CHAPTER 4

RESULT AND DISCUSSIONS

4. RESULT AND DISCUSSIONS

4.1 Position of Car

Position of car in CFD was same with position in wind tunnel experiment. The dimension car in wind tunnel experiment was measured and applied in CFD. Figure below showed dimension of the model in wind tunnel.

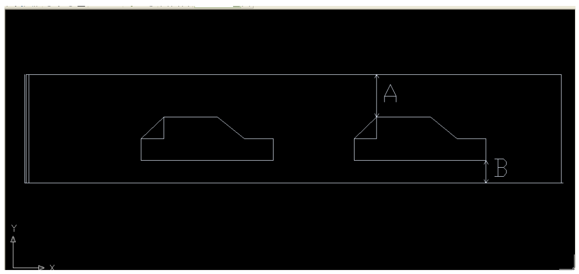

Figure 4.1: Front view of wind tunnel

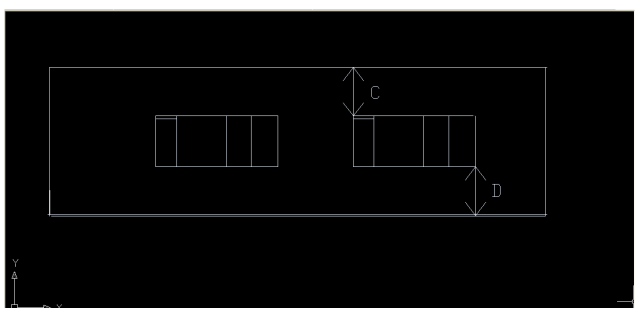

Figure 4.2: Top view of wind tunnel

DIMENSION:

1) A = 10 cm

2) B = 7 cm

3) C = D = 9.2 cm

4.2 Boundary Condition

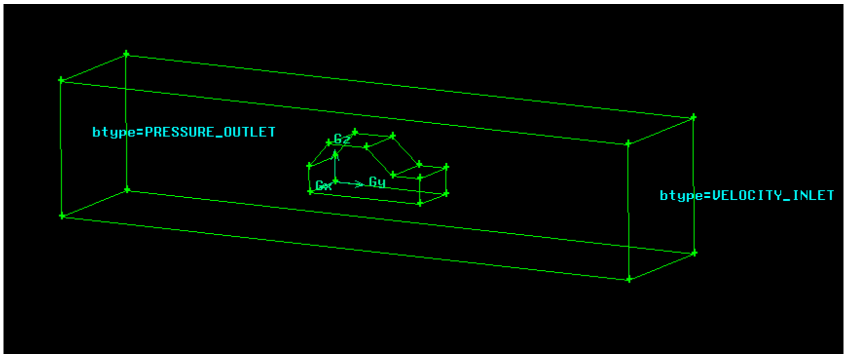

Figure 4.3: Boundary types

The figure shows the outer edges of car geometry those present wall boundaries. For example, the front and the back will show the velocity inlet and pressure outlet.

4.3. Meshing Process

The model of car and wind tunnel were split into two because in the meshing process, only wind tunnel model was meshed. The parameters of the meshing process for single model and double model were same. Figure below showed the meshing process for single model and double model which separating distance were 12.5 cm.

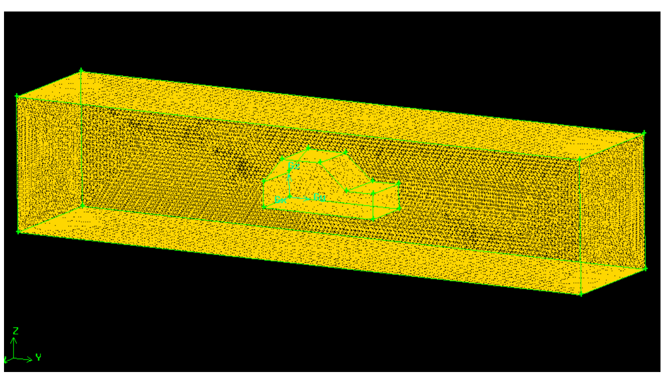

Figure 4.4: Meshing process for single model

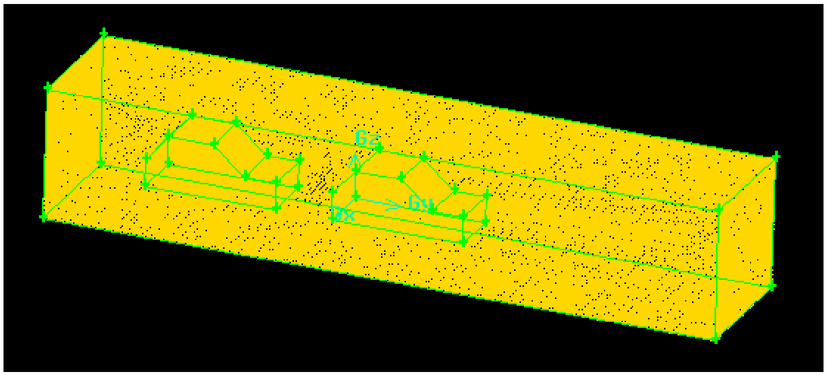

Figure 4.5: Meshing Process for double model (12.5 cm)

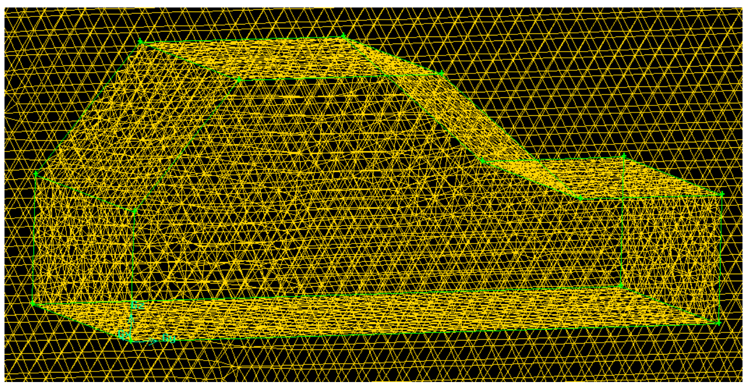

Figure 4.6: Meshing on body of the car

4.4 Postprocessing

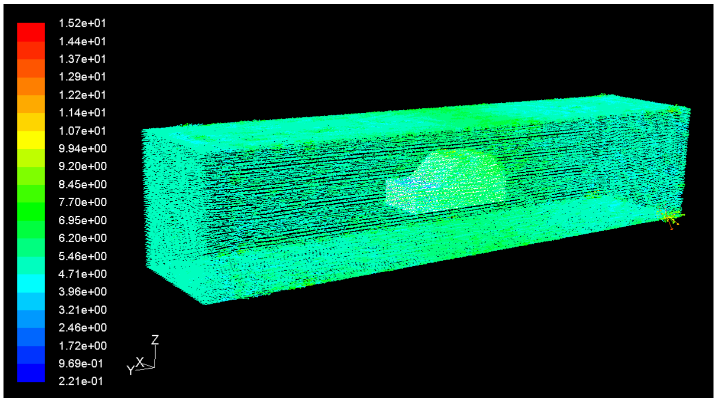

Figure 4.7: Velocity vector in wind tunnel

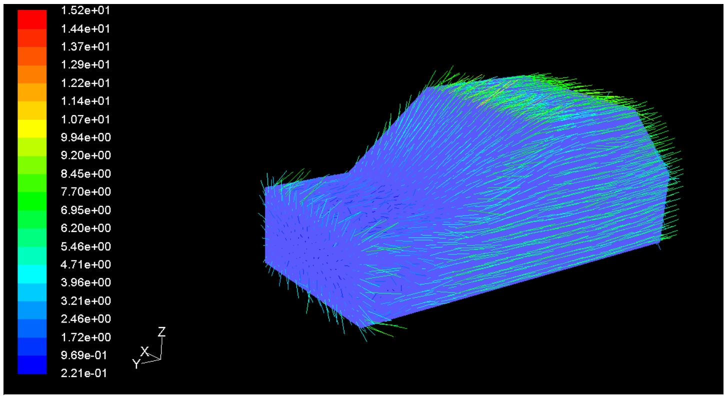

Figure 4.8: Velocity vector in m/s for single car

This figure illustrated the flow of velocity vector when simulation was run. The magnitude of the velocity changes from 5.46 m/s until 9.2 m/s when it flows into the model.

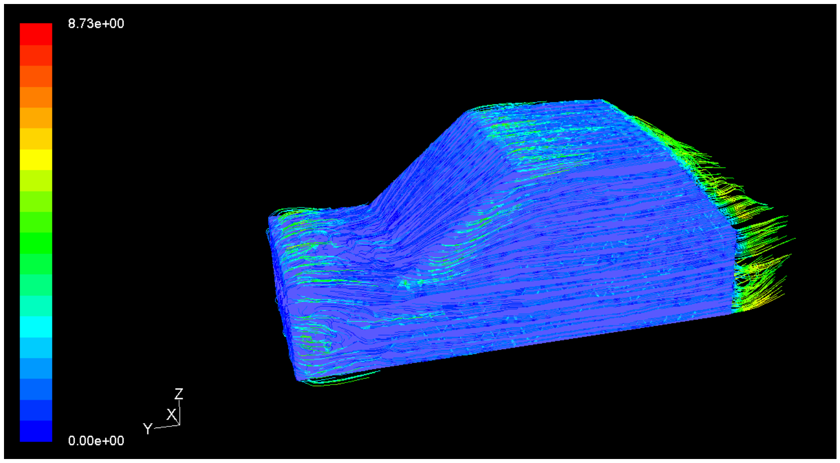

Figure 4.9: Path lines

Pathlines are the lines traveled by neutrally buoyant particles in equilibrium with the fluid motion. This figure shows that pathline that flow into model colored by velocity magnitude. The maximum velocity of air that flow into model is 8.73 m/s.

