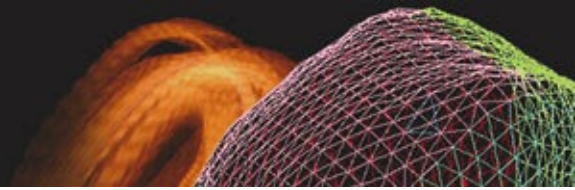

A CFD Study of Preventing Snow Accumulations on Roofs using Airflows

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Risky snow removals from roofs

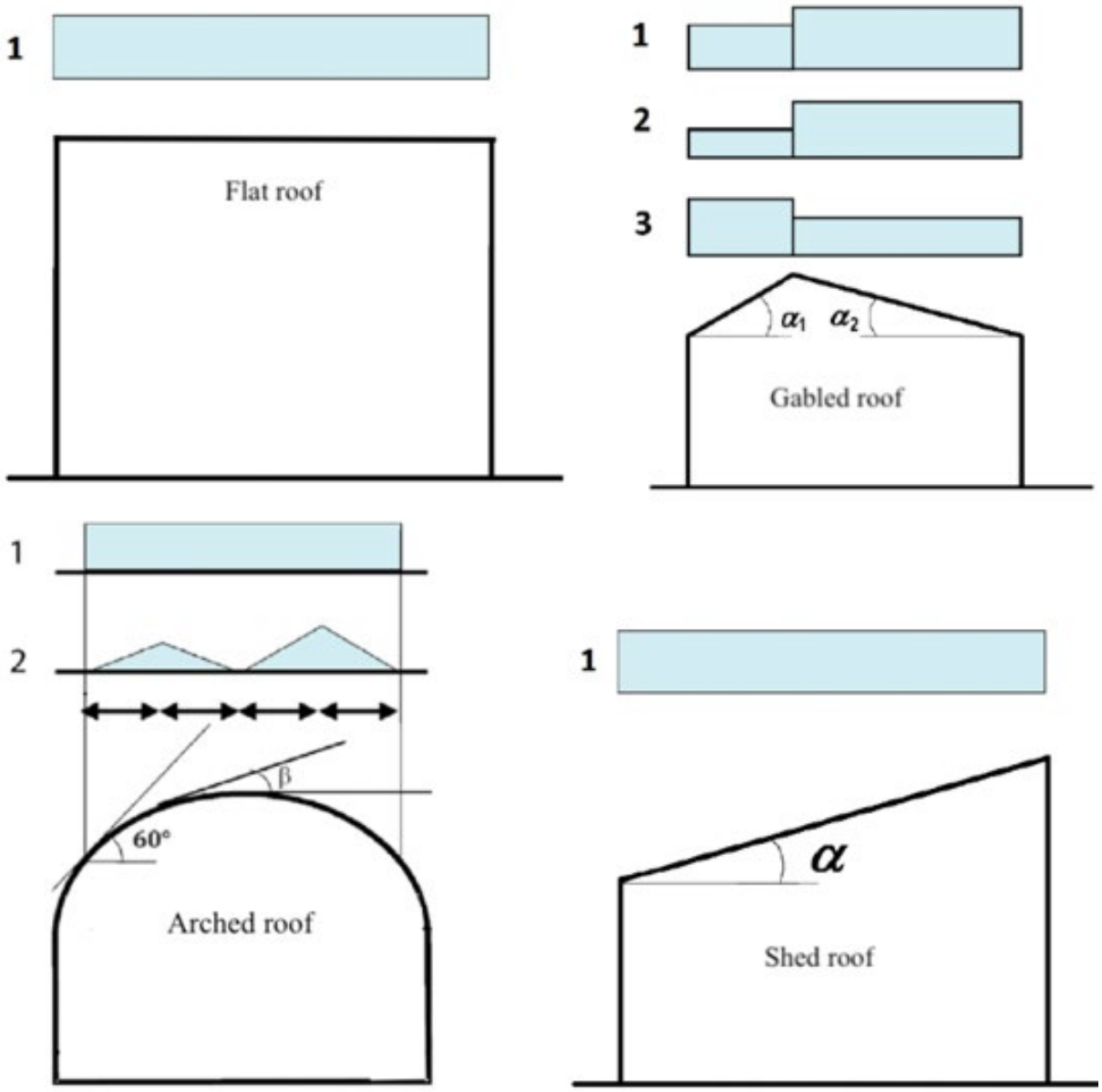
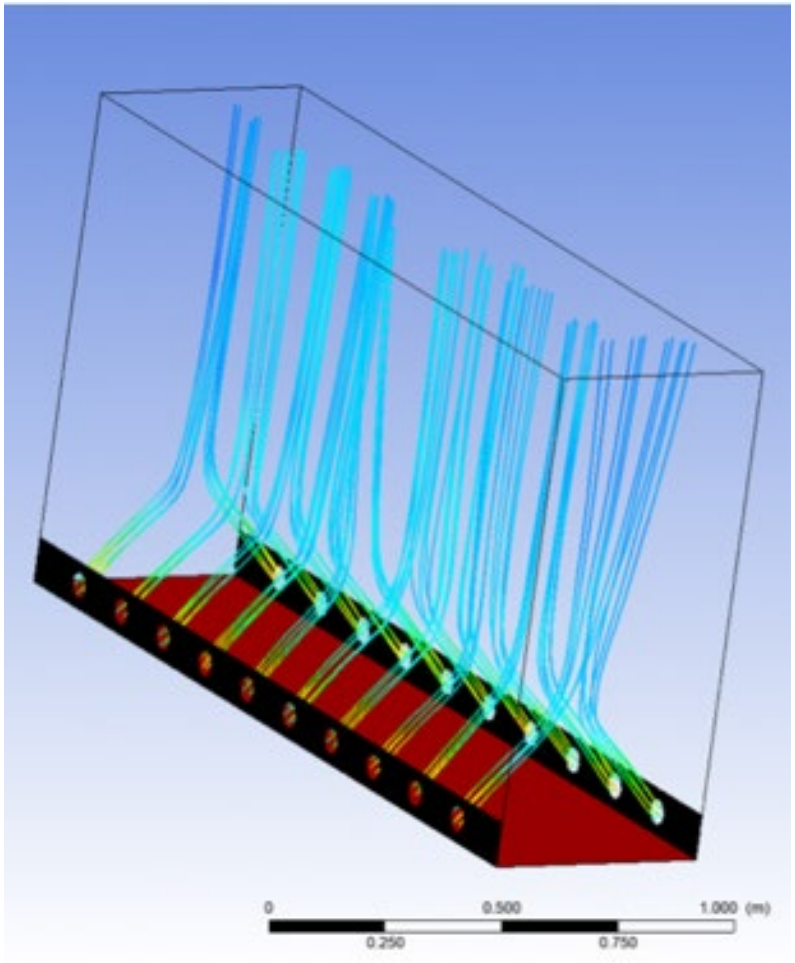


Figure 1: Snow load cases on characteristic roofs [1]

