II.D. PRINCIPLES OF FLIGHT

OBJECTIVE & COMPLETION STANDARDS

The learner develops an understanding of the principles of flight. They understand why planes are designed in certain ways and the forces acting on planes, and how to apply that knowledge to in flight.

The learner understands the principles of flight and can answer questions regarding lesson concepts and apply the concepts in flight.

KEY POINTS

- Stability vs Maneuverability
- Left Turning Tendencies
- Load Factors

ELEMENTS

1. Forces of Flight
2. Airfoil Design
3. Wing Planform
4. Stability & Controllability
5. Turning Tendencies
6. Load Factors in Airplane Design
7. Wingtip Vortices

REFERENCES

- Pilot's Handbook of Aeronautical Knowledge
- Airplane Flying Handbook

SCHEDULE

- Introduction
- Development
- Conclusion

EQUIPMENT

- White board
- Markers
- References

INSTRUCTOR

- Present Content
- Ask/Answer Questions
- Assign Homework

STUDENT

- Participate in learning
- Take notes
- Ask/Answer Questions

LEGEND & ABBREVIATIONS

SECTION HEADER FOR EACH LESSON ELEMENT

Light blue for ***Main points and/or brief section summary***

- **Orange** text is used for mnemonics or things to remember
- **RM**: Teal RM denotes an ACS Risk Management concept
- **CE**: Red CE shows an Airplane Flying Handbook listed Common Error

IA: Instructor Action (ex. hop out of the lesson & review a checklist) – Coming soon!

Light gray for notes, examples, extra details & explanations, etc.

INTRODUCTION

ATTENTION

Interesting fact or attention-grabbing story

Everything you ever wanted to know about the science of the airplane, which will result in a considerably better understanding of the airplane and hopefully make you a better pilot.

OVERVIEW

Review Objectives, Elements, and Key Points

Every single Knowledge & Risk Management task is annotated! Find whatever info you need.

WHAT

Principles of Flight are the characteristic forces of flight as well as why and how the airplane performs certain ways.

WHY

To become a pilot, a detailed technical course in the science of aerodynamics is not necessary. However, with the responsibilities for the safety of passengers, the competent pilot must have a well-founded concept of the forces which act on the airplane, and the advantageous use of these forces, as well as the operating limitations of the airplane.

HOW

1. FORCES OF FLIGHT

AI.II.D.K4

A. Overview

i. **Four Forces of Flight**

- **Lift**: Upward force created by the effect of airflow as it passes over and under the wing
- **Weight**: Opposes lift, and is caused by the downward pull of gravity
- **Thrust**: Forward force which propels the airplane through the air
- **Drag**: Opposes thrust, and is the backward/retarding force, which limits the speed of the plane

ii. **Terminology:**

- **Chord Line**: Imaginary straight line joining the leading and trailing edges of an airfoil
- **Relative Wind**: Direction of movement of the wind relative to the aircraft's flight path
- **Angle of Attack**: Angle between the chord line and the relative wind

B. Lift

The force that opposes weight

i. Principles of Lift

- **Bernoulli's Principle: As the velocity of a fluid (air) increases, its internal pressure decreases**
- Newton's Laws of Motion:

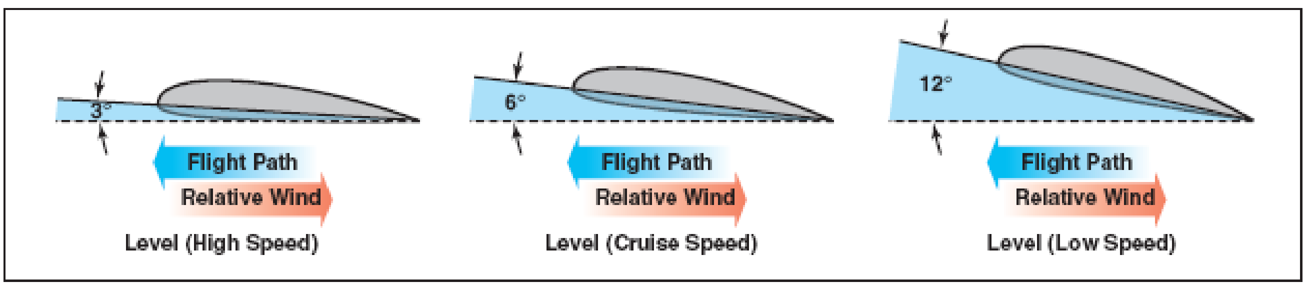
- 1st Law: A body at rest tends to remain at rest, and a body in motion tends to remain in motion
- 2nd Law: Force = Mass x Acceleration (F=ma)
- **3rd Law: For every action there is an equal and opposite reaction**

