

# **Relationship of spoiler created drag and downforce at altering angles**

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## Tiivistelmä

Sitä mukaan kun autot kehittyvät nopeammiksi ja nopeammiksi, huomattiin että autoihin kohdistui yhä suurempi ja suurempi ylöspäin nostava voima. Tämä voima johti ilmanohjaimen keksimiseen, takasiivekkeen tarkoituksena oli luoda alaspäin työntävä voima joka tasapainottaisi ylöspäin suuntautuvan voiman ja näin lisäten auton hallittavuutta lisäisi auton pitoa ajopinnasta. Ilmanohjain ei vain lisää auton pitoa ajopinnasta vaan se myös lisää auton ilmanvastusta, joka hidastaa kulkuneuvon nopeutta. Tämän laajan esseen tutkimuksen aihe onkin miten ilmanvastus ja alaspäin suuntautuva voima ovat riippuvaisia ilmanohjaimen kulmasta.

Teoriat kehitettiin ennen varsinaista koetta. Ajateltiin että ilmanvastuksen määrä lisääntyisi sitä mukaan kun takasiivekkeen kulma suurenisi ja että alaspäin työntävä voima lisääntyisi johonkin tiettyyn kulmaan asti ja sitten sen jälkeen alkaisi vähentyä.

Kokeen suorittamiseen tarvittavat menettelytavat määriteltiin. Päätettiin että koe jaettaisiin kahteen osaan. Ensimmäinen osa tutkimuksesta tutki ilmanohjaimen luomaa alaspäin työntävää voimaa. Toinen osa tutkimuksesta käsitteli ilmanvastusta. Itse tehty ilmanohjain ja tuuletin olivat tärkeitä välineitä käytännön kokeissa. Kokeiden jälkeen päätettiin vielä tehdä yksi ylimääräinen koe ja verrata tuloksia aiemmista kokeista tähän enemmän todellisuutta replikoivaan kokeeseen. Tässä ylimääräisessä kokeessa tutkittiin pienoisauton kulkemia matkoja, kun sen ilmanohjaimen kulman suuruus vaihteli.

Tutkimuksista havaittiin, että alaspäin työntävä voima kasvoi kunnes ilmanohjaimen kulma oli 20- 30 asteen luokkaa, jonka jälkeen pitoa edistävä voima alkoi huveta. Ilmanvastus kasvoi sitä mukaan kuin ilmanohjaimen kulma kasvoi, suurin ilmanvastus havaittiin kun ilmanohjaimen kulma oli lähemmäs 80 astetta. Pienois-autolla tehdyt kokeet vahvistivat tuloksen että mitä suurempi kulma ilmanohjaimessa sitä suurempi ilmanvastustuksen määrä.

Tutkimus herätti uusia potentiaalisia tutkimuskysymyksiä ilmanohjaimista, kysymyksiä kuten yhä suurempien nopeuksien vaikutus ilmanohjaimen kulmaan ja erimuotoisten ilmanohjaimien käyttäminen

## Abstract

As automobiles became faster and faster, it was noticed that the vehicles experienced an uplift force at higher speeds. This led to the invention of a spoiler, its pure purpose was to create a downforce to eliminate the uplift force and increase the handling by increasing the traction. Spoiler increases the traction by increasing the downforce, it also increases the drag which slows the vehicle down. The research question of this Extended Essay is 'How do drag and downforce depend on the angle of the spoiler?'

Hypotheses were developed before the experiment. It was thought that the drag increased as the angle increased and downforce increased up to a certain angle and then decreased.

Method of performing the whole experiment was determined. It was decided to split the experiment into two parts. The first one investigated the downforce created by the spoiler. The second one dealt with drag. A self-built spoiler and a fan were the essential parts of the experiments. After these experiments it was decided to perform an additional one and compare the previous findings with the real life situation. In the additional experiment, the distances traveled by a toy car with a spoiler mounted at different angles were investigated.

It was found out that the downforce increased up to the angle of 20°-30° and then started to decrease. The drag increased as the angle increased, the maximum drag occurred around the angle of 80°. The toy car experiment proved the findings that the increased angle increases the drag.

The experiment raised new ideas that could be investigated relating to the issue concerning spoilers, such as the effects at higher velocities and behavior of differently shaped spoilers.

## 1. Introduction

A spoiler is an aerodynamic wing, except instead of creating uplift it creates downforce. The invention of the spoiler was inevitable, since automobiles became faster and lighter. It was noticed that an automobile experiences an uplift force while traveling at higher speeds. Therefore, the automobile loses traction with the road and there's a significant loss of control.<sup>1</sup> This led to the invention of the spoiler, and its purpose was to decrease and eliminate the uplift by creating a force downwards. This idea was based on Bernoulli's principle. Bernoulli's principle states that where the velocity of a fluid is high, the pressure is low, and where the velocity is low, the pressure is high.<sup>2</sup> Bernoulli's principle is an essential part of fluid motion in Physics. This principle applies to gases as well. As the upside of the spoiler is an increased control, its downside is a force created in the opposite direction of the motion, called drag, which slows down the moving vehicle. As the spoiler increases the handling, it decreases the speed in two ways. The downforce makes the automobile heavier and it increases its normal force and increased normal force increases the frictional force that starts to slow down the automobile. The other way is that spoiler increases the overall cross area of the car, meaning it collides with the air molecules more frequently. The research question of this extended essay is 'How do drag and downforce depend on the angle of the spoiler?' Any kind of spoiler causes different magnitude forces at different angles. The hypothesis is that drag force increases as the angle increases, since the intersection area increases. The downforce, unlike the drag force, should not change in a clear pattern; since the pressures on the different sides of the spoiler will significantly differ while the angle is being altered.

## 2. The Experiment Planning

In order to investigate the relationship of downforce and drag, an experiment had to be carried out. It was thought that a self-built spoiler and a fan would be the essential parts of the experiment. The next step was to find a way to measure the forces. The first idea was to use spring scales. The obvious main problem was that the springs must be extremely sensitive, since high forces would not be created in the experiment. Therefore, a different method was created using a digital scale. The scale would've measured the differences in masses and forces could've been easily calculated. It was decided to split the experiment into two separate ones. The first experiment, Downforce Experiment, was to measure the downforce and the second part, Drag Experiment, was to investigate the drag. This method didn't seem to have any flaws that would've suggested a need of creating a different technique.

