Extended Essay In Physics

The Vertical Component Of The Reaction Force Of An Inclined Surface Against The Wind Load Acting On It

Ted Ankara College Foundation Private Highschool

MAY 2013

Student’s name: Kaan Yorgancıoğlu

Supervisor’s name: Mine Gökçe Şahin

Candidate number: D1129 – 036

Word count: 3004

Kaan YORGANCIOGLU
MAY 2013
001129-036

The abstract:

This experimental study is carried out to investigate the effects of the angle between an inclined surface on a building and the direction of the wind flowing towards it on the vertical component of the reaction force of the inclined surface against the wind load acting on it. An experimental approach is chosen for the study. Wind effect and the surface of the building are modeled by using a leaf blower which creates a wind flow towards a plate that is standing on an electronic scale with an angle. The change in the mass measured by the electronic scale was used to calculate the vertical component of the reaction force. The graph of the angle between the plate and the wind flow versus vertical component of the reaction force indicates that the force is directly related with both sine and cosine values of the angle. More specifically the vertical component of the force is directly proportional with the multiplication of sine and cosine values, that is $F = k.\sin\theta .\cos\theta$, the constant k is a numerical constant calculated as 0,1808 ± 0,006 Newton for the model constructed in the experiment. The experimental error is determined as 3.3%.

Contents:

1. Introduction

1.1. Background Information

Wind is caused by air flowing from high pressure to low pressure. The differences between air pressures cause various speeds of wind.[1]

Certain magnitudes of wind such as hurricanes and tornados can be dangerous. They can damage buildings and sometimes they even topple houses.

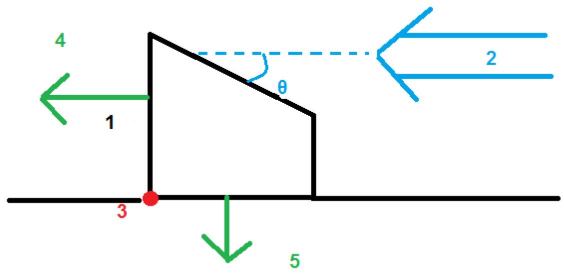


Figure1: The illustration of the forces acting on a building (1: The building, 2: the wind flow, 3: the pivot point, 4: the wind load, 5:the sum of the weight of the building and the vertical component of the reaction force of the inclined surface against the wind load, θ: the angle between the wind flow and the inclined surface)

The wind load applies a horizontal force on the building. Opposing to this force the building applies a reaction force perpendicular to the inclined surface.

When the wind hits the building it applies a horizontal force which can topple the building around the pivot point by applying a torque. There are two forces that prevent the wind load from toppling the building by applying a torque opposite to the wind load. The first one is the weight of the building and the second one is the vertical component of the reaction force mentioned above. The vertical component of the reaction force will be referred as F_w in this essay.

To make the building more stabilized this force must be maximized. One of the variables that affect this force is the angle between the wind flow and the surface of the building so this angle can be used to maximize the force. The relation between F_w and the angle of the plate with the wind direction should be known to calculate the angle that maximizes the F_w value.

1.2. Objective

This investigation is performed to find the relation between the vertical components of the reaction force exerted by the building which opposes the wind load (F_w) and the angle of the inclined surface of the building with the direction of the wind.

1.2.1. **Research Question**:

How is the vertical component of the reaction force exerted by an inclined wooden plate to oppose the wind load affected by the angle of the plate with the wind flow?

1.2.2. **Hypothesis**:

The reaction force perpendicular to the plate is dependent on the cross sectional area of the plate perpendicular to the wind direction so reaction force should be directly proportional to the sine of the angle of the plate with the wind direction. Also the vertical component of any force is calculated by multiplying it with the cosine of the angle of the direction of the force with the horizontal so vertical component of the reaction force should be directly proportional to the cosine of the angle of the plate with the direction of the wind. In conclusion the F_w is dependent on both sine and cosine of the angle of the plate with the wind direction.

