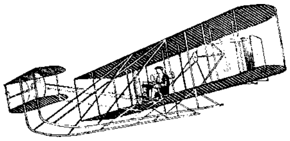


Getting the "Wright" Pitch
Activity 1

It is now 98 years later and a replica of the Wright Brothers' airplane, the *Flyer,* is mounted in a wind tunnel at Ames Research Center. History tells us that only the Wright Brothers could successfully pilot this airplane design. According to the records that the brothers themselves kept, the aircraft did not have good longitudinal stability. That means that it had a tendency to pitch wildly when hit by a strong gust of wind. The AIAA pilots need information about how this replica's longitudinal stability performs. This information will assist the AIAA pilots to modify the replica so that any of the pilots scheduled to fly the aircraft in 2003 will be able to successfully maneuver the airplane.

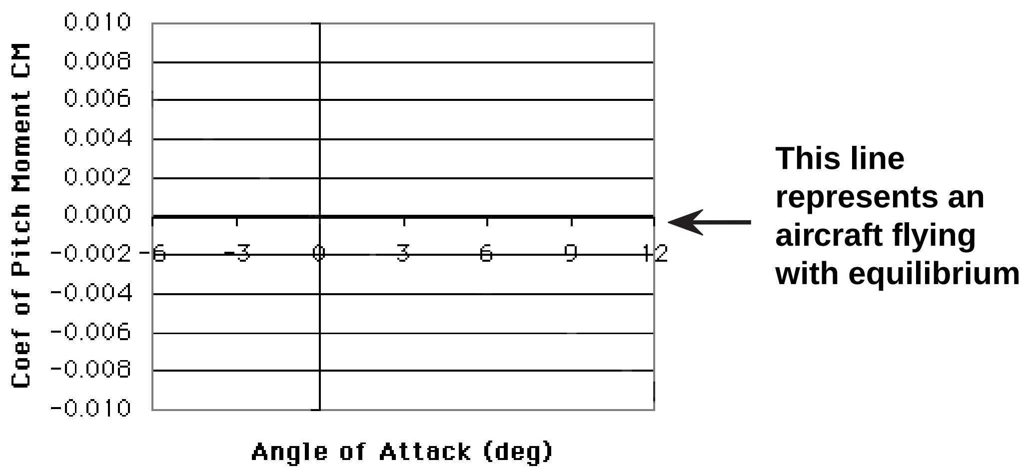
To gather this data, researchers will place special instruments on various parts of the airplane. Each instrument is designed to gather a specific type of information. For example, some instruments will collect information about how the air flows to the airplane. Other instruments will also measure how fast the air flows or how great the air pressure is at certain points along the aircraft. To gather the information needed by the AIAA pilots, the balance will measure the forces and where those forces are located along the center of gravity.

Remember, the center of gravity (CG) is the point where the entire weight of the airplane is considered to be concentrated. On a paper airplane you could find the general location of that point by balancing the paper airplane on your finger. The point at which the airplane balances on your finger would be considered the center of gravity (CG). All three motions (roll, pitch, yaw) pass through this point. All four forces interact on the airplane as it moves about this point.

Getting the "Wright" Pitch (continued)

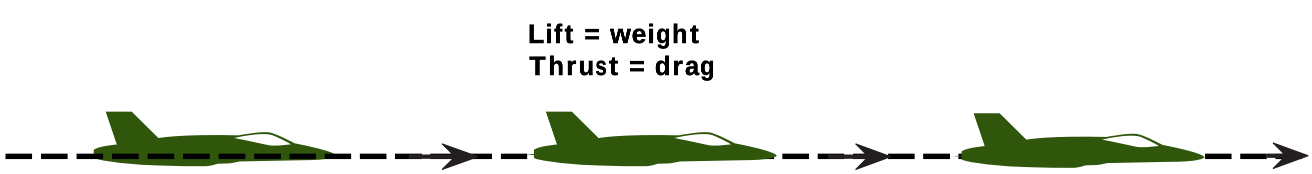
Designing airplanes with static stability is important. (For the purposes of our discussion we are not considering military jet fighters as some form of instability is preferred which make these aircraft more quickly maneuverable when managed by computer and pilot.) Stability is the tendency of an airplane to fly with equilibrium on its flight path. To fly with equilibrium means that the sum of all forces and moments acting on the airplane will equal zero. See the graph below.

Graph #1 "Equilibrium Graphed"



For example, let's look at an airplane that is flying straight and level. For this airplane to fly with equilibrium in its straight and level flight path, the four forces must be in balance. That means the lift will be equal to the weight and the thrust will be equal to the drag. It also means that there are no moments acting on it. These moments are trying to make the aircraft rotate about the center of gravity either by pitch, roll or yaw.

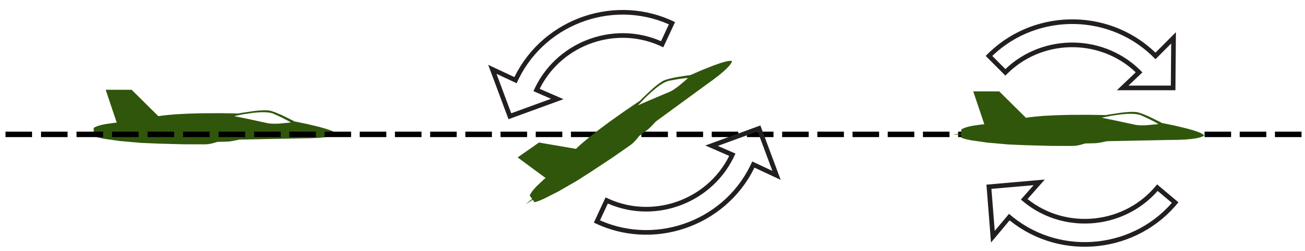
Picture #1 "Equilibrium Flight



Getting the "Wright" Pitch (continued)

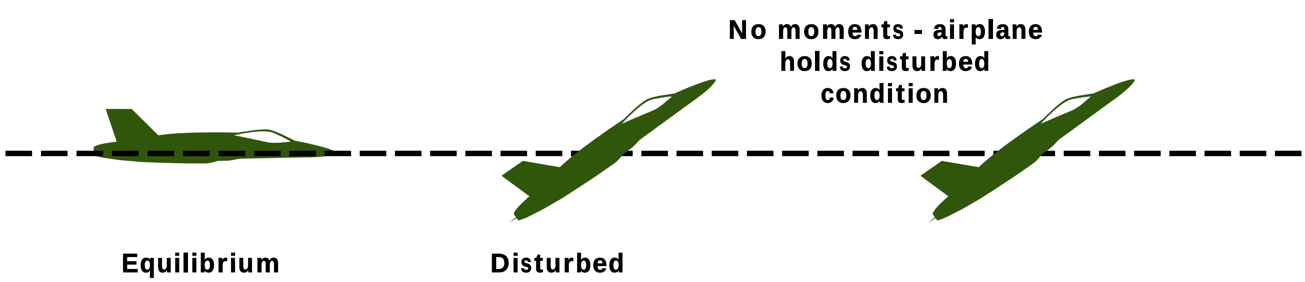
Now let's have the airplane encounter some minor turbulence. This turbulence causes the airplane to nose up or increase its angle of attack. If the airplane reacts to this disturbance by returning itself to its straight and level flight path (without the pilot having to make the adjustments), then the airplane has static stability.

Picture #2 "Static Stability"



Now let's have the airplane encounter some minor turbulence again. This turbulence causes the airplane to nose up or increase its angle of attack. If the airplane holds its new angle of attack after the turbulence has passed, then it is considered to have neutral static stability.