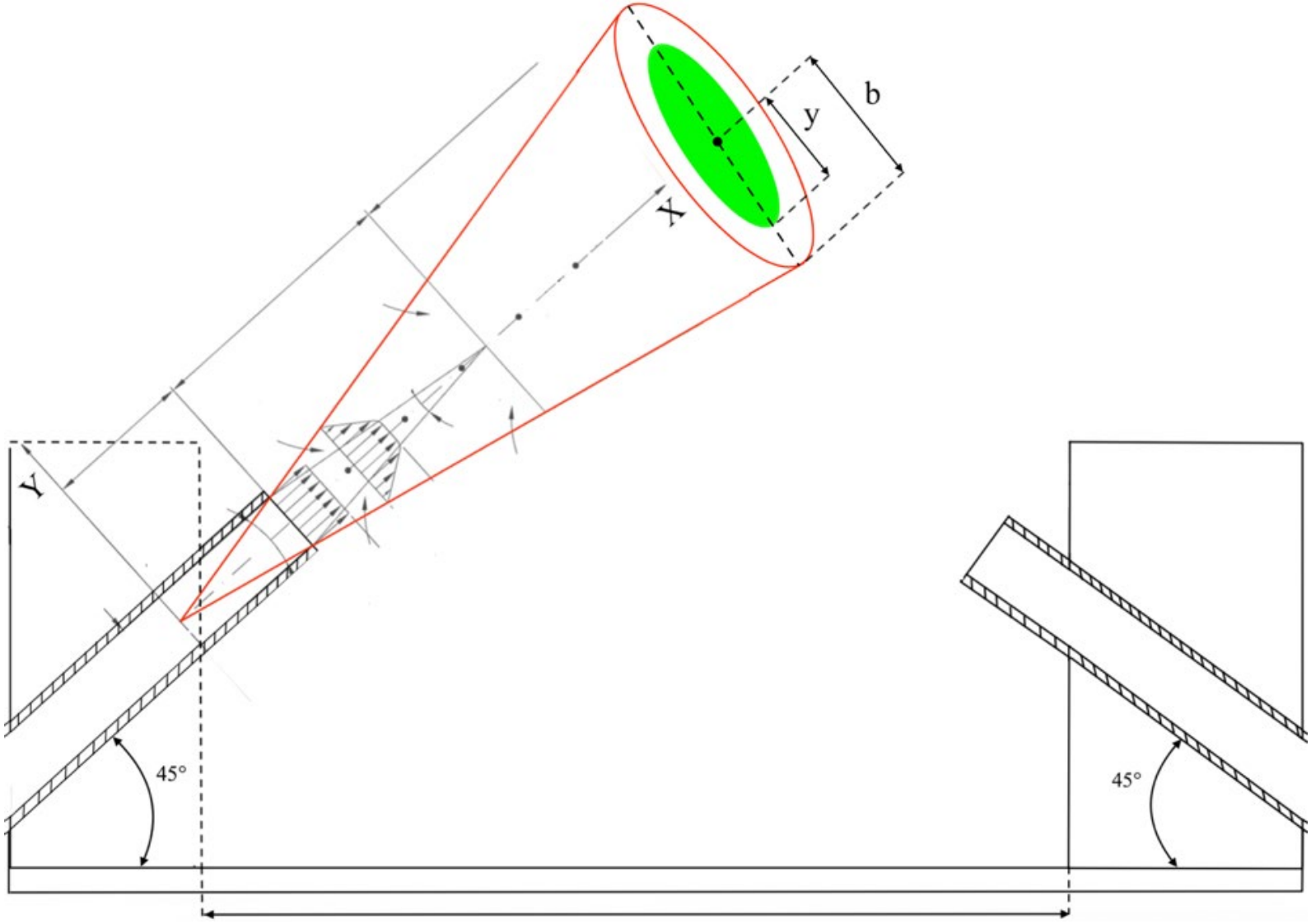
Research Methodology



CFD model with airflow trajectories

- The air flows towards the center of the flat surface from both sides with an inclination to create a "wall of air“ to prevent the snow from depositing and to keep the particles airborne.

Research Methodology



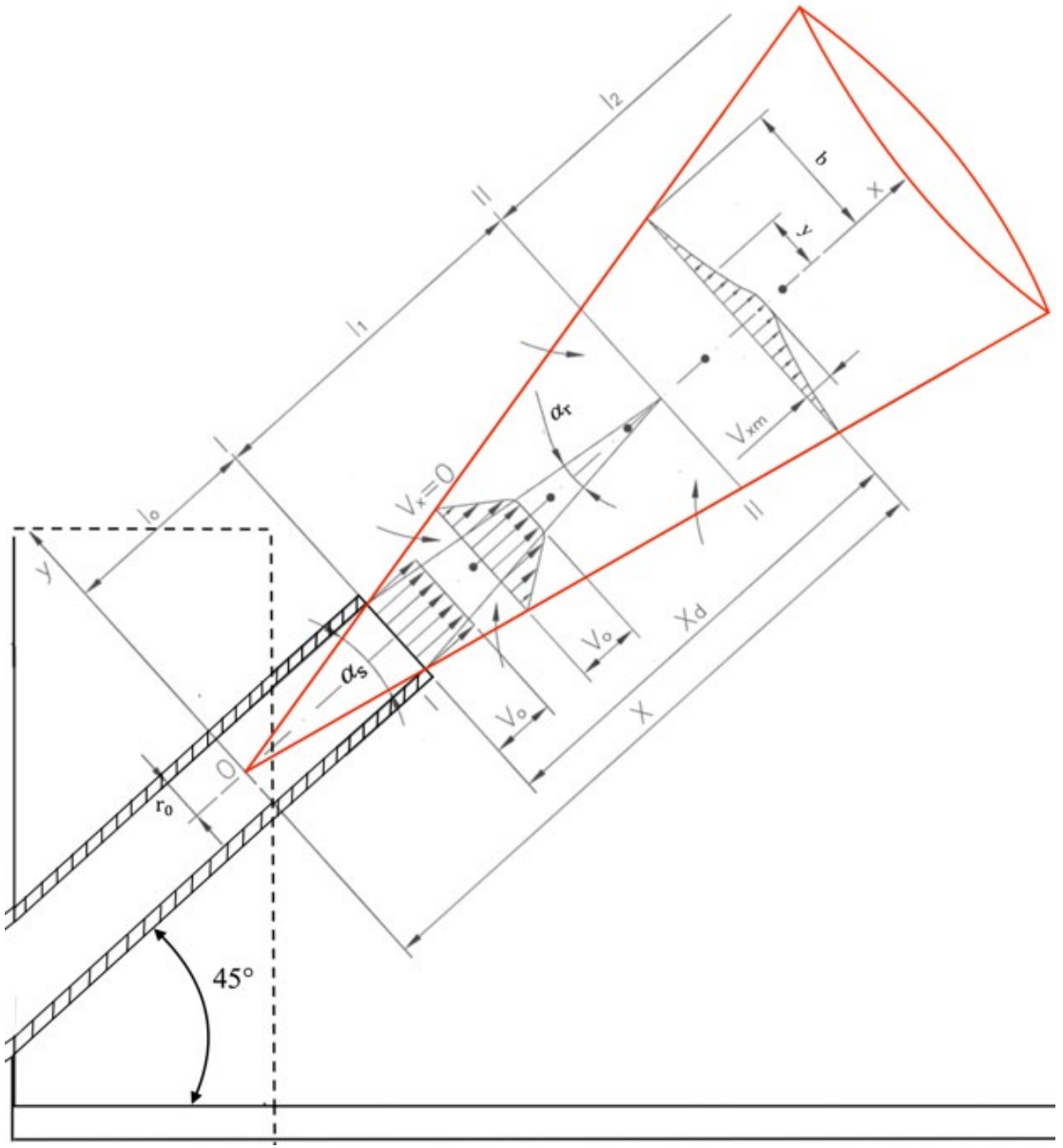
Airflow from circular cross-section

Diffusion of airflows

- Illustration of Zawadzki et al. (2010, p. 39) schematic view of turbulent free airflow from a circular cross-section.

- $V_x = V_{xm}[1 - \left(\frac{y}{b}\right)^{\frac{3}{2}}]^2$
- $V_{xm} = \frac{const}{x}$
- $const = 0.96\, V_0 \frac{r_0}{a}$
- $V = \pi r_0^2 V_0$

- the value for *a* is 0.068
- $r_0 = 6\, mm$

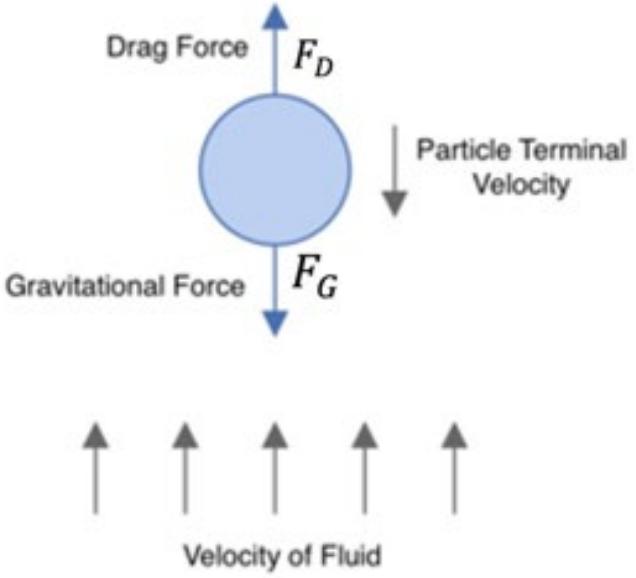


Drag Force (Moeslund, Madsen, Aagaard & Lerche)

$$F_D = \frac{U_{fluid}^2 \cdot m_{snow} \cdot g}{U_{max}^2}$$

$$U_{fluid}^2 = (U_{wind} - U_{snowflake})^2$$

$\boldsymbol{U_{fluid}}$ – velocity of the air moving the snowflake in the same direction as F_D
$\boldsymbol{U_{wind}}$– velocity of the wind interacting on the particle
$\boldsymbol{U_{snowflake}}$ – velocity of the snowflake
$\boldsymbol{U_{max}}$– maximum vertical velocity taking wind resistance into consideration (terminal velocity)
$\boldsymbol{m_{snow}}$ – mass of the snowflake
g – gravity constant



