# Ground Effect Aircraft

## Society of Physics Students

## Towson University

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**Introduction**

Ground Effect Aircraft present an incredible avenue for future transportation technology. The efficiency of such designs in both commercial and public sectors would allow for more cost efficient vehicles able to transport significantly larger loads. So far the exploration of such technology has been limited to private investors and older military groups. With energy at such a premium, it would be advantageous to utilize modern technology to its maximum potential. Through testing of several wing designs in a synthetic environment, the potential of such vehicles can be explored.

**Theory**

In normal flight, lift is caused by two major factors. The first is Newton's third law which states "There are no isolated forces; for every external force that acts on an object, there is a force of equal magnitude but opposite direction which acts back on the object that exerted the external force".[1] As the wing moves through the air at a given speed, air particles exert a force back upon it that generate lift. This is done by having the wing move through the air at an angle (called the angle of attack) so that the air particles exert a vector force both up, which is called lift, and opposite of the wings motion, which is called drag. In general aircraft design, a key point of focus is to maximize the lift force while minimizing drag.

The second major factor contributing to lift is due pressure difference. Bernoulli's principle of fluid mechanics explains this. As air moves around the wing during flight air molecules above and below the wing move at two different speeds in order to keep in place with each other. The air moving across the top of the wing generates an area of low pressure. Since the pressure below the wing is still at atmospheric pressure, the wing will move to the area of lower pressure and thus generating lift.

Ground effect occurs as a plane flies closer to the ground. As the factors of lift remain constant throughout altitude difference, Bernoulli's principle becomes even more important in the role it plays in ground effect. As the wing moves at higher altitudes, higher pressure above the wing escapes around the wings edges. However as the wing moves closer to the ground that pressure is captured between the wing and the ground creating a cushion of air that the wing then rides on. Many pilots feel this effect as they are trying to land their aircraft.

By considering the most general forms of the wing, it is possible to analyze the aspects of the wing in order to produce viable conclusions about what parts of design affect ground effect most. The airfoil, wing shape and front profile will be tested for several designs. These three aspects of the wing will be tested separately in order to provide a three-dimensional basis for ground effect design. By putting these three parts together, a complete design of the most effective aircraft can be assembled. The data obtained will hopefully provide a solid foundation for future considered designs.

**Experimental Procedure**

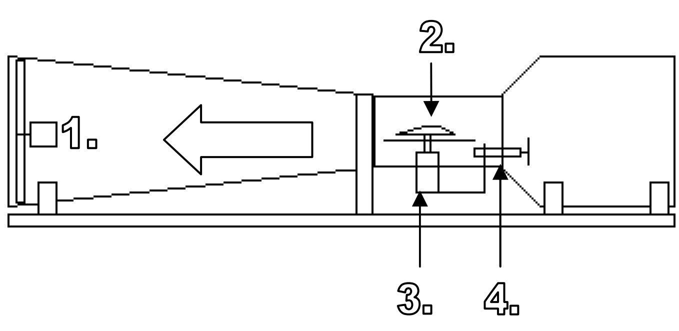
Three experiments were administered. The first experiment determined what airfoil shape was the most efficient. The second experiment took the knowledge gained form the first one and applied it to the front profile of the wing. The third experiment was used to analyze whether a wider and shorter wing worked best or if a thinner longer wing does.

In order to accurately compare the efficiency of each wing design in each experiment a lift to thrust ratio was used. For each design the average lift was divided by the average thrust in order to determine the lift to thrust ratio. Each wing design was also tested the same. Each test was timed and started with the wind tunnel off. After five seconds of testing the wind tunnel was engaged. This provided a mock take off experience for the wing and allowed us to determine more about the flight characteristics of each design. After fifty seconds the wind tunnel was turned off and at one minute the test was stopped. Each design followed this procedure in order to produce comparable results throughout the experiment.

**Experiment 1**

This experiment was designed to evaluate the types of airfoil that would provide the most efficient lift for a ground effect vehicle. There are four separate models that will be tested. Two of these models are symmetrical about the center of the airfoil, while the other two wing designs have the apex of their airfoil placed one third of the length of the wing down from one end. The two models that are not symmetric about the center will be tested twice in order to observe what flow direction provides greater lift. These six separate tests should provide a general conclusion for which airfoils work best under the conditions presented by ground effect.

