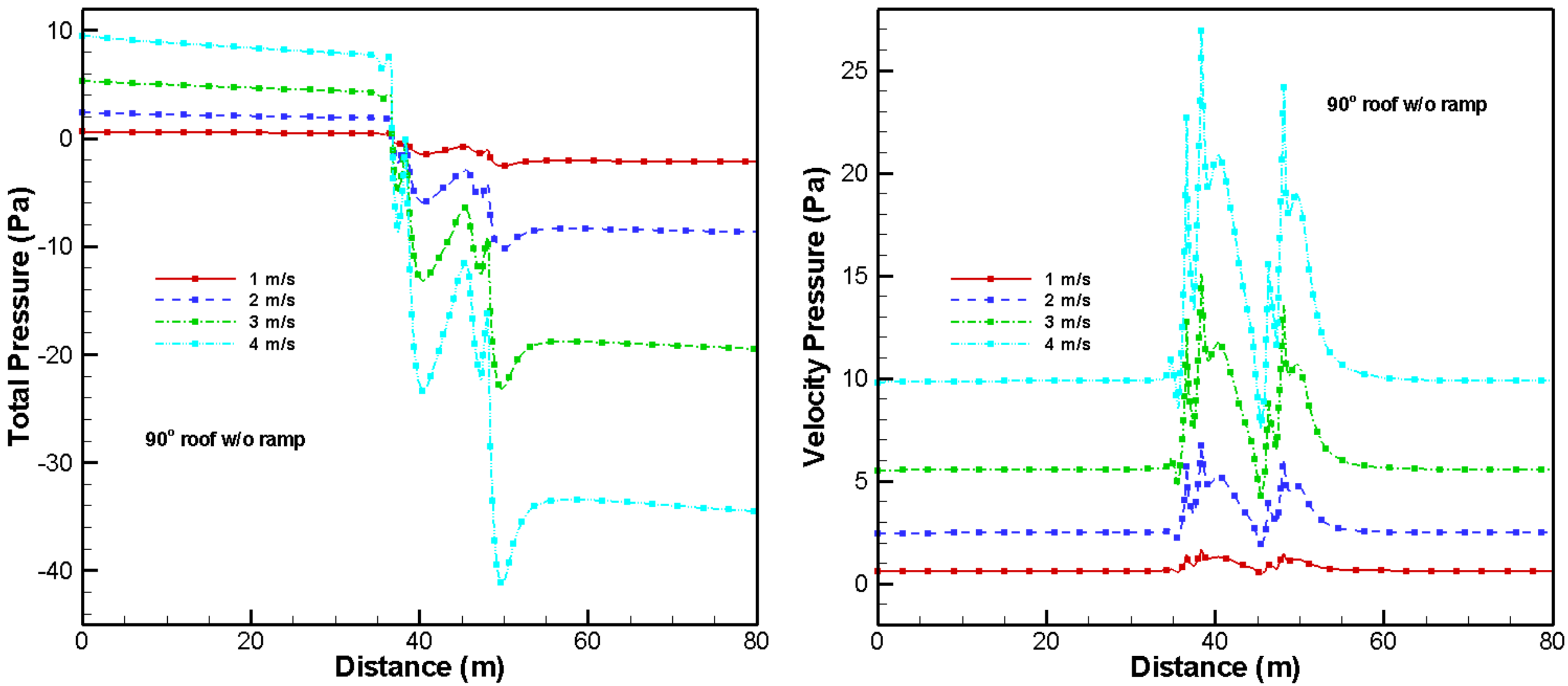
Total and Velocity pressure distributions for different overcast geometries

