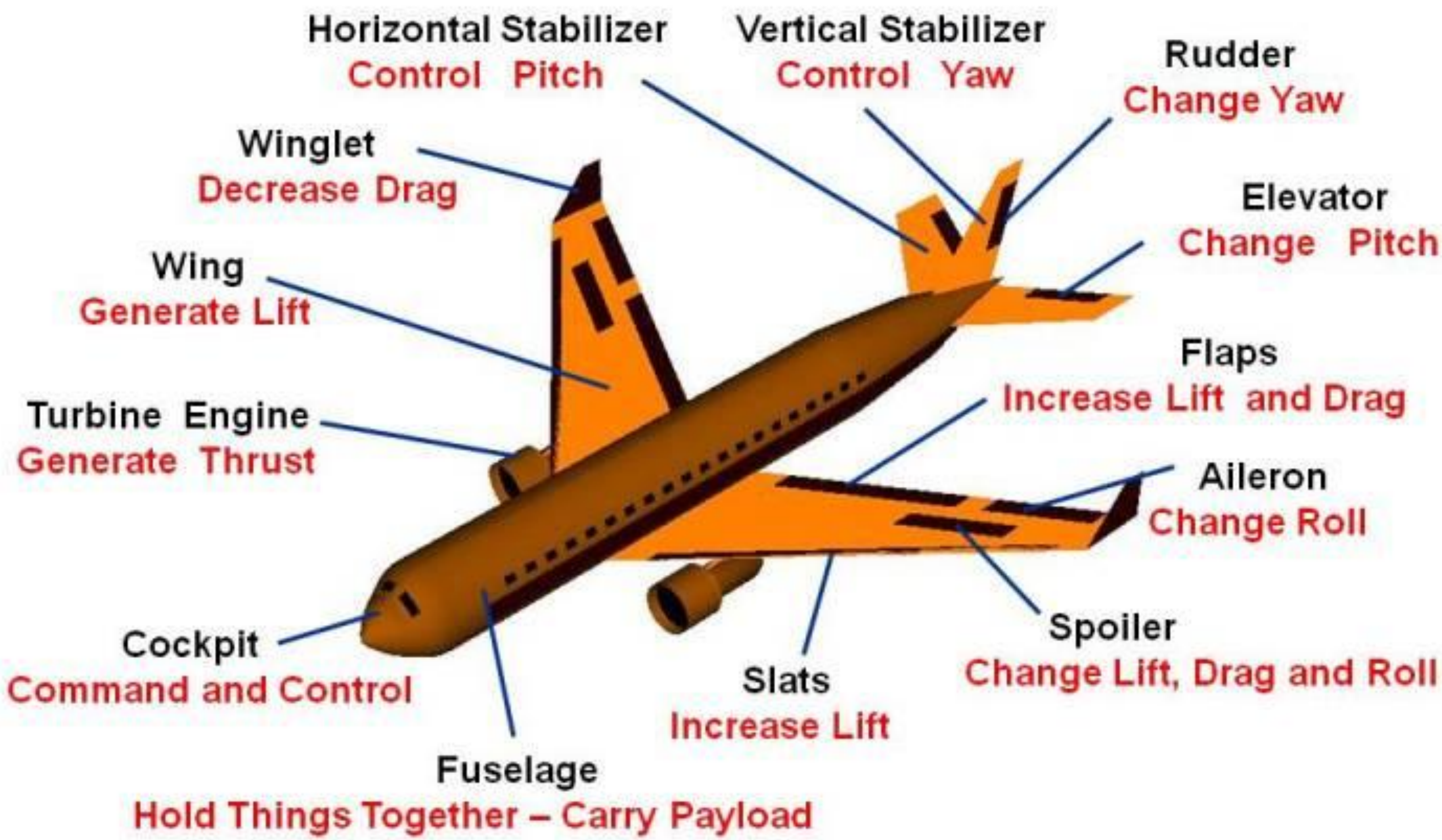
Basic Principles of Flight

Innova Lee(이상훈)
gcccompil3r@gmail.com

Airplane Parts and Function



Simplified Aircraft Motion

Unbalanced Forces

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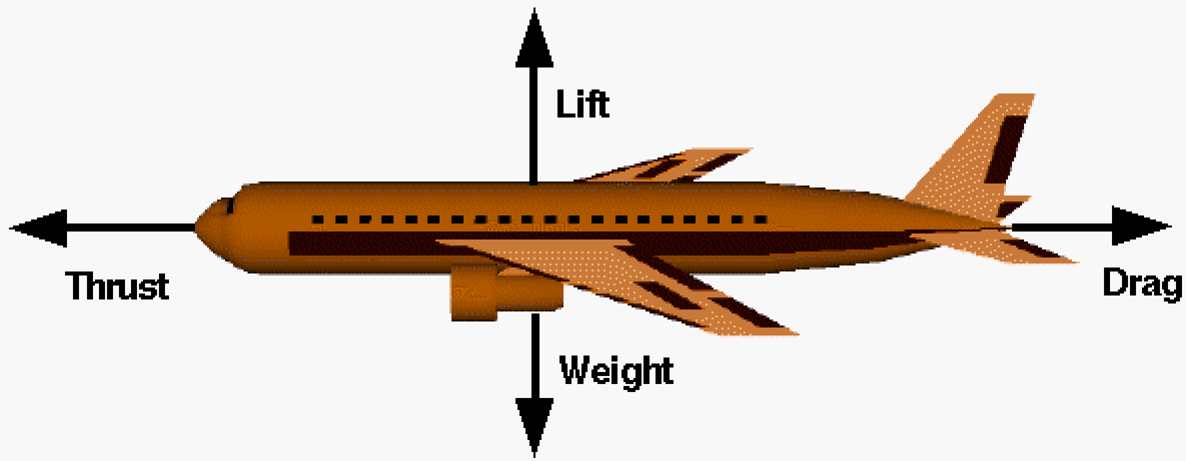

Flight Condition	Effect
Lift > Weight	Plane Rises
Weight > Lift	Plane Falls
Drag > Thrust	Plane Slows
Thrust > Drag	Plane Accelerates

Vectored Thrust

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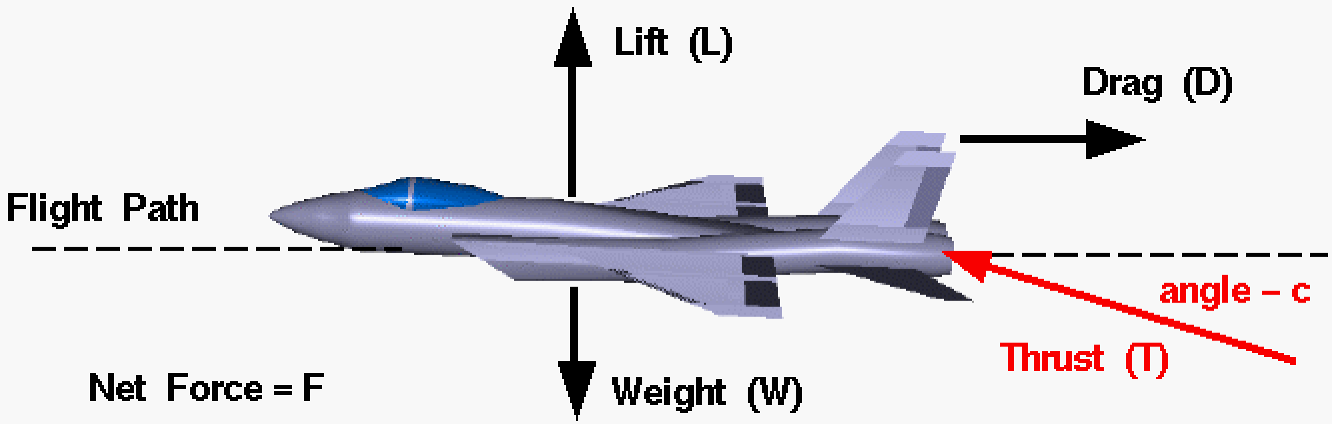

Force Equations

Vertical	*Horizontal*
$L - W + T \sin(c) = F_v$	$T \cos(c) - D = F_h$
$a_v = F_v / m$	$a_h = F_h / m$

a = acceleration of aircraft

m = mass of aircraft

Modern Lift Equation

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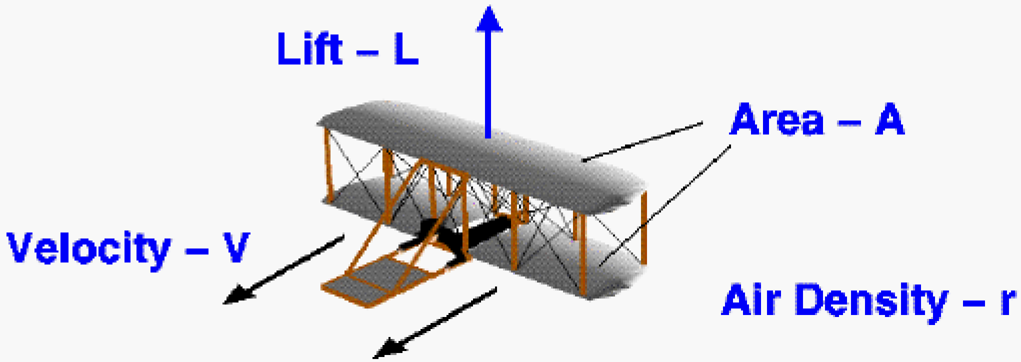


$$L = Cl \; \frac{r \; V^2}{2} \; A$$

Lift = coefficient x $\frac{\text{density x velocity squared}}{\text{two}}$ x wing area

Coefficient **Cl** contains all the complex dependencies.

density

wing surface area

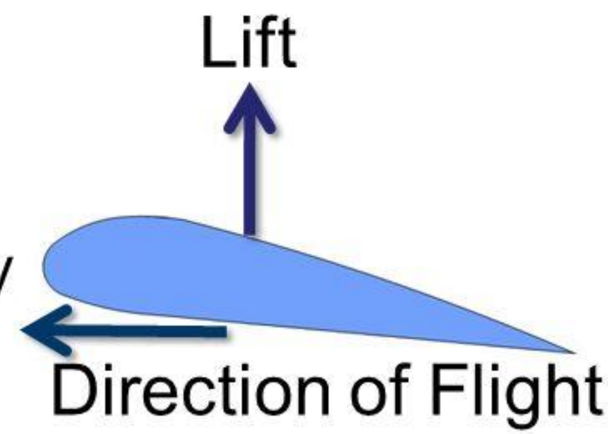
$$L_{ift} = C_L \times \boxed{{}^1\!/_2\,\rho}\; v^2 s$$

