# FLIGHT MECHANICS

**II B. Tech IV semester (Autonomous IARE R-18)**

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| CO's | Course outcomes |
| --- | --- |
| CO1 | Understand the design mission, performance, standard atmosphere, aerodynamic and propulsive forces, different speeds and estimation methods of aircraft.. |
| CO2 | Remember and describe the cruise performance of an airplane in relation with range and endurance with different types of engines also to understand effects of weight, altitude and temperature on performance. |
| CO3 | Determine and apply the concept of climb and descent performance and to calculate power for best climb and descent performance. |
| CO4 | Describe about aircraft maneuver performance in turn, pull-ups by considering limitations of power for military and civil aircrafts. |
| CO5 | Explore the methods to calculate take off and landing runway distances and to understand fuel planning, safety and environment effects of aircraft performance |

# MODULE-I

# INTRODUCTION TO AIRCRAFT PERFORMANCE

| CLOs | Course Learning Outcome |
| --- | --- |
| CLO1 | Remember the atmospheric conditions that a suitable for better performance of an aircraft. |
| CLO2 | Understand the basics of mathematics, science and engineering for problem solving. |
| CLO3 | Describe different atmospheric models that an aircraft encounters in its real-time flight. |
| CLO4 | Demonstrate different methods for the measurement of air data and their respective systems working principle. |


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# The Role and Design Mission of an Aircraft

## Civil Aircraft

- Agriculture
- Sports
- Trainer
- Air Transport
- Cargo
- Early warning and control (AEW&C)
- Chartered Aircraft
- Etc…

## Military Aircraft

- Fighter
- Interceptor
- Bomber
- Spying
- Electronic warfare (EW)
- Maritime patrol
- Expérimental
- Reconnaissance
- Surveillance
- Tanker
- Trainer
- Transport

# Civil Aircraft

- Agriculture
- Sports
- Air Transport
- Cargo
- Trainer
- Early warning and control (AEW&C)
- Chartered Aircraft
- Photo Etc…

# Agriculture Aircraft spreading Manure

**Agriculture Aircraft used for spreading Manure on the fields which takes lesser time and efficient to undertake more area**

# Agriculture aircraft in Grassy Runway

**These aircrafts are used for landing in fields of grassy areas Which can be used for agricultural activities.**

# Kite Type Sports Aircraft

These aircrafts are used for sports and recreational activities. This is the part of general aviation activities.

# FAA Light Sport Aircraft

- Max. Gross Takeoff Weight: 1,320 lbs (600 kg) or 1,430 lbs for seaplanes (650 kg)
- Max. Stall Speed: 45 knots (83 km/h; 52 mph) CAS
- Max. Speed in Level Flight (at sea level In the US Standard Atmosphere): 120 knots (220 km/h; 140 mph) CAS
- Max. Seats: Two
- Max. Engines / Motors: One (if powered)
- Propeller: Fixed-pitch or ground adjustable
- Cabin: Unpressurized
- Fixed-pitch, semi-rigid, teetering, two-blade rotor system, if a gyroplane.
- Landing Gear: Fixed (except for seaplanes and gliders)

# Aircraft data

| Manufacturer | Engine | Max. cruise | Max. range | Type |
|---|---|---|---|---|
| **3Xtrim** | 100 HP Rotax 912 S | 104 kn (193 km/h) | 747 NM | Certified |
| **Advanced Composites Solutions** | | 120 kn (222 km/h) | | Kit |
| **Aeropro / fly-Aerotrek.com** | Rotax 912 A/ 912 S | 115 kn (213 km/h) | 570 NM (1056 km) | Certified |
| **AeropraktManufacturing** | Rotax 912UL,Rotax 912ULS or Rotax 912 iS | 110 kn (210 km/h) | 594 NM (950 km) | Certified |
| **The Airplane Factory** | Rotax 912S or 912 ULS | 110 kn (201 km/h) | 880 NM (1600 km) | Certified, |
| **Aviasud Engineering** | Rotax 582DCDI | 65 kn (120 km/h) | 270 NM, 500 km | Certified |

# Trainer aircraft

## Trainer Aircraft and its different types

A trainer is a class of aircraft designed specifically to facilitate flight training of pilots and aircrews. The use of a dedicated trainer aircraft with additional safety features

- Tandem
- Side By Side

# Contd---

## Trainer Aircraft

- **Basic training**
- **Advanced training**
- **Lead-in fighter training**
- **Multi-engine trainers**
- **Navigation trainers**
- **Combat use of trainers**

# Tandem Trainer Aircraft

## Tandem Trainer Aircraft used to train the pilot

In tandem, usually with the pilot in front and the instructor behind.

# Side by side trainer aircraft

## Side By Side

The *two* seating configurations for trainer aircraft are: pilot and instructor side by side

# Transport Aircraft

- Airliners, aircraft, usually large and most often operated by airlines, intended for carrying multiple passengers or cargo in commercial service

- Cargo aircraft or freighters, fixed-wing aircraft designed or converted for the carriage of goods, rather than passengers, lacking in passenger amenities and generally featuring one or more large doors for loading cargo; also known as freight aircraft, freighters, airlifters, or cargo jets.

# Contd---

## Transport Aircraft

- Mail planes, airplanes used for carrying mail

- Military transport aircraft, airplanes or helicopters used to deliver troops, weapons. and military equipment, usually outside of the commercial flight routes in uncontrolled airspace, and employed historically to deliver airborne forces and tow military gliders; sometimes also called military cargo aircraft.

# Passenger Transport Aircraft

Passenger Transport Aircrafts are shown below with two different airplane


# Cargo Transport Aircraft

Two different types of cargo aircrafts are shown with loading a big helicopter like Chinook and troops from one place to another.


# Military Transport Aircraft

These helicopters can be used for military and civil use to lift heavy loads to carry in hilli terrain.

# DRDO AEW&CS

The DRDO Airborne Early Warning and Control System (AEWACS) is a project of India's Defence Research and Development Organisation to develop an airborne early warning and control system for the Indian Air Force. It is also referred to as DRDO NETRA AEW&CS system.

# Chartered Aircraft

A charter flight is an unscheduled flight that is not part of a regular airline routing. With a charter flight, you rent the entire aircraft and can determine departure/arrival locations and times. There are several types of charter flights.

# Types of Military Aircraft

- Fighter
- Interceptor
- Bomber
- Spying
- Electronic warfare (EW)
- Maritime patrol
- Expérimental
- Reconnaissance
- Surveillance
- Tanker
- Trainer
- Transport

# Interceptor

An interceptor aircraft, or simply interceptor, is a type of fighter aircraft designed specifically to attack enemy aircraft, particularly bombers and reconnaissance aircraft, as they approach.

Su-15, one of the principal Soviet Air Defence interceptors

# Fighter

A **fighter aircraft** is a military aircraft designed primarily for air-to-air combat against other aircraft, as opposed to bombers and attack aircraft, whose main mission is to attack ground targets. The hallmarks of a fighter are its speed, maneuverability, and small size relative to other combat aircraft.

# Bomber

**Bomber**, military aircraft designed to drop bombs on surface targets.

# Spying Aircraft

A reconnaissance aircraft is a military surveillance aircraft designed or adapted to perform aerial reconnaissance with roles including collection of imagery intelligence (including using photography), signals intelligence, as well as measurement and signature intelligence. Modern technology has also enabled some aircraft and UAVs to carry out real-time surveillance in addition to general intelligence gathering.

ScanEagle reconnaissance UAV on its catapult launcher

# Electronic warfare (EW)

An electronic-warfare aircraft is a military aircraft equipped for electronic warfare, that is, degrading the effectiveness of enemy radar and radio systems by using radar jamming and deception methods. In 1943, British Avro Lancaster aircraft were equipped with chaff in order to blind enemy air defence radars.

# Experimental Aircraft

An **experimental aircraft** is an aircraft that has not yet been fully proven in flight. Often, this implies that new aerospace technologies are being tested on the aircraft, though the label is more broad.

# Tanker Aircraft

Aerial refuelling, also referred to as air refuelling, in-flight refuelling, air-to-air refuelling, and tanking, is the process of transferring aviation fuel from one military aircraft to another during flight.

## Performance Requirements and Mission Profile

- Takeoff and Landing Distances
- Rate of Climb
- Ceiling
- Speed
- Payload
- Fuel Economy
- Maneuvering

# Aircraft Design Performance

1. Range
2. Takeoff distance
3. Stalling velocity.
4. Endurance **[imp for reconnaissance airplanes; an overall dominating factor for the new group of very high-altitude uninhabited air vehicles (UAVs) ]**
5. Maximum velocity
6. Rate of climb
7. For dogfighting combat aircraft, maximum turn rate and sometimes minimum turn radius
8. Maximum load factor
9. Service ceiling
10. Cost
11. Reliability and maintainability
12. Maximum size **(so that the airplane will fit inside standard hangers and/or be able to fit in a standard gate at airline terminals)**

# ISA

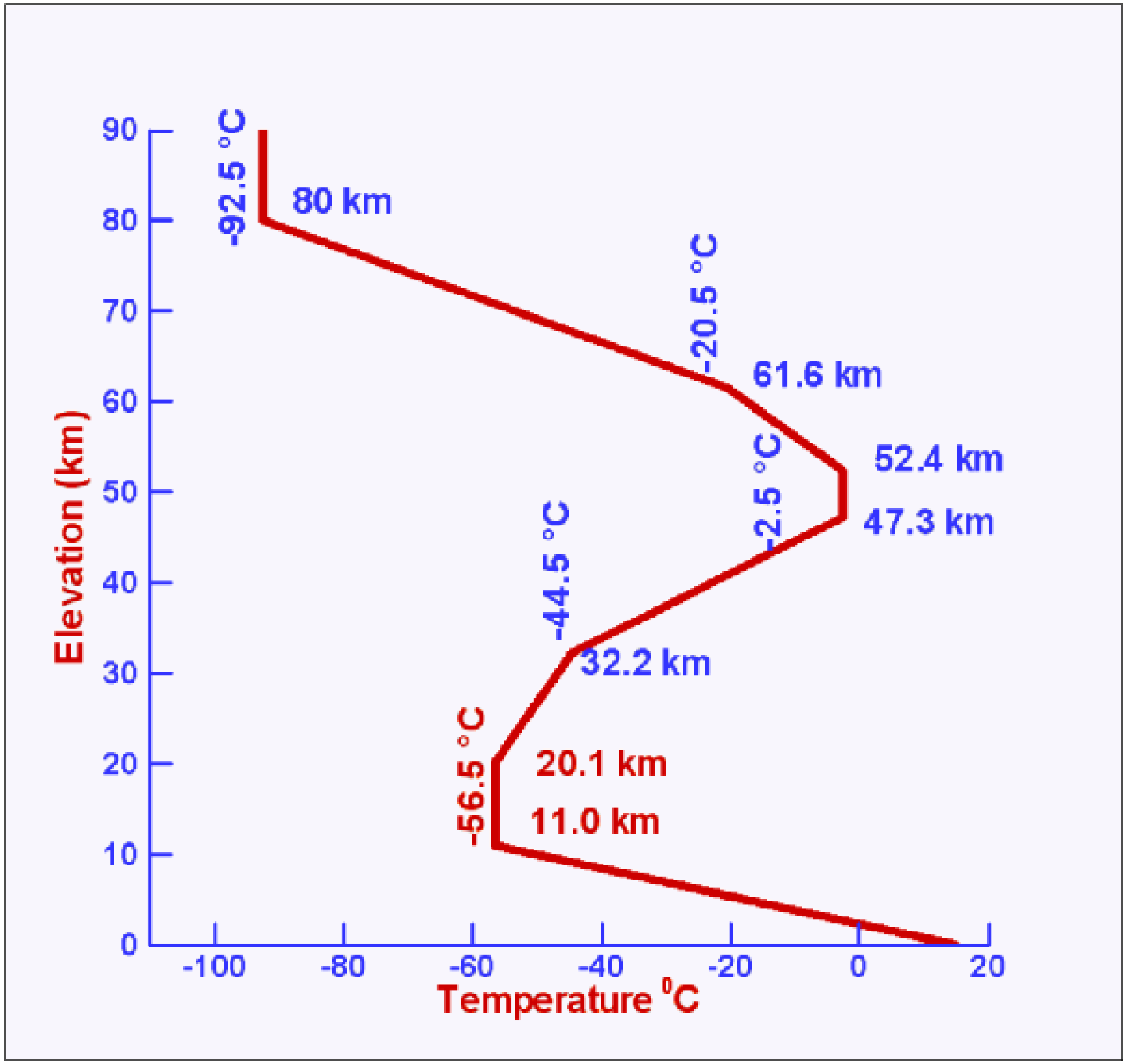
**The International Standard Atmosphere**

**The International Standard Atmosphere** (ISA) is a static **atmospheric** model of how the pressure, temperature, density, and viscosity of the Earth's **atmosphere** change over a wide range of altitudes or elevations.

# The International Standard Atmosphere 1976

| Layer | Level Name | Base Geopotential Altitude above MSL[5] h (m) | Base Geometric Altitude above MSL[5] z (m) | Lapse Rate ( °C/km)[a] | Base Temperature T (°C) | Base Atmospheric Pressure p (Pa) | Base Atmospheric Density ρ (kg/m3) |
|---|---|---|---|---|---|---|---|
| 0 | Troposphere | -610 | -611 | +6.5 | +19.0 | 108,900 (1.075 bar) | 1.2985 |
| 1 | Tropopause | 11,000 | 11,019 | 0.0 | −56.5 | 22,632 | 0.3639 |
| 2 | Stratosphere | 20,000 | 20,063 | -1.0 | −56.5 | 5474.9 | 0.0880 |
| 3 | Stratosphere | 32,000 | 32,162 | -2.8 | −44.5 | 868.02 | 0.0132 |
| 4 | Stratopause | 47,000 | 47,350 | 0.0 | −2.5 | 110.91 | 0.0020 |
| 5 | Mesosphere | 51,000 | 51,413 | +2.8 | −2.5 | 66.939 | |
| 6 | Mesosphere | 71,000 | 71,802 | +2.0 | −58.5 | 3.9564 | |
| 7 | Mesopause | 84,852 | 86,000 | — | −86.28 | 0.3734 | |

# ISA contd--




International Standard Atmosphere (Temperature Profile)

# Off-standard and Design Atmosphere

## Atmospheric Model

- Jackhia -71
- Jackhia -77
- Exponential Model

## Purpose

- Re-entry of space craft
- Ballistic Missile
- Space Launch Vehicle
- Low Earth Orbiting Objects

## Modelling Consideration

- Seasonal effect
- Latitude & Longitudinal Effect
- Earth Oblateness effect

# Altitudes

Relation Between Geo Potential Height And Geometric Height

$$g = g_o \left( \frac{r}{h_a} \right)^2 = g_o \left( \frac{r}{r + h_g} \right)^2$$

$$dP = -\rho g dh_g$$

# Relation between hg and h

## Relation Between Geo Potential Height And Geometric Height

$$\frac{\rho T}{\rho_1 T_1} = \left(\frac{T}{T_1}\right)^{-\frac{g_o}{\alpha R}}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-\frac{g_o}{\alpha R}-1}$$

$$\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-\left(\frac{g_o}{\alpha R}+1\right)}$$

| Variables | Gradient layer | Isothermal layer |
|---|---|---|
| Pressure | $\frac{P}{P_1} = \left(\frac{T}{T_1}\right)^{-\frac{g_o}{\alpha R}}$ | $\frac{P}{P_1} = e^{-[g_o/(RT)](h-h_1)}$ |
| Density | $\frac{\rho}{\rho_1} = \left(\frac{T}{T_1}\right)^{-\left(\frac{g_o}{\alpha R}+1\right)}$ | $\frac{\rho}{\rho_1} = e^{-[g_o/(RT)](h-h_1)}$ |

# Measurement of Air Data

Measuring Parameters

- Temperature
- Pressure
- Density
- Moisture etc..

