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AIRCRAFT TURN

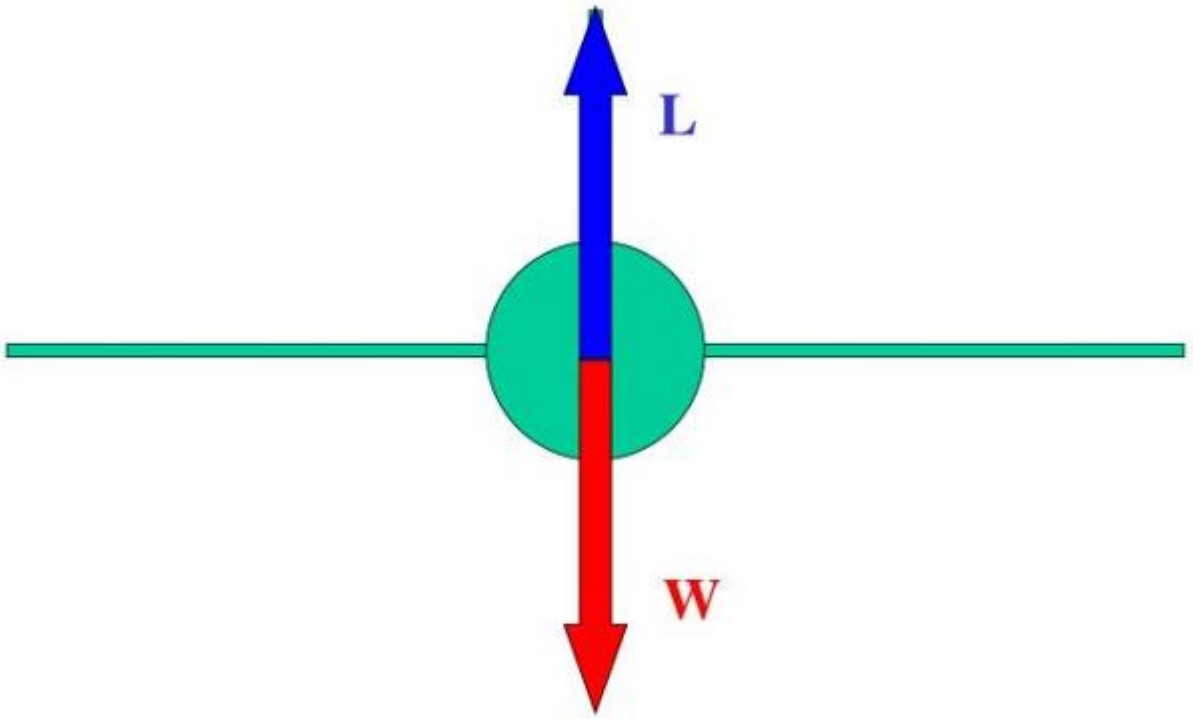
Aircraft in Steady Level Flight

- If aircraft is in steady level flight have seen from front view then there are two forces acting on it.

1. Lift
2. Weight

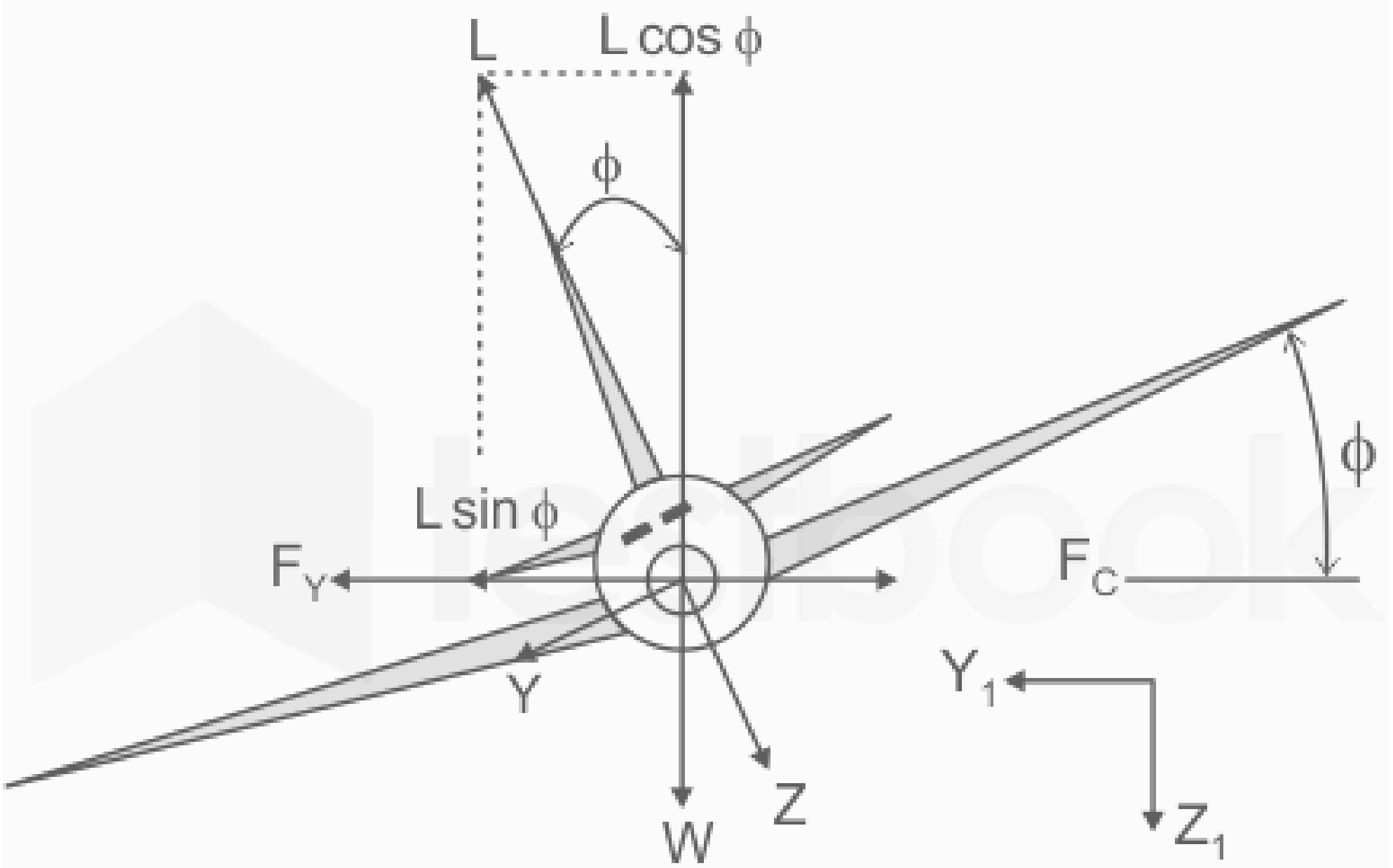
In steady level flight

L = W



Banking angle (φ)

- The angle between the wings and the horizon, as viewed from the rear of the airplane. An airplane with its wings level has zero degrees of bank.
- A fundamental aircraft motion is a banking turn. This maneuver is used to change the aircraft heading. The turn is initiated by using the ailerons or spoilers to roll, or bank, the aircraft to one side. On the figure, the airliner is banked to the right by lowering the left aileron and raising the right aileron.