Angle of Attack

wing shape

speed

Lift Equation



- Coefficient of Lift, C_l
  - Determined experimentally
  - Combines several factors
    - Shape
    - Angle of attack

$$C_l = \frac{2L}{A\rho v^2}$$

Alternate format

$$C_l = \frac{L}{qA}$$

$C_l = Coefficient\ of\ Lift$

$D = Drag\ (N)$

$A = Wing\ Area\ (m^2)$

$\rho = Density\ \left(\frac{kg}{m^3}\right)$

$v = Velocity\ \left(\frac{kg}{m^3}\right)$

$q = Dynamic\ Pressure\,(Pa)$

http://jennarocca.com/aerodynamic-drag-equation/

Modern Drag Equation

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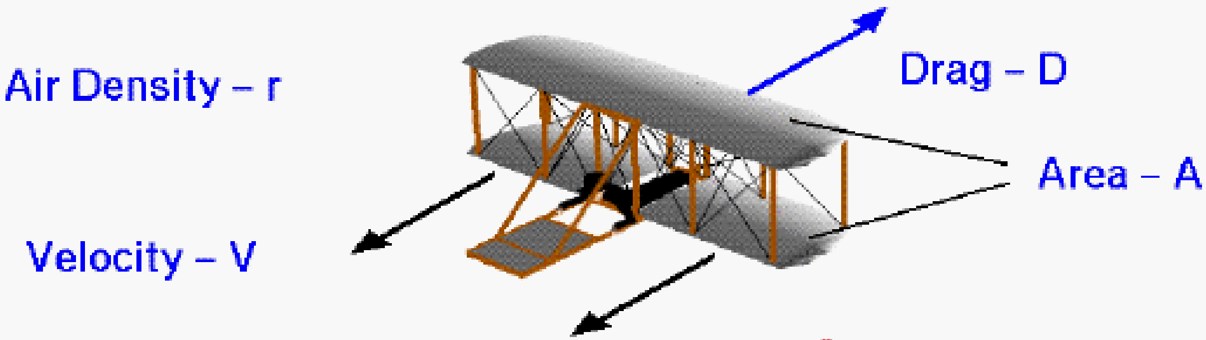


$$D = Cd \, \frac{r \, V^2}{2} \, A$$

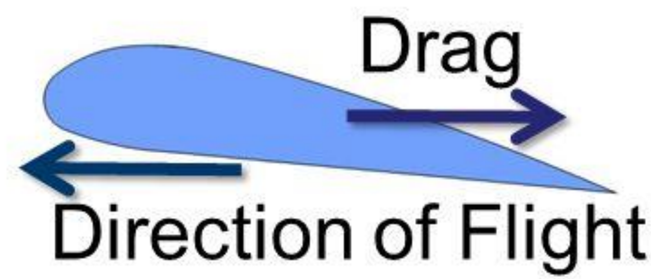
$$\text{Drag} = \text{coefficient} \times \text{density} \times \frac{\text{velocity squared}}{\text{two}} \times \text{reference area}$$

Coefficient Cd contains all the complex dependencies and is usually determined experimentally.

For an aircraft: $Cd = Cd_0 + \dfrac{Cl^2}{\pi \, Ar \, e}$

(aircraft) = (skin friction + form) + (induced)

Drag Equation



Coefficient of drag, C_d

- Determined experimentally
- Combines several factors
  - Shape
  - Angle of attack

$$C_d = \frac{2 \times D}{A \times \rho \times v^2}$$

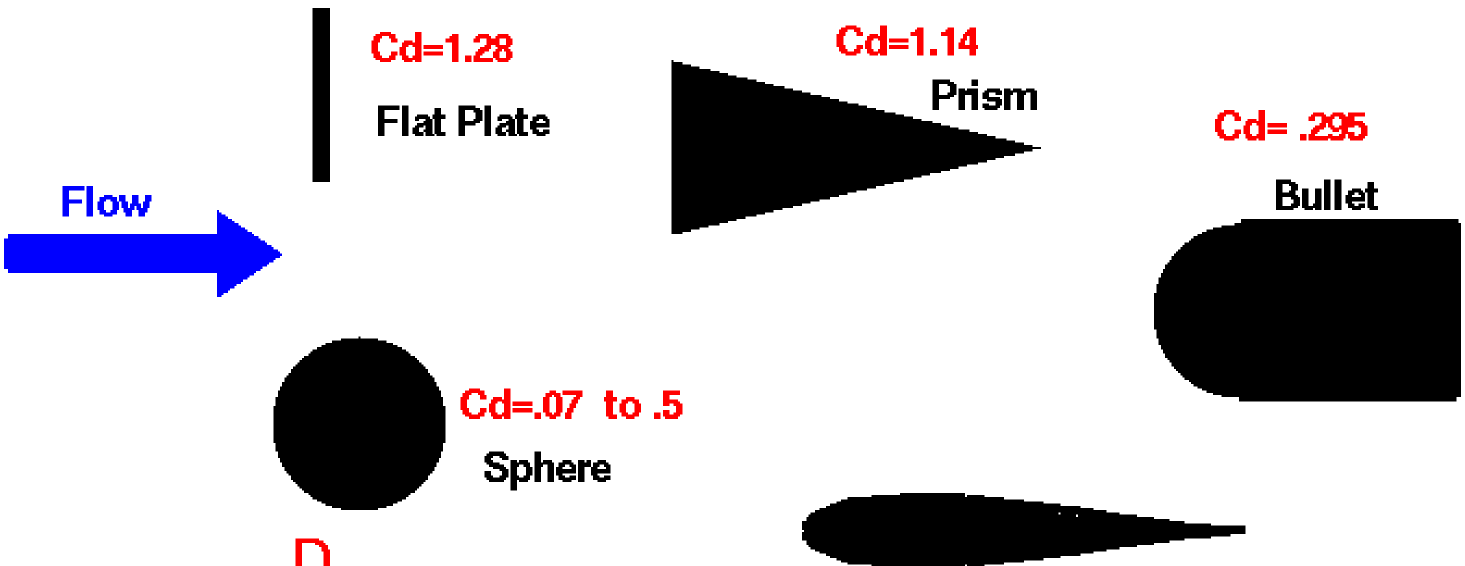
Alternate format

$$C_d = \frac{D}{q \times A}$$

$$C_d = Coefficient\ of\ Drag$$
$$D = Drag\ (N)$$
$$A = Wing\ Area\ (m^2)$$
$$\rho = Density\ \left(\frac{kg}{m^3}\right)$$
$$v = Velocity\ \left(\frac{m}{s}\right)$$
$$q = Dynamic\ Pressure\ (Pa)$$

Shape Effects on Drag

The shape of an object has a very great effect on the amount of drag.



$$Cd = \frac{D}{\rho V^2 A / 2}$$

A = frontal area

All objects have the same frontal area.

Lift to Drag Ratio

(L / D ratio)

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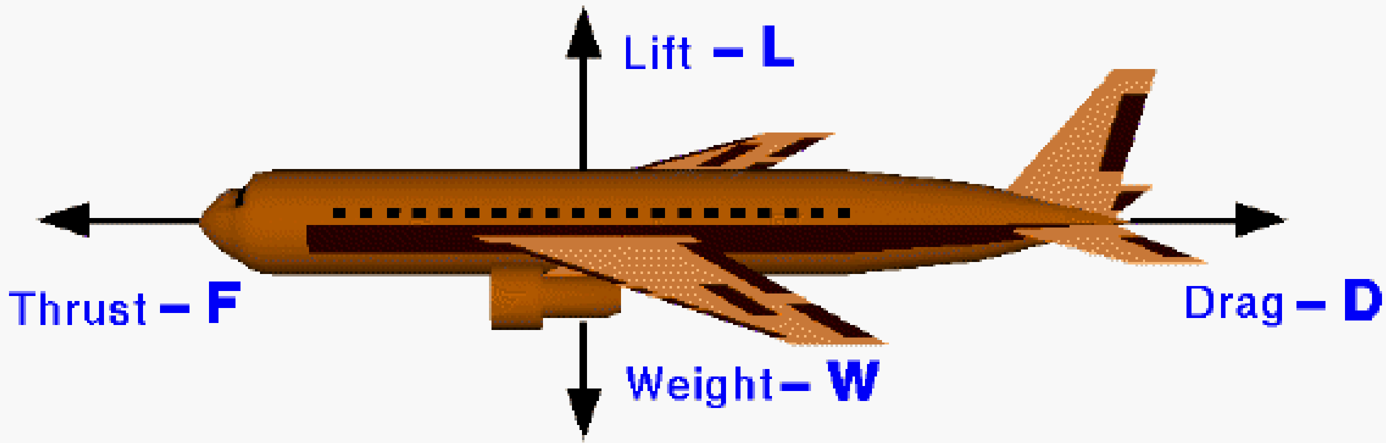

$$\frac{\mathbf{L}}{\mathbf{D}} = \frac{\text{Lift}}{\text{Drag}} = \frac{\text{Cl}\ \cancel{(.5\ \rho\ V^2 A)}}{\text{Cd}\ \cancel{(.5\ \rho\ V^2 A)}}$$

High L/D = High efficiency = Long range

High L/D = Large payload = Low fuel usage

Incorrect Theory #1

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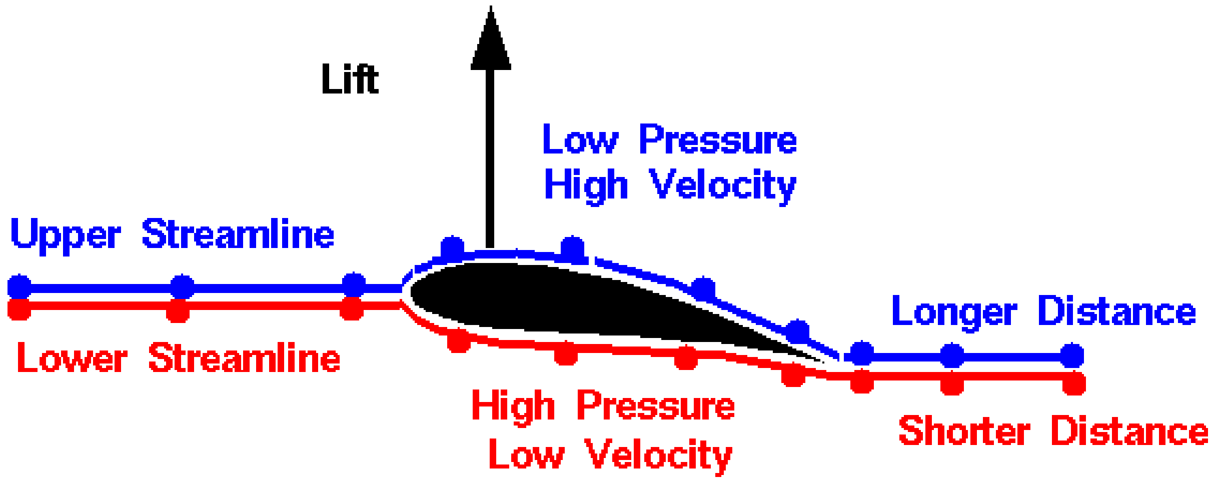


