The Effect of Wind on the Emission of Grass Pollen

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August 3, 2004

Abstract

Despite common misconceptions, physical laws dictate that the pollen grains of wind-pollinated grasses should remain on the anthers after dehiscence until disturbed by an external force. Upon controlled observation of the flowering processes of rye-grass and Bermuda grass, it was found that only 5-20% of the pollen escaped during dehiscence, leaving a majority of the pollen on the anthers. With the use of a miniature wind tunnel, it was discovered that a minimum threshold wind speed of 2.5 m/s was required to remove the remaining pollen. Experiments were performed with harvested flowers and artificial anthers made of pollen-coated substrates. The minimization of surface attractions resulting from nanostructures on the surfaces of the pollen and anthers, coupled with an absence of electrostatic forces, caused the velocity threshold for the natural and artificial anthers to be lower than that of the other surfaces dusted with pollen.

1 Introduction

Although pollen has been studied for many centuries, little is known regarding the mechanisms of grass flowering and pollen shedding. Within the scientific community, a number of contradictory notions exist concerning the actual means by which pollen grains enter the air. In some scientific literature, pollen is said to roll off the anthers upon anther dehiscence (opening). Others claim that the grains are catapulted into the air by unspecified mechanisms. A number of sources state that pollen can float away when the air is entirely still. A few even use the terms dehiscence and pollen shedding interchangeably, even though they refer to two separate processes [1]. Not only is there no direct observation of any such phenomena for most allergy-triggering plants, but also these proposals seem to deny the basic laws of physics.

First, due to van der Waals attractive forces, the force required to overcome the attractive forces between the particle and another surface is inversely proportional to the size of the particle. Thus, pollen would not simply roll off the anther, even though the rugged pollen and anther surfaces have evolved to minimize these attractions. Secondly, pollen has a fall-rate of around 2-3 cm/s [2]. Therefore, catapulting grains into the still air would not cause them to be suspended for any significant period of time. Floating away in total stillness is inconceivable, particularly when pollen originates from grass anthers that are only a few centimeters above the ground. In other words, pollen grains should adhere to the anther surface until disturbed by a significant external force, which is frequently wind.

By determining the speed of the wind required to release pollen grains from their anthers, it may be possible to better understand the mechanisms by which these particles enter the free air. This kind of insight may lead to better forecasting of the abundance of allergenic particles in the outdoor air, aiding allergy patients in planning allergy avoidance. Greater understanding of flowering and pollen shedding may also be useful in agriculture for the optimization of seed and fruit formation of wind-pollinated crops.

2 Methods and Materials

This experiment was divided into two parts. The first aim was to observe and understand the mechanisms involved in the flowering process of two species of wind-pollinated grasses. The second aim was to quantify the process of pollen emission by measuring the external force required to dispel the pollen remaining on the anthers. In order to perform the second part of the experiment, it was first necessary to find evidence of pollen retention after dehiscence and to observe and control the process of anther exsertion and dehiscence so that the inflorescences could be induced to flower at will. Therefore, it was vital to complete the investigation of the flowering process before beginning the experiments on pollen shedding.

2.1 Observation and Control of Flowering Process

Humidity was found to be the key component in the flowering process. In the moist environment of the early morning, flower spike samples of *Lolium perenne* (rye-grass) and *Cynodon dactylon* (common Bermuda grass) were collected before exposure to the sun and placed in a sealed container at 90% relative humidity (RH). Flower spikes were next exposed to 60% RH and bright lighting and carefully observed. Anther exsertion was generally observed within 10 minutes, and dehiscence was observed within 20 minutes. In still conditions, while 5-20% of the pollen escaped during dehiscence, possibly as a result of electrostatic or vibrational forces or the release of elastic energy during the drying and opening of the anther, a majority of the pollen remained on the anthers (Figure 1). No additional pollen shedding was observed after dehiscence.