2. Equipment & Description of the setup

2.1. Material list

- A plate (made of balsa wood, 10cmX10cm wide and 5 mm thick, weights 3.650 grams)
- A leaf blower which has a wind speed of 170 mph
- An electronic scale (±0.001 g)
- A goniometer (±0.5˚)
- A stand will be used as a base for the plate (made of aluminum, 3cmx3cm wide base and 20cm high, 15.06 grams)
- A Silicone gun will be used to glue other equipment to each other
- A ruler (±0.1cm)
- Wooden blocks will be put under the leaf blower to adjust its height(books may also be used)

2.2. Experimental setup:

The base of the stand is glued on the electronic scale by using the silicon gun. This keeps the plate at the exact same spot during the experiment so that the random error is minimized also it prevents the plate from flying off because of the wind during the trials. Similarly the plate is glued on top of the stand from its center of gravity which is 5cm apart from each side. The angle of the plate is measured by using a goniometer before sticking it on the stand. To change the angle of the plate between trials the plate is taken off the stand then the silicon residue on the stand and the plate is cleaned and the plate is glued again at the desired angle.

The leaf blower is placed in front of the plate. The height of the blower is adjusted by putting wooden blocks under it so that the blower is at the same level with the plate and the wind flows right in the middle of the plate. (*See Figure 2*)

When the wind starts flowing it hits the plate and the wind load that is acting On the plate changes the value that is measured by the electronic scale. The change in the mass value that is measured by the electronic scale is used to calculate the vertical force acting on the plate. (this process will be further explained in section 3)

An illustration of the experiment setup is provided below for better understanding of the setup.

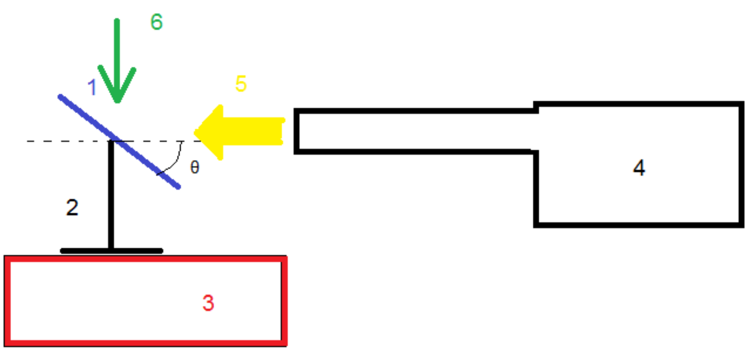


Figure 2: The schematic illustration of the experimental setup (1: the plate, 2: the stand, 3: electronic scale, 4: leaf blower, 5: the direction of the wind, 6: direction of the force which is measured ,θ: the angle between the plate and the ground)

2.3. Key variables

2.3.1. Dependent variable:

The vertical force acting on the plate (it is calculated by using the change in the mass value that was measured by the electronic scale)

2.3.2. Independent variable

The angle between the plate and the ground (it is adjusted by using the goniometer before every trial)

2.3.3. Controlled variables

- The **speed of the wind** is kept constant because it is one of the primary variables that affect the force on the plate. The settings of the leaf blower are kept unchanged during the experiment so the speed of the wind is assumed to be constant.
- The **direction of the wind** is kept constant by keeping the blower at the exact same position during the whole experiment.
- The **dimensions of the plate** are kept constant at 10cmx10cm because it affects the force that is applied on the plate by the wind.
- The **thickness of the plate** is kept constant at 5mm to minimize the error of the experiment.

- The **mass of the plate and the stand** is kept constant in order to minimize the error of the experiment.
- The **distance between the plate and the wind blower** is kept constant at 30cm because it may affect the force applied on the plate. Both the blower and the electronic scale are kept at the same place through the experiment so the distance between the tip of the blower and the plate is 30cm.

3. Experiment

3.1. Preparation

The following steps are taken to prepare the experimental setup.

The stand is put on the center of the electronic scale and the base of the stand is glued to the electronic scale by using a silicone gun. The plate is glued to the tip of the stand from its center of gravity which is 5cm apart from each side by using the silicone gun. The angle of the plate is adjusted by using the goniometer before the silicone gets cold. The plate is kept at the same position until the silicone gets cold to ensure that the angle of the plate remains unchanged.

The leaf blower is put in front of the electronic scale facing the plate at a distance of 30 cm between the tip of the blower and the plate. The height of the blower is adjusted to the same level with the plate by putting wooden blocks under it (books can also be used instead of blocks)

The leaf blower and the scale is kept at the same position until the experiment is done to minimize the error. Also the electronic scale is set to zero before every trial so that it shows the exact value of the change in the weight.

