Economic Stagnation Aerodynamics

What is stagnation point in basic aerodynamics?

2 Answers

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Stagnation point - Wikipedia

Movement of the stagnation point with the change in angle of attack is the key to understanding airfoil performance, and, therefore, wing performance.

▲ *A Lockheed L-1011 Tristar of the days gone by. All the action takes place over the wings!*

As a wing is propelled through the atmosphere, the molecules of air it encounters are moved aside and forced to flow past the wing's contoured shape.

When such movement and redirection of the airflow occurs, forces are created that act on the surfaces of the wing. **Aero + Dynamics!**

The air increases in velocity as it flows toward the thick portion of the wing, just as water flowing in a brook speeds up as it bends around a rock lodged next to the bank.

After passing the thickest portion of the wing, the air starts to slow down as it heads toward the trailing edge.

To illustrate what happens to the air, consider a vertical slice of the wing extending from the leading edge to the trailing edge and paralleling the path a stream of molecules takes as it flows past the wing.

What we are examining is an airfoil—the cross-sectional shape of the wing.

Also, picture the air rushing past the airfoil, rather than the wing moving through the air; the forces generated are the same, and the same principles of nature apply.

Since some of the air moves under the wing and some moves over it, there is a dividing point where a molecule of air would hit the airfoil if it could not decide which way to go.

That point is known as the forward stagnation point, and it is important because its location on the airfoil has much to do with how the air flows around the wing and thereby generates forces.

Camber, which is the degree of upper-surface curvature compared with that of the lower surface (essentially, the amount of upper-surface bulge), causes the forward stagnation point to be situated lower on the leading edge than it would be if the airfoil had no camber.

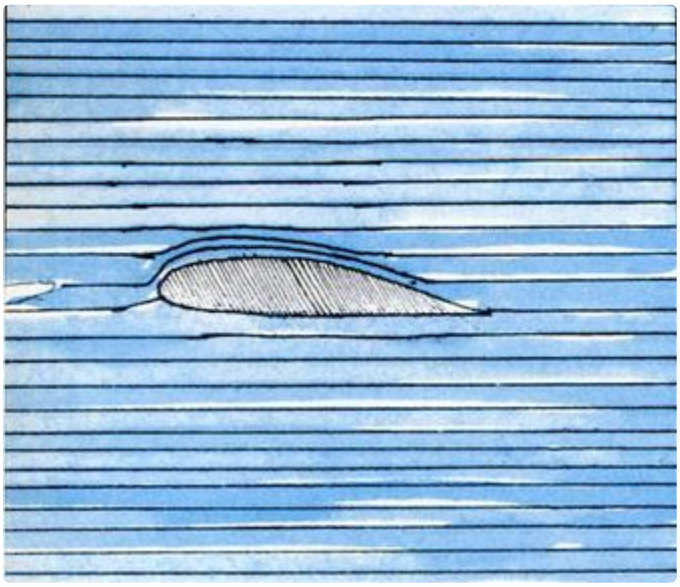
There also is a rearward stagnation point, essentially located at the trailing edge, where the molecules of air rejoin their neighbors after parting at the forward stagnation point.