Front View

BANKING

AIRCRAFT IN TURNING

- **If aircraft is banked then lift vector is tilted with the banking angle. So that when aircraft banks then lift vector is divided into two components**

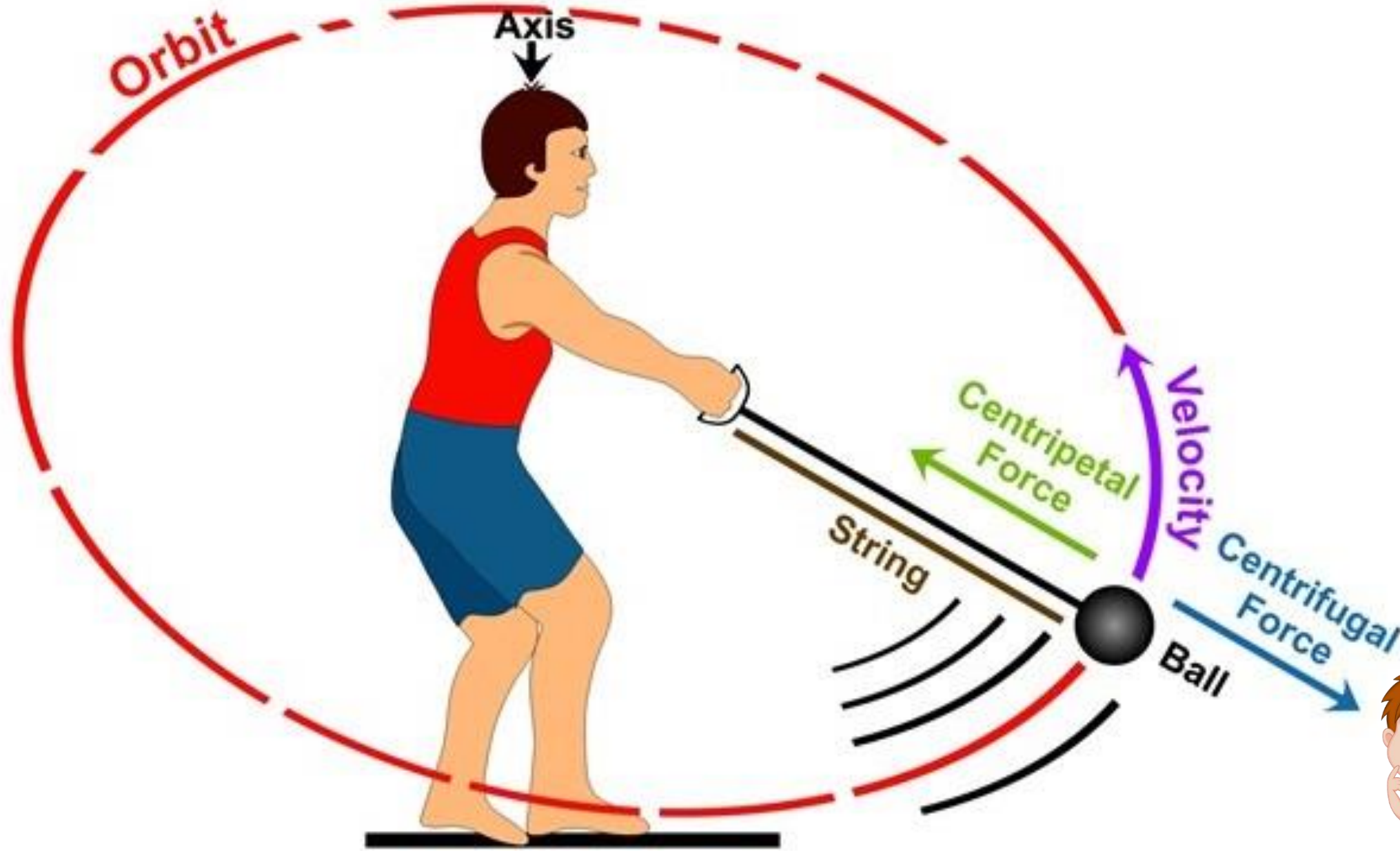
1. **Vertical Lift Component (L_V)**

   This vector act toward vertical upper direction and opposite to weight vector.

1. **Horizantal Lift Component (H_V)**

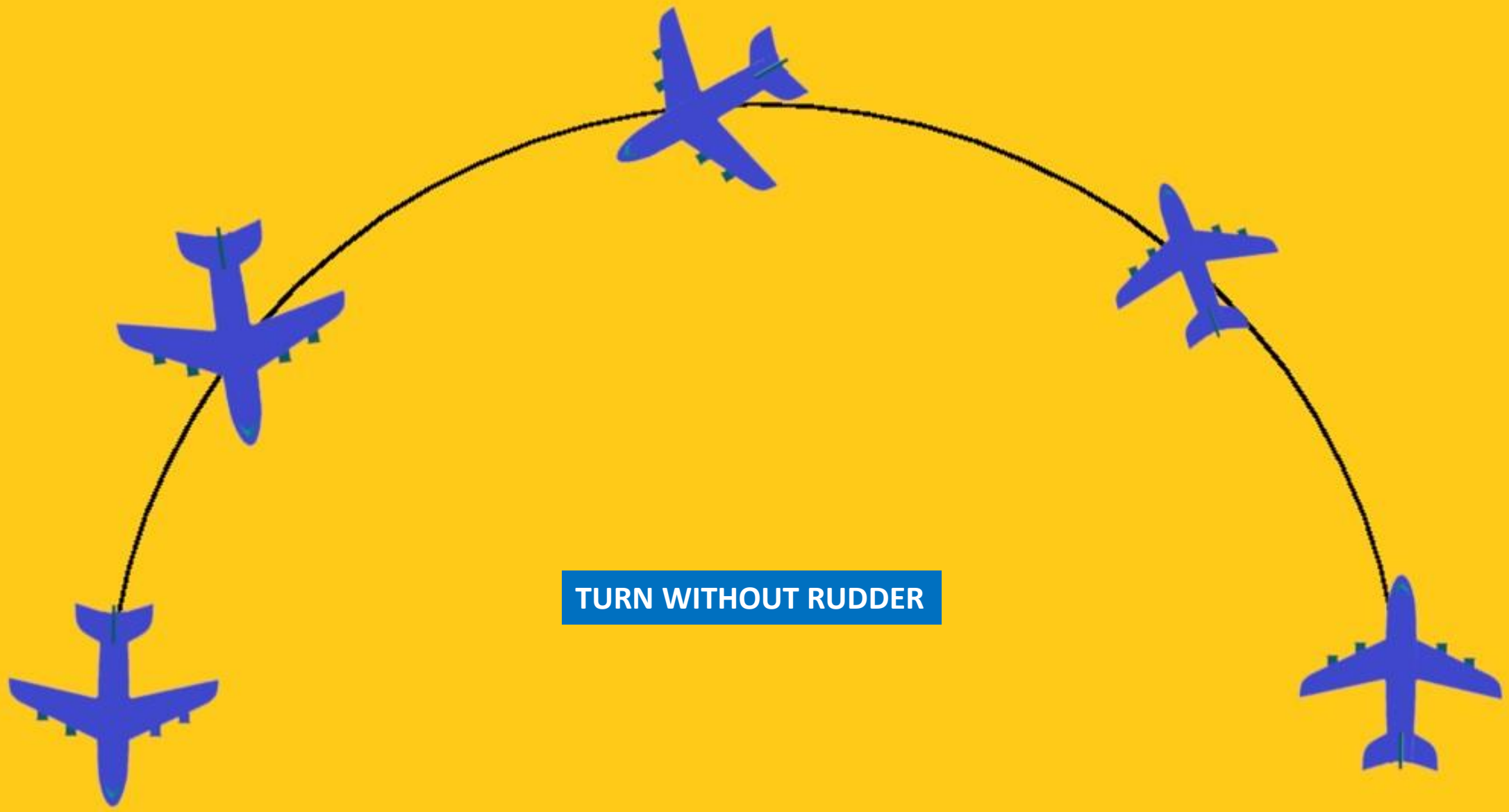
   This horizontal force vector is nothing but centripetal force which is equal and opposite to centrifugal force.

