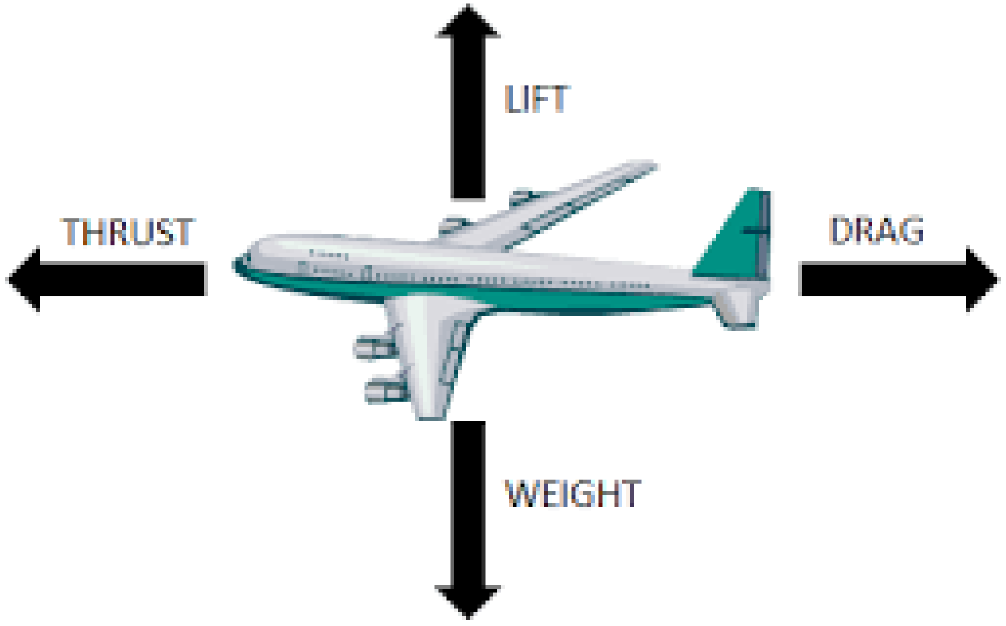
The Four Forces

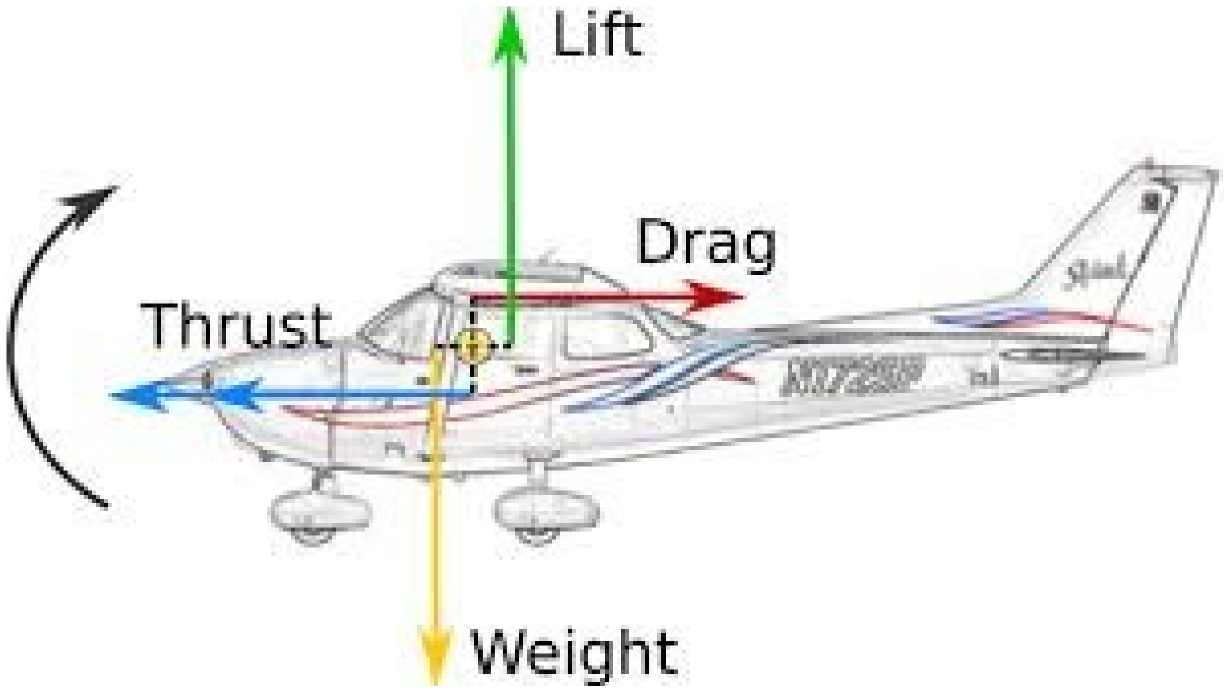
Quick Ground Lesson

Lesson Objective

To develop understanding of the forces that act on an airplane. Everything in the air relates back to this.

First the Diagrams





Weight

A plane like anything else has weight.

The Earth has **gravity**.

The force of gravity acts through the **center of gravity** on the plane in a **vertical direction** towards the Earth.

Weight On the Ground vs Air

While the airplane is on the ground, its weight is supported by the force of the ground on the airplane, which acts upward through the **wheels**.