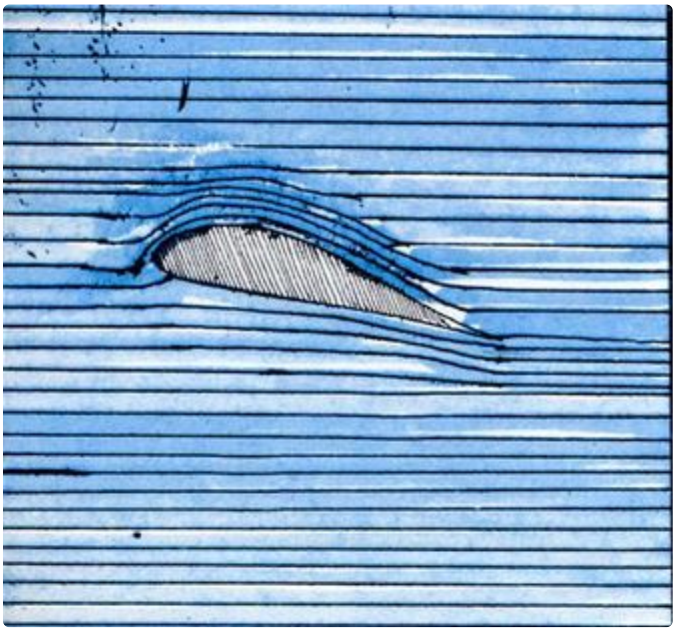
The angle of inclination between the airfoil's chord line and the direction of the airflow is defined as its angle of attack. Therefore, angle of attack is the angle between the wing's average chord line and the direction the wing is moving through the air, since a wing consists of an airfoil shape repeated over the length (span) of the wing, and the forces created are the same with the air moving toward a stationary wing or with a wing moving in still air.

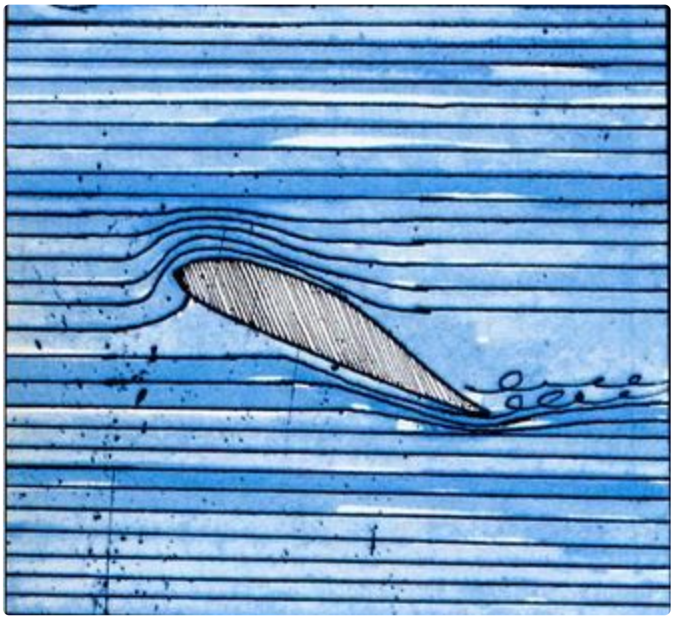
An airfoil or wing will continue to generate more lift with more angle of attack **provided the air is able to make the trip from the forward to the rearward stagnation point.**

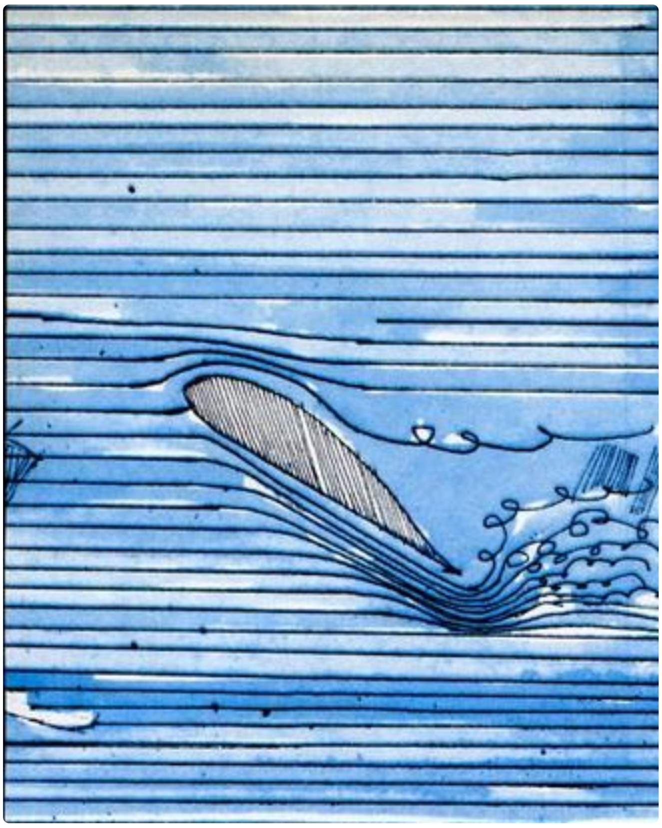
When the angle of attack reaches too high a value—about 16 to 18 degrees for typical general aviation unflapped airfoils but about three to four degrees less for the same airfoils with flaps and considerably greater angles for ones with special leading-edge devices—the air no longer can follow the upper surface contour.