   Actually horizontal force vector or centripetal force component pull the aircraft from straight flight path and make aircraft turn.

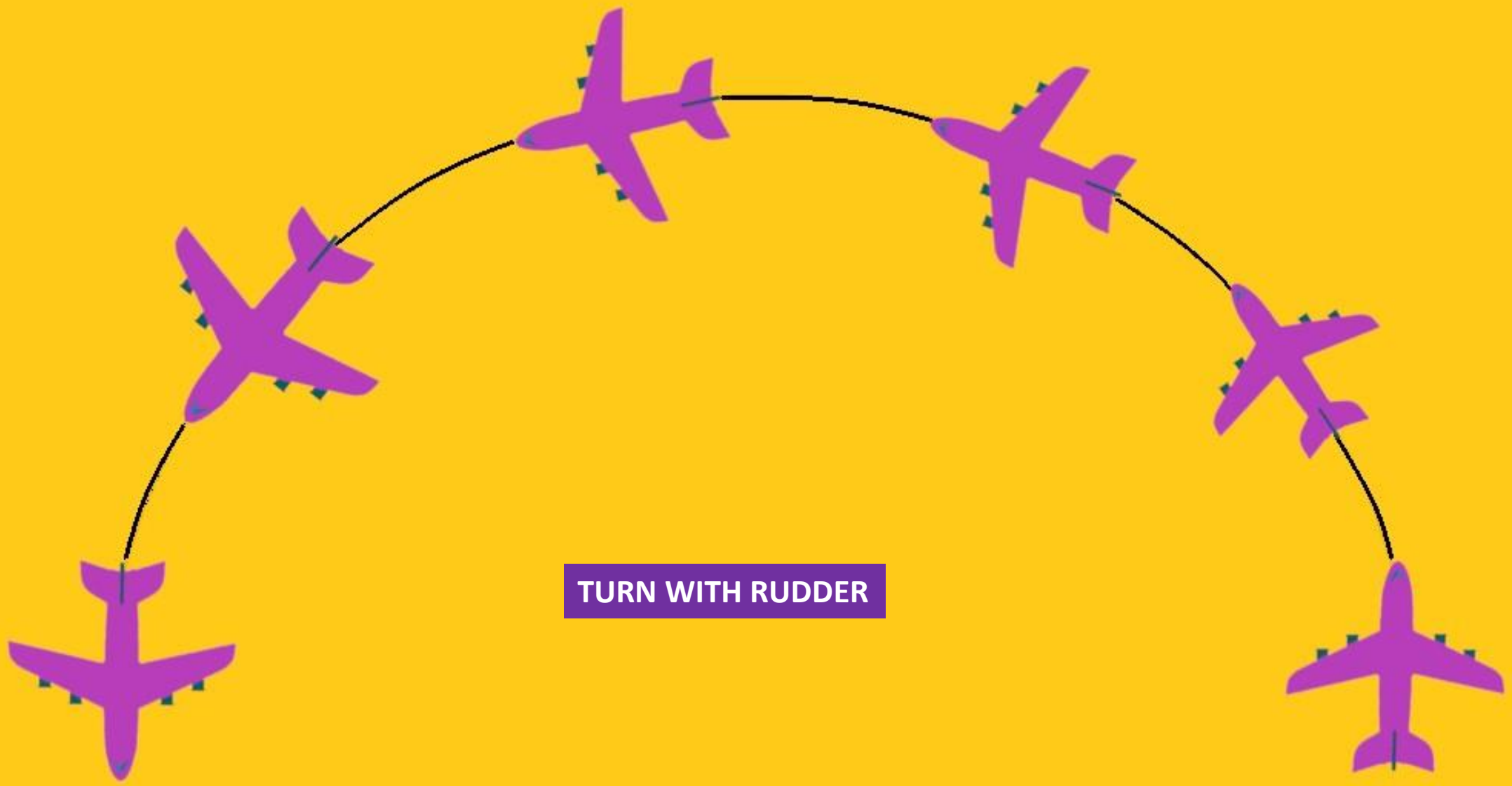

Orbit
Axis
Centripetal Force
Velocity
String
Centrifugal Force
Ball

Use of Rudder in Turning

- Force for turn is not supplied by the rudder.
- Rudder is used for correct the deviation between straight tractor nose and tail of the aircraft along with the same path.
- If NO rudder is used for turn then nose of aircraft will yaws outside the of turn path.
- Rudder is used for bring back the nose of the aircraft in regular path of turn or the line of relative turn.
- Without banking aircraft turn is not possible because then is no force to pull aircraft from straight path.



TURN WITHOUT RUDDER



TURN WITH RUDDER

- When aircraft takes turn then lift component is tilted and divided into two components.