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<sup>1</sup> [http://en.wikipedia.org/wiki/Spoiler\\_\(automotive\)](http://en.wikipedia.org/wiki/Spoiler_(automotive))

<sup>2</sup> Douglas C. Giancoli *Physics, Principles with Applications, Sixth Edition*. Upper Saddle River, NJ: Pearson Education, Inc, 2005

### 3. The Downforce Experiment

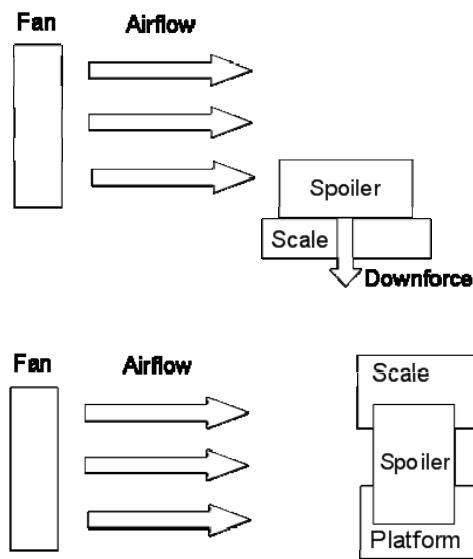


Figure 1: Sketch of The Downforce Experiment

The figure above (Figure 1) represents a rough sketch of The Downforce Experiment. The fan in front of the spoiler would create airflow and in a different frame of reference, it would be as if the spoiler is moving and the air is still. The airflow and the spoiler would create a downforce which would be noticed in the change of mass reading of the scale. The top part illustrates the experiment from the side, whereas the bottom part from the top. If the spoiler would be right on top of the scale, the airflow that wouldn't affect the spoiler might affect the reading of the scale. In order to avoid this problem, it was decided to put a platform. The spoiler would be touching the scale and the platform by its edges, so there would be nothing under the spoiler. This means that the airflow should have a significantly lower influence on the scale by itself. Therefore, wrong future measurements were decreased.

It was decided to choose the shape of the spoiler based on an equation  $y=7/X$ . The equation was plotted using AnalyticMath<sup>1</sup> software. It was decided to use the range from 2 to 6 for the spoiler's shape.

It was decided to make the spoiler out of thin cardboard. Three pieces of thicker cardboard were made to hold the shape of the spoiler. Each piece had a gap, which was the shape of the spoiler. Therefore, the cardboard went through those gaps and was bent into the desired shape.

The length of the spoiler was 29.6 cm. The width of the thin cardboard that was bent into the shape was 8.2 cm. The spoiler had three supporting pieces.

The following thing was to make it possible to tilt the spoiler at different angles. It was determined that two pieces of cardboard would be attached to both sides of the spoiler by two clothespins on each side. Then different angles were labeled by drawing lines.

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<sup>1</sup> AnalyticMath 1.1.3 – [www.analyticmath.com](http://www.analyticmath.com)

As all the parts of the experiment were produced, it was time to build the experiment. The equipment needed for this experiment:

- Fan - Warmos VT6A-23 9" DESK FAN
- Digital Scale – uncertainty of  $\pm 0.005\text{g}$
- Books
- Spoiler system [spoiler, 4 clothespins, 3 supporting pieces, 2 angle measuring pieces]
- 3m Steel Tape – uncertainty of  $\pm 0.0005\text{m}$

A fan was put on the floor in the middle of the room. Then, the scale was raised to the same height as the midpoint of the fan and was placed 0.40m away from it. The platform was made to be the same height as the top of the scale, meaning that the spoiler was in a horizontal position. Books were used to build the platform and raise the scale. Figure 2 is a picture taken of the set up experiment.



**Figure 2: Set up drag experiment**

The fan had two different speeds ( $v_1$  and  $v_2$ ). It was decided to measure the downforce at  $v_1$  and at  $v_2$ .

### **3.1. The Downforce Experiment – Execution**

It was chosen to carry out a test run experiment and observe if the experiment seemed to run as it was supposed to. The procedure for the test run was decided.

1. The spoiler is set to  $0^\circ$ .
2. The scale is turned on.
3. The spoiler is placed on the scale and the platform, by its very edges.
4. The reading on the scale is observed.

5. The fan is switched on at v1 speed.
6. The reading on the scale is observed.
7. The fan is turned off.
8. The spoiler is taken off the scale.
9. The scale is turned off.

After carrying out the test run, it was noticed that there was one problem. The mass of the spoiler varied under airflow and it was hard to choose a single value for it. It was decided to use a camera<sup>1</sup> to record the readings. It was chosen to record 4 seconds of the readings.

As the only problem was solved, the procedure for The Downforce Experiment was decided as follows.

1. The spoiler is set to 0°.
2. The scale is turned on.
3. The spoiler is placed on the scale and the platform, by its very edges.
4. The reading on the scale is recorded.
5. The fan is switched on at v1 speed.
6. The reading on the scale is recorded using a camera for 4 seconds.
7. The fan is switched on at v2 speed.
8. The reading on the scale is recorded using a camera for 4 seconds.
9. The fan is switched off.
10. The spoiler is taken off the scale.
11. The scale is turned off.
12. Steps 1-11 are repeated for 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80° and 90°.

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<sup>1</sup> Camera model - Sanyo Xacti S3

### 3.2 The Downforce Experiment – Data and Data Processing

Table below (Table 1) shows the masses under airflow. Every video clip was 4 seconds long, so readings at 0s, 1s, 2s, 3s, and 4s were noted down and the lowest and the highest values were extracted.