3.2. Method

The angle of the plate(*see figure 2*) is adjusted to 0 degrees so that the plate is parallel to the ground and it is glued by using the silicone gun. The scale is set to zero. The leaf blower is started and kept on for 10 seconds until the speed of the blower stabilizes. Then the change in the value that is measured by the scale is noted. The process is repeated three times to minimize the random error (the average of the collected data will be used). The plate is taken off and the silicon residue is cleaned off the tip of the stand. The process is repeated from the start by adjusting the angle to 10, 20, 30, 40, 50, 60, 70, 80 and finally 90 degrees.

4. Data processing

4.1. Raw data tables

The angle of the plate with the wind flow/˚ (± 0.5)	The change in the value of mass that is measured by the electronic scale /g(±0.001) (Δm)		
	Trial 1	Trial 2	Trial 3
0.0	1.435	1.341	1.538
10.0	5.120	5.315	5.216
20.0	7.645	7.755	7.850
30.0	9.991	10.188	9.791
40.0	10.840	10.840	10.540
50.0	10.455	10.355	10.540
60.0	10.060	9.867	9.962
70.0	7.975	7.679	7.677
80.0	5.235	5.045	5.140
90.0	1.713	1.707	1.710

Table1: The raw data table including the Δm data that is collected in three trials for each angle value.

4.2. Processing data

The force acting on the plate makes a change in the value of mass that is measured by the electronic scale. The vertical component of the force acting on the target plate can be calculated by using newton's second law of motion which includes the equation F = m.a where f is the force acting on the plate, m is the change in the measured mass due to the external force and a is the acceleration of free fall which is 9,79 in Ankara[2] (where the experiment took place). Initially Δm values must be converted into kilograms before using them in calculating force.

So the force is calculated by using the equation; F = 9,79 x Δm

The Δm values are converted into Force values and are presented below.

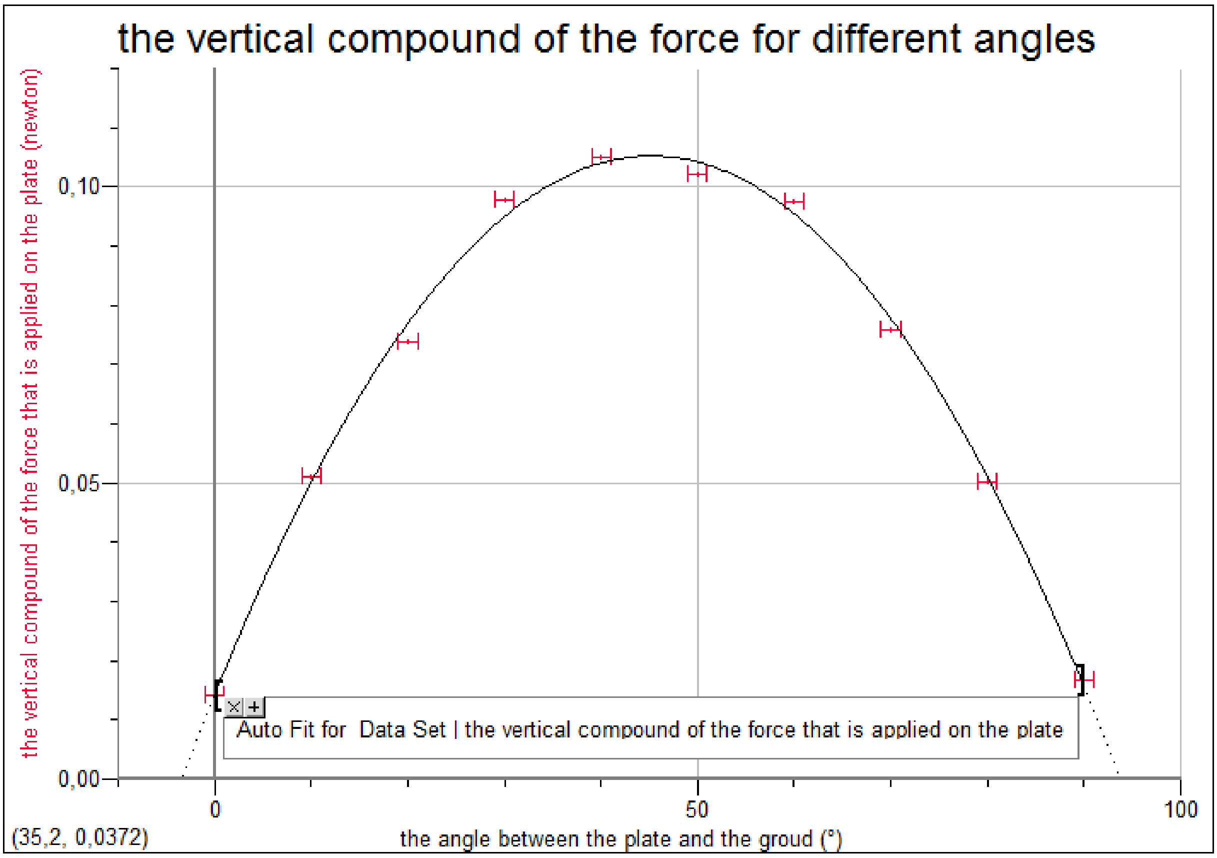
The angle of the plate with the wind flow /˚(± 0.5)	Average value of the change in the value of mass that is measured by the electronic scale /g (±0.001) (Δm)	F_w /Newton	The percentage uncertainty of force.
0	1.438	0,01406	0,0695
10	5.217	0,05102	0,0191
20	7.750	0,07383	0,0129
30	9.990	0,09770	0,0100
40	10.740	0,10510	0,0093
50	10.450	0,10220	0,0095
60	9.963	0,09744	0,0100
70	7.777	0,07599	0,0128
80	5.140	0,05027	0,0195
90	1.710	0,01672	0,0585