Figure 1: Dehisced rye-grass anthers revealing pollen inside

2.2 Use of Wind Tunnel to Quantify Pollen Emission

To understand the force required to dispel the pollen from the anthers, a miniature wind tunnel was created to measure the size and number of particles shed from anthers at varying wind speeds (Appendix A). This apparatus, combined with control of the grass-flowering process, enabled measurement of the force required to overcome surface attractions and release pollen grains into the air. Emphasis was placed on determining a threshold wind velocity at which the sample began to release pollen grains.

Because rye-grass came to the end of its flowering season before the wind-tunnel experiments could be started, pollen-emission data from live flowers were only collected for Bermuda grass. Bermuda grass flower spikes, collected and prepared in the manner described above, were exposed to 60% RH, trimmed to a height of approximately 4 cm, and inserted into the sample chamber of the wind tunnel. Upon microscopic observation of the exsertion and dehiscence of the anthers, the velocity of air flow through the wind tunnel was varied by control of the voltage provided to the fan over a range from 10-100% of the maximum. The Aerodynamic Particle Sizer (APS), which sampled for 55 seconds every minute, counted the number of particles detected and arranged them by size into bins. Bin numbers from 590-1000, corresponding to an approximate particle diameter range of 10-25 μm, were considered to be pollen grains. The voltages, having been calibrated to manometer pressure readings, were then converted to velocities (m/s). The number of particles considered to be pollen were later counted by hand from the raw data tables.

In order to study specifically the pollen-pollen surface interactions, "artificial anthers" were created. Boats made from 1.5 x 0.5 cm sheets of aluminum foil were dusted with a monolayer of commercially purchased rye-grass pollen, which adhered strongly to the surface, and subsequently coated with more layers of pollen. Wind speeds were increased uniformly until no pollen remained on the foil except for the monolayer.

By determining the wind speeds necessary to emit pollen from the top layers, it was possible to achieve a better understanding of the minimized adhesive forces among the individual pollen grains. An additional experiment was conducted with artificial anthers constructed from plastic sticky tape in order to measure the significance of electrostatic forces on pollen emission.

The minimized attractive forces between anther and pollen surfaces were observed again independently by measuring the amount of pollen emitted when pollen was placed on other surfaces. A monolayer of commercially purchased rye-grass pollen was sprinkled onto a plain sheet of aluminum foil, a cotton bud, and a blade of rye-grass and was subsequently placed in the wind tunnel for observation.