At those larger angles of attack, the forward stagnation point moves down to the vicinity of the airfoil's bottom surface, far from its low angle-of-attack position near the lower portion of the leading edge.



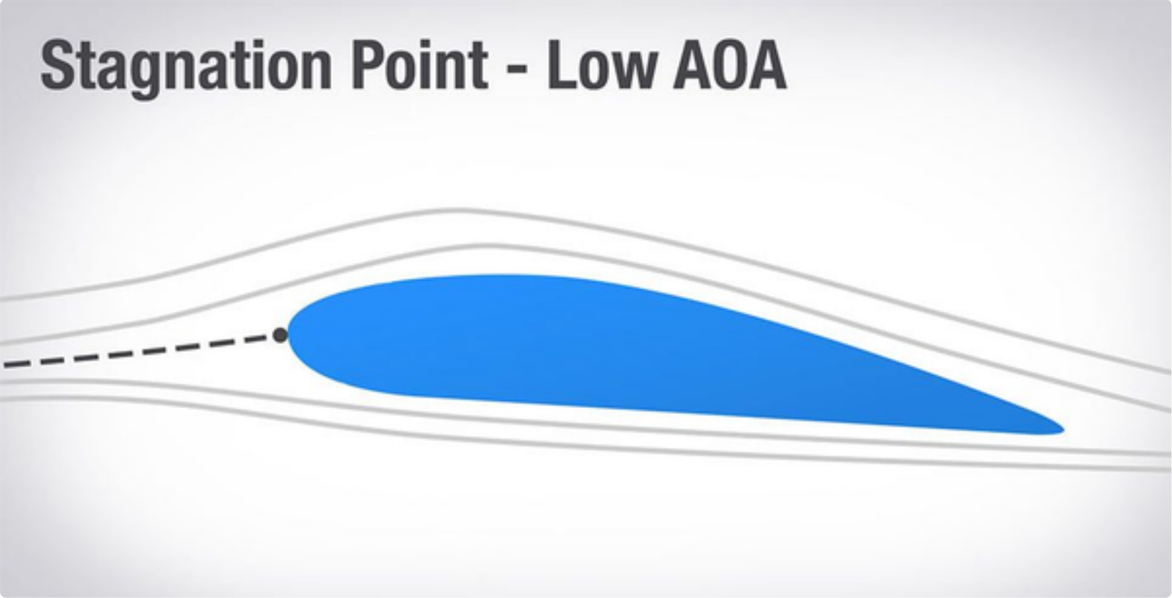


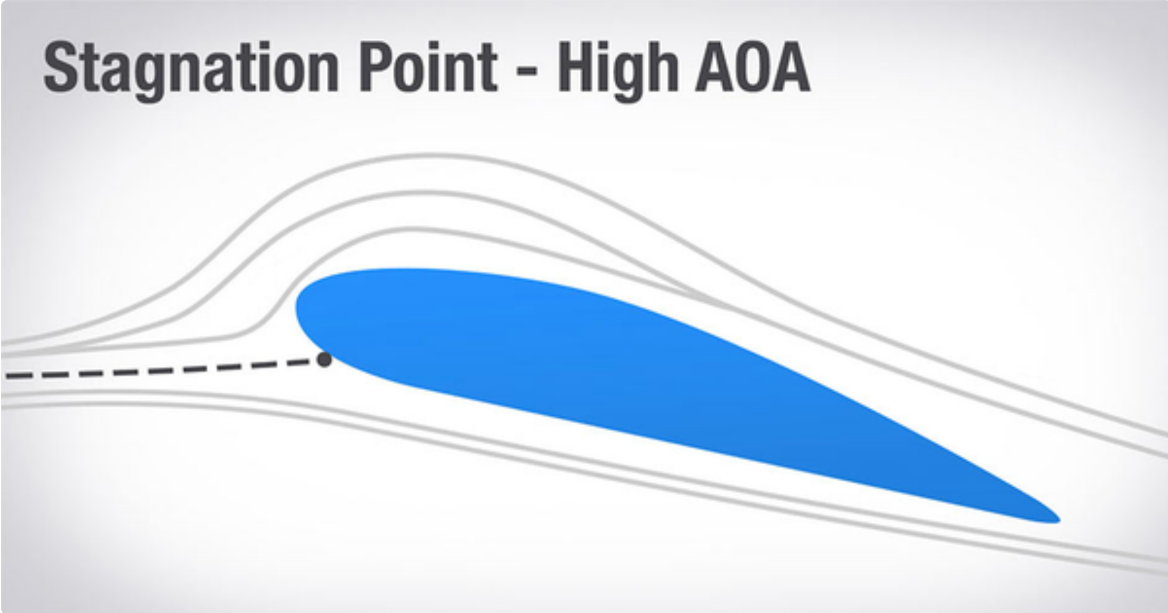




From that stagnation-point position, the air no longer can turn the corner around the leading edge and still have sufficient energy to negotiate the route along the airfoil's upper surface. Being unable to follow the shape of the airfoil, the air separates from its normal path and cannot produce the velocity distribution over the upper surface that is needed to generate lift.

This inability of the air to follow the upper surface shape causes a stall.





Here is a good story of a very useful safety device based on the stagnation point.

From the stall on upward, the airspeed spectrum is posted with milestones and warnings: speed for best angle of climb, speed for best rate of climb, best single-engine speed, speed for best range, maximum-gear and flap-operating speed, turbulence-penetration speed, maneuvering speed, and so on up to those speeds, VNE and VMMO, beyond which be monsters.

Most of these speeds are affected by weight and also by load factor; in a 60-degree bank, for instance, the stalling speed is 40 per cent higher than in level flight.

The approach speed may be 15 percent higher at gross weight than at minimum weight.

In the case of most of the speeds that are of operational concern to us, **the variable that really interests us is angle of attack, not speed.**