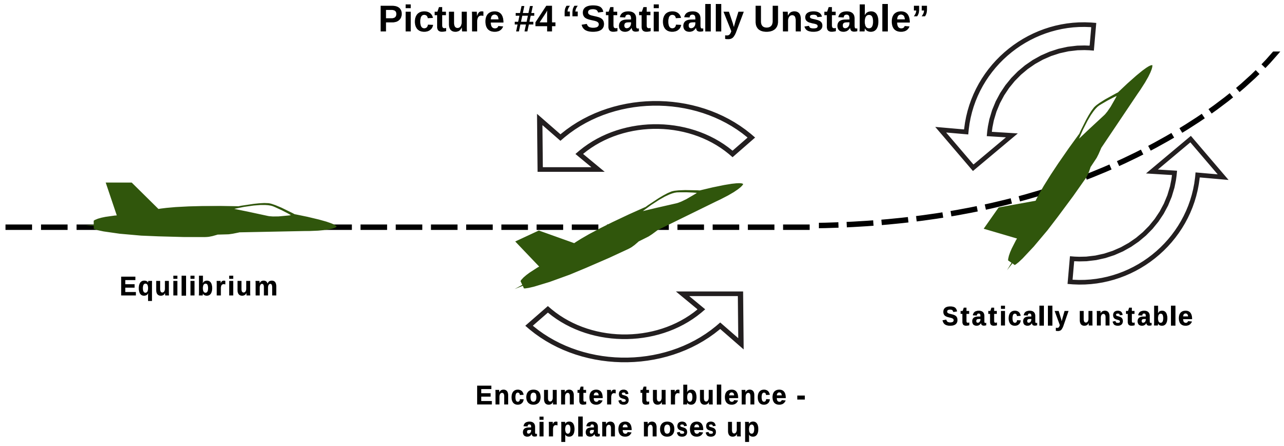
Picture #3 "Neutral Static Stability"



Getting the "Wright" Pitch (continued)

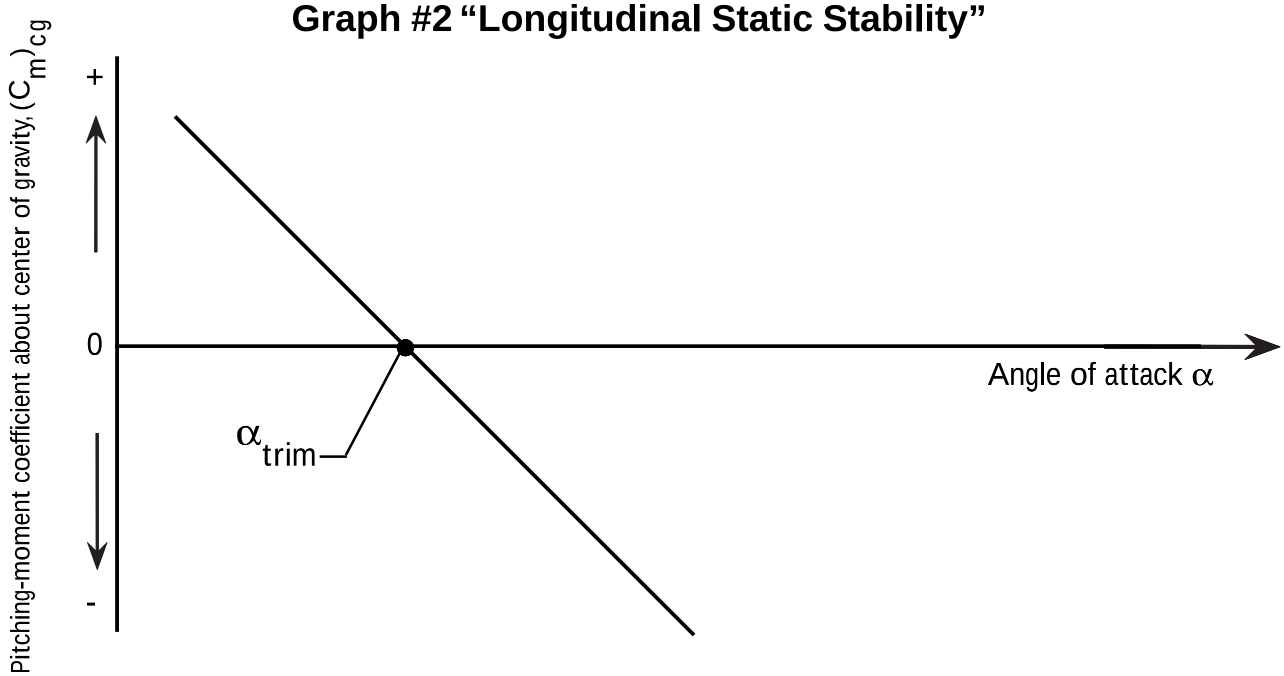
We'll return the airplane to its state of equilibrium. Let's have it encounter some more minor turbulence. This turbulence also causes the airplane to nose up. Even after the turbulence has passed, however, the airplane continues to nose up and does not automatically return to its previous flight path without the pilot having to make adjustments in the controls. This airplane is then considered to be "statically unstable".

Picture #4 "Statically Unstable"



When graphing data related to longitudinal static stability of an airplane, the graphs of airplanes with static stability have a similar slope.

Graph #2 "Longitudinal Static Stability"



Getting the "Wright" Pitch (continued)

Let's take a look at some actual data and graph it. The chart on the next page contains some hypothetical wind tunnel test data on a small airplane. As researchers we will be considering only the columns marked "Alpha (deg)" and "CM". The "Alpha (deg)" column tells us the angle of the nose up or down relative to the airflow. This is the angle of attack. Remember, increasing angle of attack will generally increase the amount of lift.

The "CM" column gives us information about the amount of pitching moment being generated by the airplane. A value (number) for CM that is positive means the airplane is pitching its nose up, and a negative value means the aircraft is pitching its nose down. The magnitude of the CM (the numbers themselves) are an indication of how fast the aircraft is pitching. The greater the absolute magnitude of the number, the faster the rotation (or pitching moment) is.

The pitching moment was converted into a coefficient in a manner similar to the lift coefficient and drag coefficient. This allows us to consider the pitch test done at other velocities, and for other wind tunnel models or aircraft that are otherwise identical, except for being a different scale.

Hypothetical Airplane Data

Run #	Point #	alpha (deg)	CM	δe
1	1	-6	0.0080	0
1	2	-5	0.0070	0
1	3	-4	0.0060	0
1	4	-3	0.0050	0
1	5	-2	0.0040	0
1	6	-1	0.0030	0
1	7	0	0.0020	0
1	8	1	0.0010	0
1	9	2	0.0000	0
1	10	4	-0.0010	0
1	11	6	-0.0020	0
1	12	8	-0.0030	0
1	13	9	-0.0040	0
1	14	10	-0.0050	0
1	15	11	-0.0060	0
1	16	12	-0.0070	0
2	1	-6	0.0100	10
2	2	-5	0.0090	10
2	3	-4	0.0080	10
2	4	-3	0.0070	10
2	5	-2	0.0060	10
2	6	-1	0.0050	10
2	7	0	0.0040	10
2	8	1	0.0030	10
2	9	2	0.0020	10
2	10	4	0.0010	10
2	11	6	0.0000	10
2	12	8	-0.0010	10
2	13	9	-0.0020	10
2	14	10	-0.0030	10
2	15	11	-0.0040	10
2	16	12	-0.0050	10
3	1	-6	0.0060	-10
3	2	-5	0.0050	-10
3	3	-4	0.0040	-10
3	4	-3	0.0030	-10
3	5	-2	0.0020	-10
3	6	-1	0.0010	-10
3	7	0	0.0000	-10
3	8	1	-0.0010	-10
3	9	2	-0.0020	-10
3	10	4	-0.0030	-10
3	11	6	-0.0040	-10
3	12	8	-0.0050	-10
3	13	9	-0.0060	-10
3	14	10	-0.0070	-10
3	15	11	-0.0080	-10
3	16	12	-0.0090	-10

Getting the "Wright" Pitch (continued)
Activity 1

Using the data from the "Alpha" and "CM" columns of the chart, complete the graph on the next page. Follow the steps listed below.

