Roll Control

Ailerons: located near the wing tips, change the lift generation over the wing

Spoilers: destroy lift by disrupting the airflow, for rapid rate of descent

For transport aircraft Spoilers part of the secondary flight control system, for control pressure relief, increase/decrease lift and braking on the ground

Pitch Control

Elevators: hinged section of the tailplane/horizontal stabilizer for creating pitching moment

Stabilators: all movable tail, no fixed horizontal stabilizer. Full length Anti-servo Tab, trim device adjusted from the cockpit to relieve control pressure and maintain the stabilator in the desired position:

1) Stabilator leading edge down, tab moves up

2) Stabilator leading edge up, tab moves down

3) Adjustment jack screw attached to the fixed structure, Stabilator restored to normal streamline position

Stabilator Anti-Servo Tab:

1) Moves in the same direction as the trailing edge of stabilator

2) Decreases the sensitivity, relieves control pressure and hold the control surface in desired position

3) Attached to the fixed structure of the horizontal stabilizer on the opposite side of the surface from the horn on the tab

Adjustable Trim Tab

adjustable trim tab on the elevator can trim the Aeroplan so it will fly hands-off at any airspeed Adjustable jack screw attached to the elevator

Balance Tab

A balance tab help the pilot in moving the control surface.

1) Moves in the opposite direction, the airflow striking the tab counterbalances some of the air pressure

2) Move more easily and hold the control surface in position.

3) Attached to the fixed structure of the horizontal stabilizer.

Variable Incidence Stabilizer2

1) move the entire stabilizer by changing the angle of incidence to reduce drag

2) Elevator remains streamlined with the horizontal stabilizer

3) On jet transports to reduce engine power requirements to overcome elevator drag

4) Governed by the flaperon setting producing corresponding changes to the stabilizer angle of incidence

Canard/Foreplan Configuration2

1) Horizontal Stability/Control Surface in front of the wing

2) Canards for stability and control and for producing lift (if >25% of produced lift)

3) Wing lift must be greater in conventional configuration to compensate tailplane download and induced drag will be smaller (Drag is reduced with canards)

4) Wing can be smaller, since lift is also produced by the canards

5) Canards mounted at larger AoA than wing to Stall first and prevent A/C from stalling

Advantages of Canard/Foreplan Configuration2

1) Better use of fuselage space in smaller aircraft

2) Main wing located at the rear for uninterrupted full depth cabin and better cabin design

3), less noise in the cabin

4) wing clear of propeller slipstream = laminar flow and less drag

Control Canard Configuration

1) Most of lift produced by the wing

2) Canard only for pitch control/stability during maneuvering

3) Set at 0 degrees AoA for no load in normal flight, Mostly in combat aircraft

Yaw control

1• Rudder in the vertical fin, connected to the two pedals controlled by pilot's

2 Right pedal depressed moves trailing edge to the right, creating force moving the tail to the left and nose to the right (left pedal opposite effect)

3 the rudder is used at the beginning of the rotation to overcome adverse yaw and during take-off and cress-landing

4 • Rudder NOT used to turn aircraft

5 • Banking used for turning the aircraft with ailerons or spoilers2

Elevons and Ruddervators Elevons

1 • Control Surfaces used both as elevators and ailerons

2 • Both control surfaces moved up or down, elevators

3 • One control surface up and other down, ailerons

4 • Produced pitching and rolling moments simultaneously3

Elevons and Ruddervators Ruddervators – V-tail

• Control Surfaces used in a V-tail configuration

• Used as both elevators and rudder

• One control surface up and other down, rudder

• Produced pitching and yawing moments simultaneously

• Smaller number of control surfaces, less drag produced and less weight3

Theory of Flight: Relationship between Lift, Weight, Thrust and Drag

Gravity:

Pulling the aircraft to the center of earth

Center of Gravity, the point at which all aircraft weight is concentrated

CG very important for stability in aerodynamic calculations

CG location depends on general aircraft design

CG fixed in a location to provide restoring moment and retain flight equilibrium for all flight conditions