But because angle of attack is comparatively difficult to measure and speed comparatively easy, pilots are brought up to consult the airspeed indicator first and foremost.

Angle of attack is usually defined as the angle between the direction of movement of the air and the wing chord line.

But that definition leads to difficulties.

For instance, think of what happens when you are near the stall and you deflect the ailerons. The up-going wingtip can stall. But why? Its angle of attack hasn't changed. So does that mean deflecting the flaps reduces the stalling angle of attack? Then why does lowering the flaps raise the stalling lift coefficient?

Lift gets a lot easier to understand if you measure angle of attack with respect to the "zero-lift line." If you keep reducing the angle of attack until an airfoil produces zero lift (mind you we're in a wind tunnel now, not over La Guardia), then a line drawn through the trailing edge parallel to the motion of the airstream is the **zero-lift line.**

If we measured angle of attack with reference to that line rather than the chord line, we'd find that all airfoils behave similarly and consistently.

It's important to notice that whatever reference line we define angle of attack in relation to, the definition has no necessary connection with speed; nor does any phenomenon related to angle of attack.

Stalling doesn't necessarily occur just because an airplane moves at less than its stalling speed; the wing of a taxiing airplane, for example, is not stalled.

Stalling speed can be used as a yardstick for measuring other speeds. Approach speed is just one example: 1.3 Vs.

Angle of attack, likewise, can be measured on a scale relative to the stall.