Table 2: The F_w values for varying angle of the plate with the horizontal.

The percentage uncertainty of force is calculated by regarding the uncertainties of multipliers. Since the uncertainty of "g" is zero only the uncertainty of the mass value is taken into account.

%uncertainty of F = % uncertainty of Δm

An angle versus force graph is drawn and presented below:



Graph 1: The relation between the F_w values and the angle of the plate with the wind direction.

Note that the uncertainties of the force values are presented in the graph but they are so small compared to the other values that they do not appear on the graph.

One of the predicted major factors on the magnitude of the force is the cross sectional area of the plate that is perpendicular to the wind direction. (see figure 3)

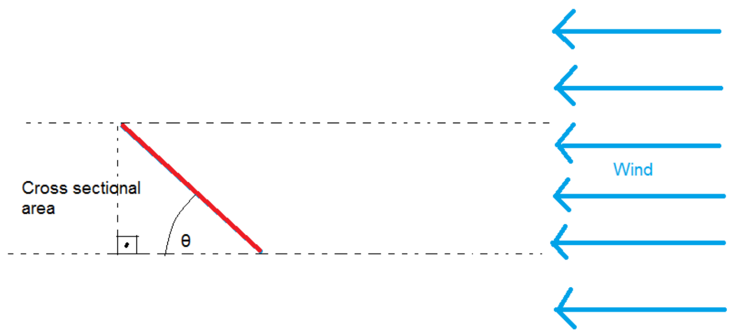


Figure 3 : the plate and the wind that is blown towards the plate

So when the angle is at 90 degrees the area that the wind hits is equal to the area of the plate because the cross sectional area is equal to the total area of the plate and when the angle is 0 degrees the wind doesn't even hit the plate because the cross sectional area of the plate is zero. The cross sectional area can be calculated by multiplying the area of the plate with the sine of the angle. So the formula of the cross sectional area is $S_{csross\ sectional} = S_{total}$ X sinθ.