1. Vertical Lift component
2. Horizontal Lift component

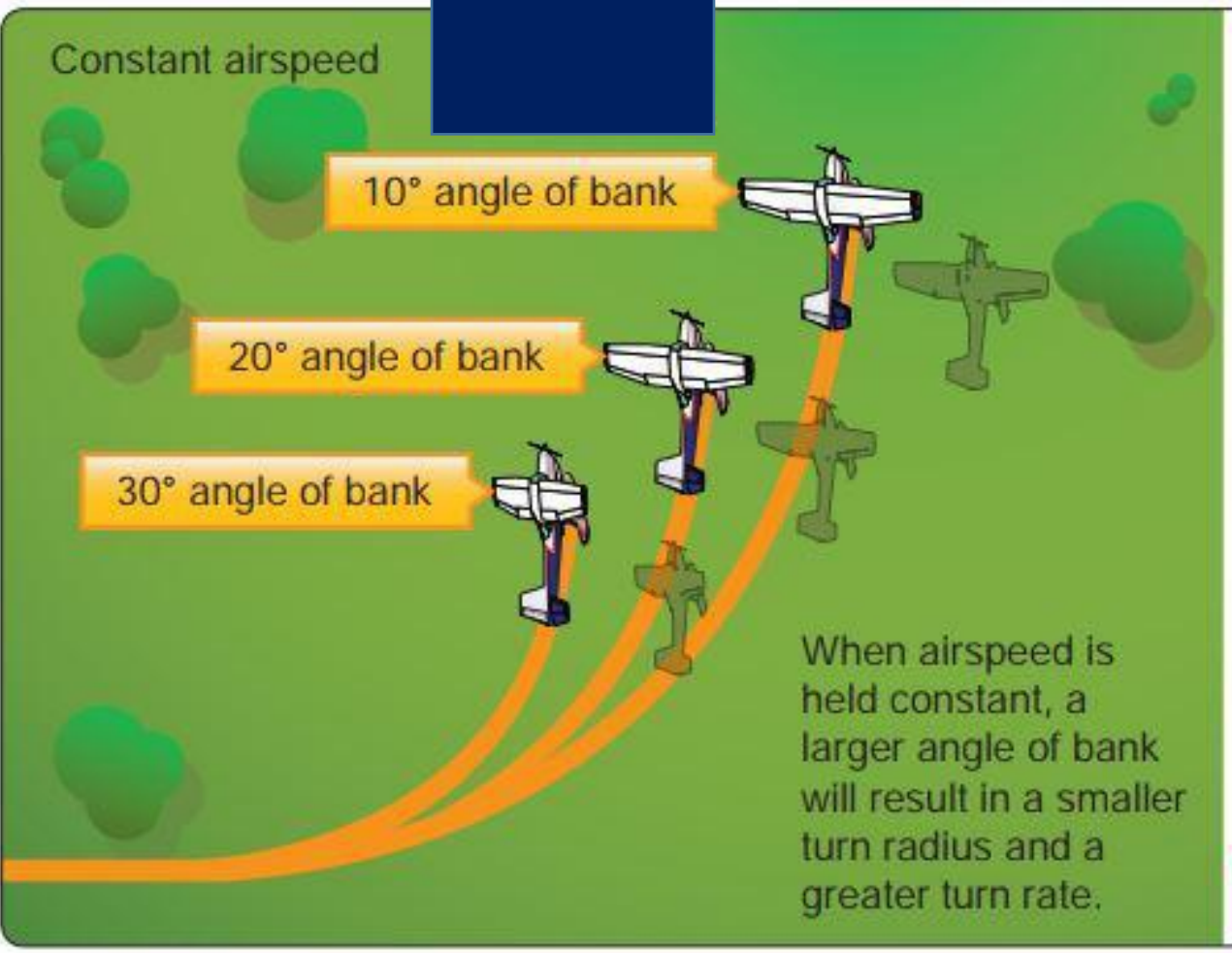
- In Banking condition , weight of aircraft is balanced by vertical lift component.
- But in banking vertical lift component is less than the weight component of aircraft so aircraft is starting to loose the altitude.
- So to maintain the same altitude pilot need to increase the vertical lift component by increasing the angle of attack.
- Angle of attack is increased by the help of elevator.
- So as Angle of Attack (AOA) increases then weight component will be equal to the vertical lift component and aircraft able to take level turn or perfect turn with banking

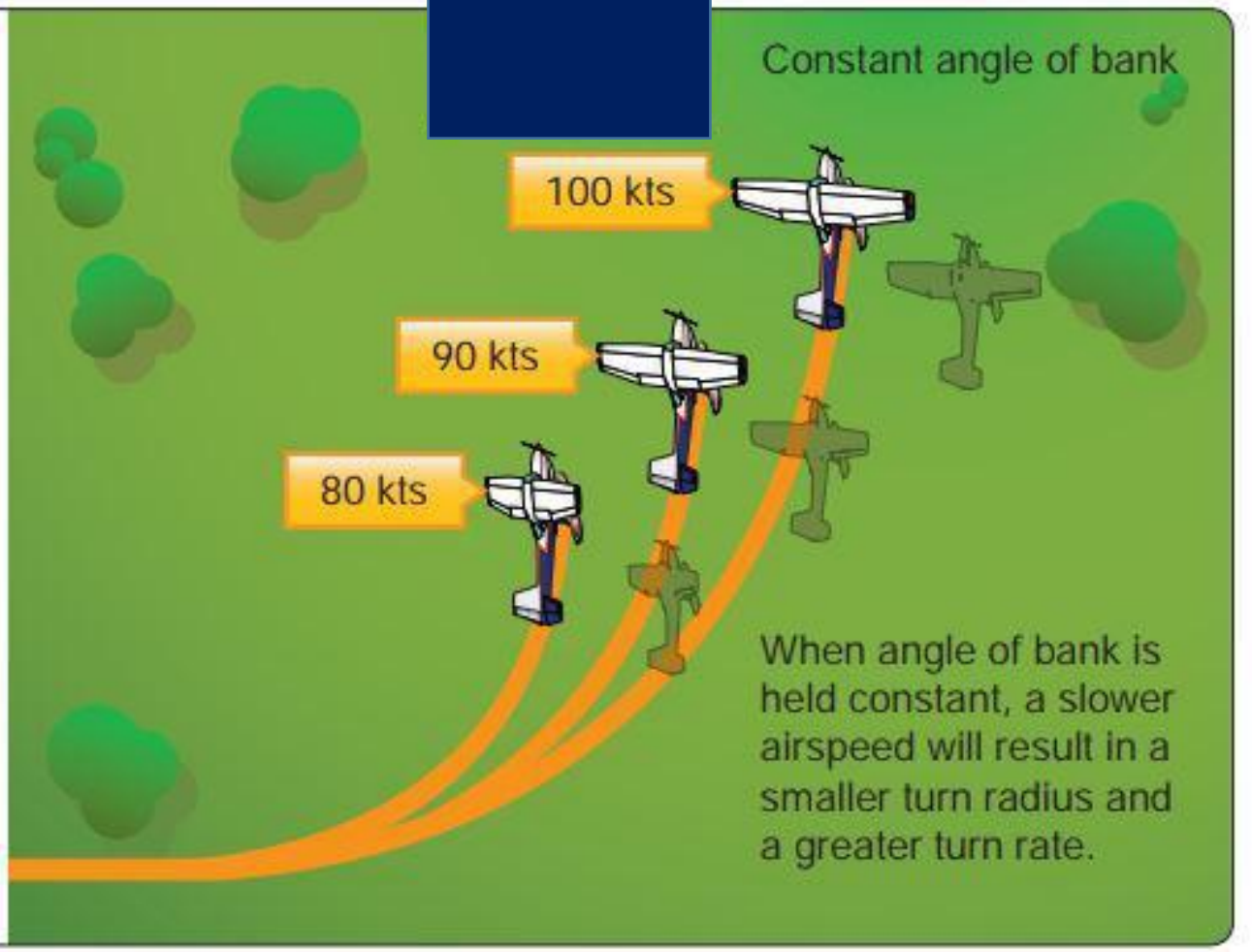
- **Rate of turn is depend on horizontal lift component of lift.**
- **If Bank angle increases (Φ) then horizontal lift component increases (LH) , vertical lift component (Lv) decreases, so centripetal force (Fcp) increases so Rate of turn increases (ROT).**
- **If Bank angle decreases (Φ) then horizontal lift component decreases (LH) , vertical lift component (Lv) increases, so centripetal force (Fcp) decreases so Rate of turn decreases (ROT).**
- **So Rate of turn can be controlled by bank angle (Φ)**

What is a Rate of Turn(ROT)?

- Rate of turn is change in angular velocity with respect to time.
- $ROT = \frac{d\omega}{dt} = \frac{V}{R}$
- Unit – Degree per second.

- ROT indicates the how fast aircraft can take turn.





