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AERODYNAMIC EFFECTS OF AN AIRCRAFT

Author: Mudassar Ghafoor Butt
Mirpur University of Science & Technology,MUST mirpur AJ&K Pakistan
Mechanical Engineering
House # NE 1292 street # 02 Dhoke Farman Ali Rawalpindi Pakistan
Zipcode:46000
Phone #: +92-3325406564
Email: mudassar10me15@gmail.com
Co Authors: Syed Rahat Hussain Shah & Qandeel Bhatti

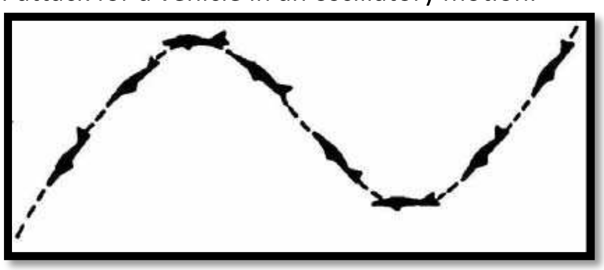
Abstract

Studying the motion of air around an object allows us to measure the forces of lift, which allows an aircraft to overcome gravity, and drag, which is the resistance an aircraft "feels" as it moves through the air. Everything moving through the air (including airplanes, rockets, and birds) is affected by aerodynamics. The analysis of aero dynamical effects on an aero plane is of prime importance. They depict that how we can achieve maximum lift through pressure differential and ram air. It has been explained how an airplane wing can sustain flight when the airplane is heavier than air. Perhaps the explanation can best be reduced to its most elementary concept by stating that lift (flight) is simply the result of fluid flow (air) about an airfoil—or in everyday language, the result of moving an airfoil (wing), by whatever means, through the air. The construction of the wing, so as to provide actions greater than its weight, is done by shaping the wing so that advantage can be taken of the air's response to certain physical laws, and thus develop two actions from the air mass; a positive pressure lifting action from the air mass below the wing, and a negative pressure lifting action from lowered pressure above the wing. The balance of an airplane in flight depends, therefore, on the relative position of the center of gravity (CG) and the center of pressure (CP) of the airfoil. Experience has shown that an airplane with the center of gravity in the vicinity of 20 percent of the wing chord can be made to balance and fly satisfactorily. All types of drags and sources of lifts either on micro or macro level are being reduced in efficient manner b applying various techniques. Moreover drag forces have also been reduced by modifying streamlined design. Coriolis Effect is also one of important terminology that has impact on moving parts during flight. Transonic and subsonic flights behave differently depending upon climatic conditions. The term Dutch roll refers to a tendency for an aircraft to roll whenever there is yaw. Swept wing aircraft are particularly susceptible, and many are equipped with yaw damper, which is an automatic device that senses yaw and counters it with corrective control inputs before the Dutch roll oscillations can develop. The effect of asymmetric thrust in multi-engine aero planes is to create what is referred to the critical engine. The critical engine is defined as the engine that, should a failure occur, will most adversely affect aircraft performance and control. The key aim of paper is to correctify misconfused terminologies regarding aerodynamic effects of air craft

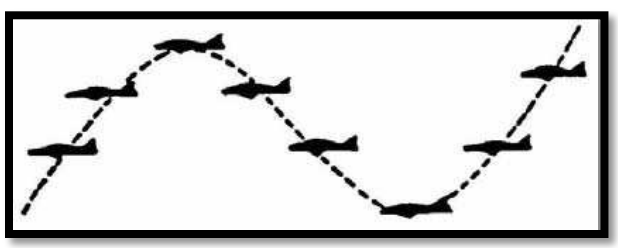
Basics of Aerodynamics of an aircraft:

The trend toward increased maneuverability and higher angles of attack in aircraft and missile design has compounded difficulties involved in dynamic stability predictions. Unsteady aerodynamic effects in general have a major impact on maneuverability and controllability of an aircraft. In a longitudinal plane, the aircraft can perform a pure sinusoidal pitching maneuver as shown, where the aircraft instantaneous angle of attack remains constant and the pitch attitude changes sinusoidally. During a pure sinusoidal plunging motion, the pitch attitude is preserved and the instantaneous angle of attack changes sinusoidally due to the induced velocity effects. However, in a sinusoidal oscillation about a fixed axis, as shown both pitch attitude and instantaneous angle of attack can be expressed as a function of both time and the angular velocity.

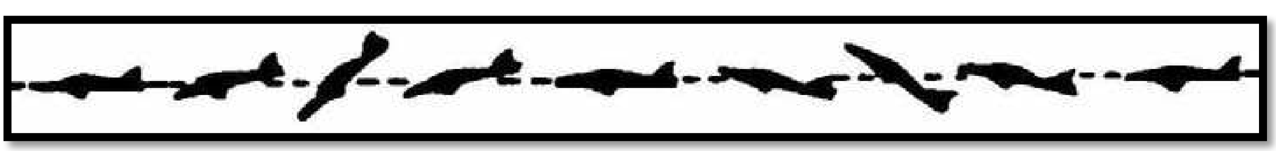
In an oscillatory motion the element of time makes the flow pattern more complicated. During pitch oscillation, the forebody vortices change their lateral and a vertical position as functions of the angle of attack, which itself is a function of time. Similarly, leading edge vortices periodically vary their longitudinal location at which they burst. Various components of the aircraft, such as fins and a horizontal tail move in and out of the local flow regions in which they are embedded. These local flow motions are not simultaneous with the aircraft motion, but with a certain delay mainly due to the convective time lag, which is a function of the distance between the station under consideration and the station at which a particular flow phenomenon originates. This delay is mainly due to the fluid inertia and can be considered as the main source of hysteresis loops observed in the force and moment variations with the angle of attack for a vehicle in an oscillatory motion.