"Longer Path" or "Equal Transit" Theory

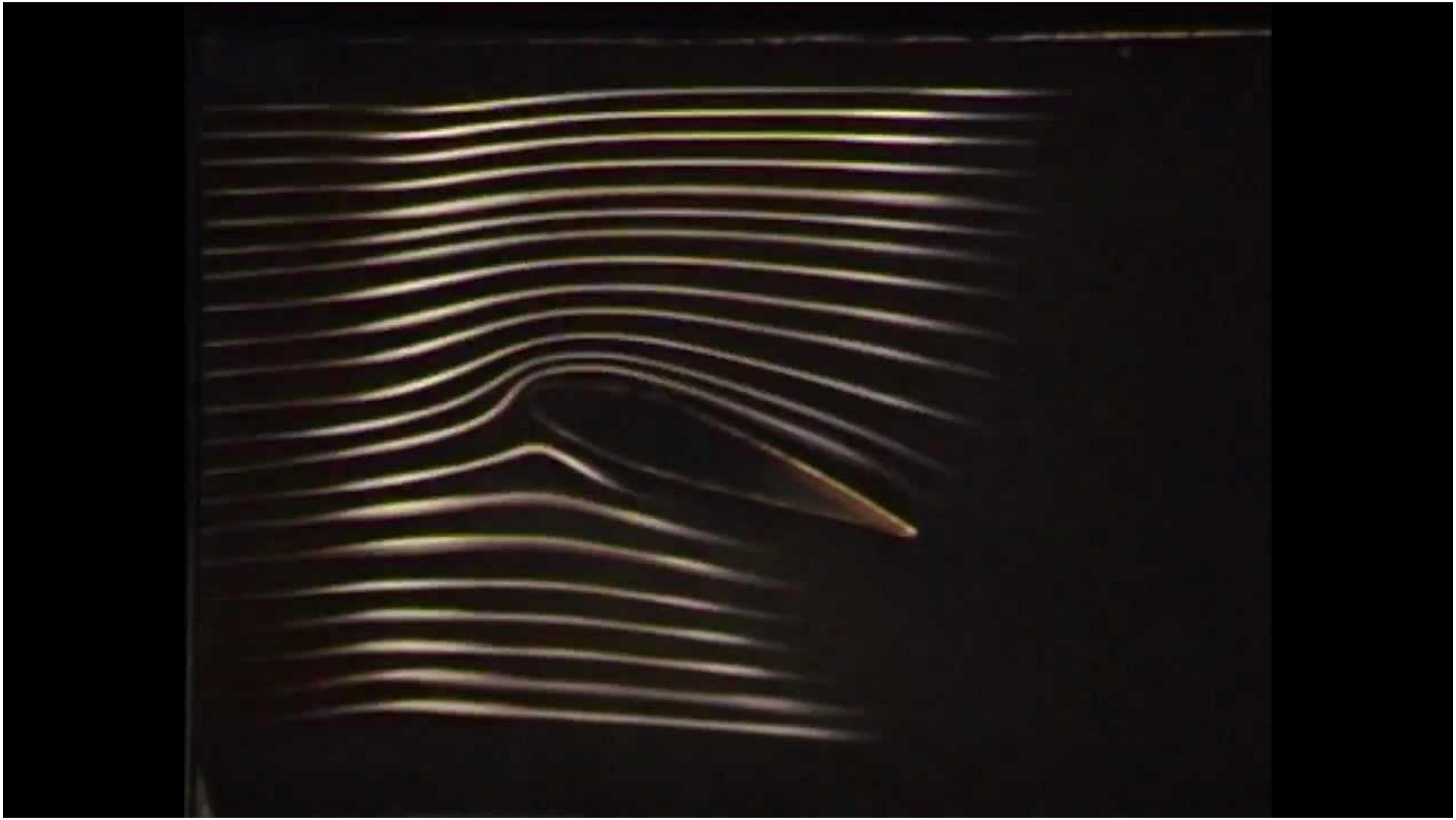
Top of airfoil is shaped to provide longer path than bottom.
Air molecules have farther to go over the top.

Air molecules must move faster over the top to meet molecules at the trailing edge that have gone underneath.

From Bernoulli's equation, higher velocity produces lower pressure on the top.

Difference in pressure produces lift.

베르누이 방식을 적용하려면 동시에 통과되야하는데 실제로 동시에 통과하지 않는다.
아래 영상을 참고하여도 실질적으로 위쪽이 훨씬 빠르고 더 긴 경로임에도 동시에 지나가지는 않는다.
https://www.youtube.com/watch?time_continue=48&v=iwA-pD96vxI



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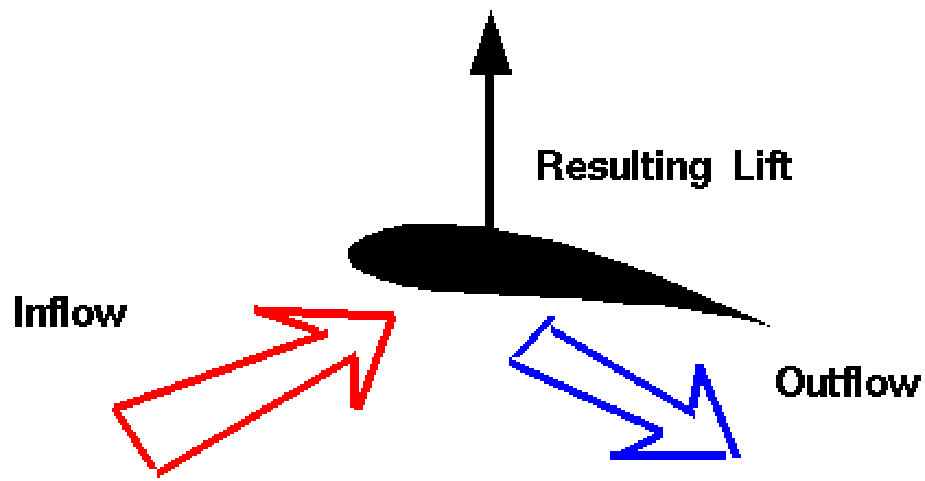
Incorrect Theory #2



"Skipping Stone" Theory

Lift is the result of simple action <--> reaction as air molecules strike bottom of the airfoil imparting momentum to the foil.

이거야말로 택도 없는 이론으로 날개 밑에 공기가 부딪혀서 그 반동으로 날개가 떠오른다는 이론이다.
실제 계산을 수행해보면 이 힘만으로 날개가 떠오르기엔 턱없이 부족하다.

Incorrect Theory #3

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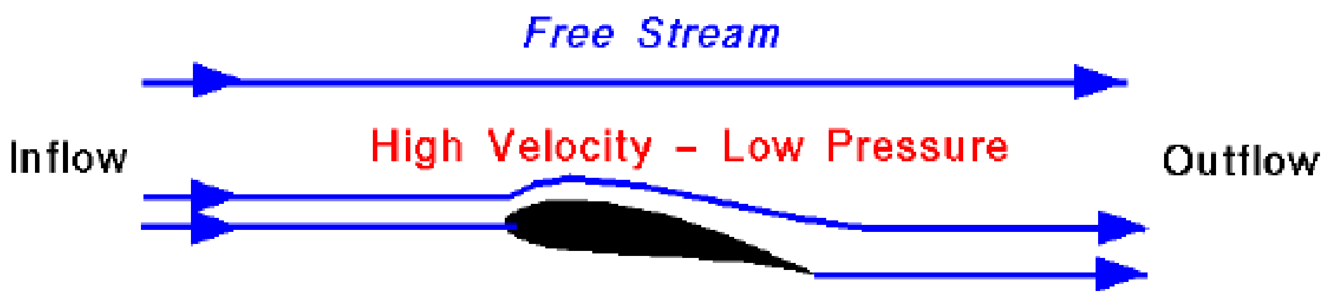