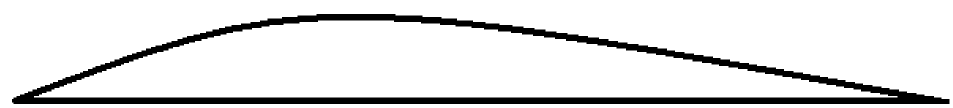
**Wind Tunnel Schematic**




1.Wind Tunnel Fan, 2.Wing Model, 3.Lift Force Meter, 4.Thrust Force Meter

A smaller school provided wind tunnel provided the necessary environment test the airfoils in. Inside the wind tunnel, the airfoil subject to testing would be attached to a force meter. The force meter would then transmit the lifting force to the computer. This allowed for a more efficient data collection. Each airfoil was positioned 15 degrees above the horizon in order to produce an optimum angle of attack. The distance between the simulated ground and the airfoil was 2 ¼ inches. The width of the wind tunnel was 11 ¾ inches.

There was no ammeter present or device to control wind speed. In order to compensate for this, since lift is dependent on velocity, a force meter was attached to a plate that was perpendicular to the wind flow. This provided a thrust force that could be analyzed proportionally with the lift force.

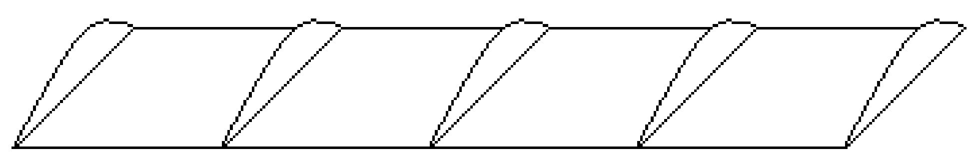


The wing models used in this experiment were of relatively small size. They were 6 inches in length and at the apex of each airfoil were ¾ of an inch high. Each wing model was 4 ½ inches wide.

**Experiment 2**

The purpose of this experiment was to compare several general front profiles of the wing. Three wing forms were tested. The first front profile was a simple flat wing. The second front profile tested was a wing that made an upside down v-shape. The last front profile tested had a normal v-shape.

The same wind tunnel used in the first experiment was used for this one. Minor repair and replacement of inefficient equipment within the testing apparatus occurred. However no real change in setup or data collection was taken.

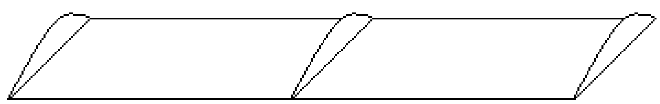


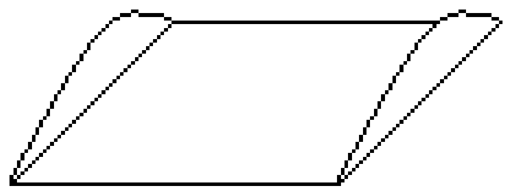
The wing models used in this experiment were twice the width of those used in the first experiment. The same airfoils were used. This was the maximum size wing models that could be made for testing. The objective behind that is that the larger the wing, the larger the lift value. This was done so that small variances in data could be ignored. Each wing model was 6 inches long and ¾ inch high and 9 inches wide.

**Experiment 3**

The objective of the third experiment was to analyze what wing shape worked best for a ground effect aircraft. Using the accumulated knowledge from the first two experiments we were able to build a cumulative design. Due to larger models used for this experiment a second wind tunnel was created. The results of this test alone present a feasible design.

The size of the models to be tested presented a challenge. In order to produce more accurate results, even larger wing models were used. A second wind tunnel was constructed in order to accommodate for the larger models.





This wind tunnel consisted of a large 2 x 4 built wooden frame with two large fans attached to one side. No sides or ceiling were used so that no reciprocation of unwanted forces occurred. Large pieces of foam were attached to the bottom of the wind tunnel in order to simulate the effect ground would have on an aircraft.

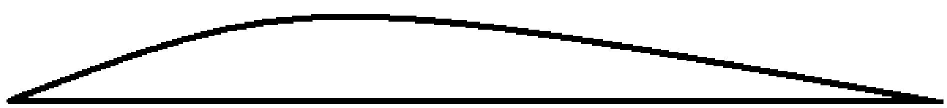
The models used for this experiment were very large in size. One reflected a glider in design, while the other represented a lifting body. The glider like design was twice the width and half the length of the lifting body design. The lifting body design was one based on the principle of the fuselage acting as a wing while the glider design reflects the idea of the wing acting as a fuselage.