3 Results and Discussion

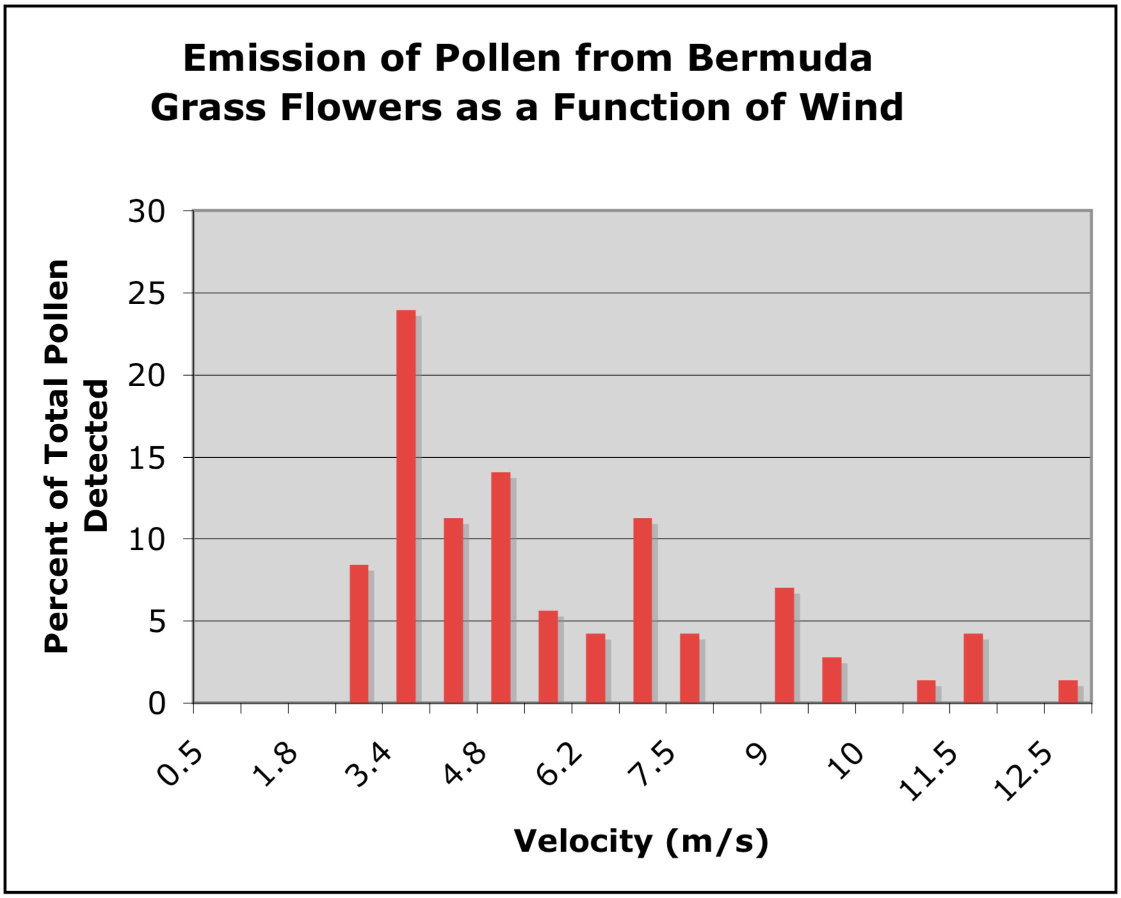

Figure 2: Pollen emission detected from Bermuda grass flowers versus wind speed

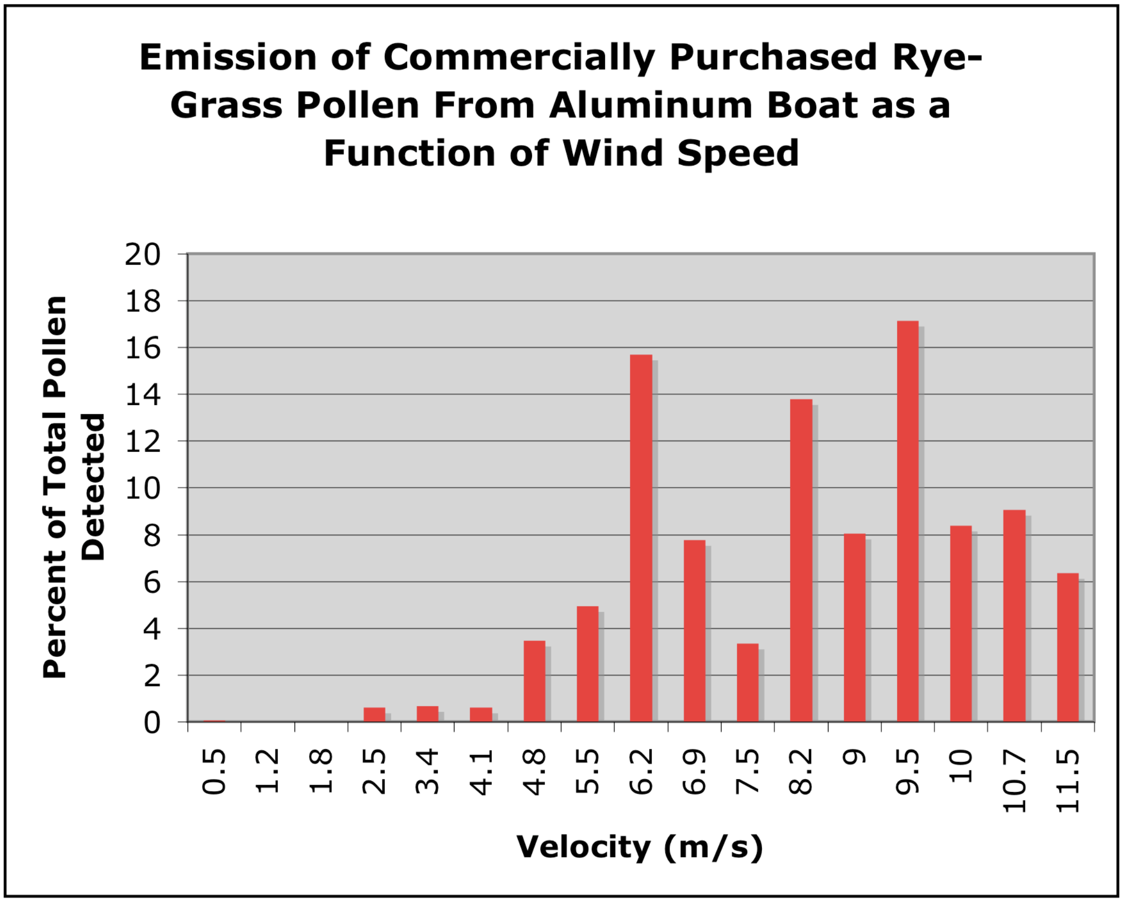

Figure 3: Pollen emission detected from artificial aluminum anther with stored pollen applied versus wind speed

For living Bermuda grass flowers, pollen emission was not observed until wind speeds reached a threshold of approximately 2.5 m/s, after which point emission levels peaked at 4.1 m/s and descended as less pollen remained on the anthers (Figure 2). Artificial aluminum anthers coated with commercially purchased rye-grass pollen had a similar velocity threshold at approximately 2.5 m/s, but emission levels peaked at 9.5 m/s (Figure 3). Since the pollen surface is structurally and chemically similar to the anther surface, pollen-pollen interactions should mimic pollen-anther interactions. However, the emission of pollen from the aluminum-foil anther, which displayed strictly pollen-pollen interactions, peaked at a much higher wind speed than that of the natural anthers, which displayed both pollen-pollen and pollen-anther interactions. This phenomenon could have resulted because the foil anther was much larger than natural anthers and contained substantially more pollen. Thus, more pollen remained to be emitted at the higher wind speeds. However, the vibration of natural anthers in the wind, a product of the anthers' unstable structure and thin, flexible filament, may have also played a role in their releasing pollen more quickly than the structurally stable artificial anthers.

Although a minimum wind speed of 2.5 m/s was required to release pollen grains from both natural and artificial anthers, this force was significantly less than that required to overcome the adhesion forces between pollen and other surfaces. Aluminum foil coated with a monolayer of pollen began to emit pollen at a wind speed of 12.5 m/s. The cotton bud began emission at 7.5 m/s. The blade of rye-grass that had been coated with pollen showed no detectable pollen emission at any wind speed. These observations strongly suggest the importance of surface nanostructures on anthers and pollen grains in minimizing surface adhesion.