Effects of different overcast configurations

Overcast Configuration		X	x_R (m)	ΔP (Pa)	Power (W)
90° roof	w/o ramp	4.324	5.0615	10.595	236.23
	w/ ramp	3.402	6.0694	8.335	185.84
	w/o ramp (half height)	7.188	5.8904	17.610	392.65
	w/ ramp (half height)	4.544	7.3795	11.134	248.24
	w/o ramp (half clearance)	12.26	6.084	30.040	669.80
	w/ ramp (half clearance)	18.49	9.2787	45.294	1009.91
60° roof	w/o ramp	3.026	4.6185	7.415	165.32
	w/ ramp	2.403	4.6655	5.888	131.28
45° roof	w/o ramp	1.988	3.2304	4.871	108.60
	w/ ramp	1.256	2.8805	3.077	68.60
	w/o ramp (0.71h)	3.011	4.7947	7.377	164.48
	w/ ramp (0.71h)	1.952	4.5175	4.782	106.63
30° roof	w/o ramp	0.966	1.1666	2.367	52.77
	w/ ramp	0.349	0	0.856	19.09

Effect of airflow rates

- Overcast with 90°roof w/o ramp is chosen for this study
- Four different air flow rates are considered



Total and Velocity Pressure variation

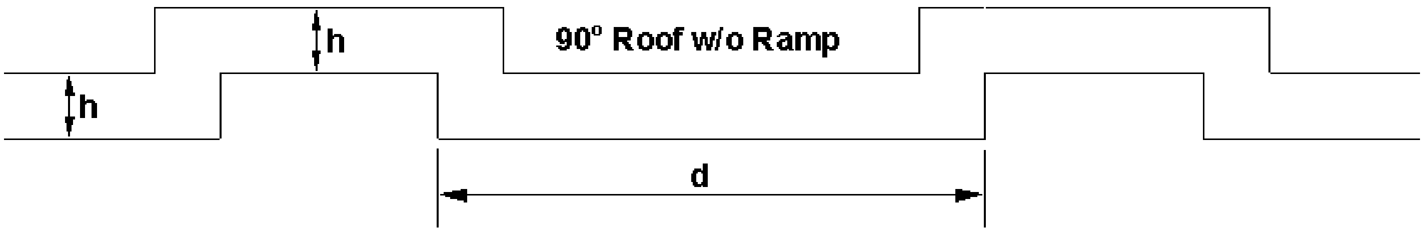
Effect of airflow rates

Air velocity (m/s)	Air Flow Rates (CFM)	X	ΔP (Pa)	Reattachment length (x_R in m)
1	23,600	4.338	2.657	5.1604
2	47,200	4.324	10.595	5.0615
3	70,800	4.322	23.827	4.9374
4	94,500	4.322	42.359	4.8475

Shock loss factor and reattachment length at different airflow rates (90° roof w/o ramp)