The plate exerts a reaction force perpendicular to it but this research investigates the vertical compound of it (see Figure 4)

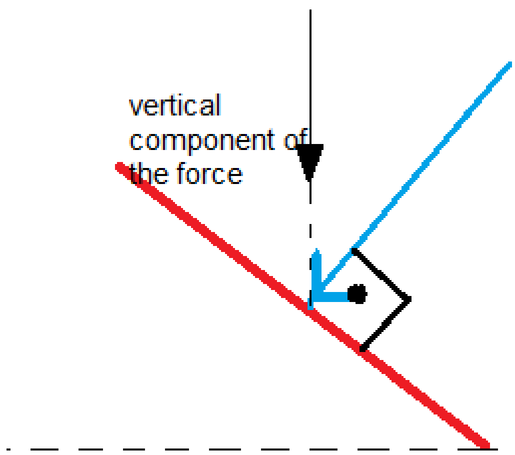


Figure 4: The reaction force applied by the plate and its vertical component

The vertical component of the force is calculated by multiplying the net force by the cosine of the angle of the plate. So the equation is $F_{vertical} = F_{net}$ x cosθ

In conclusion the vertical compound of the force that is applied by the wind is affected by both sinθ and cosθ so the sinθxcosθ values must be calculated for each angle to find the relation between the angle and the vertical compound of the force.

The percentage uncertainties of sinexcosine values are calculated by adding the percentage uncertainties of sine and cosine of θ;

% uncertainty of sinθxcosθ = %uncertainty of sinθ + %uncertainty of cosθ

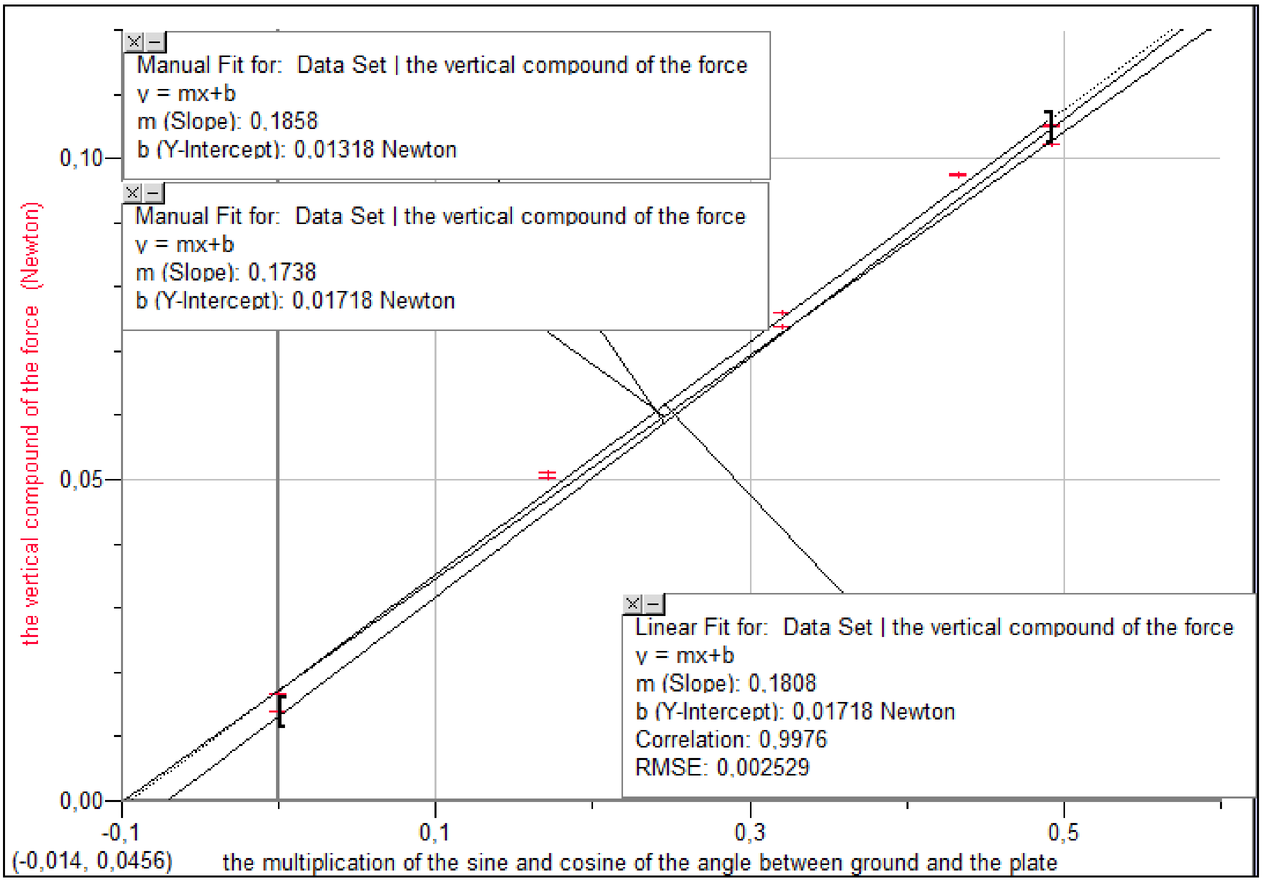
The sinθxcosθ values are calculated for each angle and presented below.