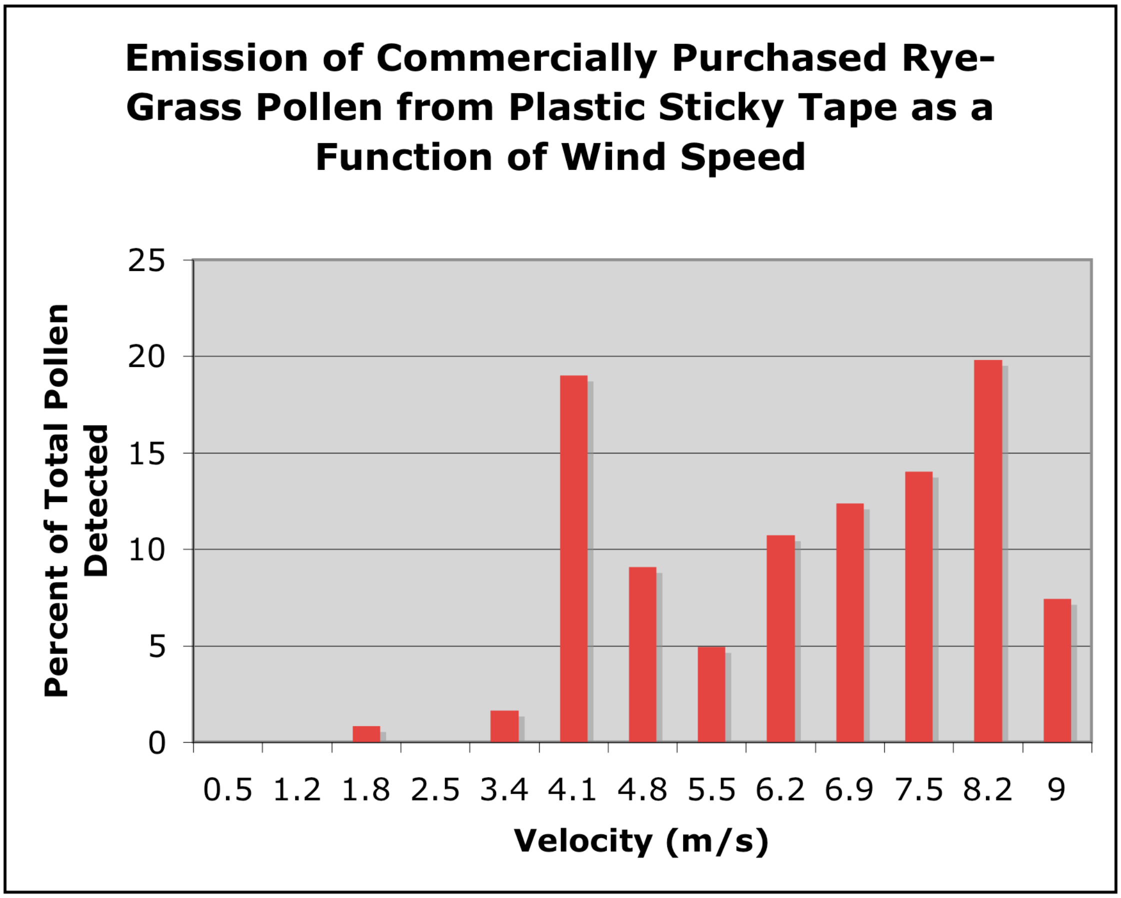

Figure 4: Pollen emission detected from plastic sticky tape with stored pollen applied versus wind speed

The sticky tape anthers had a velocity threshold of approximately 4.1 m/s, which was higher than the 2.5 m/s observed for the aluminum foil anthers (Figure 4). This suggests that electrostatic forces do play a role in pollen adhesion to surfaces.

Several modifications to the experiment could improve the accuracy of results. First, it would be useful to perform a more thorough calibration of voltage output and wind speeds and to collect more data so that the mean and standard deviation for threshold data can be calculated. Second, as humidity was the key to grass flowering, a precision humidity probe located in the sample chamber of the wind tunnel would be helpful. Extreme swings in RH were also observed to result in improper flowering. Anthers became too desiccated to dehisce or dehisced prematurely. Therefore, a more practical method of controlling the humidity within the chamber would facilitate experiments of this type. In addition, since the HEPA filter was observed to tear in wind speeds above 10 m/s, it would be sensible to obtain a thicker and more durable filter. Finally, modifications to the position of the probe and the relative size of the sample chamber may decrease the likelihood of pollen escaping the APS sampler, which also would improve the accuracy of results.