ii. Airfoils

- Airfoil: Any surface which provides aerodynamic force when it interacts with a moving stream of air
- The wing's shape is designed to take advantage of Newton's Laws and Bernoulli's Principle
  - Greater curvature on the upper portion causes air to accelerate as it passes over the wing (Bernoulli)
  - A downward-backward flow of air also is generated from the top surface of the wing
    - The reaction to this downwash results in an upward force on the wing (Newton's 3rd Law)
  - Newton's 3rd law is also apparent as the airstream strikes the bottom of the wing when inclined
    - The air is forced downward and therefore causes an upward force resulting in positive lift

iii. Pilot Control of Lift

- Lift = ½ pC_Lv^2S (Memory Aid: **½ P**int, **C**hug a **L**iter, **V**omit **twice**, **S**leep it off)
  - P = Rho or a pressure constant
  - C_L = Coefficient of Lift – A way to measure lift as it relates to the angle of attack
  - V = Velocity
  - S = Surface Area (Constant)
- The amount of lift generated is controlled by the pilot and determined by aircraft design factors
  - The pilot can change the **Angle of Attack (AOA), airspeed, and the shape of the wing (flaps)**



C. Weight

Force of gravity which acts vertically through the center of the plane toward the center of earth

i. When lift = weight, the plane is in equilibrium and doesn't gain or lose altitude

If weight > lift, the plane descends and if lift > weight, the plane climbs

D. Thrust

Forward-acting force which opposes drag and propels the airplane

i. F = MA (Force comes from the engine, mass of air is accelerated opposite the direction of flight)

ii. Thrust starts the airplane moving, it continues to move and gain speed until thrust and drag are equal

If thrust > drag, the plane accelerates & if thrust is < drag, the plane decelerates

E. Drag

Rearward, retarding force, caused by disruption of airflow by the wing, fuselage, or other objects

Opposes thrust, and acts rearward and parallel to the relative wind

Two types of drag: Parasite & Induced

i. **Parasite Drag** - Caused by surfaces which deflect/interfere with the smooth airflow of the airplane
- **Form Drag**: Shape of the aircraft/separation of airflow from the surface of the structure

  Basically, how aerodynamic is the aircraft?
- **Interference Drag**: Occurs when varied currents or air over an airplane meet and interact

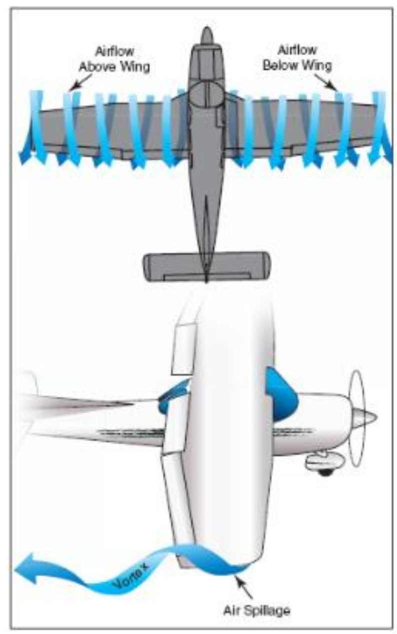
  Mixing of air over structures (wings, tail, gear, struts, etc.)
- **Skin Friction Drag**: Caused by the roughness of the airplane's surfaces

