Introduction to Aeronautics and Airframe

Kamal Darlami

Institute of Engineering (IOE)
Tribhuwan University

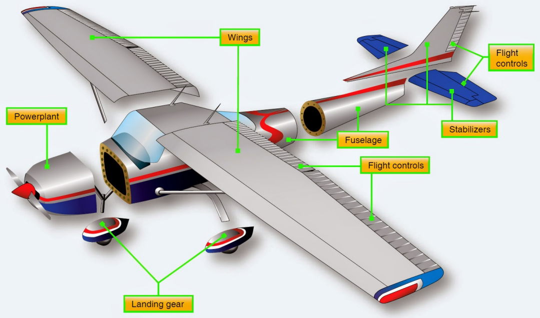
November 27, 2017

Outline

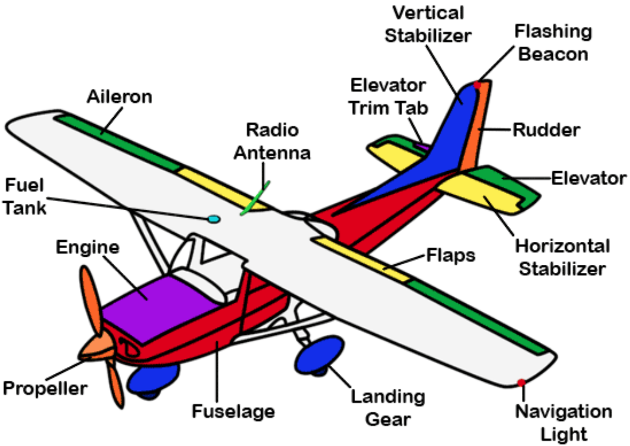
Outline

Main Components

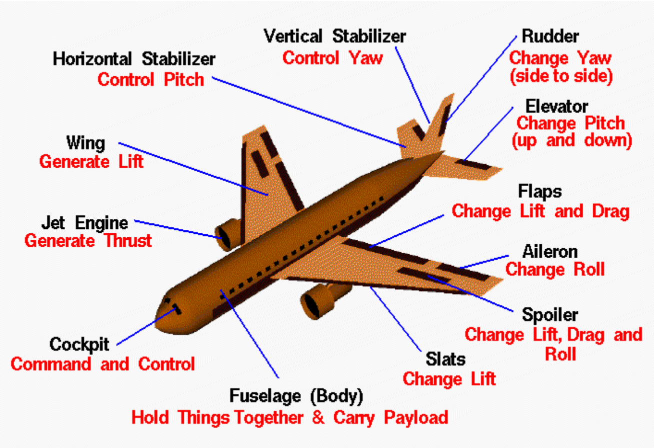
- Fuselage
- Wings
- Empenage
- Power Plant
- Landing Gear



Aircraft Components

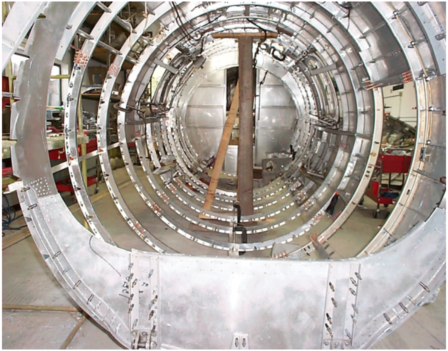


Aircraft parts and their Functions



Airframe Material Properties

- High Strength to Weight ratio
- Light weight
- Corrosion Resistant
- Should be non flammable
- High quality



Airframe Material Properties

Selection Criteria for materials

Materials selection is quite frequently a compromise involving various considerations and the more important considerations have historically been those associated with mechanical properties.

- Static strength efficiency
- Fatigue
- Fracture toughness and crack growth
- Corrosion and embrittlement
- Environmental stability

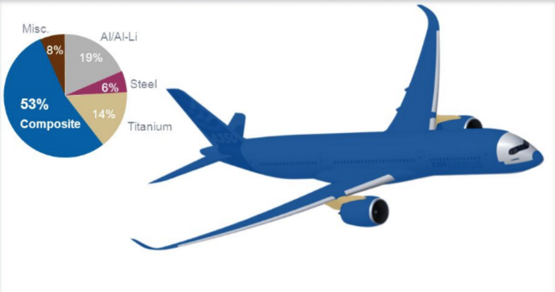
Selection Criteria for producing materials

Other criteria equally important are the criteria associted with producing the basic material in the forms requred and fabricating the end product at the resonable cost.

- Availability and producibility
- Materials cost
- Fabrication characteristics

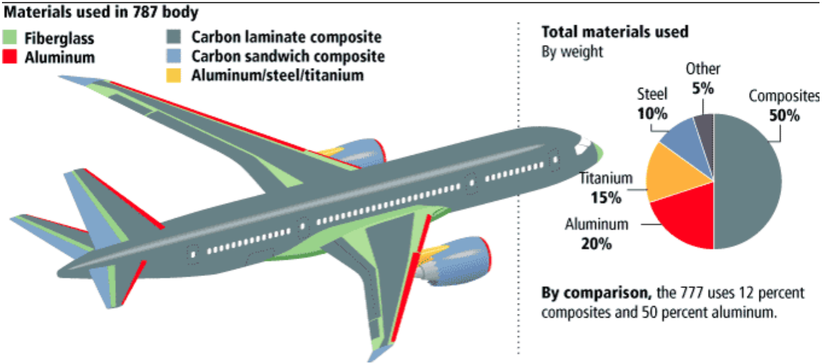
Material use in Airframe Construction

- WOOD (Spruce)
- STEEL & ITS ALLOYS (Strong)
- ALUMINIUM & ITS ALLOY (Commonly use)
- TITANIUM ALLOYS (Heat Barriers)
- MAGNESIUM ALLOYS (3 times lighter than AL)
- PLASTICS & COMPOSITE MATERIAL



A350 XWB. New design, new materials

Material use in Airframe Construction



Comparison of current material properties and efficiencies

Material	Conditions	Properties (room temp.) F_{tu} (ksi)	F_{ty} (ksi)	F_{cy} (ksi)	E (10^6 psi)	Density ρ (lb/in^3)	Structural Efficiency F_{tu}/ρ (10^3 in)	E/ρ (10^6 in)
Aluminum	2014-T6	68	56	48	10.7	.101	673	106
	2024-T4 Extrusion	57	42	38	10.7	.100	570	107
	2024-T81	64	56	57	10.8	.101	634	107
	7075-T6	78	71	70	10.3	.101	772	102
	7075-T6 Extrusion	78	70	70	10.4	.101	772	103
Titanium	6A1-4V Annealed	134	126	132	16.0	.160	838	100
	6A1-4VHeat-treated	157	143	152	16.0	.160	981	100
Steel	4340 180 Ksi H.T.	180	163	173	29.0	.283	636	102
	17-7PHTH1050	177	150	160	29.0	.276	641	105
	AMS6520 Maraging steel	252	242	255	26.5	.283	890	94
	H-11	280	240	240	30.0	.281	996	107
	300M	280	230	247	29.0	.283	989	102
Nickel	Inconel X-750	155	100	100	31.0	.300	517	103
	A-286	130	85	85	29.1	.287	453	101
Beryllium	Be Cross-rolled, SR200D	65	43	43	42.5	.067	970	634
Magnesium	AZ31B-H24	40	30	25	6.5	.064	625	102
Fiber-glass	Glass/Epoxy*	80		60	5	.065	1230	77
Kevlar	Kevlar/Epoxy*	160		40	12	.05	3200	240
Graphite	Graphite/Epoxy*	170		140	22	.056	3040	393

* Unidirectional with 60% of fiber contents.