During the takeoff roll, the task of supporting the weight of the airplane is **transferred from the ground to the wings**.

Lift

While in level flight, the weight of the airplane is supported by the lift force, which is generated **aerodynamically by the flow of air around the wings**.

Once you take off, you can not control weight, but you can control lift by Angle of Attack.

Angle of Attack

AOA = **angle between the chord line of an airfoil and the oncoming air/relative wind**

"The angle between the direction the plane is moving in and the direction the plane is pointing"

Credit to Yoel Gilman

https://youtu.be/3OEWguuPEPE&t=240

Weight <-> Lift

Lift > Weight

Aircraft will **climb** to higher altitudes

Weight > Lift

Aircraft will **descend** to lower altitudes

Thrust and Drag

Thrust, whether caused by a propeller or a jet engine, is the aerodynamic force that pushes or pulls the airplane forward through space.

As the airplane moves through the air it will experience a **retarding force** known as **drag**, which, unless counteracted, will cause the airplane to decelerate and lose speed.

In unaccelerated straight-and-level flight, the drag is neutralized by the thrust.

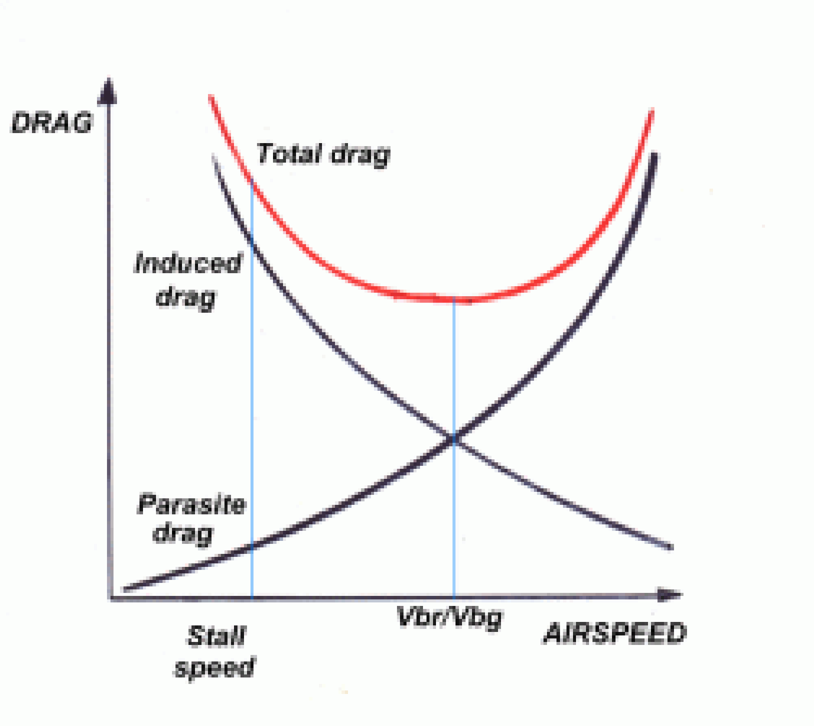
Thrust <-> Drag

Thrust > Drag

Aircraft will **accelerate** to a greater speed

Drag > Thrust

Aircraft will **decelerate** to a slower speed



Types of Drag

Drag is the force that resists movement of an aircraft through the air.

There are two basic types:

Parasite drag greatly affects when going **fast**

Induced drag greatly affects when going **slow**

Parasite Drag

Parasite drag is comprised of all the forces that **work to slow an aircraft's movement**.

As the term parasite implies, it is the drag that is **not associated with the production of lift**.

This includes:

Displacement of the air by the aircraft

Turbulence generated in the airstream

Hindrance of air moving over the surface of the aircraft

There are three types of parasite drag: form drag, interference drag, and skin friction.

Form Drag

Form drag is the portion of parasite drag generated by the aircraft **due to its shape and airflow around it**.

Examples:

Engine cowlings

Wheels

Antennas

Aerodynamic shape of other components.

Think of a moving truck vs a sports car

Interference Drag

Interference drag comes from the **intersection of airstreams** that creates currents, turbulence, or restricts smooth airflow.

For example, the intersection of the wing and the fuselage at the wing root has significant interference drag.

Skin Friction Drag

Skin friction drag is the **aerodynamic resistance** due to the contact of moving air with the surface of an aircraft. Every surface, no matter how apparently smooth, has a rough, ragged surface when viewed under a microscope.

Induced Drag

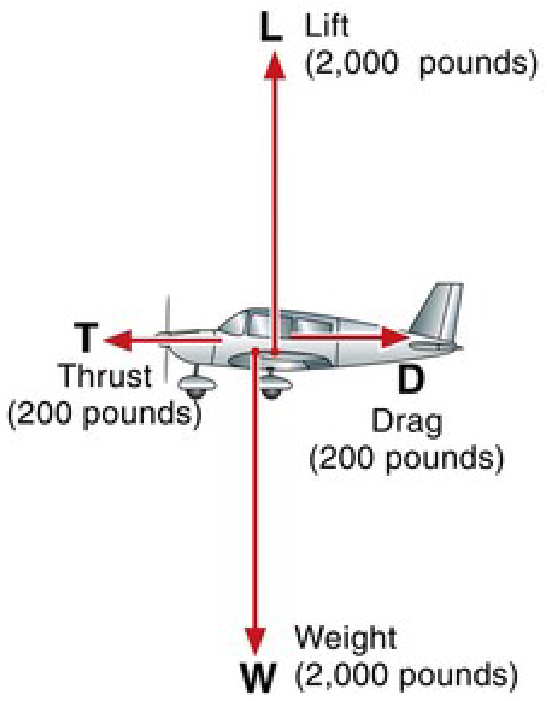
The second basic type of drag is induced drag.