  A thin layer of air clings to the plane's skin creating small eddies which add to drag
- As airspeed increases, Parasite drag increases
  - Varies proportionately to the square of the airspeed

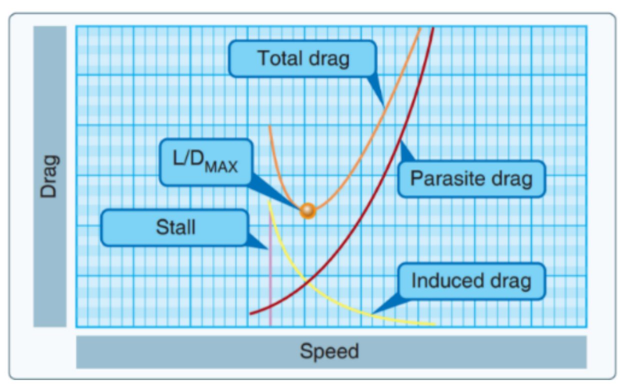
    A plane has 4x the parasite drag at 160 knots vs 80 knots

ii. **Induced Drag** – As lift increases, so does induced drag
- Lift is produced at the expense of induced drag
- How it Works
  - Air flows from high-pressure below the wing to low-pressure above the wing creating vortices
  - Vortices create an upward flow of air beyond the wingtip/downwash behind the trailing edge
    - This downwash is the source of induced drag
  - Downwash – The source of Induced Drag
    - Tilts the wing's vertical lift back – this is the induced drag

      The wing operates in an average relative wind which is inclined rearward & downward by the vortices – the wing's lift is perpendicular to the relative wind
    - The greater the vortices strength/downwash, the more the lift tilts back, and the greater induced drag
- As lift increases, Induced drag increases



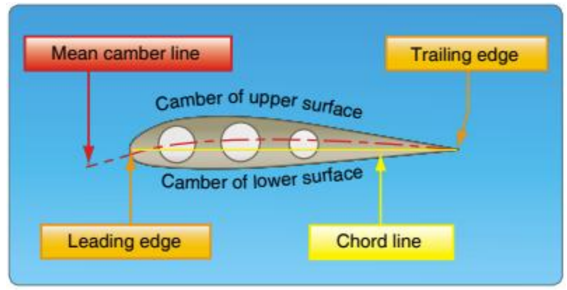
iii. **Total Drag**
- The sum of induced and parasitic drag
- **Region of Normal Command**
  - As airspeed decreases, total drag decreases, to a point (L/D_{MAX})
  - Higher speeds require higher power
- **Region of Reversed Command**
  - As airspeed decreases below L/D_{MAX}, total drag increases



2. AIRFOIL DESIGN AI.II.D.K1

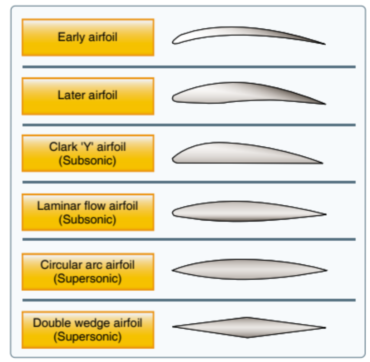
Airfoil: Structure designed to obtain reaction upon its surface from the air

A. Terminology

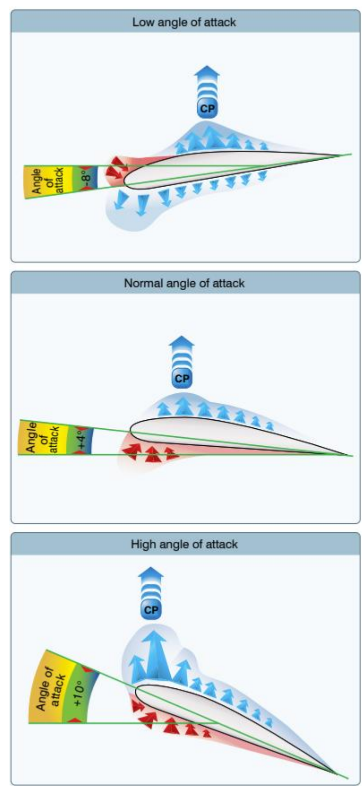


- i. Camber
- ii. Leading edge / Trailing edge
- iii. Chord Line
- iv. Mean Camber Line