"Venturi" Theory

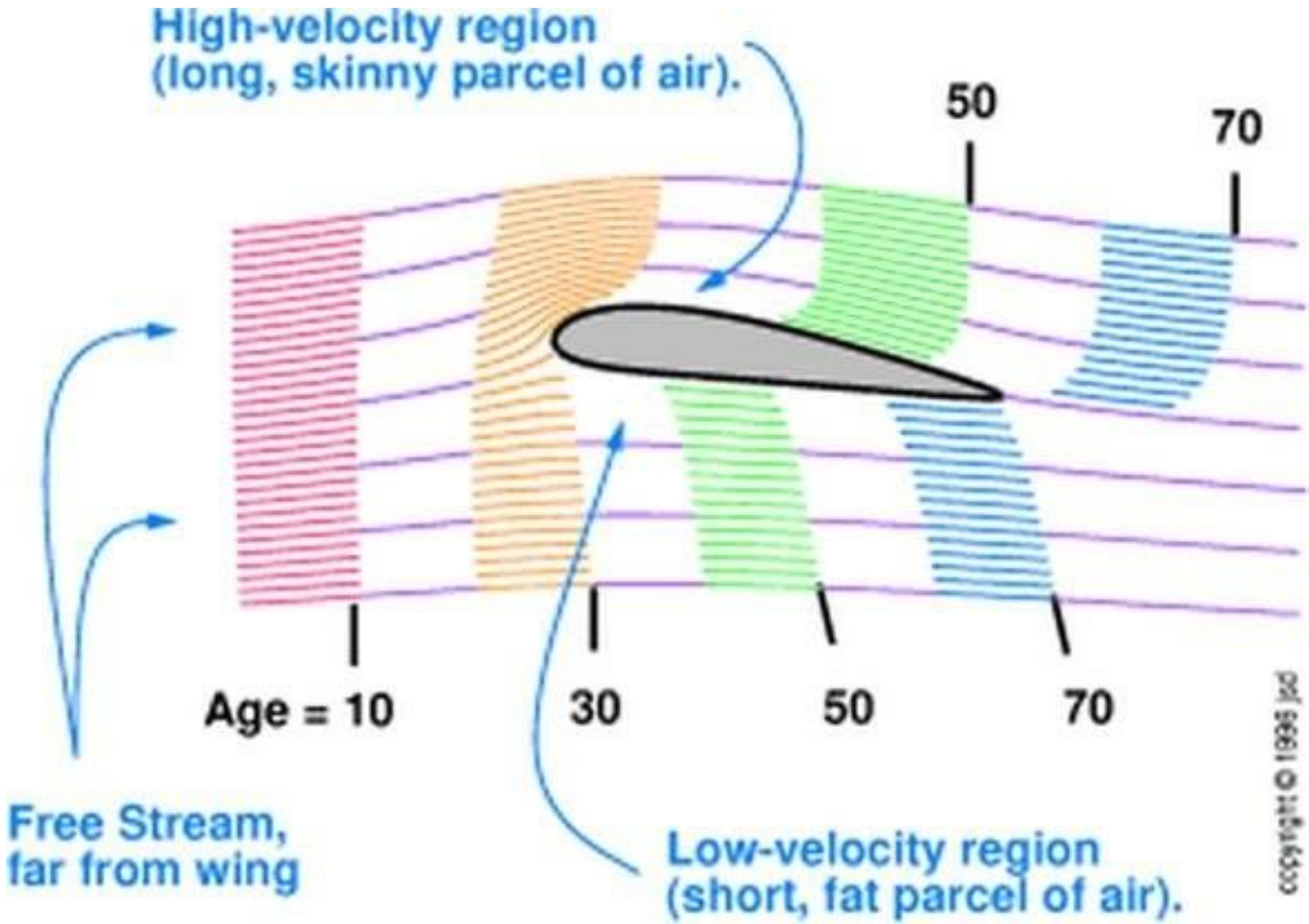
Upper surface of airfoil behaves like a Venturi nozzle constricting the flow.

Through the constriction, flow speeds up (velocity times area equals a constant).

From Bernoulli's equation, high velocity gives low pressure.

Decreased pressure on upper surface produces lift.

굉장히 그럴듯하지만 이 내용은 관내 유동에서 통용되는 이론이다.
물체 외부의 유동이므로 잘못된 이론이다.



https://www.quora.com/Air-pressure-under-wing-is-greater-than-over-the-wing-so-airplanes-fly-because-of-push-not-lift

Wing Geometry Definitions

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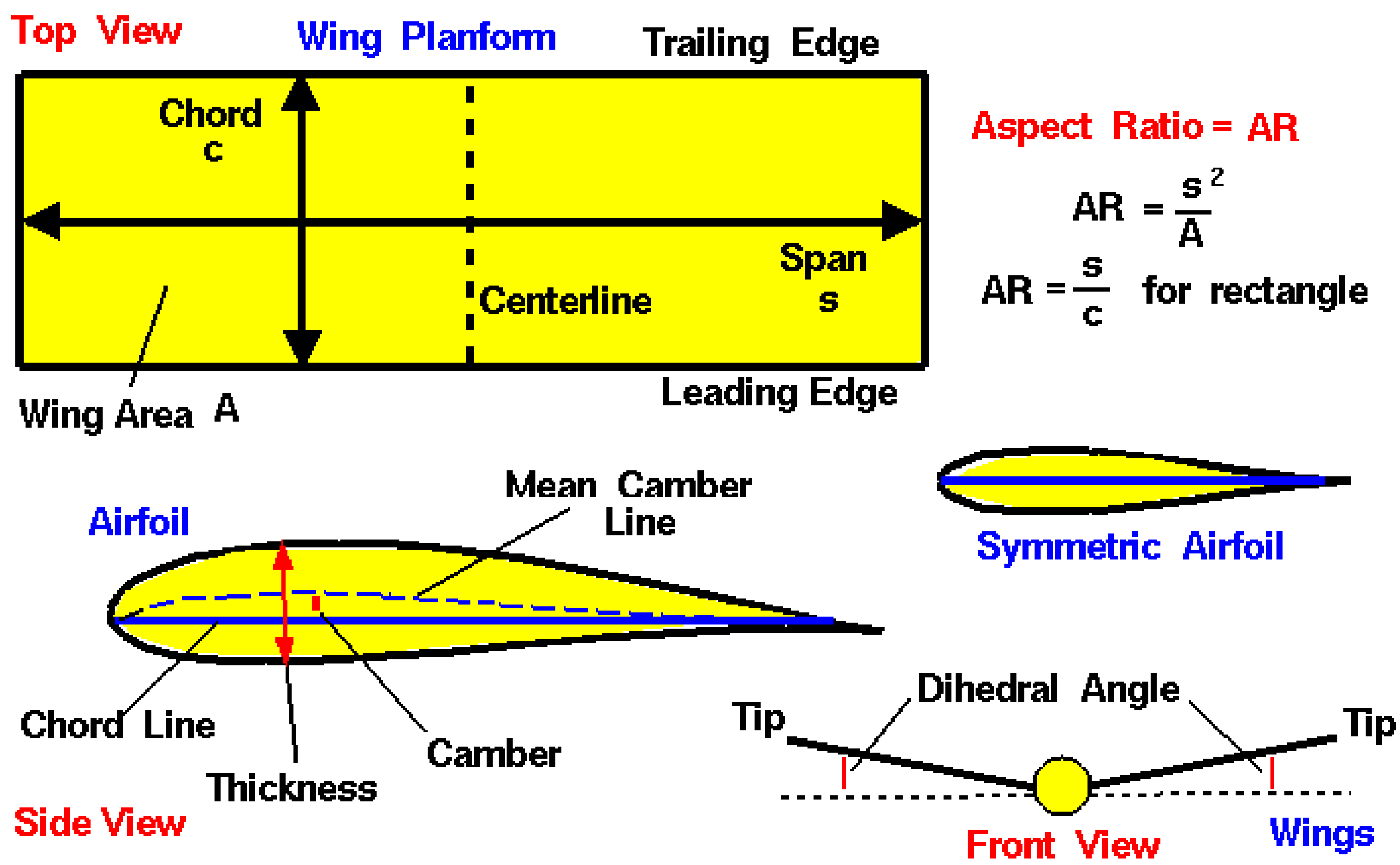
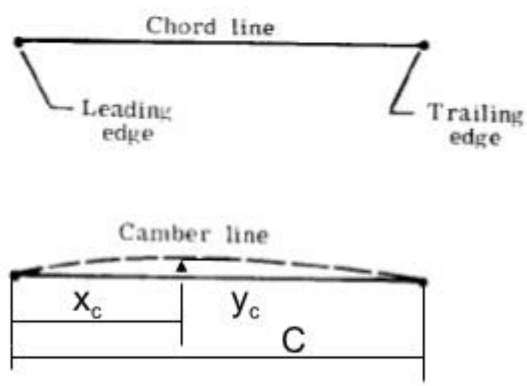


►NACA Four-Digit Series

Example: NACA 2412

NACA 2 4 12

- **2** → Camber in percentage of chord $y_c = 0.02\ C$
- **4** → Position of camber in tenths of chord $x_c = 0.4\ C$
- **12** → Maximum thickness (t) in percentage of chord $(t/c)_{max} = 0.12$



Prof. Galal Bahgat Salem
Aerospace Dept. Cairo University

https://www.slideshare.net/anashalim/aer-101-chapter-5

►NACA Five-Digit Series

Example: NACA 23012

NACA 2 30 12

When multiplied by 3/2 yields the design lift coefficient C_l in tenths. $C_l = 0.3$

When divided by 2, gives the position of the camber in percent of chord $x_c = 0.15\ C$

Maximum thickness (t) in percentage of chord $(t/c)_{max} = 0.12$

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Aerospace Dept. Cairo University

►NACA Six- Series

Example: NACA 64-212

NACA 6 4 - 2 12

Series designation 6

Location of minimum pressure in tenths of chord (0.4 C)

Design lift coefficient in tenths (0.2)

Maximum thickness (t) in percentage of chord $(t/c)_{max} = 0.12$

►Note that this is the series of laminar airfoils . Comparison of conventional and laminar flow airfoils is shown in the following Figure.

Center of Pressure – cp

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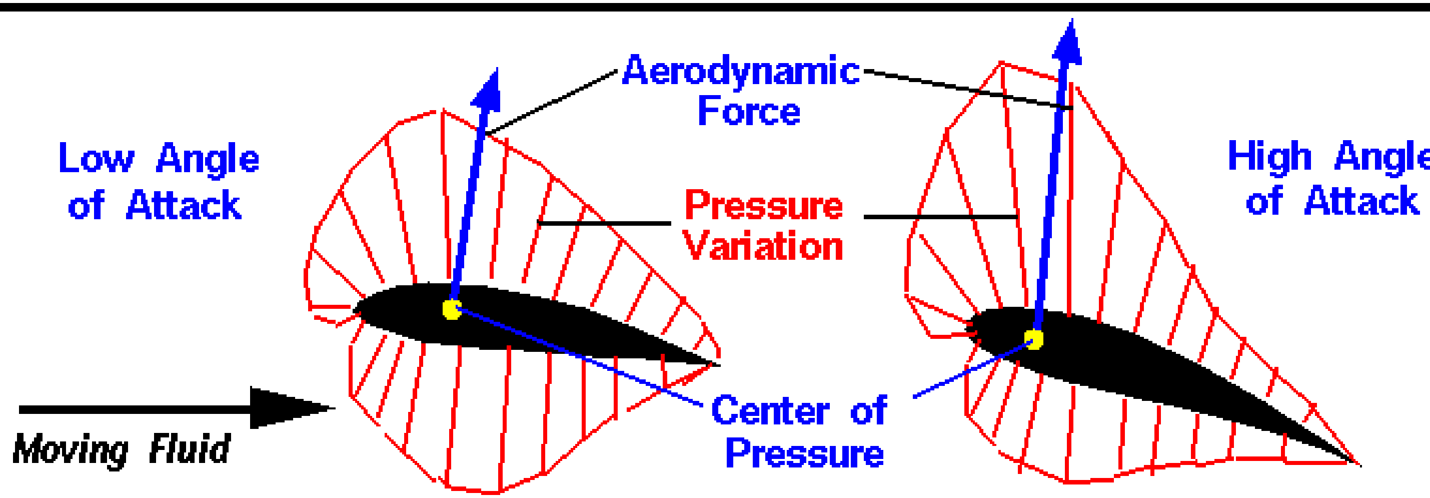

Center of Pressure is the average location of the pressure.