Measuring Techniques

- Barometer
- Thermometer
- Thermal Infra-red

Relations

- Atmospheric Pressure
- Temperature, Pressure & Density Relations

# Air Data Computers

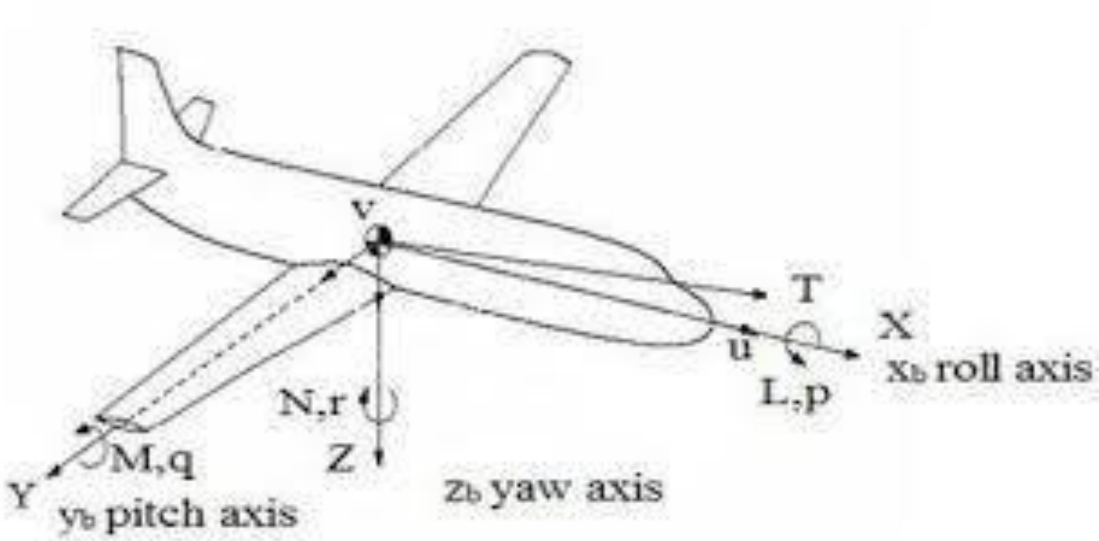
An **air data computer** (ADC) is an essential avionics component found in modern glass cockpits. This **computer**, rather than individual instruments, can determine the calibrated airspeed, Mach number, altitude, and altitude trend **data** from an aircraft's pitot-static system.

# EOMs

## Equations of Motion for Performance

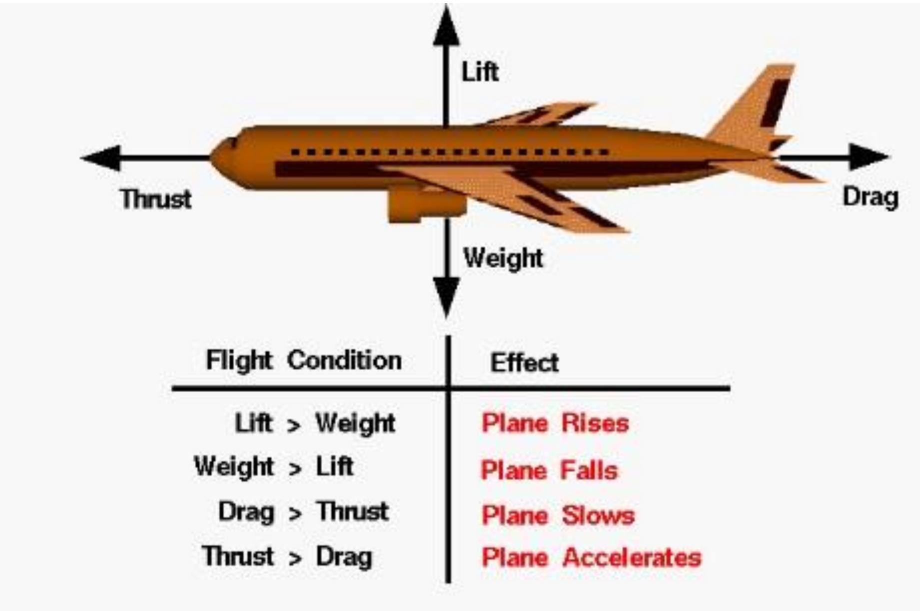
Governing Parameters

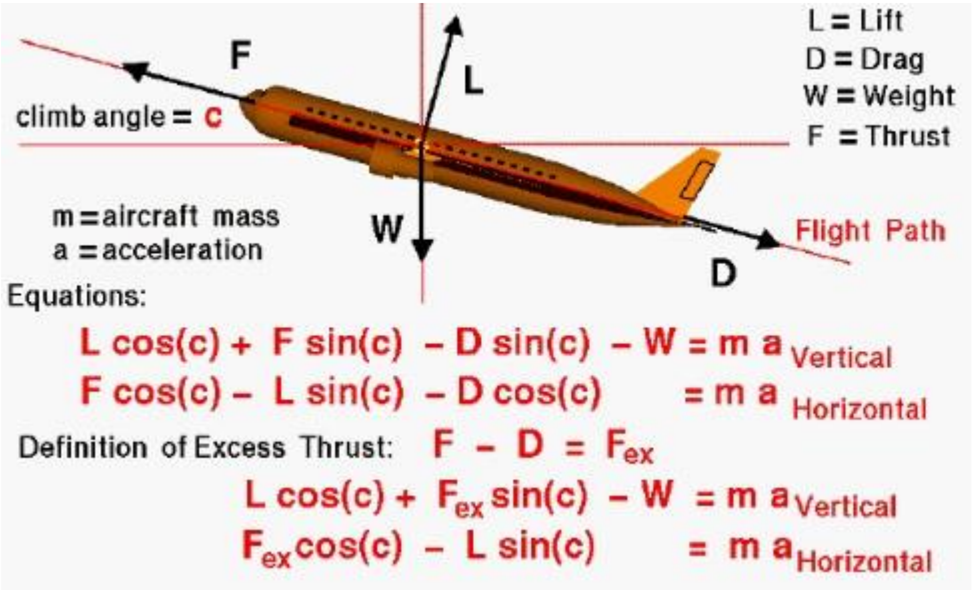
- Lift
- Drag
- Weight
- Thrust
- Velocity
- Flight path
  - Velocity & horizontal
- Pitch angle
  - Nose & horizontal



# Force system of an aircraft

## The Aircraft Force System



# Drag and estimation

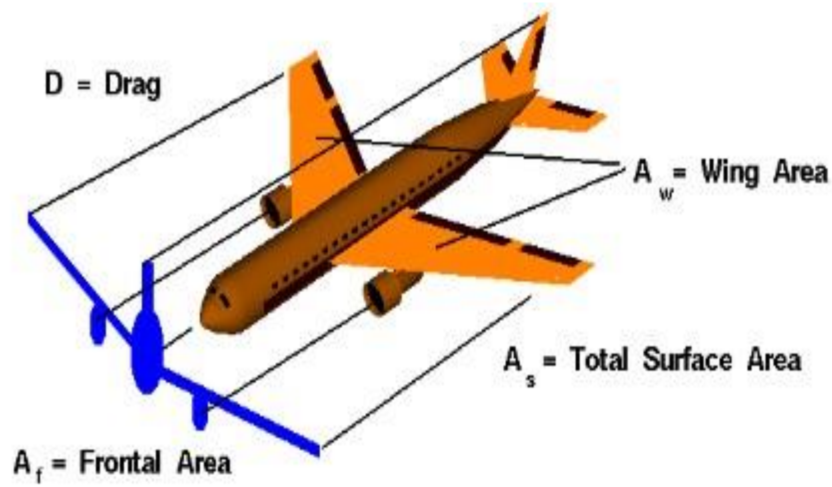
## Total Airplane Drag Estimation

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

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

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

Choice of reference area A affects the value of Cd .




$A_s \sim A_f \sim A_w$

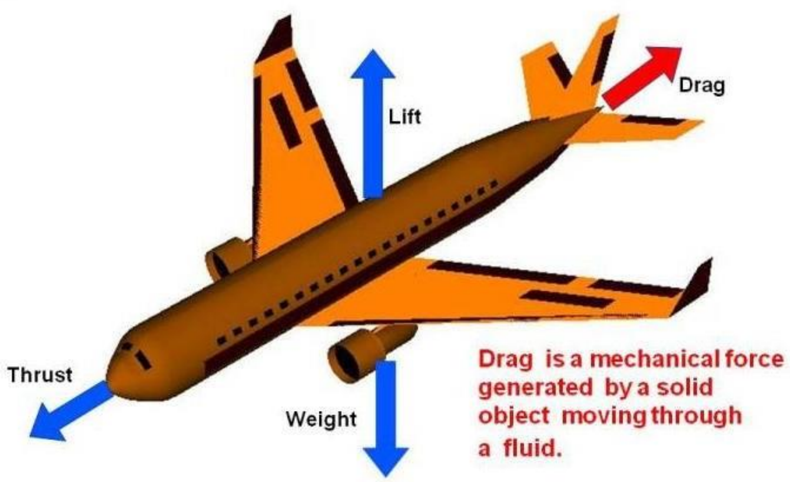
Drag is directly related to reference area

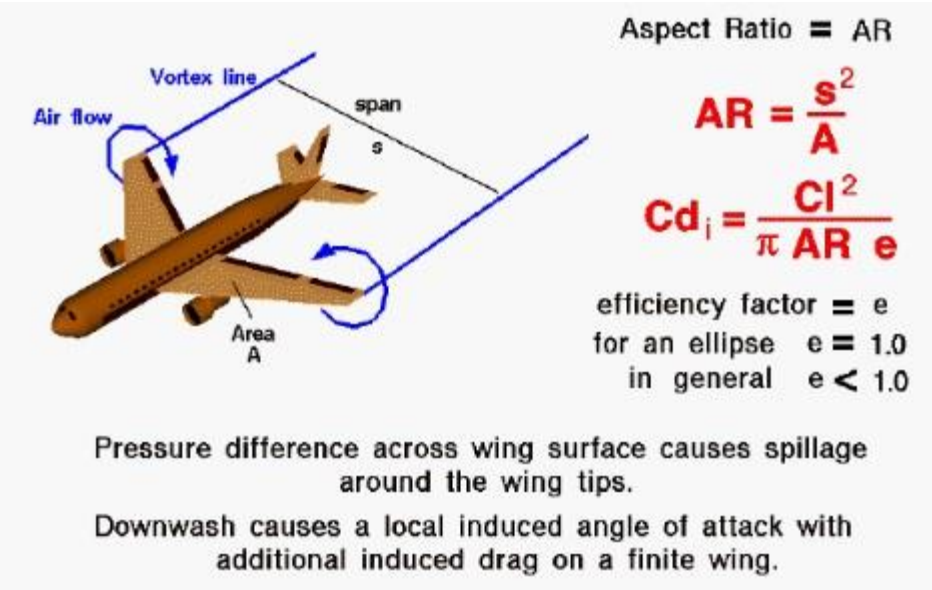
$D = \text{Constant} \times A_{ref}$

Double the Area --> Double the Drag

# Drag calculation

## Total Airplane Drag Estimation



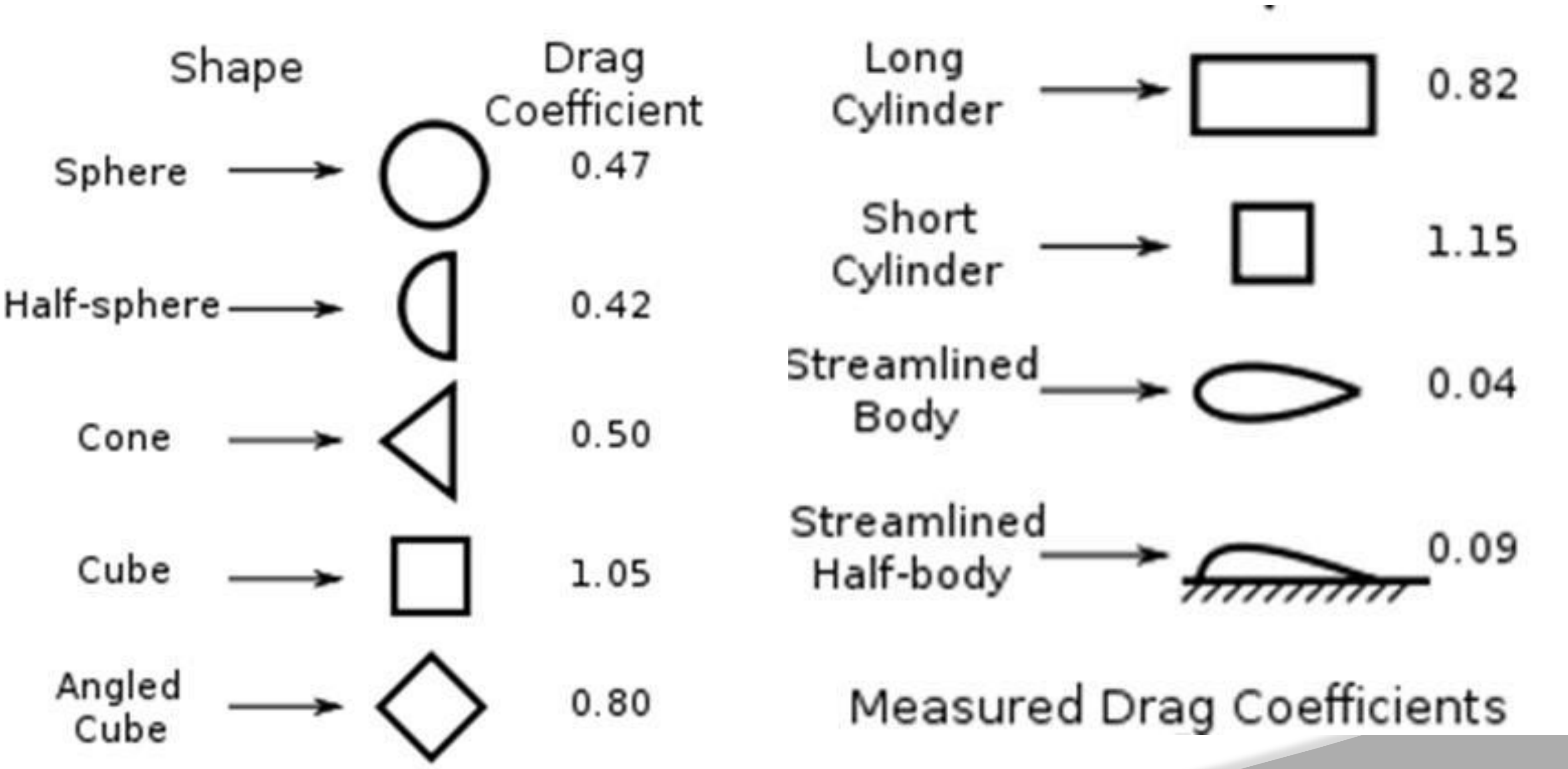
# Total Airplane Drag Estimation

## Factors Affecting Drag

**Shape and size**
**Velocity and inclination to flow**
**Mass, Viscosity, Compressibility**

## Total Airplane Drag Estimation

**Shape Affecting Drag**



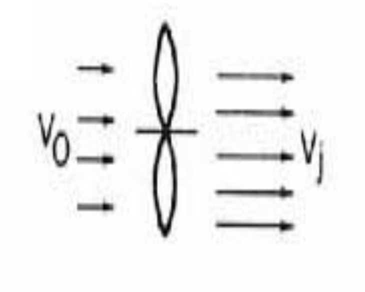
# Drag Reduction Methods

SKIN FRICTION DRAG

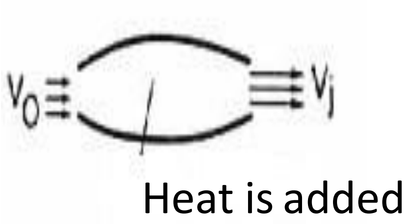
1. Turbulent drag reduction
   A. Riblets
   B. Large eddy break-up devices
   C. Surface coatings
2. Laminar flow control
   A. Boundary layer suction
   B. Hybrid laminar flow concept
   C. Boundary layer flow control
   D. Wing tip devices
   E. Vortex generators