Equation(15)

mN=milli Newton

$$F_D = \frac{(Uwind - Usnowflake)^2 \cdot Msnow \cdot g}{Umax^2} \text{ [N]}$$

Example:

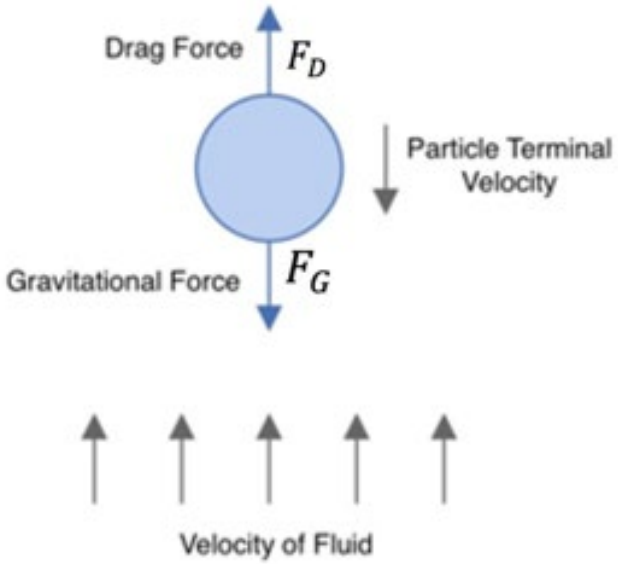
Uwind [m/s]	3
Usnowflake [m/s]	0,5
Umax [m/s]	1,5
Msnow [kg]	6,00E-08
g [m/s^2]	9,81
Fd [N] =	1,64E-06

			dry snow	*wet snow*	*dry snow*	*wet snow*	*dry snow*	*wet snow*	
Snow type	**Mass [kg]**	**Fall velocity [m/s]**	**Fd(3 m/s) [mN]**	**Fd(3 m/s) [mN]**	**Fd(27 m/s) [mN]**	**Fd(27 m/s) [mN]**	**Uwind ≥ [m/s]**	**Uwind ≥ [m/s]**	**Fg [mN]**
Powder snow	6,00E-08	0,5	1,64E-03	9,20E-04	1,84E-01	1,03E-01	1,58	2,06	5,89E-04
Needles	4,00E-09	0,5	1,09E-04	6,13E-05	1,22E-02	6,89E-03	1,58	2,06	3,92E-05
Spatial dendrites	1,50E-07	0,6	3,77E-03	2,12E-03	4,56E-01	2,56E-01	1,62	2,09	1,47E-03
Rimed crystals	1,80E-07	1	3,14E-03	1,77E-03	5,31E-01	2,98E-01	1,80	2,24	1,77E-03
Graupels	8,00E-07	1,8	5,02E-03	2,83E-03	2,22E+00	1,25E+00	2,34	2,69	7,85E-03

Drag Force

$$F_D = -\frac{\pi}{8}.d^2.\rho_f.C_D.v^2$$

(Huang, Sang & Han, 2011, p. 2)



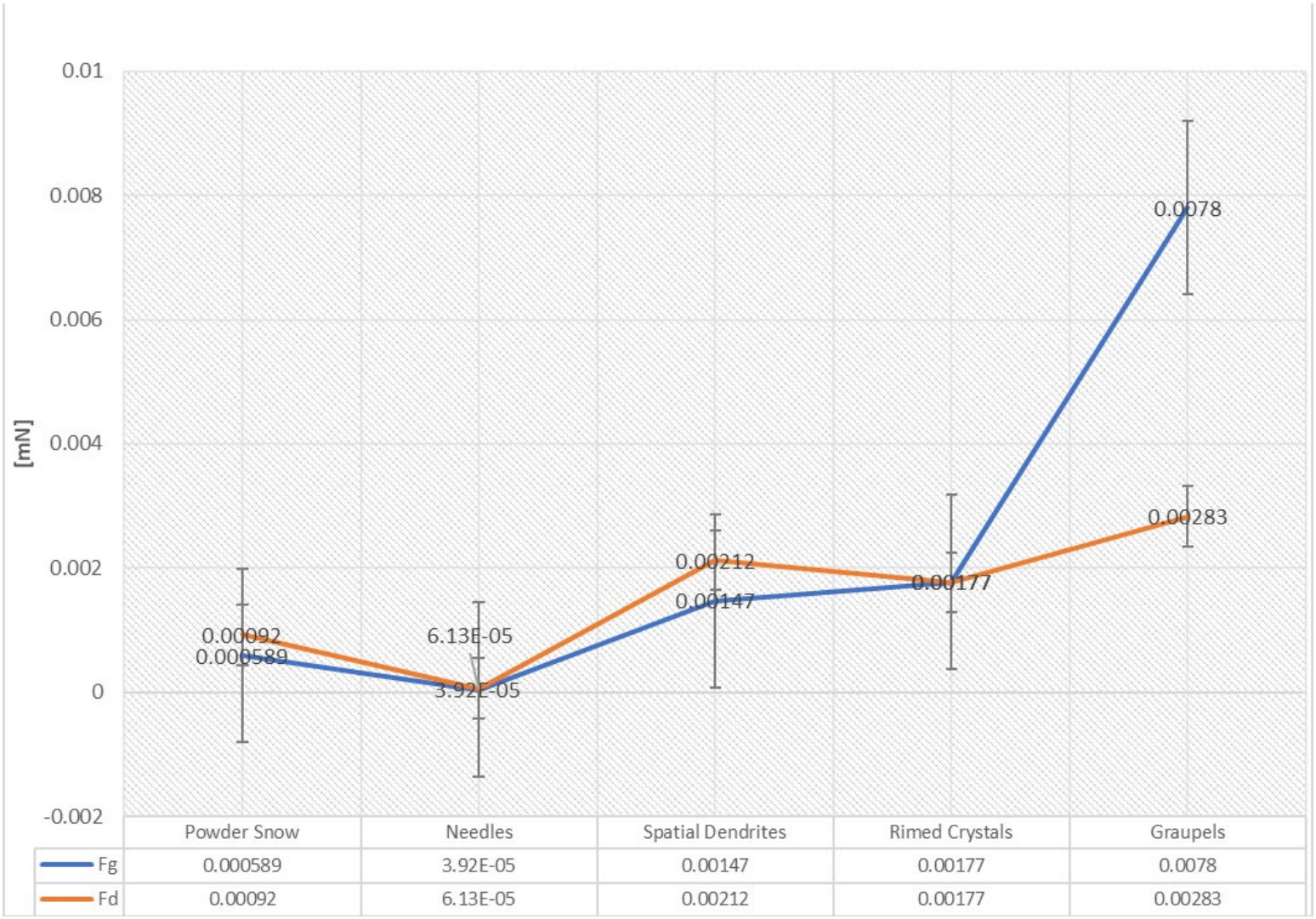
d – particle diameter
ρ_f – air density
C_d – drag coefficient
v – velocity of a particle