4.5 Convergence History

For the single model, with steady state condition, the simulation was started with speed 5 m/s. in this case the residuals scale were monitored and it showed that, the residuals have stagnated and do not changed with further iteration.

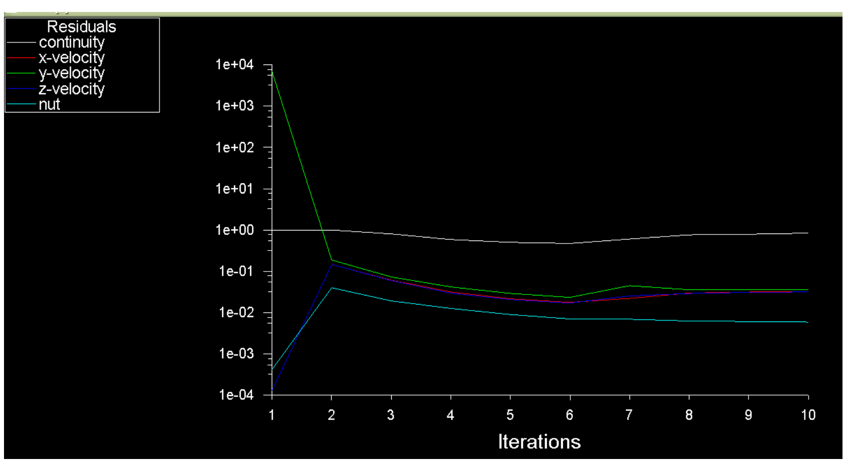

Figure 4.10: Residuals for the 10 iterations.

From the graph, the value of the Drag coefficient was not constant from 0 till 40 iterations but become constant from 50 until 90 iterations. The constant value means that the exact value for Drag coefficient.

Different value of speed will give different value for Drag coefficient. The same iteration was used for each speed and the value of Drag coefficient was used to calculate Drag force.

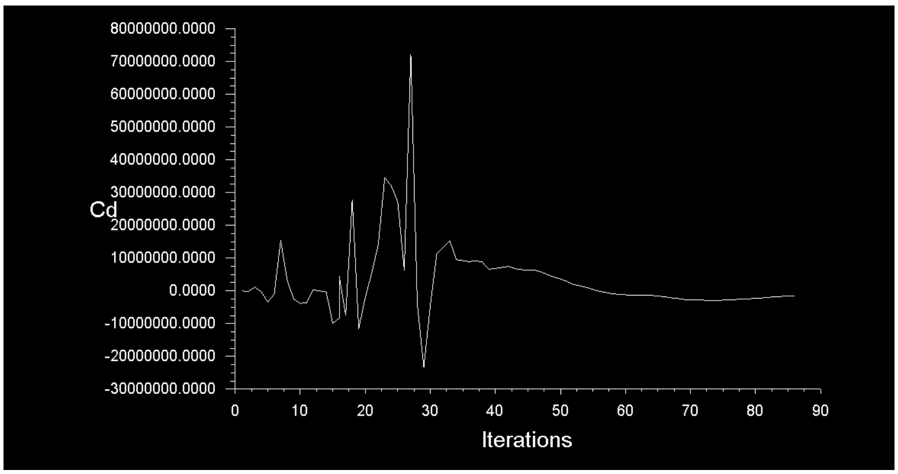

Figure 4.11: Convergence history for Drag coefficient

For double model with different separating distances, the same conditions such as the speed and steady state condition were used.

4.6 Single Model

The simulation was run on different velocity which is from 5 m/s with increment of 5 m/s until 30 m/s. By increasing this value, the drag and lift force can be obtained. Below are the equation that used to get value of drag force, lift force and Reynolds number.

$$F_D = 0.5\rho V^2 A_f C_D \qquad \text{..................} \quad (4)$$

$$F_L = 0.5\rho V^2 A_p C_D \qquad \text{..................} \quad (5)$$

$$\mathrm{Re} = \left[\frac{\rho V L}{\mu}\right] \qquad \text{..................} \quad (6)$$

- A_f is the frontal area (0.01476 m^2)
- ρ is the density of the air (1.185 kg/m^3)
- V is the speed of the air
- C_D is drag coefficient
- µ is Kinematics viscosity (1.572×10^{-5} m^2/s)
- A_P is the top area (5.085×10^{-3} m^2)
- L is the width of the Car (12.5 cm)

Below are the results of the test for single model:

Table 4.1: Single Model

VELOCITY (m/s)	DRAG FORCE (N)	DRAG COEFFICIENT	LIFT FORCE (N)	LIFT COEFFICIENT	REYNOLDS NUMBER
5	10.5310903	48.168	1.954368582	25.947	4711.354962
10	16.2610108	18.594	3.169832636	10.521	9422.709924
15	20.1531066	10.242	3.941276079	5.814	14134.06489
20	24.1790054	6.912	4.522909185	3.753	18845.41985
25	25.0880794	4.59	4.626626977	2.457	23556.77481
30	26.0679902	3.312	4.88083725	1.8	28268.12977
35	29.1179136	2.718	5.248255832	1.422	32979.48473
40	32.1127416	2.295	5.4231525	1.125	37690.83969
45	34.9048973	1.971	5.490941906	0.9	42402.19466
50	37.3861575	1.71	5.694310125	0.756	47113.54962

The table showed the result for all the force that react on the model of the car like Drag force and Lift force. Based on this result several graphs were plotted to see the relationship between the forces.

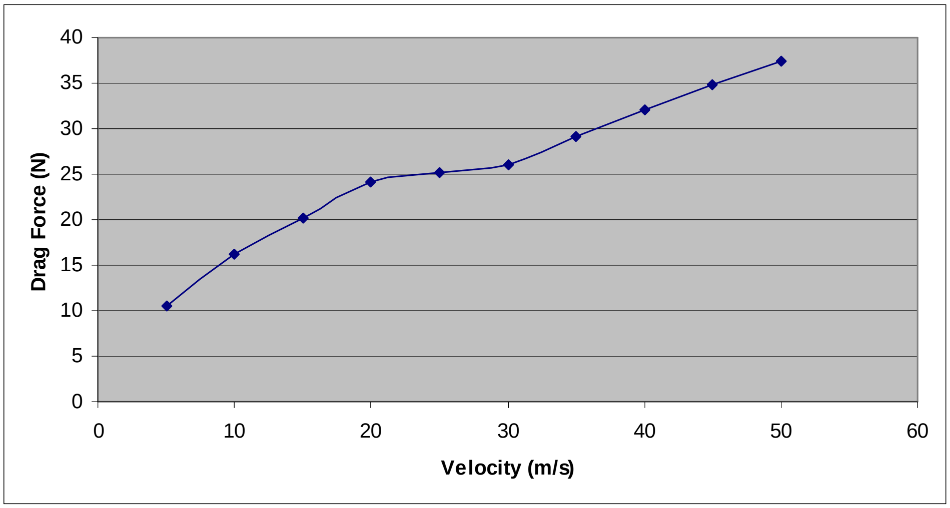

Figure 4.12: Drag force versus velocity

From the graph, the Drag forces showed directly proportional with velocity. The slope increased until maximum drag force which is 37.39 N at 50 m/s.

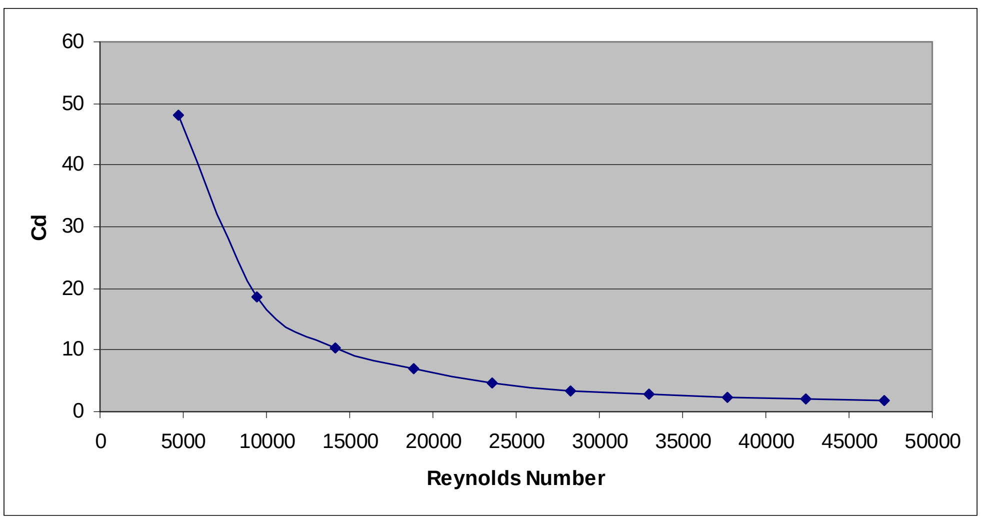

Figure 4.13: Drag coefficient versus Reynolds number

For the Drag coefficient, it showed that drag coefficient inversely proportional with Reynolds number. The slope decrease until certain constant of drag coefficient.

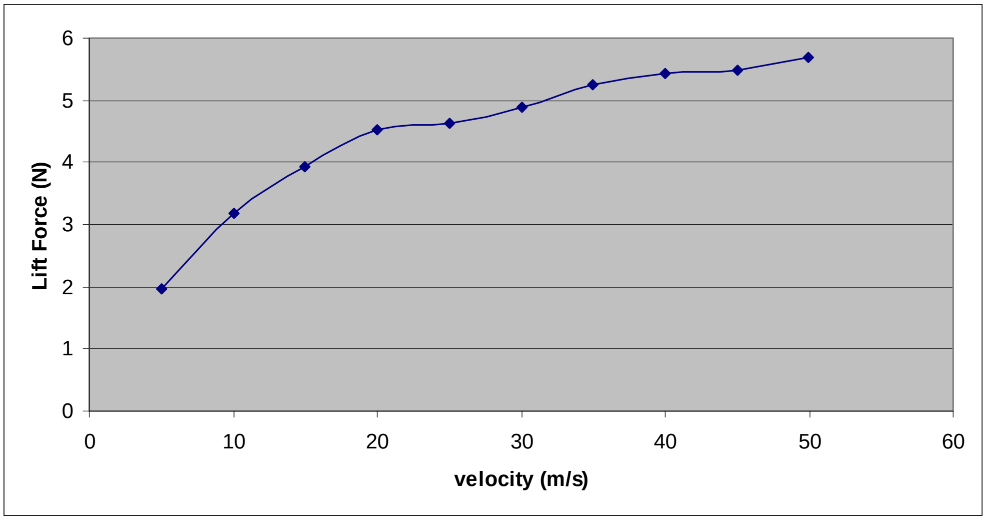

Figure 4.14: Lift force versus velocity

The value of lift force smaller compared to drag force which is 5.69 N when velocity of air is 50 m/s. Plotting Lift force against velocity showed the relationship of two variables which is directly proportional to each other.