Angle [degrees]	Velocity	0s [g]	1s [g]	2s [g]	3s [g]	4s [g]	Low [g]	High [g]
<b>0</b>	v1	25.11	26.35	24.93	26.11	25.05	24.93	26.35
	v2	26.17	25.59	25.37	26.12	27.08	25.37	27.08
<b>10</b>	v1	27.05	27.57	27.10	26.76	26.04	26.04	27.57
	v2	28.50	27.63	26.15	26.40	28.04	26.15	28.50
<b>20</b>	v1	28.11	27.42	29.16	30.56	28.65	27.42	30.56
	v2	27.40	28.63	28.42	27.95	29.53	27.40	29.53
<b>30</b>	v1	27.36	26.21	28.41	29.38	27.76	26.21	29.38
	v2	29.31	30.41	30.22	30.65	28.91	28.91	30.65
<b>40</b>	v1	25.30	26.70	25.89	25.97	25.16	25.16	26.70
	v2	26.66	27.35	27.27	26.71	25.72	25.72	27.35
<b>50</b>	v1	25.60	26.22	25.54	25.02	25.53	25.02	26.22
	v2	26.19	26.81	25.87	25.83	26.31	25.83	26.81
<b>60</b>	v1	24.77	25.58	24.64	25.35	25.17	24.64	25.58
	v2	26.06	25.27	26.10	25.66	25.50	25.27	26.10
<b>70</b>	v1	23.79	24.31	24.34	24.26	24.21	23.79	24.34
	v2	24.07	24.59	24.63	24.66	24.69	24.07	24.69
<b>80</b>	v1	22.69	22.70	23.21	22.88	23.04	22.69	23.21
	v2	23.31	23.31	23.54	22.64	23.27	22.64	23.54
<b>90</b>	v1	22.07	22.71	23.00	22.53	23.15	22.07	23.15
	v2	22.81	22.79	22.57	22.83	22.67	22.57	22.83

**Table 1: Data from The Downforce Experiment**

Table below (Table 2) shows the mass increases of the spoiler under airflow, using the lowest and highest values of mass of spoiler under airflow; data was used from Table 1.

Angle [degrees]	Velocity	Initial m [g]	Low m [g]	$\Delta m_L$ (Low m – initial m) [g]	High m [g]	$\Delta m_H$ (High m – initial m) [g]
0	v1	23.00	24.93	1.93	26.35	3.35
	v2	23.00	25.37	2.37	27.08	4.08
10	v1	22.72	26.04	3.32	27.57	4.85
	v2	22.72	26.15	3.43	28.50	5.78
20	v1	23.02	27.42	4.40	30.56	7.54
	v2	23.02	27.40	4.38	29.53	6.51
30	v1	23.36	26.21	2.85	29.38	6.02
	v2	23.36	28.91	5.55	30.65	7.29
40	v1	22.81	25.16	2.35	26.70	3.89
	v2	22.81	25.72	2.91	27.35	4.54
50	v1	22.87	25.02	2.15	26.22	3.35
	v2	22.87	25.83	2.96	26.81	3.94
60	v1	23.06	24.64	1.58	25.58	2.52
	v2	23.06	25.27	2.21	26.10	3.04
70	v1	22.74	23.79	1.05	24.34	1.60
	v2	22.74	24.07	1.33	24.69	1.95
80	v1	22.94	22.69	-0.25	23.21	0.27
	v2	22.94	22.64	-0.30	23.54	0.60
90	v1	22.98	22.07	-0.91	23.15	0.17
	v2	22.98	22.57	-0.41	22.83	-0.15

Table 2: Highest and lowest mass increases

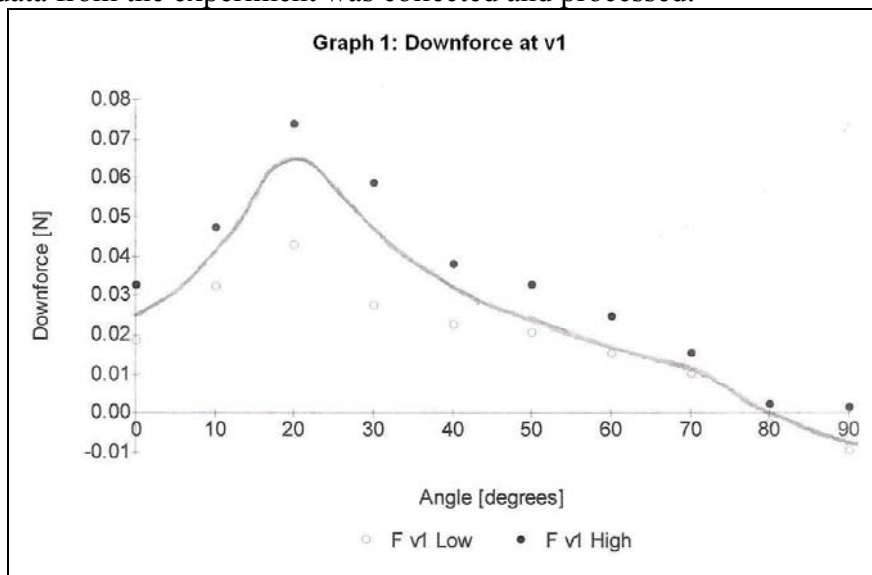
The mass increases from Table 2 were changed into forces using the weight formula  $F=mg$ , where  $m$  is the mass increase and  $g$  is gravity ( $9.81 \text{ ms}^{-2}$ ). When increase in mass was  $\Delta m_L$  the uncertainty of the scale ( $\pm 0.005\text{g}$ ) was subtracted and when the increase was  $\Delta m_H$  the uncertainty was added. This lead to the lowest and highest possible values. These forces are shown in the following table (Table 3)

Angle [degrees]	Force at v1 ( $F_L=\Delta m_{Lv1}g$ )[N]	Force at v1 ( $F_H=\Delta m_{Hv1}g$ )[N]	Force at v2 ( $F_L=\Delta m_{Lv2}g$ )[N]	Force at v2 ( $F_H=\Delta m_{Hv2}g$ )[N]
0	0.0189	0.0329	0.0232	0.0401
10	0.0325	0.0476	0.0336	0.0568
20	0.0431	0.0740	0.0429	0.0639
30	0.0279	0.0591	0.0544	0.0716
40	0.0230	0.0382	0.0285	0.0446
50	0.0210	0.0329	0.0290	0.0387
60	0.0155	0.0248	0.0216	0.0299
70	0.0103	0.0157	0.0130	0.0192
80	-0.0025	0.0027	-0.0030	0.0059
90	-0.0090	0.0017	-0.0041	-0.0014