**Data and Analysis**

**Experiment 1**

**Test 1-A**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -1.29 ± 0.41 | 1.01 ± 0.08 |
| Run 2 | -1.47 ± 0.47 | 0.81 ± 0.06 |
| Run 3 | -1.79 ± 0.35 | 0.83 ± 0.06 |
| Run 4 | -1.45 ± 0.35 | 0.89 ± 0.06 |
| Total Avg. | -1.50 ± 0.47 | 0.89 ± 0.08 |



$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-1.50}{.09} = -1.683$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 1-A Reversed**

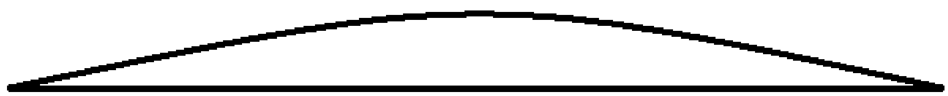
| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -3.29 ± 1.47 | 1.26 ± 0.04 |
| Run 2 | -3.15 ± 0.43 | 1.24 ± 0.03 |
| Run 3 | -3.10 ± 0.37 | 1.24 ± 0.04 |
| Total Avg. | -3.18 ± 1.47 | 1.25 ± 0.04 |

$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-3.18}{1.247} = -2.550$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 1-B**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -2.09 ± 0.34 | 1.03 ± 0.07 |
| Run 2 | -2.12 ± 0.34 | 1.03 ± 0.07 |
| Run 3 | -1.84 ± 0.32 | 1.02 ± 0.06 |
| Total Avg. | -2.11 ± 0.34 | 1.03 ± 0.07 |

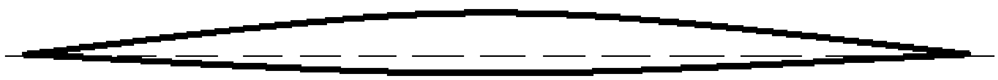


$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-2.017}{1.027} = -1.964$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 1-C**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -1.75 ± 0.94 | 1.19 ± 0.51 |
| Run 2 | -2.26 ± 0.99 | 1.25 ± 0.53 |
| Run 3 | -2.31 ± 1.16 | 1.21 ± 0.53 |
| Total Avg. | -2.11 ± 1.16 | 1.22 ± 0.53 |

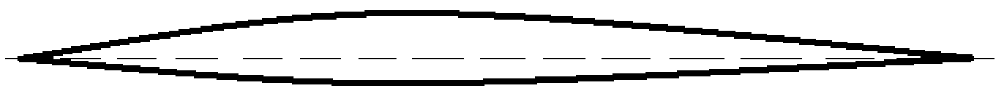


$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-2.106}{1.216} = -1.73$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 1-D**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -1.80 ± 0.32 | 1.30 ± 0.04 |
| Run 2 | -2.42 ± 1.08 | 1.31 ± 0.04 |
| Run 3 | -2.24 ± 0.30 | 1.30 ± 0.04 |
| Total Avg. | -2.15 ± 1.08 | 1.30 ± 0.04 |

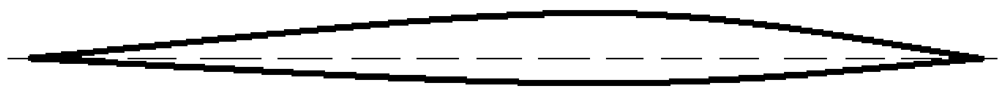


$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-2.133}{1.303} = -1.632$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 1-D Reversed**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -2.27 ± 0.42 | 1.42 ± 0.04 |
| Run 2 | -2.59 ± 1.18 | 1.43 ± 0.04 |
| Run 3 | -2.77 ± 0.38 | 1.43 ± 0.04 |
| Total Avg. | -2.54 ± 1.18 | 1.43 ± 0.04 |



$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-2.543}{1.427} = -1.782$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Conclusion Experiment 1**

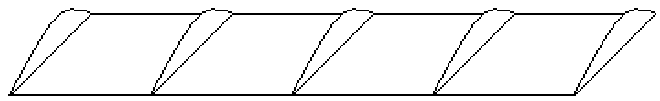
| Test | Lift/Thrust Ratio |
|---|---|
| 1-A | -1.685 |
| **1-A Reversed** | **-2.55** |
| 1-B | -1.964 |
| 1-C | -1.73 |
| 1-D | -1.652 |
| 1-D Reversed | -1.782 |

By analyzing the magnitude of the thrust-lift ratio, it is possible to discern the most efficient airfoil. The airfoil design that produced the greatest ratio was in Test 1-A Reversed. With an efficiency of 2.550, it was far superior to the other designs.

**Experiment 2**

**Test 2-A**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -7.67 ± 3.58 | 0.81 ± 0.00 |
| Run 2 | -7.89 ± 3.70 | 0.82 ± 0.34 |
| Run 3 | -8.49 ± 3.50 | 0.76 ± 0.31 |
| Total Avg. | -8.02 ± 3.70 | 0.80 ± o.34 |