Equation (16)

$$F_D = -\frac{\pi}{8} \cdot d^2 \cdot \rho_f \cdot C_D \cdot V^2 \text{ [N]}$$

Example:			**Cd = 0,07**	**Cd = 0,5**	**Cd = 0,07**	**Cd = 0,5**	**Cd = 0,07**	**Cd = 0,5**
Diameter [m]	0,002							
ρf [kg/m^3]	1,342	**Snow type**	**Diameter [m]**	**Fd(27 m/s) [mN]**	**Fd(27 m/s) [mN]**	**Fd(3 m/s) [mN]**	**Fd(3 m/s) [mN]**	**Uwind ≥ [m/s]**	**Uwind ≥ [m/s]**
Cd [dimensionless]	0,07	Powder snow	2,00E-03	1,08E-01	7,68E-01	1,33E-03	9,49E-03	2,00	0,75
V [m/s]	3	Needles	1,50E-03	6,05E-02	4,32E-01	7,47E-04	5,34E-03	0,69	0,26
Fd [N] =	1,32805E-06	Spatial dendrites	4,00E-03	4,30E-01	3,07E+00	5,31E-03	3,79E-02	1,58	0,59
		Rimed crystals	2,50E-03	1,68E-01	1,20E+00	2,08E-03	1,48E-02	2,77	1,04
		Graupels	2,00E-03	1,08E-01	7,68E-01	1,33E-03	9,49E-03	7,29	2,73

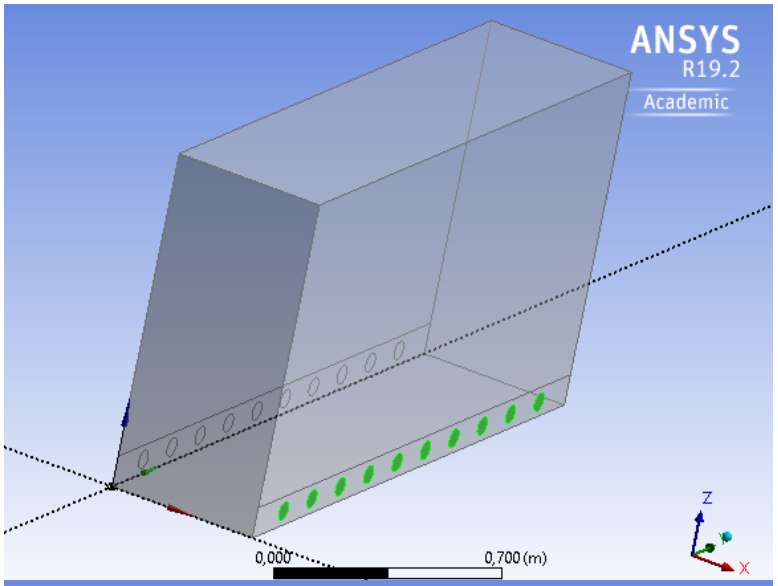
Drag Force from wind velocities 3 m/s compared to gravity force (Fg) - sorted by type of crystals

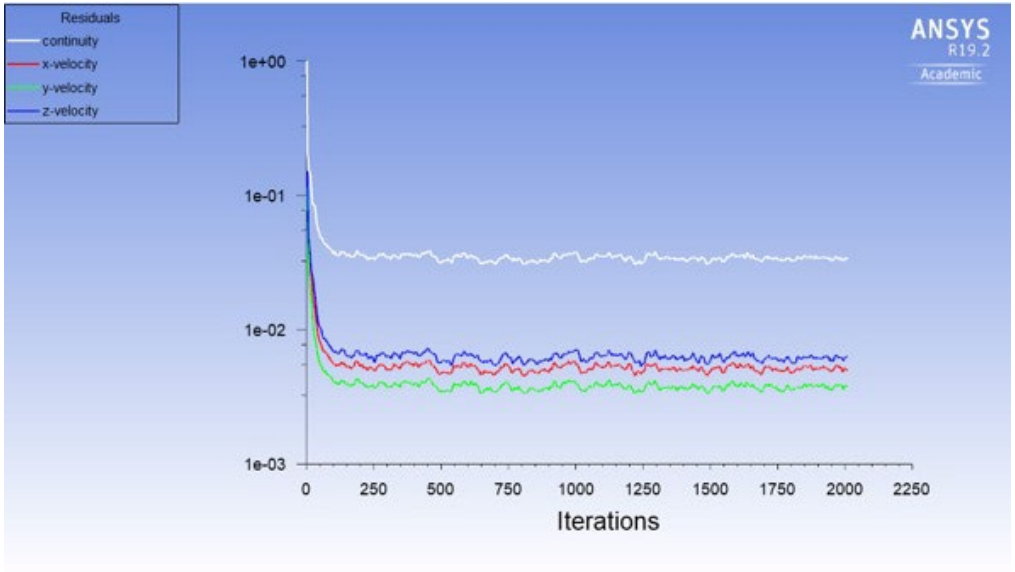


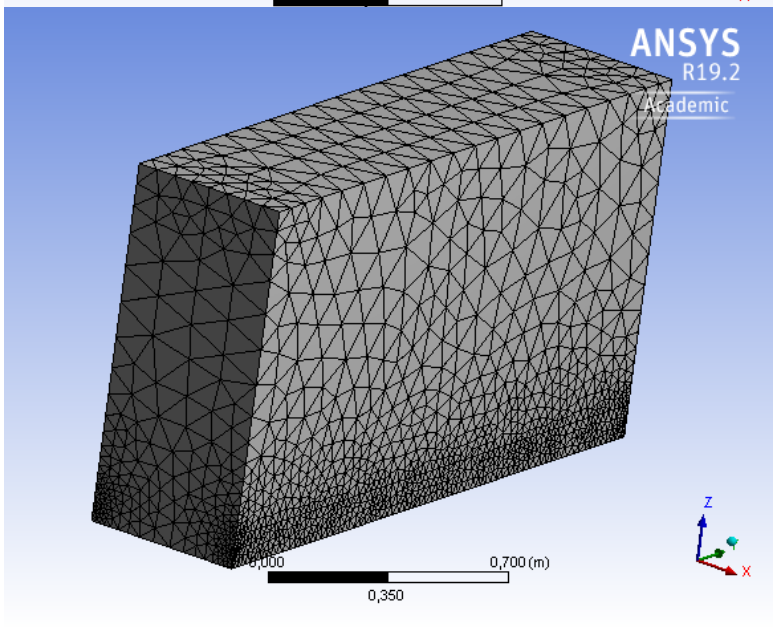
	Powder Snow	Needles	Spatial Dendrites	Rimed Crystals	Graupels
Fg	0.000589	3.92E-05	0.00147	0.00177	0.0078
Fd	0.00092	6.13E-05	0.00212	0.00177	0.00283

CFD Analysis

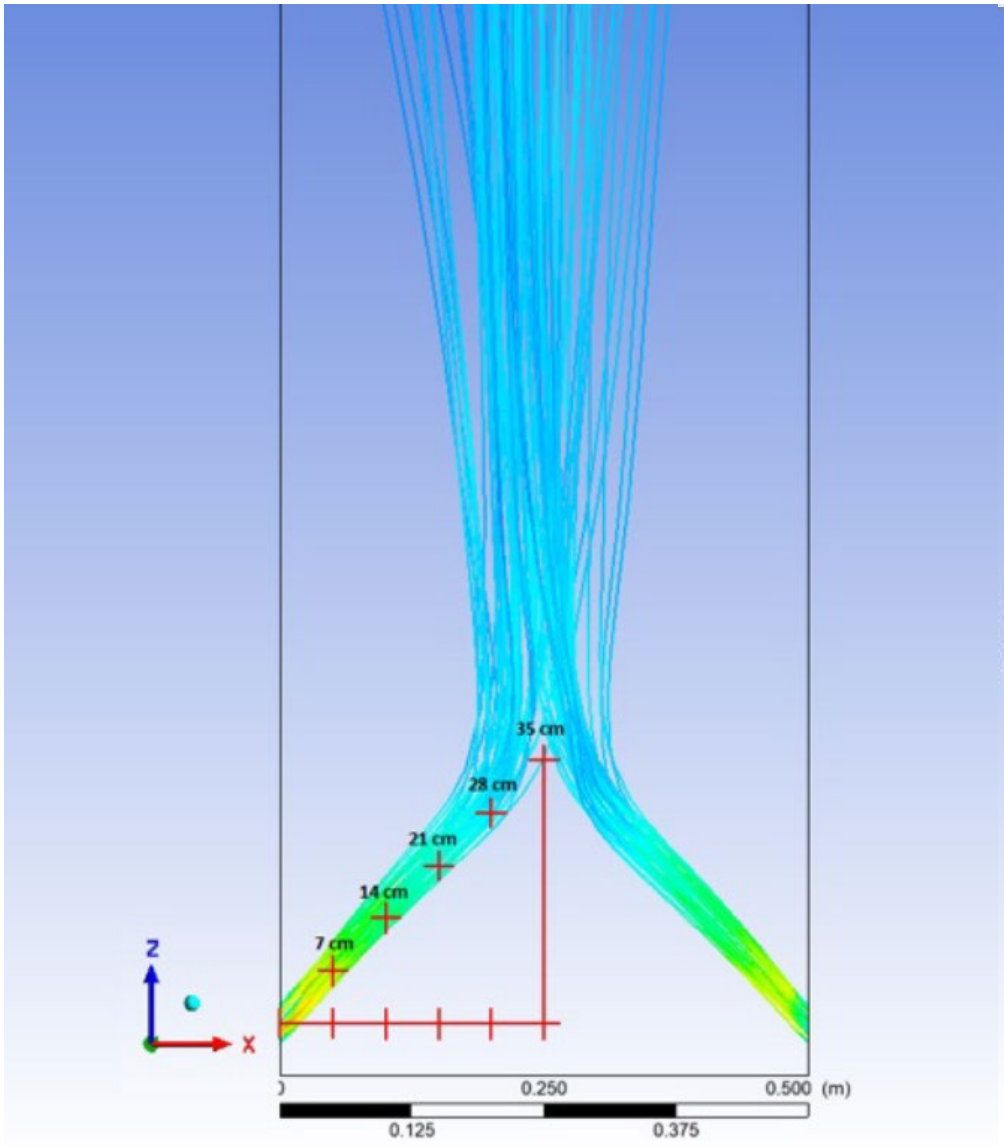
- 0.5 m x 2.0 m
- 10 outlets at each side
- 6 mm outlets for air flow
- 7.7 cm distance between holes
- Element type: Quadratic
- Mesh sensitivity analysis performed