- If bank angle (Φ) increases then vertical lift component decreases so pilot need to increase angle of attack (AOA) then lift of the aircraft increases.
- Induced drag is proportional to the lift of the aircraft so induced drag increases with Increasing angle of attack and aircraft speed decreases.
- To maintain the constant speed , aircraft engine thrust must be increases by using throttle.
- So we can say that additional thrust is proportional to bank angle(Φ).

1. **If aircraft need to maintain the constant altitude at turn and velocity increases then**

To maintain same altitude, angle of attack must decreases

OR

Bank angle must increases

(Increases lift is decreased by reducing AOA or increasing bank angle)

2.If bank angle is constant and angle of attack is decreases then

Rate of Turn decreases

(because velocity increases due to less AOA)

3. If Rate of Turn is constant and velocity of aircraft increases with angle of attack is constant then

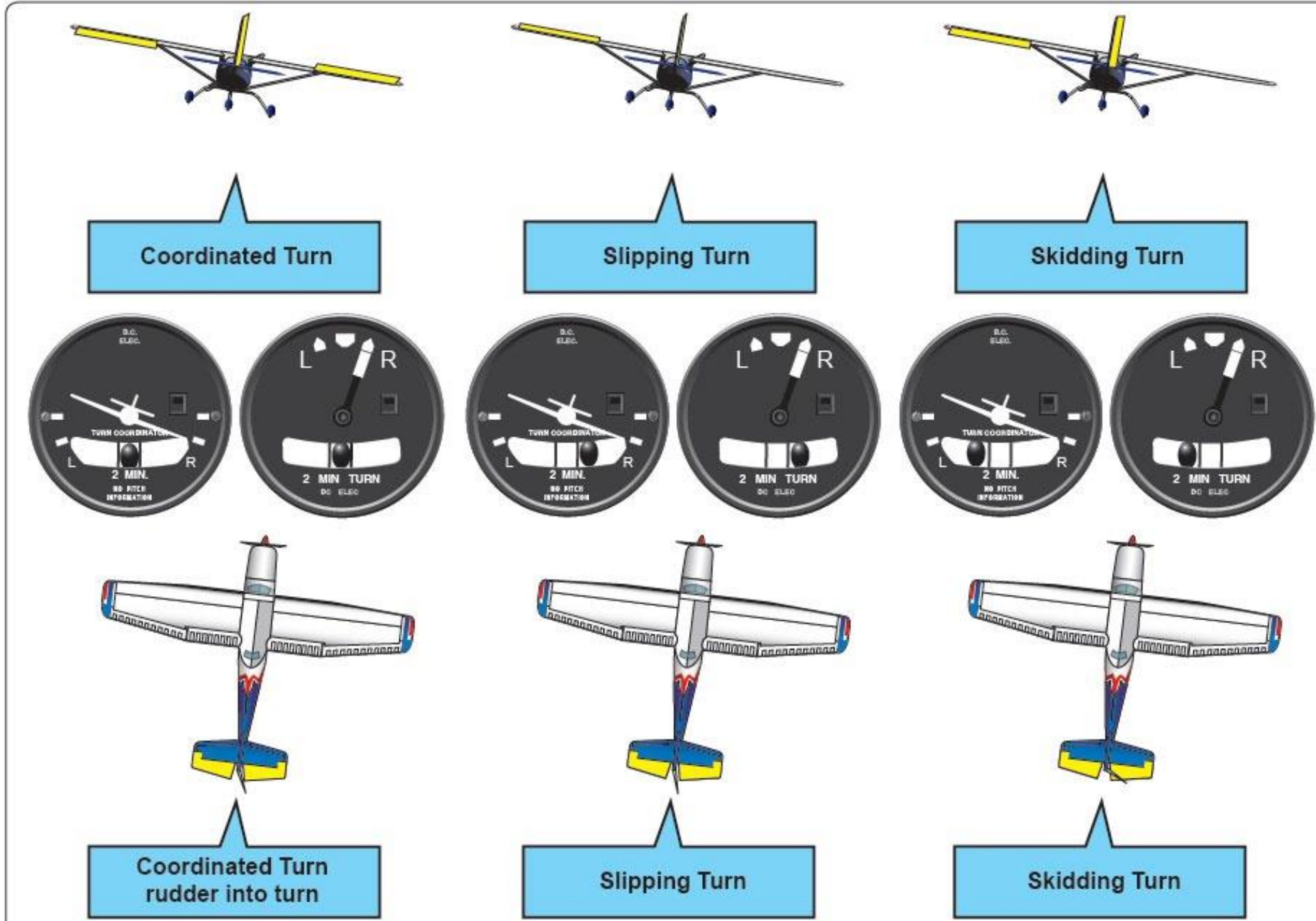
Bank angle must be increases

- If airspeed increases then aircraft turn radius also increases.
- Centrifugal force is proportional to radius of turn so Centrifugal force also increases.
- So maintain constant rate of turn horizontal lift component (LH) or centripetal force must be increases to balance the centrifugal force.
- It can be increased by increasing Bank angle
- For coordinated turn Centrifugal and centripetal force must equal.ie CF = CP = LH

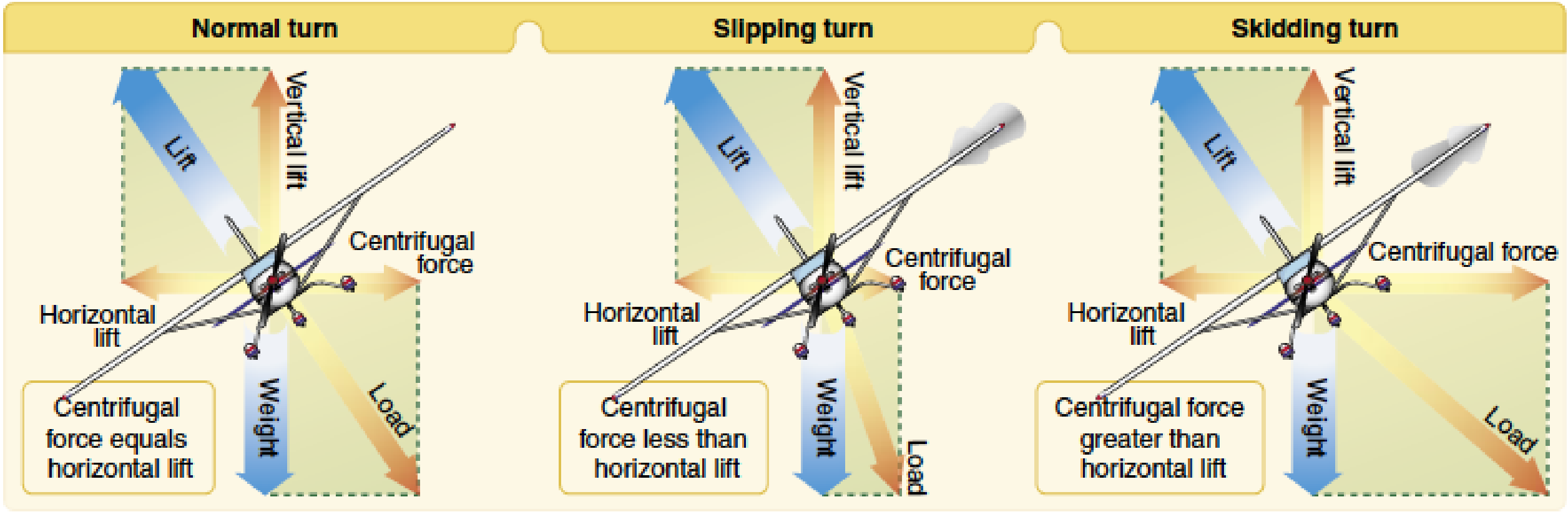
MORE ON TURNING

- If aircraft turning rate is not suitable for bank angle then aircraft will yaws outside or inside the of the turning path.
- when pilot uses less rudder or more rudder than required then also this situation occurred.
- There are three types of turning

1. Slipping Turn / Adverse Yaw
2. Skidding Turn
3. Coordinated Turn



Note the slight differences in rudder placement.