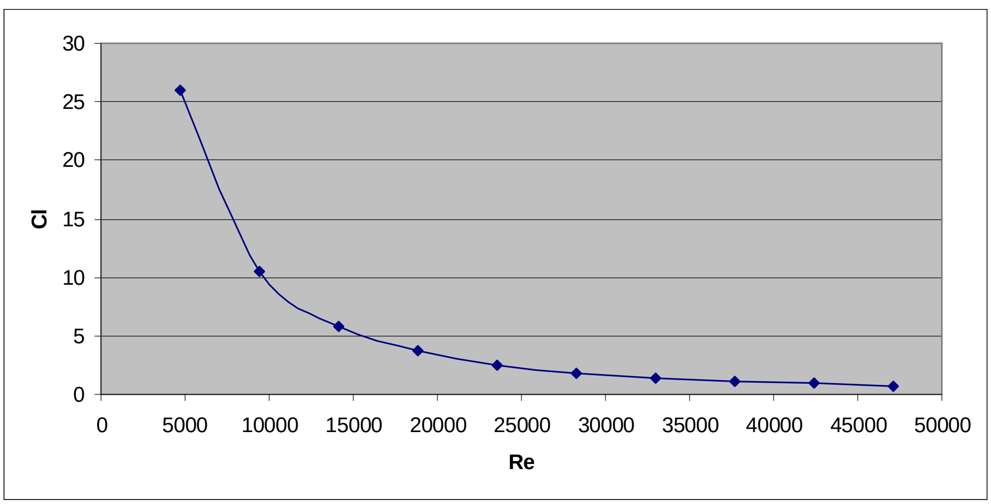

Figure 4.15: Lift coefficient versus Reynolds number

For lift coefficient versus velocity and Reynolds number, it showed that there are indirectly proportional each other. The Lift coefficient was decreased until certain constant value when Reynolds number increases.

4.7 Two Models

The distance between two cars in the simulation must be same with the distance that test in wind tunnel. In the wind tunnel test, the distance was set up according to certain value. Therefore the setups for computational simulation were:

- Half width distance (0.5W) between the models – approximately 6.25cm
- One width distance (1W) between the models – approximately 12.5cm
- One and Half width distance (1.5W) between the models – approximately 18.75cm
- Twice width distance (2W) between the models – approximately 25.0cm

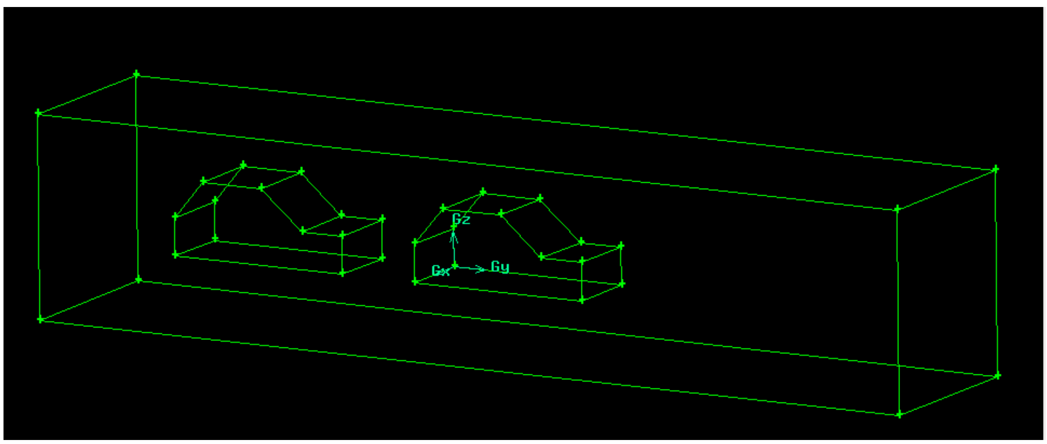

Figure 4.16: Position of two cars

4.7.1 Half Width Distance (6.25cm)

For the first case, the distance was half width separating distance which is 6.25 cm. between two cars. Below was the result for this distance.

Table 4.2: Half Width Distance (6.25cm)

VELOCITY (m/s)	DRAG FORCE (N)	DRAG COEFFICIENT	LIFT FORCE (N)	LIFT COEFFICIENT	REYNOLDS NUMBER
5	0.491923125	2.25	0.648744618	8.613	4711.354962
10	0.88152624	1.008	3.430143956	11.385	1085.496183
15	1.540703228	0.783	10.35957706	15.282	1628.244275
20	1.7315694	0.495	20.75982777	17.226	2170.992366
25	2.262846375	0.414	37.06385787	19.683	2713.740458
30	3.89603115	0.495	62.59673773	23.085	3256.48855
35	5.39934822	0.504	85.30076567	23.112	3799.236641
40	7.30407456	0.522	111.2830893	23.085	4341.984733
45	8.447303903	0.477	148.7496162	24.381	4884.732824

The simulation was started with speed 5 m/s. the speed was increased until 45 m/s with increment 5m/s. The density, area of the car and viscosity were same with single model. Using the same equation, the drag force and lift force were calculated. The graph was plotted to see the relationship between drag force and lift force with velocity.

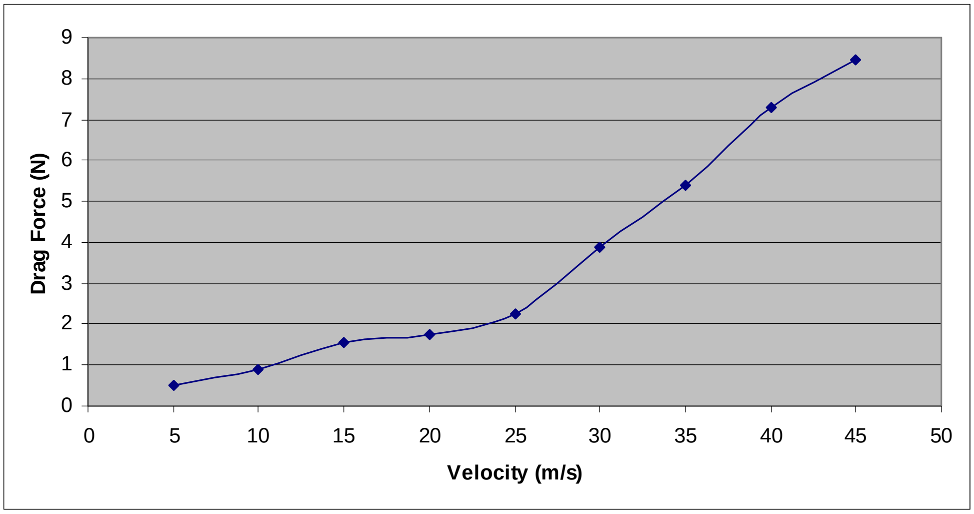

Figure 4.17: Drag Force versus velocity (0.5W)

It is observed from the graph that when velocity of air increase, the drag force increase as well. But in this case the drag force much smaller compare to single model. For the maximum speed which is 45 m/s, the drag force is 8.45N.

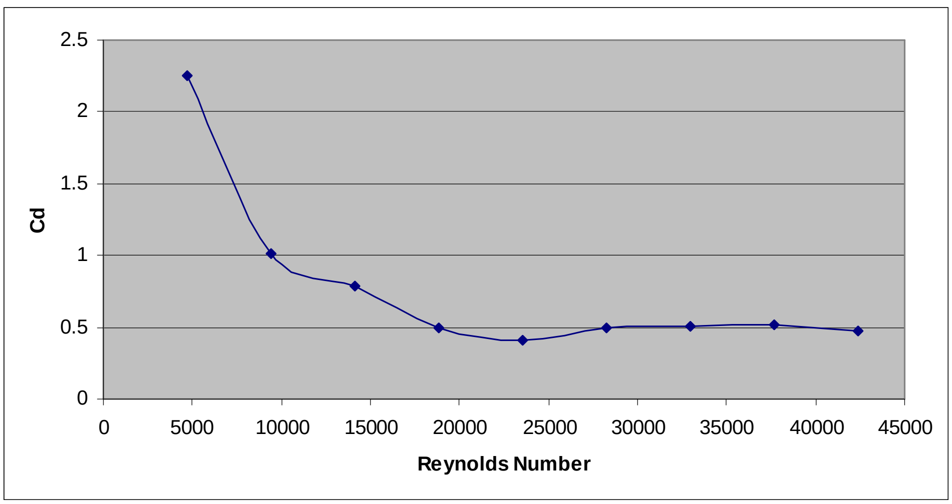

Figure 4.18: Drag coefficient versus Reynolds number (0.5W)

The Reynolds number still same for this case because the density and viscosity same as well. The drag coefficient was decreased until certain value when Reynolds number increased.