Induced drag is the consequence of lift and is produced by the passage of an airfoil (wing or tail) through air.

High pressure air below the wing seeks equilibrium with the lower pressure air above the wing. This creates a vortex flow from the bottom of the wing to the top.

Air flowing over the top of the wing tends to flow inwards.

Air flowing below the wing tends to flow outwards.



State of Equilibrium

In unaccelerated straight-and-level flight, forces are equal and opposite, canceling each other out.

The resultant force acting on the airplane is zero, and it will neither accelerate nor decelerate.

Weight = Lift

Drag = Thrust

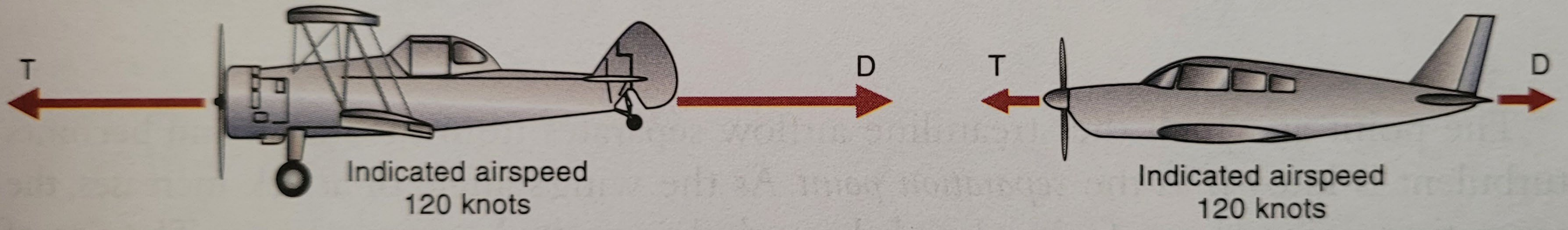


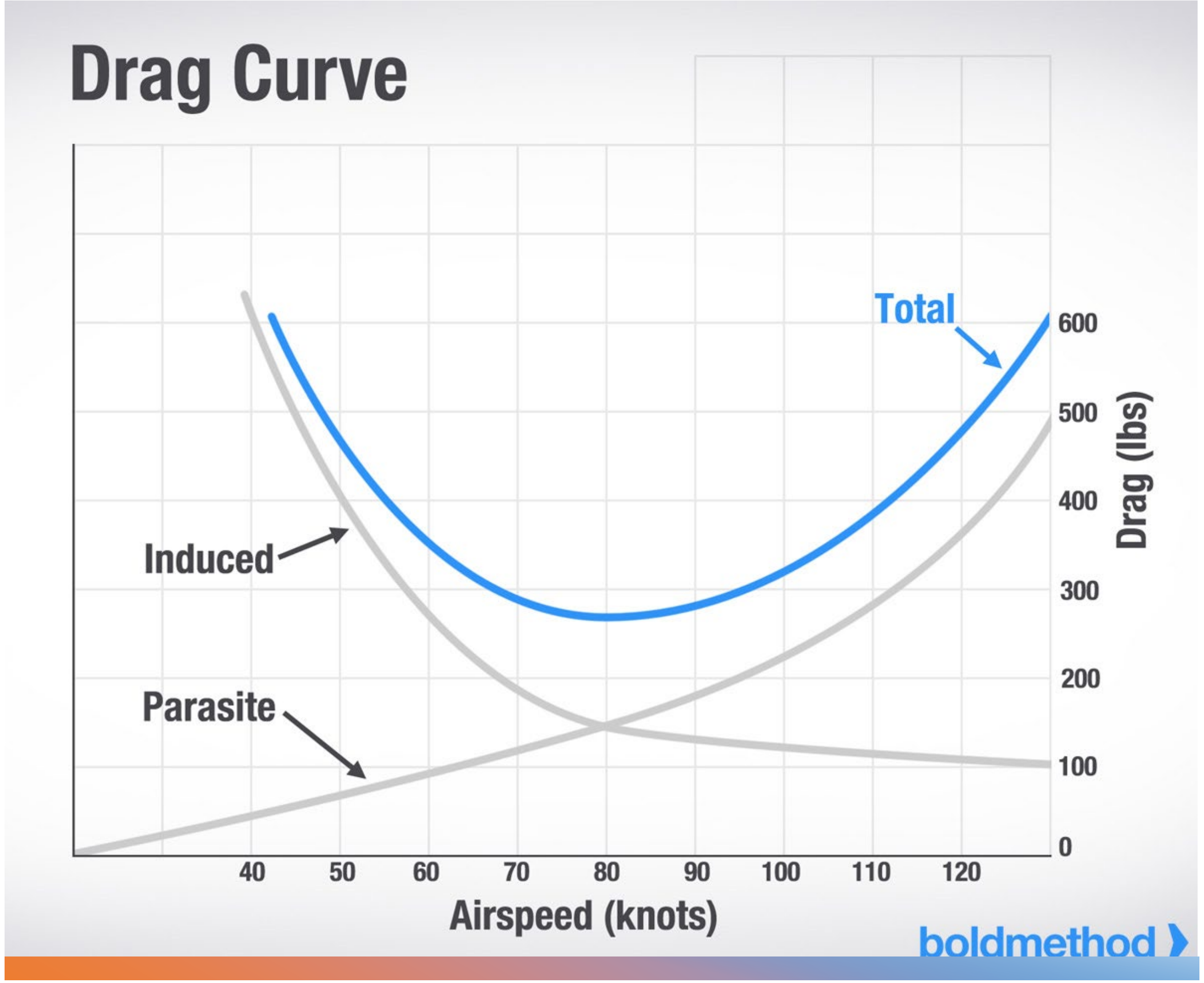
Figure 1-34 Low drag requires only low thrust to counteract it.

