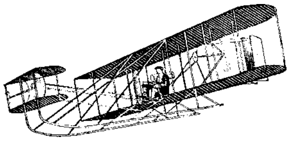


Know All the Angles

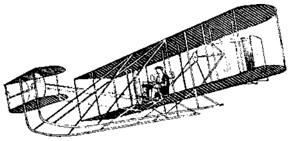
In July of 1901, the Wright Brothers were at Big Kill Devil Hill in North Carolina for more tests on their glider. On one day in particular, July 27th, there were many unsuccessful launches. The glider did get into the air, but it would stall. The stall occurred under the same circumstances for each flight. It happened when the glider slowed its speed. When its speed slowed, the pilot would increase the wing angle to compensate and maintain lift. At a certain critical point when the angle was very steep, the airflow over the top of the wing would become turbulent. This meant that the wing stopped generating lift.

When the brothers returned to Dayton, Ohio, for the winter, they needed to perform some experiments on the angle of attack for the 1901 glider. They used their own wind tunnel to test airfoil shapes.

One day, the boy who lived down the road from the Wright Brothers, young Martin Northrop, brought in a glider he had made and asked if the brothers would test his model. Marty wanted some test data so he could fly his glider more efficiently, and even improve his glider design. Marty had these questions about his glider:

- Which angle of attack would give the glider the greatest amount of lift?
- What cruising angle would be the most efficient for flight?
- What is the stall angle for his glider?

The Brothers agreed to help. They told Marty to return in a few days and they would have the data for him. When Marty returned, he received the results found on the data table on the next page. First, read the section "Understanding Wind Tunnel Test Results" carefully. Then, review the information found on the data table and the graphs. Finally, help Marty find the answers to his questions.



Marty Northrop's Glider
Wind Tunnel Data Table

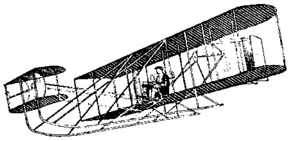
Run #	Point #	alpha (deg)	Lift (lbs)	Drag (lbs)	CL	CD	L/D
1	1	0	0.10	0.02	0.14	0.03	5.00
1	2	1	0.30	0.04	0.41	0.05	7.50
1	3	2	0.50	0.05	0.68	0.07	10.00
1	4	4	0.66	0.06	0.89	0.08	11.00
1	5	6	0.88	0.07	1.19	0.09	12.57
1	6	8	1.10	0.08	1.49	0.10	14.67
1	7	9	1.20	0.12	1.62	0.16	10.00
1	8	10	1.00	0.16	1.35	0.22	6.25
1	9	11	0.99	0.24	1.34	0.32	4.13
1	10	12	0.77	0.50	1.04	0.68	1.54
2	1	0	0.40	0.08	0.14	0.03	5.00
2	2	1	1.20	0.16	0.41	0.05	7.50
2	3	2	2.00	0.20	0.68	0.07	10.00
2	4	4	2.64	0.24	0.89	0.08	11.00
2	5	6	3.52	0.28	1.19	0.09	12.57
2	6	8	4.40	0.30	1.49	0.10	14.67
2	7	9	4.80	0.48	1.62	0.16	10.00
2	8	10	4.00	0.64	1.35	0.22	6.25
2	9	11	3.96	0.96	1.34	0.32	4.13
2	10	12	3.08	2.00	1.04	0.68	1.54

Understanding Wind Tunnel Test Results

Runs, Points, Angles, Lift and Drag

The type of wind tunnel test that was run would be called a “sweep test”. The glider was run through the same test twice. During the test, the angle of attack of the glider was changed from 0 degrees through to 12 degrees. So for test 1 (Run # 1) there were actually 10 points in the test when data was taken (Point 1 through 10). The test was repeated (Run #2) and at 10 points in the test, data was taken (Point # 1 through 10). For each point in the test, the angle of attack for the glider was changed (alpha: degrees). At each point in the test, measurements were taken for lift and drag. At each point, the amount of lift was measured in pounds (Lift: lbs.) and the amount of drag was measured in pounds (Drag: lbs.).

For example, in Run #1, Point #2 with an angle of attack of 1 degree, Martin’s glider generated 3 tenths of a pound of lift. It also created 4 one-hundredths of a pound of drag. Compare that to Run #1 at Point #8 with 10 degrees angle of attack when Martin’s glider generated 1 pound of lift and created only 16-hundredths of a pound of drag.