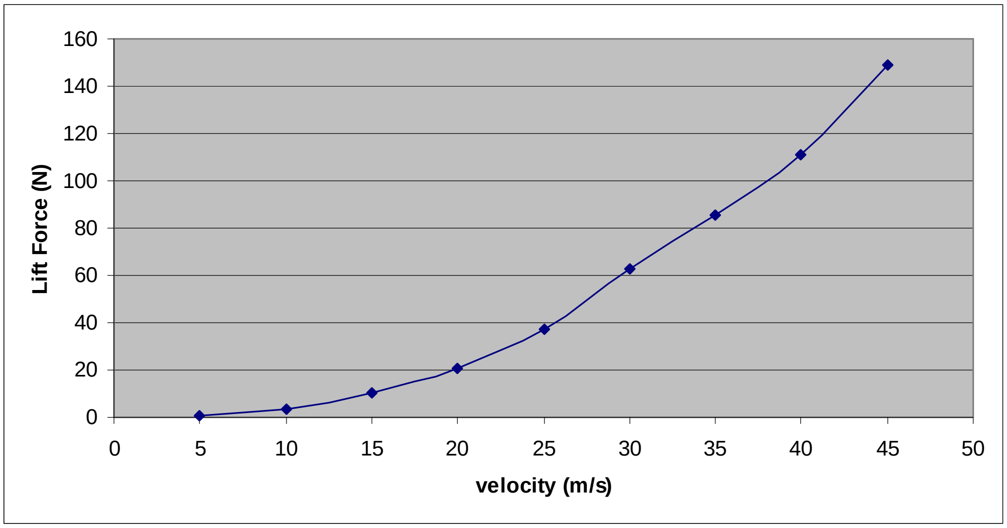

Figure 4.19: Lift force versus velocity (0.5W)

Plotting the lift force against velocity showed the relationship between two variables which is directly proportional to each other. The maximum value of the lift force is 148.75 N when the velocity is 45 m/s.

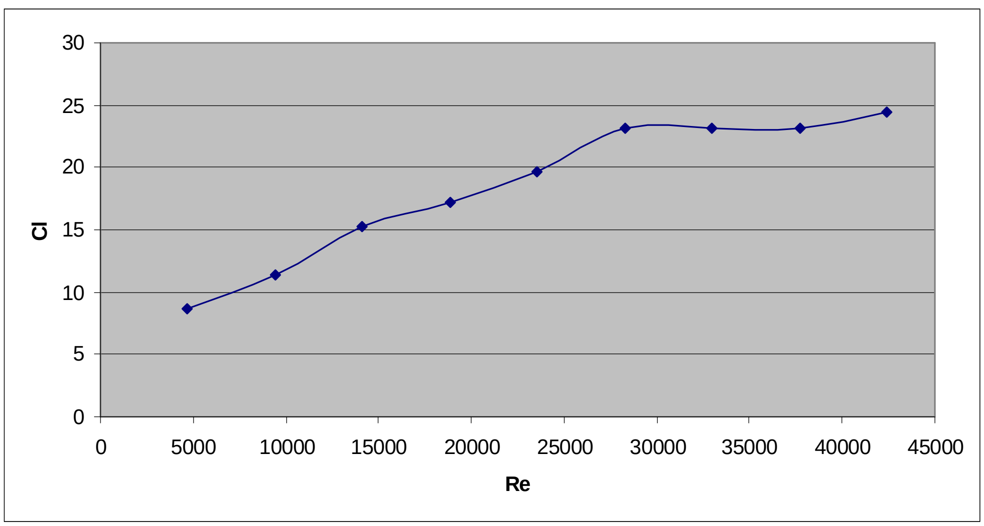

Figure 4.20: Lift coefficient versus Reynolds number (0.5W)

For Lift coefficient, the value is much lower than single model, but the relationship with velocity and Reynolds number still same as single model which is indirectly proportional to each other.

4.7.2 One Width Distance (12.5 cm)

The simulation continued with one width separating distance which is 12.5 cm between two cars. The density, viscosity and temperature still same as single model. Table below illustrate the drag and lift force that get from the calculation.

Table 4.3: One Width distance (12.5 cm)

VELOCITY (m/s)	DRAG FORCE (N)	DRAG COEFFICIENT	LIFT FORCE (N)	LIFT COEFFICIENT	REYNOLDS NUMBER
5	11.54641959	52.812	1.296811342	17.217	4711.354962
10	20.62928817	23.589	6.857576336	22.761	9422.709924
15	25.82006099	13.122	20.71305308	30.555	14134.06489
20	28.20883968	8.064	41.50880924	34.443	18845.41985
25	32.56531088	5.958	74.11076838	39.357	23556.77481
30	36.55185588	4.644	125.1934755	46.17	28268.12977
35	38.66318993	3.609	170.5683145	46.215	32979.48473
40	39.29088384	2.808	231.1998374	47.961	37690.83969
45	42.07713642	2.376	297.4443231	48.753	42402.19466
50	43.09246575	1.971	371.7571039	49.356	47113.54962

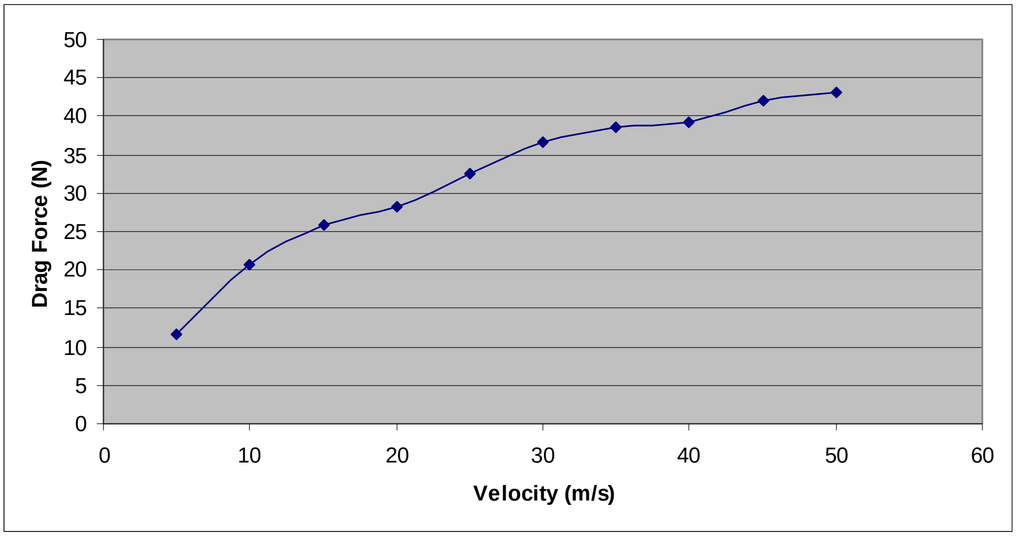

Figure 4.21: Drag force versus velocity (1W)

The speed of the air that flow in the simulation was started by 5 m/s. After that, the speed was increased by 5 m/s until up to 50 m/s. At the maximum speed which is 50 m/s, the drag force is 43.09 N. at this case, the drag value much higher compared to previous case.

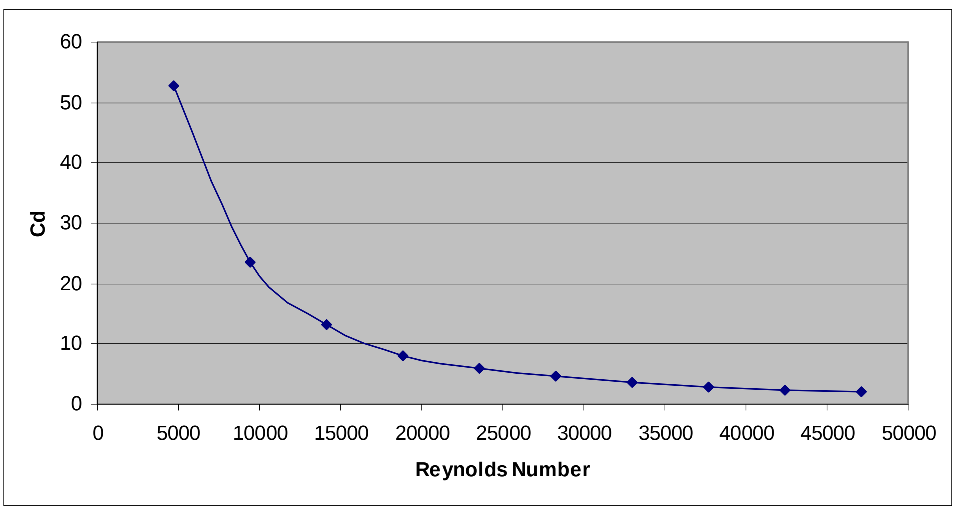

Figure 4.22: Drag coefficient versus Reynolds number (1W)

The relationship between drag coefficient and Reynolds number still same as previous case which is indirectly proportional to each other. The drag coefficient becomes smaller as Reynolds number decrease until certain constant value which is 1.97.

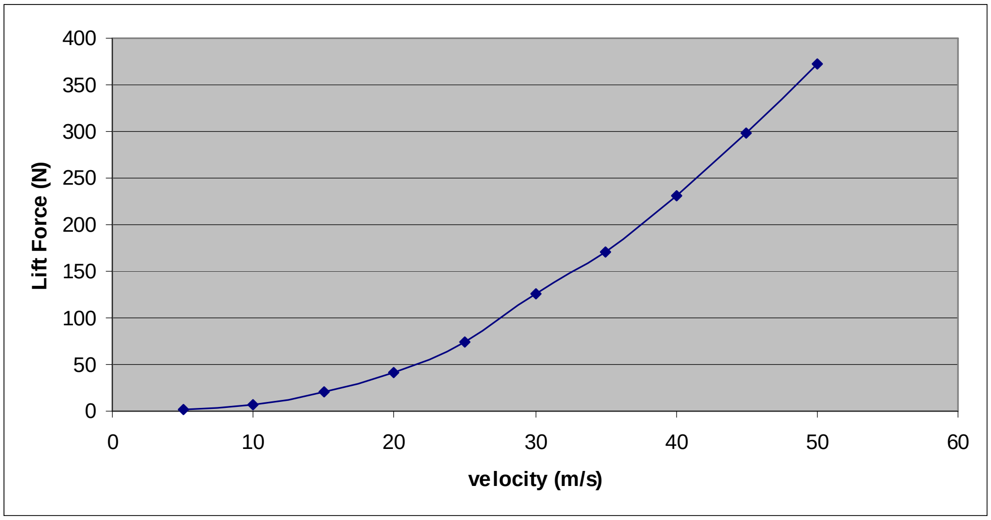

Figure 4.23: Lift force versus velocity (1W)

The lift force also showed same pattern as previous case but the value of lift force much higher. At 50 m/s, the lift force is 371.76 N.