Total Drag

Total drag =

Parasite Drag + Induced Drag

The airspeed at which **total drag is lowest** will determine the **best glide speed** of that plane.



Now the Deep Dive

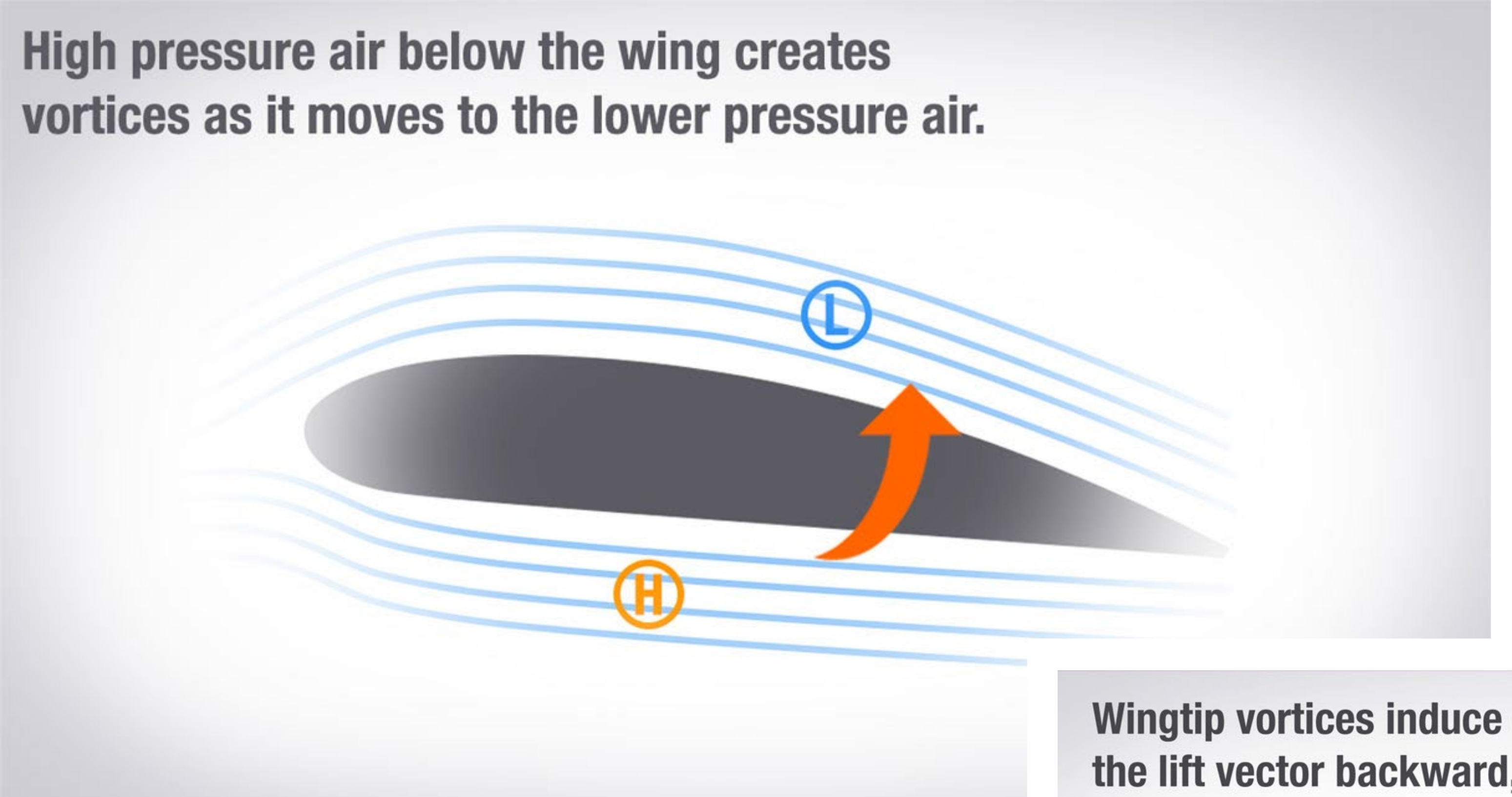
Induced Drag and Aspect Ratio

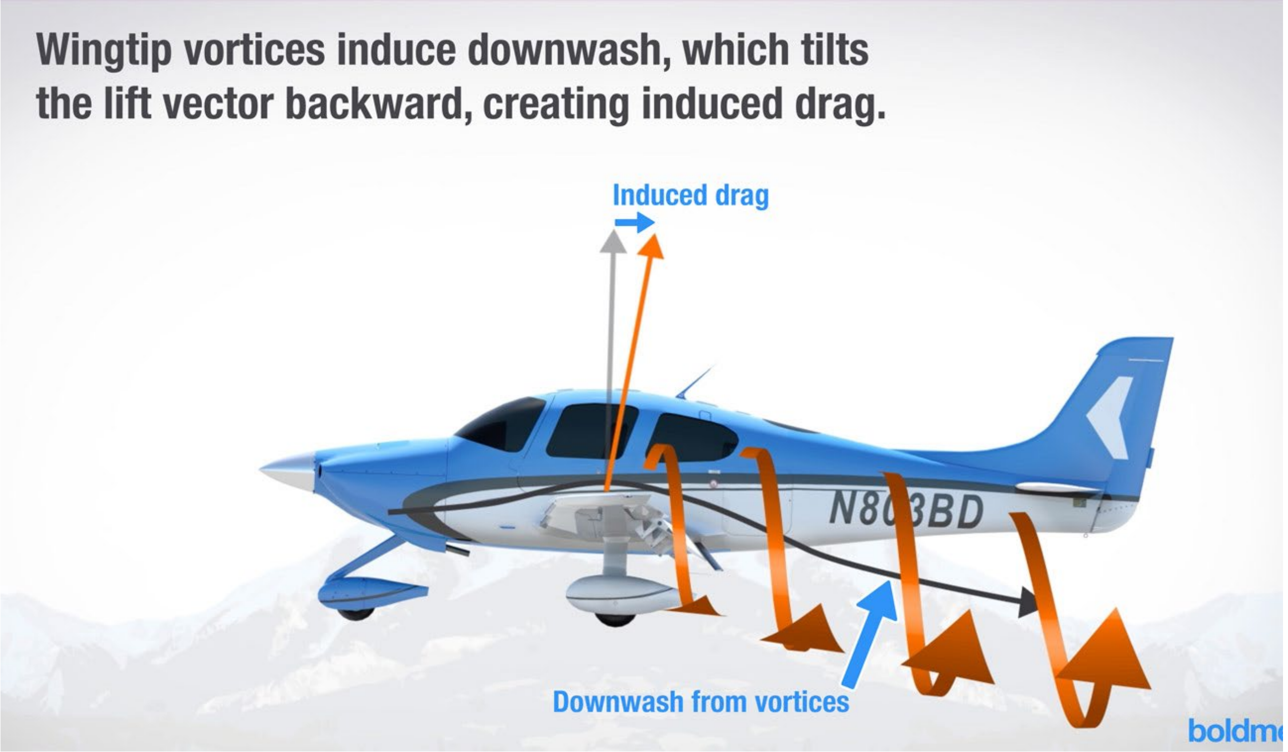
A high aspect ratio wing is better as the proportion of air which moves in this way is reduced so it generates more lift.

The higher the aspect ratio, the less disturbance at the tip.

As the air (and vortices) roll off the back of your wing, they angle down, which is known as downwash.

When you have more downwash, your lift vector points back more, causing induced drag.


High pressure air below the wing creates vortices as it moves to the lower pressure air.
L
H


Wingtip vortices induce downwash, which tilts the lift vector backward, creating induced drag.
Induced drag
Downwash from vortices

Induced Drag

By definition lift is said to act at right angles to the remote free stream of air. It is the vertical component of the total reaction. At lower airspeeds, the angle of attack is higher, and the total vector is tilted rearwards. The increasing horizontal component is induced drag. It is an unavoidable cost for the generation of lift.