B. General Design Characteristics



- i. Air Pressure
  - Airfoil is constructed to take advantage of physical laws
    - Low pressure (negative pressure lifting action) above the wing
    - High pressure (positive pressure lifting action) from below
  - Aircraft weight, speed, purpose dictate shape
- ii. Low Pressure Above
  - Faster moving air over the upper surface – Bernoulli's Principle
  - Down/backward flow of air creates downwash – Newton's 3rd Law
- iii. High Pressure Below
  - Positive pressure from below the airfoil – Newton's 3rd Law
  - Stagnation Point: Air is virtually stopped at the leading edge
    - Slower airflow = increased pressure (Bernoulli's principle)
- iv. Aircraft weight, speed & purpose dictate the airfoil shape (pictured, right)
- v. Pressure Distribution (pictured, right)
  - At different AOAs, pressures vary between positive / negative
  - Center of Pressure (CP): Average of the pressure variations at a given AOA
    - Aerodynamic forces act through the CP
    - Higher AOAs: CP moves forward
    - Lower AOAs: CP moves aft
  - CP movement affects aerodynamic balance and controllability



***Note**: Production of lift is much more complex than simple differential pressures between the upper / lower surfaces, but these concepts suffice for this discussion*

3. WING PLANFORM & TERMINOLOGY

A. Planform – Wing's outline from above

i. Characteristics / advantages to each shape

ii. Load factors, maneuverability and stability, stall/spin characteristics, fuel tanks, speed, gear, etc. all affect the shape