Pure pitching motion



Pure plunging motion



Combination of pitching and plunging motions

Following are the terms that are extensively misconfused.

Airfoil

An airplane wing has a special shape called an airfoil.
As a wing moves through air, the air is split and passes above and below the wing. The wing's upper surface is shaped so the air rushing over the top speeds up and stretches out. This decreases the air pressure above the wing. The air flowing below the wing moves in a straighter line, so its speed and air pressure remains the same.
Since high air pressure always moves toward low air pressure, the air below the wing pushes upward toward the air above the wing. The wing is in the middle, and the whole wing is "lifted." The faster an airplane moves, the more lift there is. And when the force of lift is greater than the force of gravity, the airplane is able to fly.

Aerodynamic Center

The aerodynamic center is a point along the airfoil or wing about which the moment coefficient does not vary with an angle of attack change.

Angle of Attack

The angle of attack is defined as the angle between the plane of the wing (airfoil chord) and the direction of motion (free stream velocity). The angle of attack can be varied to increase or decrease the lift acting on the wing. An increase in lift often results in an increase in drag

Center of Pressure

A point along the airfoil about which the moment due to the lift is zero, i.e., it is the point of action of the lift. The center of pressure will change its position when the angle of attack changes.

Chord

The chord is the dimension of the airfoil from its leading edge to trailing edge. The chord of an airfoil is an imaginary straight line drawn through the airfoil from its leading edge to its trailing edge. We might think of this chord line as the starting point for drawing or designing an airfoil in cross section. It is from this baseline that we determine how much upper or lower camber there is and how wide the wing is at any point along the wingspan.

Circulation

Circulation is a measure of the vorticity in the flow field. For an inviscid flow field, the lift is equal to the product of the circulation about the airfoil, the density and the velocity.

Computational Fluid Dynamics (CFD)

Computational fluid dynamics is the term given to a variety of numerical mathematical techniques applied to solving the equations that govern fluid flows and aerodynamics.

Drag

Drag is an aerodynamic force opposing the direction of motion. Drag can be due to surface viscosity (friction drag), pressure differences due to the shape of an object (form drag), lift acting on an finite wing (induced drag) and other energy loss mechanisms in the flow such as wave drag due to shock waves and inefficiencies in engines.

Drag Coefficient

The drag coefficient is defined as the drag/ (dynamic pressure * reference area). The reference area is usually the plan-form or flat projection (the wing's shadow at noon) area of the wing.

Dynamic Pressure

The dynamic pressure is defined as the product of the density and the square of the velocity divided by two. The dynamic pressure has units of pressure, i.e. Force/Area. The dynamic pressure is used to non-dimensionalize forces and pressures in aerodynamics.

Flap Deflection Angle

The flap deflection angle is the angle between the deflected flap and the chord line. The angle is positive for a downwards deflection of the flap. Deflect the flap downwards to increase the airfoil's lift.

Lift

The lift is a force acting perpendicular to the direction of flight. The lift is equal to the fluid density multiplied by the circulation about the airfoil and the free stream velocity. In level flight, the lift developed by an airplane's must be equal to the weight of the entire airplane.

Mean aerodynamic chord

This chord is located along the wing and has the aerodynamic property of the two-dimensional wing.

. **Pressure Coefficient**

The pressure coefficient is a non-dimensional form of the pressure. It is defined as the difference of the free stream and local static pressures all divided by the dynamic pressure.

Stall

At low angles of attack, the lift developed by an airfoil or wing will increase with an increase in angle of attack. However, there is a maximum angle of attack after which the lift will decrease instead of increase with increasing angle of attack. This is known as stall. Knowing the stall angle of attack is extremely important for predicting the minimum landing and takeoff speeds of an airplane.

Streamlines

Contours in the flow field that are tangent to the velocity vector

Wing Loading

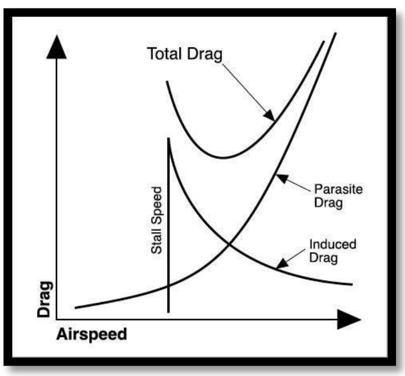
The total weight of the airplane divided by the planform area of the wing.

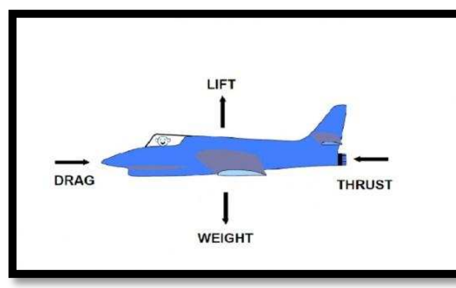
Wing Span

The span is the total length of the wing.