4 Conclusion

After having observed the flowering of rye-grass and Bermuda grass, it was noted that 80-95% of the pollen remained on the anthers after dehiscence. Further tests with a miniature wind tunnel revealed that a minimum amount of external force, that which was provided by 2.5 m/s of wind speed, was necessary for pollen emission. This figure is relatively low in comparison with the amount needed to overcome attractive forces between pollen and other surfaces. In the future, it may be useful to investigate pollen and anther surfaces for their potential use in the fabrication of superhydrophobic surfaces in materials science. Artificial anthers also hold potential scientific interest for examining the pollen-pollen interactions of other species of plants. Pollen rupture and the release of cytoplasmic fragments as aerosols could also be studied, as these fragments have been associated with the triggering of asthma. The results of this experiment have shed light on a long-standing dilemma concerning the mechanisms behind the flowering and pollen-shedding processes of allergenic grasses.

Acknowledgments

I would like to extend my sincere gratitude to Dr. Richard Flagan and Dr. Philip Taylor for their invaluable guidance and direction throughout the course of this project. I would also like to express my thanks to tutors Ms. Jacqueline Choi and Mr. David Zhang and to Ms. Emma Schmidgall for their critique and input in the writing of this paper. Finally, I extend the utmost appreciation to the Center for Excellence in Education for making possible my priceless summer experience at the twenty-first annual Research Science Institute held at the California Institute of Technology.

References

[1] P. E. Taylor. "Anther dehiscence and pollen shedding (emission/release) in anemophilous plants, or: How the 'wind' was omitted from 'wind pollination.'" (private communication).

[2] P. E. Taylor, and H. Jonsson. Thunderstorm asthma. *Current Allergy and Asthma Reports* (2004), 4: 409-413.

Appendices

A Wind Tunnel Theory and Construction

As can be seen in Figure 5, the wind tunnel consists of several main parts. The wind is induced by a fan at the bottom of the instrument linked to a variable autotransformer, which is used to control the velocity. Air first passes through a HEPA filter, which is kept flat by two mesh screens, to remove all aerosol particles. A fiberglass contraction chamber then accelerates the air into the sample chamber, where it picks up pollen grains and fragments. A copper probe directs a sample of this air into an APS, which counts the number of aerosol particles of each size range and arranges them into bins. To minimize the turbulence caused by the 90-degree bend in the tunnel, an airflow straightener is installed in the sample chamber, and the copper probe is situated in front of both the flow straightener and the bend to ensure a direct flow of air into the sampler. The entire instrument is tightly sealed to avoid the leaking of wind and aerosol particles; however, it is not possible in this experiment to achieve an entirely particle-free environment. To compensate for the irreducible number of particles constantly in the background, the APS has been calibrated at various wind speeds so that this number would be subtracted from the particle count during actual data collection.