B. Taper – Ratio of root chord to tip chord

i. Decreases drag, increases lift

ii. Decreases weight of the wing

C. Aspect Ratio (Wingspan ÷ Ave Chord)

i. High aspect ratio decreases drag

ii. Low Aspect Ratio for extreme maneuverability/strength

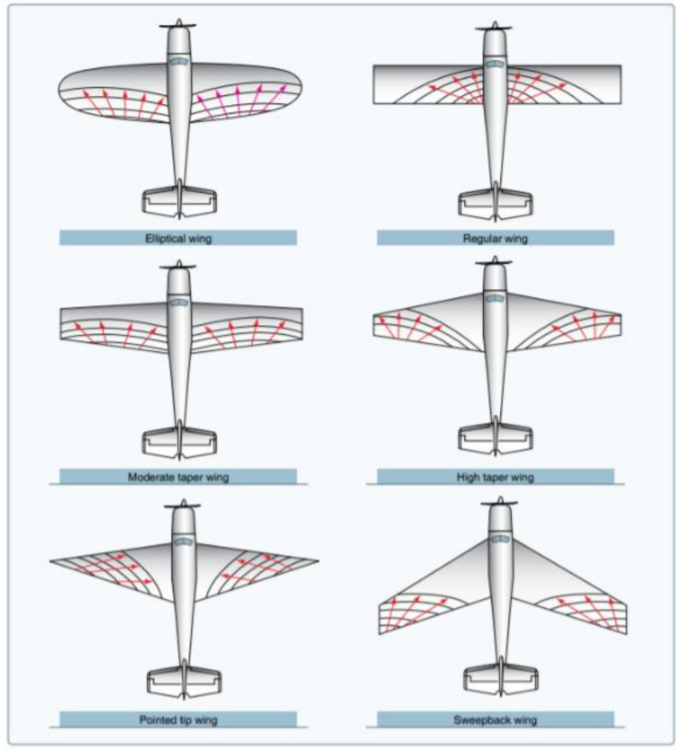
D. Sweep – Slant of the wing

i. Usually rearward but can be forward

ii. Helps flying near the speed of sound

iii. Helps lateral stability in slow planes

iv. Tends to stall at wingtips



4. STABILITY & CONTROLLABILITY AI.II.D.K2

A. Stability (Static and Dynamic)

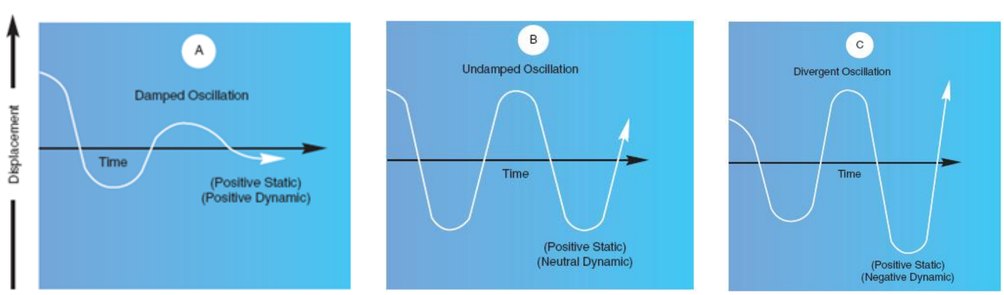
Inherent quality to correct for disturbances & return the original flight path – Primarily a design characteristic

i. **Static Stability** (SS): The ***initial tendency***; aircraft's initial response when disturbed

- **Positive** SS: Initial tendency to return to the original state of equilibrium
- **Negative** SS: Initial tendency to continue away from the original state of equilibrium
- **Neutral** SS: The initial tendency to remain in a new condition

ii. **Dynamic Stability** (DS)

- The aircraft's **response to a disturbance over time**
- Positive, Negative, and Neutral – Same as SS, but over time (overall tendency)

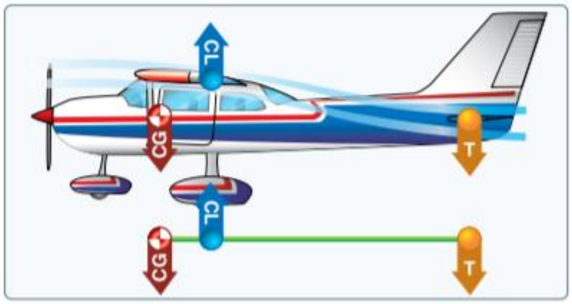


iii. Stability significantly **affects Controllability & Maneuverability**
- **Controllability**: Aircraft's ability to respond to control inputs
- **Maneuverability**: Permits an aircraft to be maneuvered easily and to withstand stresses
- **Stability, Controllability, and Maneuverability must be balanced**

B. Longitudinal Stability (LS) – About the Lateral Axis (Pitch)

i. The wing and tail moments need to be balance
- Ex: If nosed up, the wing/tail moments will change to bring the nose back down

ii. Static LS is dependent on 3 factors:
- Location of the wing in relation to the CG



The CG is often ahead of the CL, resulting in nose down pitch. The pitch is balanced by a tail down force (negative AOA on horizontal stabilizer). The 3 forces act as a lever – if the nose is pitched up, airspeed decreases, reducing the tail down force, pitching the nose down, increasing the tail down force, etc. until balanced

- Location of the horizontal tail with the CG

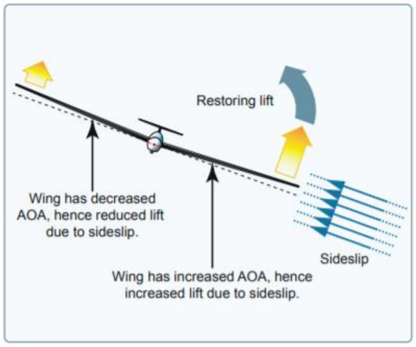
***Forward CG**: More tail down force is necessary. This adds to LS, since the nose heaviness makes it harder to raise the nose & the extra tail down force makes it difficult to pitch down*

***Aft CG**: Less stable – If the CG is behind the CL, the tail must exert upward force. If a gust pushes the nose up, less airflow over the tail will cause the nose to pitch up further*