Drag Reduction Possibilities

As most of you know, one kind of drag results from the work being done by the wing to sustain flight. It is called **induced drag** and, like it or not, it is a fair price paid in exchange for the lift produced by the wing. After all, it does play a part in keeping us airborne. There is another kind of drag known as **parasite drag**. It is not the result of anything productive and serves no useful purpose. In short, it is an airborne freeloader, a parasite that contributes nothing to flight but a needlessly eroded performance.





In short, all airplanes suffer from it. This is because parasite drag is produced by most any surface or object protruding from the surface of the airplane that interferes with the smooth flow of the slipstream.
It is reasonable to assume, therefore, that by reducing parasite drag wherever you can, you will enjoy the benefits of reduced fuel expenditures and an ego enhancing increase in airspeed . . . however infinitesimal that may be.
Obviously, the more effective your drag reduction efforts, the greater the rewards.

Any Aircraft Can Benefit

How about those speedy composites? Sure, we know that even the slickest high powered composite can be made to be imperceptibly faster by further reducing its parasite drag. Otherwise, what other explanation could there be for two like aircraft differing considerably in performance? However, the aircraft most likely to benefit from a drag reduction effort is the typical "plain Jane" variety. These aircraft have modest cruise speeds ranging between 100 mph and, let's say, 150 mph.What about light aircraft and ultra light aircraft? Well, these are obviously designed to operate efficiently on a minimum of horsepower. They fly slow and low and anyone who owns one is more concerned with the importance of keeping the weight down than in trying to go supersonic by reducing parasite drag. Unfortunately, streamlining efforts usually do equate to added weight, hence most ultralight builders don't bother. Nevertheless, some parasite drag reduction can often be achieved for these aircraft or, for that matter, for any aircraft without adding appreciable weight.

Is Drag Reduction Worth The Effort?

Yes, indeed. Reducing parasite drag is always beneficial regardless of the aircraft's classification or speed range.

Builders of medium powered aircraft (85 hp to 150 hp) often fail to take advantage of numerous drag reduction opportunities and settle for modest mid-range cruise speeds of 100 mph to 140 mph. And yet, many of these same aircraft have the potential for achieving a 10% to 20% increase in cruise. Of course, how much depends on the basic design of the aircraft and the skill and determination of the builder or owner.

Many of the higher powered homebuilt (160 hp to 200 hp) are already quite fast because their designers took advantage of certain obvious drag reduction options during the basic design process.

Incidentally, except for special purpose aircraft, there is no aerodynamic reason why a one mph per hp (or better) speed cannot be achieved. Naturally, the ultimate refinement and speed that can be achieved always rests with the amateur builder . . . especially one who is not satisfied with just average performance.

We all know from observation that most composites are molded to highly contour aerodynamic curves and are relatively free of many of the parasite drag elements found in other types of construction. But these designs are not alone in aerodynamic refinement.

The metal RV's, T-18's and Mustangs (I and II), in spite of their rivets and lapped joints, are just about as fast because their builders, as a group, tend to vie with each other in reducing or eliminating parasite drag wherever they can.

This seems to be a good place to spring another generalized observation. Here it is:

The faster the airplane, the more pronounced the benefits of a reduction in parasite drag. For example, removing an externally mounted antenna from a slow J-3 Cub will, at best, result in an imperceptible increase in speed.

However, removing a similar antenna from a Lancair or Glasair would, undoubtedly, net a measurable increase in speed.

Four Ways to Reduce Drag

1. *Remove it.*
2. *Streamline it.*
3. *Seal it.*
4. *Smooth it.*

Let's explore each method in detail:

1. Remove It - Anything that is not there cannot create drag. So, if you can remove the object from the surface of the aircraft you will reduce its overall drag and increase the cruise speed. Naturally, this will result in a corresponding reduction in the amount of fuel required to push the airplane through the air. Of course, you should understand that some of your efforts to eliminate parasite drag by removing some small objects from the slipstream may yield only minuscule changes.

Many of you will say it is not worth messing with. However, rest assured, the effect of all gains is cumulative and will be noticeably beneficial . . . very much like the success of the ant in piling up a large impressive mound . . . grain by grain.

By now you may be trying to think of some of the drag producing objects you could remove from the external surfaces of your aircraft. Let me give you a hand. Here are a few that create drag producing turbulent wakes:

- Landing Gear - Removing (retracting) the gear would, naturally, involve structural changes and I certainly wouldn't consider doing it unless it was a designer offered option . . . but it is the biggest drag producer of them all. Incidentally, a partially retracted gear may actually produce more drag than a well streamlined fixed gear.
- Antennas - Some homebuilt have an external communications antenna, a navigation antenna, a transponder antenna and a loran antenna - all drag producers. Remove them if you can.
- Externally Mounted Nav/Strobe Lights - This may not be easy because when you bury the lights inside the wing tip, you may be reducing areas of their projected coverage. The FAA thinks your lights should, ideally, be visible from all directions.
- Fuel Caps - Some of these project considerably above the cowl or wing surface.
- Protruding screws, bolt heads, rivets, brackets.
- Pilot/Static tube installation.
- Temperature probe.
- External handles.
- Fuel vents.
- Control Balances - Submerging balance weights for control surfaces is a nice effective way to minimize drag. However, making it work may not be worth the effort. It could require a critical structural and aerodynamic change. Changes like that should be cleared with the designer.