Weight and lift:

Weight act downwards through the CG

Lift acts upwards on the wing, perpendicular to the relative wind

• If lift = weight, Stabilized Flight

If lift > weight, aircraft gains altitude

If lift < weight, aircraft loses altitude

Changing Angle of Attack:

• As AoA increases, boundary layer detach point moves forward This causes dramatic increase in pressure on the upper surface

• Drastic loss of lift, Stalling

• Pressure drag due to separation

Lift

• As Angle of Attack (AOA) increases, Lift increases

• After maximum (Stalling) AOA, Lift decreases rapidly

• wing/airfoil must keep moving to produce lift

• Lift is proportional to the square of aircraft's velocity:

$$Lift = C_L \cdot 1/2 \cdot Air\_density \cdot Aircraft\_velocity^2 \cdot Wing\_Area$$

• If velocity is increased, Lift will increase and Aircraft will climb

• Need to reduce AOA to reduce CL to keep Lift constant and balanced with Weight

• Lowering the nose will result in reducing AOA

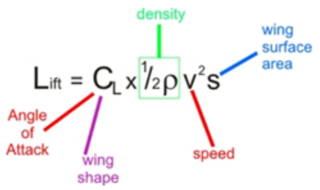
• Conversely, as velocity is decreased, need to increase AOA to keep aircraft balanced

• Lift also varies with Wing Area

• Twice the wing area, twice the lift generated

• For straight and level flight at a constant airspeed, to keep constant altitude, lift is kept equal to weight by adjusting CL

• During landing, to keep airspeed low, lift is kept equal to weight by adjusting CL



• For any given AOA and all other factors constant, there is an airspeed for steady unaccelerated flight

• If aircraft weight is increased, aircraft velocity must be increased if AOA constant to increase lift and maintain steady flight

Lift also depends on air density:

• Density depends on pressure, temperature and humidity

• Density varies in direct proportion with pressure

• At higher altitude, smaller density, need to fly at higher airspeed for any given AOA

• Density varies inversely with temperature

• In warmer air, with less density, need to fly at higher airspeed for any given AOA

• Density varies inversely with humidity

Factors usually changed by the pilot to control the Lift are:

• Angle of Attack, AOA and • Airspeed

Aerodynamic Drag 5

• Aerodynamic force that opposes an aircraft's motion through the air.5

• Drag is generated by every part of the airplane

• Drag acts in a direction that is opposite to the motion of the aircraft

• Drag is consisted of the Parasite Drag and the Induced Drag: $D = D\text{parasaite} + D\text{induced}$

Parasite Drag

$D\text{parasaite}$ = D skin friction + D form + D interference

• Two additional sources of drag are wave drag and ram drag.

Lift Induced Drag 5

• Drag due to lift occurs on finite, lifting wings.

• Distribution of lift is not uniform on a wing but varies from root to tip.

• Vortices are formed at the wing tips, which produce a swirling flow

• Swirling flow decreases toward the wing root.

• Long, thin (chord-wise) wings have low induced drag.

• Short wings with a large chord have high induced drag.

• Wings with an elliptical distribution of lift have the minimum induced drag.

• Modern airliners use winglets.

Thrust and Drag

• Thrust and drag have a direct relationship important for aerodynamics

• Wing Area, measured in square feet, the area of shadow cast by the wing generating lift

• Lift and drag proportional to the Wing Area

• Double the Wing Area, double the Lift and Drag

• Thrust is generated based on Newton's Third Law of motion:

1Turbine engine causes air mass to move backward at high velocity and a reaction is caused moving the aircraft forward

2In a propeller/engine combination, air mass produces lift in a horizontal direction, pulling aircraft forward

• To move the aircraft, Thrust be exerted and gain speed until thrust equals drag

• In a steady speed: thrust = drag, lift = weight for steady horizontal flight

• If RPM reduced, Thrust is reduced, and aircraft slows down

• If RPM increased, Thrust is increased and airspeed increases

Level flight: : thrust = drag, lift = weight

Steady State Flight

• When thrust equals drag, and lift equals weight the aircraft is flying in a state of equilibrium.