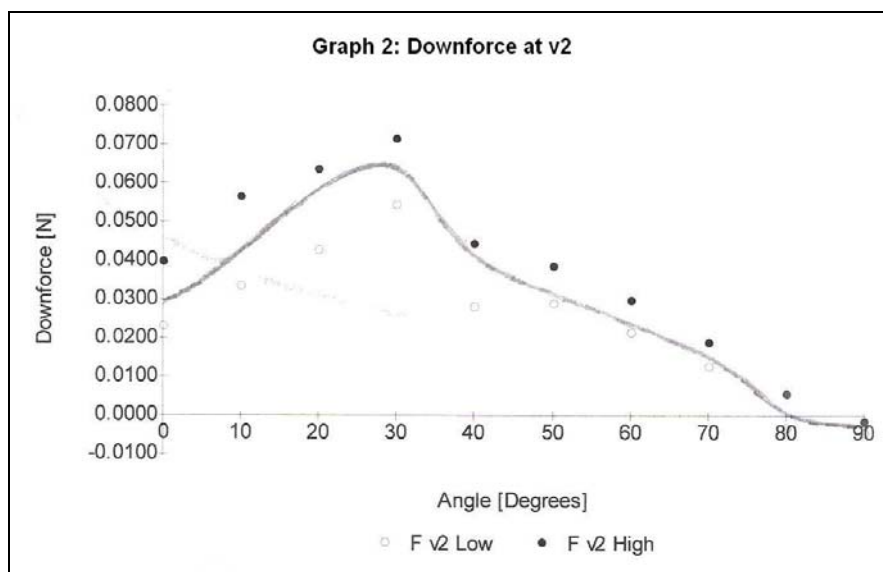
Table 3: Highest and lowest values for downforce

### 3.3. The Downforce Experiment – Results

The data from the experiment was collected and processed.



The graph above (Graph 1) represents the downforce at v1. It shows the downforces created by the spoiler; the data is used from Table 3. Points were plotted and a best fit line was drawn. It is clearly seen that the downforce is the highest at a 20° angle.



Graph 2, represents the downforce of the spoiler at v2. The data was used from Table 3. Individual points were plotted and the best fit line was drawn. From this graph, it is seen that the spoiler is most efficient, downforce wise, at 30°.

The gaps between the lowest and the highest values show how much results varied. The bigger the vertical gap between those points, the more turbulence occurred at that angle. Turbulence, unlike laminar flow, means that air does not glide away; it creates loops and other kind of routes to travel.<sup>1</sup> During turbulence, the air pressure is not constant, this means that the pressure varies. It seems at angle of 10° there is a lot of turbulence, unlike at the angles

<sup>1</sup> Laminar flow - <http://en.wikipedia.org/wiki/Laminar>

bigger than  $50^\circ$ . There, the gap is smaller and means less turbulence. At those angles the downforce is more constant but not as vast as at the angles with high turbulence.

#### 4. The Drag Experiment

The next phase was to carry out The Drag Experiment. The experiment was sketched out as Figure 3 shows.

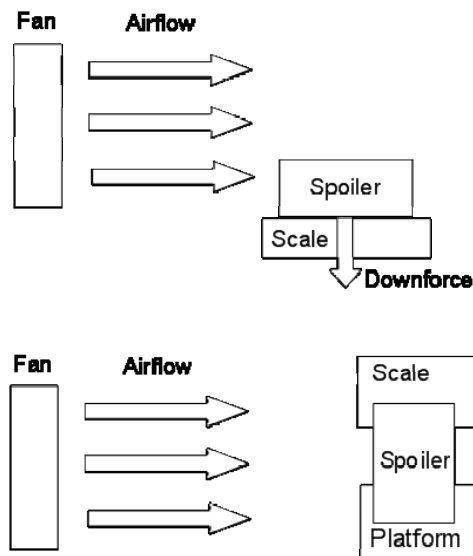


Figure 3

The Figure 3 represents the Drag Experiment. The fan is raised above the spoiler by 0.40 meters as it was the same distance between the fan and the spoiler in the Downforce Experiment. The airflow from the fan will hit the spoiler and cause drag. This is exactly the same experiment as downforce. Everything is rotated by  $90^\circ$  except the scale, since drag is perpendicular to the downforce. The top part shows the experiment from the side and the bottom part shows it from the top. The fan is above the spoiler, but not above the scale. This prevents the readings caused by airflow that did not affect the spoiler. The spoiler is placed on the scale and the platform by its edges.

The equipment needed for the experiment:

- Fan - Warmos VT6A-23 9" DESK FAN
- Digital Scale – uncertainty of  $\pm 0.005\text{g}$
- Books
- Spoiler system [spoiler, 4 clothespins, 3 supporting pieces, 2 angle measuring pieces]
- 3m Steel Tape – uncertainty of  $\pm 0.0005\text{m}$
- 2 chairs
- Thread
- Camera – Sanyo Xacti S3
- 2 walking sticks

The two platforms raising the fan were made out of chairs and books. Two walking sticks were placed on top of the platform. They were suspended by a thread. The fan was attached to the sticks using another thread. The platform that held the spoiler was made out of books. Figure 4 shows how the set up experiment looked like.



**Figure 4: The Drag Experiment**

#### **4.1. The Drag Experiment – Execution**

The procedure was determined as follows.

1. The spoiler is set to  $0^\circ$ .
2. The scale is turned on.
3. The spoiler is placed on the scale and the platform, by its very edges.
4. The reading on the scale is observed.
5. The fan is switched on at  $v_1$  speed.
6. The reading on the scale is recorded using a camera for 4 seconds.
7. The fan is switched on at  $v_2$  speed.
8. The reading on the scale is recorded using a camera for 4 seconds.
9. The fan is switched off.
10. The spoiler is taken off the scale.
11. The scale is turned off.
12. Steps 1-11 are repeated for  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ ,  $40^\circ$ ,  $50^\circ$ ,  $60^\circ$ ,  $70^\circ$ ,  $80^\circ$  and  $90^\circ$ .

## 4.2. The Drag Experiment – Data and Data processing

The masses at v1 and v2 were recorded using a camera, just like in The Downforce Experiment. The following table (Table 4) shows the scale readings at 0s, 1s, 2s, 3s, and 4s. The table also shows the lowest and the highest values.