2. Streamline It - If you can't remove it, streamline it by fitting it with a fairing of some sort. In this respect, the tubular landing gear legs and the tail gear installation are about as dirty (drag wise) as they come. Streamline them and you will realize a fairly large increase in speed.

It is very important that the interference between parts be reduced by reshaping the intersection. To do this you may have to reshape the area by adding material (foam, wood, fiberglass, etc.) to it. This reshaping can be in the form of an add-on fairing, or it can be one permanently attached to the structure.

Keep in mind the need for future disassembly of some parts. These should be fitted with removable fairings.

The juncture between the landing gear leg and wheel pants needs to be faired as does the point of attachment for a wing strut.

The junction between the wheel pants and the landing gear leg is another drag area requiring streamlining.

Exhaust pipes that jut straight down out of the cowling are big drag producers. Slant the pipes so they exit the cowling more or less parallel with the slipstream and you may even benefit from the jet-like effect of the exhausts.Some of Streamlined planes are shown

Cowling inlets on many aircraft are excessively large. Reduce the inlet openings and you will obtain an increase in speed. Unfortunately, you may also obtain an increase in oil temperature. It is a delicate process and you should approach it with caution. Carve foam fillers to fit the inlets and attach them with strips of duct tape to reduce the openings temporarily.

If your oil temperature is still in the green, close off a bit more. Get the idea?

On my Falcon I obtained a very noticeable airspeed increase along with an uncomfortably high oil temperature on my first try.

You may have to readjust the inlet openings two or three times before you hit on the ideal size openings for your airplane.

3. Seal It - Every gap on the airplane is a drag producer. The most common offenders include cabin doors, canopies, oil inspection doors, fairings and cowls. These must seal tightly and should not suck open in high speed flight. You might have to get someone in a chase plane to check your airplane for improperly closed landing gear doors.

Control surface gaps are notorious drag producers. Sealing them, in addition to reducing drag, also enhances the effectiveness of the rudder, elevator and aileron controls.

Most everyone who has ever raced an airplane has spent much time taping over all gaps and openings with masking tape before a race. This preparation alone can result in a faster airplane.

If ordinary masking tape is offensive to your aesthetic senses you could use colored or transparent tape for sealing the gaps and openings.

The basic idea is to keep the inside air in, and the outside air out. But, most of all, you want to keep the air on the bottom of the wing from leaking up through the top surfaces.

4. Smooth It - The objective is to achieve and maintain a smooth flow of air from the nose of the airplane to the tail and beyond.

If your airplane is still under construction, don't miss the opportunity to get all external surfaces as smooth as possible. Fill all dents and imperfections before priming the aircraft.

After your airplane is completed, a little cosmetic smoothing is still possible but you may be reluctant to undertake it because the paint job will be affected.

Wing walks as large and as coarse as they are will destroy the laminar flow in that area and produce turbulence and drag. This is because the surface texture of the wing walks is larger than the aircraft's

boundary layer. The boundary layer next to the surface skin is extremely shallow . . . something on the order of 1/1000 of an inch for average lightplane speeds.
You can make your wing walks smaller or install them in narrow strips rather than as a single large carpet-like mat.

Other Drag Reduction Options

Installing smaller wheels or tires and closer fitting wheel pants could be considered. Remember, however, if you are operating from unpaved strips, smaller wheels may not be advisable as they would transfer higher taxiing and landing stresses to the structure.
A poor job of rigging could saddle you with unnecessary drag. For example, if the wing/tail incidence is incorrect, drag may be excessive for all flight regimes. Or if the flaps are not properly rigged, you may be flying with the flaps partially deployed all the time. For that matter, one side may even be set lower than the other.
A mismatch between the spinner and the cowling is a common drag producer. A spinner can be much too small or too large.
The propeller blade cut-out behind the prop hub should be sealed with a plate. Try to provide a clearance all around of about 1/8".
A large gap or space between the rear of the spinner and the face of the cowling could mess up the smooth flow of air and cause a turbulent entry into the air inlets. This, in turn, might also affect engine cooling.
A wing that is painted with span wise stripes will produce drag because the slipstream may burble across the paint line ridge left after the masking tape was removed. Maybe you can minimize the protruding ridge by buffing it out. Be careful though, because you might mess up the paint line.
At any rate, remember that the smooth flow of air over the first top third of the wing is the most critical drag-wise.

Afterthoughts

Some of you can undertake this business of drag reduction as a casual matter and be happy with whatever increase in indicated airspeed shows up on your airspeed indicator.
Others of you with a scientific bend will not be content until each and every drag reduction change you make has been calibrated, flight tested and duly documented. Lotsa luck, amigo, this may be difficult to do because the smaller changes will yield almost immeasurable results. However, I'm sure that won't deter the true experimenters among you.
Back in 1977 all out drag reduction effort on a 150 hp Mustang II reportedly paid off with a top speed increase from an original 170 mph to 229.66 mph at 11,000'. This speed was clocked during one of the Pazmany contests conducted at Oshkosh.
Can you top such an astounding increase over the original top speed?

Stability of Aircraft

An airplane in flight is constantly subjected to forces that disturb it from its normal horizontal flight path. Rising columns of hot air, down drafts gusty winds, etc., make the air bumpy and the airplane is thrown off its course. Its nose or tail drops or one wing dips. How the airplane reacts to such a disturbance from its flight attitude depends on its **stability** characteristics.

