School of Engineering


# Evaluation of wind load and prediction of critical wind speed of the Bigfoot

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## Document information summary

| Item | Description |
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## 1. Test Scope

The objective of the testing is to evaluate the aerodynamic force coefficients of a signage provided by Eurotech and to predict the critical wind speed at which it is about to tip over.

A series of tests at different wind speed (from 3.4 *m/s* – 7.06 *m/s*, or 8.64 *km/h* – 25.4 *km/h*) were conducted in the wind tunnel of The University of Western Australia using a 6-component load cell (Figure 1a). The captured data include the force in the wind direction and the overturning moment. Based on these data, the drag coefficient and the force acting location are evaluated. The tests show that the force coefficient and the acting location do not change apparently with the wind speed. Therefore, the results obtained at low speed in the wind tunnel can be extrapolated to higher speed in nature. In addition to these tests, the signage fixed to its base was also put in the wind tunnel to check if it will be tipped over in the wind tunnel (Figure 1b). The test setup is shown in Section 2. The test results are shown in Section 3. The prediction of the critical wind speed is done in Section 4. Further test of the signage with base to verify the critical wind speed is discussed in Section 5, and finally a summary is given in Section 6.

## 2. Testing Arrangements

### Test facility

The tests were undertaken in the low-speed closed-loop wind tunnel at The University of Western Australia (UWA). The dimensions of the test section are 2.8 *m* (width) x 2.2 *m* (height) x 6 *m* (length). The tunnel can provide a wind speed up to 7.06 *m/s* (or 25.4 *km/h*). The turbulence intensity and the uniformity of the wind flow across the wind tunnel are less than 0.8% and 1%, respectively. The air density is taken as 1.225 $kg/m^3$ at 15°C.

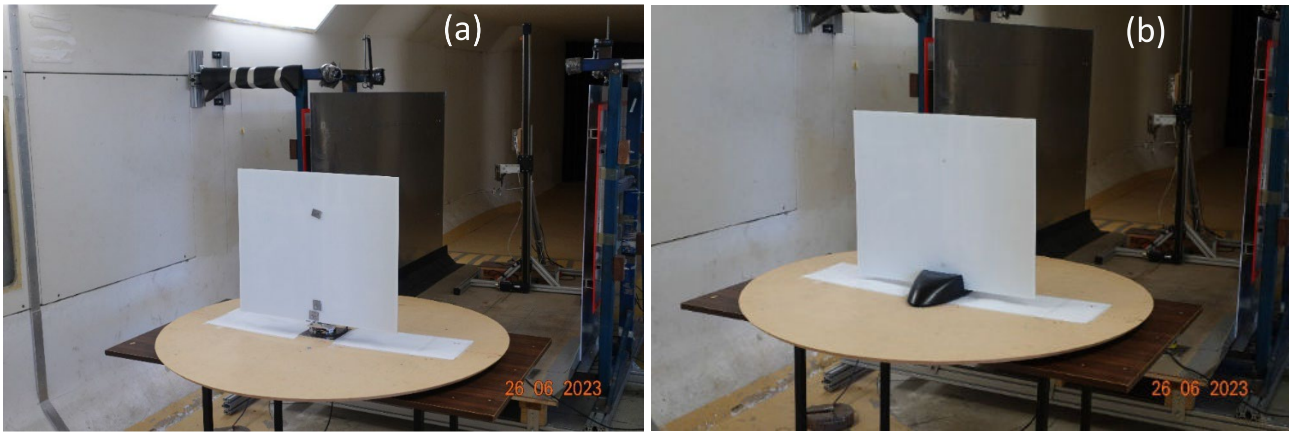


Figure 1. Model used for the tests. (a) Model fixed to one load cell for force measurements; (b) Model fixed onto its original base.

## The model

We used the real size (Figure 1b with a total weight of 2.167 *kg*, or 21.26 *N* and a base length of 340 *mm*) signage as the model for the wind tunnel tests. The model was attached to a load cell (GAMA). Figure 2 shows the dimensions of the model and the way that it is attached to the load cell.

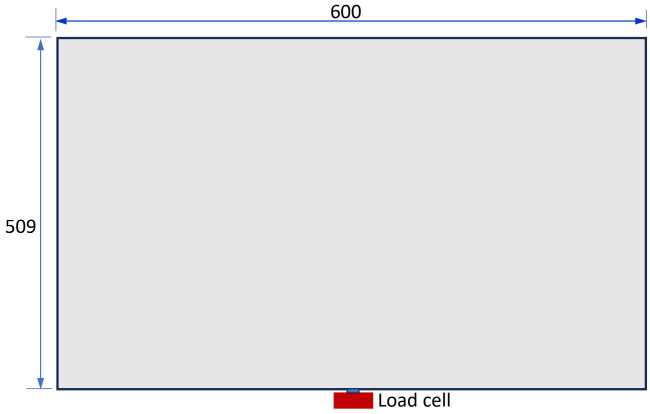


Figure 2. Dimensions of the model.

## 3. Test results

Forces ($F_D$) and overturning moments ($M$) were examined in the wind tunnel for free stream velocity $U = 3.4$ *m/s* – 7.06 *m/s* to check their dependence on wind speed. The test data and the results of drag coefficient $C_D$ and force acting location $Y_M$ are shown in the table below. The drag coefficient is evaluated as

$$C_D = \frac{F_D}{0.5\rho U^2 A} \tag{1}$$

where $F_D$ is the force measured by the load cell, $A$ is the area of the model projected to a plane perpendicular to the wind direction and $U$ is the free stream velocity of the wind tunnel. The force acting location can be evaluated as

$$Y_M = \frac{M}{F_D} \tag{2}$$

where, $M$ is the overturning moment measured by the load cell.

