The ultimate objective of an \textit{airfoil} is to obtain the \textit{lift} necessary to keep an \textit{airplane} in the air. Although a flat plate at an \textit{angle of attack}, for example, could be used to create the necessary lift its drag would be excessive. Sir George Cayley and Otto Lilienthal in the 1800s demonstrated that curved surfaces produce more lift and less drag than flat surfaces.

In the early days of flight, when canvas and wood wings were used, few airfoil shapes evolved from theory. The usual procedure at that time was the "cut and try" method. Improvements came from experimentation. If the modification helped performance, it was adopted. Early tests showed, in addition to a curved surface, the desirability of a rounded leading edge and a sharp trailing edge.

The hit and miss methods of these early days were replaced by much better, systematic methods used at Gottingen, by the \textit{Royal Aircraft Factory} (not to be confused with the Royal Air Force), and finally by the \textit{National Advisory Committee for Aeronautics} (NACA). The purpose here was to determine as much information as possible about "families" of airfoil shapes. During World War II, NACA investigations produced results that are still in use or influence the design of most of today's airplanes.

When an airfoil is constructed, the following events take place:

1. The desired length of the airfoil section (the distance from the leading edge to the trailing edge) is determined by placing the leading and trailing edges the desired distance apart. (An airfoil section is a cross section of the wing as viewed from its end.) The chord line is drawn connecting the two points together.

2. The amount of curvature is determined by the \textit{camber} line. This curvature greatly aids an airfoil lifting abilities.

3. A thickness function is "wrapped" about the camber line, that is, one adds the same amount of thickness above and below the camber line; this thickness determines the upper and lower surfaces.

4. The final airfoil has a specific set of aerodynamic characteristics all its own that may be determined from wind tunnel testing.

If the camber line is the same as the chord line, then the airfoil is symmetrical (the upper surface is a mirror image of the lower surface about the chord line). When the velocity of the oncoming air is aligned along the chord line, no lift is produced. The angle of attack \(\alpha\) is the angle between the chord line and the velocity vector. It is zero in this case, that is, \(\alpha = 0^\circ\). Thus, the angle of attack for zero lift is zero, or \(a_{L=0} = 0^\circ\)

If the camber line lies above the chord line, then the airfoil section is asymmetrical. (The upper surface is not a mirror image of the lower surface.) When the velocity of the oncoming air is aligned along the chord line (\(\alpha = 0^\circ\)), a positive lift results. The chord line must be negatively inclined with respect to the airflow to obtain zero lift (that is, the angle of zero lift \(a_{L=0}\) is less than \(0^\circ\)).
In a similar manner, negative camber yields an asymmetrical airfoil where the angle of zero lift $a_{L=0}$ is greater than 0°.

A two-dimensional wing is a wing that has no variation of aerodynamic characteristics anywhere along its span and is limitless (infinite) in span. (The wingspan is the length of the wing from the fuselage to the wingtip.) The goal of such a wing is to prevent air from flowing around the wingtips and causing three-dimensional effects.

Of course, no wing is infinite in length but a close simulation may be obtained by ensuring that the model of the airfoil section, when placed in the wind tunnel for measurements, spans the wind tunnel from one wall to the other. In this case (except for minor tunnel-wall effects that can be corrected for), the wing behaves two dimensionally, that is, the airfoil section's aerodynamic characteristics are uniform for the entire span of the airfoil.

The airflow about an airfoil may be viewed as consisting of two superimposed patterns—one is the free-stream motion of the air about the airfoil and the other is a circulatory flow, or circulation, around the airfoil. These two flows coexist to give the total flow pattern. The question is, if the free-stream flow is prescribed or set, can the circulation, represented by $G$ be of any value? A physical condition provides the answer. The flow about the pointed trailing edge cannot turn a sharp corner without the velocity becoming infinite. As this is not possible in real airflow conditions, the flow instead leaves the trailing edge tangentially and smoothly. This is the Kutta condition and it sets the required value of $G$ so that the rear stagnation point moves to the trailing edge. The Kutta-Joukowsky theorem relates the circulation to the section lift by the equation:

$$ l = r \gamma V_\gamma G $$

where

- $l$ lift/unit span of two-dimensional wing.
- $r \gamma$ free-stream air density.
- $V_\gamma$ free-stream velocity.
- $G$ circulation strength.

Thus, the circulation strength $G$ is set by a necessary physical condition, and the lift $l$ is uniquely determined. For a perfect fluid (one with no skin-friction or pressure drag), the drag per unit length is zero. However, in a viscous airflow, one must include skin-friction drag and pressure drag along with the resulting loss of lift.


For Further Reading:


<table>
<thead>
<tr>
<th>Educational Organization</th>
<th>Standard Designation</th>
<th>Content of Standard</th>
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<tbody>
<tr>
<td>International Technology Education Association</td>
<td>Standard 2</td>
<td>Students will develop an understanding of the core concepts of technology.</td>
</tr>
<tr>
<td>International Technology Education Association</td>
<td>Standard 8</td>
<td>Students will develop an understanding of the attributes of design.</td>
</tr>
<tr>
<td>National Council of Teachers of Mathematics</td>
<td>N/A</td>
<td>Instructional programs from prekindergarten through grade 12 should enable all students to understand measurable attributes of objects and the units, systems, and processes of measurement.</td>
</tr>
<tr>
<td>National Council of Teachers of Mathematics</td>
<td>N/A</td>
<td>Instructional programs from prekindergarten through grade 12 should enable all students to understand numbers, ways of representing numbers, relationships among numbers, and number systems.</td>
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