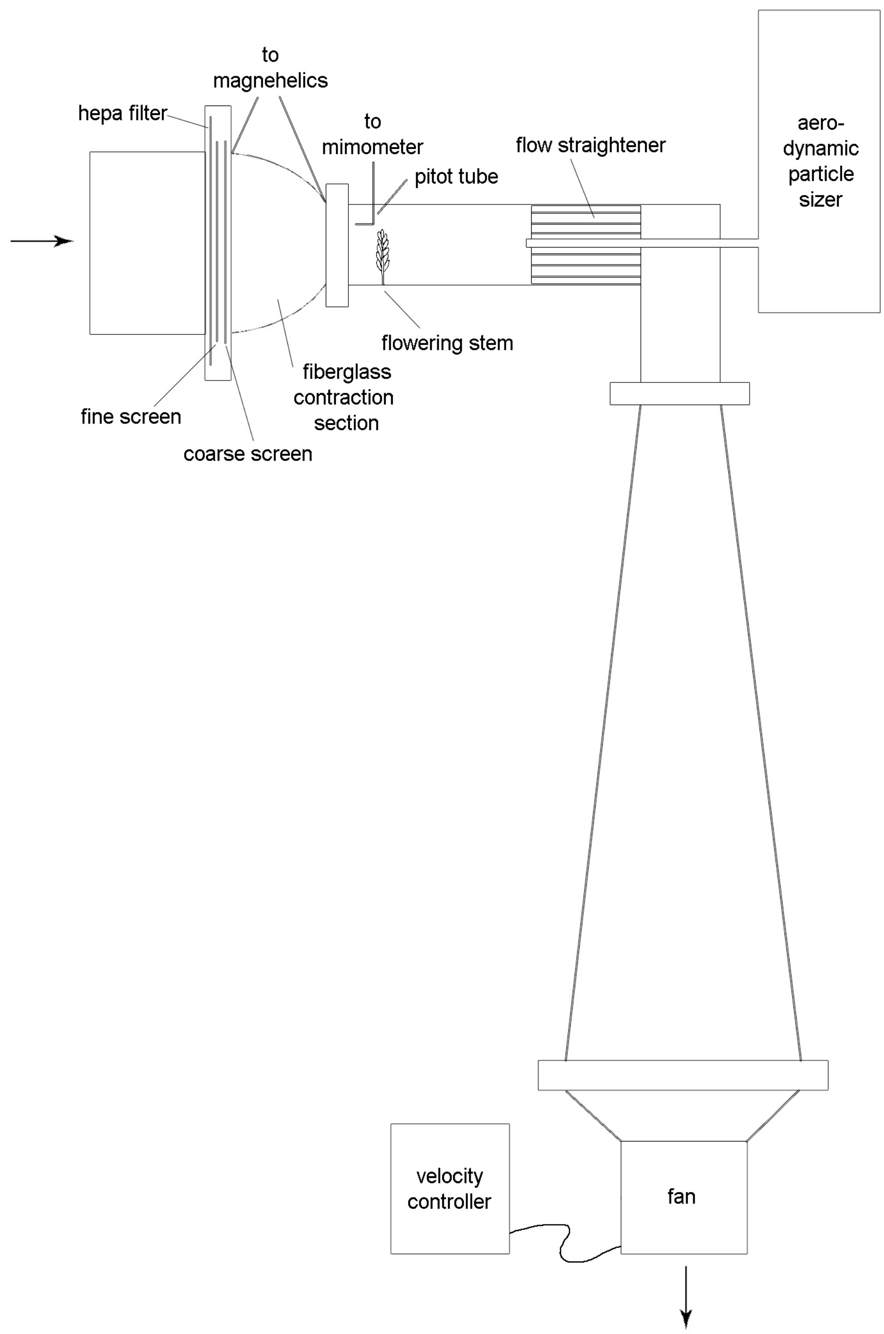

Figure 5: Diagram of Miniature Wind Tunnel

To determine the velocity of the wind in the tunnel, a manometer is used to measure (in inches of water) the change in static and stagnant air pressure via a pitot tube located at the front of the sample chamber. After manipulating Bernoulli's equation for an incompressible fluid regime, the resulting equation yields velocity in terms of the stagnation pressure, static pressure, and the air density, ρ:

$$v = \sqrt{\frac{2}{\rho}\left(p_{stagnation} - p_{static}\right)}$$

Equation 1: Velocity for Incompressible Flow

This equation was used to calculate the wind speeds that corresponded with the percent of maximum output voltage used to power the fan.