• If any of those element's change, either increase or decrease, the aircraft begins to accelerate/decelerate based on the opposing force.

Glide Ratio

• Forward distance travelled by the aircraft with power off t altitude lost is:

• 10,000' forward and descending 1,000' then Glide Ratio=10/1

• Glide Ratio affected by all four forces, Weight, Lift, Thrust, Drag

• Wind greatly affects Glide Ratio, Headwind vs. Tailwind

• L/D ratio determines distance glided by the aircraft and Glide Ratio

• Weight has great effect on the airspeed required to maintain the same Glide ratio

• The heavier the aircraft the higher airspeed to maintain the same Glide Ratio and the faster it will arrive at same touchdown point

• As Drag is increased with flaps and landing gear, airspeed is decreased, unless pitch down, and distance travelled reduced

• Windmilling Propeller creates additional drag, retarding forward movement

• In gliding, pitch is adjusted to maintain constant airspeed

Best Glide Speed, the airspeed at which aircraft travels the greatest forward distance for given altitude loss in still air

Best Glide Speed corresponds at an AOA for least drag and maximum lift-todrag ratio, $L/\mathrm{D}\mathrm{max}$

Any Glide Speed other than BGS results in more Drag and higher Rate of Descent7

• Below BGS, Induced Drag increases

• Above BGS, Parasite Drag increases

• If back-elevator applied (pitch up), airspeed will be reduced below BGS and Rate of Descent and Angle of Descent will increase

Polar Curve

• A graph contrasting the sink rate of an aircraft with its horizontal speed Used to show glide performance

• Know the best speed important for gliding performance

• Key measures of gliding performance:

1 Minimum Sink Rate

2 Best Glide Ratio, occurring at different speeds

• Polar Curve shows that at minimum sink rate aircraft stays airborne as long as possible and climbs as quickly as possible

• At BGS, aircraft travel forward as far as possible

• Sink Rates measured at different airspeed and plotted at a graph to generate the Polar Curve

• Each glider has a unique Polar Curve

• Polar Curve degraded by debris, bugs, and rain on the wing

• Origin of Polar Curve where airspeed is zero and sink rate is zero

• Slope of line from origin gives the Glide Angle, as the ratio of distance travelled along the airspeed axis to the distance along the sink rate/vertical axis

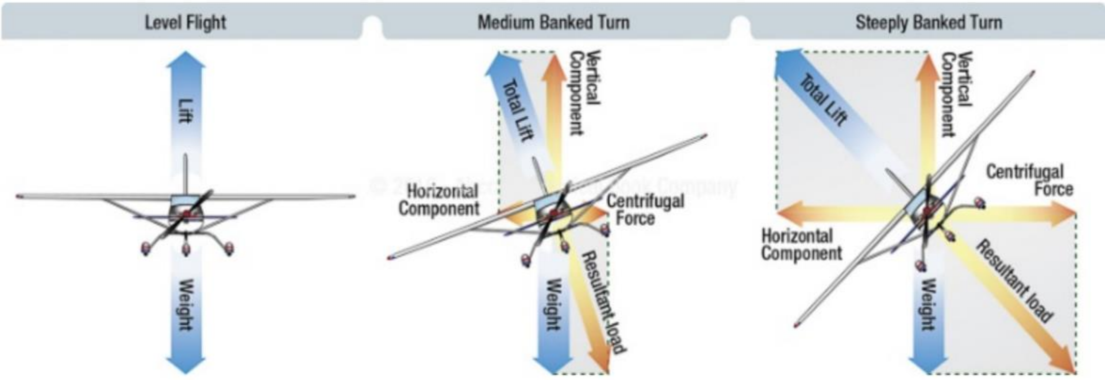
• Slopes of line from origin to any airspeed give the different Glide Angles