Stability is the tendency of an airplane in flight to remain in straight, level, upright flight and to return to this attitude, if displaced, without corrective action by the pilot.
Static stability is the *initial* tendency of an airplane, when disturbed, to return to the original position.
Dynamic stability is the *overall* tendency of an airplane to return to its original position, following a series of damped out oscillations.
Stability may be (a) **positive,** meaning the airplane will develop forces or moments which tend to restore it to its original position; (b) **neutral,** meaning the restoring forces are absent and the airplane will neither return from its disturbed position, nor move further away; (c) **negative,** meaning it will develop forces or moments which tend to move it further away. Negative stability is, in other words, the condition of **instability.**
A stable airplane is one that will fly "hands off" and is pleasant and easy to handle. An exceedingly stable airplane, on the other hand, may lack maneuverability.
An airplane which, following a disturbance, oscillates with increasing up and down movements until it eventually stalls or enters a dangerous dive would be said to be unstable, or to have negative dynamic stability.
An airplane that has positive dynamic stability does not automatically have positive *static* stability. The designers may have elected to build in, for example, negative static stability and positive dynamic stability in order to achieve their objective in maneuverability. In other words, negative and positive dynamic and static stability may be incorporated in any combination in any particular design of airplane.
An airplane may be *inherently stable,* that is, stable due to features incorporated in the design, but may become *unstable* due to changes in the position of the center of gravity (caused by consumption of fuel, improper disposition of the disposable load, etc.).
Stability may be (a) **longitudinal,** (b) **lateral,** or (c) **directional,** depending on whether the disturbance has affected the airframe in the (a) **pitching,** (b) **rolling**, or (c) **yawing** plane.

Longitudinal stability

Longitudinal stability is pitch stability, or stability around the lateral axis of the airplane.
To obtain longitudinal stability, airplanes are designed to be nose heavy when correctly loaded. The center of gravity is ahead of the center of pressure. This design feature is incorporated so that, in the event of engine failure, the airplane will assume a normal glide. It is because of this nose heavy characteristic that the airplane requires a tail plane. Its function is to resist this diving tendency. The tail plane is set at an angle of incidence that produces a negative lift and thereby, in effect, holds the tail down. In level, trimmed flight, the nose heavy tendency and the negative lift of the tail plane exactly balance each other.
Two principal factors influence longitudinal stability:
(1) size and position of the horizontal stabilizer, and
(2) position of the center of gravity.

The Horizontal Stabilizer

The tail plane, or stabilizer, is placed on the tail end of a lever arm (the fuselage) to provide longitudinal stability. It may be quite small. However, being situated at the end of the lever arm, it has great leverage. When the angle of attack on the wings is increased by a disturbance, the center of pressure moves forward, tending to turn the nose of the airplane up and the tail down. The tail plane, moving down, meets the air at a greater angle of attack, obtains more lift and tends to restore the balance.
On most airplanes, the stabilizer appears to be set at an angle of incidence that would produce an upward lift. It must, however, be remembered that the tail plane is in a position to be in the downwash

from the wings. The air that strikes the stabilizer has already passed over the wings and been deflected slightly downward. The angle of the downwash is about half the angle of attack of the main airfoils. The proper angle of incidence of the stabilizer therefore is very important in order for it to be effective in its function.

Center of Gravity

The center of gravity is very important in achieving longitudinal stability. If the airplane is loaded with the center of gravity too far aft, the airplane may assume a nose up rather than a nose down attitude. The inherent stability will be lacking and, even though down elevator may correct the situation, control of the airplane in the longitudinal plane will be difficult and perhaps, in extreme cases, impossible.

Lateral stability

Lateral stability is stability around the longitudinal axis, or roll stability.
Lateral stability is achieved through
(1) dihedral,
(2) sweepback,
(3) keel effect, and
(4) proper distribution of weight.

Dihedral

The dihedral angle is the angle that each wing makes with the horizontal. The purpose of dihedral is to improve lateral stability. If a disturbance causes one wing to drop, the unbalanced force produces a sideslip in the direction of the down going wing. This will, in effect, cause a flow of air in the opposite direction to the slip. This flow of air will strike the lower wing at a greater angle of attack than it strikes the upper wing. The lower wing will thus receive more lift and the airplane will roll back into its proper position.
Since dihedral inclines the wing to the horizontal, so too will the lift reaction of the wing be inclined from the vertical. Hence an excessive amount of dihedral will, in effect, reduce the lift force opposing weight.
Some modern airplanes have a measure of negative dihedral or **cathedral,** on the wings and/or stabilizer. The incorporation of this feature provides some advantages in overall design in certain type of airplanes. However, it does have an effect, probably adverse, on lateral stability.

Keel Effect

Dihedral is more usually a feature on low wing airplanes although some dihedral may be incorporated in high wing airplanes as well.
Most high wing airplanes are laterally stable simply because the wings are attached in a high position on the fuselage and because the weight is therefore low. When the airplane is disturbed and one wing dips, the weight acts as a pendulum returning the airplane to its original attitude.

Sweepback

A sweptback wing is one in which the leading edge slopes backward. When a disturbance causes an airplane with sweepback to slip or drop a wing, the low wing presents its leading edge at an angle that is perpendicular to the relative airflow. As a result, the low wing acquires more lift, rises and the airplane is restored to its original flight attitude.
Sweepback also contributes to directional stability. When turbulence or rudder application causes the airplane to yaw to one side, the right wing presents a longer leading edge perpendicular to the relative airflow. The airspeed of the right wing increases and it acquires more drag than the left wing. The additional drag on the right wing pulls it back, yawing the airplane back to its original path.