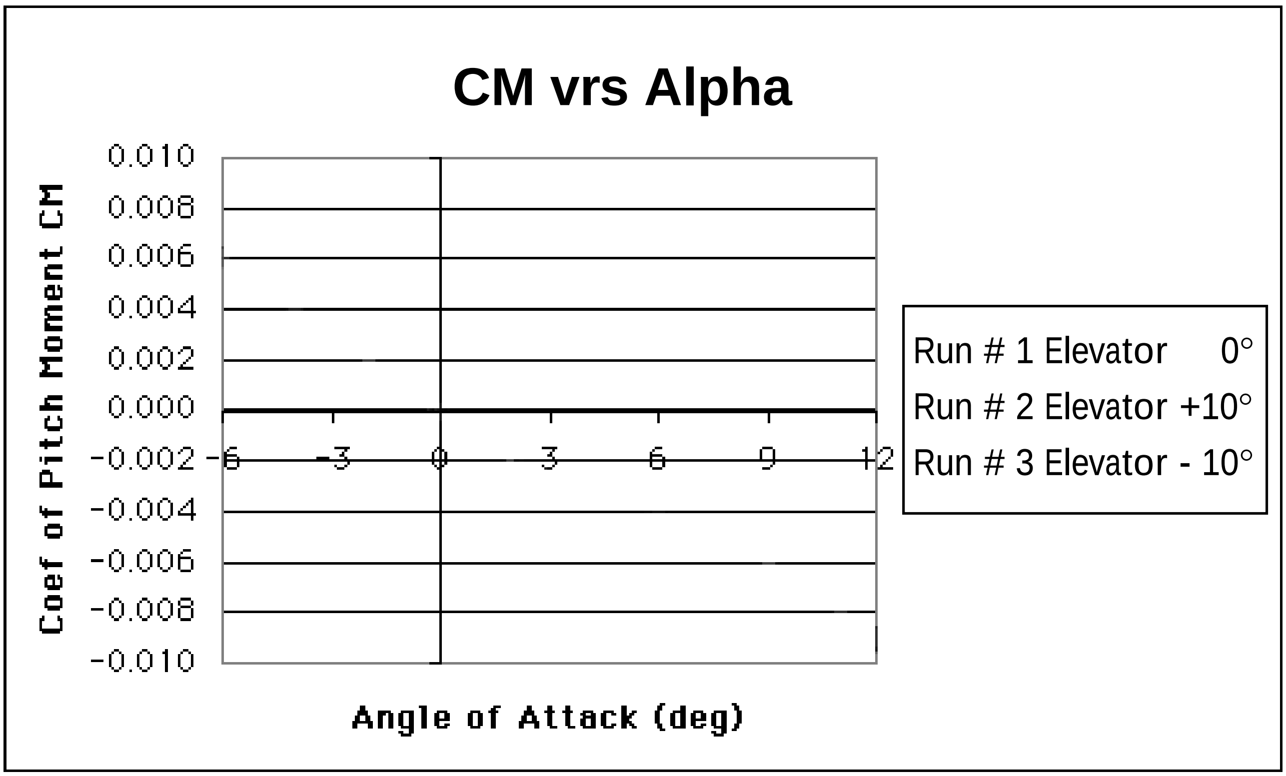
First, plot the points for only "Run #1" from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at 0 degrees angle of attack. The angle of attack is indicated by the data in last column which is the delta sub "e" (elevator deflection angle). Connect these points with a black line.

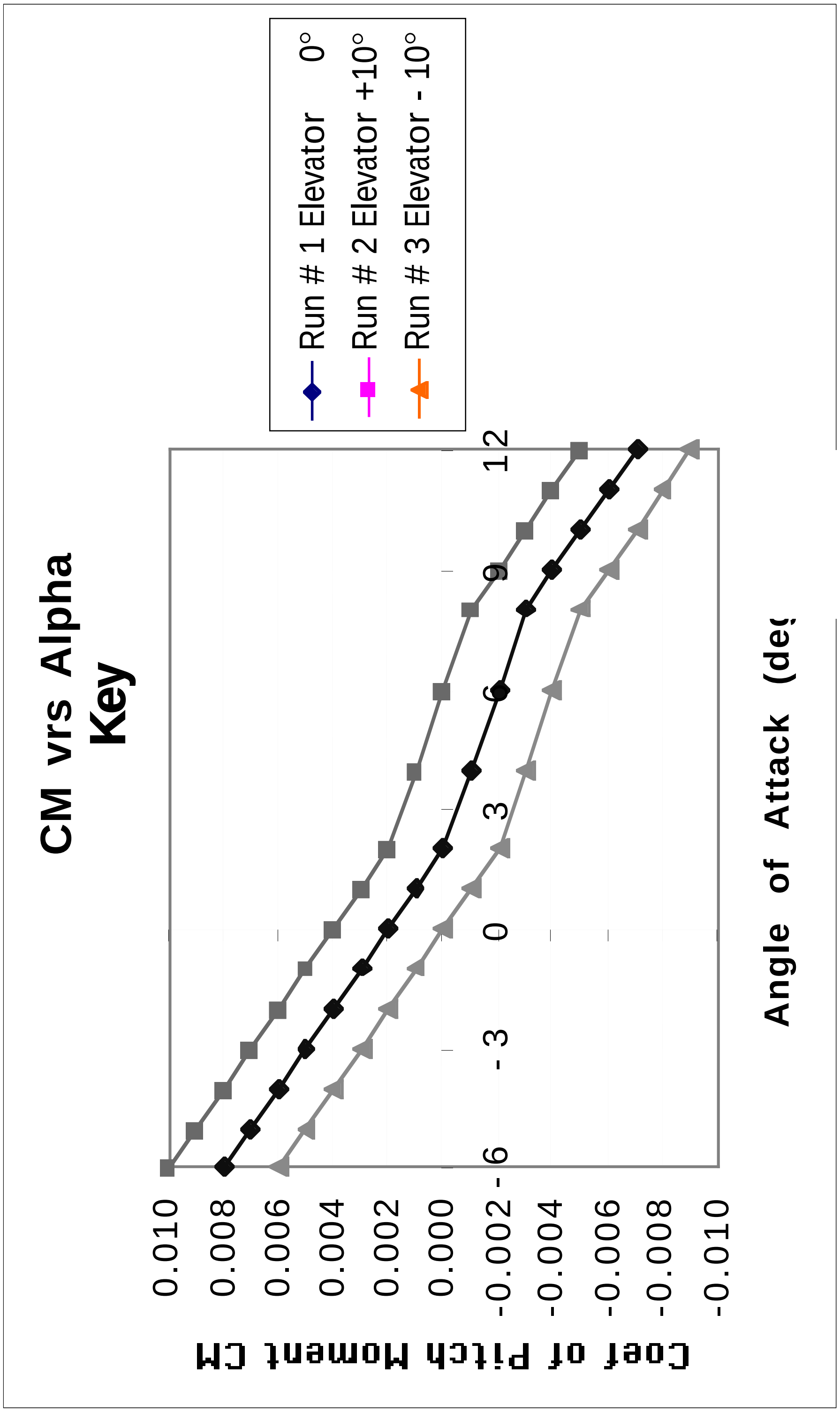
Second, plot the points for "Run #2" from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at a positive pitch of +10 degrees. The angle of attack is indicated by the data in the column which is the delta sub "e" (elevator deflection angle). Connect these points with a blue line.

Third, plot the points for "Run #3" " from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at a negative pitch of -10 degrees. The angle of attack is indicated by the data in last column which is the delta sub "e" (elevator deflection angle). Connect these points with a red line.

Fourth, label point (0, 2) with the letter "A". This is the point at which the aircraft encounters turbulence. The nose pitches up. The pilot takes no action.

Fifth, label point (-0.002, 6) with the letter "B". The aircraft responds to the turbulence by pitching the nose back to its original position, so the airplane returns to point "A".


CM vrs Alpha
Coef of Pitch Moment CM
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-6
-3
0
3
6
9
12
Angle of Attack (deg)
Run # 1 Elevator 0°
Run # 2 Elevator +10°
Run # 3 Elevator - 10°


CM vrs Alpha
Key
Run # 1 Elevator 0°
Run # 2 Elevator +10°
Run # 3 Elevator - 10°
Coef of Pitch Moment CM
0.010
0.008
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-6
-3
0
3
6
9
12
Angle of Attack (de

Getting the "Wright" Pitch (continued)
Activity 1

The time it takes the airplane to return to its original flight path after it encounters a wind gust is nearly instantaneous. No human even with computerized assistance could react as quickly.

Despite the differences in the angle of attack (as shown by the 3 similar slopes), a stable airplane upon encountering such minor turbulence will return to its original flight position. This will occur without the pilot having to take additional action. The test results you have just graphed demonstrate that this airplane is a stable airplane.

Wind tunnel tests never actually test for turbulence. A wind tunnel test is always performed statically. That means the aircraft is set in one position and air is blown by it. Data is recorded. The model is then set to a slightly different position and the test is repeated. A huge amount of data is gathered at each position. From these static wind tunnel tests the dynamic behavior (movements) of the model can be inferred from the data that's been gathered.