# The Propulsive Forces

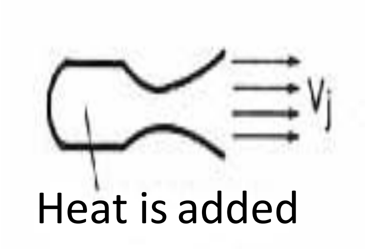
**Propeller**




**Turbojet and Ram Jet**




**Rocket**




force = mass x acceleration

force = rate of change of momentum or

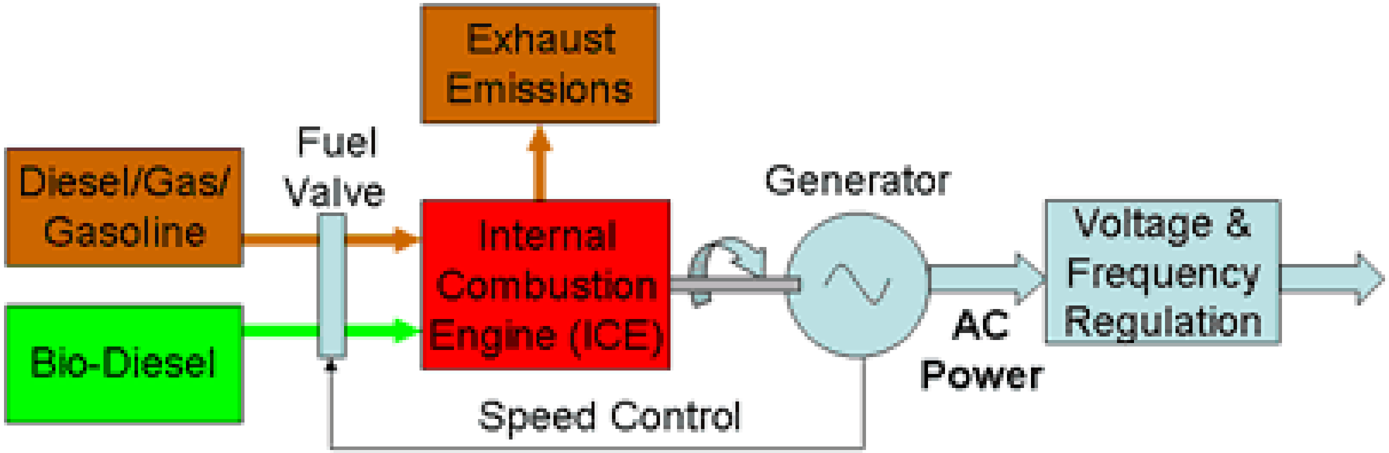
force = mass flow rate . change in fluid velocity

## The Thrust Production Engines

A piston **engine** cannot **produce thrust** on its own. The exhaust gases **produced** by a propeller, jet or rocket, due to Newton's Third Law, are feeling a force opposite and equal to **the thrust**, and therefore are moved in the direction opposite to **the thrust** of the **engine**. Hence, the exhaust is the effect of **thrust**

# Power Producing Engines

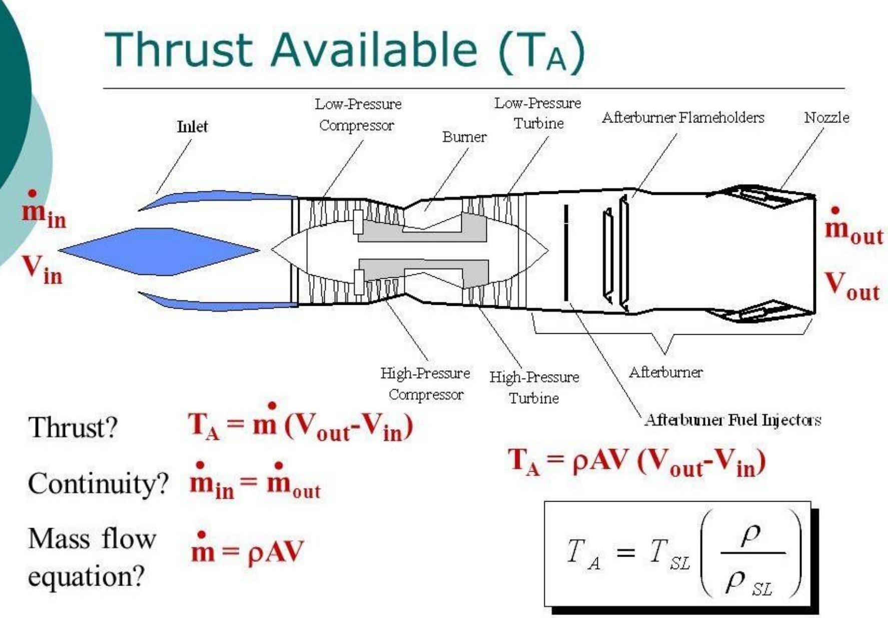
An **engine power plant** is a power station in which power comes from the combination of a reciprocating engine and an alternator.

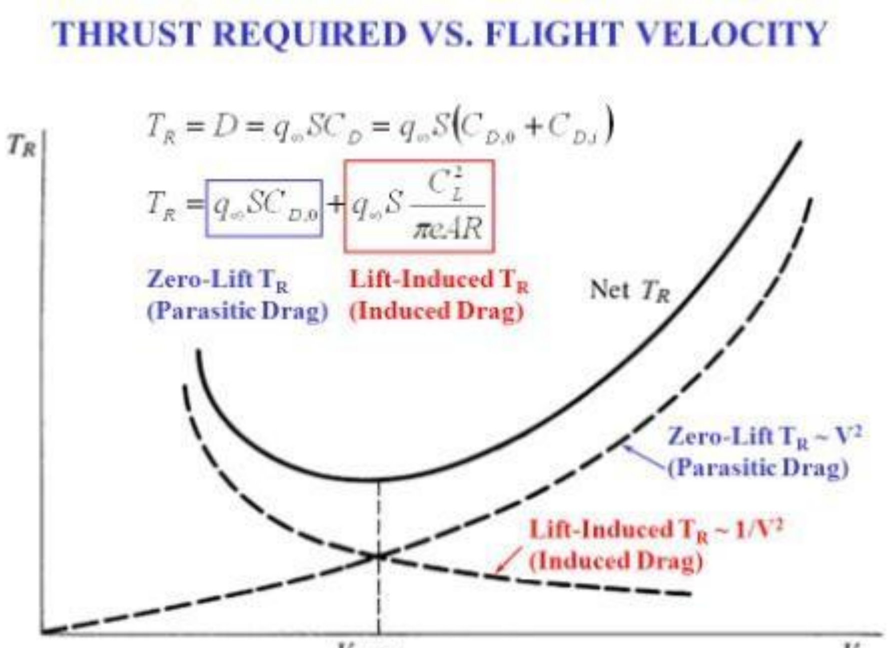



Electric Power Generation by Internal Combustion Engine (ICE)

# Variation of Thrust

**Thrust** is produced by accelerating air. Therefore **thrust** decreases with increasing airspeed. In level flight, an aircraft could not be accelerated above the engine exhaust gas speeds because then the incoming air would be faster than the exhaust air - resulting in a deceleration.



Propulsive power and specific fuel consumption with altitude and flight speed

***Thrust Specific Fuel Consumption***
*(TSFC)*

$\dot{m}_f$ = fuel mass flow rate

$\dot{m}_a$ = air mass flow rate

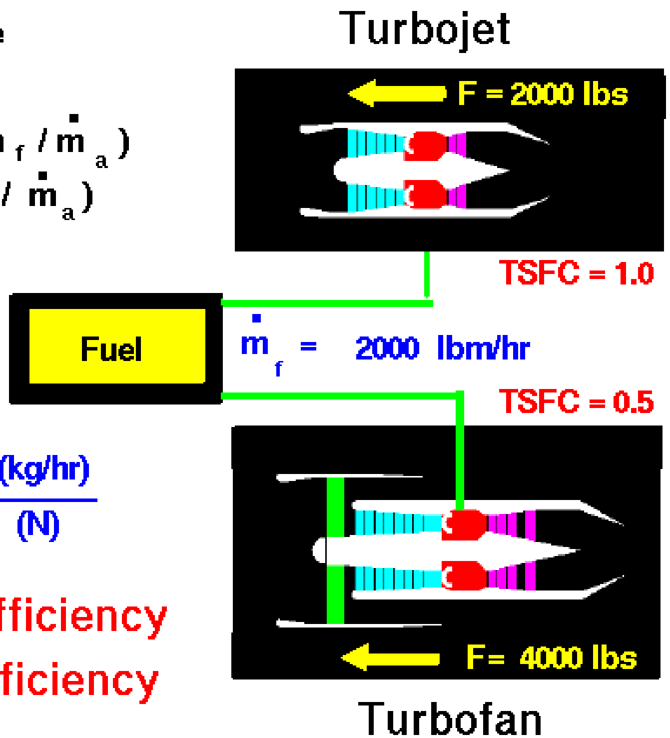
$f$ = fuel to air ratio $(\dot{m}_f / \dot{m}_a)$

$Fs$ = specific thrust $(F / \dot{m}_a)$

$F$ = net thrust

$$TSFC = \frac{f}{Fs}$$

$$TSFC = \frac{\dot{m}_f}{F} \quad \frac{(lbm/hr)}{(lbs)} \text{ or } \frac{(kg/hr)}{(N)}$$




Low TSFC = High efficiency

High TSFC = Low efficiency

# TSFC

To move an airplane through the air, a propulsion system is used to generate thrust. The amount of thrust an engine generates is important. But the amount of fuel used to generate that thrust is sometimes more important, because the airplane has to lift and carry the fuel throughout the flight. Engineers use an efficiency factor, called **thrust specific fuel consumption**, to characterize an engine's fuel efficiency. "Thrust specific fuel consumption" is quite a mouthful, so engineers usually just call it the engine's **TSFC**. .

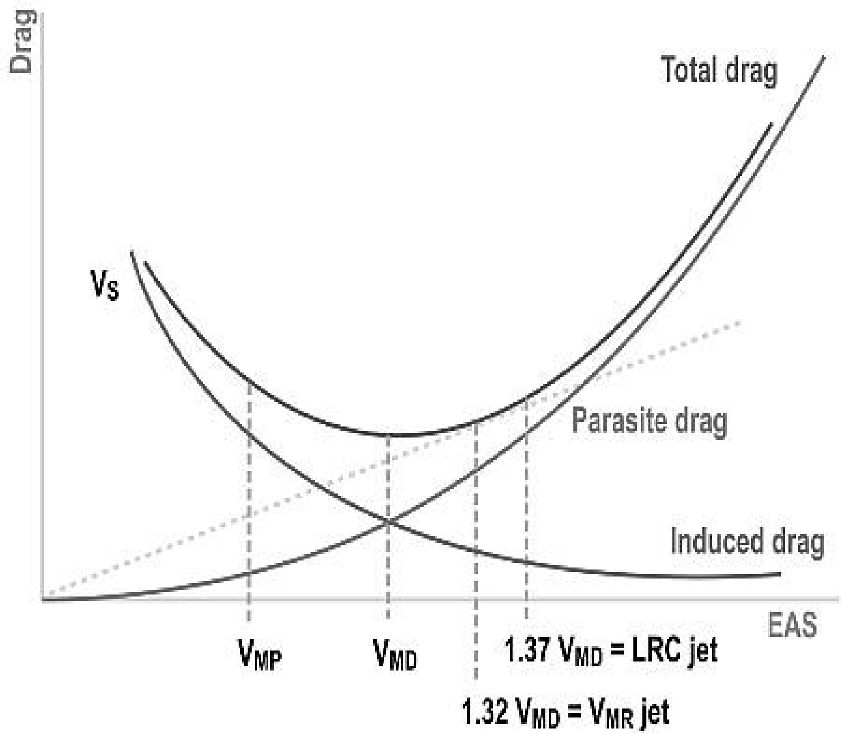
# SFC and BSFC

The fuel consumption of TSFC is "how much fuel the engine burns each hour." The specific of TSFC is a scientific term meaning "divided by mass or weight." In this case, **specific** means "per pound (Newton) of thrust." The **thrust** of TSFC is included to indicate that we are talking about gas turbine engines. There is a corresponding **brake specific fuel consumption** (**BSFC**) for engines that produce shaft power. Gathering all the terms together, TSFC is the **mass of fuel burned by an engine in one hour divided by the thrust** that the engine produces. The MODULEs of this efficiency factor are mass per time divided by force (in English MODULEs, pounds mass per hour per pound; in metric MODULEs, kilograms per hour per Newton).

Mathematically, **TSFC** is a ratio of the engine fuel mass flow rate **mdot f** to the amount of thrust **F** produced by burning the fuel.

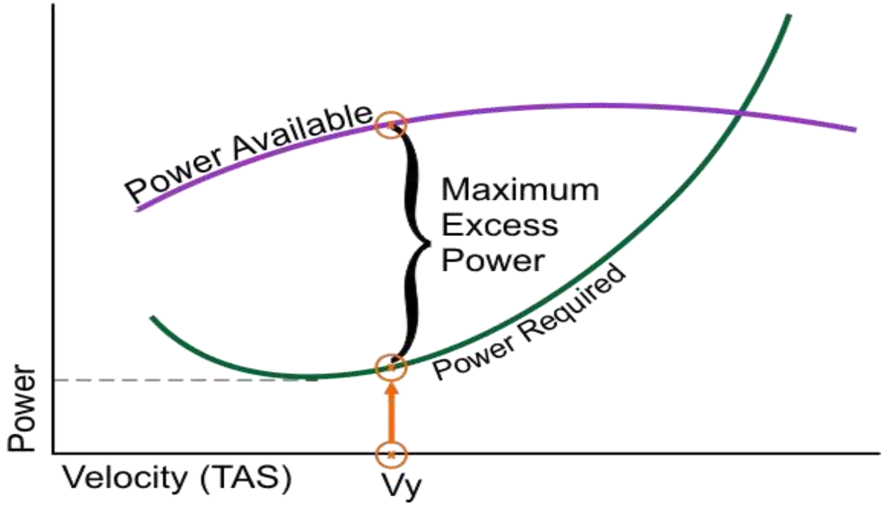
# Minimum drag speed

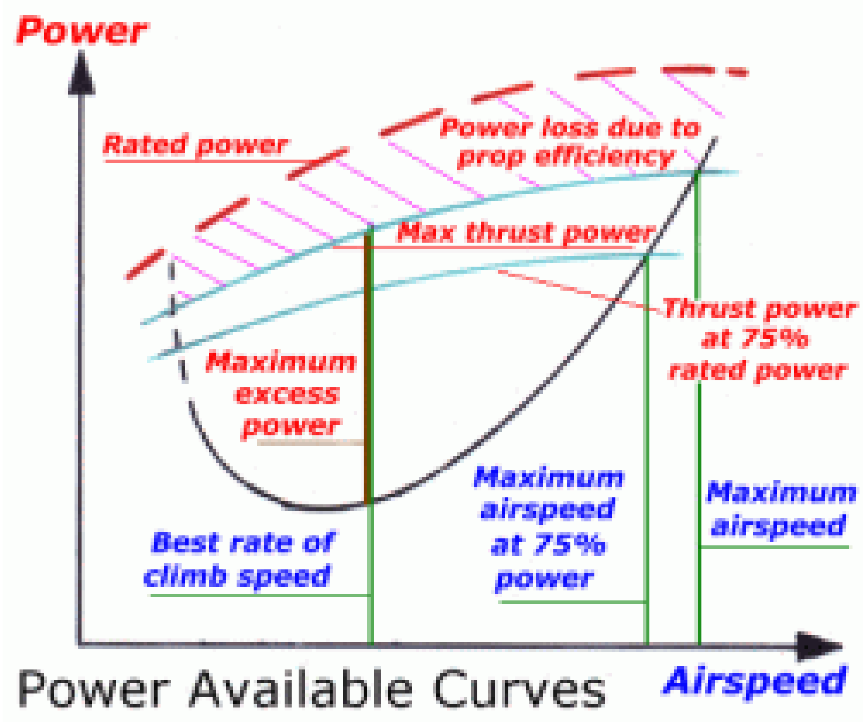
There is a **speed** for **minimum** power required to maintain level flight (VMP) and this is where the product of **speed** and **drag** are at a **minimum** (where the two values make a square with the axes of the graph).VMP is the **speed** for **minimum** fuel consumption (max endurance) in a propeller driven aircraft.