Pressure varies around the surface of an object. $P = P(x)$

$$cp = \frac{\int x \ p(x) \ dx}{\int p(x) \ dx}$$

Aerodynamic force acts through the center of pressure.

Center of pressure moves with angle of attack.

Inclination Effects on Lift

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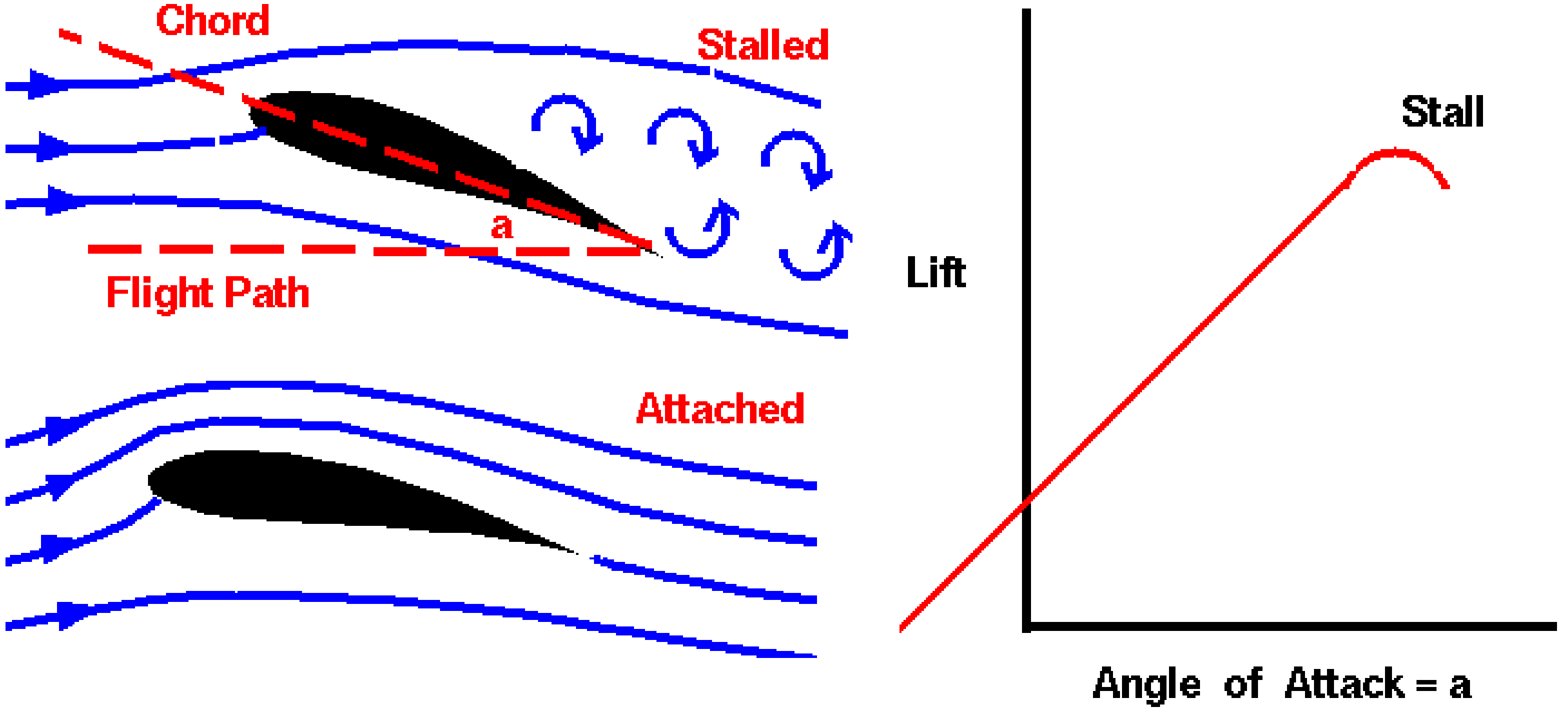
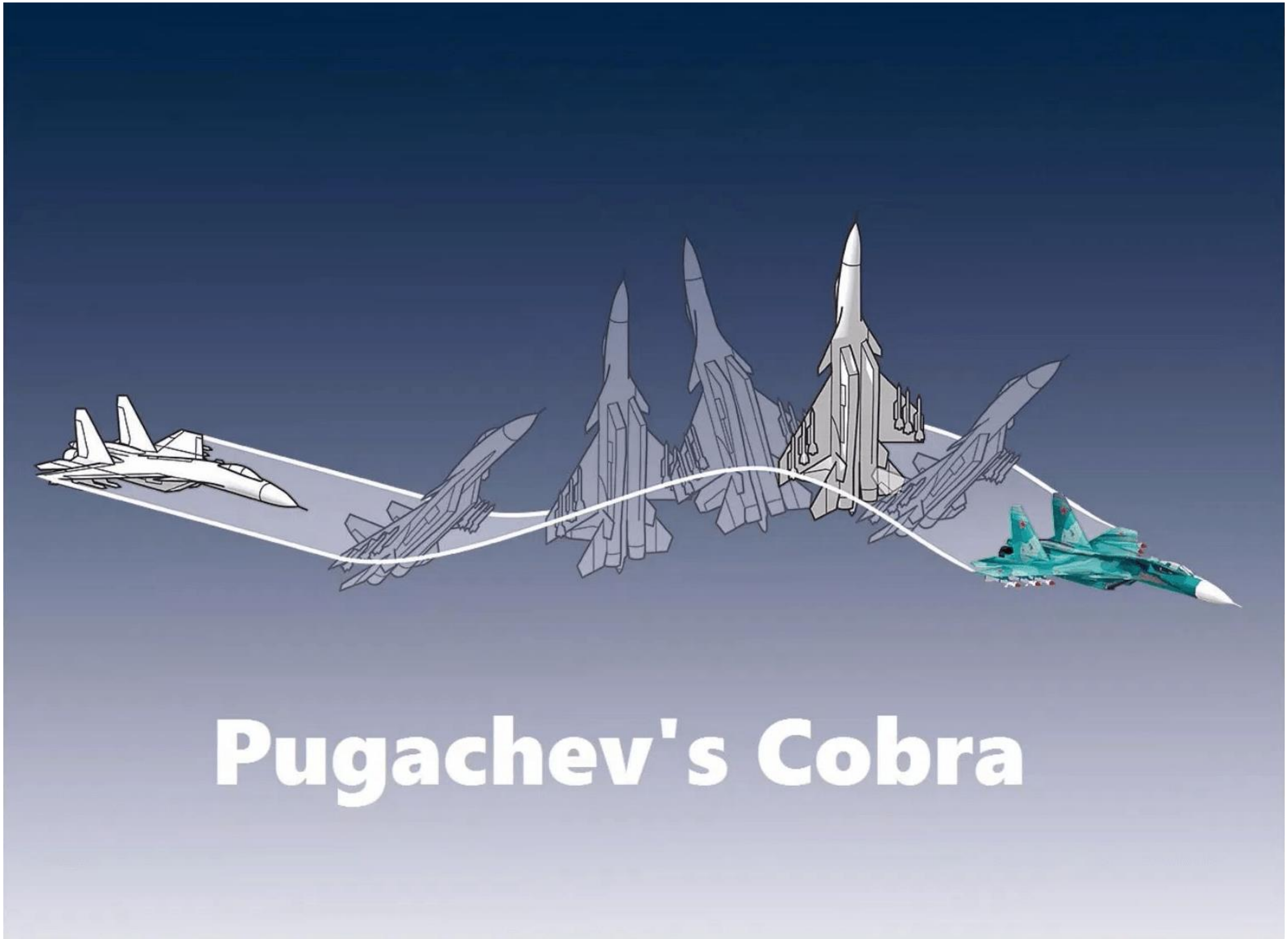


For small angles, lift is related to angle.

Greater Angle = Greater Lift

For larger angles, the lift relation is complex.

Included in Lift Coefficient



이와 같이 코브라 기동에 실질적으로 응용된다.
https://www.nolimitszone.com/the-most-incredible-maneuver-pugachevs-cobra

Aerodynamic Center – ac

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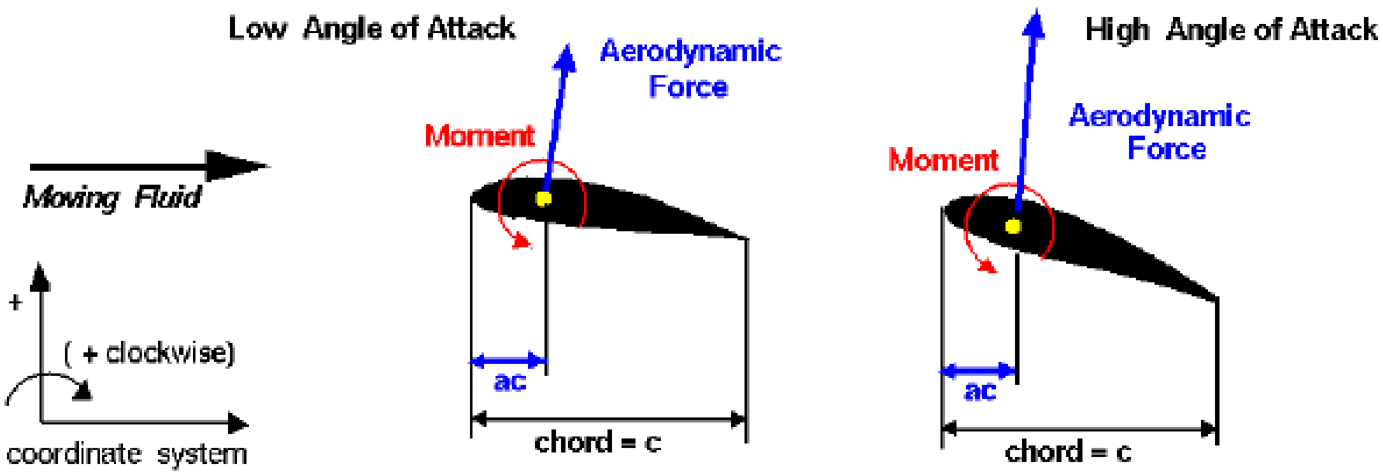