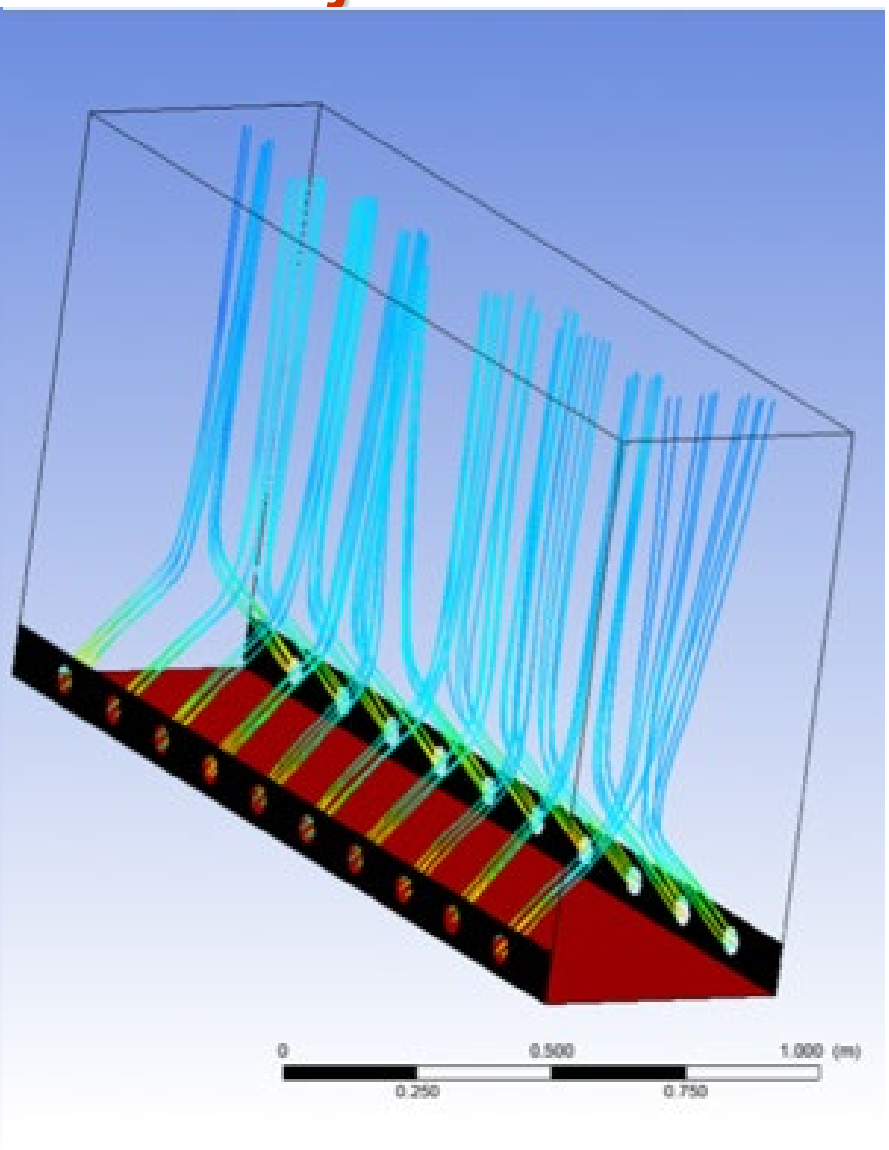




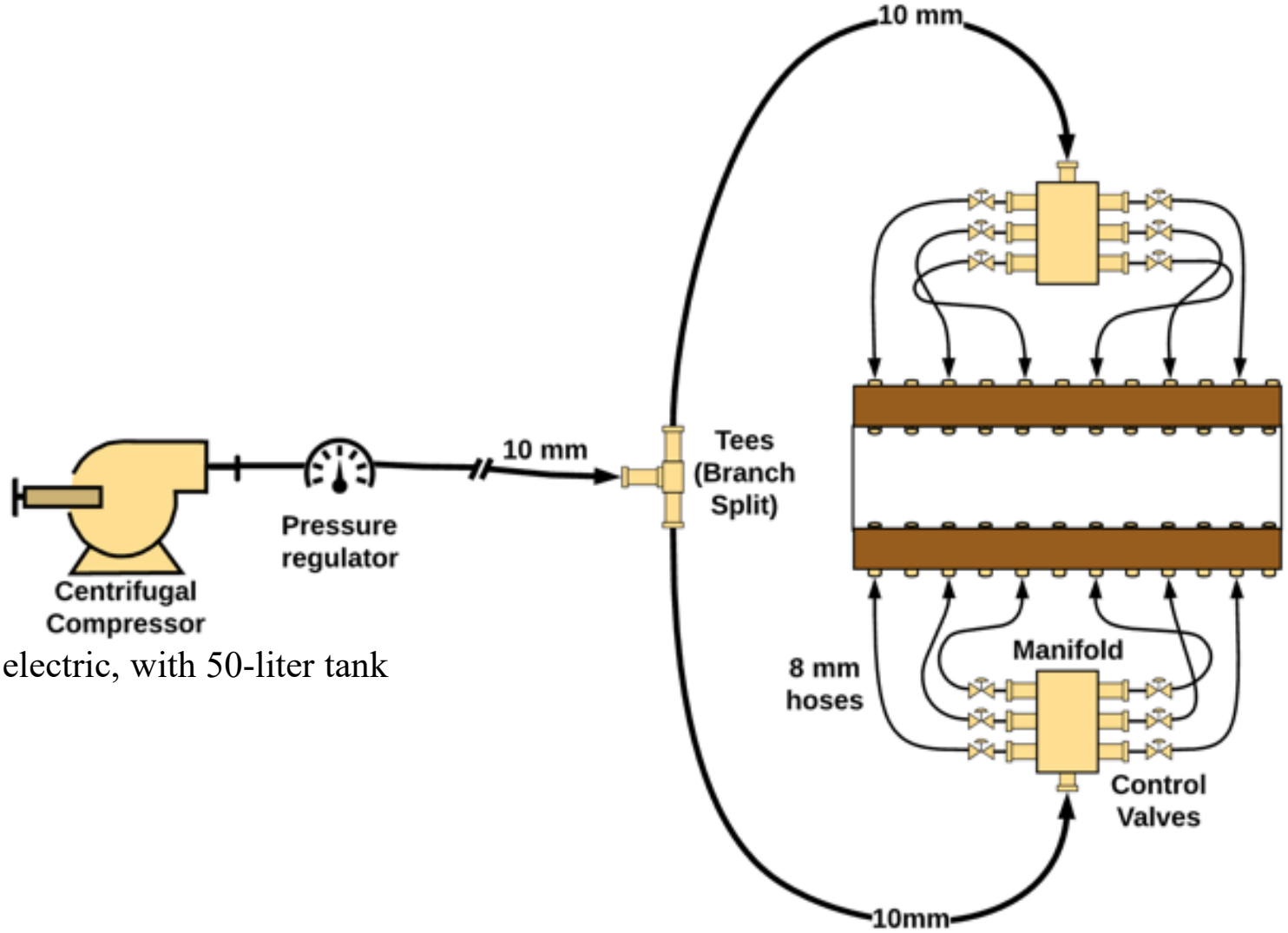


CFD model with airflow trajectories



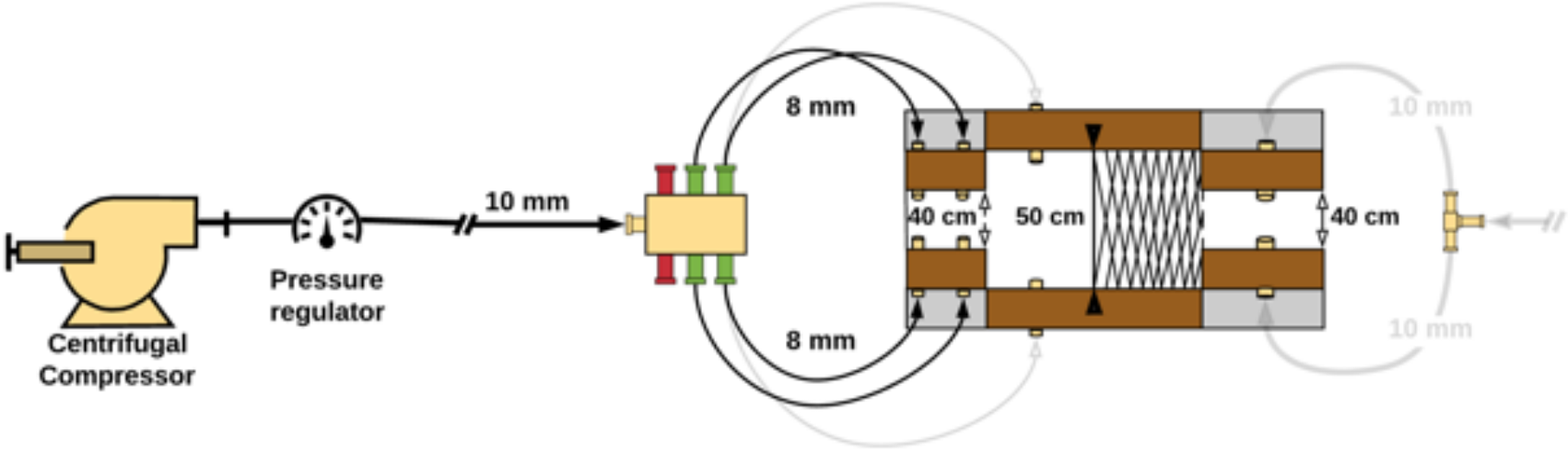


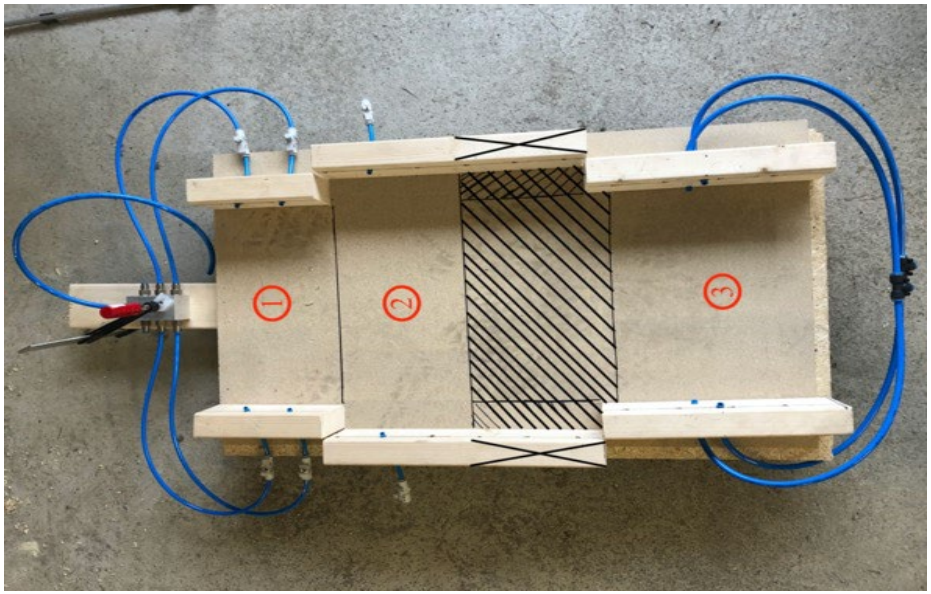