Directional stability

Directional stability is stability around the vertical or normal axis.
The most important feature that affects directional stability is the vertical tail surface, that is, the fin and rudder. Keel effect and sweepback also contribute to directional stability to some degree.

The Design of Fin

An airplane has the tendency always to fly head-on into the relative airflow. This tendency which might be described as weather vaning is directly attributable to the vertical tail fin and to some extent also the vertical side areas of the fuselage. If the airplane yaws away from its course, the airflow strikes the vertical tail surface from the side and forces it back to its original line of flight. In order for the tail surfaces to function properly in this weather vaning capacity, the side area of the airplane aft of the center of gravity must be greater than the side area of the airplane forward of the C.G. If it were otherwise, the airplane would tend to rotate about its vertical axis.

Wing construction is basically the same in all types of aircraft. Most modern aircraft have all metal wings, but many older aircraft had wood and fabric wings. Ailerons and flaps will be studied later in this chapter.

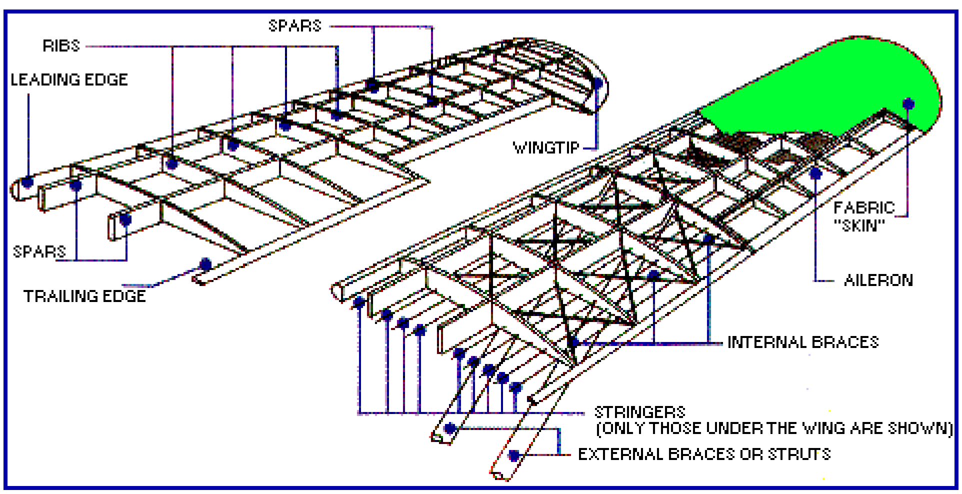


Figure 1-5 Wood-and-fabric-type wing structure

To maintain its all-important aerodynamic shape, a wing must be designed and built to hold its shape even under extreme stress. **Basically, the wing is a framework composed chiefly of spars, ribs, and (possibly) stringers** (see figure 1-5). Spars are the main members of the wing. They extend lengthwise of the wing (crosswise of the fuselage). All the load carried by the wing is ultimately taken by the spars. In flight, the force of the air acts against the skin. From the skin, this force is transmitted to the ribs and then to the spars.

Most wing structures have two spars, the front spar and the rear spar. The front spar is found near the leading edge while the rear spar is about two-thirds the distance to the trailing edge. Depending on the design of the flight loads, some of the all-metal wings have as many as five spars. In addition to the main spars, there is a short structural member which is called an aileron spar.

The **ribs** are the parts of a wing which support the covering and provide the airfoil shape. These ribs are called forming ribs. And their primary purpose is to provide shape. Some may have an additional purpose of bearing flight stress, and these are called compression ribs.

The most simple wing structures will be found on light civilian aircraft. High-stress types of military aircraft will have the most complex and strongest wing structure.

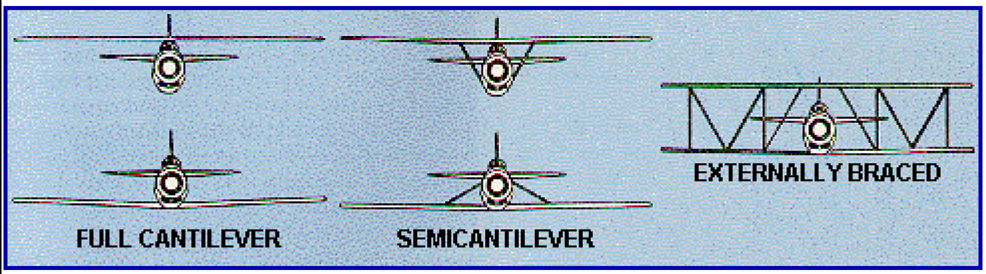


Figure 1-6 Wing and fuselage attachments

Three systems are used to determine how wings are attached to the aircraft fuselage depending on the strength of a wing's internal structure. The strongest wing structure is the full cantilever which is attached directly to the fuselage and does not have any type of external, stress-bearing structures. The semi cantilever usually has one, or perhaps two, supporting wires or struts attached to each wing and the fuselage. The externally braced wing is typical of the biplane (two wings placed one above the other) with its struts and flying and landing wires (see figure 1-6).