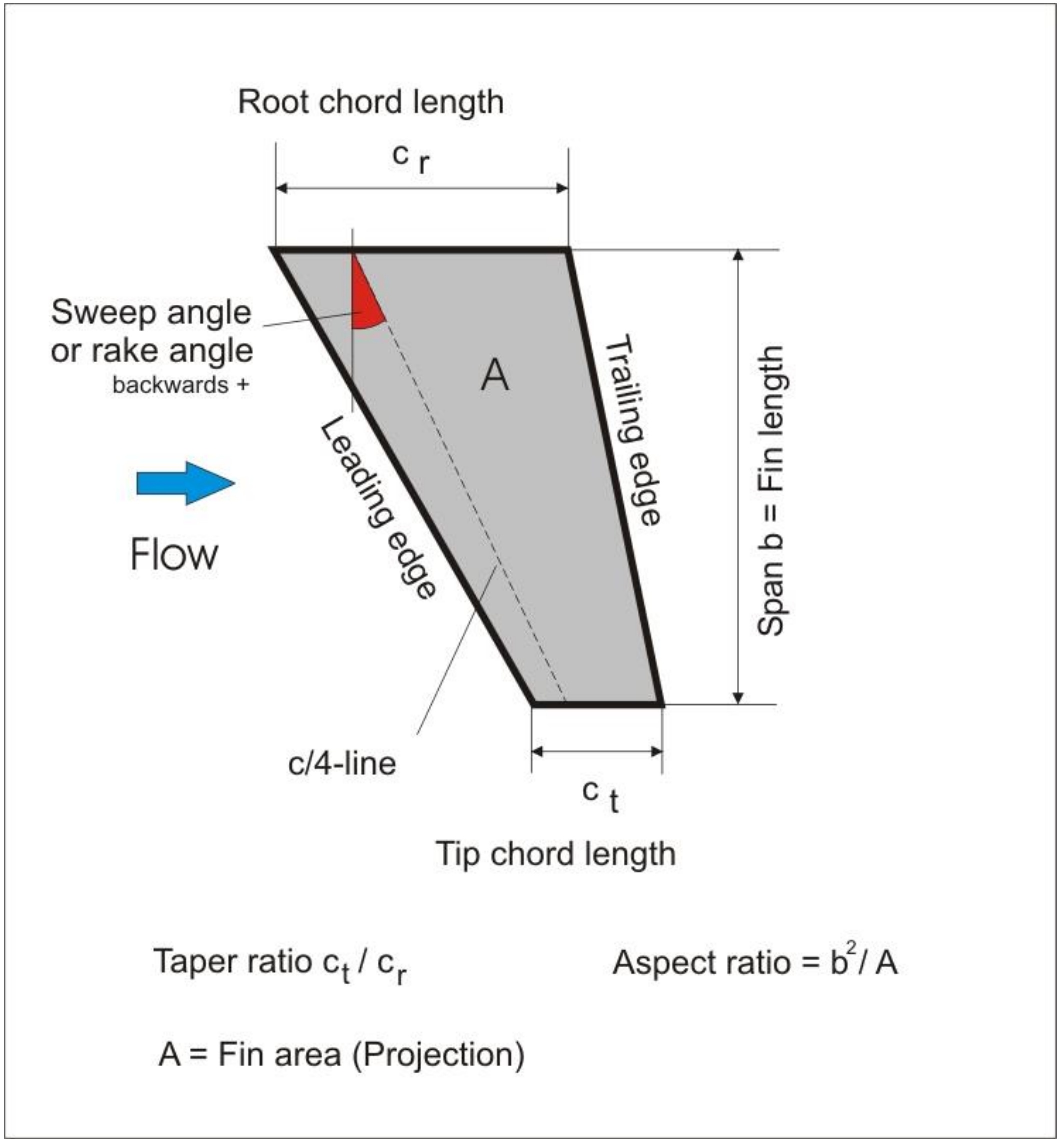
Aerodynamic Center

For low speed, thin airfoils (flat plate):

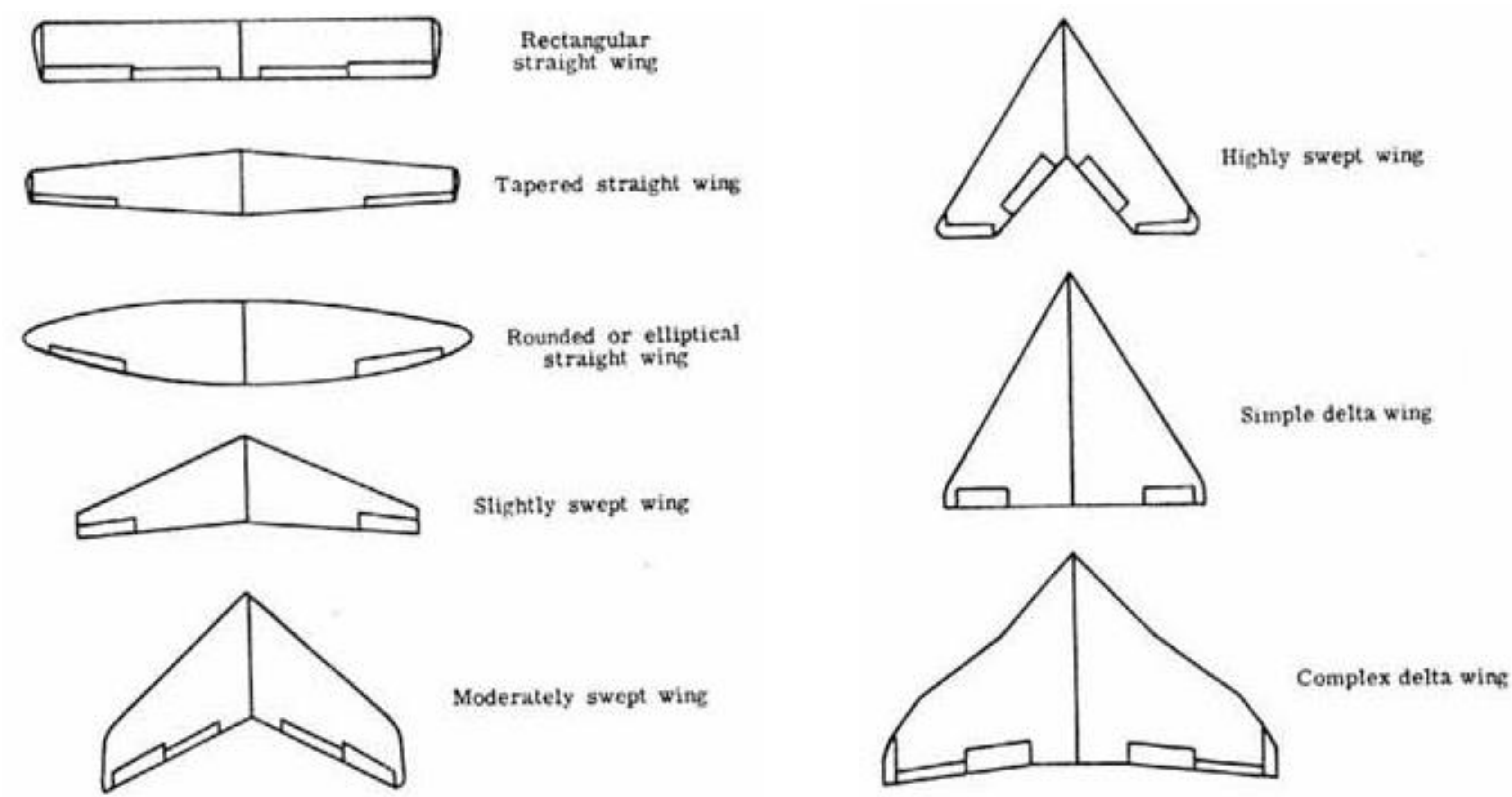
$$ac = \frac{c}{4}$$

Moment about the aerodynamic center is constant with angle.

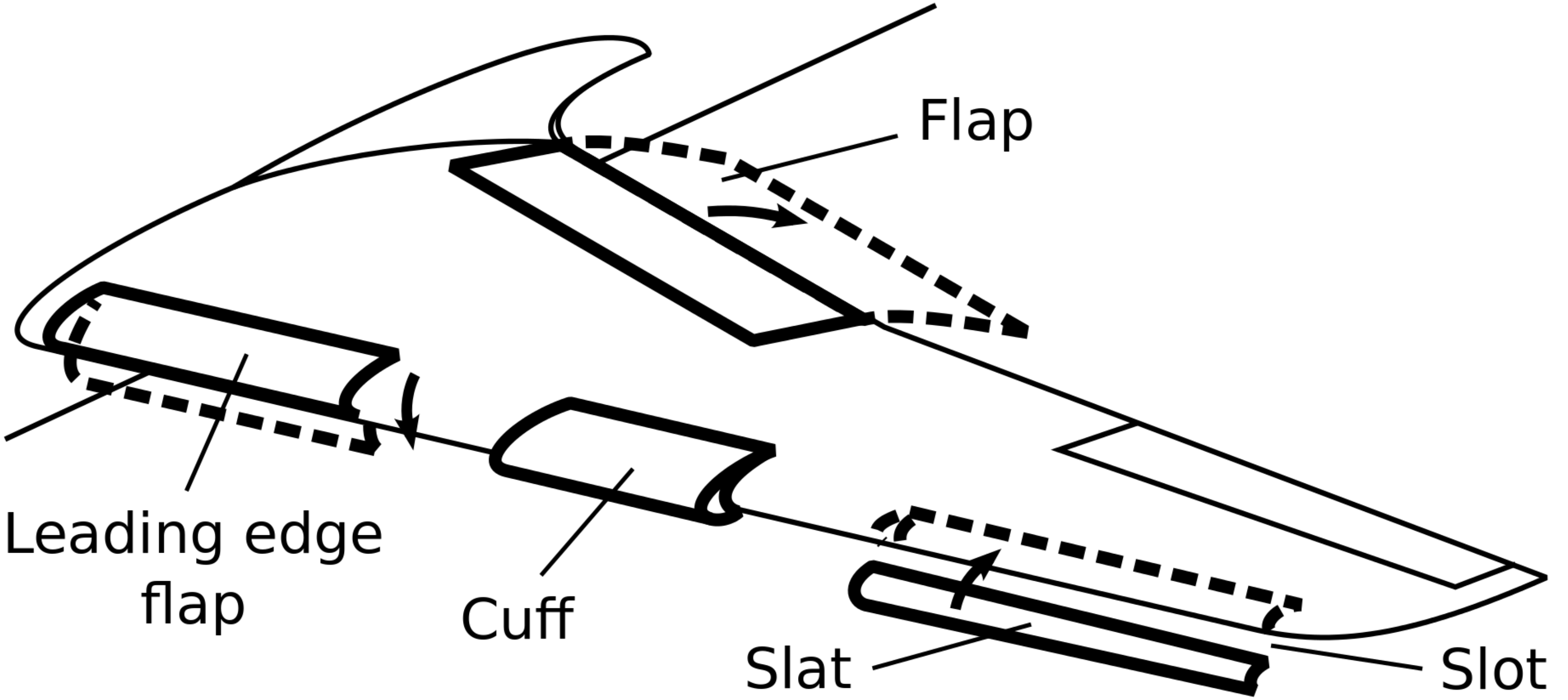
Aerodynamic center does not move with angle.