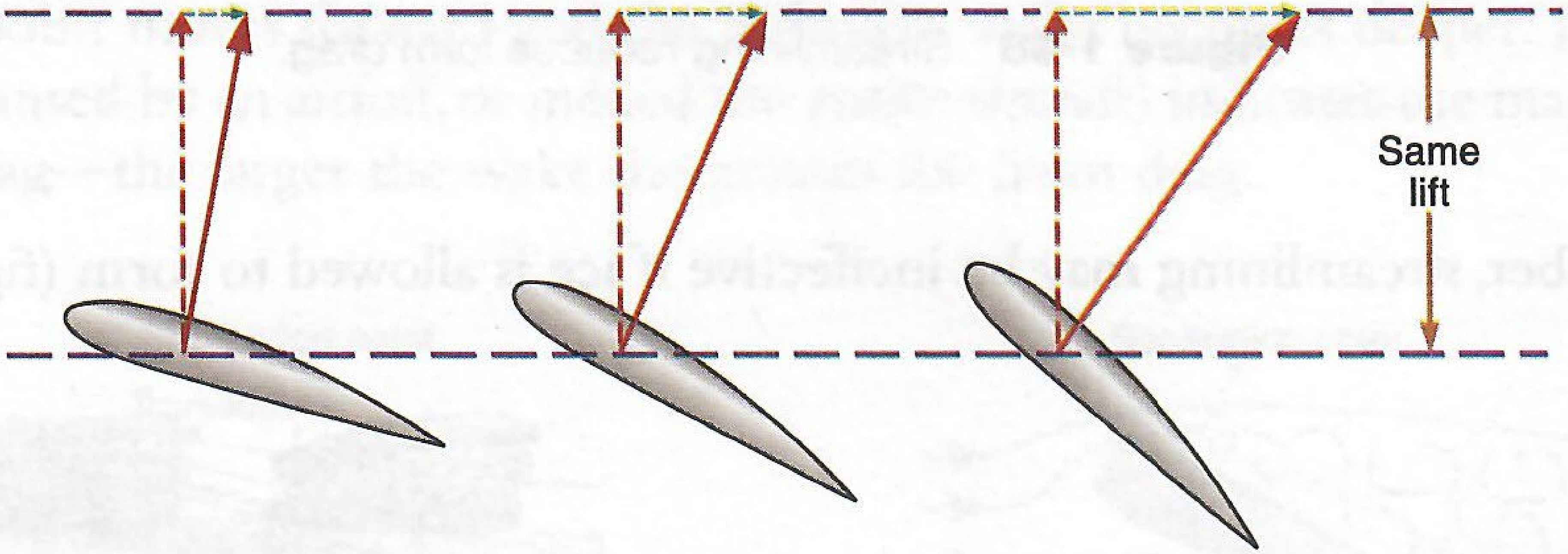


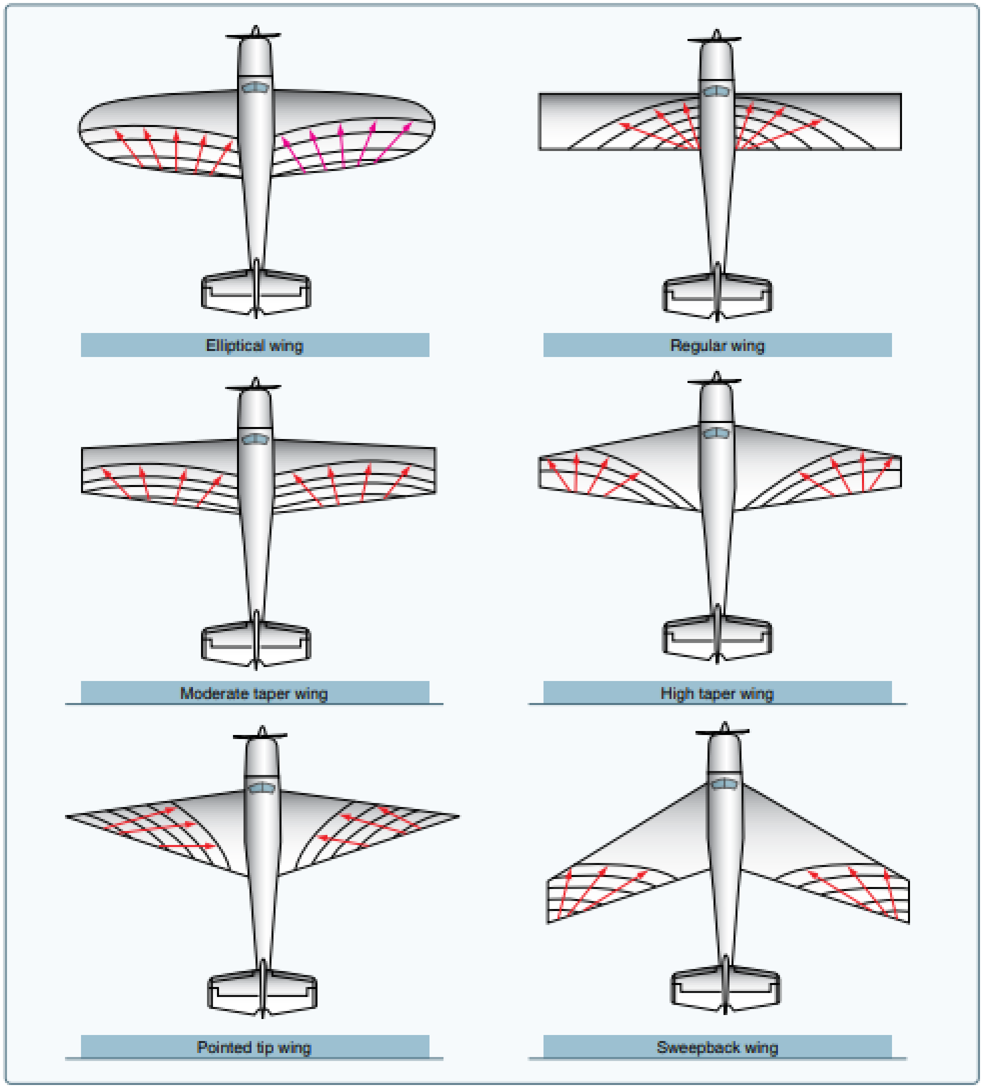
Figure 1-41 Induced drag increases as angle of attack increases.

Induced Drag

Other ways to reduce induced drag and tip vortex strength in a wing design are also based upon reducing the amount of air movement upwards at the wing tip by aiming to generate relatively more of the lift away from tips.

Wing taper towards the tip assists this as does wing twist.

The Boeing 767 is a example of a twisted wing.