Understanding Wind Tunnel Test Results (continued)

<u>L over D (L/D)</u>

The values of lift and drag are also shown as a ratio. We call it “L over D” (L/D). If the L/D number is high, then the design being tested can fly efficiently. When an airplane flies efficiently, it is creating the needed lift while creating little drag. This is important to flying because such an airplane can fly farther using less fuel.

The “L/D” column or last column on the right of the chart shows Lift divided by Drag. For example, look at the first line of data (Run #1 and Point #1):

.10 (Lift) **divided** by **.02** (drag) = **5.00** (L/D)

This ratio tells us how efficiently lift is being made. Let’s look at four basic ways the lift and drag numbers could turn out in a test:

1. If the lift number is high and the drag number is low, then we say that L/D is high. That is a good thing!

2. If the lift number is high and the drag number is high, also, then we say that L/D is low and that the design is less efficient. That’s not a very good thing! We would need to redesign the airplane to lower the drag number. Or, we can increase the thrust by putting on larger (and heavier) engines.

3. If the drag number is high and the lift number is low, then we say that the L/D is real low. That means the design is very inefficient. That is not a good thing!

4. If the lift number is low and the drag number is low, then we say that the L/D is low and that it is not an efficient design. That’s not a very good thing! We would need to redesign the airplane to increase its lift.

Understanding Wind Tunnel Test Results (continued)

Coefficient of Lift = CL

Knowing the amount of lift and drag that is generated by the design being tested is important. Just knowing how much lift is made though is not enough. We need to know other things, too. The amount of lift that is made during a test depends on many things. Here are some examples:

1. A big wing makes more lift than a smaller wing.
2. Flying faster makes a wing produce more lift.
3. Air of greater density will be able to make more lift than air of lesser density.

By combining all these variables into one number, researchers can compare test results more easily. This is done for lift by combining the following measurements:

1. Amount of lift (measured in pounds)
2. Wing area (measured in square feet)
3. Speed (measured in feet per second)

This one number is called the "coefficient of lift" or "CL". The mathematical equation used to get this one number (CL) is given below:

$$\mathbf{CL} = \frac{\text{Lift}}{\text{Wing area} \;\mathbf{X}\; \text{air density} \;\mathbf{X}\; \text{speed} \;\mathbf{X}\; \text{speed} \;\mathbf{X}\; 0.5}$$

This number is used to compare the airplane's flight performance without having to run more tests. This means, for example, that a small-scale model of the space shuttle being tested in a wind tunnel will have the same CL as the full-size shuttle flying through the upper atmosphere.

Understanding Wind Tunnel Test Results (continued)

<u>Coefficient of Drag = CD</u>

The CD is the coefficient of drag. It's another calculation that is very important in wind tunnel tests. The CD includes the same measurements as CL except it uses drag instead of lift. This number can be used to make comparisons in much the same way as the CL.

Researchers make greater use of CL and CD because they work with models when performing wind tunnel tests. By converting a lot of the data to numbers like CD, researchers can compare data more accurately. Researchers can compare data from different tests. They can compare data of models to full size aircraft. And they can compare data from different aircraft designs. Researchers can then make predictions about how the model will fly based upon the CL and the CD.

Now that you have some insight into what the data means, help Martin Northrop answer some questions using the data table and the graphs that show the results of the tests.

Know All the Angles
Activity Sheet #1

Directions: Use the data table below to help Martin Northrop answer his questions.

Run #	Point #	alpha (deg)	Lift (lbs)	Drag (lbs)	CL	CD	L/D
1	1	0	0.10	0.02	0.14	0.03	5.00
1	2	1	0.30	0.04	0.41	0.05	7.50
1	3	2	0.50	0.05	0.68	0.07	10.00
1	4	4	0.66	0.06	0.89	0.08	11.00
1	5	6	0.88	0.07	1.19	0.09	12.57
1	6	8	1.10	0.08	1.49	0.10	14.67
1	7	9	1.20	0.12	1.62	0.16	10.00
1	8	10	1.00	0.16	1.35	0.22	6.25
1	9	11	0.99	0.24	1.34	0.32	4.13
1	10	12	0.77	0.50	1.04	0.68	1.54
2	1	0	0.40	0.08	0.14	0.03	5.00
2	2	1	1.20	0.16	0.41	0.05	7.50
2	3	2	2.00	0.20	0.68	0.07	10.00
2	4	4	2.64	0.24	0.89	0.08	11.00
2	5	6	3.52	0.28	1.19	0.09	12.57
2	6	8	4.40	0.30	1.49	0.10	14.67
2	7	9	4.80	0.48	1.62	0.16	10.00
2	8	10	4.00	0.64	1.35	0.22	6.25
2	9	11	3.96	0.96	1.34	0.32	4.13
2	10	12	3.08	2.00	1.04	0.68	1.54