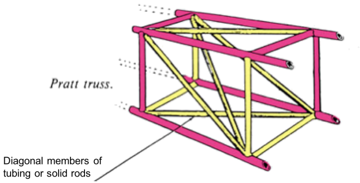
Outline

Truss Types

- Most early aircraft used this technique with wood and wire trusses.
- Still in use in many lightweight aircraft using welded steel tube trusses.
- Assembled with members forming a rigid frame e.g. beams, bar, tube etc.
- Primary members of the truss are 4 longerons.

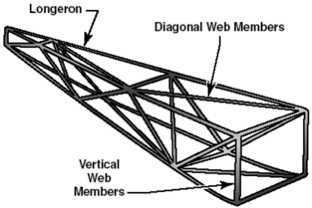
Pratt Truss

- Early days
- Wooden or metal structure
- Great weight
- Difficult to streamline
- Box with tubular longerons + vertical members

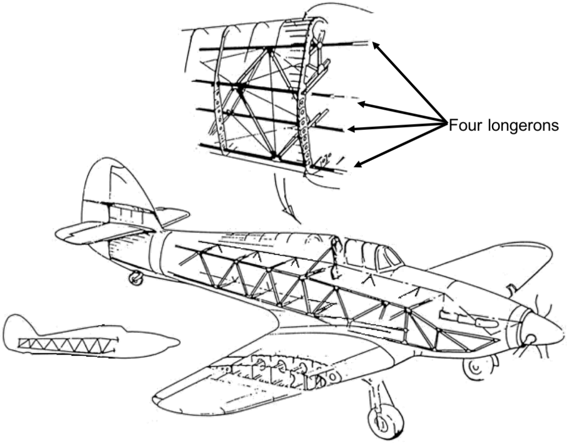


Warren Truss

- Longerons + only Diagonal Members
- Force transfer to every others structure
- Capable to carry tension + compression
- Reduce amount of webs work
- More space , strength , rigidity
- Better streamline



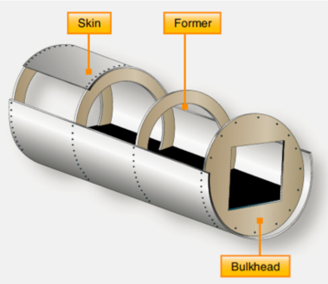
Warren Truss Structure of an airplane



Outline

Monocoque

- The exterior surface of the fuselage is also the primary structure
- Early form of this was built using molded plywood.
- A later form of this structure uses fiberglass cloth impregnated with polyester or epoxy resin, instead of plywood, as the skin.



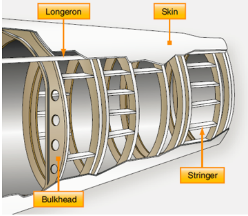
Monocoque

- The true monocoque construction uses formers, frame assemblies, and bulkheads to give shape to the fuselage.
- The heaviest of these structural members are located at intervals to carry concentrated loads and at points where fittings are used to attach other units such as wings, powerplants, and stabilizers.
- Since no other bracing members are present, the skin must carry the primary stresses and keep the fuselage rigid.
- The skin must be fairly thick to take all loading encountered in flight and on the ground.
- Thus, the biggest problem involved in monocoque construction is maintaining enough strength while keeping the weight within allowable limits.

Outline

Semi-Monocoque

- This is the preferred method of constructing an all-aluminum fuselage.
- First, a series of frames in the shape of the fuselage cross sections are held in position on a rigid fixture, or jig.
- These frames are then joined with lightweight longitudinal elements called stringers.
- These are in turn covered with a skin of sheet aluminum, attached by riveting or by bonding with special adhesives.
- Most modern large aircraft are built using this technique, but use several large sections constructed in this fashion which are then joined with fasteners to form the complete fuselage.



Semi-Monocoque

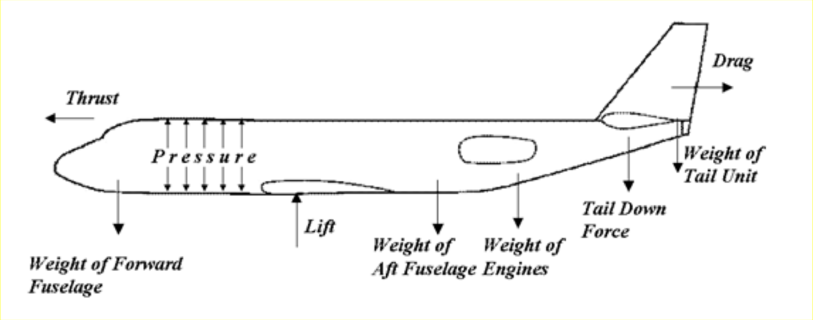
- To overcome the strength/weight problem of monocoque construction, a modification called semimonocoque construction was developed.
- It also consists of frame assemblies, bulkheads, and formers as used in the monocoque design but, additionally, the skin is reinforced by longitudinal members called longerons.
- Longerons usually extend across several frame members and help the skin support primary bending loads. They are typically made of aluminum alloy either of a single piece or a built-up construction.
- Stringers, the longitudinal members are typically more numerous and lighter in weight than the longerons.
- Stringers have some rigidity but are chiefly used for giving shape and for attachment of the skin.
- Stringers and longerons together prevent tension and compression from bending the fuselage.

Semi-Monocoque

- To summarize, in semimonocoque fuselages, the strong, heavy longerons hold the bulkheads and formers, and these, in turn, hold the stringers, braces, web members, etc.
- The fuselage skin thickness can vary with the load carried and the stresses sustained at a particular location.
- The bulkheads, frames, stringers, and longerons facilitate the design and construction of a streamlined fuselage that is both rigid and strong.
- Spreading loads among these structures and the skin means no single piece is failure critical.
- This means that a semimonocoque fuselage, because of its stressed-skin construction, may withstand considerable damage and still be strong enough to hold together.