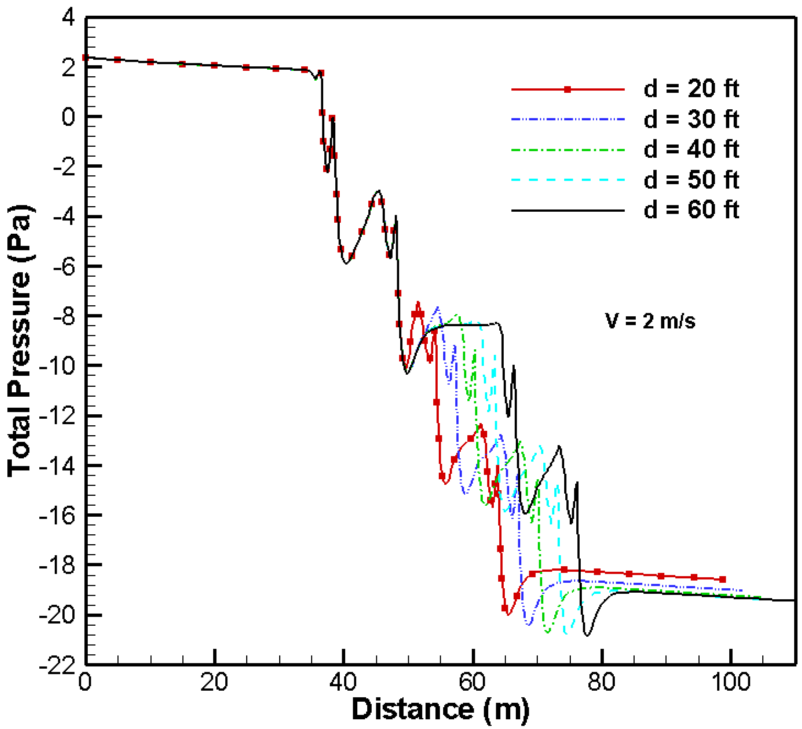
Overcast in Series

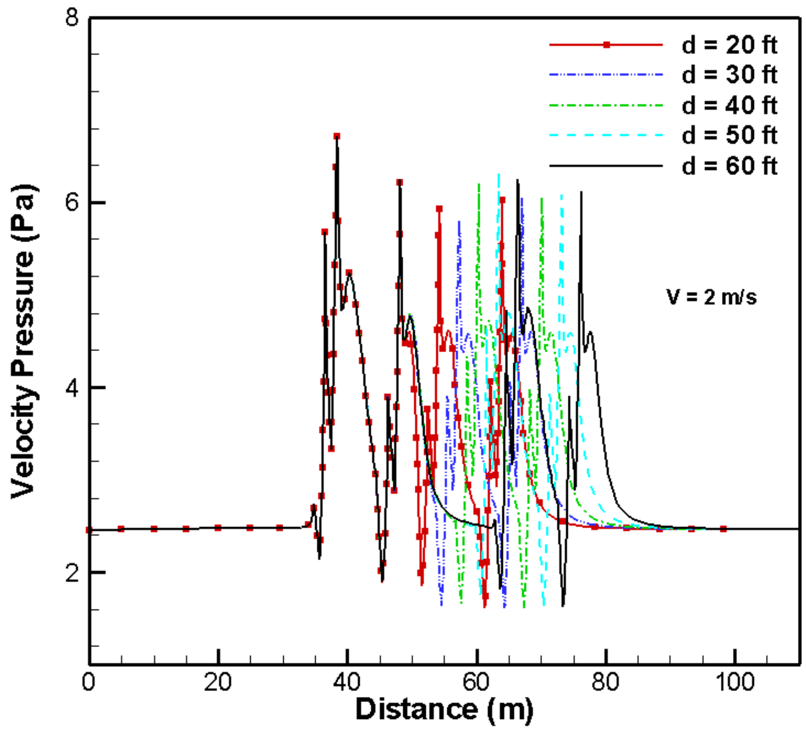
- Two overcast in series is considered for this study
- Overcast has 90°roof w/o ramp
- Air flow rate is fixed at 47,000 cfm
- Spacing between the overcast is also changed to study its effect on shock loss



Schematic of overcast in series

Overcast in Series





Total and Velocity pressure distributions for different overcasts spacing

Overcast in Series

Distance, d (ft)	ΔP (Pa)	X
20	20.628	8.42
30	21.060	8.60
40	21.319	8.70
50	21.451	8.76
60	21.503	8.78

Shock loss factor for different spacing between two overcast

Distance, d (ft)	ΔP (Pa)	X
20	10.595	4.324

Shock loss for Single Overcast

Conclusions

- The total pressure drop decreases with the decrease in the roof angle.
- The total pressure drop also decreases with the addition of a ramp for all overcast configurations with the exception of overcast with half clearance before the overcast.
- For a given airflow rate, the maximum pressure drop occurs for the case with half clearance before the overcast and with a ramp.
- The length of the airway required for the flow to refill the entry height downstream from the overcast decreases with the decrease in the roof angle.

Conclusions

- The shock loss factor is a function of geometry and does not depend on the airflow rates when the flow is fully turbulent.
- When airway has two overcasts operating in series, the total pressure drop is twice than that for airway with single overcast.
- Also for overcasts operating in series the distance between them has negligible effect on the overall pressure losses across the overcasts

THANKS

QUESTIONS?