# Minimum Power Speed

The **minimum power** required (maximum endurance) occurs when is a maximum. Thus the **minimum power**(maximum endurance) condition occurs at a **speed** which is $3^{-1/4}$ = 76% of the **minimum** drag (maximum range) condition.



# Parabolic drag polar

Aerodynamic relationships for a parabolic drag polar

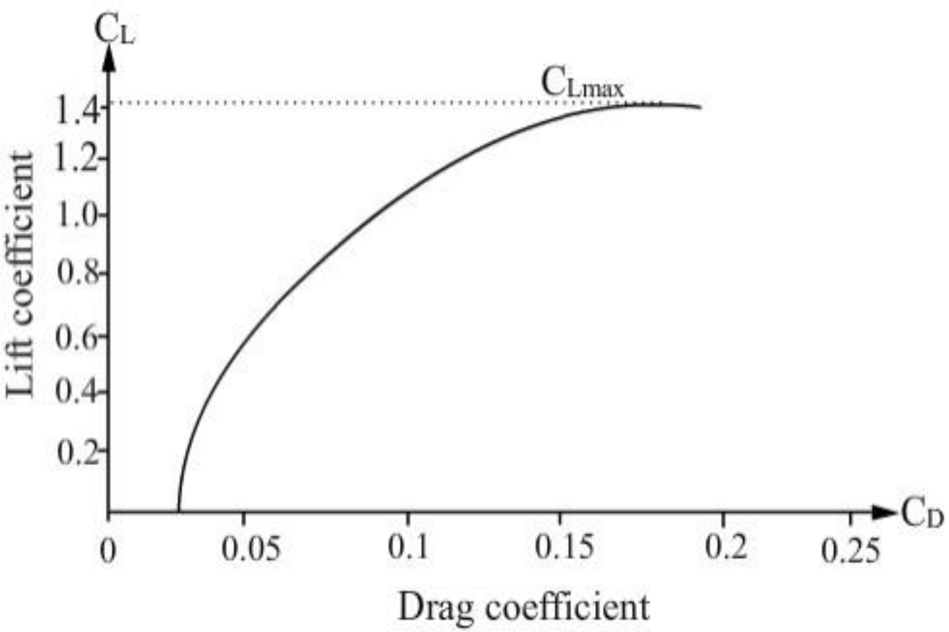
The relationship between the drag coefficient and the lift coefficient is called drag polar.

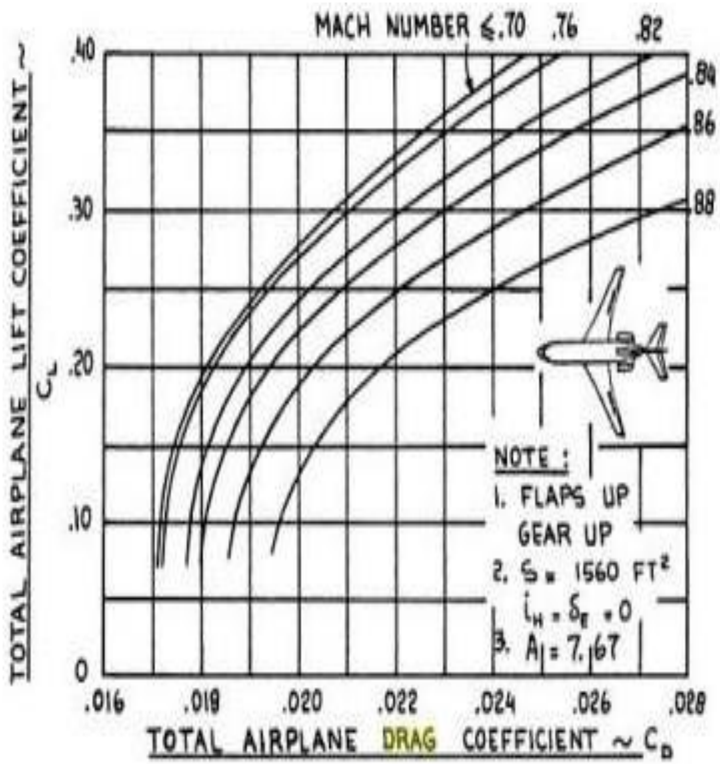
$$\text{Thus, } D = D_{wing} + D_{fuse} + D_{ht} + D_{vt} + D_{nac} + D_{lg} + D_{etc}$$

# Equation for drag polar

- ❖ Drag polar with Varying AR
- ❖ Drag polar with Varying $Cd_0$

$$C_D = C_{D0} + \frac{C_L^2}{\pi A\!\!R e}$$



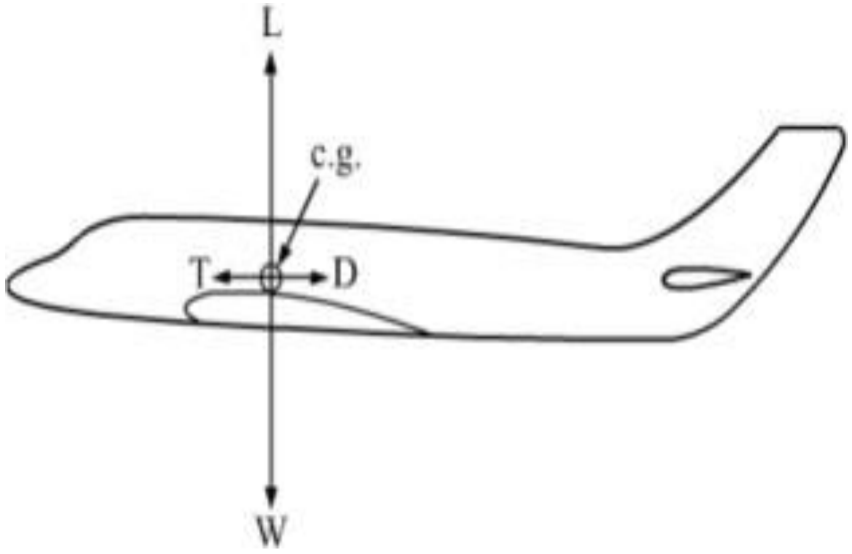
# MODULE-II
# CRUISE PERFORMANCE

# Course Learning Outcomes

| CLOs | Course Learning Outcome |
| --- | --- |
| CLO5 | Describe mission profiles that an aircraft adapts depending upon its category and requirements. |
| CLO6 | Understand different phases of design process from performance standpoint |
| CLO7 | Identify definition of aircraft performance for different categories of aircraft. |
| CLO8 | Explain the force system of the aircraft and the development of equations of motion |

# CRUISE PERFORMANCE

- Level Flight
  - At constant speed
  - At acceleration
- Takeoff flight
- Landing
  - Shallow angle
  - Steep angle
- Circular flight
- Turn/Banking Flight
- Push over
- Pull out

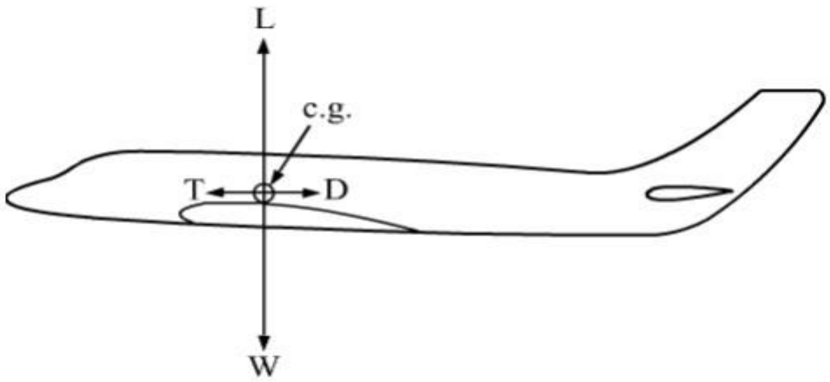


## Maximum and minimum speeds in level flight

Level Flight

- At constant speed

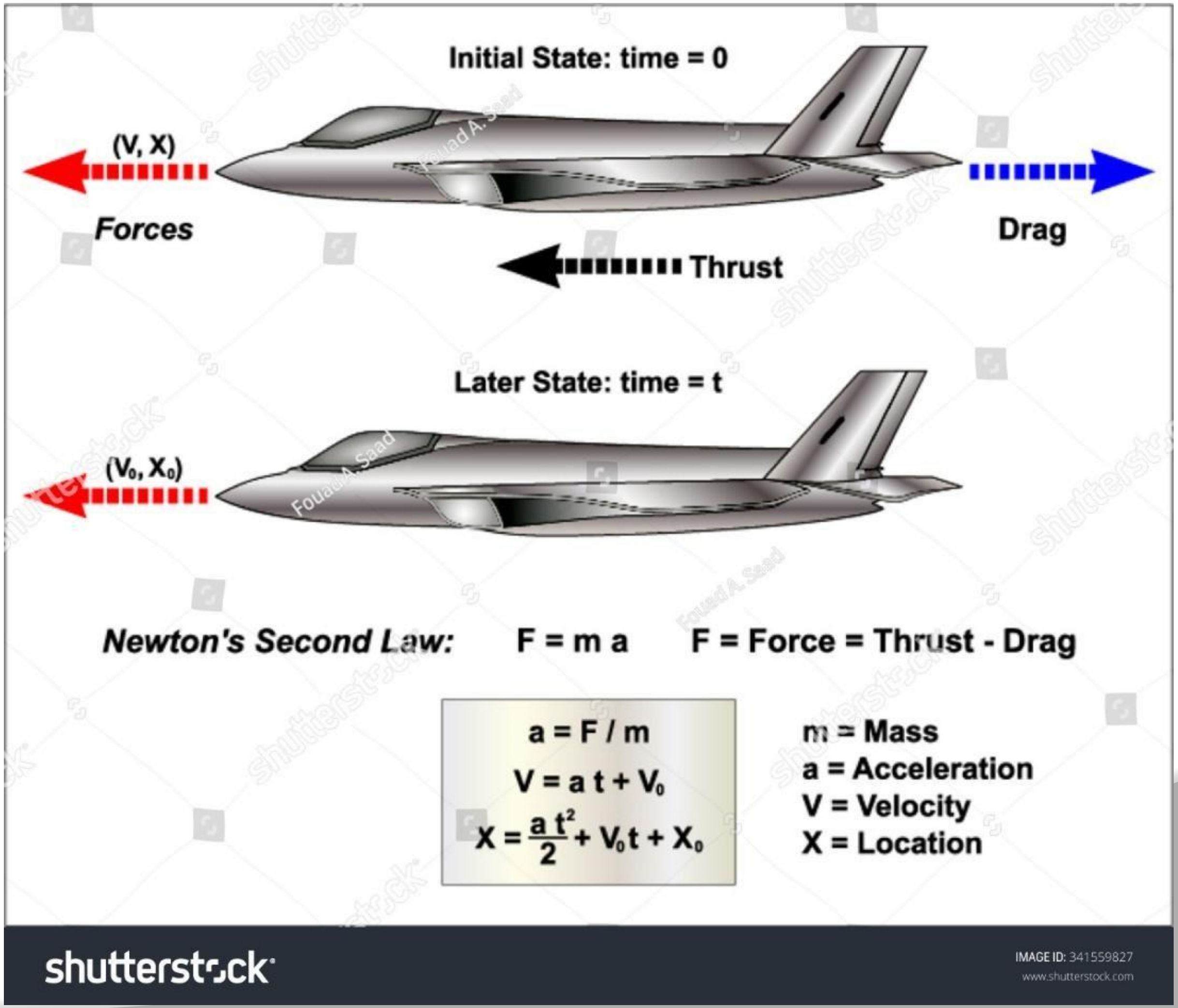
In a steady level flight an airplane moves with constant velocity at a constant altitude. This analysis would give information on the maximum level speed and minimum level speed at different altitudes.



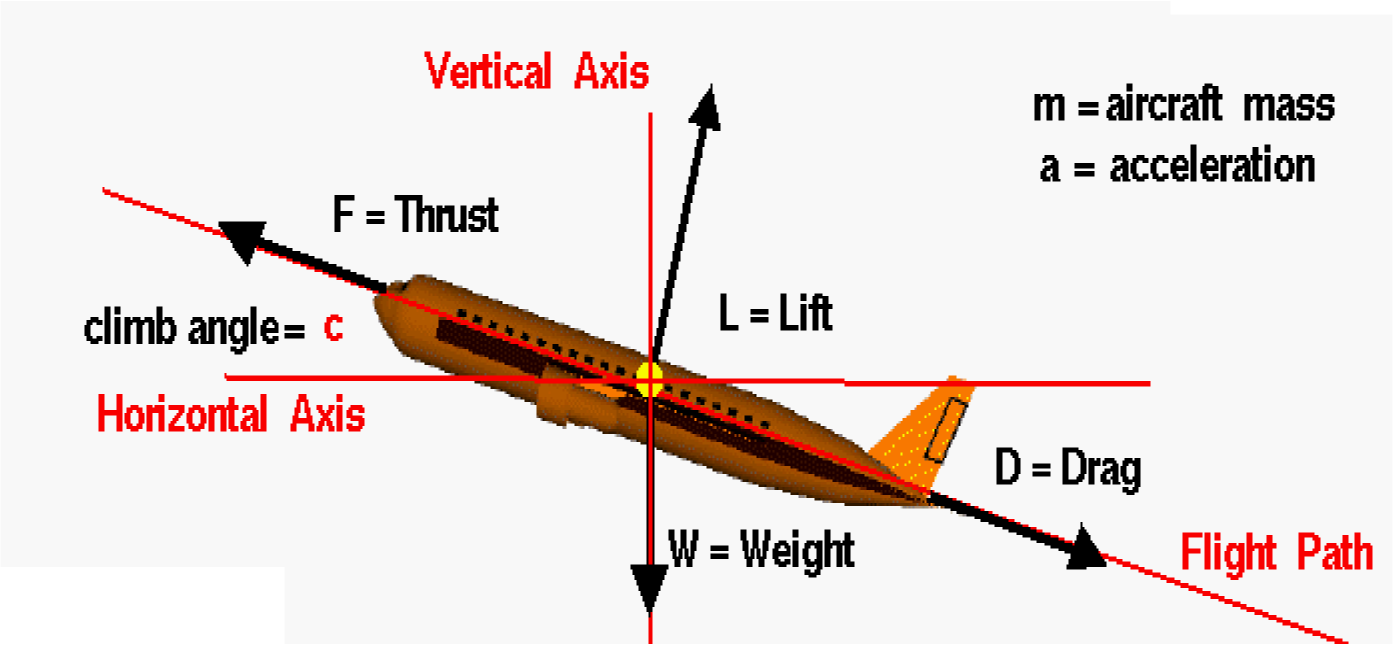
# Maximum and minimum speeds in level flight