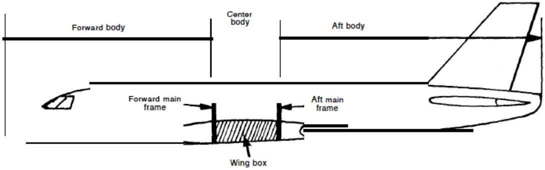
Outline

Aircraft Loads



Detailed loads on an aircraft

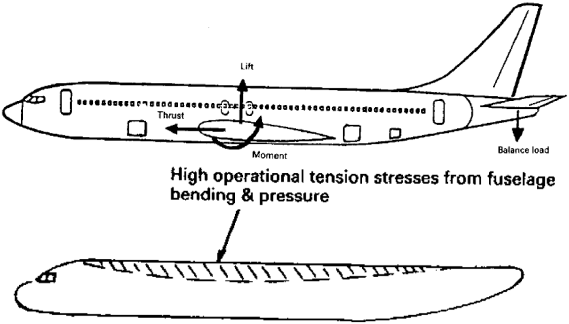
Fuselage Loads



Forebody Loads

- Vertical airloads are generally neglected in forebody loads calculations except for wide body fuselage or their affect on local structure.
- Side loads (in the y direction) are caused by side and yawing accelerations and airloads incurred during unsymmetrical maneuvers
- Here the airloads make up a large part of the net loads and therefore cannot be neglected.
- Critical forebody loadings may also be experienced from application of nose landing gear loads

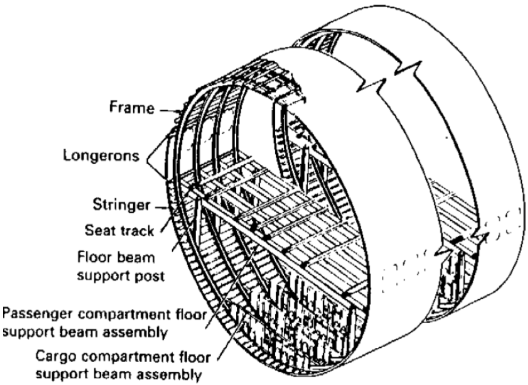
Fuselage Loads



Aftbody Loads

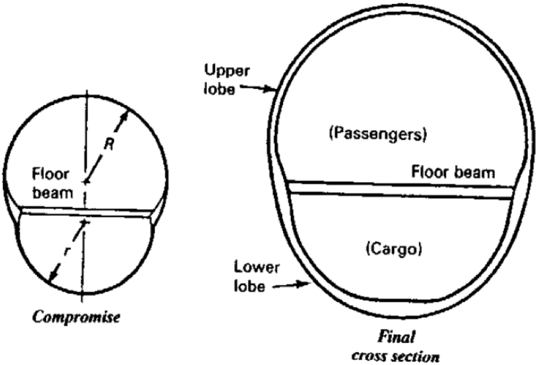
- Aftbody vertical flight loads are a critical combination of inertia loads and horizontal tail balancing loads.
- Airloads on the fuselage aftbody are generally neglected, both in the vertical and side directions.

Fuselage Structure



Major Fuselage Components: Skin, Frames, Bulkheads, Stringers and Longerons.

Fuselage Cross-section



A typical double lobe fuselage cross-section

Fuselage Cross-section

Fuselage Loads

Ultimate design Conditions

- Flight loads (acting alone)
- Flight loads + cabin pressure (p = maximum differential pressure loads)
- Cabin pressure only (1.33 x p)
- Landing and ground loads

Fail-safe design conditions

- Fail-safe flight loads (acting alone)
- Fail-safe flight loads + cabin pressure
- Cabin pressure only

Fuselage Loads

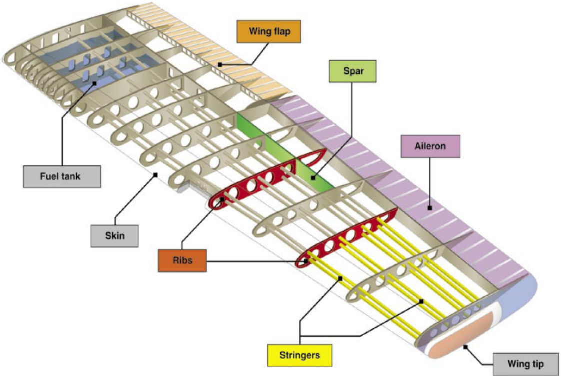
Fatigue

- Fatigue loads based on flight profiles developed by manufacturer to encompass anticipated airplane usage
- Fatigue Objective design flight hours of service life without modification of primary structure

Special area conditions

- Depressurization of one compartment
- Bird strike
- Hail strike
- Cargo and passenger loads on floors
- Crash loads (emergency landing)

Wing Structure



Outline

Ideal and real fluids

Mechanics of fluids become easier by studying ideal fluids instead of real fluids.

Ideal Fluids

- Incompressible
- It has zero viscosity
- No resistance is encountered as the fluid moves.

Real Fluids

- Compressible
- Viscous in nature
- Certain amount of resistance is always offered by these fluids as they move.

Ideal and real fluids

Real Fluid is further classified into two types.

Newtonian fluid

The fluids which obey Newtons law of viscosity are called as Newtonian fluids such fluids exhibit linear relationship between shear stress and rate of angular deformation. Eg. - water , air etc.

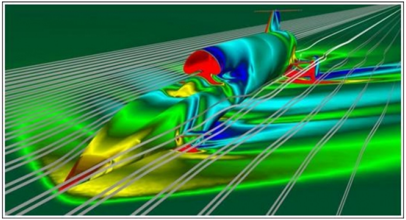
Non-Newtonian Fluid

Fluids which do not follow the linear relation between shear stress and rate of angular deformation are termed as Non Newtonian fluids. Eg. - silly putty, ketchup etc.

https://www.youtube.com/watch?v=G1Op_1yG6lQ

Air flow around a body

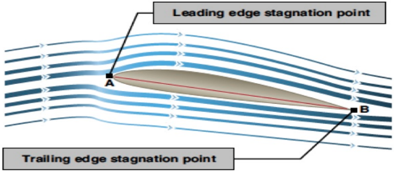
Streamline: Streamline represents an imaginary flow line which is always tangent to the velocity vectors of an elementary fluid particles (for every point and every time instant).



For the presence of the body, the streamlines are forced to deviate from their path → the body presence influences the trend of the streamlines up to a certain distance (beyond this distance the undisturbed free-flw condition exists).

Streamlines have aspects and trends that depends on the shape of the body (with same frontal area).

Air flow around a body



Inside the fluid flow, other elements can be detected.

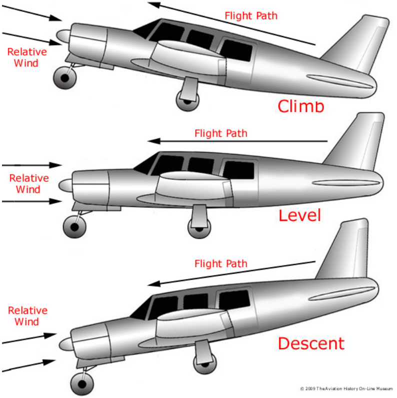
- Upwash: upwards flow
- Downwash: downwards flow
- impact point: point of flow seperation
- Stagnation point: a small area near the impact point where the fluid particles have no speed (compared to the body) and where an area a high pressure is created.