1. For Test #1 looking at points #1 – 10, what is the difference in lift between the greatest weight and the lowest weight?

2. For Test #2 looking at points #1 – 10, what is the difference in drag between the lowest weight and the highest weight?

3. Which angle of attack (alpha) overall generated the greatest amount of lift?

4. Which angle of attack (alpha) overall generated the least amount of drag?

Know All the Angles
Activity Sheet #1 (continued)

5. Which angle of attack (alpha) overall generated the lowest L/D?

6. Which angle of attack (alpha) overall generated the greatest L/D?

7. For Run #1, looking at Points # 1-10, find the greatest L/D. __________

8. For Run #1, looking at Points #1-10, give the number following the greatest L/D. __________

9. Using the information from questions 7 and 8, what is the angle of attack (alpha) at which the glider is not generating as much lift as it was before?

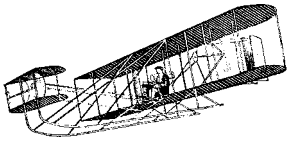
10. Overall, which angle of attack (alpha) generates the greatest CL?

11. Overall, which angle of attack (alpha) generates the lowest CL?

12. Overall, which angle of attack (alpha) generates the greatest CD?

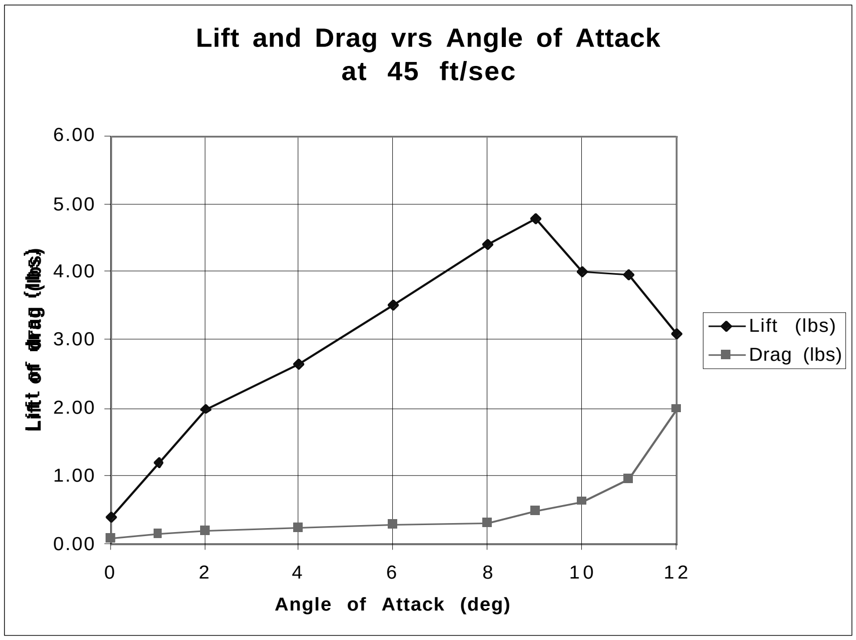
13. Overall, which angle of attack (alpha) generates the lowest CD?

14. Overall, which angle of attack (alpha) do you think is the stall angle? Explain your reasoning. (Hint: Look over your answers for questions 7 – 12.)



Know All the Angles
Activity Sheet #2

Directions: Use the graph below to help Martin Northrop answer his questions. This is a graph showing the data collected on Martin's glider. It displays the lift and the drag at different angles of attack when the glider is flying at 45 feet per second.