• Best Glide Angle, the line with the least slope, tangential to the Polar Curve

• Best Glide Ratio different from glide ratio for minimum sink7

Aerodynamic Forces in Turns

• Forces acting on an aircraft for level flight, medium banked and steeply banked turns



• Aircraft in a bank, lift acts in the direction of the bank or When aircraft banks, lift acts inward toward the center of the turn and upwards

• Newton's First Law of Motion: To turn the aircraft, a sideward force is required

• Banking the aircraft, lift exerted inwards and upwards

• Lift separated into two components

• One component acting vertically opposite to the weight, vertical lift component

• Another component acting horizontally toward the center of the turn, horizontal lift component, Centripetal Force

• Centripetal Force makes the aircraft turn

• Centrifugal Force is the equal and opposite reaction of the aircraft

• Aircraft turns with banking not with the force supplied by the rudder

• Rudder is used to correct deviation between straight track of the nose and tail, Rudder brings nose back in line with relative wind

• Amount of lift opposing gravity is reduced

• Altitude is lost, unless additional lift created

• Increasing AOA, vertical lift component increased to support aircraft's weight8

• Rate of turn (ROT) at any given airspeed depends on the magnitude of Lift's horizontal component, i.e. from the bank angle, formula:

$$ROT = \frac{g\sqrt{n^2-1}}{V_\infty}$$

with Load Factor n =L/W = 1/cos(bank angle), $V\infty$ airspeed and gg gravitational

- Turn radius (TR) is the radius of the turn and is equal to:

$$TR = \frac{V_\infty^2}{g\sqrt{n^2 - 1}}$$

- Ideally, for best maneuvering performance, want smallest TR and largest ROT, i.e. highest possible load factor $\boldsymbol{nn}$ and smallest possible airspeed $\boldsymbol{V}\infty$

- As bank angle increases, n = 1/cos(bank angle) will increase and ROT will increase

- As bank angle increases, AOA required needs to be increased for holding constant altitude (to increase vertical component of lift)

- As AOA increases, induced drag increases and airspeed is decreased

- More Thrust is required during turns, proportional to bank angle

- If airspeed is increased, AOA must be decreased for constant altitude

- If airspeed is increased, bank angle must be decreased for constant altitude

- If airspeed is increased, turn radius and centrifugal force will increase

- So, for constant ROT level turn if airspeed is increased, bank angle must be increased

- Slipping Turn: centrifugal force smaller than horizontal component of lift, pushing the aircraft toward the inside of the turn

- ROT too small for bank angle, increase ROT or decrease bank angle or both

- Skidding Turn: centrifugal force larger than lift's horizontal component, pulling the aircraft toward the outside of the turn

- ROT too big for bank angle, decrease ROT or increase bank angle or both

- To maintain a ROT, the angle of the bank and the flight speed must be changed accordingly

Stalls

An aircraft stall results from a rapid decrease in lift caused by the separation of airflow from the wings surface brought on by exceeding the critical AOA.

• As AOA increases Lift Coefficient is increased until CL–MAX in critical AOA

• Usually wing root stalls first and wing tip follows, to maintain controllability with ailerons, use wing twist (washout) or stall strips in wing root to stall wing root first

• Most training aircraft designed to drop nose during to stall, to reduce AOA and 'unstall' the wing

• Nose down by having Center of Gravity range such that CG forward of Center of Lift

• CG range very important for stall recovery, If CG too aft, not sufficient force from elevator to counteract excess weight aft of CG

• Stalling speed not fixed, but stalling AOA is constant for all values of airspeed, weight, load factor and density altitude

• Critical AOA, where airflow separates from the upper surface, 16 – 20o

• Three flight conditions, in which critical AOA can be exceeded:

1. Low Speed

2. High Speed

3.Turning flight

• Low Speed Stall, flying too slow, AOA is increased to increase Lift Coefficient and maintain Lift until reach Critical Angle

• In a dive and high speed, when pilot pulls back sharply the elevator control: Flightpath and oncoming air determine relative wing direction, AOA suddenly increased reaching stalling (critical) angle at a higher speed

• In a level turn, centrifugal force added to the aircraft's weight

centrifugal force = قوة الطرد المركزي

• More Lift required to balance Weight and Centrifugal

• As bank angle increased:

more back pressure to elevator

generate more Lift until critical angle and aircraft stall

• As the aircraft banks more in a turn, Load Factor and Stall Speed are increased

• Aircraft can stall in a high airspeed during a level turn

• With CG forward of the CL, when aircraft stalls in a turn:1. Lift and downward Tail Force cuts 2. Aircraft pitches down unexpectedly, rotating about the CG 3. AOA decreased and Lift is produced again

Flight Envelope and Structural Limitations

• Flight Envelope is related to capabilities/limitations of an aircraft

• Need to fly 'within the envelope' to avoid structural failure

• Load Factor: is ratio of maximum load on aircraft to aircraft's gross weight

• Load Factor, measured in G's: : 3 G's total load on structure three times the weight

• High Load Factor a serious threat to aircraft's structural

• High Load Factor increases stalling

Load Factors in Aircraft Design

$$Factor\_of\_Safety = 1.5 \cdot Limit\_Load\_Factor$$

• Limit Load Factors, the highest Load Factors expected under various operational conditions that the aircraft can withstand, such as in gusts, maneuvers, landings

Gust loading requirements control the aircraft design, same for most general aviation type aircraft for non-acrobatic usage (for >4,000lbs LLF reduced by 50%)

Typical Category Limit Load Factors

Normal (3.8 to -1.52) Utility (mild acrobatics, including spin) (4.4 to -1.76)
Acrobatic (6.0 to -3.0)

• Placard in flight deck states operational category

For normal operation, LLF

less than LLF for a training and acrobatic maneuvering type aircraft

For aircraft with no placard (constructed earlier) and> 4,000lbs, Normal category requirements

For aircraft with no placard (constructed earlier) and<4,000lbs, Utility category requirements

HIGH SPEED FLIGHT Speed of Sound

Sound is a compression wave travelling through a material

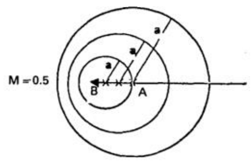
• As an object velocity increases towards the sound speed, the sound waves are compressed

• Area of increased density created

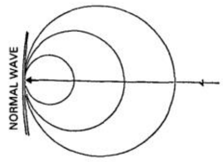
• As the airplane flies, every point on the airplane that causes a disturbance creates sound energy in the form of pressure waves.

• These pressure waves flow away from the airplane at the speed of sound, which at standard day temperature of 59°F, is 761 mph.

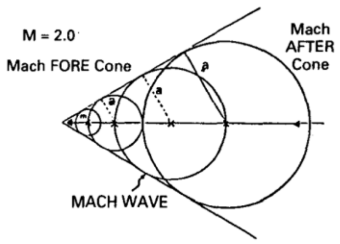
• The speed of sound in air changes with temperature, increasing as temperature increases.



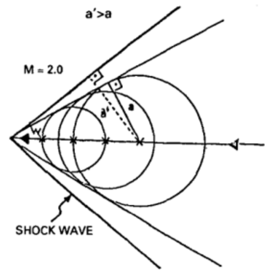
Pressure waves formed by object moving forward at less than local speed of sound



Pressure waves formed by object moving forward at local speed of sound



Pressure waves forming Mach cone with object moving forward at speed greater than the local speed of sound



Mach angle becoming more acute as speed increases

- Due to the change in air density, airflow over the A/C surfaces is changed
- Air becomes compressible in transonic and supersonic speeds

Subsonic vs. Supersonic Flow

- At high AOA, speed of air over the top surface can exceed sound speed
- Shock waves formation, drag increase, buffeting, stability/control issues
- Subsonic flow principles not valid (e.g., Bernoulli principle, continuity equation)

Subsonic, Transonic and Supersonic Flight

- Airplane flying at subsonic speed, all the air flowing around the airplane at a velocity of less than the speed of sound, known as Mach 1.