The angle between the ground and the plate /˚ (± 0.5)	The multiplication of the sine and the cosine of the angle (sinθxcosθ)	The vertical component of the reaction force /Newton
0,0	0,000	0,01406
10,0	0,171	0,05102
20,0	0,321	0,07383
30,0	0,433	0,09770
40,0	0,492	0,10510
50,0	0,492	0,10220
60,0	0,433	0,09744
70,0	0,321	0,07599
80,0	0,171	0,05027
90,0	0,000	0,01672

Table 3: The multiplication of sine and cosine for each angle in the experiment and the vertical component of the reaction force.

Since sine and cosine of an angle equals the cosine and sine of its complementary angle some datas have the same sinexcosine value and they overlap.

Sineθxcosineθ versus force graph is drawn and presented below.



Graph2: The relation between the sineXcosine values of the angles and the vertical compound of the force with its best fit line and the maximum/ minimum values.

4.3. Calculating uncertainty

The slope of the best fit line is 0.1808N, the slope of the steepest line is 0.2088 N and the slope of the most gradual line is 0.1508 N.

$\Delta k = (k_{max} - k_{min})/2 = \pm 0.006$ N

4.4. Percentage error

%Error = $(\Delta k/k) \times 100 = 3.3\%$

4.5. Equation

It can be seen that graph 2 is linear. This means the force applied vertically on the plate is directly proportional with the multiplication of the sine and cosine of the angle between the plate and the ground. So the equation should be;

$F = k.\sin\theta.\cos\theta$

Where F is the vertical component of force, θ is the angle between the plate and the ground and k is a numerical constant which is 0.1808 (±0.006) Newton.

The constant k might be affected by the speed of wind, area of plate, air pressure, friction coefficient of the plate, etc.

5. Conclusion and Evaluation

The building constructions are getting taller and taller each day thanks to the progressing technology. During the designing progress of these tall building the effects of the wind that they will endure should also be taken into account. One of the main reasons that constructing a tall building is a very hard task is the wind load acting on it caused by the fast flow of wind. In this study the vertical component of the reaction force exerted by the building as a reaction against the wind load is investigated. This vertical component is predicted to have a reducing effect on the damaging effect of the wind load because it will apply a torque against the wind load around the pivot point of the building so that the magnitude of the wind load will not be enough to topple the building.

The building and the wind is modeled by using a leaf blower which creates a wind flow towards an inclined plate. As a result of the experiment the vertical component of the reaction force increases between the angles 0˚ - 45˚ and after it reaches its maximum value at 45 degrees it starts to decrease. The relation between the angle of the plate with the direction of the wind and the vertical compound of the reaction force is derived as $F = k.\sin\theta.\cos\theta$ where F is the vertical component of the reaction force θ is the angle and k is a numerical coefficient which is 0.1808 $Kg.m.s^{-2}$ (±0.006) for the model constructed in the experiment. The effect of the angle between the inclined surface and the wind flow on the vertical compound of the reaction force can be calculated by using this equation.

Although a successful conclusion this study has some error sources. Firstly the stand under the plate may slow down the wind flow at some angles. According to the “Bernoulli effect” the fluids that flow slower has a higher pressure. This means that the pressure under the plate might be higher than the pressure over the plate and this difference can create an uplifting force on the plate. Also the friction on the surface of the plate might cause changes on the flow of the wind and this may be a source of error. On the other hand in Graph 2 it can be seen that the best fit line is passing through the origin which means that there is small or no systematic error in experiment. But there might be some random errors because the experiment deals with extremely small values of forces and this makes the experiment very fragile. Some sources of random error might be mistakes at measuring the angle of the plate with the direction of wind or small disturbances of the wind flow could cause serious changes in the results.

References:

1. http://www.universetoday.com/
2. http://www.fizikinfo.com/