Summary of the test data, $C_d$ and $Y_M$

| Wind speed U ($m/s$) | Mean Drag $F_D$ ($N$) | Projected Area of the model II ($m^2$) | Drag Coefficient $C_d$ | Averaged Moment ($N$▪$m$) | Drag acting location $Y_M$ ($m$) |
|---|---|---|---|---|---|
| 2.689 | 2.427 | 0.305 | 1.794 | 0.586 | 0.241 |
| 3.418 | 3.978 | 0.305 | 1.820 | 0.968 | 0.243 |
| 4.146 | 5.894 | 0.305 | 1.833 | 1.444 | 0.245 |
| 4.875 | 8.180 | 0.305 | 1.840 | 2.016 | 0.246 |
| 5.603 | 10.811 | 0.305 | 1.841 | 2.675 | 0.247 |
| 6.332 | 13.787 | 0.305 | 1.838 | 3.423 | 0.248 |
| 7.060 | 17.085 | 0.305 | 1.832 | 4.249 | 0.249 |

To see the variation trend of $C_d$ with wind speed more clearly, the results are also plotted in Figure 3.

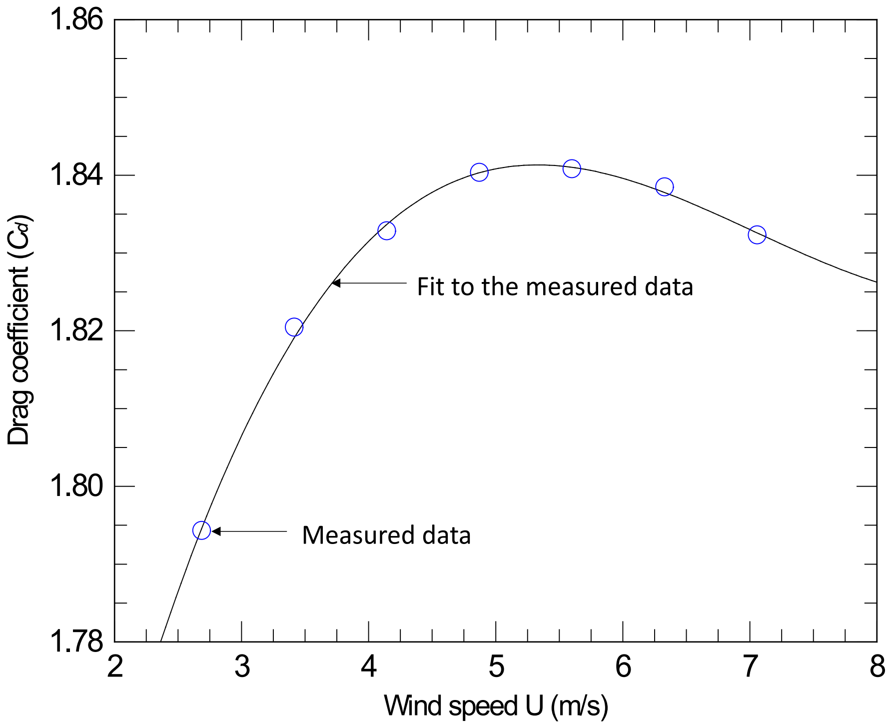


Figure 3. Variation of drag coefficient Cd with wind speed.

It can be seen that the drag coefficients $C_d$ increase with wind speed initially, approaching a peak value when wind speed is high enough. This trend should be related with the resolution of the load cells. For low wind speed, as the force is quite small, the load cells are not sensitive enough. With the increase of wind speed, $C_d$ reaches a peak value of about 1.841 at a wind speed of 5.25 *m/s*, and then decreases with the increase of wind speed. This could be due to the slight deflection of the plate after this wind speed. Therefore, a maximum drag coefficient $C_d = 1.841$ is obtained.

It needs to be noted that the results shown in Figure 3 are within ±2% of their averaged values. This range should be smaller than the experimental uncertainty and the drag coefficient can therefore be considered as a constant value over the tested velocity range.

From the above table, it can be seen that the force acting location is around $Y_M = 0.248$ *m*, which is independent of the wind speed.

### 4. Prediction for the critical wind speed when the models are tipped over

The drag coefficient is $C_d = 1.841$ acting at $Y_M = 0.248$ *m*. The wight of the base and the signage is 2.167 *kg*, or 21.26 *N* and the base length is 340 *mm*.

For the signage to be tipped over, the overturning moment should achieve:

$M = 21.26\ (N) \times 0.17\ (m) = 3.614\ (N{\cdot}m)$.

This corresponds to a wind force $F_D = M/Y_P = 3.614/0.248 = 14.57\ N$.

The corresponding critical wind speed is

$$U = \left(\frac{F_D}{0.5\rho C_D A}\right)^{1/2} = \left(\frac{14.57}{0.5\times1.225\times1.841\times0.3054}\right)^{1/2} = 6.505\ m/s, \text{ or } 23.4\ km/h$$

## 5. Further test of the signage with base to verify the critical wind speed

Further test of the signage with the base shown in Figure 1b was also conducted at various wind speeds. The base was put both on a smooth table and on a rug to achieve different friction at the base. It has been found that for both cases, the signage is deflected slightly when the wind speed is at about 5.3 *m/s*. With the increase of the wind speed, the deflection of the plate becomes more apparent. When the wind speed reaches about 6.5 m/s, the signage is tipped over. This result is consistent with the prediction shown in Section 4.

## 6. Summary of the wind tunnel tests

The force coefficient $C_d$ of the tested model is 1.841 acting at $Y_M = 0.248\ m$. The critical wind speed for the signage to be tipped over is about 23.4 *km/h*.