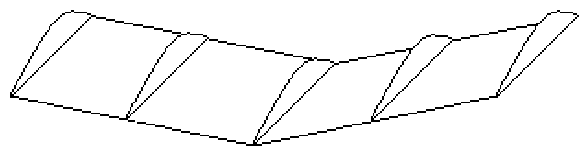


$$Lift\ Thrust\ Ratio = \frac{Lift}{Thrust} = \frac{-8.016}{.796} = 10.07$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 2-B**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -6.17 ± 2.63 | 0.68 ± 0.26 |
| Run 2 | -7.99 ± 3.50 | 0.79 ± 0.31 |
| Run 3 | -6.92 ± 0.78 | 0.81 ± 0.32 |
| Total Avg. | -7.03 ± 3.50 | 0.76 ± 0.32 |

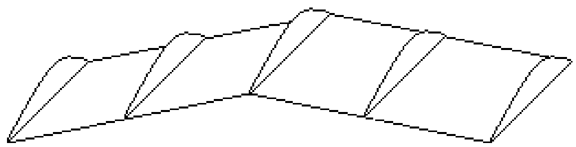


$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-7.026}{.76} = 9.24$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 2-C**

| | Lift Force (Newtons) | Thrust Force (Newtons) |
|---|---|---|
| Run 1 | -7.63 ± 3.21 | 1.06 ± 0.41 |
| Run 2 | -8.18 ± 3.56 | 0.96 ± 0.36 |
| Run 3 | -7.13 ± 3.32 | 0.91 ± 0.34 |
| Total Avg. | -7.65 ± 3.56 | 0.98 ± 0.41 |



$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-7.646}{.976} = 7.83$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Conclusion Test 2**

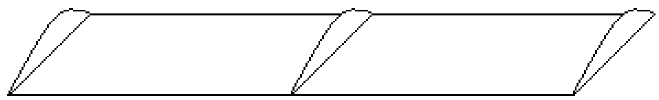
| Test | Lift/Thrust Ratio |
|---|---|
| **2-A** | **10.07** |
| 2-B | 9.24 |
| 2-C | 7.83 |

From the data obtained in this experiment, Test 2-A yielded the best results. With a thrust-lift ratio of 10.07 Newton's, it was far more efficient than the other two wing designs. This is an interesting outcome and an unexpected result. It was hypothesized that the wing with the downward v-shape would have performed the best by trapping more vortices. It is has been concluded post experiment that due to the varying distance between the bottom of the wing and the ground the same amount of vortices are trapped but are weaker in strength.

**Experiment 3**

**Test 3-A**

| | Lift Force (Newtons) | Thrust Velocity (m/s) |
|---|---|---|
| Run 1 | -2.12 ± 1.32 | 1.06 ± 0.01 |
| Run 2 | -1.45 ± 1.19 | 0.96 ± 0.01 |
| Run 3 | -1.93 ± 1.34 | 0.91 ± 0.01 |
| Total Avg. | -1.83 ± 1.34 | 0.98 ± 0.01 |

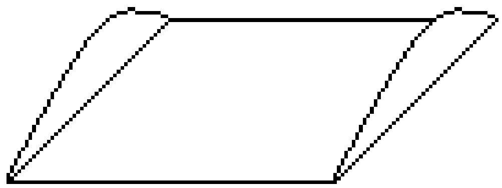


$$Lift\,Thrust\,Ratio = \frac{Lift}{Thrust} = \frac{-1.83}{.98} = 1.87\ Ns/m$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Test 3-B**

| | Lift Force (Newtons) | Thrust Velocity (m/s) |
|---|---|---|
| Run 1 | -0.22 ± 0.62 | 1.06 ± 0.01 |
| Run 2 | -0.40 ± 0.76 | 0.96 ± 0.01 |
| Run 3 | -0.15 ± 0.77 | 0.91 ± 0.01 |
| Total Avg. | -0.26 ± 0.77 | 0.98 ± 0.01 |



This was an extremely inefficient design whose lift value was even less than that of the deviation calculated by the testing program.

$$Lift\ Thrust\ Ratio = \frac{Lift}{Thrust} = \frac{-.26}{.98} = .27\ Ns/m$$

Note: Lift is negative with respect to the position of the measuring device. The value of the magnitude is the most important since the measuring device was used upside down.

**Conclusion Test 3**

The results for test three concluded that the glider design was much more efficient than the lifting body design. This is an interesting result, but one that solidifies the theory behind ground effect. Since the glider has a wider wing more of the escaping vortices are trapped under the wing due to its shorter length.

| Test | Lift/Thrust Ratio |
|---|---|
| **3-A** | **1.87 Ns/m** |
| 3-B | 0.27 Ns/m |

**Research Summary**

By analyzing the results of the three experiments a general conclusion about the most effective wing design was determined. Since each of the three experiments represent one view in a three dimensional analysis of a wings shape by putting them together.

The design that represents the most effective use of ground effect is one with an airfoil that has its apex towards the back of the wing with a flat lower edge. The wing design should be wider than it is long and have a straight profile when viewed from the front.

**Acknowledgements**

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