Getting the "Wright" Pitch Vocabulary

angle of attack The angle of the wings to the oncoming airflow.

center of gravity The point on an airplane where the entire weight of the airplane is considered to be concentrated. The location of the center of gravity is an important factor in a stable airplane.

equilibrium The ability of an airplane to maintain balanced flight during which all the forces and moments acting on it equal zero. That means lift = weight, and thrust = drag and there are no rotating moments acting on it.

longitudinal static stability The ability of an airplane to pitch itself back into a state of equilibrium after being disturbed along its longitudinal axis.

neutral static stability The tendency of an airplane to hold the new angle of attack it encounters after having its flight disturbed.

stability The tendency, or lack of it, of an airplane to fly a prescribed flight condition or in steady flight.

static stability The tendency of an airplane after being disturbed to generate its own restoring forces that bring it back to its initial state of equilibrium.

statically unstable The tendency of an airplane after being disturbed to continue its new motion without being able to return on its previous state of equilibrium.

trimmed flight The attitude held by an airplane at which it will continue in level flight without the pilot having to exert additional control.

turbulence a disturbance in the airflow around an airplane that causes a disruption in its equilibrium.

Getting the "Wright" Pitch
Activity 2

Teacher Directions

Review Graph "A" from an overhead transparency. This is another look at the data the students graphed in Activity 1. Spend time pointing out the features of the airplane illustration (i.e. the direction of the wind gust, the restoration of the pitch moment, the similarity, in this case, of the beginning and ending flight path angle.

Next, closely review the graph relating what the airplane is doing in the illustration to the points indicated along the slope. The text in between the illustration and the graph contains that information. Note that the airplane will react in a similar manner even if the elevator was set at –10 degrees or +10 degrees, hence the similar slope of all 3 lines.

Change the graph scenario by stating that instead of encountering turbulence, the pilot changed the elevator to +10 degrees.

Ask the question: What would be the new position for point "B"?
Answer: 0.002, 2

Ask the question: What would be the new position for point "C"?
Answer: 0.000, 6

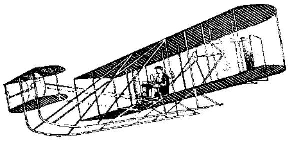
Change the graph scenario again by stating that instead of encountering turbulence, the pilot changed the elevator to –10 degrees.

Ask the question: What would be the new position for point "B"?
Answer: -0.002, 2

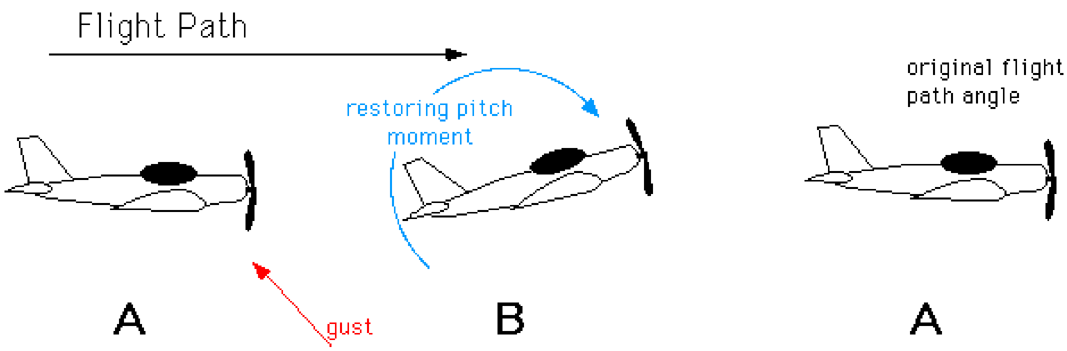
Ask the question: What would be the new position for point "C"?
Answer: -0.004, 6

Instruct the students that while working in small groups they will be given a graph to analyze. They must determine which of the following 4 scenarios below is being shown by the data on their graph. Have them follow the steps below:

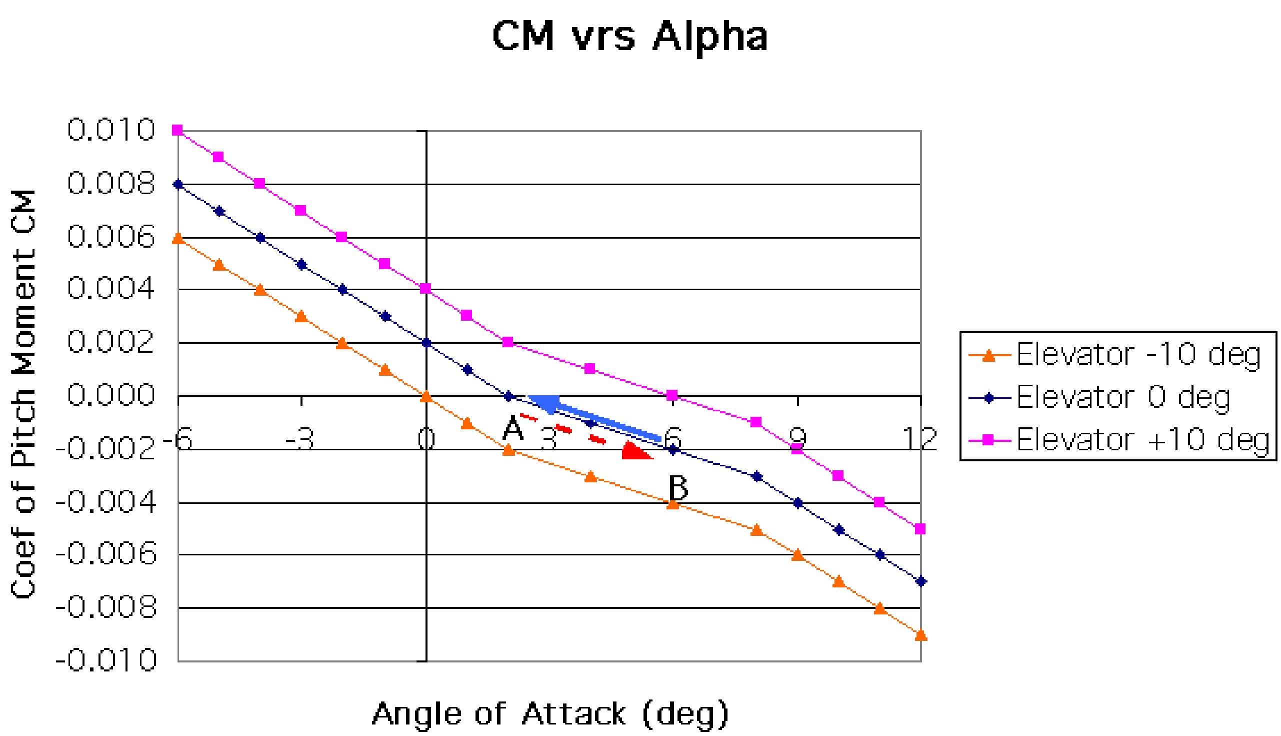
1. Analyze the graph noticing the arrows.
2. Draw a diagram of an airplane as it moves according to the information depicted in the graph.
3. State which scenario the graph and drawing represent.



Getting the "Wright" Pitch
Activity 2   Graph A



Aircraft at flight condition A, is hit by a gust that pitches its nose up to B. The new pitching moment created by the aircraft at condition B pitches the nose back down, so the aircraft returns to condition A. No action on the part of the pilot was required for the airplane to return to trimmed flight. This is a STABLE airplane.



Getting the “Wright” Pitch (continued)
Activity 2

<u>Scenario 1</u>

Aircraft at flight condition “A” encounters a gust of wind that pitches the nose down. The aircraft responds with a new pitching moment and pitches the nose up again to its original flight path angle.

<u>Scenario 2</u>

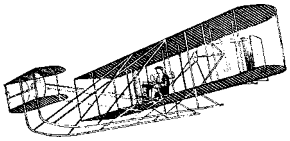
Aircraft at flight condition “A”, the pilot changes the elevator position to +10 degrees. Aircraft responds by pitching up to new trimmed flight path.

<u>Scenario 3</u>

Aircraft at flight condition “A”, encounters a gust of wind that pitches the nose up to position “B”. The pilot responds to the gust by setting the elevator to +10 degrees. The aircraft is at its new trimmed flight path at position “C”.