Initial Experimental Setup



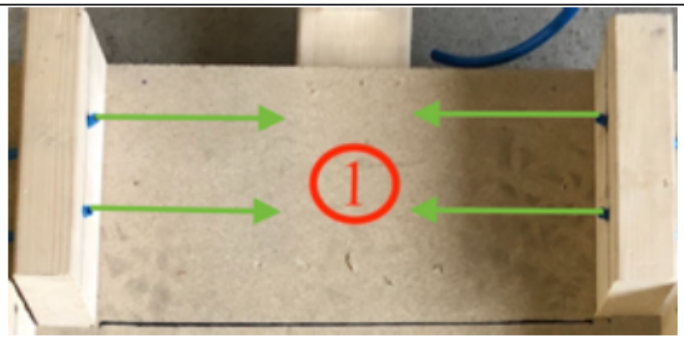
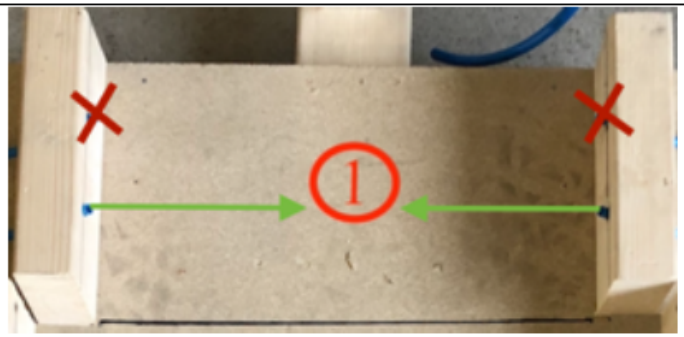
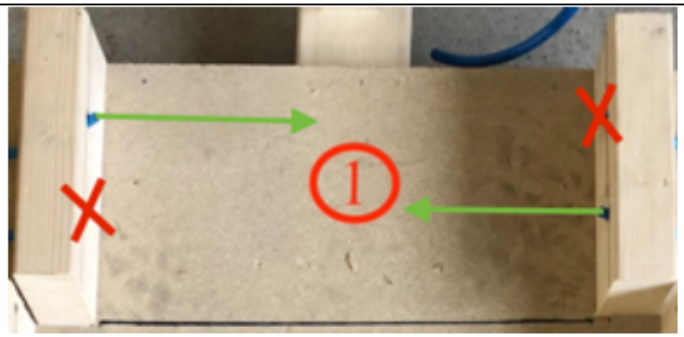
2200 W electric, with 50-liter tank