An airfoil is any part of an airplane that is designed to produce lift. Those parts of the airplane specifically designed to produce lift include the wing and the tail surface. In modern aircraft, the designers usually provide an airfoil shape to even the fuselage. A fuselage may not produce much lift, and this lift may not be produced until the aircraft is flying relatively fast, but every bit of lift helps.

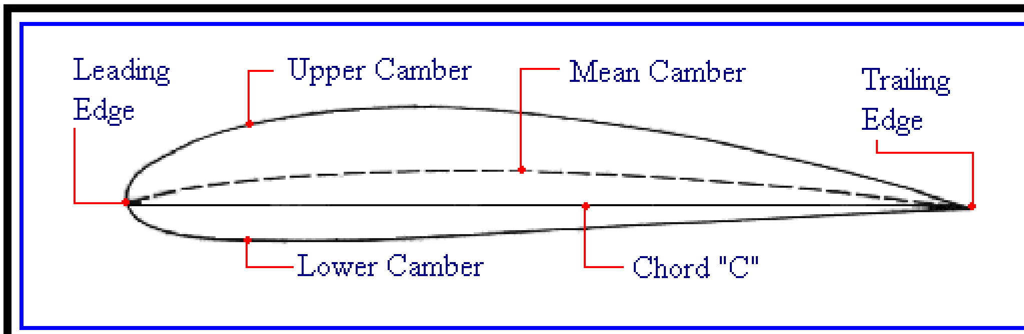


Figure 3-1 Cross section of an airfoil

Figure 3-1 shows a cross

section of a wing, but it could be a tail surface or a propeller because they are all essentially the same. Locate the **leading edge**, the **trailing edge**, the **chord**, and the **upper and lower camber** on Figure 3-1.

Leading Edge

The leading edge of an airfoil is the portion that meets the air first. The shape of the leading edge depends upon the function of the airfoil. If the airfoil is designed to operate at high speed, its leading edge will be very sharp, as on most current fighter aircraft. If the airfoil is designed to produce a greater amount of lift at a relatively low rate of speed, as in a Cessna 150 or a Cherokee 140, the leading edge will be thick and fat. Actually, the supersonic fighter aircraft and the light propeller-driven aircraft are virtually two ends of a spectrum. Most other aircraft lie between these two.

Trailing Edge

The trailing edge is the back of the airfoil, the portion at which the airflow over the upper surface joins the airflow over the lower surface. The design of this portion of the airfoil is just as important as the design of the leading edge. This is because the air flowing over the upper and lower surfaces of the airfoil must be directed to meet with as little turbulence as possible, regardless of the position of the airfoil in the air.

NACA AIRFOIL NUMBERING SYSTEM

Many times you will see airfoils described as NACA xxxx or NACA xxxxx or NACA xx_y-xxx series. From the book *Airplane Aerodynamics*, by Dommasch, Sherby and Connally, Pitman Press, 1967, the following definitions are given to this nomenclature.

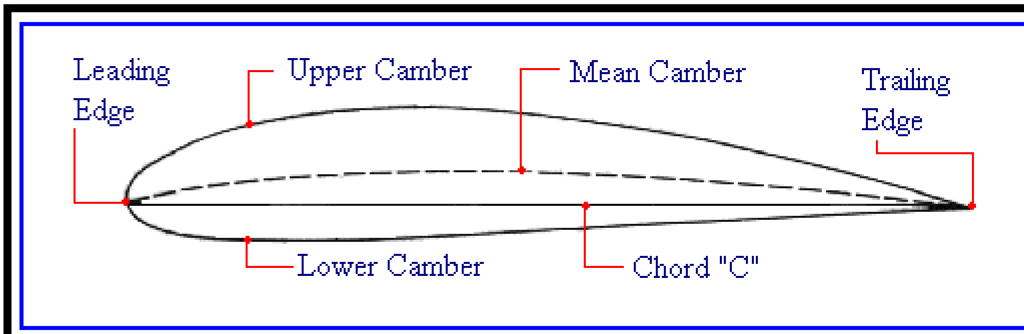


Figure 3-1 Cross section of an airfoil

The NACA 4-digit airfoils mean the following: The first digit expresses the camber in percent chord, the second digit gives the location of the maximum camber point in tenths of chord, and the last two digits give the thickness in percent chord. Thus 4412 has a maximum camber of 4% of chord located at 40% chord back from the leading edge and is 12% thick, while 0006 is a symmetrical section of 6% thickness.

The NACA 5 digit series airfoil means the following: The first digit designates the approximate camber in

percent chord, the second digit indicates twice the position of the maximum camber in tenths chord, the third (either 0 or 1) distinguishes the type of mean-camber line, and the last two digits give the thickness in percent chord. Thus, the 23012 airfoil has a maximum camber of about 2% of the chord located at 15% of the chord from the leading edge (3 tenths divided by 2) and is 12% thick.
The NACA six, seven and even eight series were designed to highlight some aerodynamic characteristic. For example, NACA 65_3-421 is a 6-series airfoil for which the minimum pressure's position in tenths chord is indicated by the second digit (here, at the 50% chord location), the subscript 3 means that the drag coefficient is near its minimum value over a range of lift coefficients of 0.3 above and below the design lift coefficient, the next digit indicates the lift coefficient in tenths (here, 0.4) and the last two digits give the maximum thickness in percent chord (here, 21% of chord). The description for this example comes from *Foundations of Aerodynamics*, Kuethe and Schetzer, 2nd Edition, 1959, John Wiley and Sons, New York.
There are formulas that define all the stations of the airfoil section from these digits and you can probably find those in your library in any good aerodynamics book. Also, you are referred to two other references listed below for more information on these classifications. HOWEVER, in all cases, the last two digits of the classification give the thickness in percent chord.

