Induce Drag byproduct = Wingtip Vortices
When on the runway, “Wake Turbulence”
Avoiding Wake Turbulence

Avoid Flying through another aircraft’s flight path or following another aircraft within 1,000 feet

Rotate prior to the point at which the preceding aircraft rotated when taking off behind an aircraft.

Approach the runway above a preceding aircraft’s path when landing behind another aircraft, and touch down after the point at which the other aircraft wheels contacted the runway.
INDUCED DRAG

Increases inversely with the square of the airspeed. Greatest at low AS.

Rearward component of lift is induced drag.
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$C_L$ Total Lift

$C_D$ Total Drag

$L/D$ Airfoil Efficiency

Airfoil Efficiency $L/D$ versus Critical Angle of attack

$L/D_{MAX}$

$C_{L_{MAX}}$

$L/D$ Stall

$C_L$ 1.8

$C_D$

$L/D$ Airfoil Efficiency
Aerodynamics: TOTAL DRAG & GROUND EFFECT

GROUND EFFECT: interference of airflow with airflow patterns of airplane. Reduces induced drag, reduces angle of attack to maintain lift. Land: FLOAT, Take-off lift off TOO SOON

POINT OF OPTIMAL LIFT/DRAG. BEST GLIDE SPEED
Ground Effect

Take Off—Decrease in induced drag causes liftoff too early, out of GE loss of altitude—too little lift.

Landing—Decrease in Induced drag causes “float” — further landing distance.

When an aircraft in flight comes within several feet of the surface, ground or water, a change occurs in the three-dimensional flow pattern around the aircraft because the vertical component of the airflow around the wing is restricted by the surface. This alters the wing’s upwash, downwash, and wingtip vortices. Ground effect, then, is due to the interference of the ground (or water) surface with the airflow patterns about the aircraft in flight.

The principal effects due to proximity of the ground are the changes in the aerodynamic characteristics of the wing. As the wing encounters ground effect and is maintained at a constant lift coefficient, there is consequent reduction in the upwash, downwash, and wingtip vortices. Distance: 1 wing span=1.4%, ¼ wingspan=23%, 1/10th wingspan=47.6% reduction of induced drag.
Aerodynamics: STABILITY

**STABILITY** is the characteristic of an airplane to return to a condition of equilibrium should its attitude be changed.

- **Static** stability: quick equilibrium.
- **Dynamic** stability: equilibrium of time.
- **Positive** (static or dynamic) returns to the desired condition.
- **Negative** (static or dynamic) gets worse instead of better over time.

**MANEUVERABILITY** allows the pilot to change the attitude of the airplane in a manner to withstand the stresses without harm to the airplane.

**CONTROLABILITY** is the capability of the airplane to respond to pilot input.

**STABILITY, MANEUVERABILITY AND CONTROLABILITY ALL INVOLVE MOVEMENT ABOUT THE **THREE AXES OF FLIGHT**.**
Aerodynamics: STABILITY

- Positive static stability
- Neutral static stability
- Negative static stability

A: Damped Oscillation
   (Positive Static) (Positive Dynamic)

B: Undamped Oscillation
   (Positive Static) (Neutral Dynamic)

C: Divergent Oscillation
   (Positive Static) (Negative Dynamic)
Aerodynamics: 3 Axes of Flight
Stability Control

Lateral Axis (Pitch) = Elevators

Longitudinal Axis (Roll) - Ailerons

Vertical Axis (Yaw) = Rudder
Longitudinal Stability

**Longitudinal Stability** is the tendency for an aircraft to *resist movement about its Lateral axis*. Dependent upon: 1-Location of wing with respect to CG, 2-Location of horizontal tail surfaces with respect to CG, and 3-Area of tail surfaces. Downwash strikes the top of the stabilizer and produces a downwash pressure which at certain speed is enough to balance the “level.”

*MOST DANGERS*

Horizontal Stabilizer subjected to downward forces – given negative angle of attack to counteract these influences.