Level Flight

- At acceleration



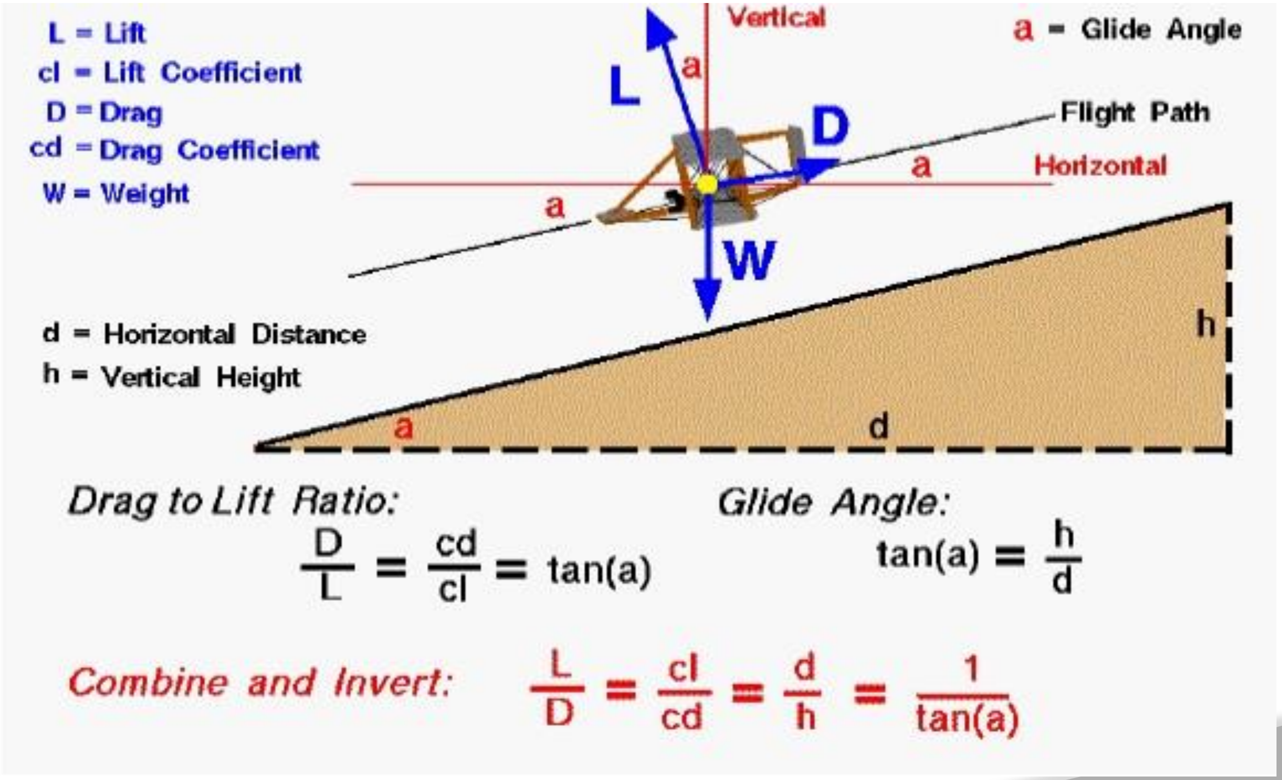
# Take-off flight



# Glide landing

Glide Landing

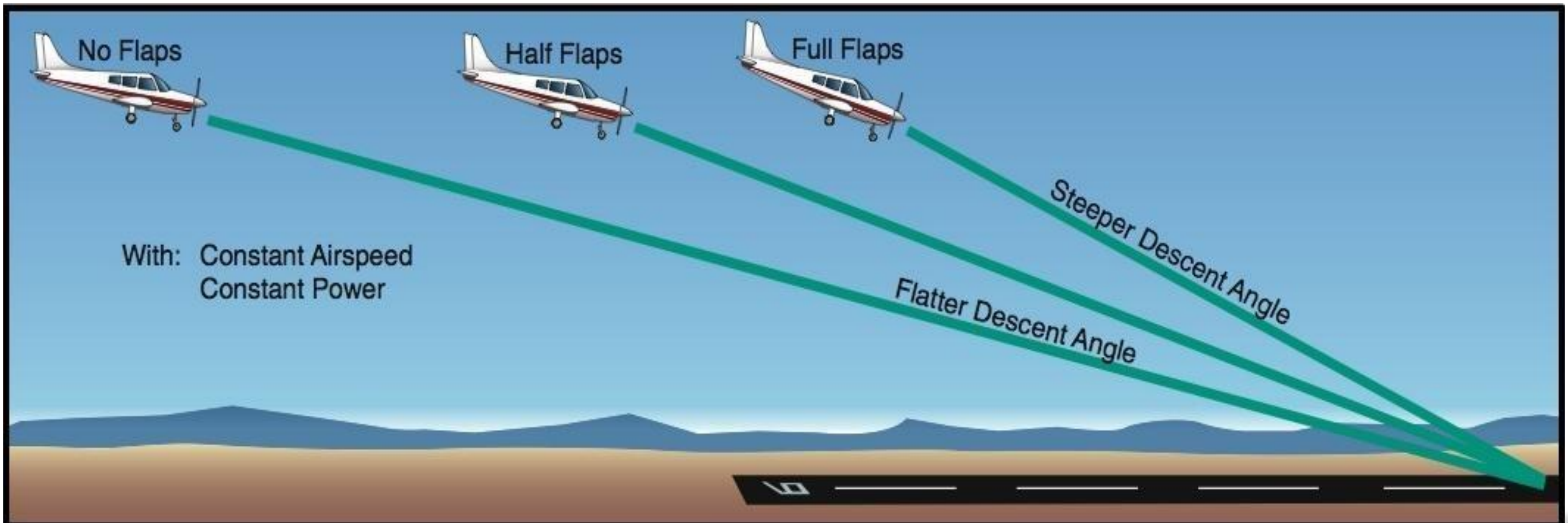
- ❖ Shallow angle



# Types of landing

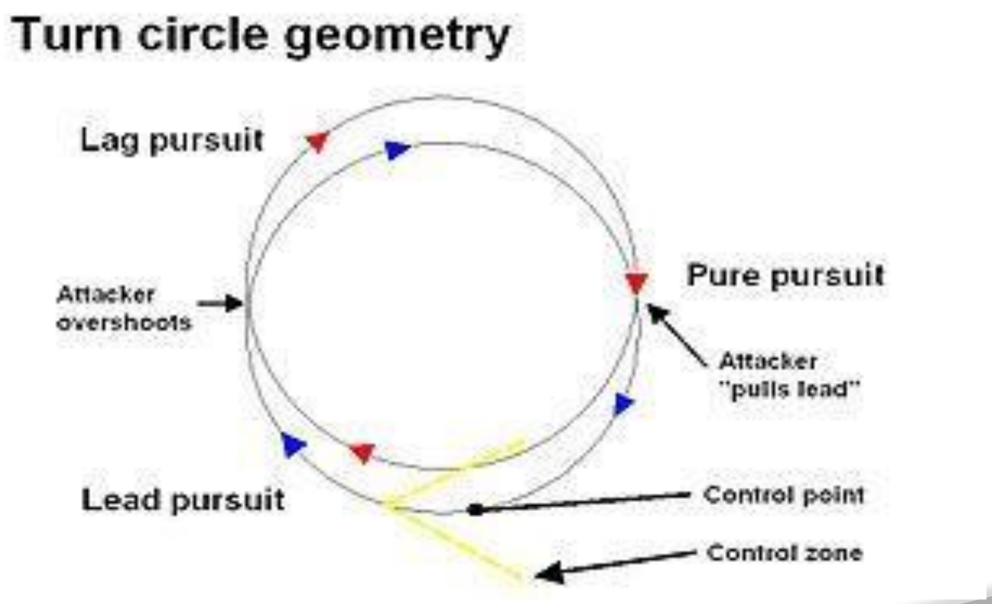
Landing

- Steep angle



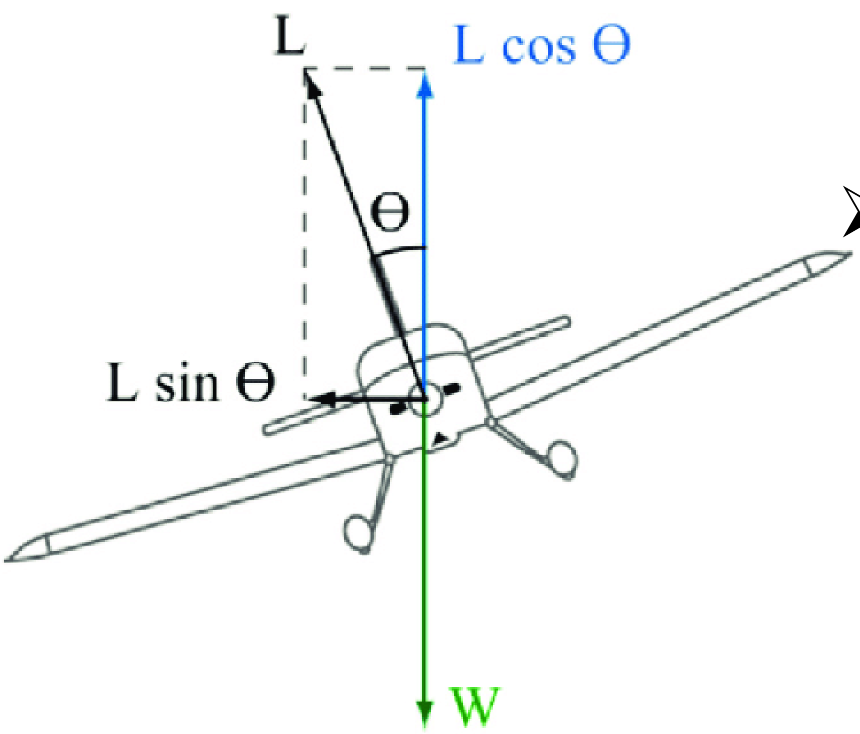
## Circular flight

Aircraft turn in circular motions, following a circumference around a central point. The circumference is often referred to as the "bubble", while the central point is often called the "post". Any change in the g-force load on the aircraft causes a change in the bubble's size as well as a change in turn radius, moving the post in relation to the fighter.



# Turn and banking

Turn/Banking Flight




- Ifairspeedismaintained,then arateofdescentwilloccuror,if heightismaintained,thenthe aircraftwilldecelerate.

- Unlessthethrustisincreasedt ocompensatefortheincrease ddragthentheturnwillcauset hespecificenergyoftheaircra fttodecrease

- Flight along a curved path is known as a manoeuvre. In this flight the radial acceleration is always present even if the tangential acceleration is zero.
- For example, from particle dynamics we know that when a body moves with constant speed along a circle it is subjected to a radial acceleration equal to ($V^2/r$) or $2\omega r$ where, V is the speed, r is the radius of curvature of the path and is the angular velocity ($\omega=V/r$).

- In a general case, when a particle moves along a curve it has an acceleration along the tangent to the path whose magnitude is equal to the rate of change of speed(V) and an acceleration along the radius of curvature whose magnitude is ($V^2/r$).
- For the sake of simplicity, the motions of an airplane along curved paths confined to either the vertical plane or the horizontal plane, are only considered here. The flight along a closed curve in a vertical plane is referred to as loop and that in the horizontal plane as turn

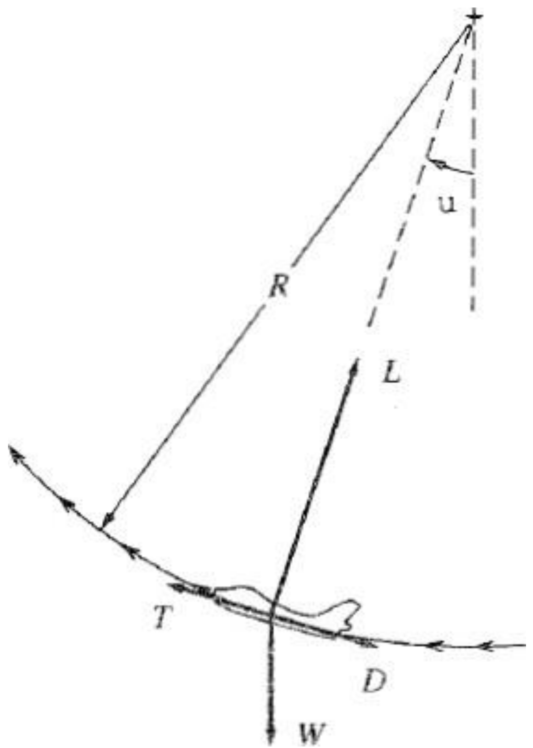
# Factors for limiting conditions

## Factors Limiting Radius Of Turn And Rate Of Turn

- Turning flight is a very important item of performance evaluation, especially for the military airplanes. Minimum radius of turn and maximum rate of turn are important indicators of the maneuverability of an airplane.
- It is observed that, at a given altitude and flight velocity, as mall radius of turn and a high rate of turn are achieved when the bank angle has the highest possible value.
- At a given altitude, the minimum radius of turn (rmin) and the maximum rate of turn (ψmax) are obtained when 'V' is low and 'n' is high. The following considerations limit the achievable values of r min and ψ max.

# Push over

Push over

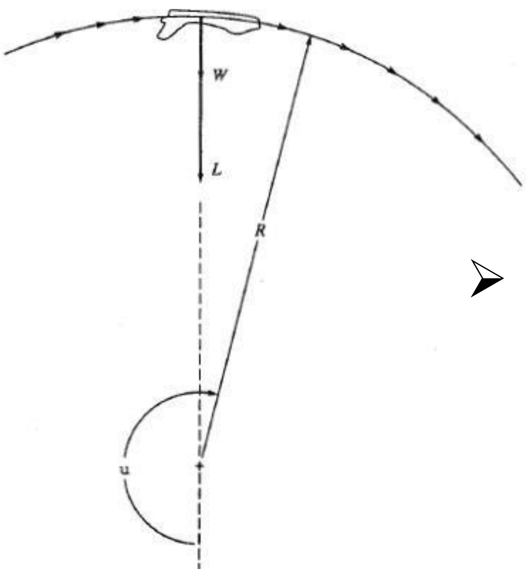



- The excess power can be used to
  - i. increase potential energy (climb), or to
  - ii. increase the potential and kinetic energies in combination to achieve the maximum rate of change of total energy,
  - iii. to minimize the time required to climb and accelerate the aircraft to its operating height and Mach number. This principle is employed by high performance air craft in the optimization of their climb profile through the transonic flight region where the excess power is reduced by the increase in drag.

Any change in the specific excess power arising from an increment in either the thrust or the drag will produce either a rate of climb or an acceleration of the aircraft. If height is maintained constant then the TAS will vary or, conversely, if TAS is maintained constant the height will vary. This principle is important in the consideration of the over all effect of a manoeuvre on the flight path of the aircraft.

# Pullout and pull down

Pull out /
Pull down flight




- The excess power can be used to (i) increase potential energy (climb), or to (ii) increase the potential and kinetic energies in combination to achieve the maximum rate of change of total energy, (iii) to minimize the time required to climb and accelerate the aircraft to its operating height and Mach number. This principle is employed by high performance aircraft in the optimization of the in climb profile through the transonic flight region where the excess power is reduced by the increase in drag.
- Any change in the specific excess power arising from an increment in either the thrust or the drag will produce either a rate of climb or an acceleration of the aircraft. If height is maintained constant then the TAS will vary or, conversely, if TAS is maintained constant the height will vary. This principle is important in the consideration of the overall effect of a manoeuvre on the flight path of the aircraft.

# Range and Endurance

Range and Endurance with thrust production

- Propeller engine
- Jet engine
- Maximum Range condition
- Maximum endurance condition

# CRUISE Techniques

Cruise techniques:

- ❖ Constant angle of attack

In fluid dynamics, **angle of attack** (**AOA**, **α**, or) is the angle between a reference line on a body (often the chord line of an airfoil) and the vector representing the relative motion between the body and the fluid through which it is moving. Angle of attack is the angle between the body's reference line and the oncoming flow. This article focuses on the most common application, the angle of attack of a wing or airfoil moving through air.

# Basic airfoil characteristics

In aerodynamics, angle of attack specifies the angle between the chord line of the wing of a fixed-wing aircraft and the vector representing the relative motion between the aircraft and the atmosphere. Since a wing can have twist, a chord line of the whole wing may not be definable, so an alternate reference line is simply defined. Often, the chord line of the root of the wing is chosen as the reference line. Another choice is to use a horizontal line on the fuselage as the reference line (and also as the longitudinal axis).Some authors do not use an arbitrary chord line but use the zero lift axis where, by definition, zero angle of attack corresponds to zero coefficient of lift.

Some British authors have used the term angle of incidence instead of angle of attack. However, this can lead to confusion with the term *riggers' angle of incidence* meaning the angle between the chord of an airfoil and some fixed datum in the airplane.

# Contd---

Cruise techniques:

- Constant Mach number

An approximate solution of the constant altitude-constant Mach number cruise range for high subsonic speed flight of the turbojet fan aircraft is proposed. The solutions considers cambered wing drag polar of modern transport aircraft, dependence of the specific fuel consumption on Mach number, and compressibility effects on aerodynamic characteristics of the aircraft. The method aims for a quick assessment of the cruise range during conceptual or preliminary design phase.

# Cruise techniques:

❖ Constant altitude

Commercial or passenger aircraft are usually designed for optimum performance at their **cruise speed** ($V_C$). Combustion engines have an optimum efficiency level for fuel consumption and power output. Generally, piston engines are most efficient between idle speed and 25% short of full throttle.