1.SLIPPING TURN

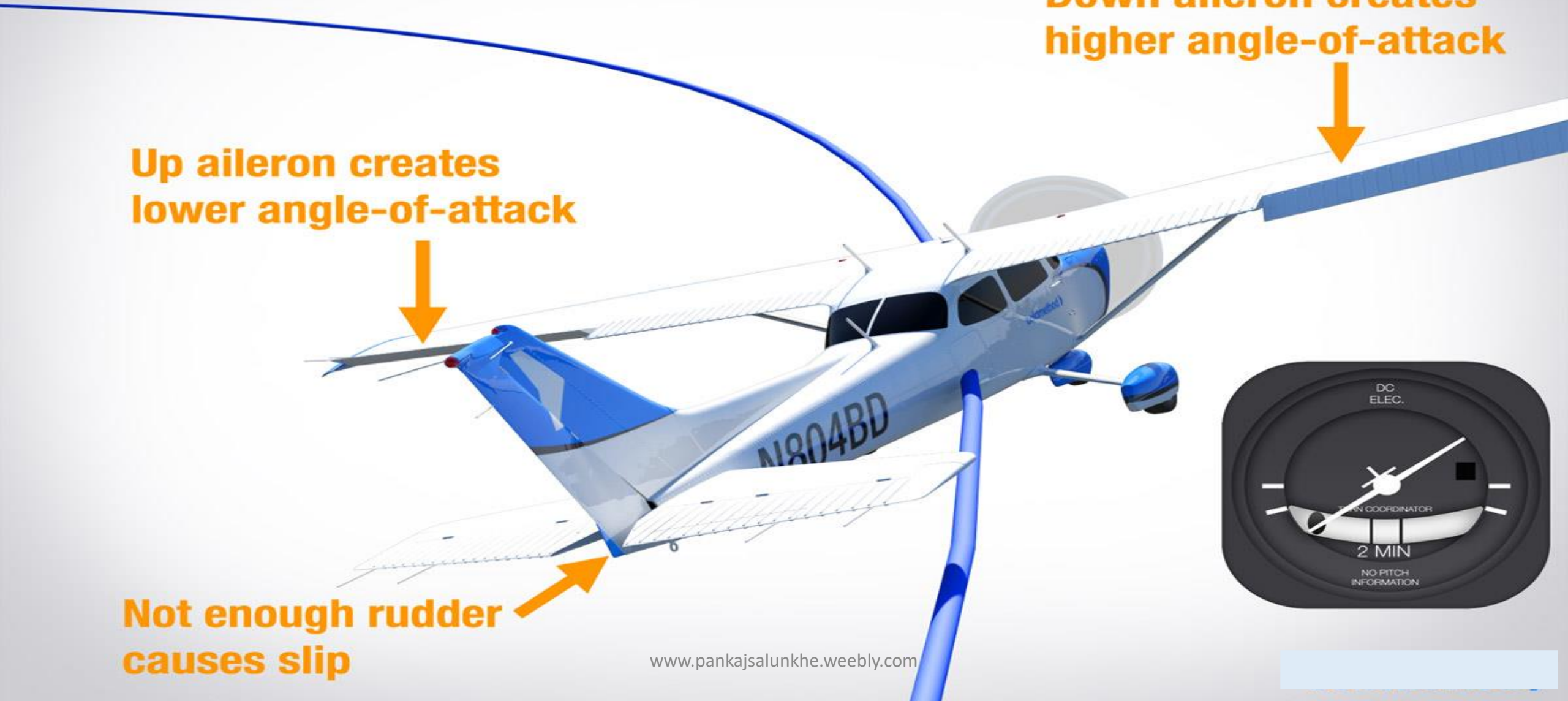
- When aircraft bank angle(Φ) is more than required for the rate of turn(ROT) then Horizontal lift component or Centripetal force is more than Centrifugal force this causes slipping.
- Pilot uses less rudder.
- In slipping turn aircraft is blanketing (Reduce the air flow and decrease the angle of attack) upper wing so upper wing loses the altitude. Then applying the rudder aircraft can be stabilized.
- slipping is safer than skidding.
- This condition can be recovered by
- Either decreasing the Bank angle (Φ) OR Increasing the Rate of turn (ROT) OR Applying Both.

Slipping Turn

Ailerons counter underbanking tendency

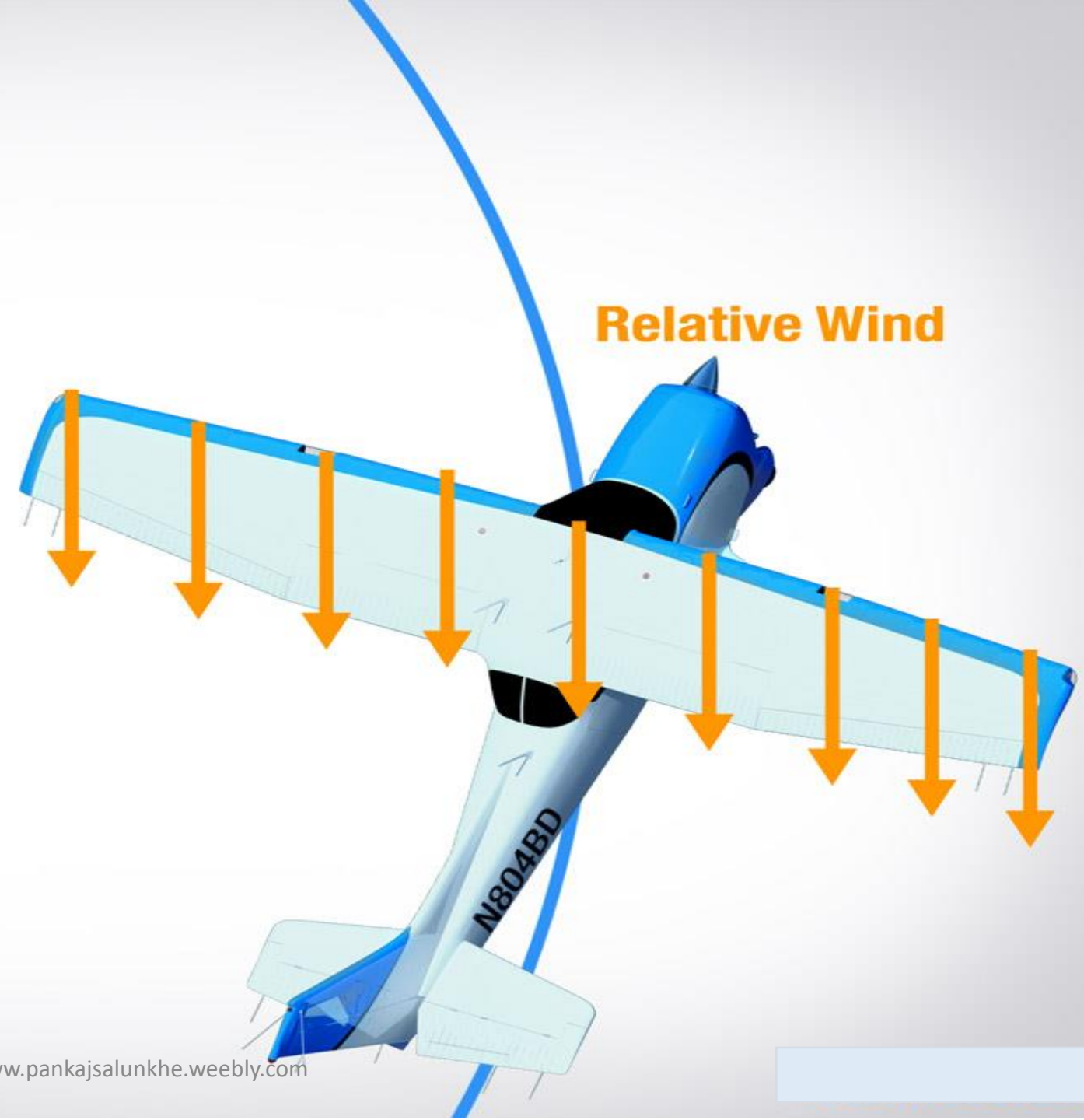
Down aileron creates higher angle-of-attack