Angle [degrees]	Velocity	0s [g]	1s [g]	2s [g]	3s [g]	4s [g]	Low [g]	High [g]
<b>0</b>	v1	22.03	22.76	22.92	22.74	22.92	22.03	22.92
	v2	23.03	22.85	22.81	22.95	23.10	22.81	23.10
<b>10</b>	v1	16.80	16.74	16.85	16.80	17.04	16.74	17.04
	v2	17.07	16.97	16.74	16.85	16.73	16.73	17.07
<b>20</b>	v1	16.83	17.02	16.74	16.94	16.94	16.74	17.02
	v2	16.29	16.89	17.10	17.08	17.30	16.29	17.30
<b>30</b>	v1	16.73	16.99	16.86	16.62	16.91	16.62	16.99
	v2	17.84	17.05	17.42	17.04	17.32	17.04	17.84
<b>40</b>	v1	18.14	18.04	18.02	18.11	18.11	18.02	18.14
	v2	18.67	18.81	18.76	18.36	18.41	18.36	18.76
<b>50</b>	v1	19.40	19.27	19.72	19.38	19.30	19.27	19.72
	v2	19.43	18.90	19.14	19.45	19.62	18.90	19.62
<b>60</b>	v1	20.27	19.81	19.43	20.25	20.18	19.43	20.27
	v2	21.07	20.87	21.70	21.61	21.31	20.87	21.70
<b>70</b>	v1	21.36	21.42	20.15	20.53	21.02	20.15	21.42
	v2	22.31	21.59	22.12	20.44	20.58	20.44	22.31
<b>80</b>	v1	21.35	21.22	22.19	21.92	22.09	21.22	22.19
	v2	24.26	23.21	23.19	23.24	22.82	22.82	24.26
<b>90</b>	v1	21.88	22.00	22.35	22.36	21.63	21.63	22.36
	v2	23.66	23.22	23.50	23.23	23.68	23.22	23.68

**Table 4: Data from The Drag Experiment**

The reason why initial mass at angle 0° is significantly higher than at other angles is that at angle 0° 4 clothespins were used and in angles 10°-90° only 2. The reason for that is that it was not possible to apply the other 2 clothespins at those angles because they interfered with the scale and the platform.

The table below (Table 5) shows the mass increases of the spoiler due to the airflow.

Angle [degrees]	Velocity	Initial m [g]	Low m [g]	$\Delta m_L$ (Low m – initial m) [g]	High m [g]	$\Delta m_H$ (High m – initial m) [g]
<b>0</b>	v1	22.90	22.03	-0.87	22.92	0.02
	v2	22.90	22.81	-0.09	23.10	0.20
<b>10</b>	v1	16.42	16.74	0.32	17.04	0.62
	v2	16.42	16.73	0.31	17.07	0.65
<b>20</b>	v1	16.30	16.74	0.44	17.02	0.72
	v2	16.30	16.29	-0.01	17.30	1.00
<b>30</b>	v1	16.16	16.62	0.46	16.99	0.83
	v2	16.16	17.04	0.88	17.84	1.68
<b>40</b>	v1	15.90	18.02	2.12	18.14	2.24
	v2	15.90	18.36	2.46	18.76	2.86
<b>50</b>	v1	15.95	19.27	3.32	19.72	3.77
	v2	15.95	18.90	2.95	19.62	3.67
<b>60</b>	v1	15.74	19.43	3.69	20.27	4.53
	v2	15.74	20.87	5.13	21.70	5.96
<b>70</b>	v1	15.77	20.15	4.38	21.42	5.65
	v2	15.77	20.44	4.67	22.31	6.54
<b>80</b>	v1	16.37	21.22	4.85	22.19	5.82
	v2	16.37	22.82	6.45	24.26	7.89
<b>90</b>	v1	16.80	21.63	4.83	22.36	5.56
	v2	16.80	23.22	6.42	23.68	6.88

**Table 5: Highest and lowest mass increases**

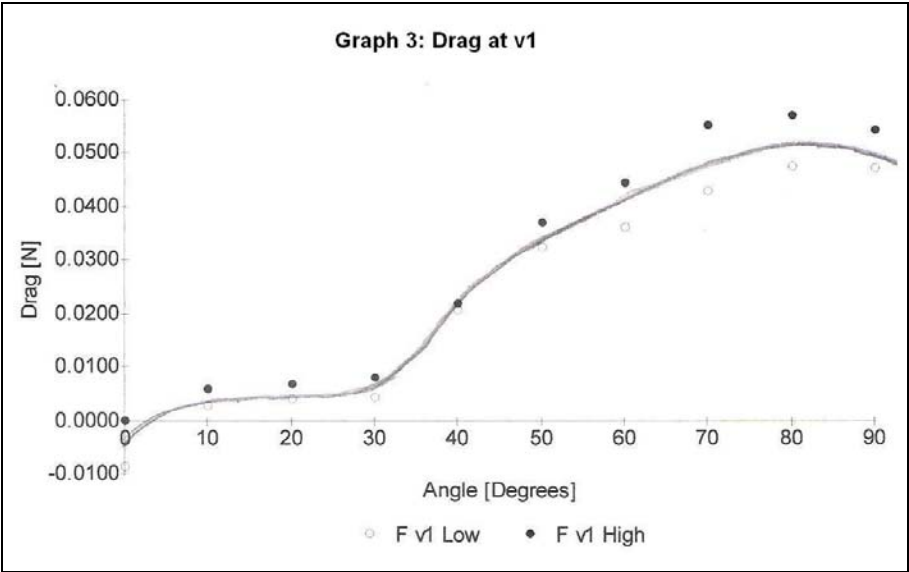
The changes in masses from Table 5 were changed into forces using the weight formula  $F=mg$ , where  $m$  is the mass increase and  $a$  is gravity. In order to achieve the lowest and the highest possible values, the uncertainty of the scale  $\pm 0.0005g$  was subtracted from  $\Delta m_L$  and added to  $\Delta m_H$ . The calculated forces are shown in the following table (Table 6).