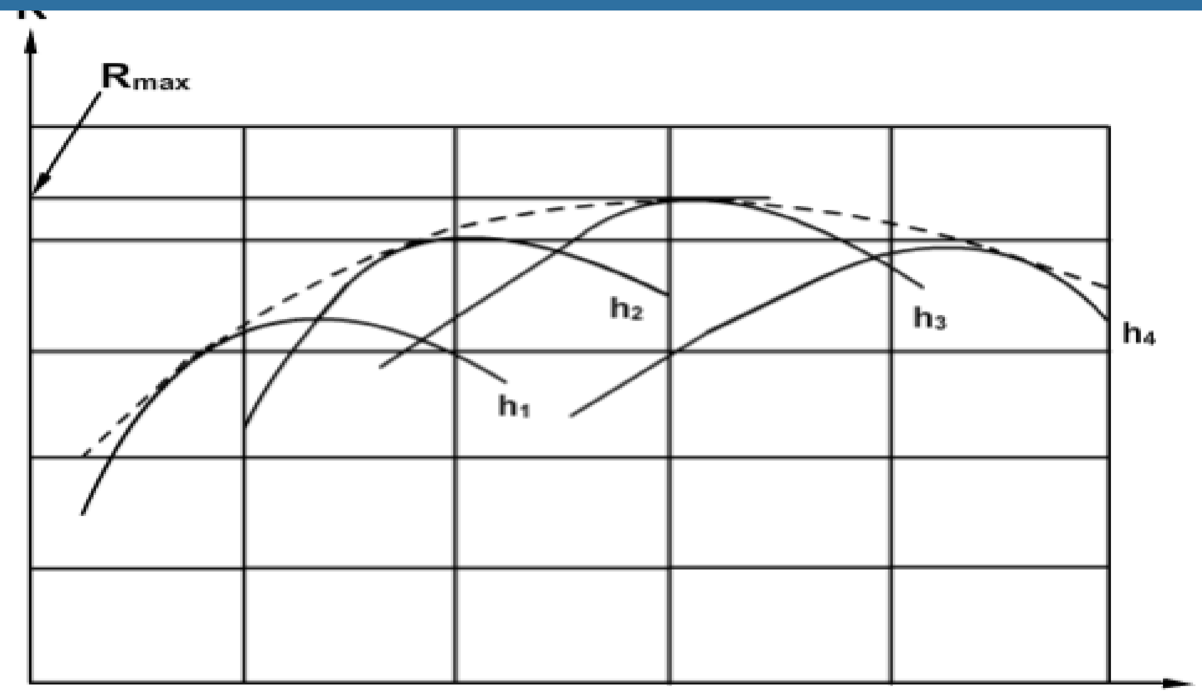
With aircraft, other factors affecting optimum cruise altitude include payload, center of gravity, air temperature, humidity, and speed. This altitude is usually where the higher ground speeds, the increase in aerodynamic drag power, and the decrease in engine thrust and efficiency at higher altitudes are balanced.

# Methods

- ✓ Methods- comparison of performance.
- ✓ The effect of weight
- ✓ Altitude and Temperature on cruise performance

- ❖ Thespeedandaltitudeatwhichthemaximumofthisenvelopo ccursiscalledthemosteconomicalcruisingspeedandaltitude .

# Contd---




In some cases this speed is rather low and a higher cruising speed may be chosen from other considerations like, shorter flight time and speed appeal .i.e. a faster airplane may be more appealing to the passengers even if it consumes more fuel per kilometre of travel

# Comparison of performance

- ✓ Methods- comparison of performance.
- ✓ The effect of weight
- ✓ Cruise performance with mixed power-Plants

- ➢ In effect describes the combination of the expression in the thrust and power into ESHP so that the performance can be estimated as if the air craft had a pure power producing engine.

- ➢ However, it is unlikely that the proportions of thrust and power will be in dependent of speed or engine output, and so the expression will need to be calculated for each combination of engine power setting and aircraft speed. Because of this, cruise performance calculations for turbo-prop aircraft will usually need to be performed in a ‘point-to-point’ manner rather than by a continuous function.

# Performance characteristic

The cruising performance characteristic of an aircraft with missed power plants lies between those of the aircraft with pure thrust- or pure power-producing power plants. It needs to be estimated by taking the proportion of direct thrust to thrust power produced by the engine. Using the cruise–climb range expression as an example, the principle can be demonstrated.

# MODULE-III

# CLIMB AND DECENT PERFORMANCE

# Course Learning Outcomes

| CLOs | Course Learning Outcome |
|---|---|
| CLO9 | Evaluate the performance of aircraft in cruising phase and appropriate conclusions are drawn. |
| CLO10 | Illustrate the climb and descent performance of the aircraft and its performance parameters are measured |
| CLO11 | Understand the concept behind various methods that are employed during takeoff and landing phases depending upon its mission. |
| CLO12 | Evaluate the factors that enhance the performance of aircraft during takeoff and landing. |

## Importance of Climb performance

- The difference between propulsive thrust and airframe drag is used to change the potential energy and kinetic energy of the aircraft. If the thrust exceeds drag the airplane will climb and if the drag exceeds thrust the airplane will descend.
- Although climb and descent imply changes to height, they may involve changes in TAS since air density decreases with altitude.
- If the rates of climb or descent are high the acceleration of the aircraft while climbing will have to be taken into consideration
- The fuel required to climb to a given height can be minimized by the use of correct climbing technique.
- Economy is not the only criteria safety comes first. The safety of the aircraft depends upon the ability of the aircraft to climb above the obstructions at all points in the flight path. Sufficient excess thrust must be available to the Pilot to ensure that the aircraft can meet certain minimum gradients of climb in any of the safety critical segments of the flight.

# CLIMB AND DECENT PERFORMANCE

- Safety related considerations will affect the choice of flight path in descent for example, the attitude of the aircraft, rate of change of cabin pressure and the need for engine to supply power for airframe services.
- For all practical purposes the climb is performed at a constant EAS. This implies that as aircraft climbs the ambient air density decreases, so TAS will increase thus the aircraft will be accelerating throughout the climb
- If the climb is based on constant Mach number then in the troposphere as altitude increases the ambient temp will be decreasing and with it the speed of sound. This implies that the TAS will be decreasing as the aircraft climbs
- In isothermal stratosphere a climb with constant Mach no. will result in constant TAS (i.e, no acceleration)

# Contd---

Climb and descent technique generalized performance analysis for thrust producing

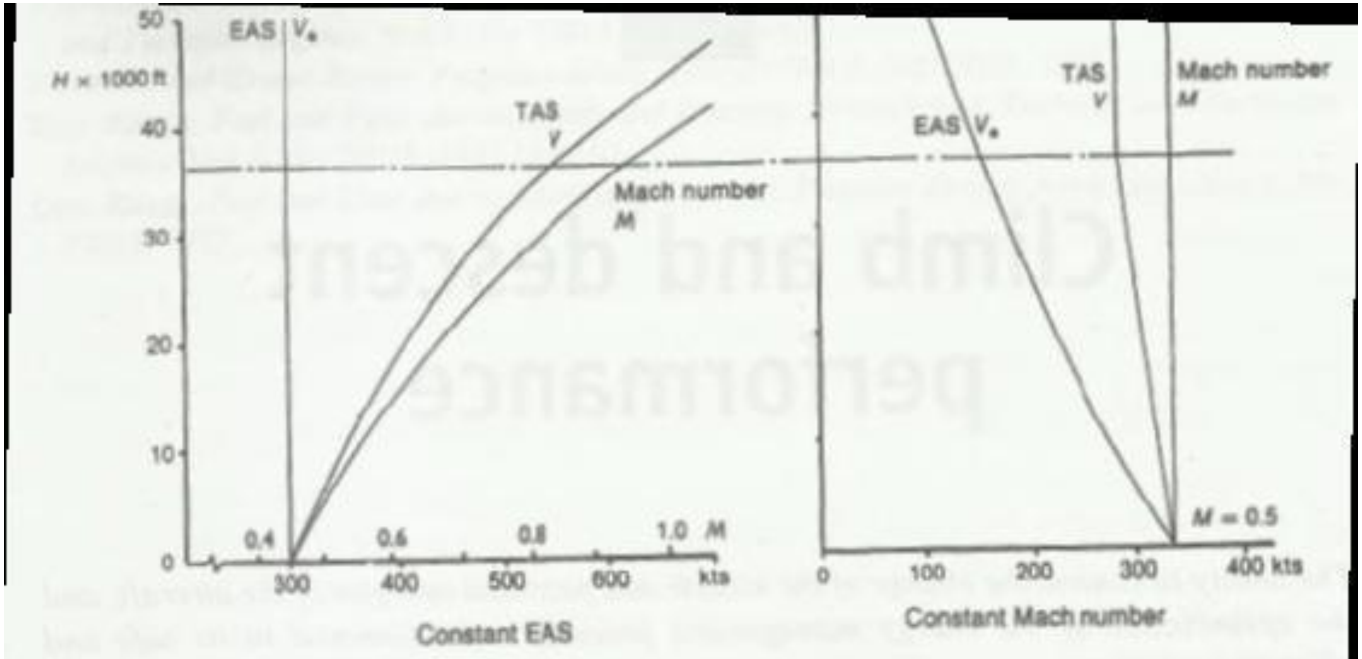



Fig. 5.1 Speed relationships in climbing flight.

# Contd---

- Figure shows the relationship between TAS, EAS and Min climbing flight
- It shows that if the climb is at constant EAS the Mach no will increase with altitude and $M_{crit}$ will be reached
- Alternatively if the climb is performed at constant Mach no then the EAS will decrease towards the stalling speed as height increases
- In practice an aircraft climbing to a height at which the Mach no. would approach its critical value would usually start the climb at a constant EAS and the Mach no. will be allowed to increase. In this state the angle of attack is constant and the climb can be made constant and possibly optimum L/D ratio. As M increases it becomes necessary to avoid the drag rise as the Mcrit is reached. The climb would then be converted into a constant M climb allowing the EAS to decrease as the climb continues.

# Thrust & Power producing engine

- Thrust producing engines produce thrust that is relatively constant with change of air speed in subsonic flights. Power producing engines produce shaft power which is relatively constant with change of air speed and which needs to be converted into propulsive thrust by a propeller. The differing characteristics of the set wo different types of engines lead to different criteria for optimum climb performance and need to be considered separately.

# EOM

$$\left.\begin{aligned} F_N - D &= W \sin\gamma_2 + m\dot{V} \\ L &= W \cos\gamma_2 \end{aligned}\right\}$$

$$\left.\begin{aligned} F_N - D &= W \sin\gamma_2 \\ L &= W \end{aligned}\right\}$$

$$[F_N - D]\frac{1}{W} = \sin\gamma_2$$

- This tells us that if the thrust is constant the best gradient of climb will be obtained by flying at the min drag speed.
- In the figure we see that the thrust does not vary with airspeed and the max excess thrust occurs at the min drag speed. In practice the airspeed is likely to influence the thrust to some extent.
- Therefore the airspeed for optimum climb gradient will be found to be close to but not necessarily at the min drag speed.

## Maximum climb gradient

- During take-off and climb phase the most critical consideration is the safety and the need to ensure that the aircraft can avoid all known obstructions along its flight path.
- So ICAO regulation mandates that before a license is given for an air field a departure path must defined along which no obstructions are permitted and the aircraft is guaranteed a clear flight path.
- For large international airports the obstacle limitation surface–which defines the safe departure path is a surface of gradient 2% extending from the end of the take off distance available on the runway to a distance of 15km. Therefore to guarantee a safe departure from the airfield the air craft must be capable of climbing at a gradient of at least 2% under all conditions, including emergency conditions with one engine in operative.
- In this phase off light the aircraft needs to be operated at an airspeed that will produce the best gradient of climb so that the departure flight path will be steep enough to exceed the minimum safe gradient specified

# Climb rate

- Aircraft with thrust producing engines have an air speed for best rate of climb that is a function no t their excess thrust; the greater the excess thrust the higher will be the airspeed for best rate of climb rate.
- As the aircraft climbs the thrust will decrease and with it the optimum airspeed for climb rate.
- The air speed used in the climb will generally be a compromise based on the excess thrust which will be a function of the weight, altitude and temperature (WAT) conditions at the start of the climb. It will take into account the anticipated WAT changes during climb to give the best average climb performance throughout the climb.
- As the climb continues the Mach number will increase as the relative atmospheric pressure decreases. It may become necessary to convert the climb to constant Mach number to avoid the drag rise that would reduce the climb performance.

# Energy height and specific excess power

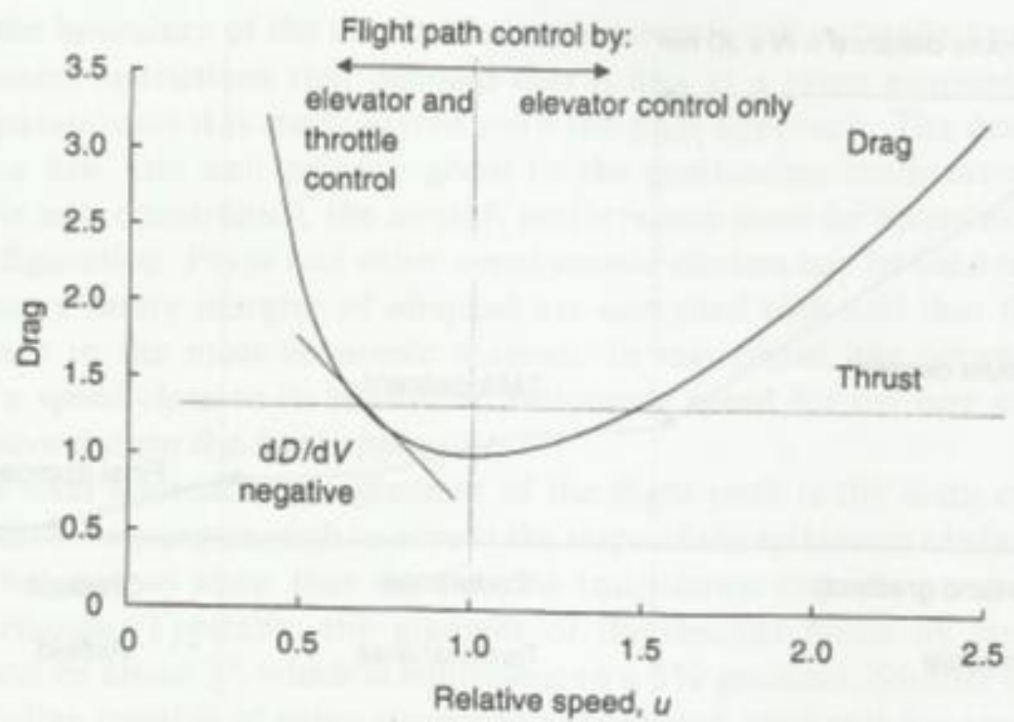



Fig. 5.11 Effect of minimum drag speed on flight path control.