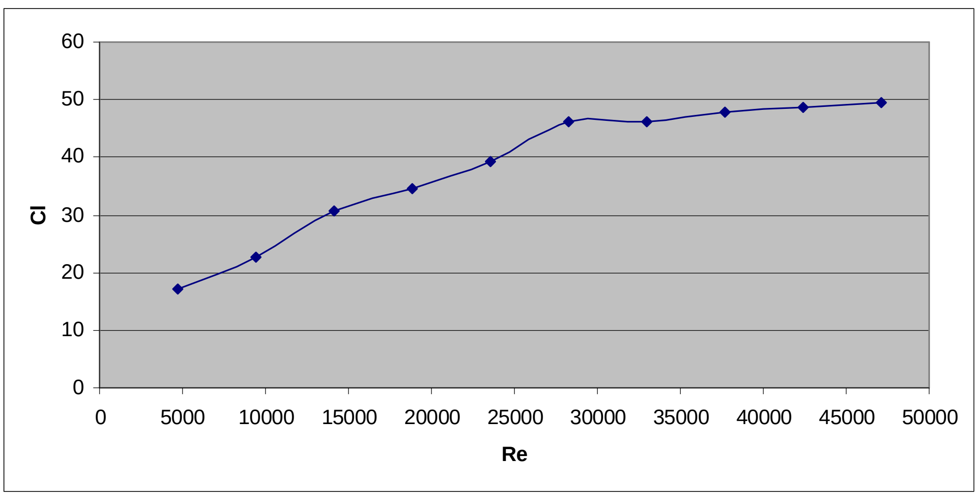

Figure 4.24: Lift coefficient versus Reynolds number (1W)

For the lift coefficient it showed different relationship with Reynolds number if compare with drag coefficient. Lift coefficient increase as Reynolds number increased.

4.7.3 One and Half Width Distance (18.75 cm)

For the third case, the distance was changed to one half width separating distance which is 18.75 cm.

Table 4.4: One and Half Width Distance (18.75 cm)

VELOCITY (m/s)	DRAG FORCE (N)	DRAG COEFFICIENT	LIFT FORCE (N)	LIFT COEFFICIENT	REYNOLDS NUMBER
5	3.31359417	15.156	1.054125267	13.995	4711.354962
10	5.63547132	6.444	6.212221189	20.619	9422.709924
15	7.68580691	3.906	18.52277736	27.324	14134.06489
20	9.88568712	2.826	37.85360445	31.41	18845.41985
25	11.7077704	2.142	67.09456484	35.631	23556.77481
30	13.2465059	1.683	108.8182665	40.131	28268.12977
35	15.4267092	1.44	153.4284411	41.571	32979.48473
40	16.119337	1.152	208.639523	43.281	37690.83969
45	17.3727571	0.981	270.6485266	44.361	42402.19466

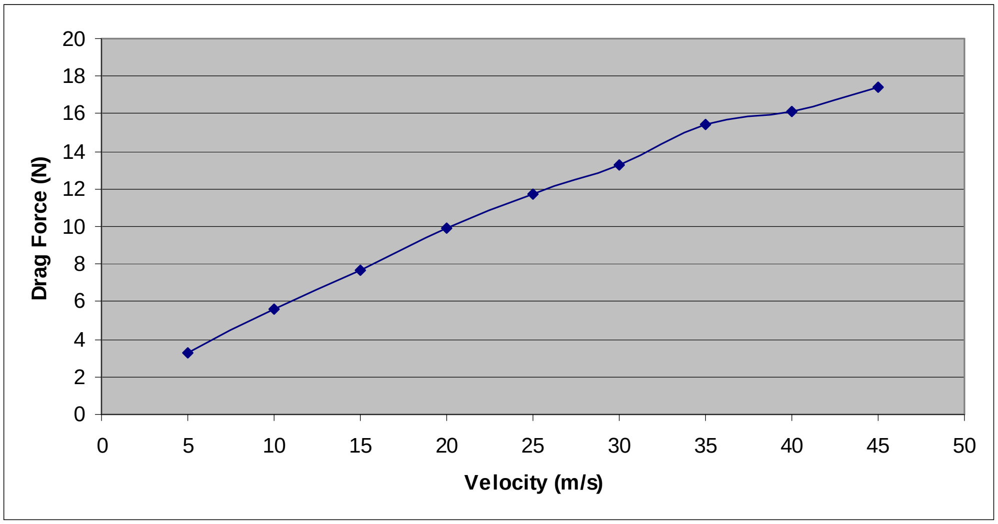

Figure 4.25: Drag force versus velocity (1.5W)

From the graph, it showed that when speed is 5 m/s, the drag force is 3.3 N. drag force increase as velocity increase until 17.37 N when speed is 45 m/s. for this case, the drag force much smaller compared to one width separating distance.

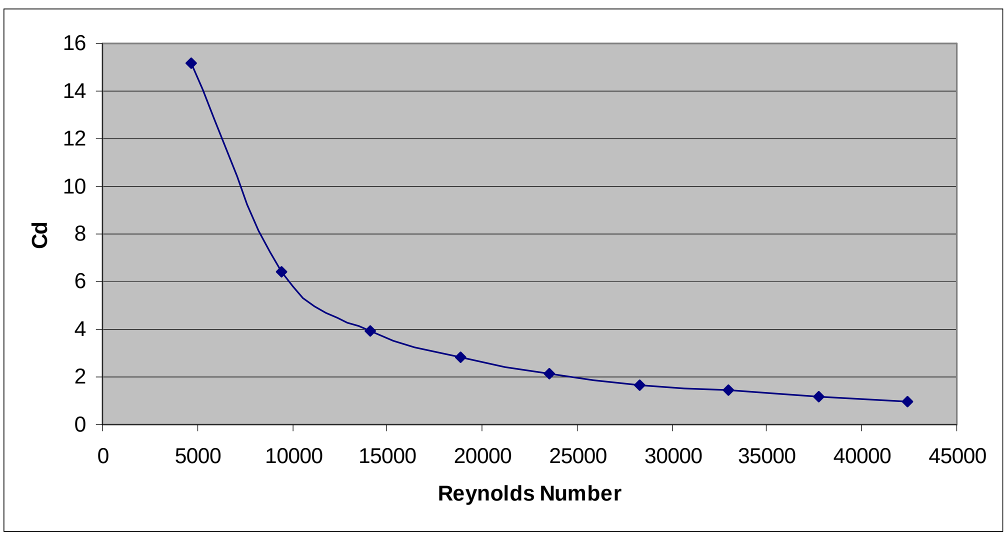

Figure 4.26: Drag coefficient against Reynolds number (1.5W)

Drag coefficient still show same relationship with Reynolds number which is indirectly proportional to each other. The slope decreased until certain value which is 0.96 when Reynolds number increases.

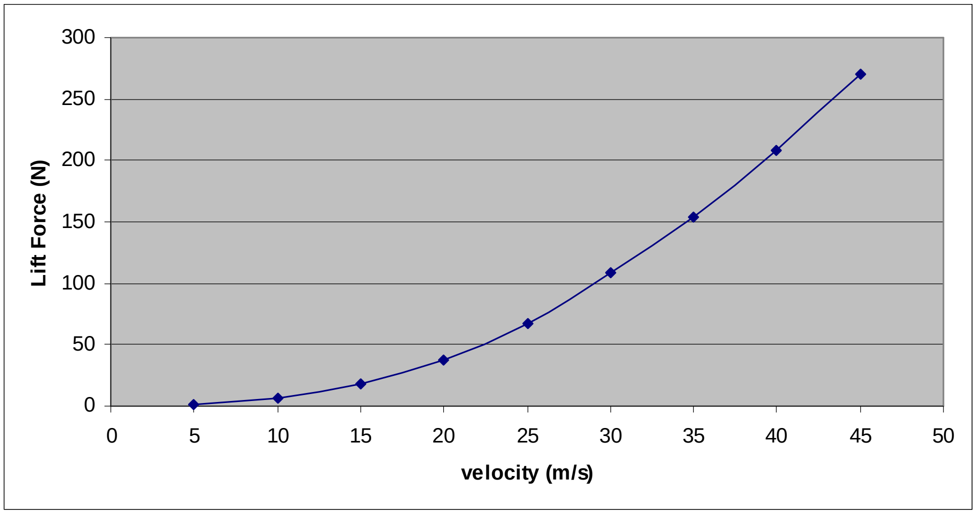

Figure 4.27: Lift force versus velocity (1.5W)

The value of lift force much smaller if compared to previous case. The maximum value of the lift force is 270.6 N when speed is 45 m/s.