Power effects can destabilize pitch (thrustline above CG and more downward force on Horizontal stabilizer)
Longitudinal Stability

Longitudinal stability is a balance of Center of Gravity (CG), Center of Life (CL), and Tail Surface (T). Most aircraft are designed so that the wing’s CL is to the rear of the CG resulting in a slight downward on the horizontal stabilizer keeping the aircraft from pitching downward.

\[ \text{Speed of airflow over the wing and downwash effects.} \]

\[ \text{Reduced Power allows pitch down} \]

\[ \text{Increase} \]

Trust Effects

\[ \text{Decrease} \]

\[ \text{Power Changes} \]

\[ \text{Decrease} \]

\[ \text{Increase} \]
Lateral Stability

Lateral Stability is the tendency for an aircraft to resist movement about its Longitudinal axis (confusing but true). Influenced by dihedral, wing sweep, and keel effects.

Dihedral: Wings angled up at fuselage helps positive lateral stability

HIGH SPEED aircraft need sweep back wings to help lateral stability.

Side of the airplane act like keel on a ship to help stabilize.
Aerodynamics: Directional (Vertical Axis) Stability

Stability about the vertical axis is called Directional Stability. The main component to resist directional instability is the vertical stabilizer. Area behind CG must be greater than area forward of CG.
Aerodynamics: Directional and Lateral Interaction

When dihedral effects are more powerful than the directional effects, then a “Dutch Roll” can result (side-to-side waggle).

When directional effects are more powerful than the dihedral effects, then a “Spiral Instability” can result (graveyard spiral).

Longitudinal, Lateral, Directional Stability is VERY IMPORTANT in preventing and permitting effective control of STALLS and SPINS
Aerodynamics: Stalls
Exceeding Critical Angle of Attack
GA aircraft 16-18 degrees

Power-On “Departure”

Accelerated (45 degree turning stall)

Power-Off “Approach”

Cross-Linked (Extremely bad on Landing)
1. Bad approach – right turn
2. Excessive right rudder
3. Left turn to counter increasing angle of bank
4. Right wing stalls and rolls to right. End of story.

Recognition and Recovery CRITICAL

DISCUSS IN DETAIL WITH YOUR FLIGHT INSTRUCTOR
31. (Refer to Figure 3 above.) The L/D ratio at a 2° angle of attack is approximately the same as the L/D ratio for a

A. 9.75° angle of attack.
B. 10.5° angle of attack.
C. 16.5° angle of attack.

Answer (C) is correct. (PHAK Chap 10)

DISCUSSION: Enter the bottom of the chart in Fig. 3 at 2° angle of attack and move vertically up to the L/D curve. From this point, move right horizontally to the point where the L/D curve intersects. Then move vertically down to the bottom of the chart to determine a 16.5° angle of attack. Thus, the L/D ratio is approximately the same at both a 2° and 16.5° angle of attack.

Answer (A) is incorrect because an angle of attack of 9.75° would have the same L/D ratio as a 3.75°, not 2.0°, angle of attack. Answer (B) is incorrect because an angle of attack of 10.5° would have the same L/D ratio as a 3.5°, not 2.0°, angle of attack.
Aerodynamics: Spins

BOTH wings must be stalled to enter a spin.

Recognition and Recovery CRITICAL
DISCUSS IN DETAIL WITH FLIGHT INSTRUCTOR
Aerodynamics: Climbing Flight

Climbing: Force of weight no longer perpendicular. Climbs also make you subject to Left-Turning Tendencies (Torque, Precession, Asymmetrical Trust and Side stream effects)
Aerodynamics: Climbing Left-Turn Tendencies

Torque (worst at low airspeed, high power, and high angle of attack)

Gyroscopic Precession

Asymmetrical Thrust (P-Factor)

Slip Stream Effects
Torque Effects

Newton’s 3\textsuperscript{rd} Law of Physics (for ever reaction there is an equal an opposite reaction) impacts flight in many ways. For instance: As internal engine parts and propeller are rotating in one direction, an equal force is trying to rotate the airplane in the opposite direction.

**In Flight**
Tendency to roll due to torque on the longitudinal axes (straight along the fuselage).

**On the Ground**
During takeoff roll, additional turning movement around the vertical axis is induced by torque. The left side of the airplane is being forced down by torque, more weight is place on the left landing gear. Results in more ground friction (drag) on left tire than On the right, causing a further turning movement to the left.
Aerodynamics: Descending Flight

Lift-to-Drag Ratio
L/D Max is best.
FIND IN P O H
Aerodynamics: GLIDING

Glide Speed (See POH for L/D Max)

Glide Ratio. Specified in # of feet forward to # of feet down (10:1)

Glide Angle. Angle between glide path and horizon.
Aerodynamics: GLIDING INFLUENCES

Landing CONFIGURATION = more drag = shorter glide distance

WEIGHT
Heavier airplanes glide the same distance as light airplanes but to do so the heavier aircraft must glide at a higher airspeed.