# Energy methods

## Energy methods for optimal climbs :–

- The accelerated or decelerated flights last only for a short duration and the weight of the airplane can be assumed to remain constant during such flights.
- The term (h+V2/2g) is denoted by he and is called 'Specific energy or Energy height'. It is called specific energy because it is equal to the sum of potential energy and kinetic energy divided by the weight. It is called energy height because this term has the dimensions of height. It may be noted that

$$\frac{(T\text{-}D)V}{W} = \frac{d}{dt}\left(h + \frac{V^2}{2g}\right)$$

(dhe/ dt) = (T-D)V/ W

- The energy height concept is used in optimization of climb performance

# CLIMB AND DECENT PERFORMANCE

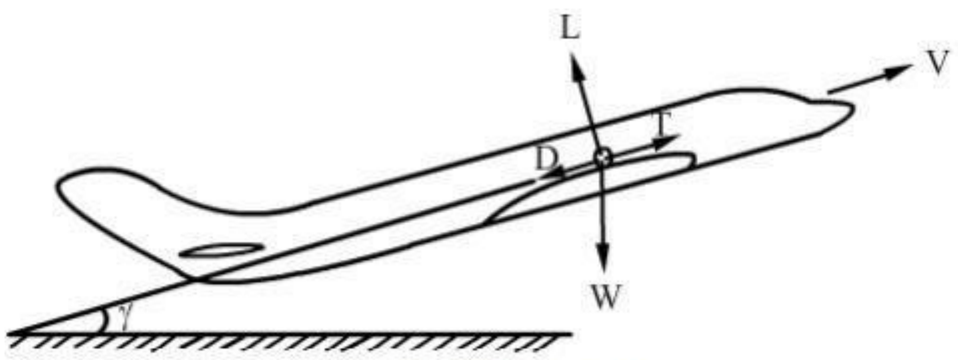



Fig.8.2 Accelerated climb

$$T - D - W\sin\gamma = \frac{W}{g}a$$

$$L - W\cos\gamma = 0$$

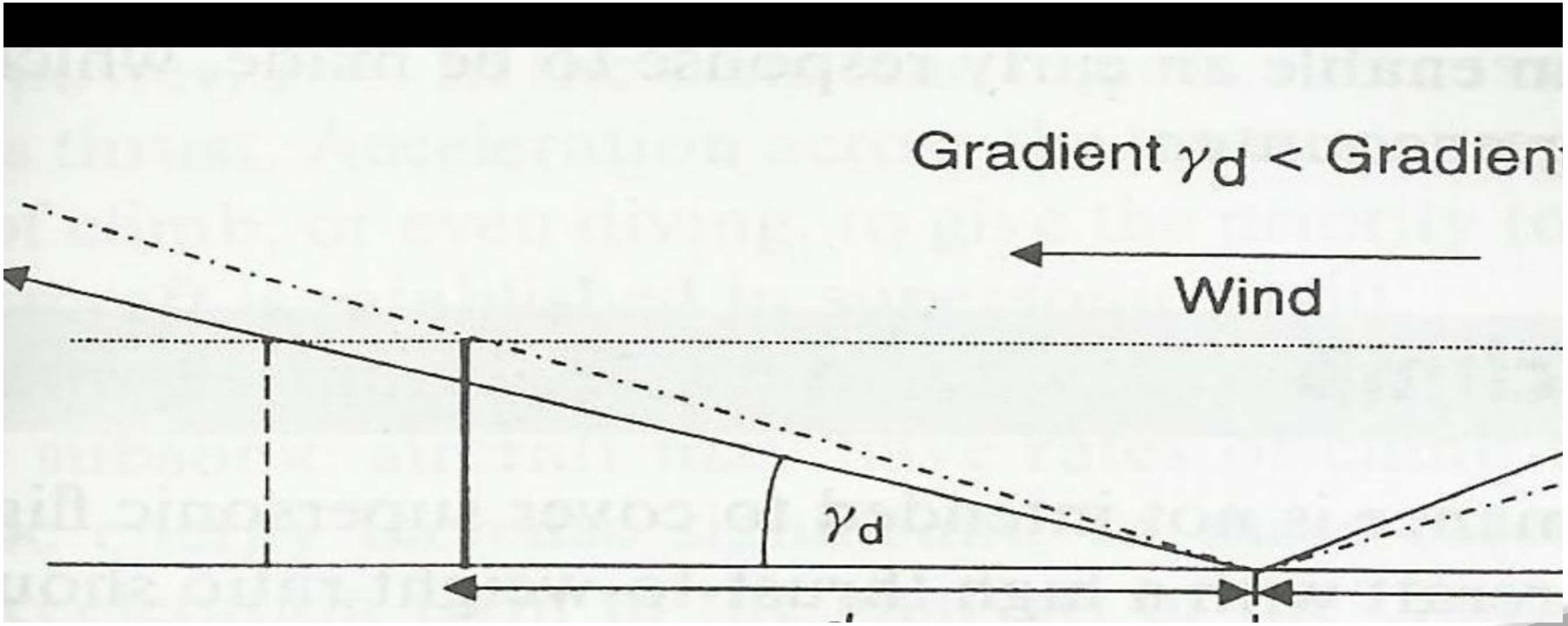
$$T - D - W\frac{V_C}{V} - \frac{W}{g}V_C\frac{dV}{dh} = 0 \quad \text{or} \quad V_C = \frac{(T-D)V}{W\left(1+\frac{V}{g}\frac{dV}{dh}\right)}$$

## Descent performance in Aircraft operations

- Aircraft will descend when the propulsive thrust is less than the airframe drag
- The descending flight path can be varied from as hallow descent to a very steep descent either by reducing the engine thrust or by increasing the air framed rag.
- The drag can be increased either by aerodynamic means oby varying the airspeed (recollect the $P_A$ and Pressure curve).
- Thus, the Pilot has in his control a wide range of descent path profiles available. In the special case of gliding flight, in which the reis no propulsive thrust, the descent will be determined by the lift—drag ratio,
  E. In this case, the minimum rate of descent occurs at the minimum power speed and the minimum gradient occurs at the minimum drags peed

# Effect of wind on climb

Effect of wind on climb and decent performance



# MODULE-IV

# AIRCRAFT MANEUVER PERFORMANCE

# Course Learning Outcomes

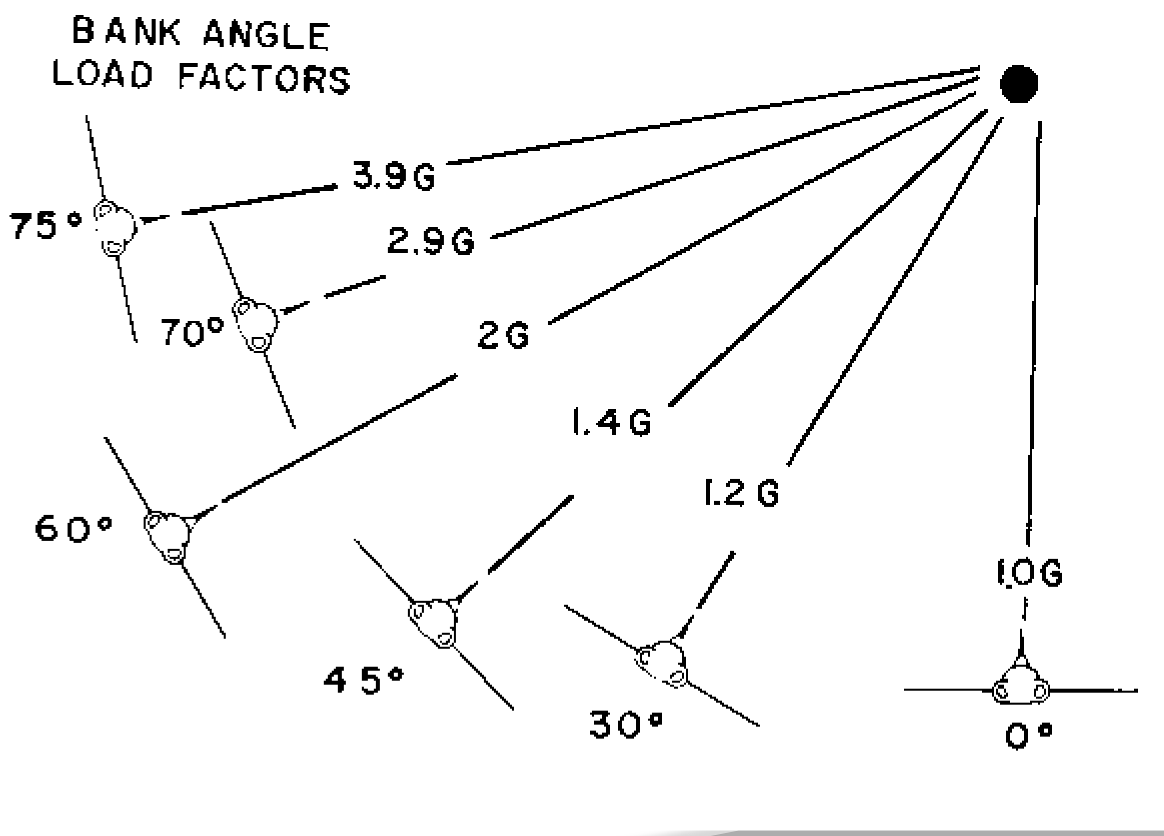
| CLOs | Course Learning Outcome |
|---|---|
| CLO13 | Understand the maneuver performance of typical transport and military aircrafts. |
| CLO14 | Understand the parametric performance data analysis for different phases of aircraft and various methods of measurement. |
| CLO15 | Understand the concept of flight planning, fuel planning and how it affects the performance of aircraft. |
| CLO16 | Understand the propulsive force characteristics like thrust that affects the aircraft performance. |

**Lateral manoeuvres**

- If the turn is initiated at an airspeed sufficiently above the minimum drag speed the airspeed will decrease, reducing the drag until the force equation is rebalanced and the level turn will continue at the lower airspeed.
- However, if the initial airspeed is close to or below the minimum drag speed, then any decrease in airspeed will lead to a further increase in drag and a consequent increase in the rate of loss of airspeed. If the thrust available is limited then the maximum airspeed in the level turn will decrease as the turn is tightened until the aircraft is at its minimum drag speed with maximum available thrust. At that point, the aircraft is performing its tightest, constant speed, level turn.
- These effects can be very important in climbing turns with very little excess thrust available, for example, the after-take-off climb with one engine inoperative. In such cases, the additional drag due to a turn can reduce the climb gradient to an unacceptably low level or even to a descent.

# AIRCRAFT MANOEUVRE PERFORMANCE

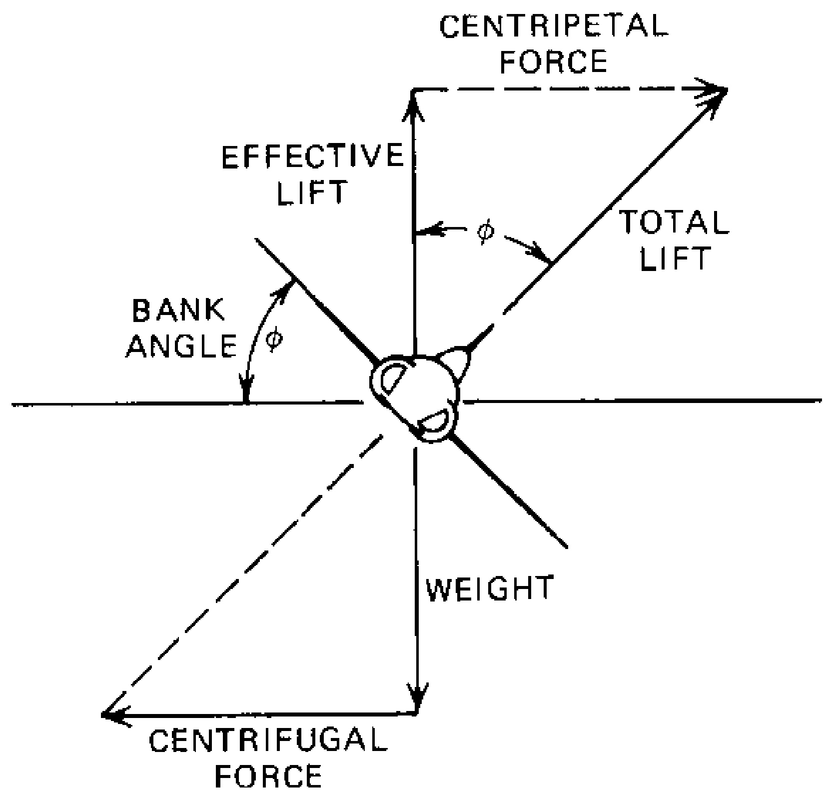
- ✓ Turn performance
- ✓ Turn rates



# Turn performance

## ✓Turn performance

❖ Turn radius



# Contd---

- Turning flight is a very important item of performance evaluation, especially for the military airplanes. Minimum radius of turn and maximum rate of turn are important indicators of the maneuverability of an airplane.
- It is observed that, at a given altitude and flight velocity, a small radius of turn and a high rate of turn are achieved when the banking le has the highest possible value.
- At a given altitude, the minimum radius of turn(r min) and the maximum rate of turn ($\psi$max) are obtained when 'V' is low and 'n' is high. The following considerations limit the achievable values of r min and $\psi$max.

## Instantaneous turn and sustained turns

- The maximum rate of turn in a steady level co-ordinated-turn is called 'Maximum sustained turn rate(MSTR)'.
- An airplane can maintain this turn rate continuously for some time.
- A rate of turn higher than MSTR can be obtained if the airplane is allowed to descend or slow down.
- In this manner, the loss of potential energy or kinetic energy can be utilized to increase the available energy during turn and increase the rate of turn.
- This rate of turn is called 'Instantaneous rate of turn'. The maximum instantenous rate of turn will be limited by other two factors viz. $C_{lmax}$ and ($n_{max}$)

# Energy turns

- The accelerated or decelerated flights last only for a short duration and the weight of the airplane can be assumed to remain constant during such flights.
- The term ($h+V^2/2g$) is denoted by he and is called 'Specific energy or Energy height'. It is called specific energy because it is equal to the sum of potential energy and kinetic energy divided by the weight. It is called energy height because this term has the dimensions of height. It may be noted that

$$\frac{(T-D)V}{W} = \frac{d}{dt}\left(h + \frac{V^2}{2g}\right)$$

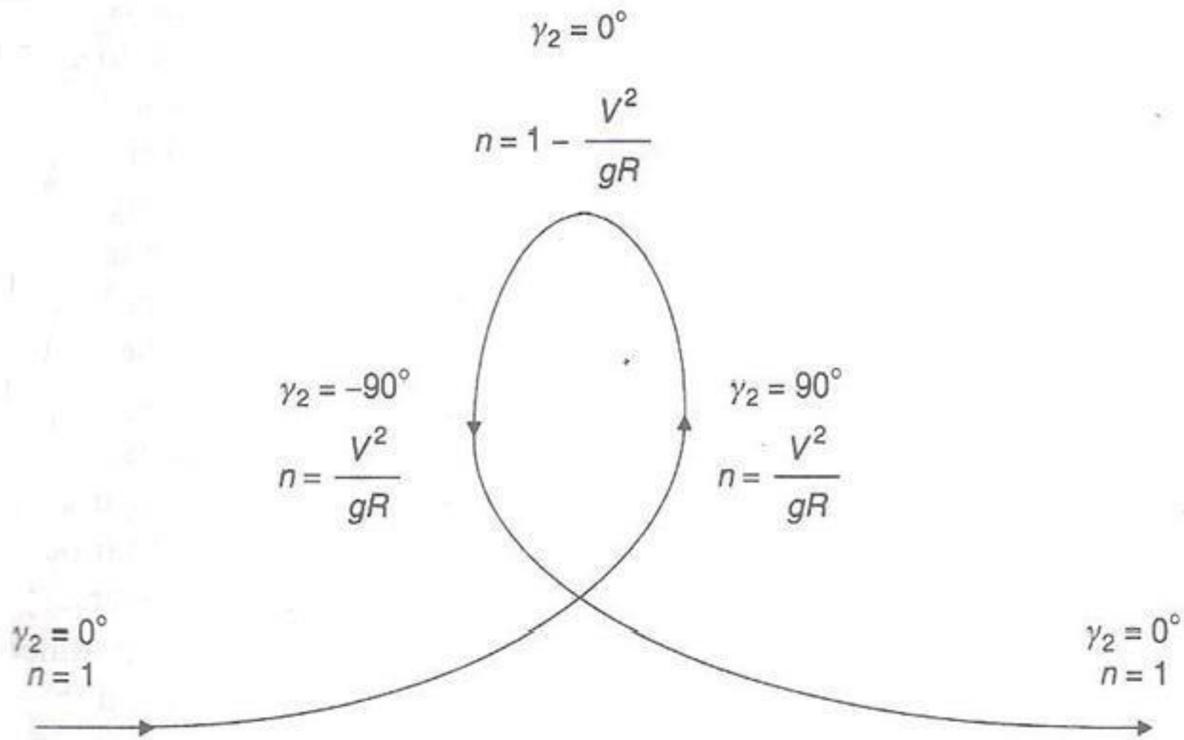
- The energy height concept is used in optimization of cimb performance

# Longitudinal aircraft manoeuvres

The longitudinal maneuver is the result of an imbalance of thrust and drag, which results in either a linear acceleration or a steady rate of climb, or a combination of both acceleration and climb, in the direction of flight. It does not involve directly the accelerations that result from rates of pitch or turn, although those maneuvers may produce increase in the drag force, which will have an indirect effect on the longitudinal force balance.