Up aileron creates lower angle-of-attack



Not enough rudder causes slip

Slipping Turn Overhead



2.SKIDDING TURN

- When aircraft Rate of Turn is more than required for the aircraft bank angle(Φ) then Centrifugal force is more than Horizontal lift component or Centripetal force this causes skidding.
- Pilot uses More rudder.
- In skidding turn aircraft is blanketing (Reduce the air flow and decrease the angle of attack) lower wing so lower wing loses more the altitude. And aircraft will enter in spinning.
- 70% to 80% of pilots dies due to spinning in skidding.
- Skidding is most dangerous situation for pilot because recovery from spin required at least 1000 feet for skilled pilot.
- This condition can be recovered by
- Either Increasing the Bank angle (Φ) OR Decreasing the Rate of turn (ROT) OR Applying Both.

Skidding Turn

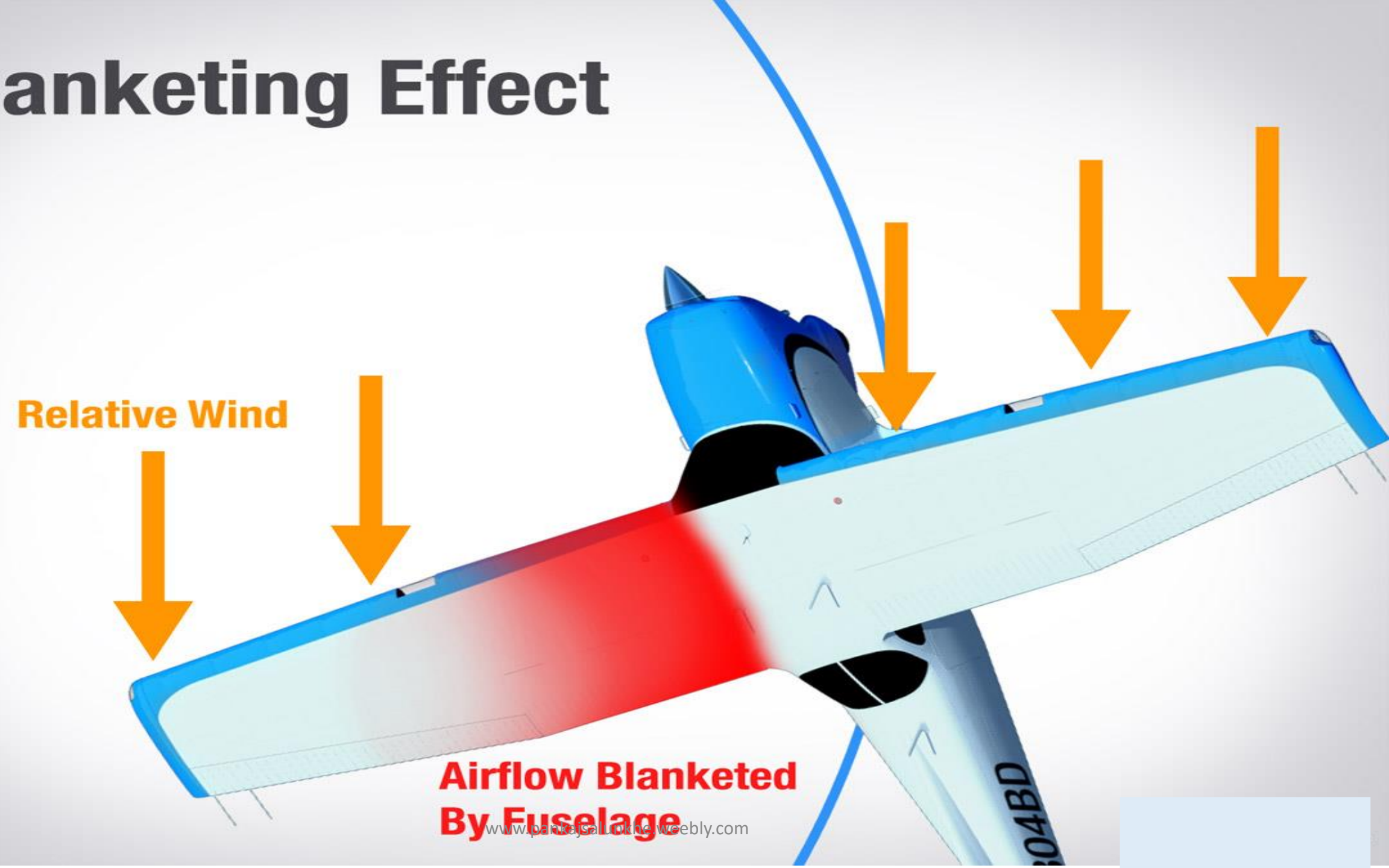