Air flow around a body

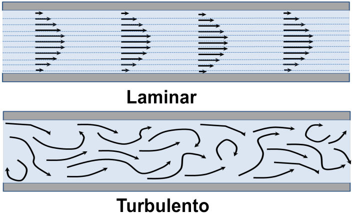
Relative wind: It is the direction of movement of the atmosphere relative to an aircraft or an airfoil.

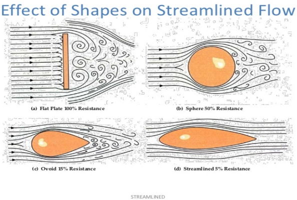
Stationary state: When the density, pressure and velocity of the fluid ata given pint remains constant over time, the particles follow line of current flow or streamline.

Free flow: Free from obstacles, streamlines are straight parallel and equidistant to one another.



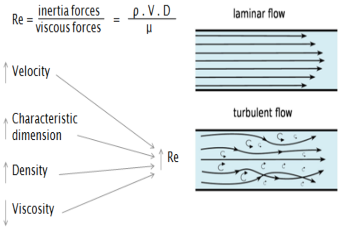
Leminar and Turbulant flow





- Laminar Flow: the flow of a fluid when each particle of the fluid follows a smooth path, paths which never interfere with one another. One result of laminar flow is that the velocity of the fluid is constant at any point in the fluid.
- Turbulent Flow: irregular flow that is characterized by tiny whirlpool regions. The velocity of this fluid is definitely not constant at every point

Reynold Number



https://www.youtube.com/watch?v=AfAM6mfuN3c
https://www.youtube.com/watch?v=GHOoZYhF6r4

The Reynolds number is the ratio of inertial forces to viscous forces and is a convenient parameter for predicting if a flow condition will be laminar or turbulent.

$$Re = \frac{\rho UL}{\mu} = \frac{Inertial}{Viscous} \tag{1}$$

Where, ρ is density (kg/m^3), U is fluid velocity (m/s), L is characteristic length (m) and μ is dynamic viscosity(Ns/m^2). It can also be expressed as:

$$Re = \frac{UL}{\nu} \tag{2}$$

Where $\nu = \mu/\rho$ is kinematic viscosity (m^2/s).

Reynold Number

The Reynolds Number can be used to determine if flow is laminar, transient or turbulent.

Laminar flow (Re $<$ 2300)

Viscous force keep streamlines constant so they flow steadily over eachother in predictable path.

Transient flow (2300 $<$ Re $<$ 4000)

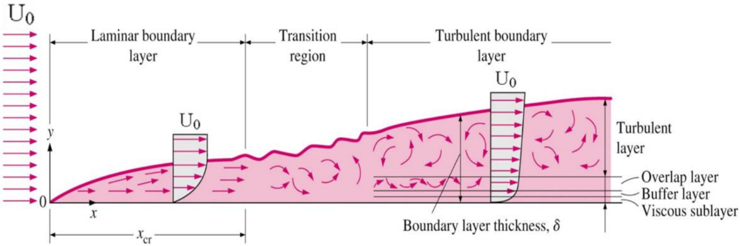
The flow of a fluid is transient or unsteady if its flow parameters (i.e. velocity and pressure) are dependent not only on the position in the coordinate system used to describe the field of flow, but also on time.

Turbulent flow(Re $>$ 4000)

Inertial forces cause circular eddies to form in the flow creating turbulence. It induces mixing of fluid with random fluctuating parameters.

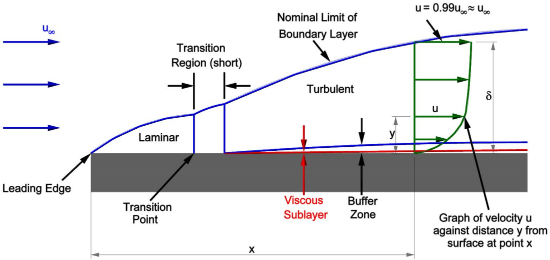
Outline

Boundary Layer



- Airflow (or any fluid flow) will be zero at the surface of the object it's passing over.
- Imagine the airflow as layers (or "streamlines"), and remember the surface layer velocity is zero.
- As you move away from the surface, each layer will be going a little faster than the one beneath it until you finally reach "free stream" velocity.
- All of these low-energy (lower velocity) layers of air between the aircraft surface and the free-stream air make up the boundary layer.

Boundary Layer



- The surface of the body has a surface roughness (at microscopic level).
- When the air passes over a body, molecules nearest the surface remain attached to the surface → craetion of the boundary layer.
- Friction slows the air particles → increase of the boundary layer thickness.
- A decrease of the kinetic energy → increase in pressure
- The increase in pressure disturb the smooth flow of the fluid → turbulent regime.

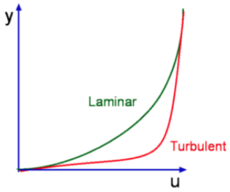
Boundary Layer

Laminar Boundary Layer:

- In a laminar boundary layer any exchange of mass or momentum takes place only between adjacent layers on a microscopic scale
- Consequently molecular viscosity μ is able predict the shear stress associated.
- Laminar boundary layers are found only when the Reynolds numbers are small.

Turbulent Boundary Layer:

- A turbulent boundary layer is marked by mixing across several layers of it.
- The mixing is now on a macroscopic scale. Packets of fluid may be seen moving across.
- Thus there is an exchange of mass, momentum and energy on a much bigger scale compared to a laminar boundary layer.
- A turbulent boundary layer forms only at larger Reynolds numbers.

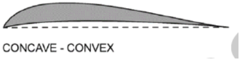


Outline

Wing profile

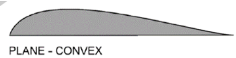
Cutting across a wing it gets its airfoil setion → wing profile
Concave-convex profile:

- They are used for gliders or for low-speed flight.
- The upper camber is convex, while the lower camber is concave.
- It generates lift when the angle of attack is 0°.



Plane-convex profile:

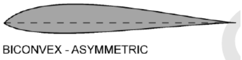
- The upper camber is convex, while the lover camber is flat
- It generates many lift when the angle of attack is 0°.
- It is very diffuse in hobby modeling due to its simplicity.



Wing profile

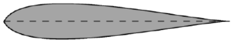
Cutting across a wing it gets its airfoil setion → wing profile
Biconvex-asymmetric profile:

- The upper camber has a higher curvature than the lower one.
- It generates little lift when the angle of attack is 0°.

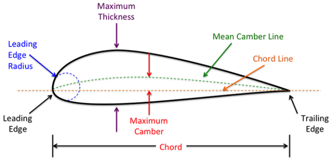


Biconvex-symmetric profile:

- They are used for acrobatic aircraft and for the tail plane of most aircraft(rudder and tailplane of airliners).
- The upper camber and the lower camber are symmetrical in relation to the chord.
- It generates lift when the angle of attace is greater than 0°.