Elliptical wing
Regular wing
Moderate taper wing
High taper wing
Pointed tip wing
Sweepback wing

NMA
N797FL

Induced Drag

The inner wing is set at a higher Angle of Attack (AOA) than the outer wing and thus generates proportionately more lift whereas the tip, at a very small Angle of Attack generates very little.

Winglets (sharklets) have also become popular, both the usual up-turned versions and the older Airbus A320 series two-way ‘wingtip fence’ versions.

Well designed winglets can prevent about 20% of the airflow spillage at the tip - and therefore 20% of the induced drag.

Induced Drag

Induced drag and its wing tip vortices are a direct consequence of the creation of lift by the wing.

Since the Coefficient of Lift is large when the AOA is large, induced drag is inversely proportional to the square of the speed whereas all other drag is directly proportional to the square of the speed.

Induced Drag

The effect of this is that induced drag is relatively unimportant at high speed in the cruise and descent where it probably represents less than 10% of total drag.

At slow speeds just after take off and in the initial climb, it is of maximum importance and may produce as much as 70% of total drag.

When looking at the potential strength of wing tip vortices, all this theory on induced drag must be moderated by the effect of aircraft weight.

Induced drag will always increase with aircraft weight.

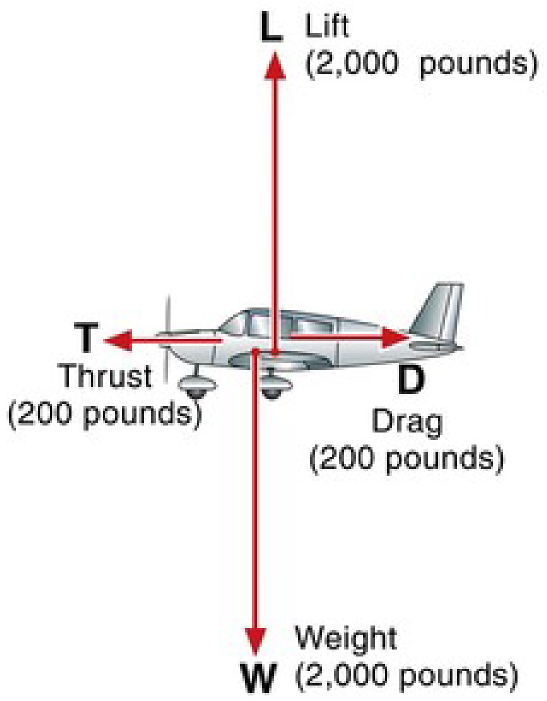
The Propeller

Also an airfoil. Wings produce lift, a propeller produces “horizontal lift” or thrust to propel an airplane forward.

Propeller Twist: To produce uniform thrust along the entire length of its blades.

Why is this Necessary?

Because the propeller blades are spinning faster at the tip and slower at the hub. Hence, the tips will need a lower angle of attack and the hub will need a greater angle of attack.



Lift/Drag Ratio

The lift-to-drag ratio (L/D) is the amount of lift generated by a wing or airfoil compared to its drag.

A ratio of L/D indicates airfoil efficiency.

Aircraft with **higher L/D ratios are more efficient** than those with lower L/D ratios.

For the plane in the diagram:

2000/200 = 10 --> L/D = 10

Lift and Drag Coefficients

The rates of change of lift and drag with angle of attack (AOA) are called lift and drag coefficients CL and CD.