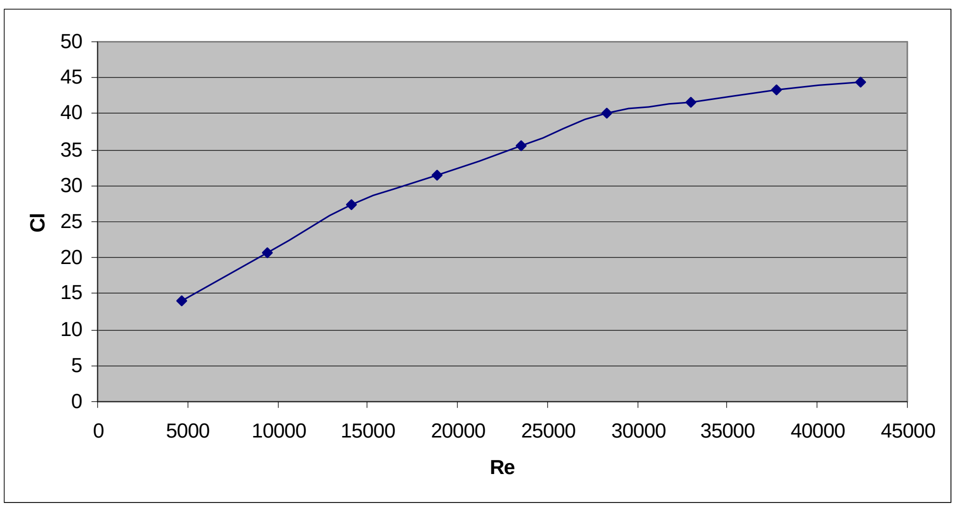

Figure 4.28: Lift coefficient versus Reynolds number (1.5W)

Lift coefficient will increase until certain value when Reynolds number increases. The maximum value for the lift coefficient is 44.36.

4.7.4 Two Width Distance (25cm)

For the last case, the simulation was done with different distance which was two width distance (25 cm). From this distance, the value of Drag force was decrease compare to first case. But, the relationship between velocity and Drag force still same which is directly proportional to each other.

Table 4.4: Two Width Distance (25 cm)

VELOCITY (m/s)	DRAG FORCE (N)	DRAG COEFFICIENT	LIFT FORCE (N)	LIFT COEFFICIENT	REYNOLDS NUMBER
5	7.62874382	34.893	1.523227958	20.223	4711.354962
10	13.789589	15.768	2.611247929	8.667	9422.709924
15	18.7894957	9.549	3.404383982	5.022	14134.06489
20	21.7862914	6.228	4.01313285	3.33	18845.41985
25	23.8582716	4.365	4.507995516	2.394	23556.77481
30	25.5721317	3.249	4.832028878	1.782	28268.12977
35	29.7928321	2.781	5.215039023	1.413	32979.48473
40	31.6090123	2.259	5.46653772	1.134	37690.83969
45	33.7892156	1.908	5.655670163	0.927	42402.19466
50	34.8281573	1.593	5.762099531	0.765	47113.54962

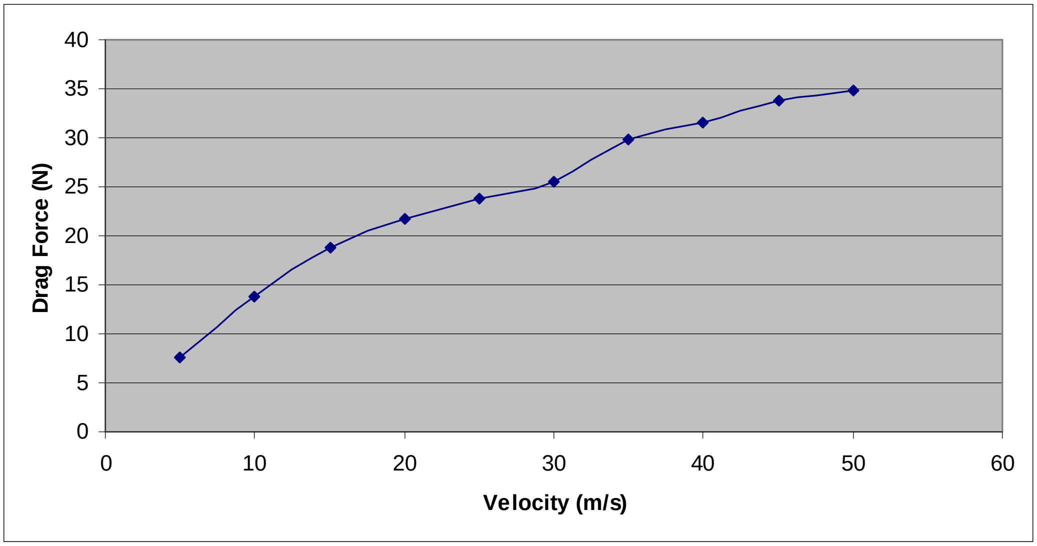

Figure 4.29: Drag force versus velocity (2W)

The graph showed the relationship between drag force and velocity which is directly proportional to each other. The drag force increase as velocity of air increased until maximum value which is 34.83 N at 50 m/s.

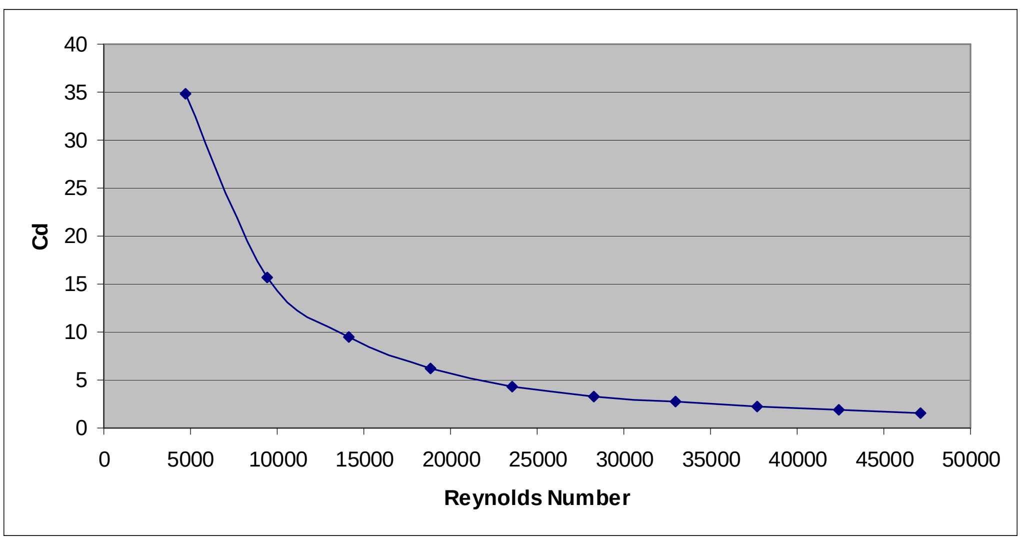

Figure 4.30: Drag coefficient versus Reynolds number (2W)

The value of Reynolds number still same as previous case. The slope decrease until certain value of drag coefficient which is 1.59.

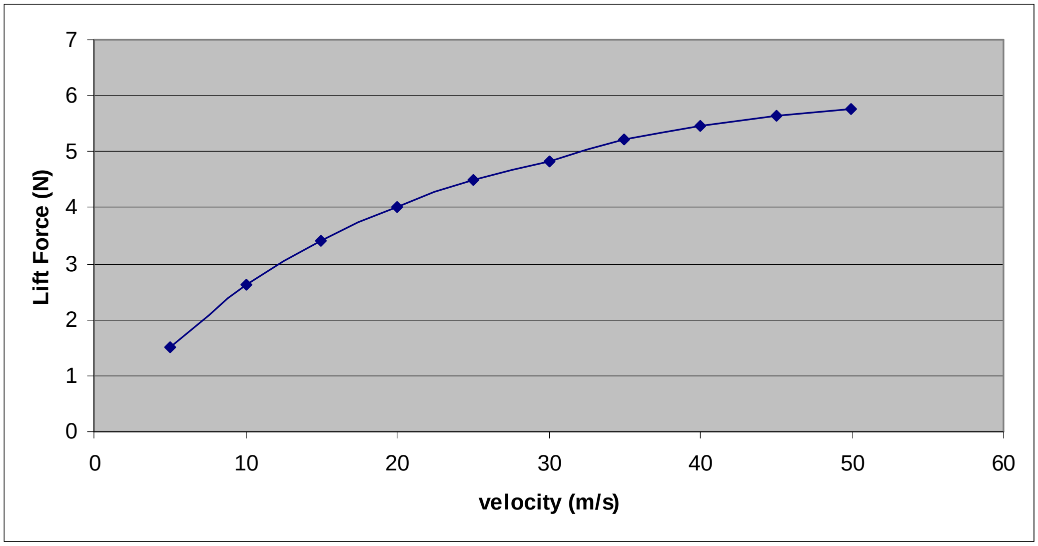

Figure 4.31: Lift force versus velocity (2W)

For the lift force versus velocity, it showed directly proportional to each other. Lift force increase higher when speed of air is 5 m/s to 20 m/s but the increment become lower from 30 m/s to 45 m/s. The maximum value for lift force is 5.76 N at 45 m/s.

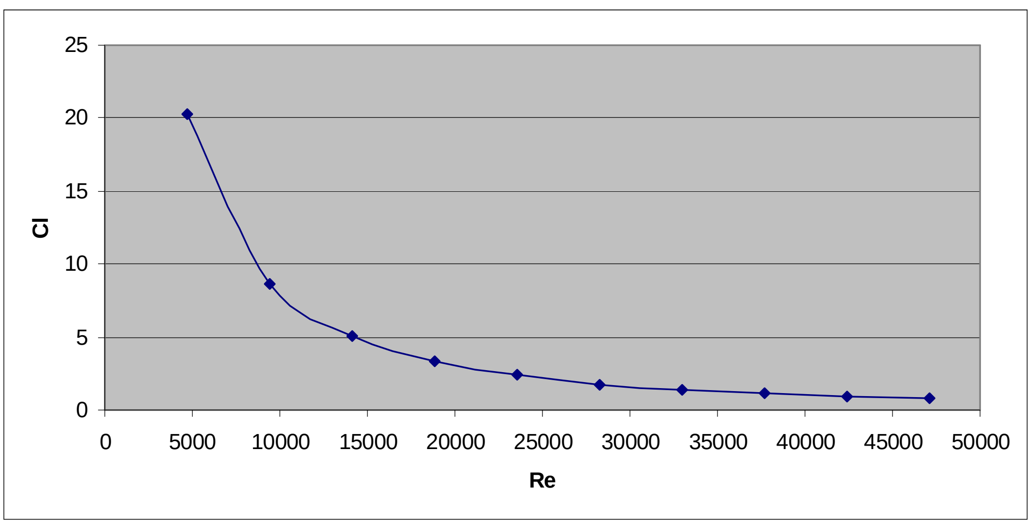

Figure 4.32: Lift coefficient versus Reynolds number (2W)

The slope was decreased until certain value of the lift coefficient which is 0.76. The relationship between lift coefficient and Reynolds number showed that indirectly proportional to each other.