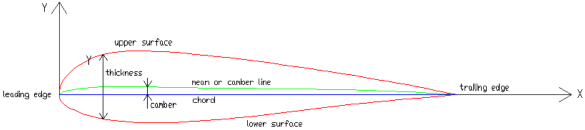


Airfoil terminology



- Leading edge: the thicker frontal edge of the profile.
- Trailing edge: the thin and tapered rear edge.
- Upper camber: the upper surface of the airfoil.
- Lower camber: the lower surface of the airfoil.
- Chord line: a straight line joining the leading edge and the trailing edge.
- Mean camber line (median line): a line drawn halfway between the upper and lower surface of the airfoil.
- Maximum camber: the maximum distance between the mean line and the chord line, measured perpendicular to the last one.
- Maximum thickness: The maximum distance between the upper and the lower surface, taken perpendicularly to the chord line. Generally it is about 1/3 from the leading edge.

Airfoil terminology



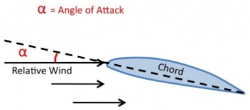
Relative thickness: the ratio of the maximum thickness to the chord length.

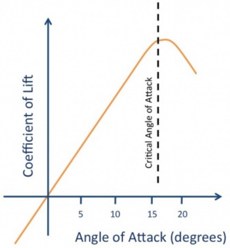
- Thin airfoil: relative thickness less than 0.08
- Half airfoil: relative thickness between (0.08 and 0.14)
- Thick airfoil: relative thickness more than 0.14

https://www.youtube.com/watch?v=wUvB6h1bZos

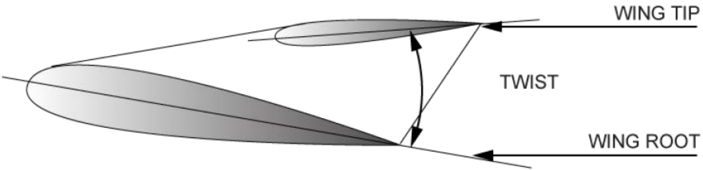
Angle of attack

- The Angle of Attack is the angle at which relative wind meets an Aerofoil.
- It is the angle formed by the Chord of the aerofoil and the direction of the relative wind
- The angle of attack can be simply described as the difference between where a wing is pointing and where it is going.
- An increase in angle of attack results in an increase in both lift and induced drag, up to a point.
- Too high an angle of attack (usually around 17 degrees) and the airflow across the upper surface of the aerofoil becomes detached, resulting in a loss of lift, otherwise known as a Stall.





Wash in and wash out



- Wing twist: an aerodynamic feature added to aircraft
- It adjust the lift distribution along the wing
- In swept-wings the stall tends to happen first at the tips
- Lift redistribution ensures the wing tip to stall at last
- Wash in is less common than wash out

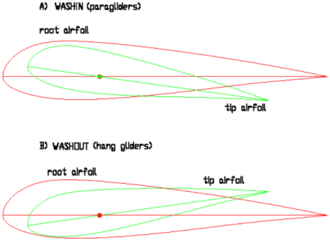
Wash in and wash out

Wash in:

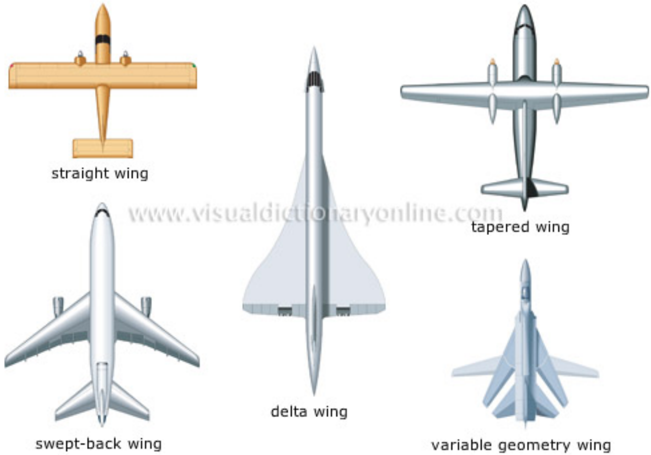
- Angle of incident increase from root to tip
- Tip will stall first

Wash out:

- Angle of incident decrease from root to tip
- Root will stall first



Wing shape


straight wing
www.visualdictionaryonline.com
tapered wing
delta wing
swept-back wing
variable geometry wing

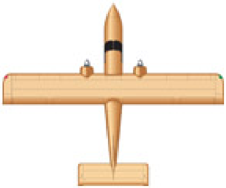
Wing shape

Straight wings

- They are the simplest configuration
- They are the first type of wing able to flight

Tapered wings (trapezoid-shaped wing)

- They are used to reduce the drag by increasing strength.
- Positive swept wings (positive swept angle/ swept back wings)
- They are the most diffuse configuration
- They reduce the drag during the flight
- They help the aircraft stability (directional stability)
- They increase the critical Mach number
- They suffer from tip stall


straight wing

tapered wing

Wing shape

Tapered wings (trapezoid-shaped wing)

- Negative swept wings (negative swept angle/ swept forward wings).
- They are not very diffused
- They have high performances
- They have structural problems
- Thet give stability reduction

Delta wings:

- They are used on all aircraft that flying at supersonic speed
- They reduce the ratio weight/wing surface (W/S)

Variable geometric wings

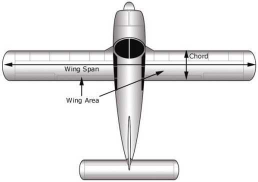
- They have the possibility to change during the flight their shape, the swept angle, the wing span and the aspect ratio.

Aspect ratio

In simple terms, Aspect Ratio is the wing span divided by the wing chord.

- Wing chord is the length of the wing from the wing leading edge to the wing trailing edge
- If the wing chord is equal throughout the length of the wing, the formula is:

$$Aspect \quad ratio(\lambda) = \frac{b}{c} = \frac{length \quad of \quad the \quad wing}{width \quad of \quad wing}$$

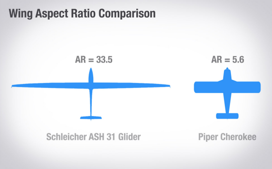


- However, because wings come in various shapes, the aspect ratio is the wing span divided by the mean wing chord.
- If the wing chord is varied throughout the length of the wing, the formula is:

$$Aspect \quad ratio(\lambda) = \frac{b^2}{s} = \frac{wingspan^2}{wingarea}$$

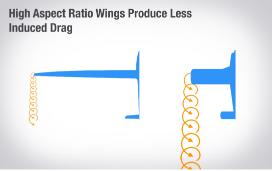
Aspect ratio

- High aspect ratio wings have one major advantage: because the wingtip has less area, there is less vortex induced downwash, which means a lot less induced drag.
- Induced drag is most significant at low speeds and high altitudes (anywhere you have a high AOA)
- since high aspect ratio wings have less of it, they perform very well in takeoff, landing, climb and cruise



So why don't all wings have a high aspect ratio?

- The longer your wing is, the stronger it needs to be.
- Air load is placed across the entire span, which creates more of a bending moment.
- The longer your wing is, the less maneuverable it is.
- Longer wings have a higher moment of inertia.



Aspect ratio

An aspect ratio of 10 means that the wing span is 10 times the mean chord.