B Variable Autotransformer – Manometer Calibration

Table 1: Calibration of Variable Autotransformer with Manometer

Percent of Maximum Output Voltage	Pressure Change (inches of water)
24	0.01
27	0.02
30	0.03
32	0.03
36	0.04
39	0.05
44	0.07
46	0.07
50	0.09
54	0.105
60	0.135
66	0.16
70	0.185
72	0.2
74	0.205
80	0.23

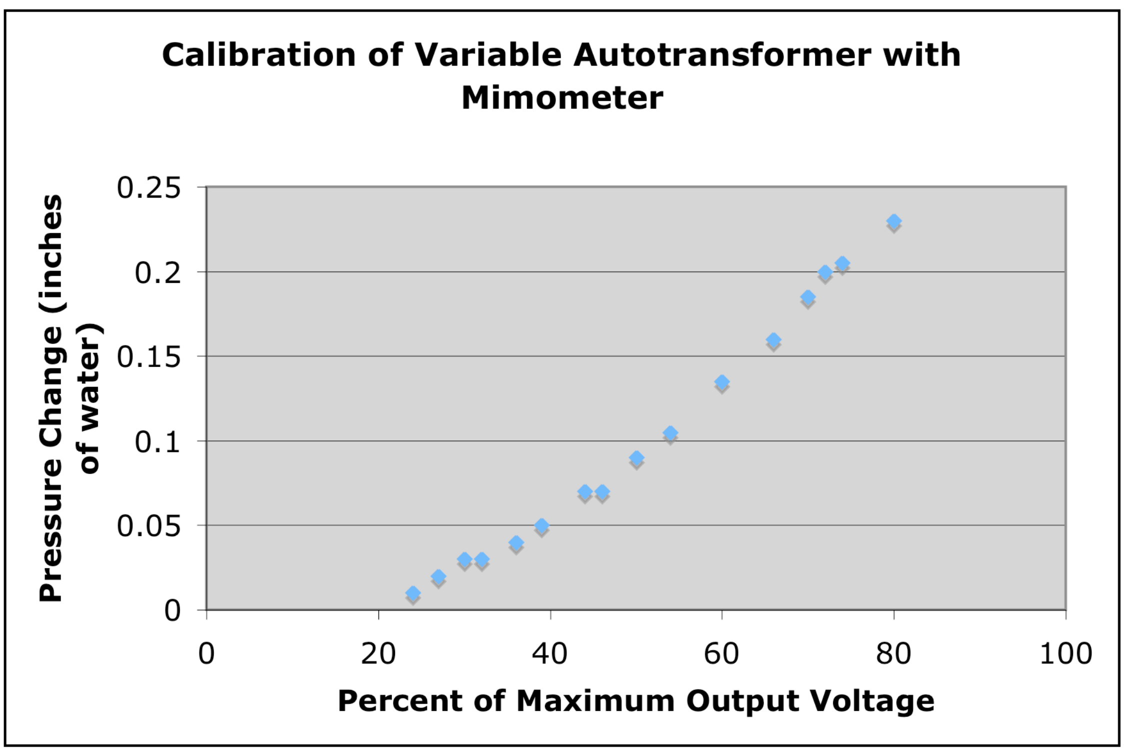

Figure 6: Pressure change versus percent of maximum output voltage to fan

C Percent Maximum Output Voltage – Velocity Conversion Table

Table 2: Conversion of Percent Maximum Output Voltage to Velocity

% Max Voltage (from 120-V)	Pressure Change (in. water)	Velocity (m/s)
10	-	0.5
15	-	1.2
20	0.0029	1.8
25	0.0134	2.5
30	0.0255	3.4
35	0.0393	4.1
40	0.0547	4.8
45	0.0718	5.5
50	0.0905	6.2
55	0.1109	6.9
60	0.1329	7.5
65	0.1566	8.2
70	0.1819	9
75	0.2089	9.5
80	0.2375	10
85	0.2677	10.7
90	0.2996	11.5
95	0.3332	12
100	0.3684	12.5

D List of Abbreviations

- APS – Aerodynamic Particle Sizer
- RH – Relative Humidity

E Glossary of Terms

- Aerosol – a gaseous suspension of fine solid or liquid particles
- Dehiscence – the process of the opening of the anther
- Exsertion –the process of the anthers coming out of the inflorescence
- Inflorescence – a flower spike
- Shedding – pollen emission