Angle [degrees]	Force at v1 ( $F_L=\Delta m_{L,v1}*g$ )[N]	Force at v1 ( $F_L=\Delta m_{H,v1}*g$ )[N]	Force at v2 ( $F_L=\Delta m_{L,v2}*g$ )[N]	Force at v2 ( $F_L=\Delta m_{H,v2}*g$ )[N]
<b>0</b>	-0.0086	0.0002	-0.0009	0.0020
<b>10</b>	0.0031	0.0061	0.0030	0.0064
<b>20</b>	0.0043	0.0071	-0.0001	0.0099
<b>30</b>	0.0045	0.0082	0.0086	0.0165
<b>40</b>	0.0207	0.0220	0.0241	0.0281
<b>50</b>	0.0325	0.0370	0.0289	0.0361
<b>60</b>	0.0361	0.0445	0.0503	0.0585
<b>70</b>	0.0429	0.0555	0.0458	0.0642
<b>80</b>	0.0475	0.0571	0.0632	0.0774
<b>90</b>	0.0473	0.0546	0.0629	0.0675

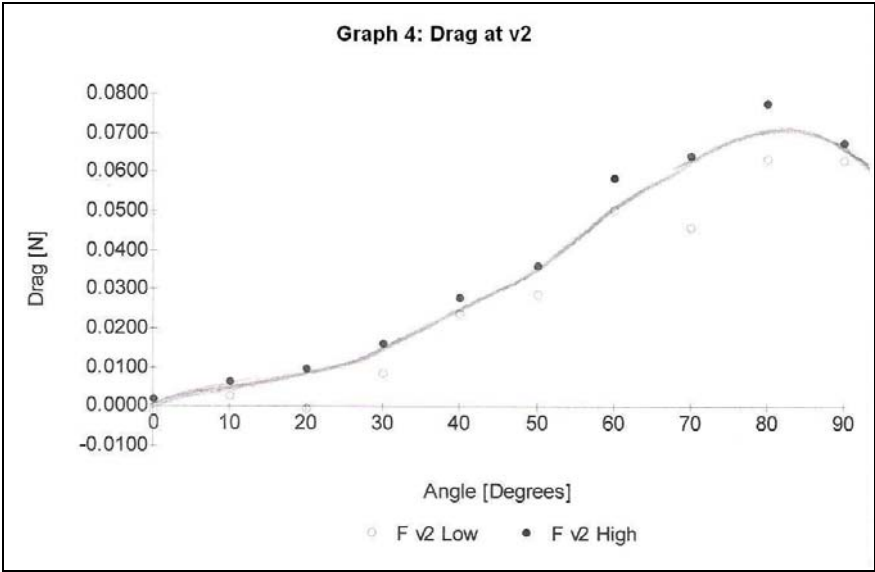
**Table 6: Highest and lowest values for downforce**

### 4.3. The Drag Experiment – Results

The data from the experiment was collected and processed.



Graph 3 shows the drag at v1 caused by the spoiler. It can be seen from the graph that the drag starts to increase rapidly after the angle of 30° and after the angle of 70° it starts to stay almost the same.



Graph 4, illustrates the drag at v2. It seems that the drag starts to increase more rapidly after 20°-30°.

From the Graph 3 and Graph 4, it can be seen that the drag increases as the angle increases. The drag increases more rapidly after 30° in both v1 and v2. This means that there is a critical angle for drag, which is the 30°. There is another critical angle for drag also, it's the one after which it decreases. From Graph 3 and 4, it can be seen that the highest drag is achieved at 80°. Therefore, the cross area that intervenes with the air is the highest than at any other angle.

## 5. The Car Experiment

After carrying out the two experiments, it was chosen to do an extra one. The purpose of the additional one was to show the effects of spoiler in real life. It was decided to mount the spoiler on a toy car and investigate how far the car traveled with the spoiler being tilted at different angles. It was decided to have a ramp, from which the car would be let go. It was hoped that the car would travel different distances from the ramp when spoiler would've been mounted at different angles. The experiment was sketched as Figure 5 shows.

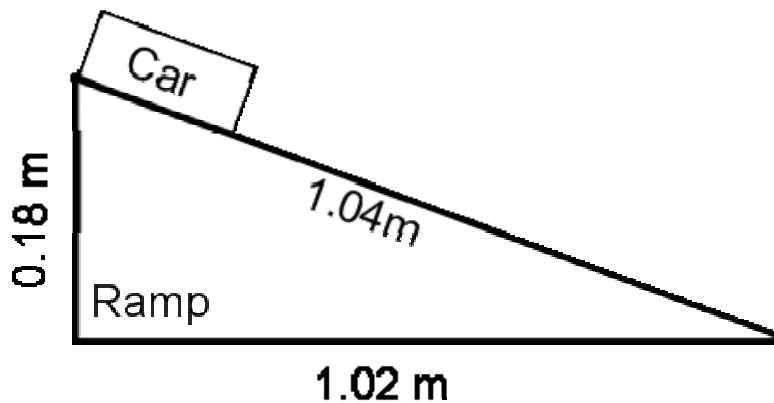


Figure 5: Sketch of the car experiment

Two clothespins were attached to the sides of the car. Four layers of cardboard were put between the clothespins and the car so that the clothespins wouldn't interfere with the wheels. Four spoiler supporting pieces were used in this experiment.

It was chosen to use the same two tilt measuring pieces of cardboard from the previous experiments to tilt the spoiler. One piece would be put on the ground next to the side of the spoiler. Then the spoiler would be adjusted so that its edge would align to the line corresponding to the wanted angle. The same thing was done with the other side.

### 5.1. The Car Experiment – Execution

The following procedure was decided.

1. The spoiler is aligned to be at  $0^\circ$ .
2. The car is put on top of the ramp and let go
3. The distance the car travels is recorded.
4. Steps 2-3 are repeated three times.
5. Steps 1-4 are repeated for  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ ,  $40^\circ$ ,  $50^\circ$ ,  $60^\circ$ ,  $70^\circ$ ,  $80^\circ$  and  $90^\circ$  angles.

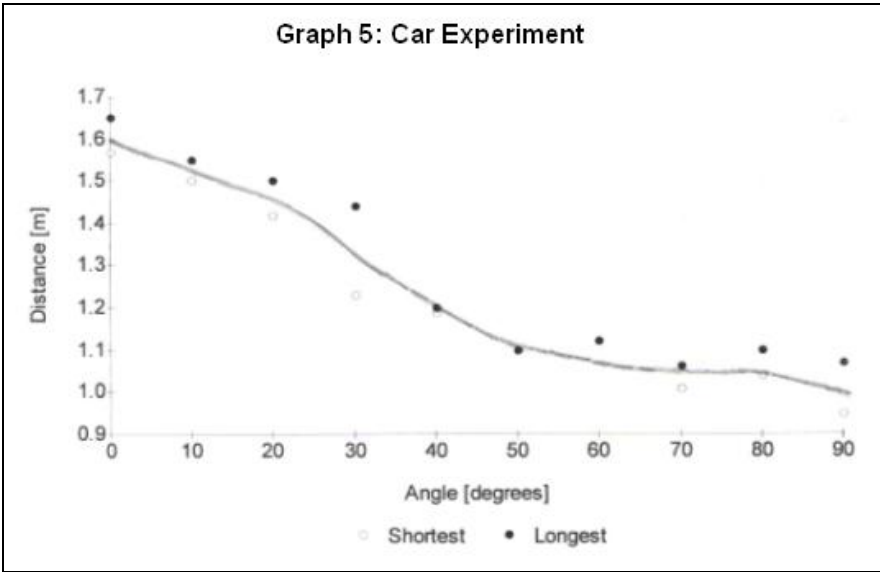
### 5.2. The Car Experiment – Data and Data Processing