WIND

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Created by Steve Reisser
Aerodynamics: TURNS

Vertical Component of Lift

Horizontal Component of Lift (Centripetal Force)

(Centrifugal Force)
Aerodynamics: TURNS

Adverse Yaw: Higher Lift and Drag on 1 wing results in opposite of turn yaw.

Over banking Tendency: Airplane wants to continue to roll (especially steep turns) even when controls neutralized.
Aerodynamics: TURNS

Angle of bank and Airspeed regulate the rate and radius of a turn.

Constant Airspeed

Constant Angle of Bank
Standard rate turn radius in NM?

- At 200 KTS, your turn radius is 1 NM so under 200KTS turn radius is $\text{TAS}/200$

  Example: 100 Kts, Radius = $100/200 = 0.5$ NM
  75 Kts, Radius = $75 / 200 = 0.375$ NM

- For High Speed (Mach) turn radius is $\text{(Mach#*10)}-2$

  Example: .8, radius = $(0.8*10) - 2 = 8 - 2 = 6$ NM

*Don't let the next slide scare you – it shows what you are calculating in graphic form 😊*
Aerodynamics: LOADS

Load is the ratio of the weight supported by the airplane’s wings to the actual weight of the airplane and its components. G-Forces produced by turns, wind shear, unusual attitudes or sudden changes in pitch.

**G-Forces produce Weight Changes**
in Turns-aircraft must support more weight (weight x load)

**Stall Speed Changes** in Turns-cannot use Vs1, increases by % below.
LOADS CAN EXCEED INTEGRITY OF STRUCTURE!!!

Level Turns: Loads increase terrifically after 45 degrees. 60 degrees = 2 Gs, 80 degrees = 5.76 Gs

Turbulence: Severe vertical gusts can cause sudden increase in angle of attack, resulting in large loads which are resisted by the inertia of the airplane.

Speed: Excess load imposed on a wing depends on how FAST the airplane is flying. At speeds below maneuvering speed an airplane will stall before a load factor becomes destructive. Above that speed, the limit load factor for which an airplane is stressed can be exceeded by abrupt or excessive application of the controls or by strong turbulence.

REMEMBER: Normal limits: +3.8 to -1.52 Gs
Utility Limits: +4.4 to -1.76 Gs
Aerobatic: +6.0 to -3.00 Gs
Aerodynamics: LOADS

- Red Line (\(V_{NE}\))
- Yellow Arc
- Green Arc

- Normal stall speed
- Maneuvering speed
- Accelerated stall
- Normal operating range
- Caution range
- Maximum structural cruise speed
- Structural Damage
- Level flight at 1 G
- Load factor vs. indicated airspeed (mph)
Transonic and supersonic flight speeds are expressed in terms of true airspeed in knots to the speed of sound in knots. This ratio is called the **mach number**.

a. This ratio is not fixed because the speed of sound varies with altitude and temperature.

At low flight speeds, the study of aerodynamics is greatly simplified by the fact that air may experience relatively small changes in pressure with only negligible changes in density.

a. This airflow is termed incompressible since the air may undergo changes in pressure without apparent changes in density.

b. The study of airflow at high speeds must account for these changes in air density and must consider that the air is compressible and there will be compressibility effects.

c. Local airflow velocities around an aerodynamic shape can be greater than flight speed

1) Thus, an aircraft can experience compressibility effects at flight speeds well below the speed of sound.

Since an aircraft can have both subsonic and supersonic airflows simultaneously, certain regimes have been defined.

a. **Subsonic**: Mach numbers below 0.75.

b. **Transonic**: Mach numbers from 0.75 to 1.20.

c. **Supersonic**: Mach numbers from 1.20 to 5.00.

d. **Hypersonic**: Mach numbers above 5.00.

The **critical mach number** is the highest flight speed possible without supersonic flow.

a. Accelerating past critical mach is associated with trim and stability changes and a decrease in control surface effectiveness.
WRAP UP

Questions???

NEXT SESSION

• Study for exam on ADM, Systems, Instrumentation, and Aerodynamics.

• Read Part III, Aviation Weather, Chapters 6 and 7.

“That’s All Folks”