4.8 Comparison between CFD and Experimental Result

After simulation for single and double models were done, the project was continued with comparing computational result with experimental result. The relationship between Drag force and Reynolds number and Drag coefficient with Reynolds number were compared. These comparisons will validate either both situation have same result or not.

4.8.1 Single Model

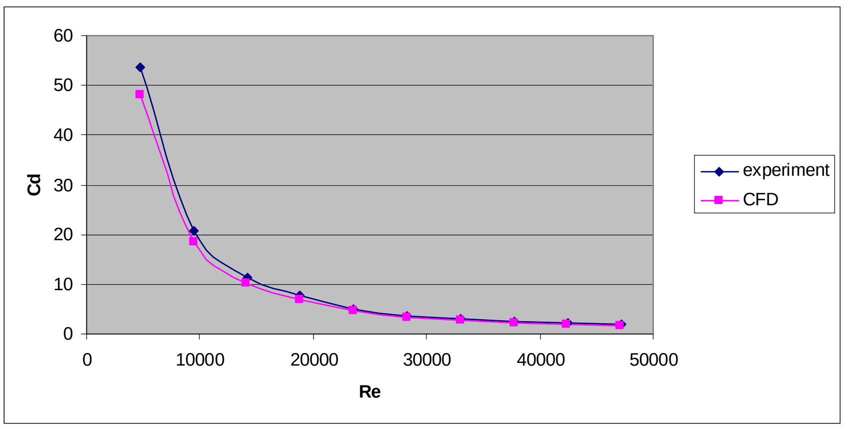

Figure 4.33: Comparison Drag coefficient versus Reynolds number for single model

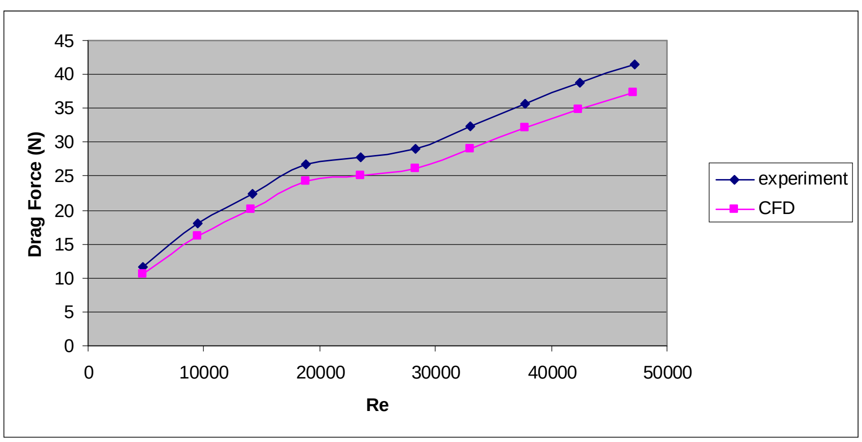

Figure 4.34: Comparison Drag force versus Reynolds number for single model

For single model, there are small different between experimental and CFD in term of Drag force and Drag Coefficient.

4.8.2 Half Width Distance (6.25 cm)

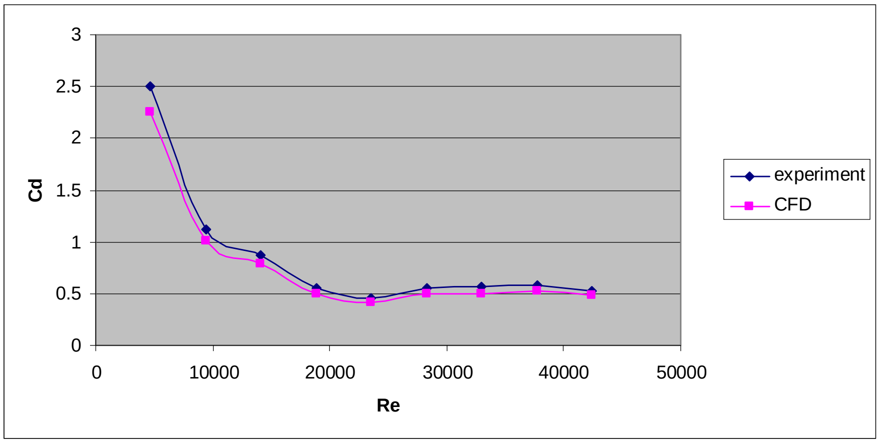

Figure 4.35: Comparison Drag coefficient versus Reynolds number (0.5W)

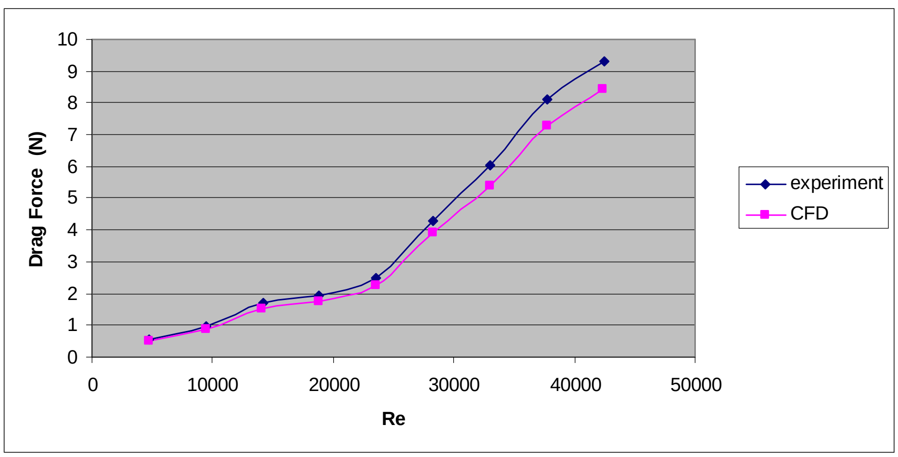

Figure 4.36: Comparison Drag force versus Reynolds number (0.5W)

For the second case which is half width separating distance, it showed that the drag force and drag coefficient almost same for both cases. From figure 4.56, the drag force has same value at early value of Reynolds number but experimental result has higher value compare to CFD result.

4.8.3 One Width Distance

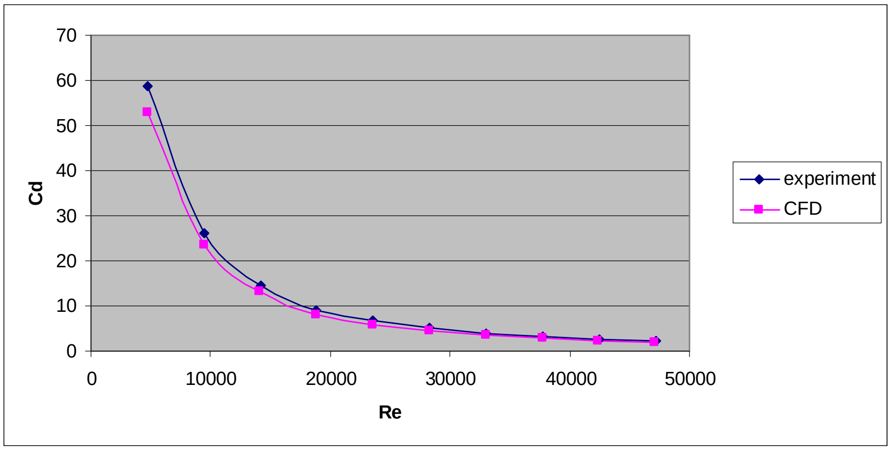

Figure 4.37: Comparison Drag coefficient versus Reynolds number (1W)

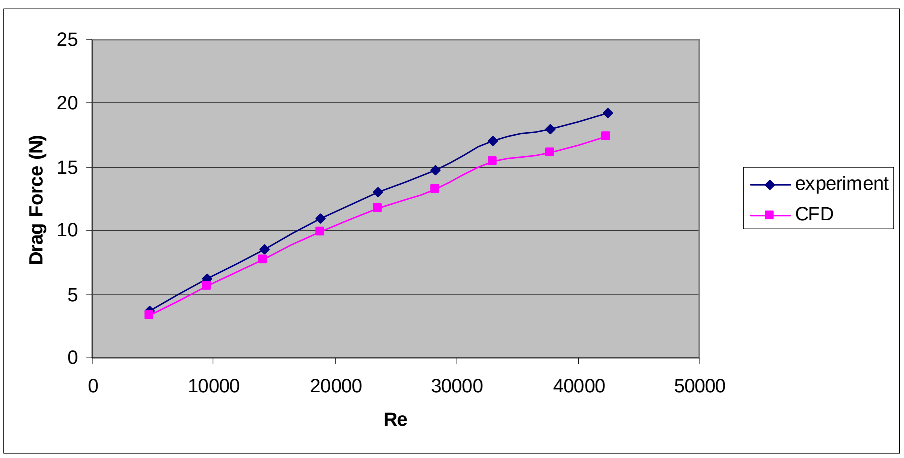

Figure 4.38: Comparison Drag force versus Reynolds number (1W)

From the graph, it showed that the value of drag force and drag coefficient in experimental have higher value compared to CFD result.