<u>Scenario 4</u>

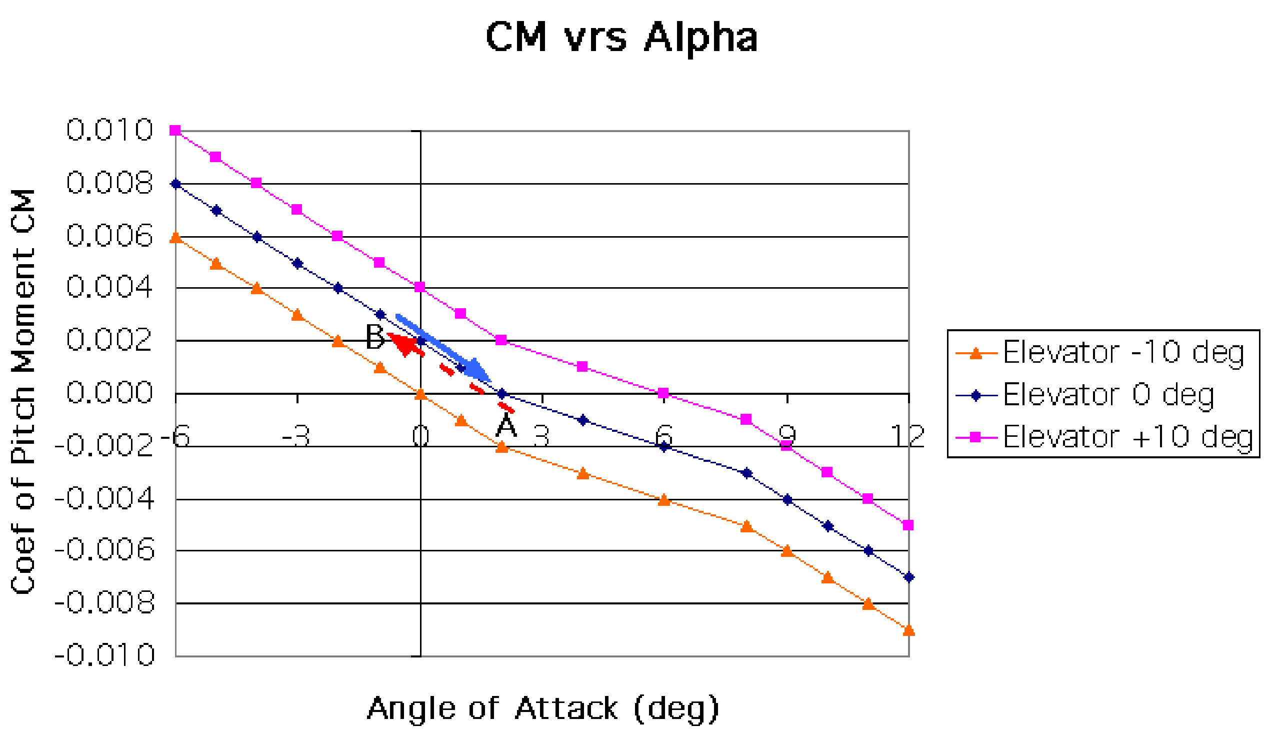
Aircraft at flight condition “A” encounters a strong gust of wind and pitches up to condition “B”. The pilot responds by setting the elevator to +10 degrees at condition “C”. This stable airplane responds by pitching the nose down to point “D” which is a new trimmed stable flight path.