Ailerons counter overbanking tendency

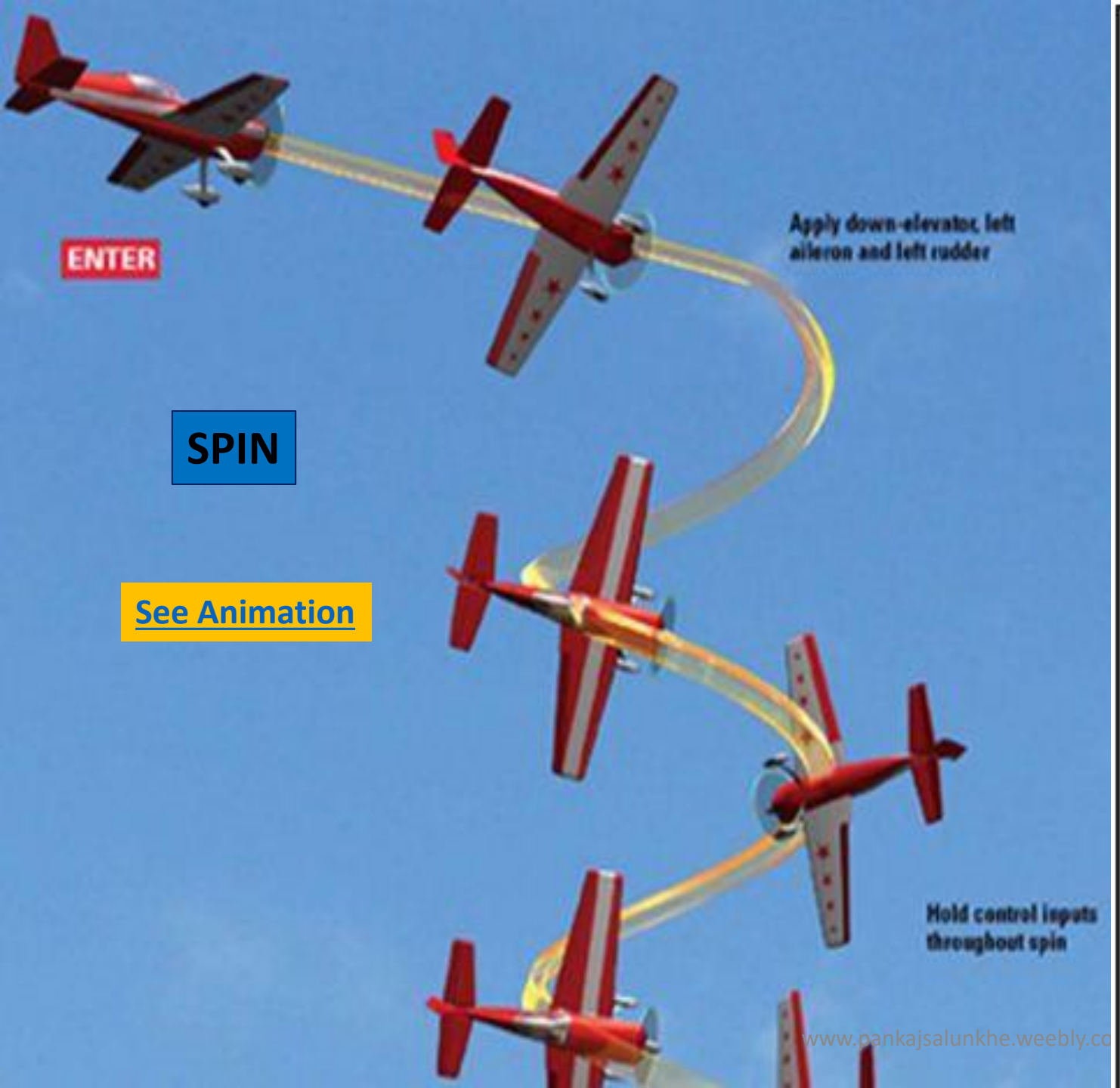
Up aileron creates
lower angle-of-attack

Too much rudder
causes skid

Down aileron creates
higher angle-of-attack

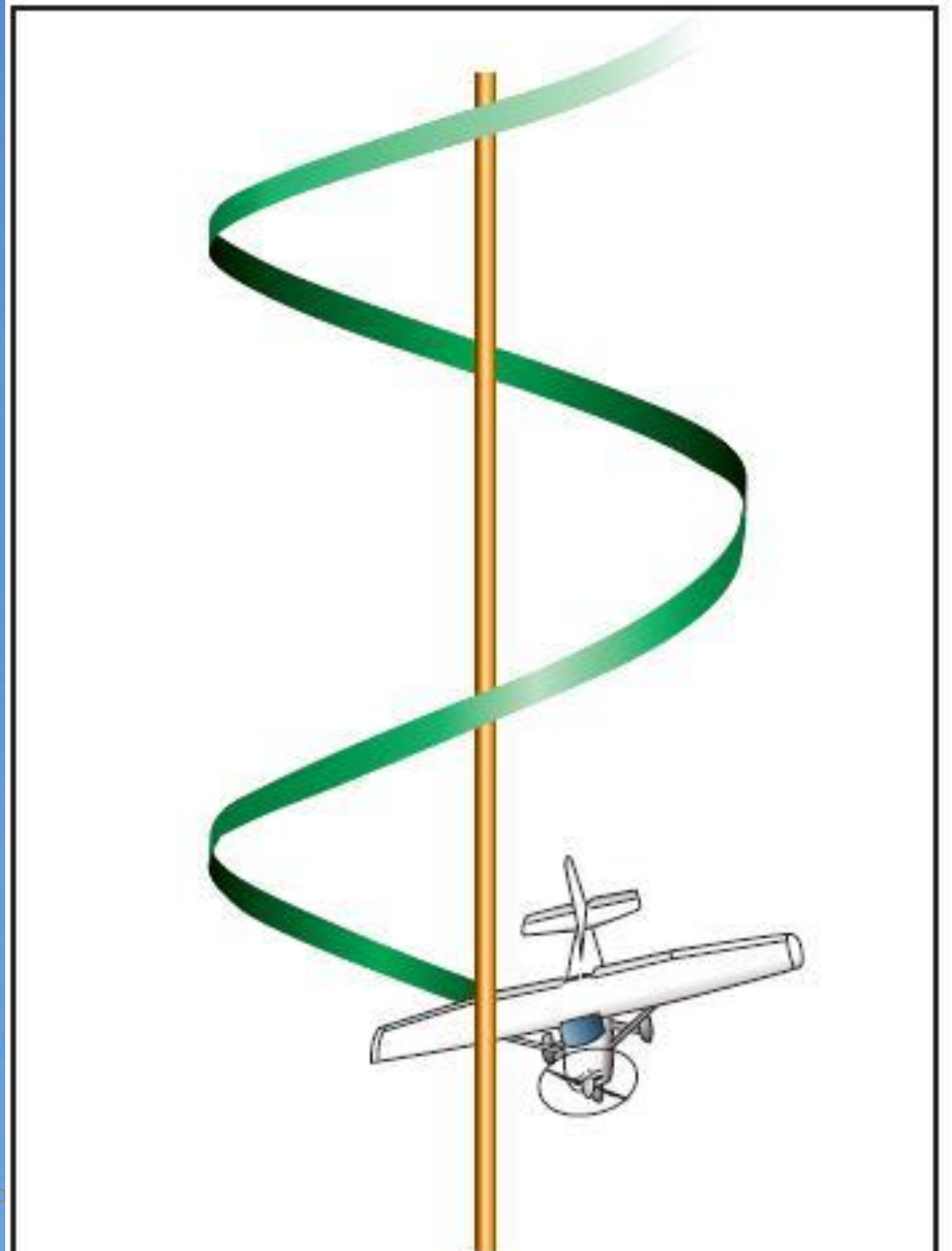
Blanketing Effect





SPIN

See Animation



3.COORDINATED TURN

- In the simplest terms, a coordinated turn is one in which the forces acting on the airplane in a turn are perfectly balanced. The plane is turning, and its occupants are not being pushed or pulled in any direction in their seats.
- If aircraft nose and tail is following same designed turning path with equal centripetal and centrifugal force as well as right rudder application.
- This is called coordinated turn.

Coordinated Turn

Nuclear fueled Nimitz-class aircraft carriers can Operate for 20 Years Without Refueling

धन्यवाद

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