- The area of the tail surfaces

The larger the tail surface, the more force exerted

C. Lateral Stability - About the Longitudinal Axis (Bank)



i. **Dihedral** - Angle wings are slanted upward (pictured, right)
- Stabilizing - Balances lift in a sideslip

The wing slipping into the wind (low wing) gets an increase in AOA & lift while the high wing gets a decrease in AOA/lift, rolling it back toward level

ii. **Sweepback** - Angle wings are slanted back
- Effectively increases dihedral (10° of sweepback = 1° of dihedral)

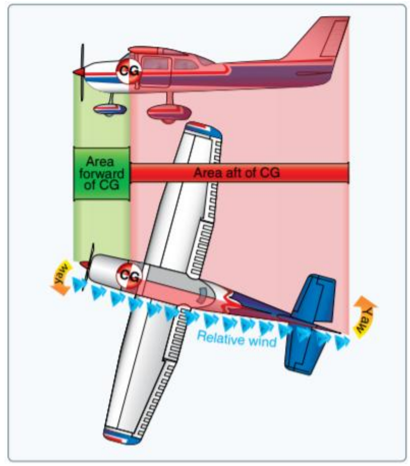
If a wing drops, the leading edge of the low wing is more perpendicular to the airflow = more lift and a roll back toward level

iii. **Keel Effect** (pictured, right)

- A greater portion of the keel is above and behind the CG
- Fuselage acts like a keel, moving the plane toward level

If the plane slips to one side, the plane's weight + the airflow against the upper portion of the keel rolls it back towards wings level

iv. **Weight Distribution**
- The plane will bank toward a heavier loaded side



D. Directional Stability (DS) - Stability about the Vertical Axis (yaw)

i. Affected by the area of the vertical fin and sides of the fuselage aft of the CG

__Vertical Fin__: Acts like a feather on an arrow – the farther aft and the larger the fin, the greater the stability – as the plane yaws in one direction, the air strikes the opposite side of the vertical fin

__Fuselage Side__: With a greater surface area behind the CG, if the nose yaws one direction, the relative wind pushes back in the other direction

ii. Plane acts like a weathervane, nose points into relative wind

5. TURNING TENDENCY — AI.II.D.K3

Made up of 4 elements which produce a twisting or rotating motion around at least 1 of the 3 axes

A. Torque Reaction – Based on Newton's 3rd Law

i. The engine parts/propeller rotate right, an equal force attempts to rotate the plane left
- In Flight: Left Rolling Tendency
- On the Ground: Left Turning Tendency

ii. Corrected by offsetting the engine, aileron trim tabs, and/or aileron and rudder use

B. Corkscrew/Slipstream Effect

i. Corkscrewing propeller air strikes the left side of the vertical stabilizer - pushes nose left

ii. Strongest at high prop speeds/low forward speeds

C. Gyroscopic Action

i. Precession - Any force takes effect 90° ahead of, and in the direction of rotation

ii. Pitch results in a yawing moment and vice versa

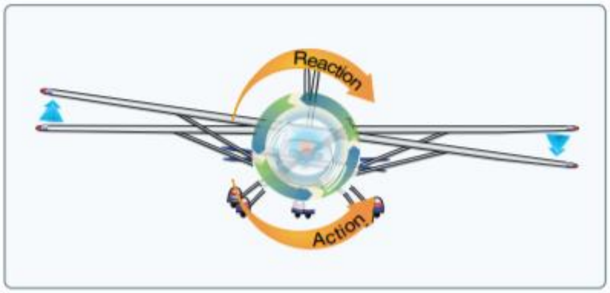
iii. Correct with rudder/elevator

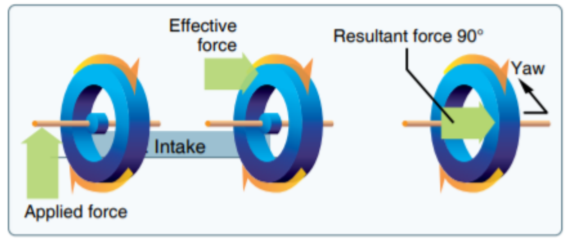
D. Asymmetric Loading (P Factor)