Getting the “Wright” Pitch
Activity 2 Graph B

Flight Path

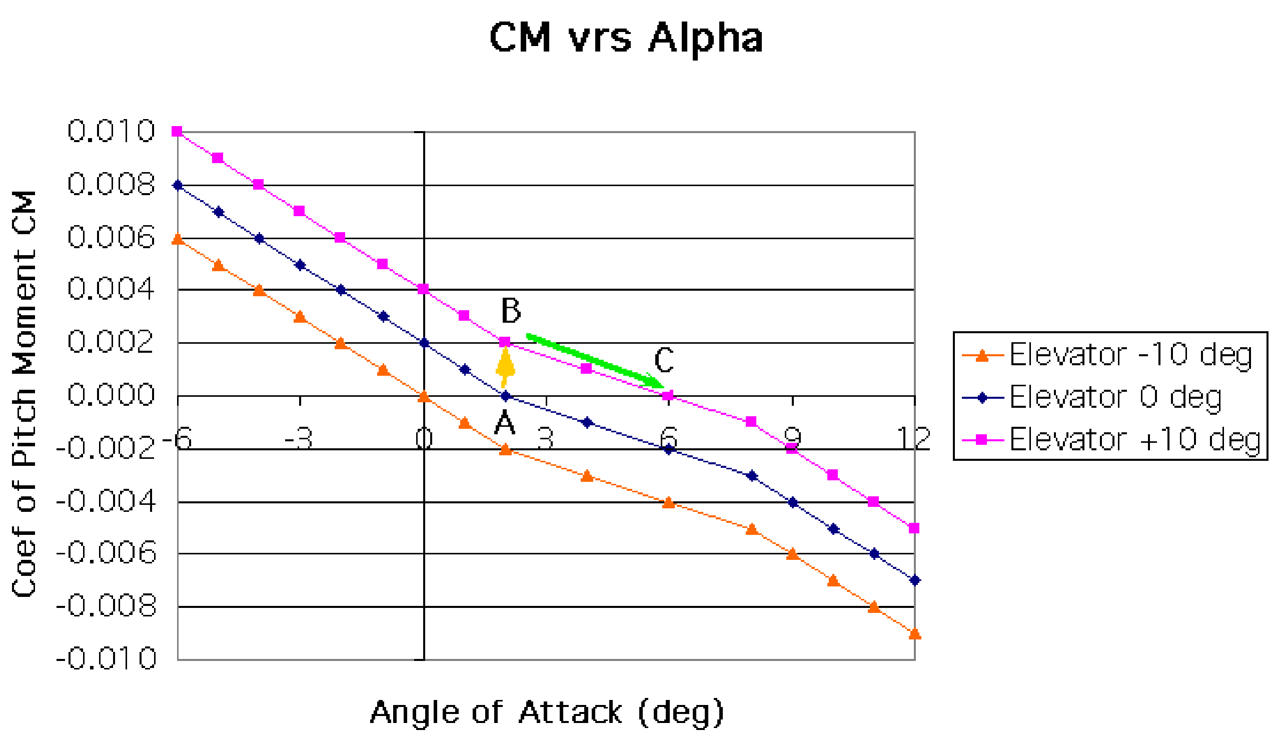
Scenario



Getting the “Wright” Pitch
Activity 2 Graph C

Flight Path

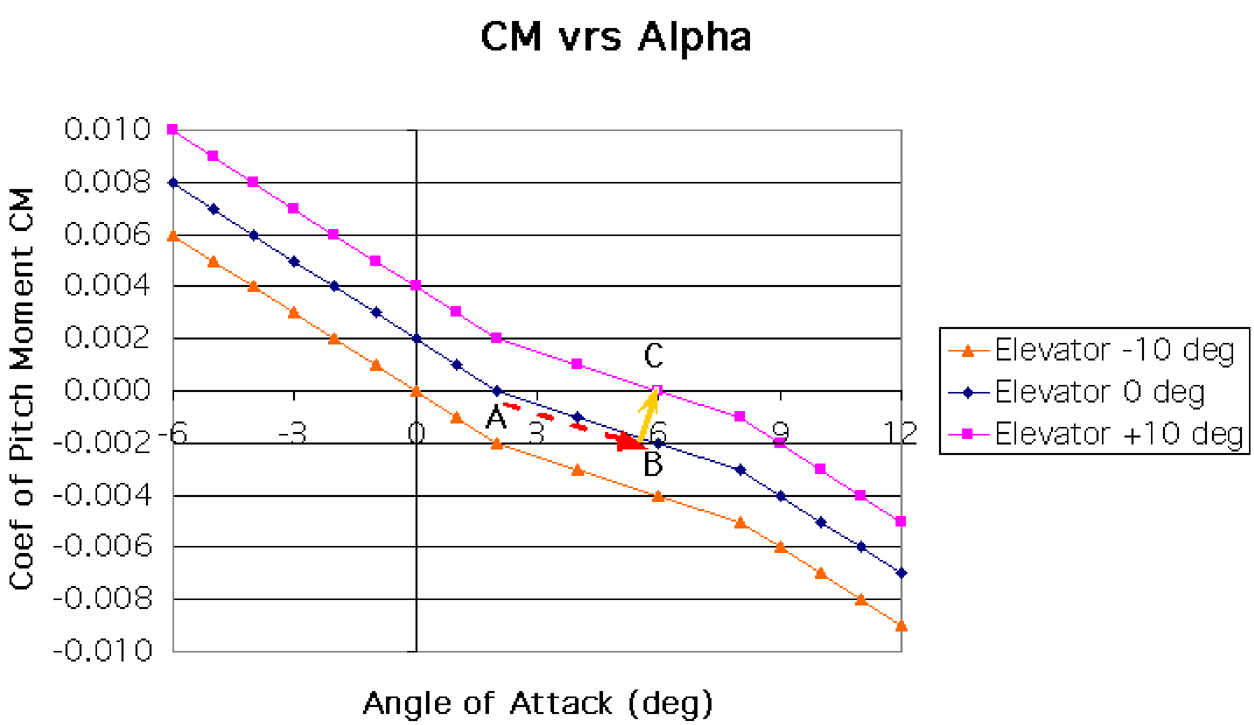
Scenario



Getting the "Wright" Pitch
Activity 2 Graph D

Flight Path

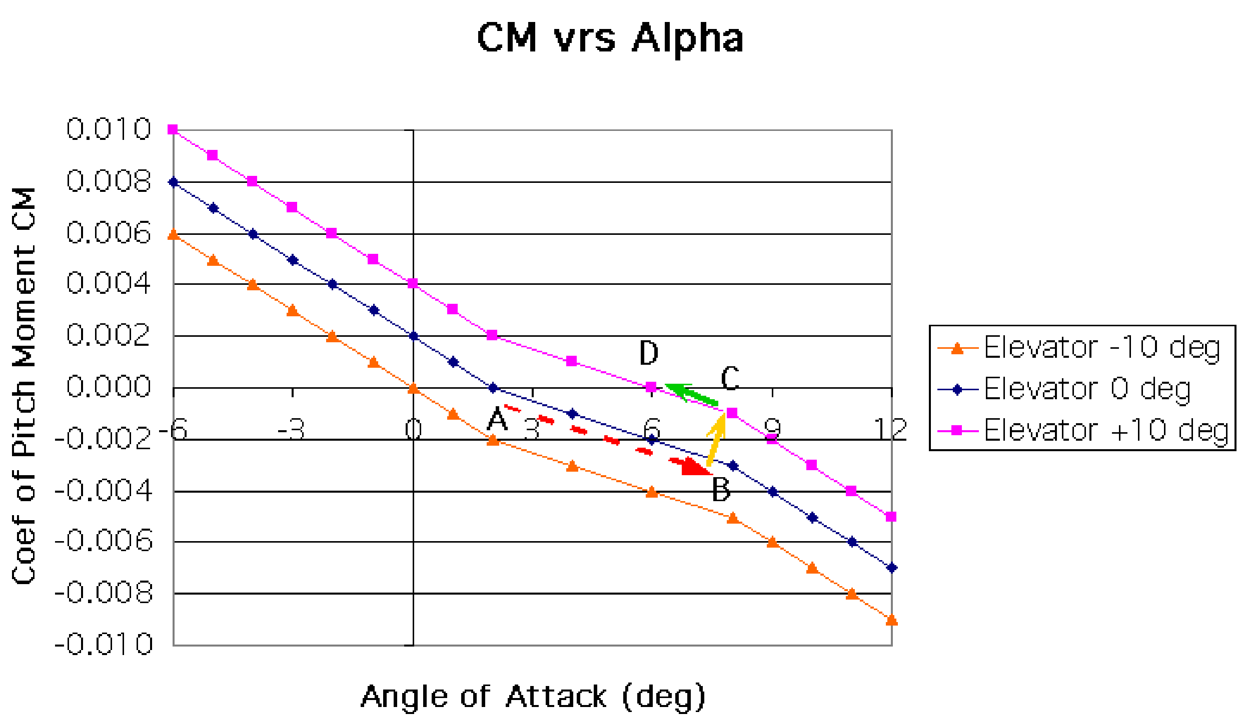
Scenario



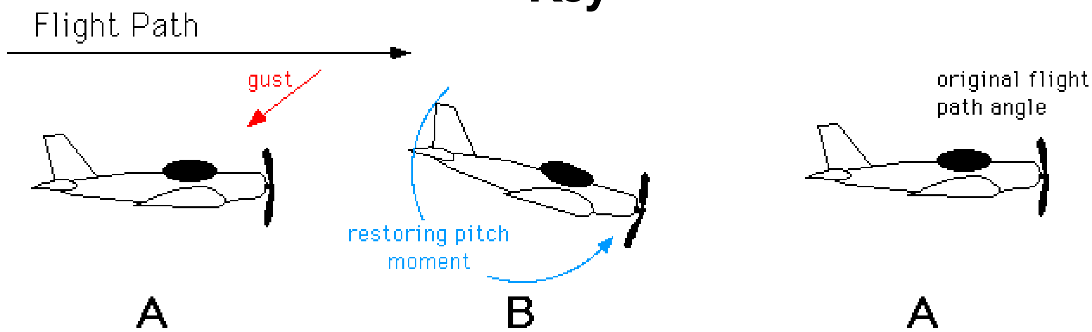
Getting the "Wright" Pitch
Activity 2 Graph E

Flight Path

Scenario

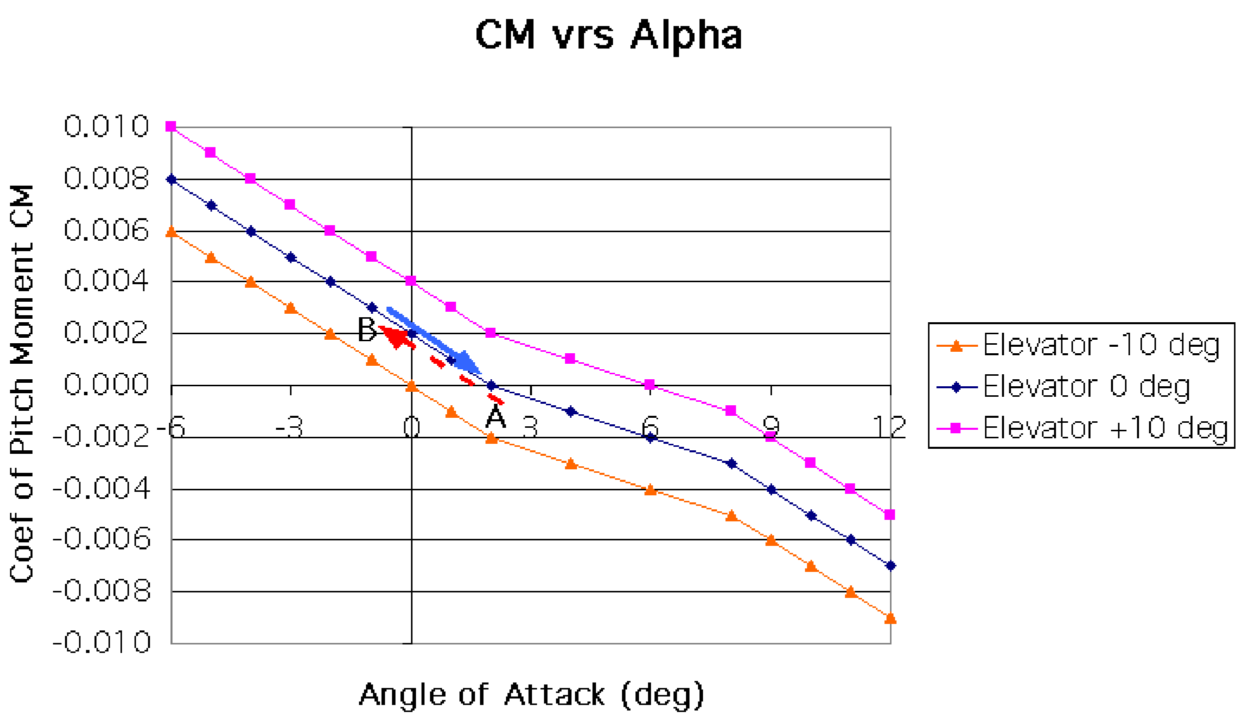


Getting the "Wright" Pitch
Activity 2 Graph B
Key

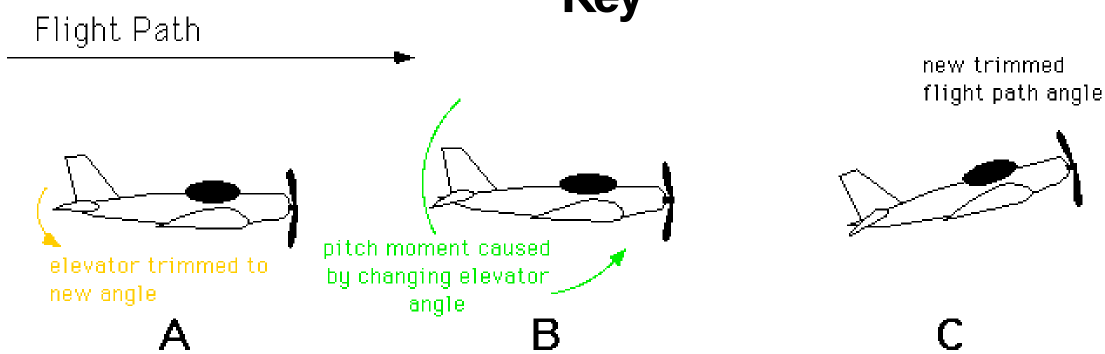


Scenario 1

Aircraft at flight condition A, is hit by a gust that pitches its nose down to flight condition B. The new pitching moment created by the aircraft at condition B pitches the nose back up, so the aircraft returns to condition A. Again, no action on the part of the pilot was required for the airplane to return to trimmed flight.