Speed Ranges Subsonic,Transonic and Supersonic Flight

How fast an airplane can fly and still be considered in subsonic flight Mach number, typically just over Mach 0.8.

Airplane flying at transonic speed, part of the airplane is experiencing subsonic airflow and part is experiencing supersonic airflow.

- Over the top of the wing, probably about halfway back, the velocity of the air will reach Mach 1 and a shock wave will form.

•aircraft faces Stability problems during transonic flight, shock wave can cause the airflow to separate from the wing.

Speed Ranges

• Subsonic – Mach number below 0.75

• Transonic – Mach numbers from 0.75-1.20

• Supersonic – Mach numbers from 1.20-5.00

• Hypersonic – Mach numbers above 5.00

• Speed of sound varies with temperature

• At sea level and 15$ooCC$, speed of sound is 661kts • At 40,000’, temperature is −55$ooCC$ and sound speed 574kts

$$\text{Mach Number} = \frac{\text{Object Speed}}{\text{Speed of Sound}}$$

• Civilian Jet Aircraft normally operate between Mach 0.7 – Mach 0.9

• Military Aircraft operate in transonic and supersonic ranges

• Critical Mach Number, airspeed in which airflow over any part of the aircraft reaches Mach 1.0

• Critical Mach Number is important in transonic flight, depends on wing and airfoil design

• At speed 5-10% above Critical Mach Number, ‘drag rise’ sharply due to compressibility effects, Drag Divergence

• VMO/MMO, the maximum operating limit speed

• VMO in knots calibrated airspeed (KCAS) operating in lower altitudes (structural loads and flutter)

• MMO in Mach number, operating in higher altitudes (compressibility, flutter)

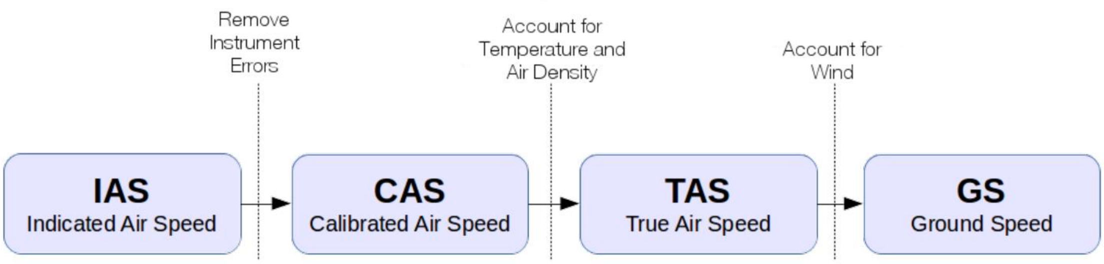
Mach Number vs. Airspeed

• Instrument Indicated Airspeed (KIAS)

• Calibrated Airspeed (KCAS)

• True Airspeed (KTAS)

• Ground Speed



• Airspeed varies with Mach Number

• Stall speed is increased as the altitude increases

• Also, as altitude increases, air temperature decreases, Speed of Sound decreases and Aircraft's Mach number is increased

• At constant Mach number climb:

• Speed of Sound is decreased

• KCAS, KIAS and KTAS need to decrease for constant M

• Until Stall Speed equal to MMO

• Coffin Corner, not possible to slow down and possible to speed up

Shock Waves

• At subsonic flight, air ahead of aircraft is warned of aircraft's coming by pressure change to move aside