PRESSURE DIFFERENTIAL OF DANIEL BERNOULLI

Daniel Bernoulli, an eighteenth-century Swiss scientist, discovered that as the velocity of a fluid increases, its pressure decreases. How and why does this work, and what does it have to do with aircraft in flight?
Bernoulli's principle can be seen most easily through the use of a venturi. The venturi will be discussed again in the unit on propulsion systems, since a venturi is an extremely important part of a carburetor. A venturi tube is simply a tube which is narrower in the middle than it is at the ends. When the fluid passing through the tube reaches the narrow part, it speeds up. According to Bernoulli's principle, it then should exert less pressure. Let's see how this works.

As the fluid passes over the central part of the tube, shown Figure 3-2, more energy is used up as the molecules accelerate. This leaves less energy to exert pressure, and the pressure thus decreases. One way to describe this decrease in pressure is to call it a differential pressure. This simply means that the pressure at one point is different from the pressure at another point. For this reason, the principle is sometimes called Bernoulli's Law of Pressure Differential.

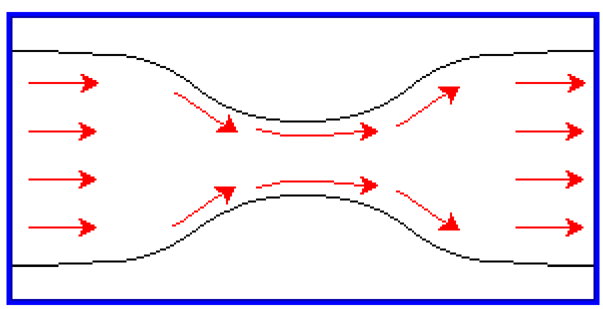


Figure 3-2 Venturi tube

Bernoulli's principle applies to any fluid, and since air is a fluid, it applies to air. The camber of an airfoil causes an increase in the velocity of the air passing over the airfoil.
This results in a decrease in the pressure in the stream of air moving over the airfoil. This decrease in pressure on the top of the airfoil causes lift.

RELATIVE WIND

In order to discuss how an airfoil produces lift or why it stalls, there are three terms we must understand. These are relative wind, angle of incidence, and angle of attack.

There is a noticeable motion when an object moves through a fluid or as a fluid moves around an object. If a thick stick is moved through still water or the same stick is held still in a moving creek, relative motion is produced. It does not matter whether the stick or the water is moving. This relative motion has a speed and direction.

Now let's replace the water with air as our fluid and the stick with an airplane as our object. Here again, it doesn't matter whether the airplane or the air is moving, there is a relative motion called relative wind. The relative wind will be abbreviated with the initials RW (see figure 3-3). Since an airplane is a rather large object, we will use a reference line to help in explaining the effects of relative wind. This reference is the aircraft's longitudinal axis, an imaginary line running from the center of the propeller, through the aircraft to the center of the tail cone.

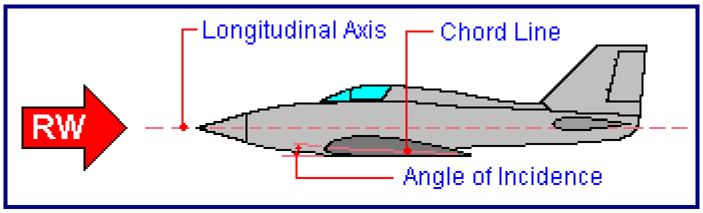


Figure 3-3 Angle of Incidence as Part of the Design

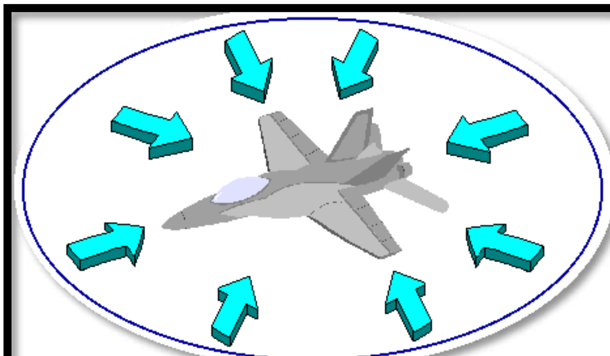


Figure 3-4 Direction of relative wind

Note in Figure 3-4 that the relative wind can theoretically be at any angle to the longitudinal axis. However, to maintain controlled flight, the relative wind must be from a direction that will produce lift as it flows over the wing. The relative wind, therefore, is the airflow produced by the aircraft moving through the air. The relative wind is in a direction parallel with and opposite to the direction of flight.

Let's look a little closer at how relative wind affects an airplane and its wings. As shown in Figure 3-3, the chord line of the wing is not parallel to the longitudinal axis of the aircraft. The wing is attached so that there is an angle between the chord line and the longitudinal axis. (We call this difference the angle of incidence.) Since we describe relative wind (relative motion) as having velocity (speed and direction), the relative wind's direction for the wing is different from that of the fuselage. It should be easy to see that the direction of the relative wind can also be different for the other parts of the airplane.

Very briefly, angle of attack is a term used to express the relationship between an airfoil's chord and the direction of its encounter with the relative wind.

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