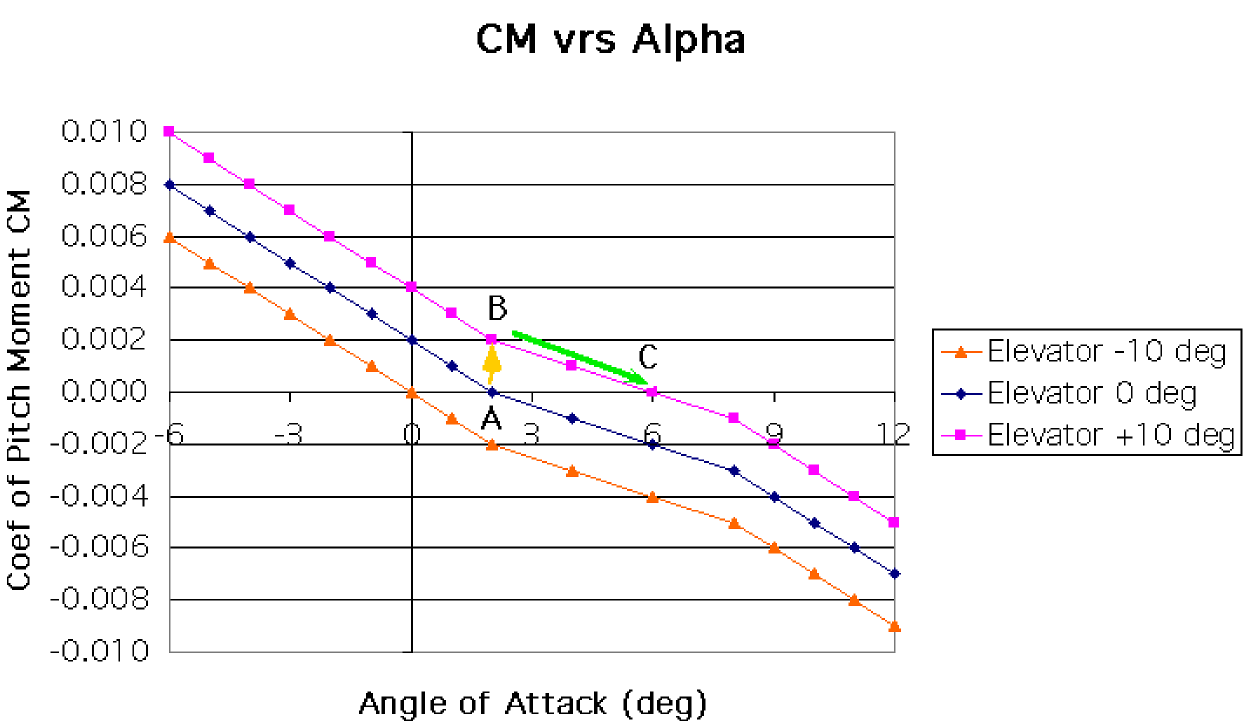


Getting the "Wright" Pitch
Activity 2   Graph C
Key

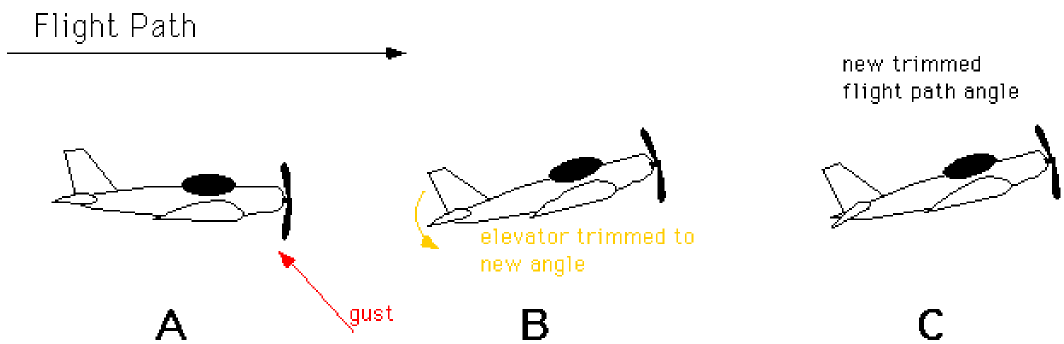


Scenario 2

In this example the pilot pulls back on the stick, changing the deflection angle of the elevator. This puts the plane at flight condition B. The aircraft generates a pitch up moment in response, and pitches up to a new angle of attack at flight condition C.