Angle [degrees]	Distance 1 [m]	Distance 2 [m]	Distance 3 [m]	Shortest [m]	Longest [m]
0	1.57	1.65	1.57	1.57	1.65
10	1.54	1.50	1.55	1.50	1.55
20	1.42	1.50	1.45	1.42	1.50
30	1.23	1.37	1.44	1.23	1.44
40	1.19	1.20	1.19	1.19	1.20
50	1.10	1.10	1.10	1.10	1.10
60	1.12	1.12	1.12	1.12	1.12
70	1.01	1.06	1.05	1.01	1.06
80	1.04	1.10	1.06	1.04	1.10
90	0.95	0.95	1.07	0.95	1.07

Table 7: Traveled distances by a toy car

Table 7 shows the distances the toy car traveled at different angles. The results were rounded to the nearest cm. Therefore the uncertainty was  $\pm 0.005\text{m}$ . The same table also shows the shortest and longest distances the car traveled.

### 5.3. The Car Experiment – Results

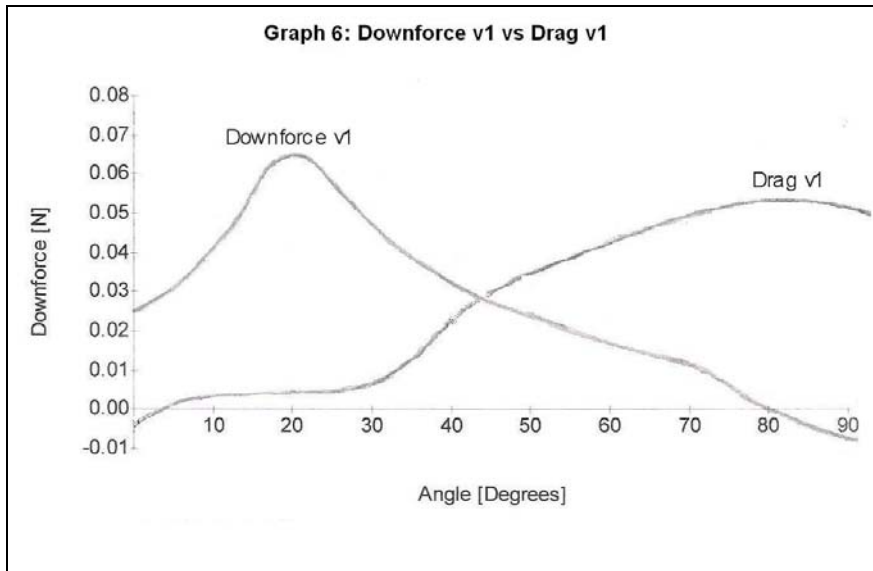


Graph 5 displays the relationship of distances traveled by the toy car over the angle of its spoiler. The data is used from Table 7. When the points were plotted, the best fit line was drawn. It can be seen that the car travels less distance when the angle is being increased. This means that the car is being slowed down more at higher angles. Therefore, the drag increases with the angle. This is the same result as the result from the drag experiment.

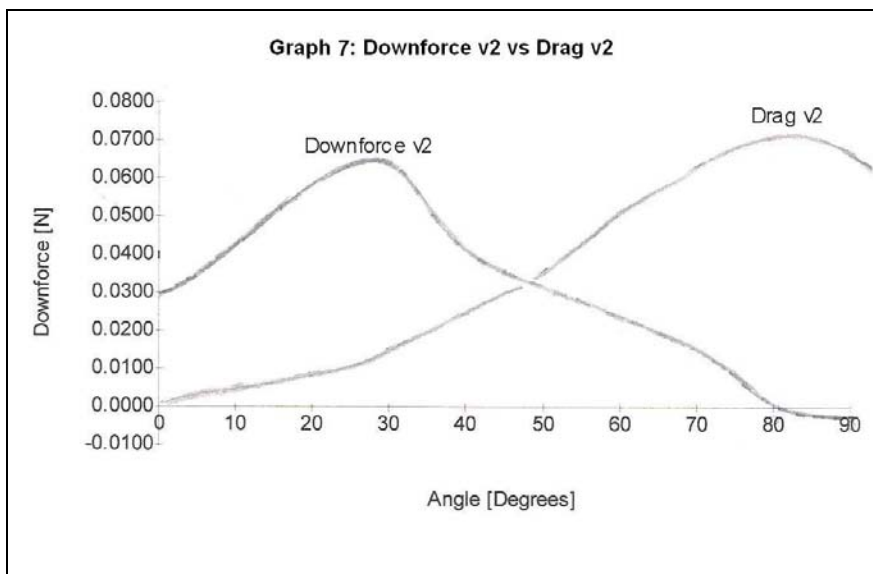
## 6. Final Results

It was found out that the downforce increases up to some angle and then it decreases. From Graph 1<sup>1</sup> this angle is 20° for v1 and 30° for v2 from Graph 2<sup>2</sup>. It was also found out that the drag increases as the angle increases, except it starts to increase more rapidly after the angle of 30°.

In order to find out the relationship of downforce and drag at different angles of spoiler, it was necessary to compare downforce vs drag..



Graph 6 represents downforce<sup>3</sup> and drag<sup>4</sup> at v1.



Graph 7 shows the relationship of drag<sup>5</sup> and downforce<sup>6</sup> at v2.