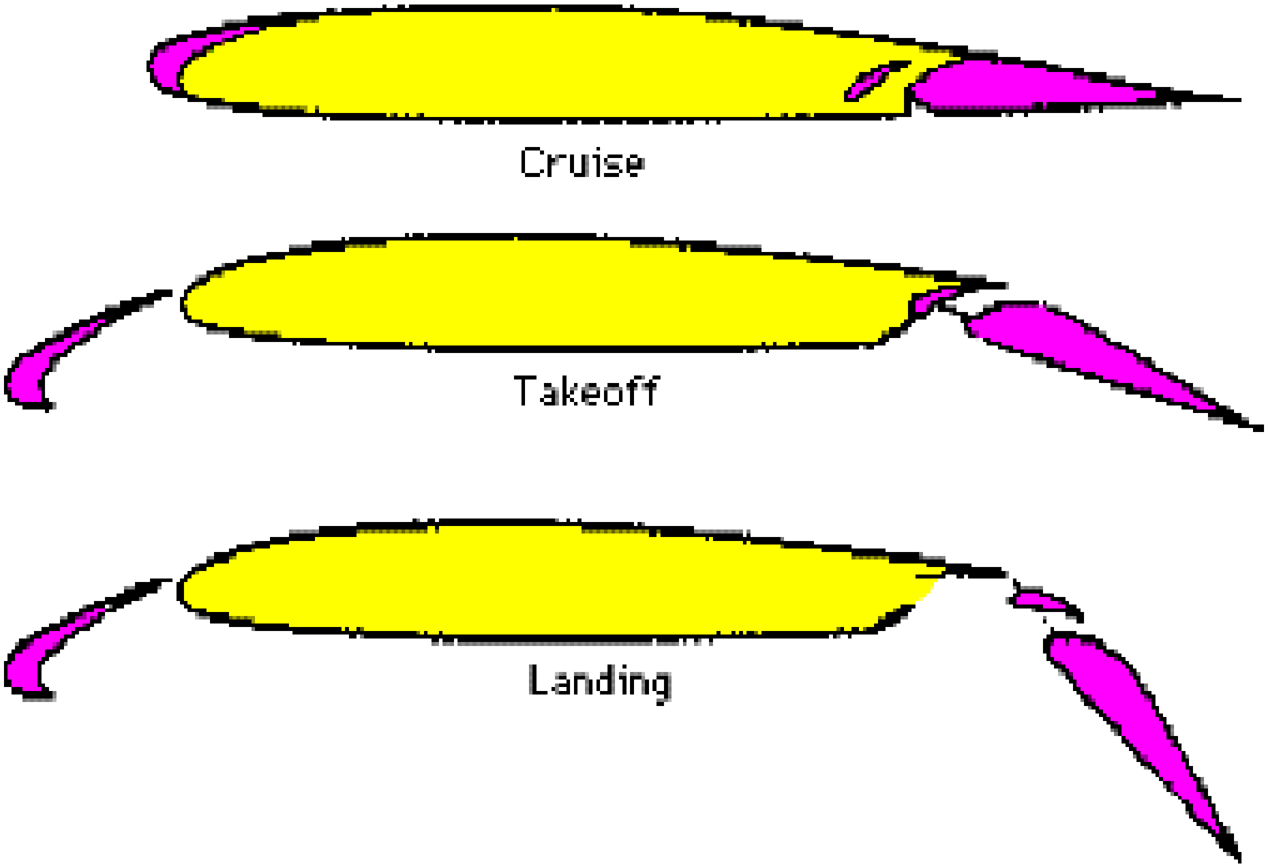
http://mauiultrafins.com/technology/fin-secrets/



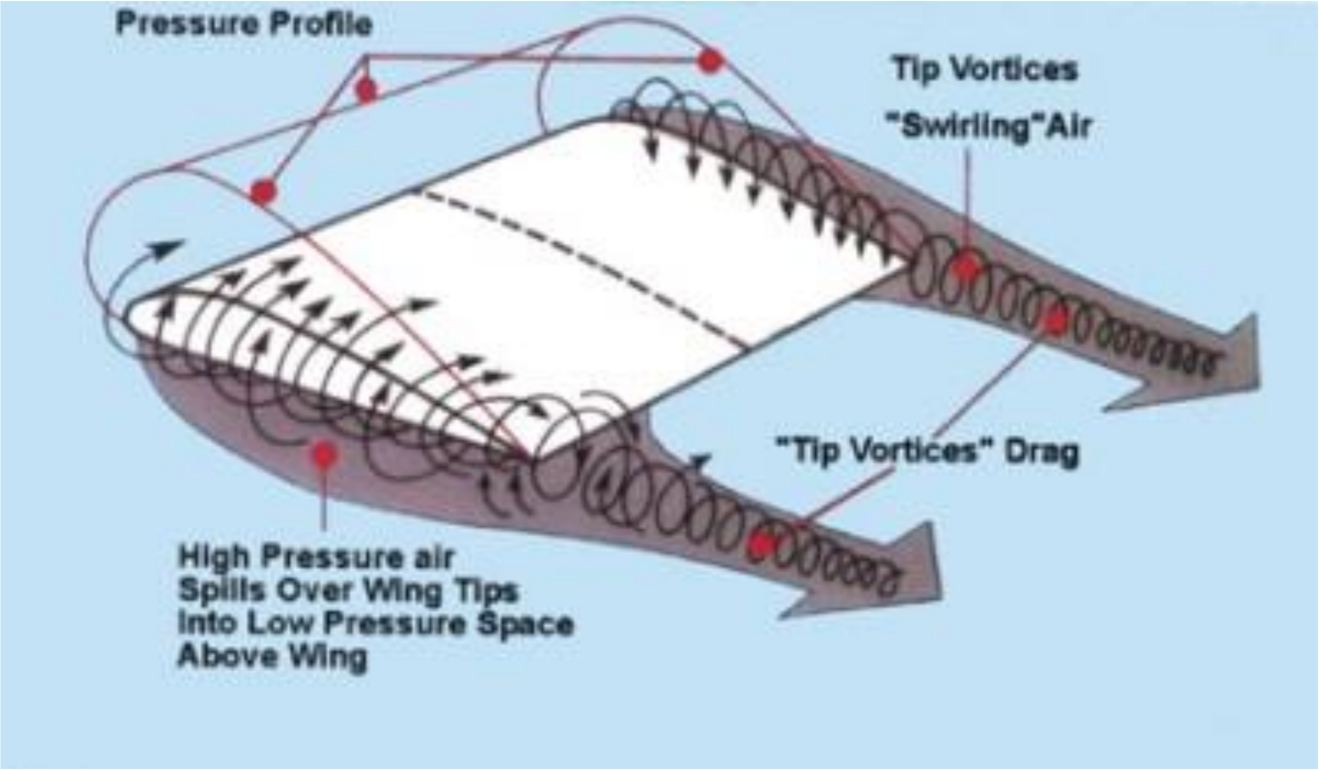
https://www.flitetest.com/articles/designing-smooth-symmetrical-airfoil-wings