Each aircraft category has a specific aspect ratio (AR)

- Fighting and supersonic aircraft: AR of about 2-3
- Airliners: AR of about 7
- Gliders: AR of about 20-30 $\rightarrow$ the total drag must be low $\rightarrow$ high AR

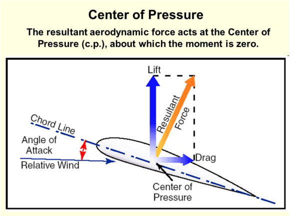
Square window
Dreamliner Window

Outline

Aerodynamic resultant

When a body moves in a fluid (or when a body is stationary relative to a fluid in motion) is subjected to a force R, which can be split into two forces:

- One parallel to the relative wind direction, opposing the motion called Drag (D).
- One perpendicular to the relative wind direction, directed upwards called Lift (L).



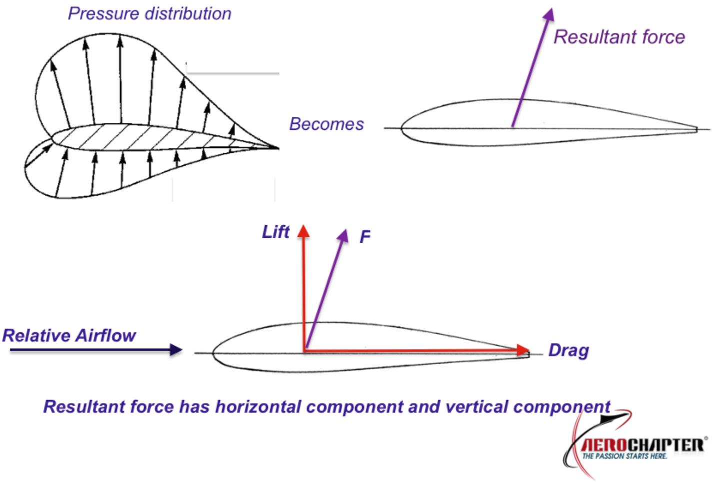
The force R, resultant of infinite infinitesimal forces acting on its surfaces:

$$R = \frac{1}{2}\rho V^2 S C_f$$

- ρ is the density [kg/m^3]
- V is the air body relative velocity [m/s]
- S is the maximum surface of the body exposed to the motion [m^2]
- C_f is the form coefficient

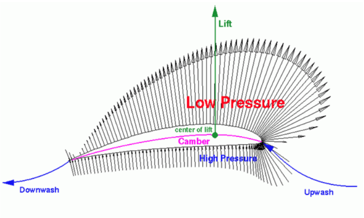
https://www.youtube.com/watch?v=VEe7NxB5Vo8

Aerodynamic resultant



Center of Pressure

The sum of all aerodynamic force on an airfoil may be represented by a single vector acting at a particular point on the chord line, called the center of pressure.



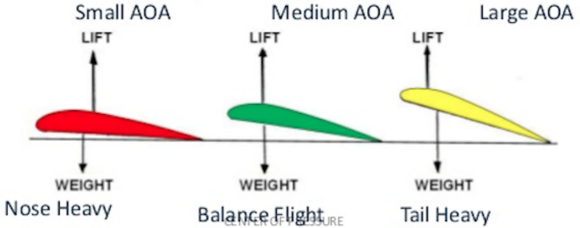
Pressure vectors and flow over a cambered section.

https://www.youtube.com/watch?v=Ti5zUD08w5s

- The location of CP is a function of camber and section lift co-efficient
- Both the resultant force and its position varying with AOA.
- As the angle of attack is increased the magnitude of the force increases and the CP moves forward.
- When the stall is reached the force decreases abruptly and CP generally moves back along the chord.

Center of Pressure

- Position of c.p varies during flight as the angle of attack (AOA) altered
  a. Increase AOA – c.p moves forward
  b. Decrease AOA – c.p moves backward
- In normal flight the AOA usually between **2° and 4°** (seldom below 0° or above 16°)



Center of Pressure

CP movement

- On a flat plate CP lies well behind the leading edge.
- Any increase in AOA tends to move the CP further back.
- This creates a nose-down pitching tendency with increasing AOA.
- Thus, CP movement on a flat plate in subsonic flow is stable.

- On a cambered aerofoil, CP moves forward with increasing AOA.
- It further accentuate the 'nose up' pitching tendency.
- Thus, CP movement on aerofoil (up to stalling AOA) is unstable.

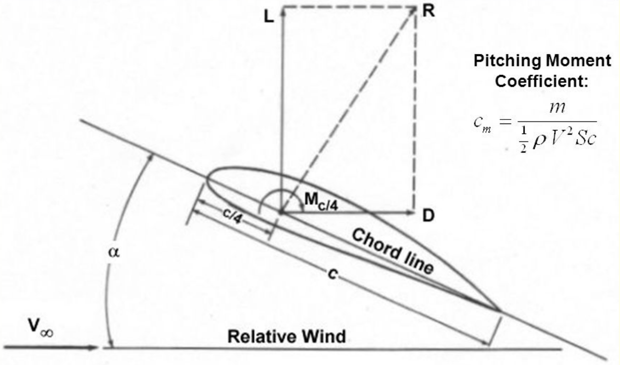
Reduction of CP movement

As movement of CP depends upon camber, any reduction in camber will reduce movement of CP.

- By providing convexity to the under surface of the aerofoil.
- By reflexing the trailing edge of the aerofoil upwards. This, however has the disadvantage of reducing lift and increasing drag.

Aerodynamic Center

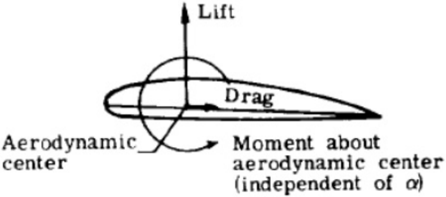
Since the c.p. varies with α, it is more desirable to use a fixed Aerodynamic Center (a.c.) as the point of action of the lift and drag. The pitching moment about this point can be calculated, and is found insensitive to α. For most airfoils, the a.c. locates at around quarter chord (x=c/4).



Pitching Moment Coefficient:

$$c_m = \frac{m}{\frac{1}{2}\rho V^2 S c}$$

Aerodynamic Center

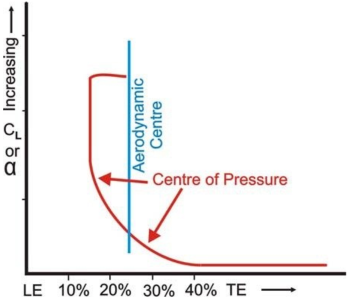


≠ Aerodynamic center: The point on the chord line about which moments does not vary with α.

- The moment about the aerodynamic center (ac) is designated M_{ac} .
- By definition, M_{ac} = constant
- For low-speed and subsonic airfoils, ac is generally very close to the quarter-chord point

Center of pressue and Aerodynamic Center

- Center of pressure of an aircraft is the point where the Lift acts.
- Aerodynamic center is the point in the wing where the pitching moments are constant.