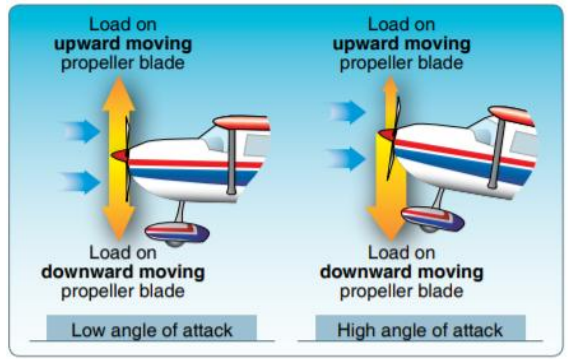
i. At high AOAs, the bite of the down moving blade is greater than the up moving blade

ii. Center of thrust moves to the right of the propeller disc, causing a yaw to the left

iii. Correct with right rudder







6. LOAD FACTORS (LF) IN AIRPLANE DESIGN AI.II.D.K5

A. General

i. Ratio of the total air load on the plane to the gross weight of the plane – Measured in Gs

Gs can be positive (sharp pull-up, force into the seat) or negative (sharp push down, floating)

1G = Normal gravitation forces & 2Gs = 2x gravitational forces, etc.

ii. Load Factor is primarily important to for two reasons:

- Increased load factor increases the stall speed, making stalls possible at seemingly safe speeds
- It is possible to impose a dangerous overload on the aircraft structures

B. Airplane Design

i. Aircraft strength is determined largely by the use it will be subjected to

The idea is to determine the 'limit load factors,' or the highest LF that can be expected in normal ops

ii. Designed in accordance with the category system:

- Normal Category Limit Load Factors: -1.52 Gs to 3.8 Gs
- Utility Category Limit Load Factors: -1.76 Gs to 4.4 Gs (Mild acrobatics, including spins)
- Acrobatic Category Limit Load Factors: -3.0 Gs to 6.0 Gs

C. Vg Diagram

i. **The Vg diagram describes the allowable airspeed/LF combinations for safe flight**

ii. Each aircraft has its own Vg diagram that is valid at a certain weight and altitude

iii. Areas to note on the Vg diagram:

- Lines of Maximum Lift Capability (curved red lines)

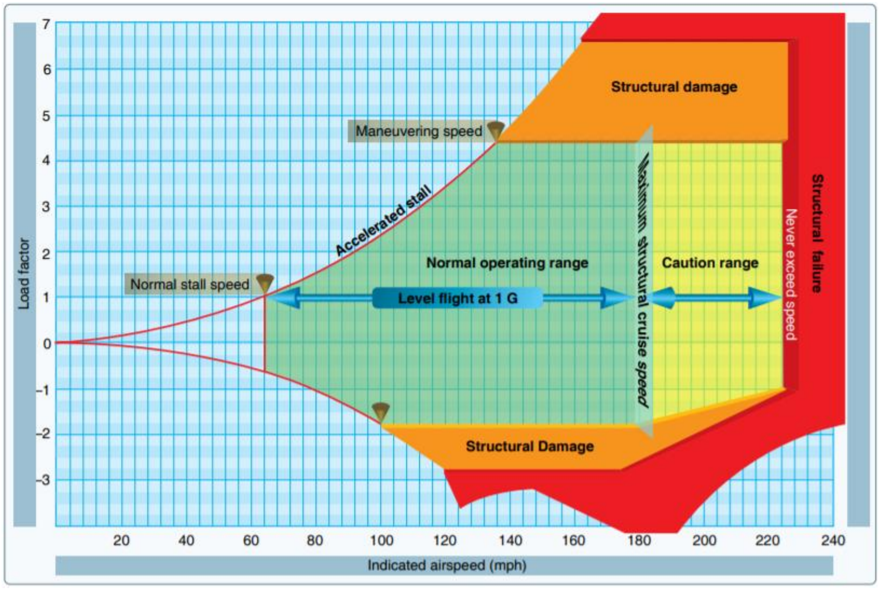
  Any LF outside of these lines is unavailable aerodynamically – i.e., the aircraft cannot fly above the *line of max lift capability because it stalls. The same applies for negative lift flight*