1. On the graph above, circle the point at which the most lift is being generated.

   A. How many pounds of lift are being generated? ___________

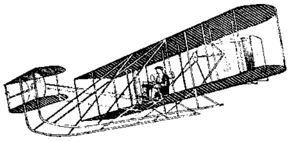
   B. What is the angle of attack? ___________

2. On the graph above, draw a box around the point at which the most drag is being generated.

   A. How many pounds of drag are being generated? ___________

   B. What is the angle of attack? ___________

3. List the 4 angles of attack during which the same amount of drag is being generated.



Know All the Angles
Activity Sheet #2 (continued)

Directions: Use the graph from page 9 to help Martin Northrop answer his questions.

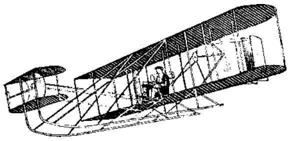
4. At which angle of attack does drag begin to steadily increase?

5. At which angle of attack does lift peak, and then begin to steadily decrease?

6. What do you think is happening between 9 and 10 degrees angle of attack?

7. A good cruise angle is one in which the design has the greatest difference between lift and drag. Doing some subtraction, calculate which angle of attack would most likely be the most efficient cruise angle? (Hint: you don't have to subtract the drag from lift of each angle of attack. Narrow the field, by looking for the biggest gap between lift and drag and then doing some subtraction.)

8. At which angle of attack does lift begin to steadily increase?



Know All the Angles
Activity Sheet #1
Key

Directions: Use the data table below to help Martin Northrop answer his questions.

Run #	Point #	alpha (deg)	Lift (lbs)	Drag (lbs)	CL	CD	L/D
1	1	0	0.10	0.02	0.14	0.03	5.00
1	2	1	0.30	0.04	0.41	0.05	7.50
1	3	2	0.50	0.05	0.68	0.07	10.00
1	4	4	0.66	0.06	0.89	0.08	11.00
1	5	6	0.88	0.07	1.19	0.09	12.57
1	6	8	1.10	0.08	1.49	0.10	14.67
1	7	9	1.20	0.12	1.62	0.16	10.00
1	8	10	1.00	0.16	1.35	0.22	6.25
1	9	11	0.99	0.24	1.34	0.32	4.13
1	10	12	0.77	0.50	1.04	0.68	1.54
2	1	0	0.40	0.08	0.14	0.03	5.00
2	2	1	1.20	0.16	0.41	0.05	7.50
2	3	2	2.00	0.20	0.68	0.07	10.00
2	4	4	2.64	0.24	0.89	0.08	11.00
2	5	6	3.52	0.28	1.19	0.09	12.57
2	6	8	4.40	0.30	1.49	0.10	14.67
2	7	9	4.80	0.48	1.62	0.16	10.00
2	8	10	4.00	0.64	1.35	0.22	6.25
2	9	11	3.96	0.96	1.34	0.32	4.13
2	10	12	3.08	2.00	1.04	0.68	1.54

1. For Test #1 looking at points #1 – 10, what is the difference in lift between the greatest weight and the lowest weight?

   1.20 - .10 = 1.10

2. For Test #2 looking at points #1 – 10, what is the difference in drag between the greatest weight and the lowest weight?

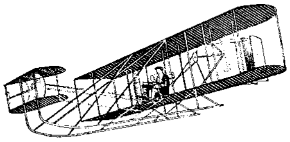
   4.80 - .40 = 4.40

3. Which angle of attack (alpha) overall generated the greatest amount of lift?

   9 degrees

4. Which angle of attack (alpha) overall generated the least amount of drag?

   0 degrees



Know All the Angles
Activity Sheet #1 (continued)
Key

5. Which angle of attack (alpha) overall generated the lowest L/D?

   12 degrees

6. Which angle of attack (alpha) overall generated the greatest L/D?

   8 degrees

7. For Run #1, looking at Points # 1-10, find the greatest L/D. *<u>14.67</u>*

8. For Run #1, looking at Points #1-10, give the number following the greatest L/D. *<u>10.00</u>*

9. Using the information from questions 7 and 8, what is the angle of attack (alpha) at which the glider is not generating as much lift as it was before?