<sup>1</sup> Page 10

<sup>2</sup> Page 10

<sup>3</sup> Data from Table 3, Page 9

<sup>4</sup> Data from Table 6, Page 14

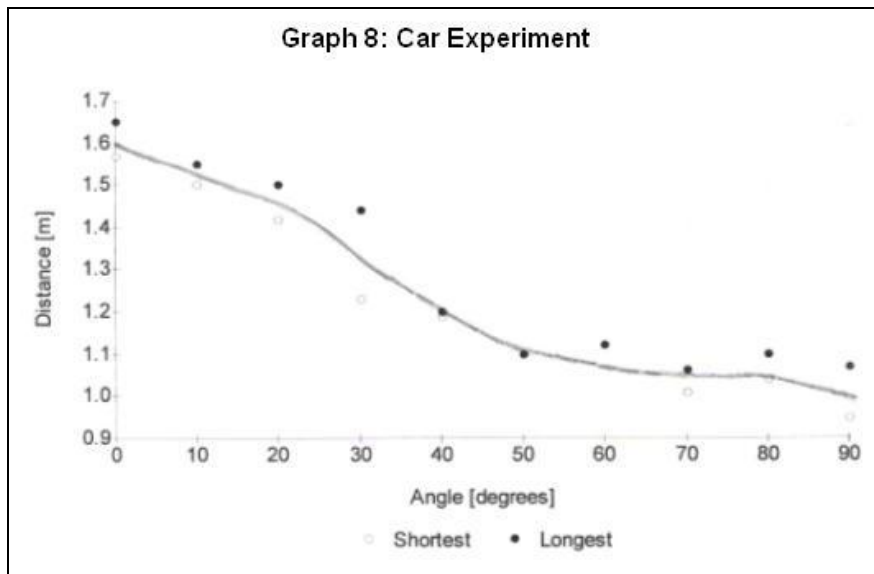
<sup>5</sup> Data from Table 3, Page 9

<sup>6</sup> Data from Table 6, Page 14

From previous graphs (Graph 6 and 7) it can be observed that the downforce and the drag have different behaviors. The highest downforce and the highest drag do not occur near each other, angle wise.

The downforce and the drag are the same around the angle of  $45^\circ$  in Graph 6 and around  $47^\circ$  in Graph 7.

As long as the downforce is above the drag, it means that the downforce is higher than the drag. Where this gap is the biggest, the spoiler is most efficient. This means that it improves handling and traction of the vehicle, without slowing the car down too much. From Graph 6, it is clearly seen that for  $v_1$  the biggest gap occurs at the angle of  $20^\circ$  and from Graph 7 it occurs at the angle of  $30^\circ$  for  $v_2$ .



The fact that the critical angle of the spoiler is  $20^\circ$ – $30^\circ$  can be explained in real life. Graph 8 shows that the traveled distances by the toy car decreased more rapidly after the angle  $20^\circ$  or  $30^\circ$ . This means that after that angle the drag increased significantly and slowed the car down more.

## 7. Conclusion and Evaluation

It was earlier stated that the maximum downforce occurred at angles of  $20^\circ$ – $30^\circ$ . This confirms the hypothesis, that spoiler has its critical angle in causing the downforce. The other hypothesis was that the drag increases as the angle increases. It was found out that it is partially true. A truer statement would be that the drag increases while the cross area of the spoiler increases.

The uncertainty of the scale was  $\pm 0.005g$  and of the steel tape  $\pm 0.0005m$ . These are very small uncertainties, but had an influence on the results, since the masses were small. That was the reason why uncertainties were taken into account when graphs were plotted.

It didn't seem like there were any systematic errors, but there always are some. Hopefully the systematic errors of the scale weren't that big that affected the final results.

Another source of mistakes could've been the fan itself. It wasn't guaranteed that the airflow is always the same at each moment. So the turbulences that were caused by the spoiler might've been caused primarily by the fan itself, since it might not have supplied the constant airflow.

Different origin of mistakes could've been the fact that the scale was only on one side of a spoiler. This means that the forces were calculated only on the edge. For this kind of measurement to be absolutely accurate, the forces caused throughout the spoiler had to be

symmetrical from the midpoint of the spoiler. This is unlikely to have happened; therefore it was a significant source of errors.

Another source of errors was the tilting mechanism. It's unlikely that the spoiler stayed at the same angle when it was under high airflow. Therefore, the forces measured might have been caused at a different angle than the spoiler was set to.

## **7.1. Conclusion and Evaluation – Improvements**

As the experiment had errors and mistakes, there could be a way on improving it. If the ultimate angle of the spoiler would be desired to find out, the same method could be used, except on a bigger scale.

First, the fan used could be a lot bigger. This would mean that the airflow would be faster and would cause higher forces. Higher velocity of airflow would also decrease the turbulence. According to the first Newton's law, the airflow would have inertia and would continue in a similar path and cause less turbulence. Wind tunnel<sup>1</sup> would be the best improvement, since it offers strong and almost perfectly laminar airflow.

If the fan used would be bigger, the spoiler should be heavier too. This is because if the airflow will be very strong the spoiler might be blown off.

The method of tilting the spoiler should be more accurate than the one in this experiment. The mechanism of tilting the spoiler should be more stationary and rigid, so that there wouldn't be any chance of the spoiler to tilt to a different angle under heavy airflow.

There should be more data taken. This would lead to possibly more accurate values. In this experiment only 10 angles were measured, the more the angles would be taken the better relationship of drag and downforce could be established. It would also be the key in determining the critical angles of the spoiler.

The devices to measure were accurate enough, so no real improvements needed there. The only improvement would be to decrease the systematic errors. The best thing would be to eliminate them; only if that would be possible.

## **7.2. Conclusion and Evaluation – Further Investigations**

The results of the experiment brought out some new questions and new potential investigations could be carried out. It was noticed that the angle which causes highest downforce was not the same for two different velocities of airflow. It would be useful to find out how the angle changes with different speeds of airflow. Experiment with different speeds of airflow could investigate and see whether the critical angle changes in a certain pattern or whether it's in the vicinity of some particular angle.

Since there was only one spoiler used in this experiment, it would be interesting to see how different spoilers behave. It's likely that all the spoilers would have the similar behavior, as in there would be a critical angle for downforce and drag. The interesting thing to investigate would be what kind of behavior of the spoiler occurs around those critical angles, are the forces almost the same and the critical angle seems pretty smooth in the graph, or is it a sharp peak.

## **8. Bibliography**

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<http://en.wikipedia.org/wiki/Laminar>

[http://en.wikipedia.org/wiki/Wind\\_tunnel](http://en.wikipedia.org/wiki/Wind_tunnel)

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<sup>1</sup> Wind tunnel - [http://en.wikipedia.org/wiki/Wind\\_tunnel](http://en.wikipedia.org/wiki/Wind_tunnel)