- Maneuvering Speed

  Intersection of positive limit load factor & the line of maximum positive lift – min speed at which the limit load can be developed aerodynamically

- Intersection of the Negative Limit Load Factor and Line of Maximum Negative Lift Capability

  Airspeeds less than this provide a negative lift capability the can damage the aircraft



- Limit Airspeed (red line)

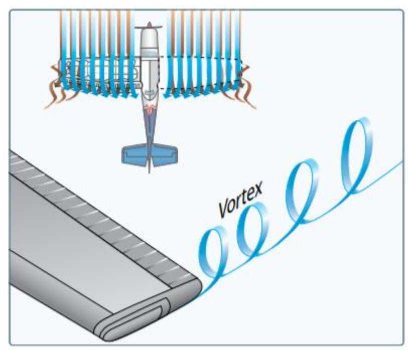
  Above this speed, structural damage or failure may result

7. WINGTIP VORTICES AI.II.D.K6

A. How They Work

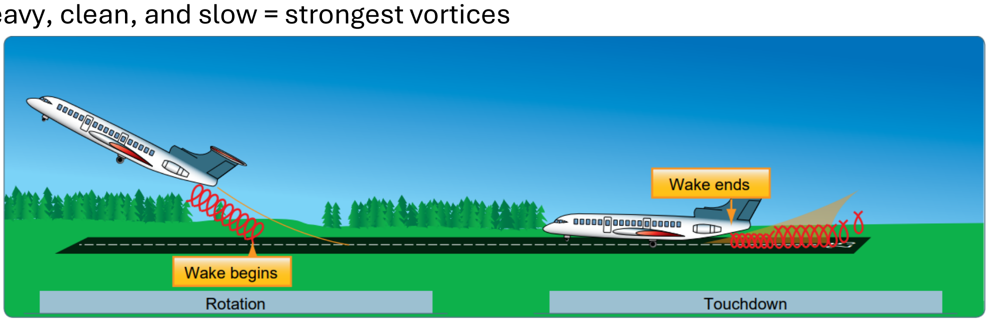
i. Why they Occur

- At positive AOA, pressure differential exists above/below the wing
- Air moves from higher to lower pressure, and the path of least resistance is the tips of the wings
- Air curls upward around the wingtip and combines with downwash to form vortices (increases drag)



ii. Vortex Strength

- The greater the AOA, the stronger the vortices
- Heavy, clean, and slow = strongest vortices



iii. Vortex Behavior

- Sink at a rate of several hundred fpm, slowing/diminishing over time
- When vortices sink to the ground, they tend to move laterally with the wind

- Crosswind decreases lateral movement of upwind vortex, but increases downwind vortex
- Tailwind can move the vortices of a preceding aircraft forward into the touchdown zone

B. Avoidance

i. **Takeoff**

- Takeoff before the other aircraft's rotation point; climb above or away from their flight path
- Takeoff beyond a landing jet's touchdown point

ii. **Enroute**

- Avoid flying through another aircraft's flight path
- Avoid following another aircraft on a similar flight path within 1,000' below

iii. **Landing**

- Stay above a preceding aircraft's path, and land past their touch down point
- Parallel runways – stay at and above the other jet's flight path for the possibility of drift
- Crossing runways – cross above the larger jet's flight path
- Land prior to a departing aircraft's takeoff point

C. For more details, see lesson **VI.B. Traffic Patterns, Wake Turbulence**

RM: BASIC AERODYNAMIC PRINCIPLES OF FLIGHT AI.II.D.R1

The lesson as a whole is a discussion of managing risk associated with aerodynamic principles

Conclusion: Brief review of the main points