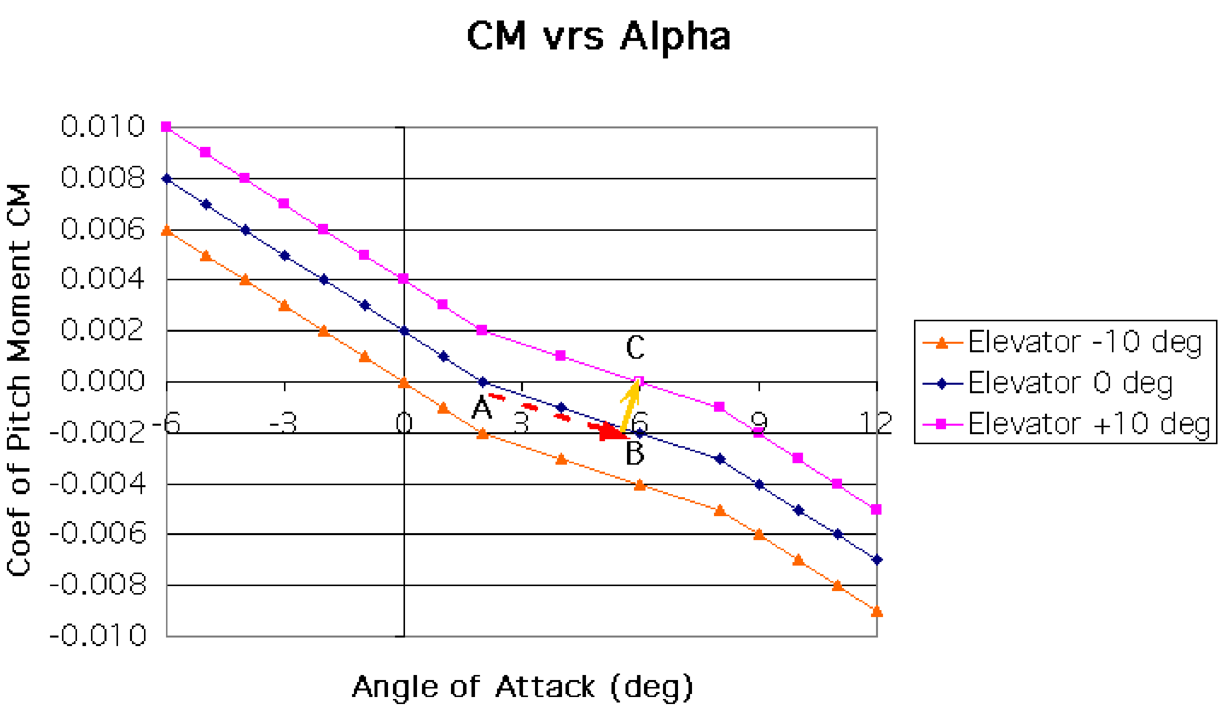


Getting the "Wright" Pitch
Activity 2 Graph D
Key

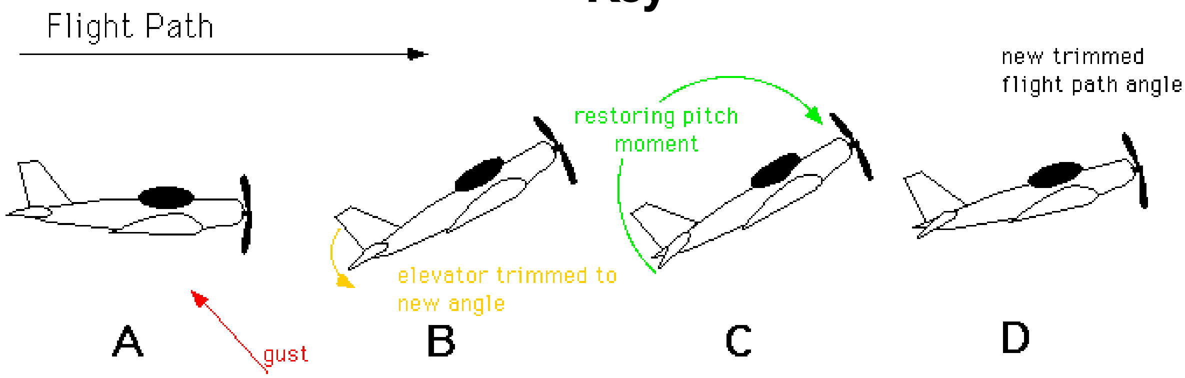


<u>Scenario 3</u>

This time the aircraft is hit by a gust that pitches the aircraft to condition B. As a response, the pilot sets the elevator to +10 deg. The flight condition is now at point C. The aircraft does not pitch the nose back down, but becomes trimmed at a new angle of attack.

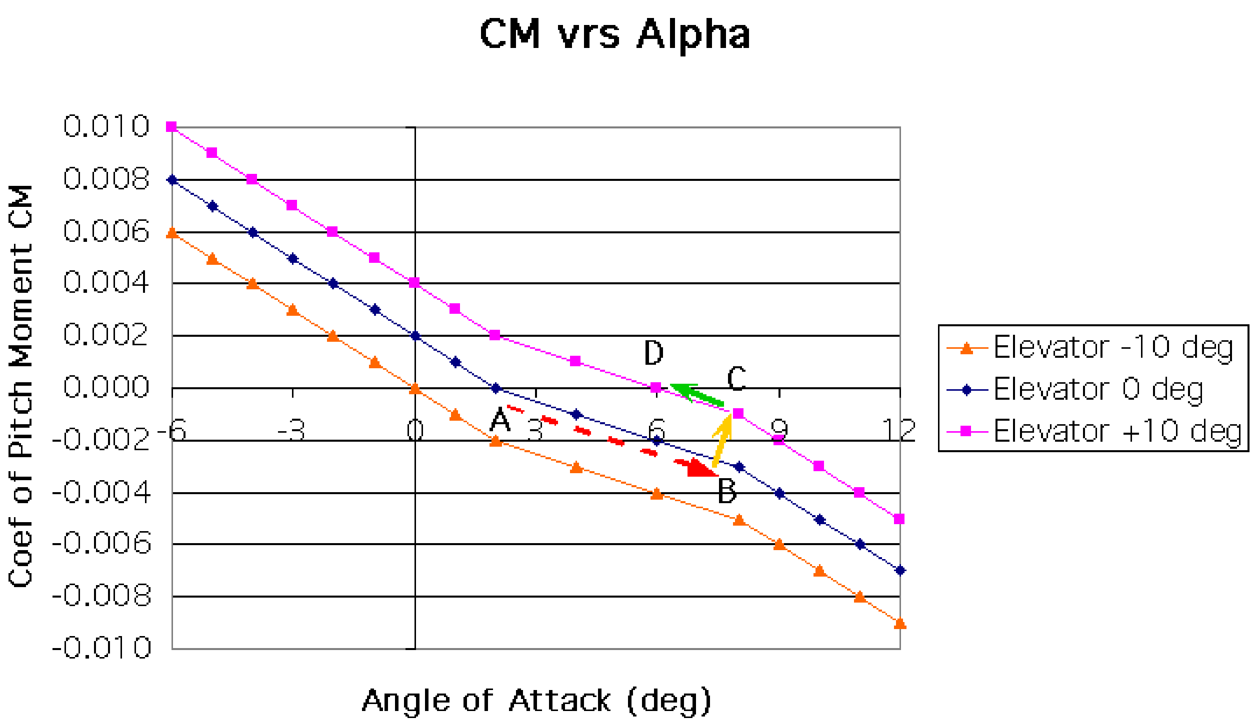


Getting the "Wright" Pitch
Activity 2 Graph E
Key



Scenario 4

In the final case, the aircraft is hit by a gust and pitched to condition B. The pilot sets the elevator to +10 deg. The aircraft is at condition C. The pitch stability of the airplane will still pitch the nose back down to point D, which will be the new trimmed flight condition.



Getting the "Wright" Pitch
Activity 3

Teacher Directions

Once the data from the 1903 Wright *Flyer* replica have been posted, have the students use the following data columns to graph the CM vrs. Alpha:

Run #61, #62, #63
Alpha = Angle of attack
CM
Delta sub e = Angle of canard

Use the guide sheet below to assist students in graphing the data.

After plotting the data for the 0°, +5°, -5° angle of attack, have the students connect the points to form the 3 slopes. Have them compare the slope to that of a stable airplane by using the answer key from Activity #1.

The students should notice that the slopes are remarkably different. That is due to the statically unstable nature of the original design in that it does not return to its original flight path without the pilot having to adjust the controls. For the most part, aeronautical researchers and historians believe that to maintain control of the aircraft, whichever brother was piloting the aircraft would continually be making adjustments to the control surfaces throughout the flight in order to maintain balance.

Getting the "Wright" Pitch (continued)
Activity 3
Student Guidesheet

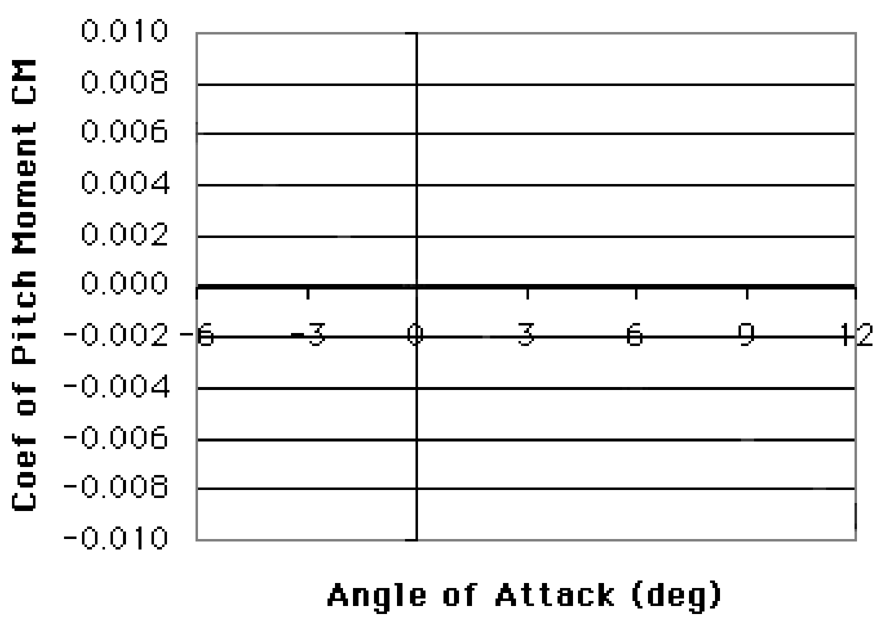
Using the data from the "Alpha" and "CM" columns of the chart, create a graph that displays the longitudinal stability of the aircraft. Follow the steps listed below.

First, plot the points for only "Run #62" from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at 0 degrees angle of attack. The angle of attack is indicated by the data in last column which is the delta sub "e" (canard deflection angle). Connect these points with a black line.

Second, plot the points for "Run #61" from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at a positive pitch of +5 degrees. The angle of attack is indicated by the data in the column which is the delta sub "e" (canard deflection angle). Connect these points with a blue line.

Third, plot the points for "Run #63" " from the "Alpha" and the "CM" columns. During this wind tunnel test, the elevator was set at a negative pitch of -5 degrees. The angle of attack is indicated by the data in last column which is the delta sub "e" (canard deflection angle). Connect these points with a red line.

Remember to begin with a graph as shown below.



Getting the "Wright" Pitch (continued)
Activity 3
KEY