https://commons.wikimedia.org/wiki/File:High-lift-devices_annotated.svg

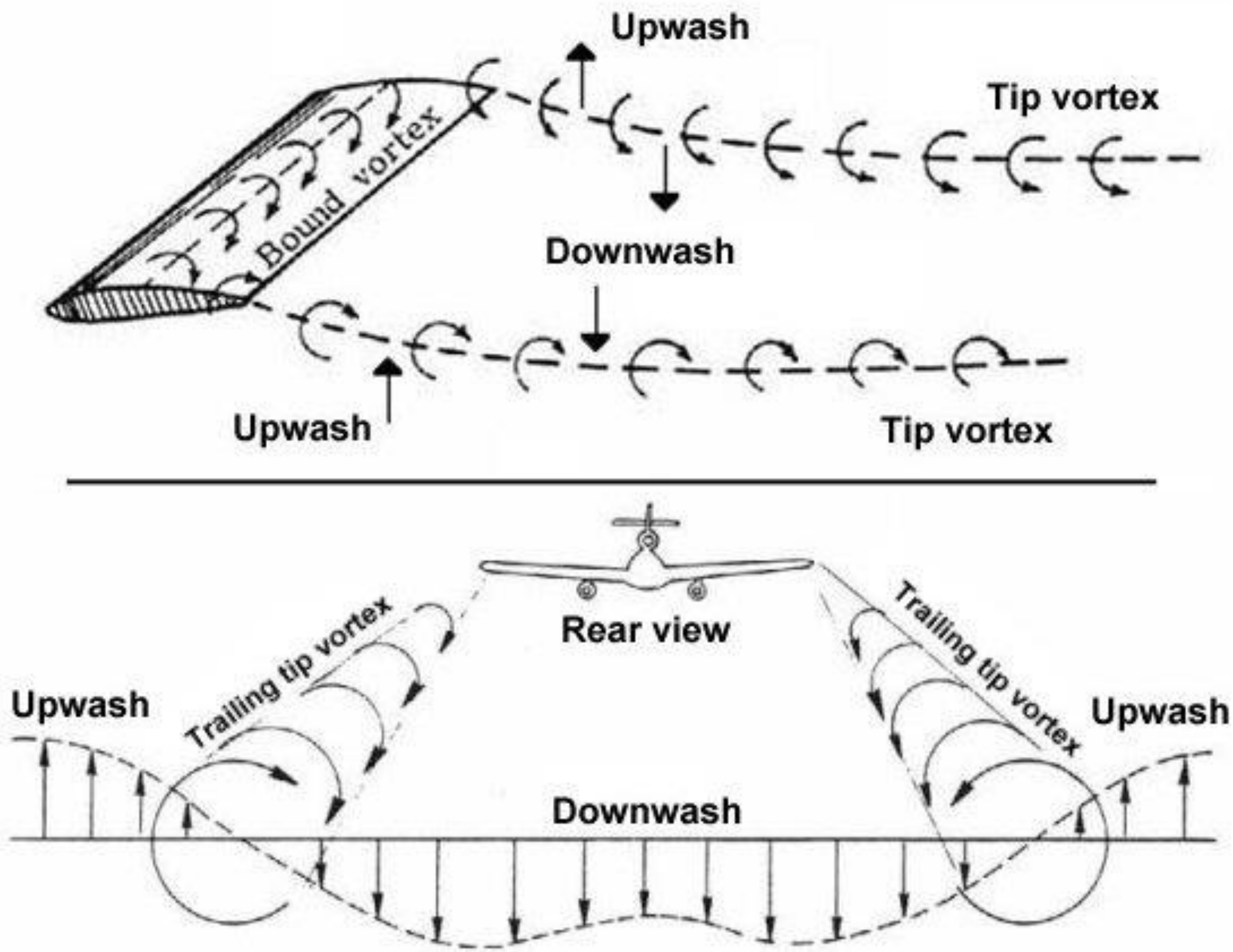


http://www.simply-rc.com/Aerodynamics/05_Stall%20&%20Spin.htm

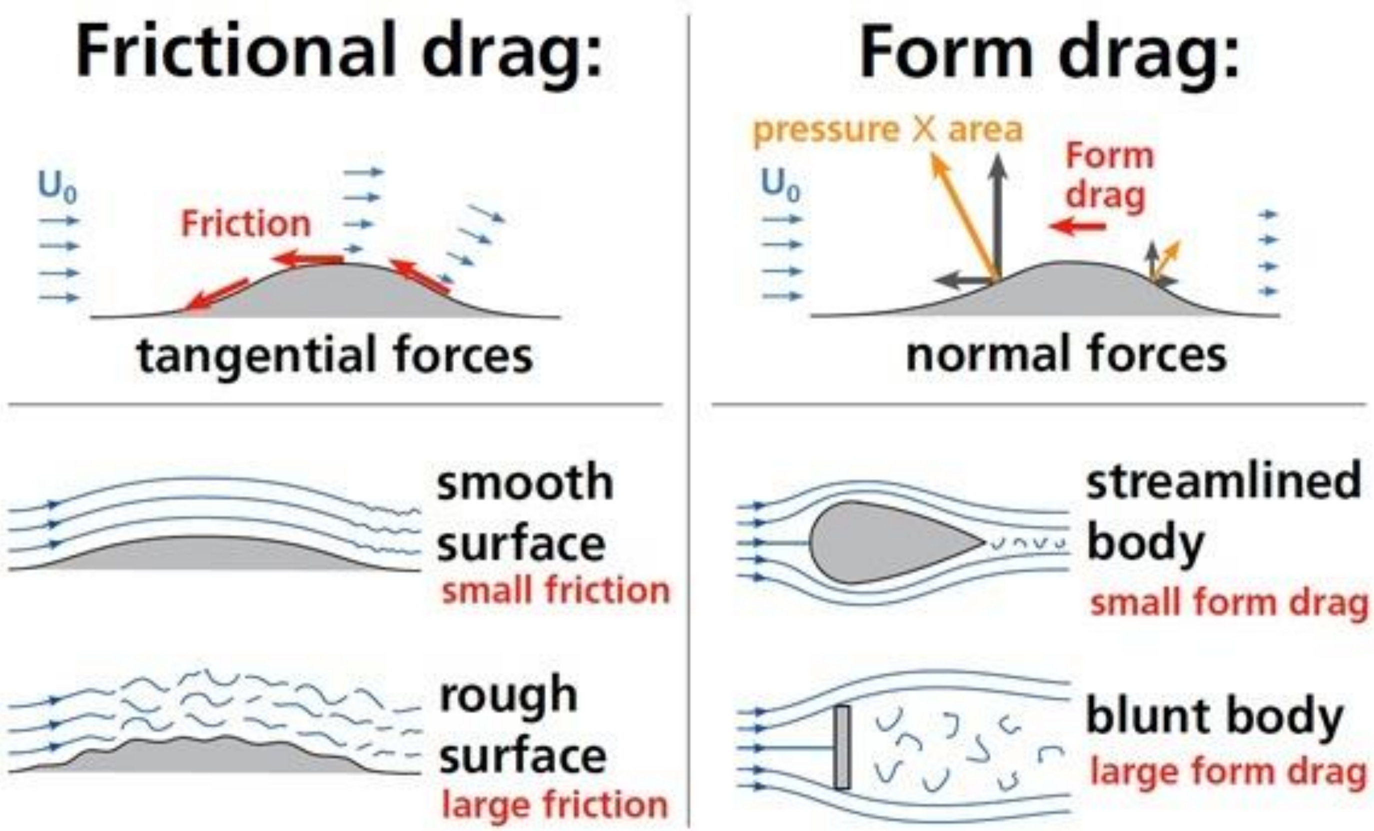


http://www.pilotfriend.com/training/flight_training/aero/wng_vort.htm

http://newcastleinnovation.com.au/portfolio-items/advanced-wing-tip-device/



https://aviation.stackexchange.com/questions/21799/why-does-the-vortex-created-by-wing-affects-its-own-angle-of-attack

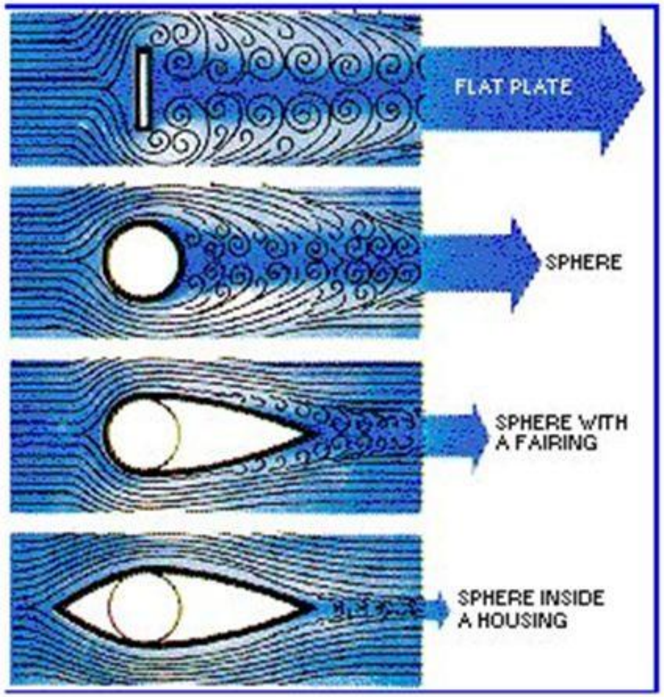


https://www.quora.com/Do-airfoils-wings-cause-drag

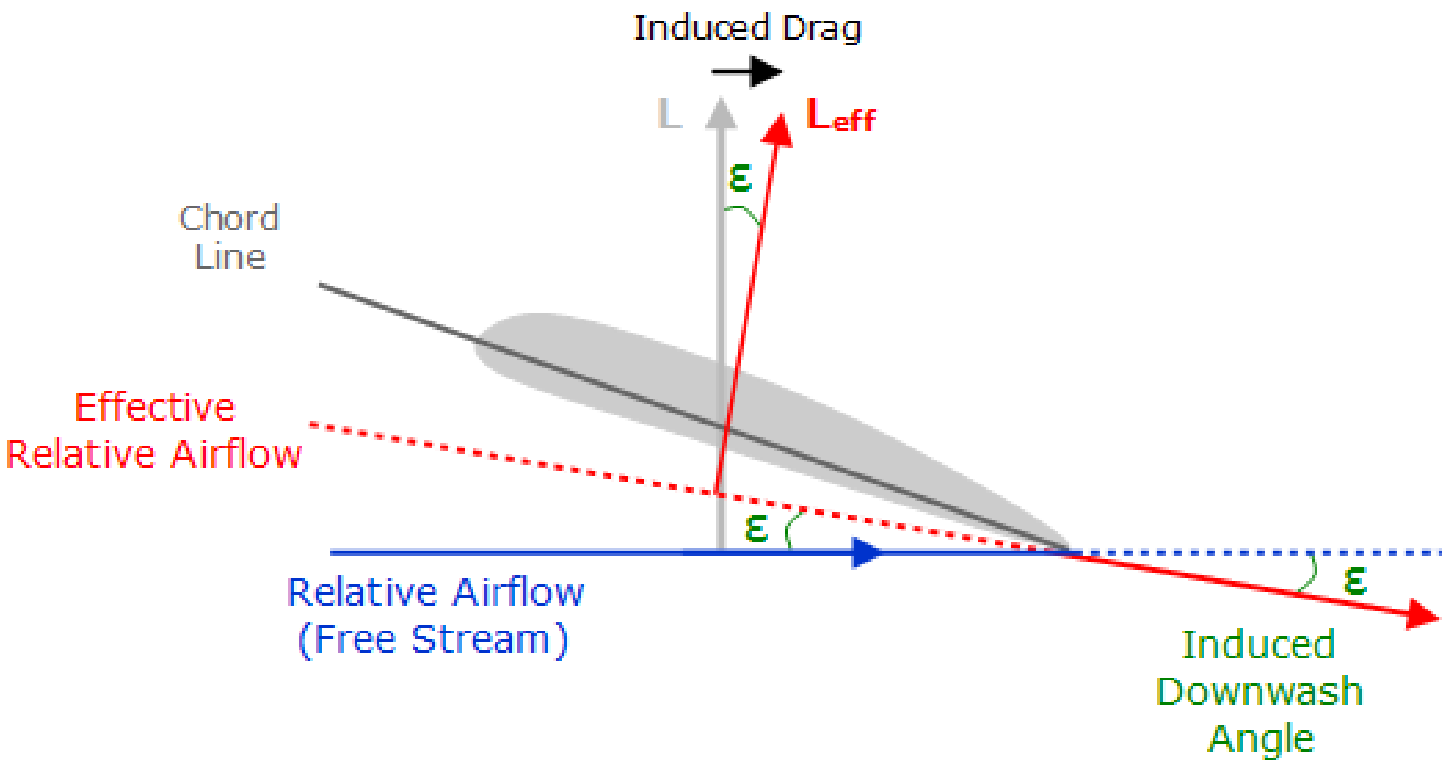
Friction and pressure drag

The picture on the right margin of this page shows examples of air flowing past a variety of objects.

The pressure drag is caused by the separation of air that is flowing over the aircraft or airfoil.



http://slideplayer.com/slide/10331626/



https://en.wikipedia.org/wiki/Lift-induced_drag