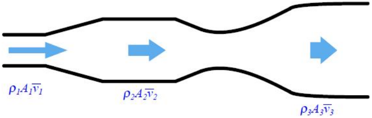


- CoP = where the wings push.
- AC = where the wings rotate.

https://www.youtube.com/watch?v=q6fy2Yq87ww
https://www.youtube.com/watch?v=ZI6ffR0lfXc
https://www.youtube.com/watch?v=

Law of Continuity

Law of Continuity: the product of average velocity (v), pipe cross-sectional area (A), and fluid density (ρ) for a given flow stream must remain constant



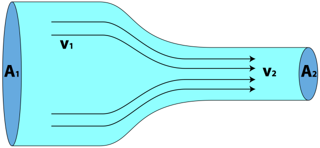
Fluid continuity is an expression of a more fundamental law of physics: the Conservation of Mass.

$$\rho A \vec{v} = \left[\frac{kg}{m^3}\right]\left[\frac{m^2}{1}\right]\left[\frac{m}{s}\right] = \left[\frac{kg}{s}\right]$$

Law of Continuity

Under the hyphothesis of incompressible fluid (constant density), the law of continuity states that, the rate of flow at a point (given by the product between fluid velocity at that point and duct section) must remain constant.

$$A_1 \vec{v}_1 = A_2 \vec{v}_2$$

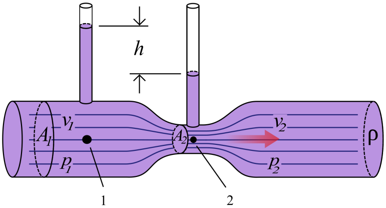


Examining this equation in light of dimensional analysis, we see that the product $A\vec{v}$ is also an expression of flow rate:

$$A\vec{v} = \left[\frac{m^2}{1}\right]\left[\frac{m}{s}\right] = \left[\frac{m^3}{s}\right]$$

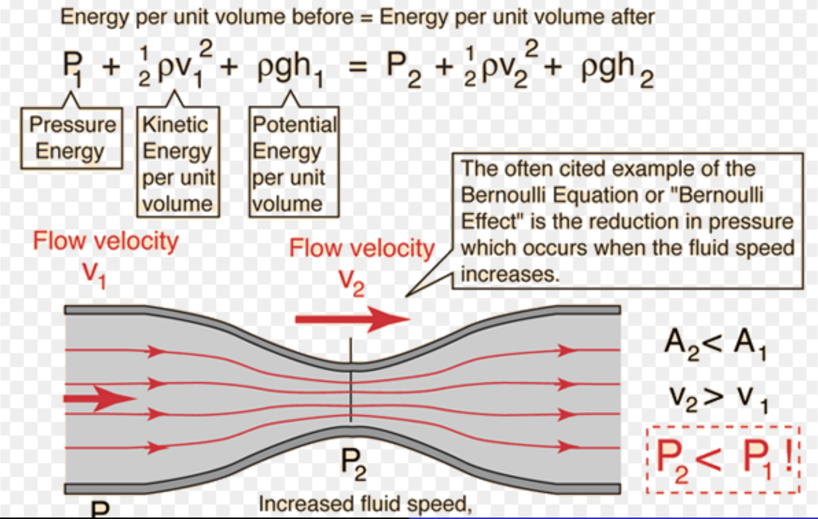
Venturi effect

The Venturi effect is the reduction in fluid pressure that results when a fluid flows through a constricted section (or choke) of a pipe. The Venturi effect is named after Giovanni Battista Venturi (1746–1822), an Italian physicist.



https://www.youtube.com/watch?v=WvFNqEPNPOc
https://www.youtube.com/watch?v=eP-YUDe9HF0

Bernoulli's Principle



Bernoulli's Principle

Conservation of energy: for an isolated system (without relation with the outside) there is the energy conservation.

Bernoulli's Principle

- If the fluid velocity increases between two contiguous sections, the the pressure decreases.
- If somehow the form of energy increases, such as kinetic one (dynamic pressure), it can only do so at the expanse of another form of energy (static pressure).

Considering contiguous sections (h varies insignificantly), then we can obtain the pressure difference (static pressure) is equal to the difference of square of the velocity multiplied by half ρ.

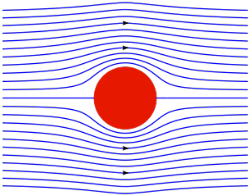
$$\frac{1}{2}\rho V_1^2 + P_1 = \frac{1}{2}\rho V_2^2 + P_2 \quad \Longrightarrow \quad P_1 - P_2 = \frac{1}{2}\rho (V_2^2 - V_1^2)$$

https://www.youtube.com/watch?v=UJ3-Zm1wbIQ

D'Alambert Paradox

For an Ideal fluid: Incompressible and non viscous.

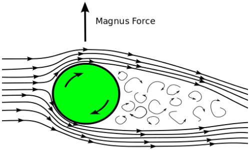
- Theoritically, if a body of any shape moves with linear translation motion in a perfect fluid, the resistance would be null.
- The threads of fluid would perfectly lap the profile of the body without generating any wake and thus the resultant of the aerodynamic force would be null.
- Without aerodynamic force, no aircraft would ever rise from the ground.
- In reality, air is a viscous fluid: so wake vortexes are created behind the body and the drag and the lift are generated.



Magnus Effect

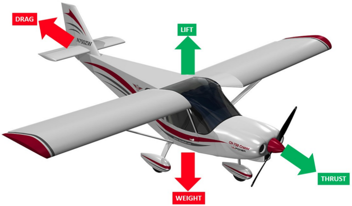
The phenomenon that causes the trajectory variations of a rotating body immeresed in a fluid in motion.

- When a circular force is added to the translational one, a force is generated.
- The force is perpendicular to the initial translational current.
- Fluid around the rotational body is dragged around it.
- The velocity of the fluid increases above or below the body, according to the direction of the rotation.



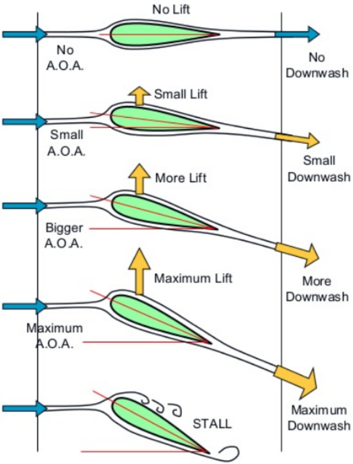
https://www.youtube.com/watch?v=2OSrvzNW9FE

Forces acting on an aircraft



- Weight is the force of gravity. It acts in a downward direction toward the center of the Earth.
- Lift is the force that acts at a right angle to the direction of motion through the air. Lift is created by differences in air pressure.
- Thrust is the force that propels a flying machine in the direction of motion. Engines produce thrust.
- Drag is the force that acts opposite to the direction of motion. Drag is caused by friction and differences in air pressure.