The term($H+V^2/2g$) is the specific energy, Es of the aircraft per MODULE weight. It is also known as the energy-height since it represents the height the aircraft would attain if all the kinetic energy were to be converted into potential energy.

## The pull-up Manoeuvres



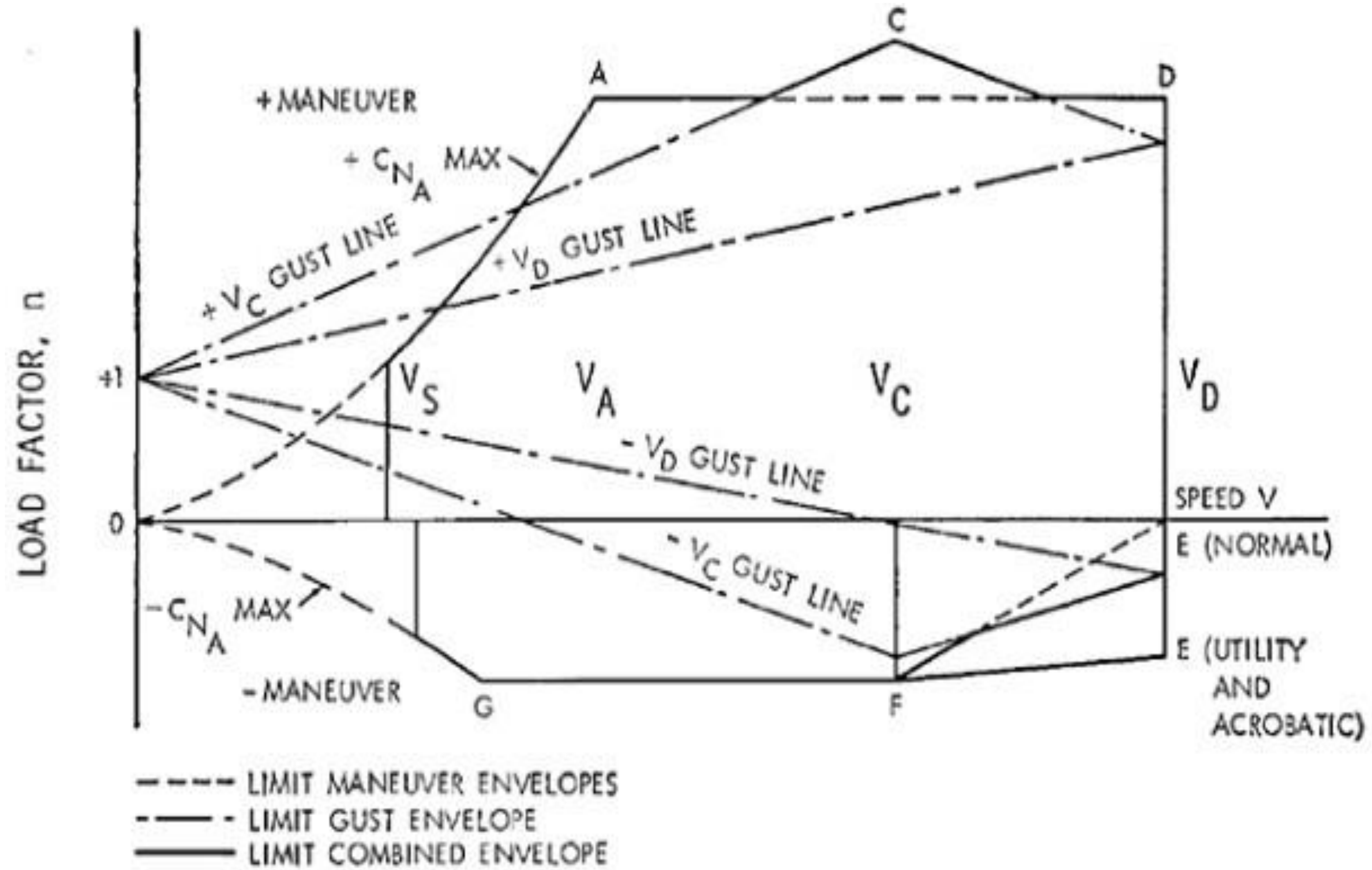
# CONTD--

- The load factor in the loop is not uniform and will vary with air speed and flight path angle as the aircraft progresses around the loop.
- In practice, the variation is complex since the increased load factor increases drag force, which, together with the weight component, affects the balance of the longitudinal forces acting on the aircraft.
- This causes a continuous change in air speed through out the manoeuvre. To control the air speed within acceptable limits the engine thrust must be increased in the upward segment of the loop and reduced in the downward segment, thus the loop can not be regarded as a steady manoeuvre.
- Similarly, the radius of the loop is not uniform but tends to decrease to a minimum at the top of the manoeuvre and increase again on the descending path. Beyond aerobatic flight and some military aircraft combat manoeuvres, there are few practical applications of the extended pull-up, or looping, manoeuvre.

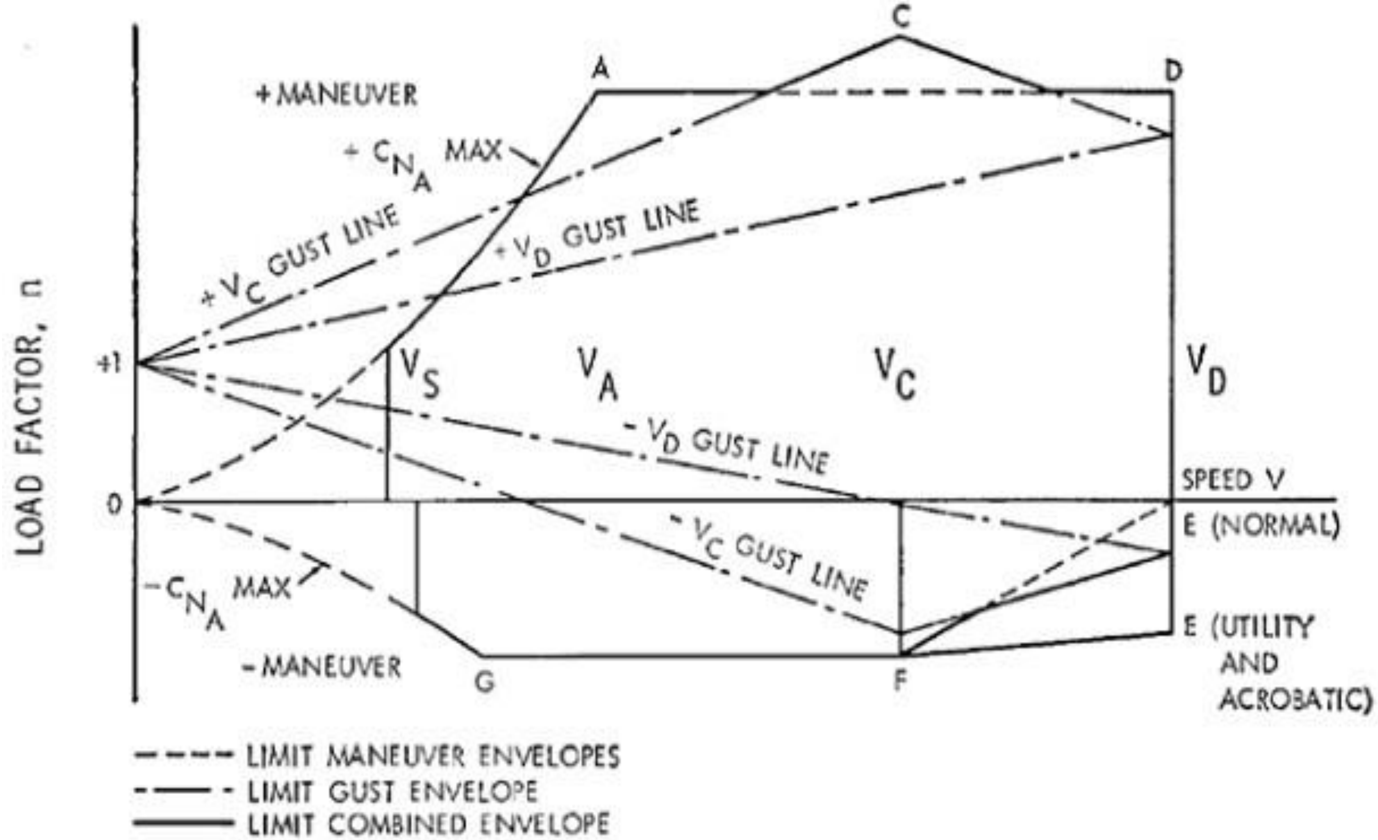
# Contd----

- It is an extreme case of pull-up manoeuvre called 'Cobra' which is a post-stall manoeuvre involving a rapid pitch-up to increase in angle of attack to a state far beyond the stalling angle of attack.
- In this state, the lift force becomes small, since the aircraft is in the stalled condition, and worse the drag increases to a very large value and acts in the wind-axis direction.
- Since the lift force is no longer significant, the aircraft will not enter a looping manoeuvre but will tend to continue in its original direction of flight together with a rapid deceleration.
- When an aircraft is engaged in combat with another aircraft of similar performance, they may become locked into a circular tail-chase, each turning at maximum rate. Neither will be able to tighten the turn to bring its adversary into line of sight to fire its weapons.

# The Manoeuvre Envelope Significance



# Manoeuvre Boundaries



# Manoeuvre Performance of Military Aircraft

Maneuvers

- Combat spread
- Defensive split
- Sandwich
- Break
- Barrel roll attack
- High-side guns pass
- Immelmann
- Split-S
- Pitchback
- Wingover
- Low Yo-Yo
- High Yo-Yo
- Lag displacement roll
- High Yo-Yo defense
- Unloaded extension
- Scissors
  - Flat scissors
  - Rolling scissors
- Guns defense
- High-g barrel roll
- Defensive spiral

# Contd----

## Manoeuvre Performance of Transport Aircraft

**There are four fundamental basic flight maneuvers upon which all flying tasks are based:**

- Straight-and-level flight
- Turns
- Climbs.
- Descents

| Type of airplane | $n_{positive}$ | $n_{negative}$ |
|---|---|---|
| General aviation-non aerobatic | 2.5 to 3.8 | -1 |
| Transport | 3 to 4 | -1 |
| Fighter | 6 to 9 | -3 |

# MODULE-V

# SAFETY REQUIREMENTS TAKEOFF AND LANDING PERFORMANCE AND FLIGHT PLANNING

# Course Learning Outcomes

| CLOs | Course Learning Outcome |
| --- | --- |
| CLO17 | Describes the flight measurement of performance, with detailed sections on airworthiness certification and the performance manual. |
| CLO18 | Evaluate the calibration methods that are used for the aircraft instruments to derive air data. |
| CLO19 | Understand the aerodynamic force characteristics like lift and drag that affects the aircraft performance. |
| CLO20 | Evaluate the full equation of motion, which are developed and used in the expressions for maneuver performance. |

# SAFETY REQUIREMENTS

Estimation of Take-off Distances

The **takeoff distance** consists of two parts

- the ground run
- the **distance** from where the vehicle leaves the ground to until it reaches 50 ft (or 15 m)

# Effect on the Take-off Distance

The Effect on the Take-off Distance of Weight

- Factors effecting
  - Density
  - Altitude
  - Atmospheric conditions (pressure, temperature etc..)

# The Effect on the Take-off Distance of Wind

- Head wind
- Tail wind
- Cross wind

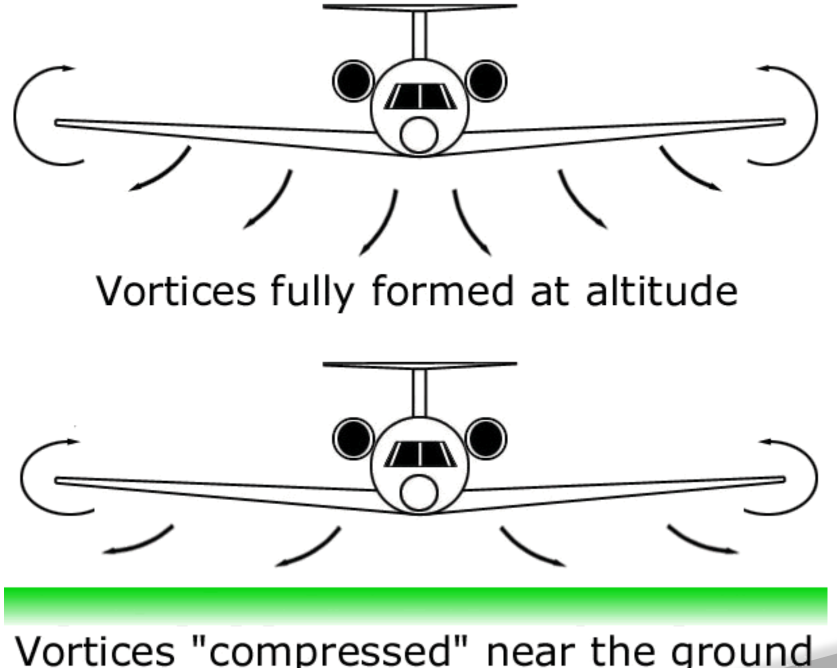
## The Effect on the Take-off Distance of Runway Conditions

- Runway Surface Conditions Defined
  - Dry **Runway**, FAA, A **runway** is dry when it is neither wet nor contaminated.
  - Dry **Runway**, ICAO, The surface is not affected by water, slush, snow, or ice.
  - Damp **Runway**, ICAO, The surface shows a change of color due to moisture
- Runway Friction Information

# Ground Effect

The effect on the take-off distance of:-
Ground Effect

- Takeoff Roll
- Lift-Off
- Initial Climb



# Take-off Performance Safety Factors

Factors affecting takeoff performance

- Weight
- Atmospheric conditions
- Load distribution
- Design factors
- Runway
- Landing gear

# Estimation of Landing Distances

- Factors effecting Landing distance
  - Weight
  - Atmospheric condition etc…
  - Landing gear design
- Landing types
  - Normal landing
  - Abnormal landing
- Landing performance

# Aborted landing

The Discontinued Landing

- ❖ Causes of discontinuity Landing
- ❖ Decision of discontinuity landing

# Balked landing

Baulk Landing/ Balked landing

A **balked landing**, also known as a go-around, is an aborted **landing** of an aircraft that is on final approach for **landing**. In most cases, this procedure is easily performed by the flight crew

# Air Safety Procedures

Air Safety Procedures and Requirements on Performance

- Air Safety Procedures authority
- Air Safety requirements
- Safety requirements on Various stages
- Air safety responsibility stack holders

# Fuel Planning

## Fuel Planning Fuel Requirement

- Additional Fuel
- Alternate Fuel
- Ballast Fuel
- Block Fuel / Ramp Fuel / Total Fuel On Board
- Contingency Fuel / Route Reserve
- Extra Fuel
- Final Reserve Fuel / Fixed Reserve Fuel / Holding Fuel
- Minimum Brake Release Fuel
- Reserve Fuel / Minimum Diversion Fuel
- Taxi Fuel
- Trip Fuel / Burn / Fuel to Destination

# Trip Fuel

The Trip fuel is the required fuel quantity from brake release on takeoff at the departure aerodrome to the landing touchdown at the destination aerodrome.

This quantity includes the fuel required for:

- **Takeoff**
- **Climb to cruise level**
- **Flight in level cruise including any planned step climb or step descent**
- **Flight from the beginning of descent to the beginning of approach,**
- **Approach**
- **Landing at the destination**

Trip fuel must be adjusted to account for any additional fuel that would be required for known ATS restrictions that would result in delayed climb to or early descent from planned cruising altitude.

# Environment Effects

- Effect of weather on aircraft flight
- Effect of atmospheric conditions on aircraft flight
- Effect of Meteorological and Geographical factors on aircraft flight
- Effect of natural calamities on aircraft flight
- Effect of Altitude on aircraft flight

# In-flight Refuelling

# Reserve Fuel

**For general aviation, ICAO Annex 6 Part II, section 2.2.3.6 "Fuel and oil supply" requires**

- For In flight Rule (IFR), enough **fuel** to reach destination, then alternate (if required), plus 45 minutes.
- For day Visual Flight Rule (VFR), enough **fuel** to reach destination plus 30 minutes.
- For night VFR, enough **fuel** to reach destination plus 45 minutes.