• At sonic flight, air ahead of aircraft not warned, because aircraft keeps up with pressure waves

• Air particles pile up in front of the aircraft, sharp flow velocity decrease, air pressure and density increase

• As speed increase beyond sound speed, pressure, density, temperature and velocity of air increase

• Boundary between undisturbed air and compressed air is a Shock or Compression Wave

• Shock Wave also formed when supersonic flow slowed to subsonic over the cambered part of the wing

• Shock Wave, boundary between subsonic and supersonic ranges

• In transonic flight, the shock wave that forms on top of the wing, and eventually on the bottom of the wing, is a normal shock wave

• Normal Shock Wave, perpendicular to the flow

• Supersonic Airstream slows down to subsonic

• Airflow behind shock wave follows the same direction

• Static pressure and density behind shock wave greatly increased

• Energy (indicated by total pressure) greatly reduced

• In supersonic flight, the sharp leading edge and trailing edge of the wing will have shock waves attach to them.

• These shock waves are known as oblique shock waves.

• Behind an oblique shock wave the velocity of the air is lower, but still supersonic, and the static pressure and density are higher.

• At supersonic speeds, air acts like a compressible fluid.

• For this reason, supersonic air wants to expand outward, creating an Expansion Wave.

• When supersonic air is flowing over the top of a wing, and the wing surface turns away from the direction of flow, the air will expand and follow the new direction.

• An expansion wave will occur at the point where the direction of flow changes.

• Behind the expansion wave the velocity increases, and the static pressure and density decrease.

Shock Waves

• Wave Drag due to airflow separation, high pressure instability and heat produced

• Airspeed greater than critical Mach number by 10% sharp increase in Wave Drag

• Thrust required to increase flight speed beyond into supersonic range

• Supersonic area enlarged as flight speed approaches speed of sound

• Drag rise associated with Mach Buffet control force effectiveness decrease

• Airflow separation produces turbulent wake behind the wing and buffeting of tail surfaces

• Increase of downwash decreases horizontal tail's pitch control effectiveness

• Change of Center of Pressure (CP) affects wing

pitching moment:

• CP moves aft, diving moment 'Mach Tuck', 'Tuck Under'

• CP moves forward, nose-up moment

• T-tail configuration for keeping horizontal stabilizer in clean, fresh air (but stall situation is aggravated)

Transonic flight most difficult flight regime for an airplane Part of the wing is experiencing subsonic airflow and part is experiencing supersonic airflow. For subsonic airfoil, aerodynamic center approximately 25 percent of the way back from the wing leading edge. In supersonic flight, aerodynamic center moves back to 50 percent of the wing's chord

AERODYNAMIC HEATING

• In high-speed flight, heat that builds up on the airplane's surface because of air friction.

• Stress on the airplane's structure due to heat obstacle in Hypersonic Flight

Sweepback

• To delay/alleviate shock wave induced flow separation

• Only one component of airflow perpendicular to leading edge affects pressure distribution and shock waves formation

• Wing with sweepback struck by the airflow at an angle smaller than 90oo like flying at a lower speed

• Increase in critical Mach number, force divergence Mach number, Mach number when drag rises up

• Force divergence Mach number, Mach number with drag coefficient rapid increase (1.05-1.1 Critical Mach number)

• Sweepback also reduces change in lift and drag coefficients

• Disadvantage is that swept wings stall first at the wing tips and then at the roots • Because wing tips are behind the Center of Lift (CL), CL is moved forward, and nose rises further

• For T-tail configuration, no/little pre-stall warning and impossible to recover from stall by reducing pitch attitude • T-tail remains effective, pilot driving wing into deeper stall • After T-tail inside the wing's wake, impossible to reduce pitch attitude and break stall • T-tail aircraft pitches up viciously in extreme nose-high attitude