Modified Experimental Setup

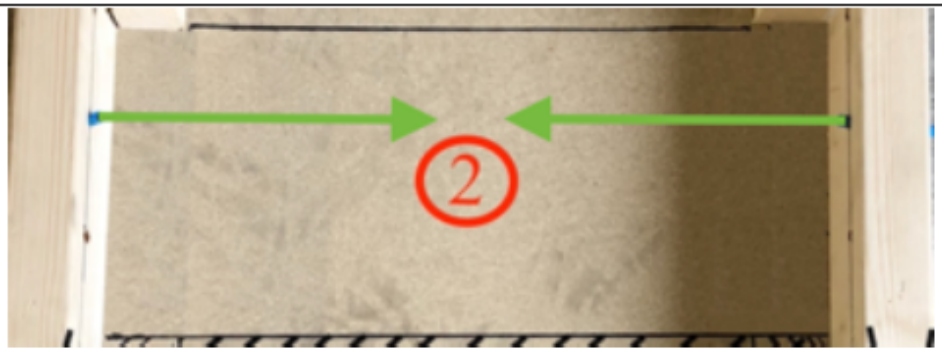
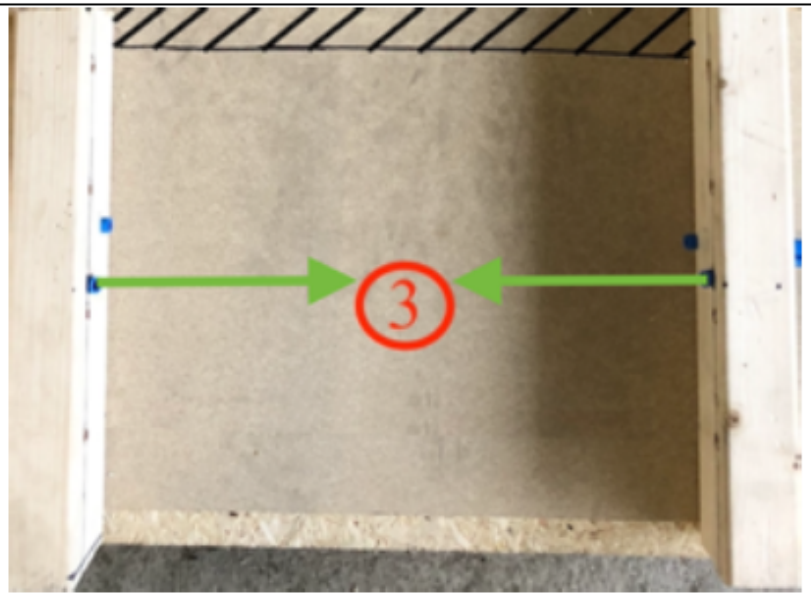




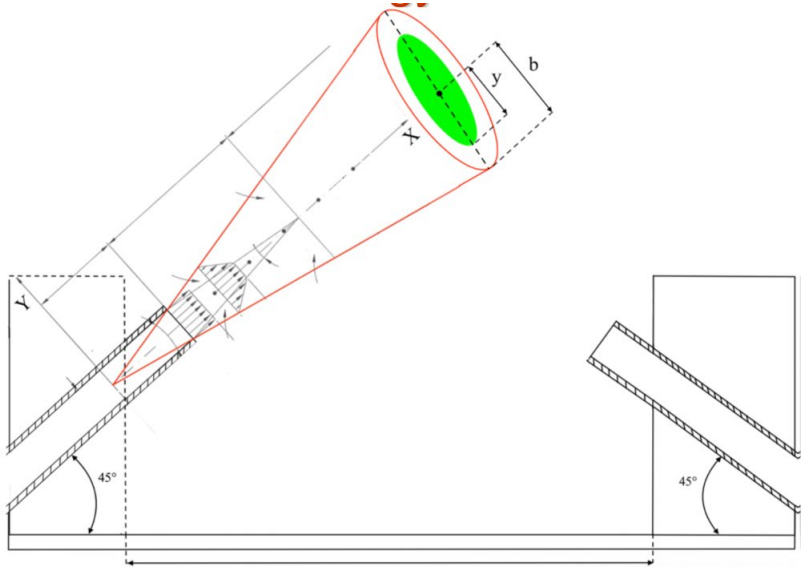
Case Review

Cases ↓	Details	Illustration
A	• 4 outlets • 8 mm hoses • Perpendicular flow • 40 cm between boards	
B1	• 2 outlets • 8 mm hoses • Perpendicular flow • 40 cm between boards	
B2	• 2 Outlets • 8 mm hoses • Parallel flow • 40 cm between boards	

Case Review

C	• 2 Outlets • 8 mm hoses • Perpendicular flow • 50 cm between boards	
D	• 2 Outlets • 10 mm hoses • Perpendicular flow • 40 cm between boards	

Experimental Results

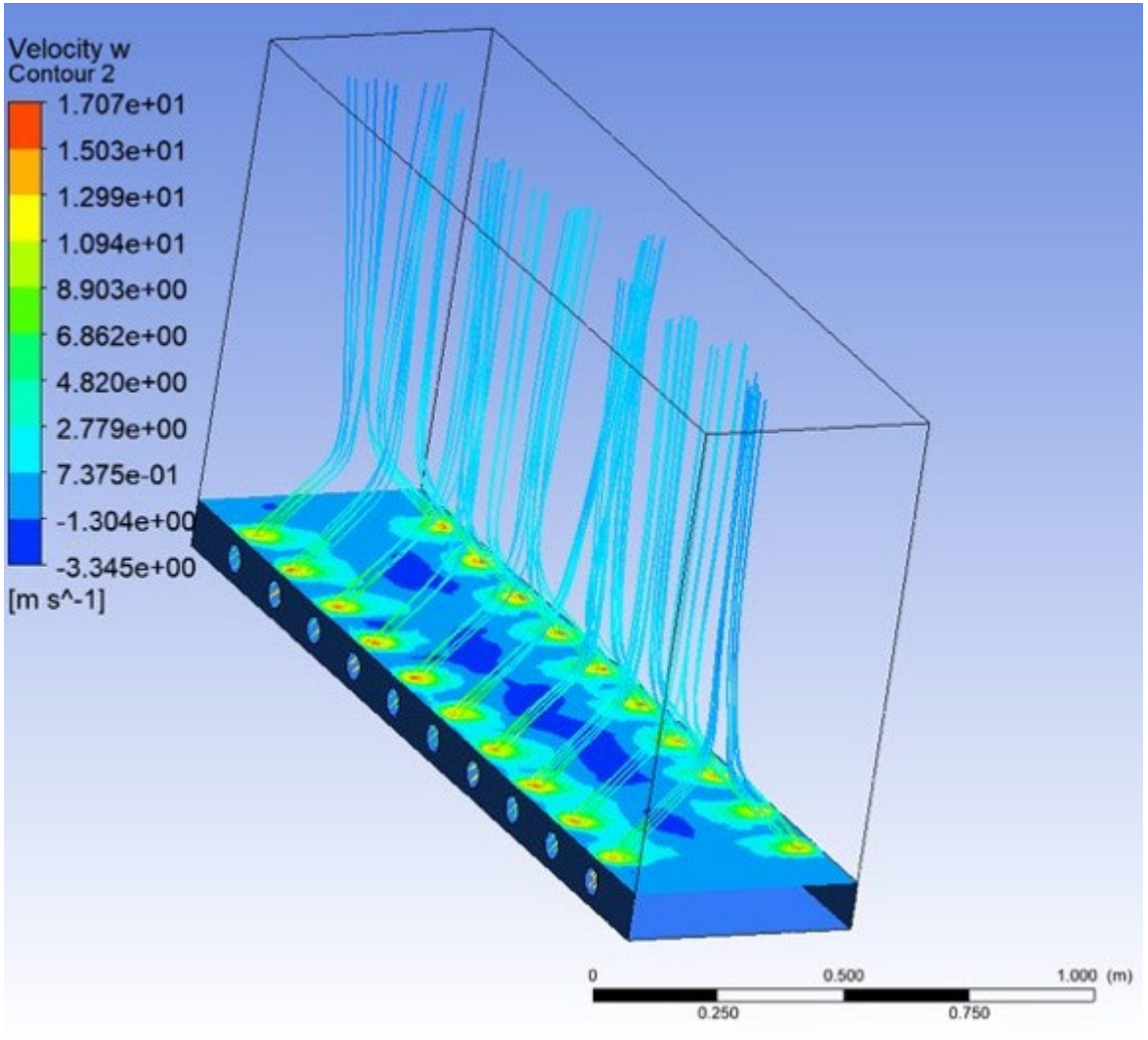


Airflow from circular cross-section

Cases	Distance to control cross-section X_d (cm)	V_0 (m/s)	V_{xm} (m/s)	y (cm)	b (cm)	Percent of the airflow ≥ 3 m/s at the control cross-section (green contour in Figure 45)
A	28	57.8	8.4	3.7	6.8	~30%
B1		115.5	16.7	4.7	6.8	~45%
B2	58	115.5	8.2	7.4	13.8	~29%
C	35	115.5	13.5	5.5	8.4	~43%
D	28	65	12.4	4.4	6.9	~39%