Lift



Lift Coefficient (C_L)

- Equation of Lift (L)= $C_L \frac{1}{2} \rho V^2 S$
- The coefficient of lift is essentially the Angle of Attack.
- As the AOA increases, the amount of generated lift increases. (up to the critical angle)
- When a symmetrical airfoil has zero AOA, there is no lift.
- Experimental results shows that there is a maximum AOA, resulting maximum lift, beyond which the lift drops off dramatically, creating a Stall condition.

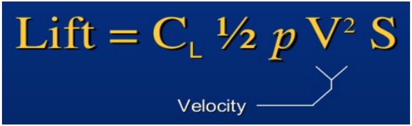
Lift

$$\text{Lift} = C_L \, \tfrac{1}{2} \, \underbrace{p}_{\text{Air Density}} \, V^2 \, S$$

Air density (ρ)

- In the context to the lift equation, Air density represents the mass of the air being encountered by the airfoil.
- Newton's third law: the more air mass we can deflect downward with the airfoil, the more airship mass we can lift into the air.
- As the altitude increases, the air density decreases.
- Plugging this into lift equation, the lift gets less as the plane gets highter.

Lift



Velocity (V)

- "V" represents true airspeed of the aerofoil moving through the air.
- "V^2" is a very significant element of the lift equation because it is "squared". A small change in velocity results in a large change in lift.
- For helicopter "V" is the rotor rpm and can be changed using the throttle.
- "V" is NOT the velocity of the helicopter itself movin through the air.

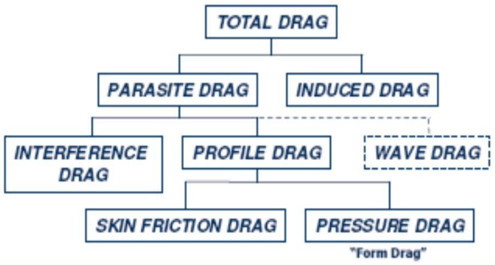
Lift

$$\text{Lift} = C_L \, \tfrac{1}{2} \, p \, V^2 \, \underbrace{S}_{\text{Surface Area}}$$

Surface Area (S)

- "S" represents the surface area of the aerofoil.
- This implies that the larger the surface area the more lift that gets produced.
- For helicopter Surface area of an aerofoil is fixed.

Drag



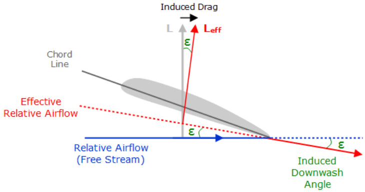
Drag (D)= $C_D \frac{1}{2}\rho V^2 S$

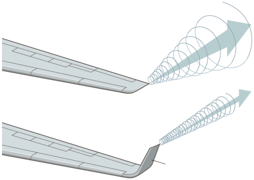
The coefficient of drag (C_D) represents the potential of a body to interfere with the smooth flow of air.

Lift Induced Drag

- Lift induced drag, as the name suggests, is a drag produced with a lift.
- At slower speed & higher angle of attack, aircraft will have more lift.
- But as an angle of attack increases, air flow pushes aircraft in the backward direction.
- This backward push is induced drag.
- Technically, change in a vector direction of lift of the aircraft results in the formation of this type of drag.
- Other type of induced drag is due to a mixture of airflow above and below the wing.

Lift Induced Drag





Lift Induced drag

Induced drag can be put in some limits by:

- Increasing the speed.
- Reducing angle of attack (α)
- Winglets
- Increasing the aspect ratio (λ)
- Flow deviators

Parasite Drag

- Any body not producing lift generates Parasite drag.
- All non lifting forms must be streamline to reduce parasite drag.
- Parasite drag is classified as form drag or pressure drag, skin friction drag and interference drag.

Parasite drag types

- Interference drag:
- Foam drag (Pressure drag):
- Skin drag:

Parasite Drag

Interference Drag

This occurs at the intersection of air currents. For example, the wing root connected to the fuselage.
`https://www.youtube.com/watch?v=nzNx0NRk7-8`

Profile Drag

Profile drag is the sum of Skin friction and Form drag.

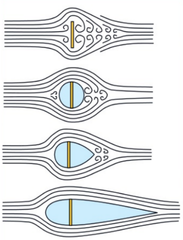
- Foam drag (Pressure drag): It is created by shape of an airfoil.
- Skin drag: Skin friction is the result of surface roughness on the blades(helicoptor) (dirt, ice, etc)

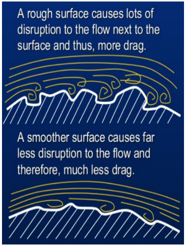
Wave Drag

Wave drag is generally produced at transonic speed (speed almost equals to speed of sound) & Supersonic speed (speed greater than speed of sound).

- Due to high speed of airflow, shock waves are produced.
- Shockwaves are nothing but the disturbance in the air.
- This disturbance increases drag of the aircraft known as wave drag.

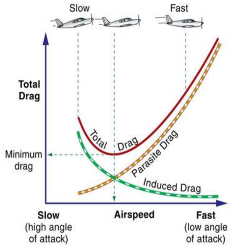
Profile Drag





- Form drag: it depends on the shape of the body and then on the aerodynamic of the body itself.
- Friction drag: It is determined by the viscosity of the boundary layer $\rightarrow$ irregularity of the body surface.
- Methods to reduce the friction drag is by reducing the thickness of the boundary layer:
  - Polishing and shinning surfaces.
  - Using air inlets.
  - Mixing a free air flow to the boundary layer $\rightarrow$ vortex generator
  - Increasing the aspect ratio (λ)
  - BLC (Boundary layer control).

Total Drag



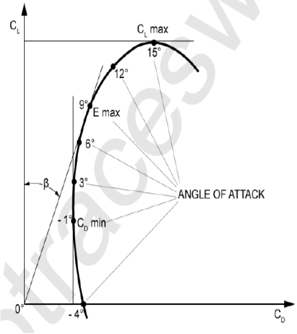
C_d = coefficient of profile drag + coefficient of induced drag

$$C_d = C_{d_0} + \frac{C_l^2}{\pi\lambda}$$

Drag is proportional to a coefficient C_d which is given by the two different components.

- Form drag: it depends on the shape of the body and then on the aerodynamic of the body itself.
- Friction drag: It is determined by the viscosity of the boundary layer $\rightarrow$ irregularity of the body surface.
- Methods to reduce the friction drag is by reducing the thickness of the boundary layer:

Efficiency



$$E = \frac{L}{D} = \frac{\frac{1}{2}\rho V^2 S C_l}{\frac{1}{2}\rho V^2 S C_d} = \frac{C_l}{C_d}$$

- The most efficient angle is the angle of attack at which the best efficiency is obtained.
- For light aircradt: the best efficiency angle of attack is approximately about 4° to 5°
- For heavier aircraft: the best efficiency angle of attack is greater than the light aircraft.

Area rule

Outline

Ice and Snow Contamination

The contamination of the aircraft surface is caused by some phenomena as ice, snow and frost.

The ice, snow and frost mainly cause a reduction of the wing aerodynamics and so they are dangerous for the flight safety.

The ice, snow and frost also make the aircraft controls ineffective.

THANK YOU FOR YOUR ATTENTION !