4.8.4 One and Half Width Distance

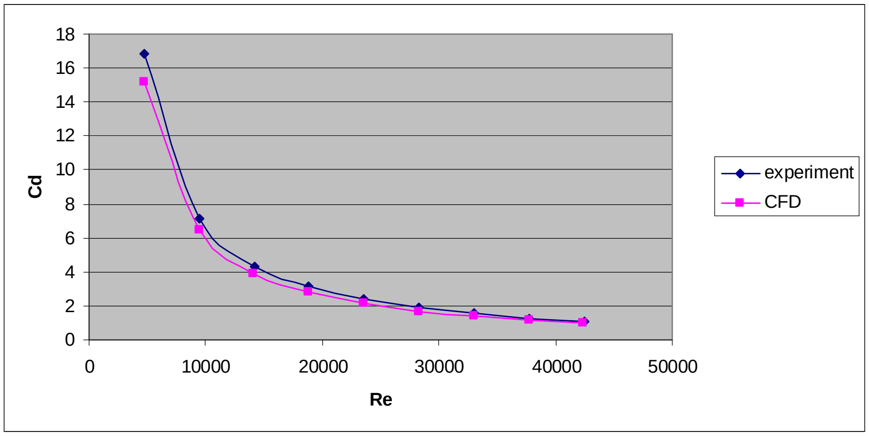

Figure 4.39: Comparison Drag coefficients versus Reynolds number (1.5W)

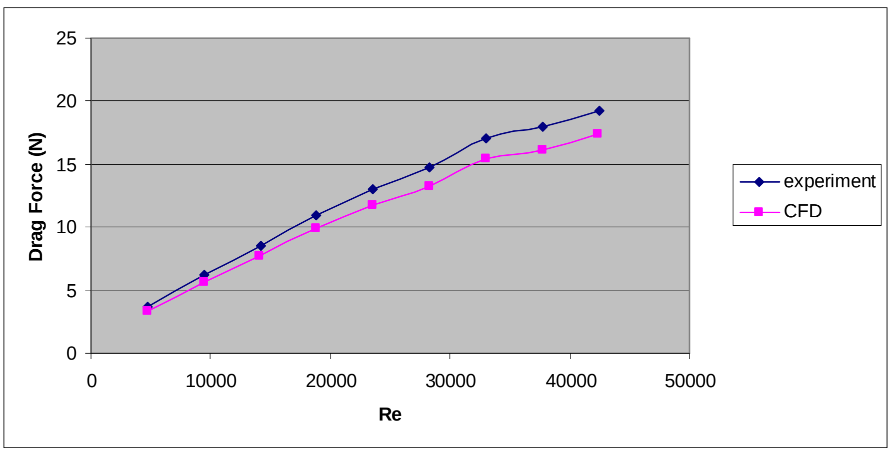

Figure 4.40: Comparison Drag force versus Reynolds number (1.5W)

For this case, experimental result still has higher value for drag force and drag coefficient. The maximum drag force for experimental is 18.45 N while CFD is 17.37 m/s.

4.8.5 Two Width Distance

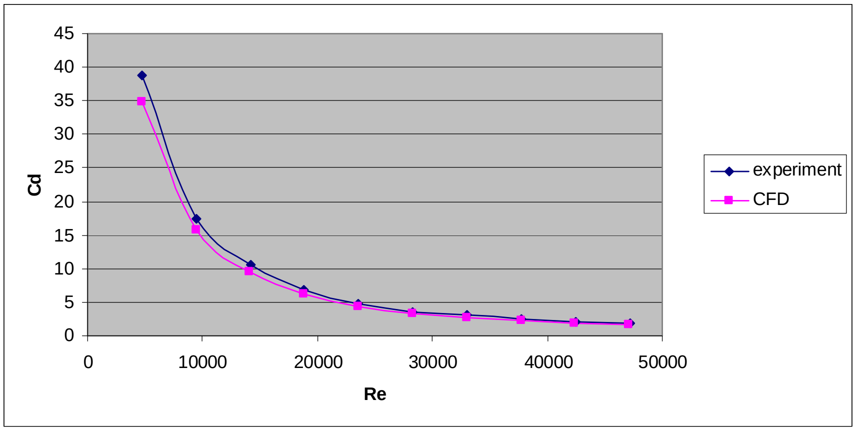

Figure 4.41: Comparison Drag coefficient versus Reynolds number (2W)

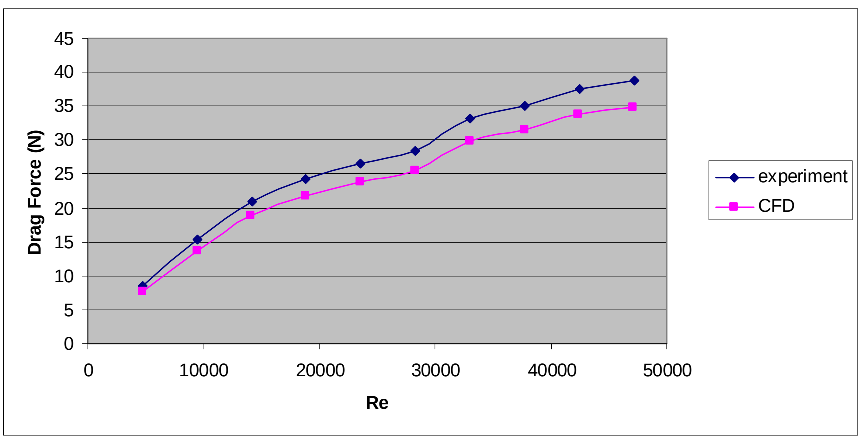

Figure 4.42: Comparison Drag force versus Reynolds number (2W)

For the last case which is two width distances, the comparison showed that the value of the drag force and drag coefficient in CFD are higher than experimental same as previous case. From this figure, it showed that the results in CFD are almost similar to experimental result.

This project was continued with comparison the relationship between Drag force with velocity and relationship between Drag coefficients with Reynolds number for all cases. Figure below illustrate the different value of drag force for each case.

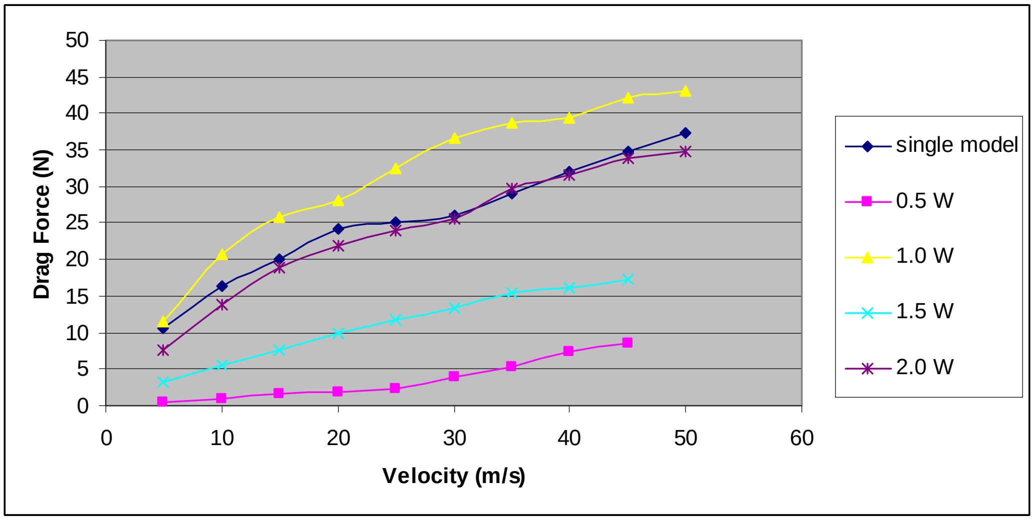

Figure 4.43: Drag Force versus Velocity for all cases

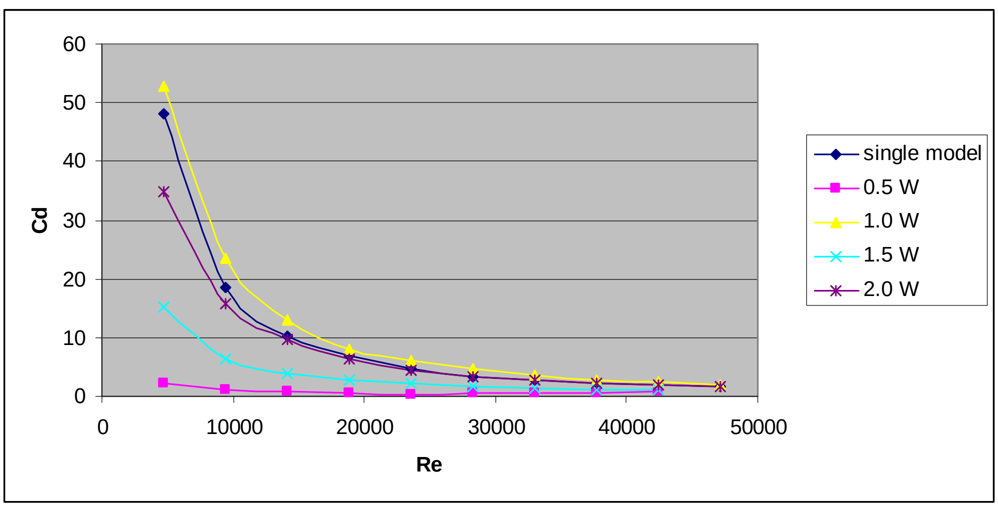

Figure 4.44: Drag coefficient versus Reynolds number for all cases

For half width distances, the second car was very near and directly behind the first car. The Drag force that reacts on second car was lesser because they were considered as one body. Thus the flow continues until the back of second car and as a result almost no Drag force in front of second car.

For the second case which is one width distance, it is observed that the Drag force increase compared to single model. The front car created a turbulent flow that is directly in front of second car which was located at the behind. This turbulent flow from front car has no time to steady down due to short distance and short in different time and resulting higher Drag force when it hit second car

The third case was one and half width distance. This distance basically located between first cases (12.5 cm) and second cases (25 cm).From this setup, the back pressure that caused by second car was caused Drag force to be low.

For the last case which is two width distances, the flow of air hit the first car and turbulent was created at the back of the car. The larger distance gives the flow time to steady itself and become less turbulent. As a result, when it hit second car, the Drag force that acting on the car is lesser. This reading shows that this setup almost the same as single model setup, almost as if there was no second car.