   9 degrees

10. Overall, which angle of attack (alpha) generates the greatest CL?

    9 degrees

11. Overall, which angle of attack (alpha) generates the lowest CL?

    0 degrees

12. Overall, which angle of attack (alpha) generates the greatest CD?

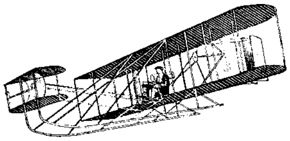
    12 degrees

13. Overall, which angle of attack (alpha) generates the lowest CD?

    0 degrees

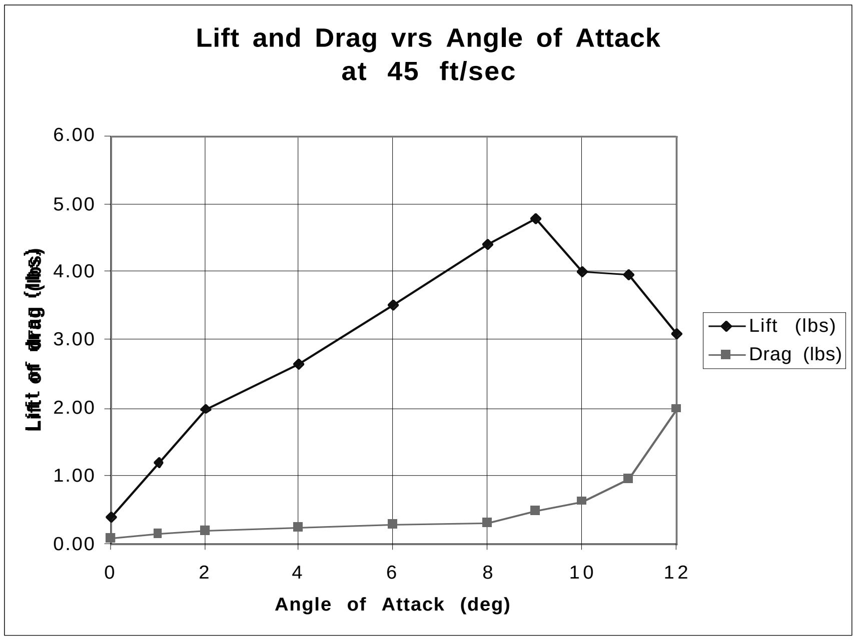
14. Overall, which angle of attack (alpha) do you think is the stall angle? Explain your reasoning. (Hint: Look over your answers for questions 7 – 12.)

    9 degrees because the model being tested is increasingly generating lift until it gets to 9 degrees and then lift begins to steadily decrease.



Know All the Angles
Activity Sheet #2
Key

Directions: Use the graph below to help Martin Northrop answer his questions. This is a graph showing the data collected on Martin's glider. It displays the lift and the drag at different angles of attack when the glider is flying at 45 feet per second.



1. On the graph above, circle the point at which the most lift is being generated.

   A. How many pounds of lift are being generated? *<u>4.80</u>*

   B. What is the angle of attack? *<u>9 degrees</u>*

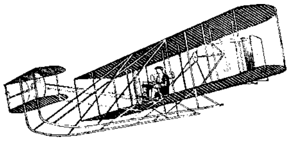
2. On the graph above, draw a box around the point at which the most drag is being generated.

   A. How many pounds of drag are being generated? *<u>2.00</u>*

   B. What is the angle of attack? *<u>12 degrees</u>*

3. List the 4 angles of attack during which the same amount of drag is being generated.

   2, 4, 6, 8



Know All the Angles
Activity Sheet #2 (continued)
Key

Directions: Use the graph from page 13 to help Martin Northrop answer his questions.

4. At which angle of attack does drag begin to steadily increase?

   9 degrees

5. At which angle of attack does lift peak, and then begin to steadily decrease?

   9 degrees

6. What do you think is happening between 9 and 10 degrees angle of attack?

   The stall angle has been reached and lift is not being generated as greatly as before.

7. A good cruise angle is one in which the design has the greatest difference between lift and drag. <u>Doing some subtraction, calculate which angle of attack would most likely be the most efficient cruise angle?</u> (Hint: you don't have to subtract the drag from lift of each angle of attack. Narrow the field, by looking for the biggest gap between lift and drag and then doing some subtraction.)

8 degrees	*9 degrees*	*10 degrees*
4.40 L	*4.80 L*	*4.00 L*
- .30 D	*- .48 D*	*- .64 D*
4.10	*4.32*	*3.36*

Somewhere between 8 and 9 degrees

8. At which angle of attack does lift begin to steadily increase?

   1 degree