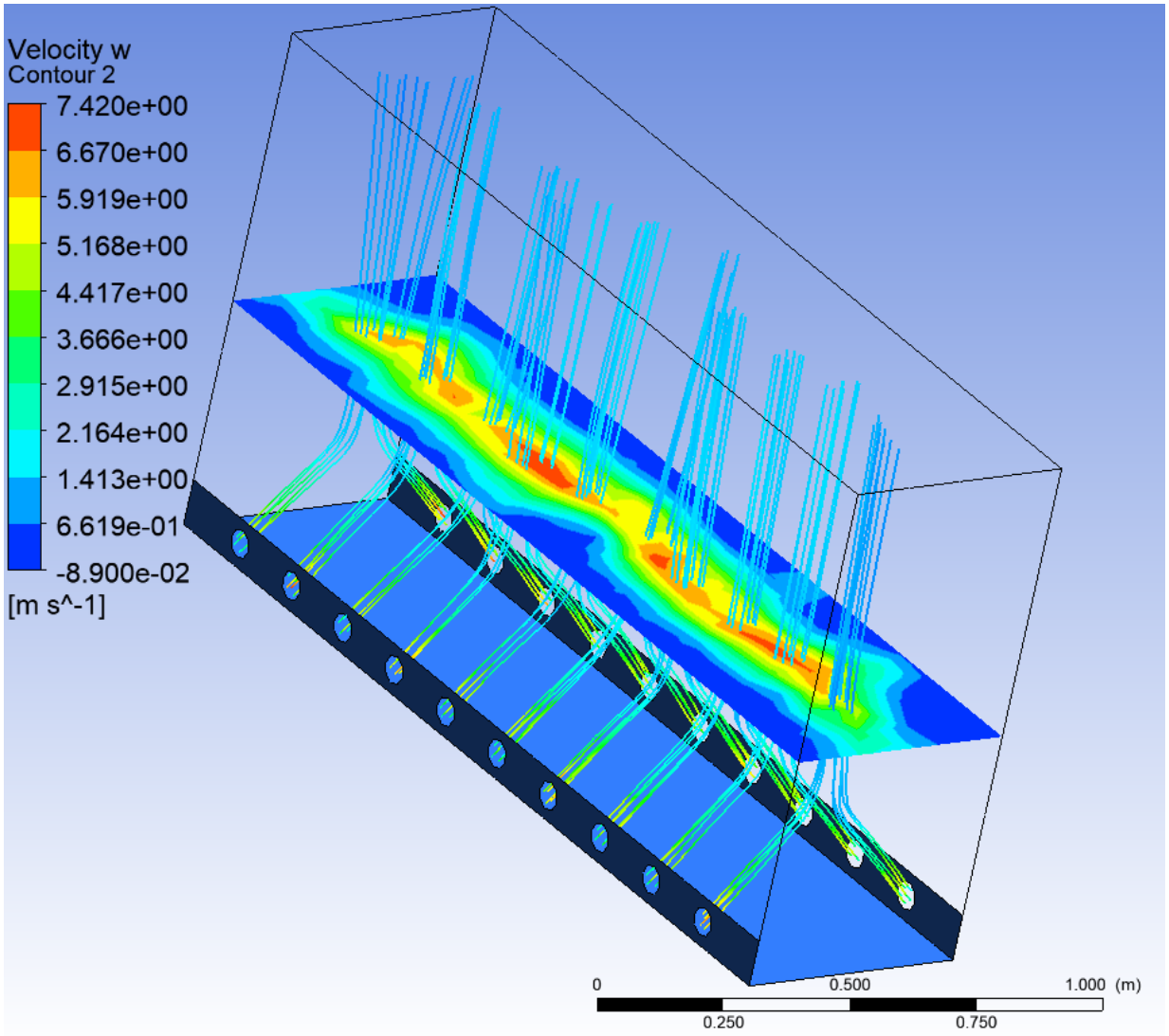
CFD Analysis Results

- *Velocity profile at 0.1m offset*



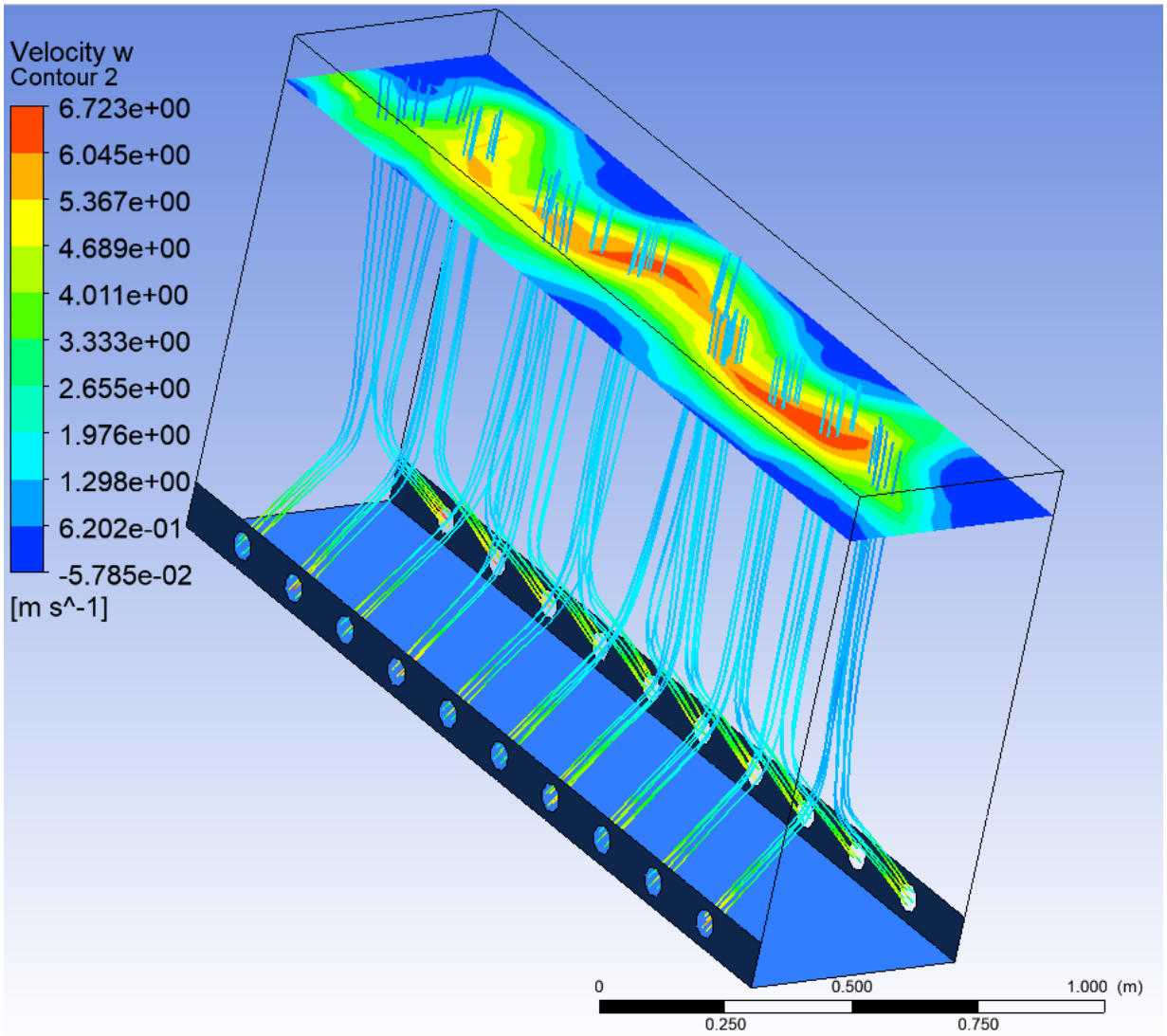
CFD Analysis Results

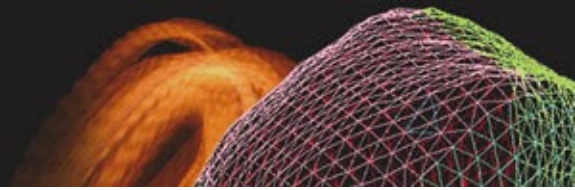
- *Velocity profile at 0.5m offset*



CFD Analysis Results

- *Velocity profile at 1.0 m offset*





Thank you