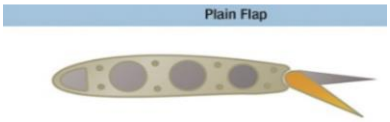
• Stick pusher to prevent from entering stall, stick forces move stick forward • G-limiter also to prevent pitch down from Stick pusher imposing excessive loads • Stick shaker, vibrating control yoke to warn for stall

Lift Augmentation

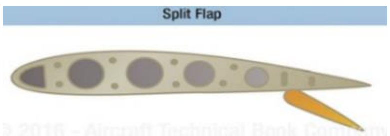
Flaps

• Plain, Split, Slotted, Fowler flaps

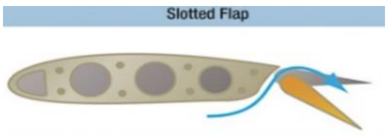
• Plain flaps • Increase airfoil camber and lift coefficient at any AOA • Increase drag • Move CP aft, resulting in nose-down pitching moment Rear portion of wing aerofoil rotates downwards



• Split flaps • Deflected from lower surface of airfoil • More drag produced due to turbulent air behind the airfoil • High drag with little additional lift Rear portion of lower surface of wing hinges downwards from leading edge Upper surface remains fixed



• Slotted Flaps • Most popular for lift coefficient increase • Hinge below lower surface of flap • Duct formed, high energy air from lower surface to upper surface • Boundary layer accelerated, delaying airflow separation at higher lift coefficient $CL{-}MAX$ • Double and Triple-slotted flaps for large aircraft Similar to the plain flap, with a gap between flap and the wing High pressure air from below flows to the upper surface, delay flow separation and flow stay laminar



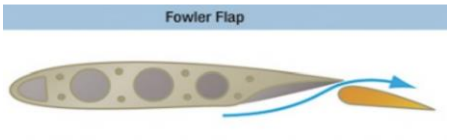
• Fowler Flaps • Slotted flaps, extend to increase wing area and also change wing camber • Flap’s extension increases lift while drag is increased very little • Flap’s deflection increases drag, while lift is increased very little

• Split flap sliding rearwards and hinging downwards

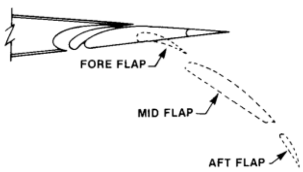
• Chord (i.e. wing area) and camber are both increased

• Partially open for takeoff and fully extended for landing

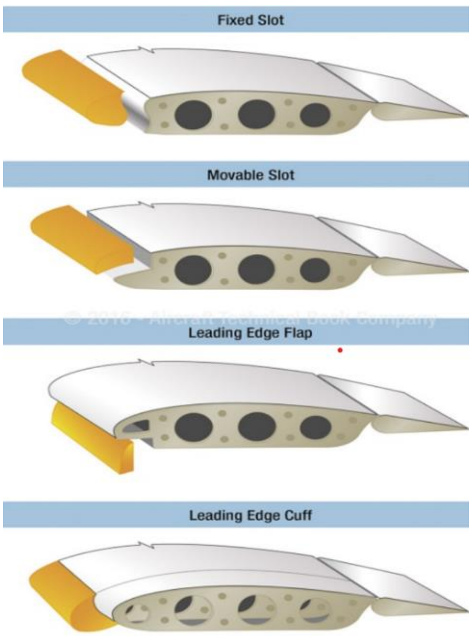
• Found on most large aircraft



• Double/Triple Slotted Fowler Flap • Incorporating the advantages of the fowler flap and the slotted flap



Leading Edge Devices • High-lift devices applied to the leading edge of the airfoil • Fixed Slots • Movable Slats • Leading Edge Flaps • Cuffs



• Fixed Slots • Direct airflow to upper wing surface, delaying airflow separation at high AOA
• Wing camber not increased but higher $CL\text{–}M$, delaying stall

• Movable Slats • Leading edge segments moving on tracks • At low AOA, slat held against leading edge • At high AOA, slat moves forward • Some are pilot-operated and deployed at any AOA