But angle of attack isn't really as good a measure of flight condition as it might be, because airplanes can modify their airfoil sections in flight (by deflecting flaps, slats or spoilers, or by lowering landing gear) and can even modify the surrounding airstream by changing the power output of engines whose propellers blow air over the wing; and all these modifications affect the angle of attack at which the stall occurs.

What we would really like to know is lift coefficient.

Even that is not enough; we would like to know the relation of our present lift coefficient to some target value.

This would normally be the maximum, or stalling, lift coefficient. In other words, we would describe the lift we are getting out of the wing as a fraction of the maximum lift we could get out of it.

Since all flight conditions that are of interest to us—best climb, best glide, approach, stall and so on—can be anchored securely to a scale of relative lift coefficient, it would seem that what aviation needs is an instrument to measure just that.

Approach speed, for instance, 1.3 Vs, would always be .59 (derived from $\frac{1}{1.3^2}$) on such a scale, regardless of weight, flap setting, angle of bank or what have you; and stall would always be 1.0.

Such an instrument has been surprisingly elusive.

For years general aviation had a practical lift indicator in the Safe Flight SC-150.

The SC-150 was an ingenious gadget, mechanically interchangeable with the stall-warning tab mounted in the leading edge of practically every general aviation airplane.

Whereas the stall warning tab operates a simple on-off switch, however, the tab of the SC-150 was spring-loaded, and sent a variable voltage to a meter on the instrument panel.

The device relied on the fact that at some point below the leading edge of an airfoil, the oncoming airstream splits; and all air arriving above that point passes over the wing, the rest beneath.

That point is called the stagnation point, and its position is a function of angle of attack; as the nose of the airfoil rises, the stagnation point moves farther and farther aft.

The SC-150 would be mounted on the lower leading edge with the tab at the stagnation point for the angle of attack corresponding to about 1.4 times the stalling speed (which represents a relative lift coefficient of .5).

As the angle of attack decreased, the stagnation point would shift ahead of the tab and the airstream would push it backward against its spring; conversely, as the nose came up the stagnation point would move aft, and the tab would be pushed forward.

The SC-150 was not a perfect instrument—its readings at a given angle of attack were somewhat influenced by speed, for example—but it was a good one.

The FAA decided that since it replaced the stall warning device with which the airplane had been certified, a retrofit approval was not enough, and the SC-150 would have to be certified in each installation as well.

Encumbered by this regulation, Safe Flight stopped producing the instrument.

An angle-of-attack or lift-coefficient measuring system possessing the inherent simplicity and cheapness of the airspeed indicator has yet to be devised, and not for lack of trying.

If the problem ever yields to human ingenuity, pilots and instructors will have reason to rejoice.

Not only would the lift coefficient instrumentation provide better information than the airspeed indicator about how the wing is feeling, but it would also foster a much clearer understanding in student pilots of what flying and stalling are really all about.

And it is all based on the movement of the forward stagnation point with changing angle-of-attack!

The Hazard of Icing

Another important effect of the location of the stagnation point on an airfoil is **icing.**

An airplane flies safely if it flies within its published limit speeds.

However, the slower it flies (still within limits), the higher the angle of attack, and so the stagnation point moves further aft on the underside of the wing.

Now **when the plane flies through icing weather**, the ice tends to form at the stagnation point, which, in a high-angle-of-attack situation, is not visible from the cockpit.

▲*Ice forming on the stagnation point at the lower surface of the wing leading edge is not visible from the cockpit……*

▲*....not even with a flashlight!*

Ice formation changes the shape of the airfoil; the stalling speed increases, and the pilot is no longer safe even when flying at handbook speeds, because those speeds are established on a clean wing, not an iced-up wing.

In the past thirty years, small general aviation airplanes have been involved in over 500 accidents in which icing was somehow or other a factor.

Susceptibility to icing is by no means limited to general aviation airplanes; air-carrier airplanes fall prey as well, most commonly to a scenario in which a small amount of ice accumulating on wings before takeoff leads to stall and loss of control just after rotation. But that is rare now; procedures are in place to avoid that situation, and the anti-icing systems are much “stronger”.

The NTSB cited several general aviation accidents of one type—loss of control during climb in icing conditions—as evidence that many pilots did not understand all the hazards of such operations.

A Beech A60 Duke climbing to 17,000 feet went out of control at 13,500. The airplane “experienced two abrupt altitude excursions” and then began a spiral dive. It exceeded its never-exceed speed and broke apart, striking the ground almost vertically. (The flight path was reconstructed from radar data; in the absence of cockpit voice or flight data recorders, more precise knowledge is unavailable.)

This accident might have remained permanently inexplicable if there had not been, in 1980, a similar occurrence from which the pilot had the good fortune to emerge alive.

In that case, which occurred in Mississippi and also involved a Model A60 Duke, the airplane was climbing through 19,600 feet msl when it began vibrating, pitched down, and rolled violently to the left.

These are, of course, classical symptoms of a stall.

The pilot briefly regained control at 14,000 feet, but the airplane stalled again, and he did not get it definitively under control until it had descended to 2,000 feet.

After landing, the pilot found that the right outboard elevator hinge bracket had broken and that the right elevator was bent down “approximately 90 degrees”.

That was what you might call a close one.

The key piece of information that the pilot was able to provide was that he had been climbing, under autopilot control, at 100 KIAS. Radar returns from the 1992 airplane, when correlated with known winds aloft, showed that its climb speed had been similarly low, varying between 82 and 123 KIAS.

The A60's pilot's operating handbook and airplane flight manual make no mention of minimum speeds for operating in icing conditions. A Beech pamphlet *entitled Beechcraft Twin Engine (Piston) Airplane Safety Information*, however, specifies minimum speeds of 130 KIAS for all Baron and Travel Air models and 140 KIAS for all other models.

The reason for minimum speed limitations has to do with the fact that **ice builds up most rapidly around the stagnation point of an airfoil.**

The stagnation point is the point where flow divides between the upper and lower surfaces.

The stagnation point is always on the lower surface, near the leading edge, at positive angles of attack, and as the angle of attack increases, the stagnation point, and with it the region of ice accumulation, moves aft.

ICE BUILDS UP MOST RAPIDLY AROUND THE STAGNATION POINT.

At sufficiently high angles of attack a significant amount of ice buildup occurs behind the trailing edge of deice boots, and, in the case of low-wing airplanes, out of sight of the pilot.

The smaller the radius of curvature of the leading edge of a body, the more sudden the change of direction of the streamlines approaching it, and therefore the less likely water droplets are to be carried be carried harmlessly around the body, rather than slamming into it.

From this basic principle one would infer—correctly—that smaller airplanes collect ice more rapidly than large ones do.

At the same time, they are more gravely affected by a given accumulation.

At high angles of attack, the buildup below the wing and out of the pilot's view may be greater than that visible at the leading edge, and so a buildup half an inch thick over, say, 80 square feet of wing, tail and body would not be unlikely, and would weigh about 200 pounds. Greater buildups than that occur rapidly in severe icing conditions.

The Beech safety pamphlet for twins presents the following assessment of flight in icing conditions: “Even though the pilot maintains the prescribed minimum speeds… under some atmospheric conditions [ice] may even build up aft of the boots … It can progress to the point where the airplane is incapable of flying … Therefore … continued flight in these conditions is extremely hazardous.”

When an airplane manufacturer uses language this apocalyptic, you suspect he is trying to get your attention.

Neither the Beech safety pamphlet nor the NTSB safety recommendation letter makes mention of the relation between airspeed and rate of climb, and the reason for pilots climbing their Dukes through icing conditions at exceptionally low indicated airspeeds.

The reason is simply that they want to get through the icing levels as quickly as possible, and they know that the way to do this is to climb at the best rate.

In fact, the speed restrictions Beech prescribes amount, for some models, to a prohibition against climbing in heavy icing conditions.

This presents a problem, since one of the generally accepted ways of escaping from icing is to climb out of it.

So the pilot is between a rock and a hard place.

You have to make your choices. You can fight nature, but you can’t always win!