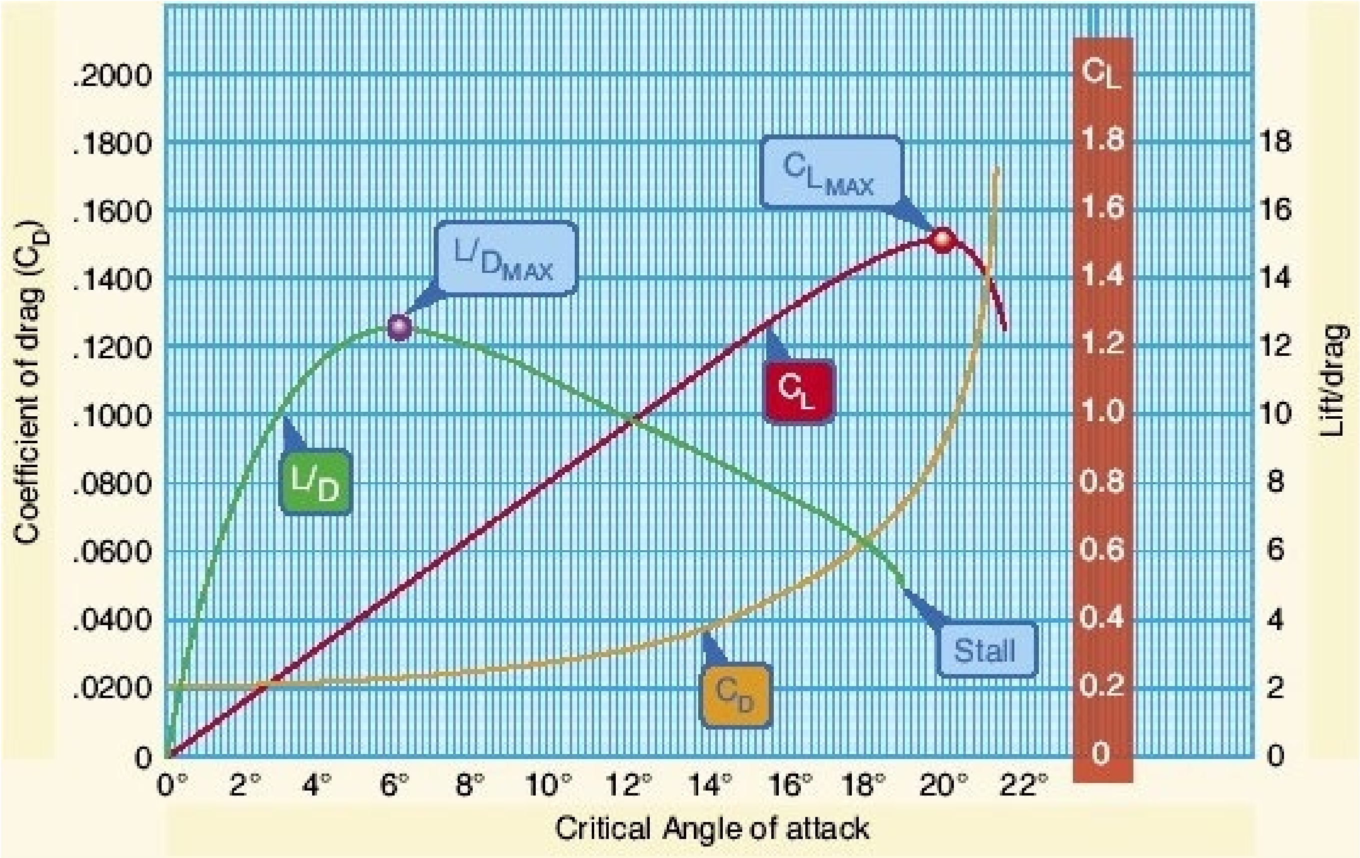
In unaccelerated flight with the lift and drag data steady, the proportions of the coefficient of lift (CL) and coefficient of drag (CD) can be calculated for specific AOA.

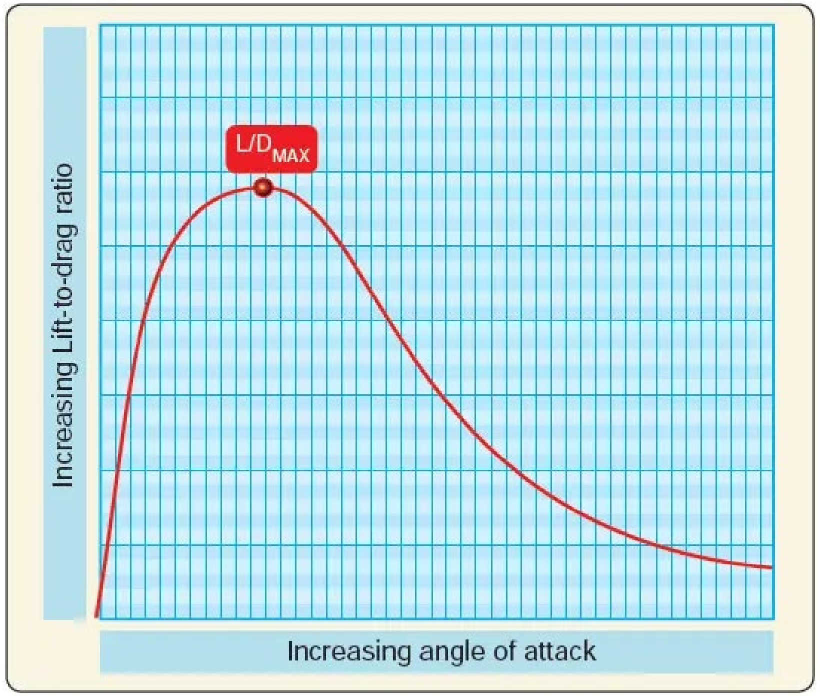
Typically, at **low AOA**, the coefficient of drag is low and small changes in AOA create only **slight changes in the coefficient of drag**.

At **high AOA**, small changes in the AOA cause **significant changes in drag**.

The shape of an airfoil, as well as changes in the AOA, affects the production of lift.

Lift and Drag Coefficients





L/D Max and Glide Speed

The best glide airspeed is used to maximize the distance flown. This airspeed is important when a pilot is attempting to fly during an engine failure.

The best airspeed for gliding is one at which the airplane travels the greatest forward distance for a given loss of altitude in still air.

This best glide airspeed occurs at the highest lift-to-drag ratio (L/D).

Why Do Planes Takeoff Into the Wind?

All airplanes generate lift. Most of an airplane's lift is generated by its wings. As air flows under the wings, it pushes the airplane up.

Against-the-wind takeoffs allow airplanes to generate more lift. Airplanes must achieve a fast enough speed when taking off to maintain airflow under their wings. If there's little or no air moving under an airplane's wings, it may fail to generate a sufficient amount of lift. This is why airplanes accelerate when taking off. While an airplane's engines create most of the propulsion needed to accelerate an airplane, against-the-wind takeoffs — also known as headwind takeoffs — can help as well.

Why Do Planes Takeoff Into the Wind?

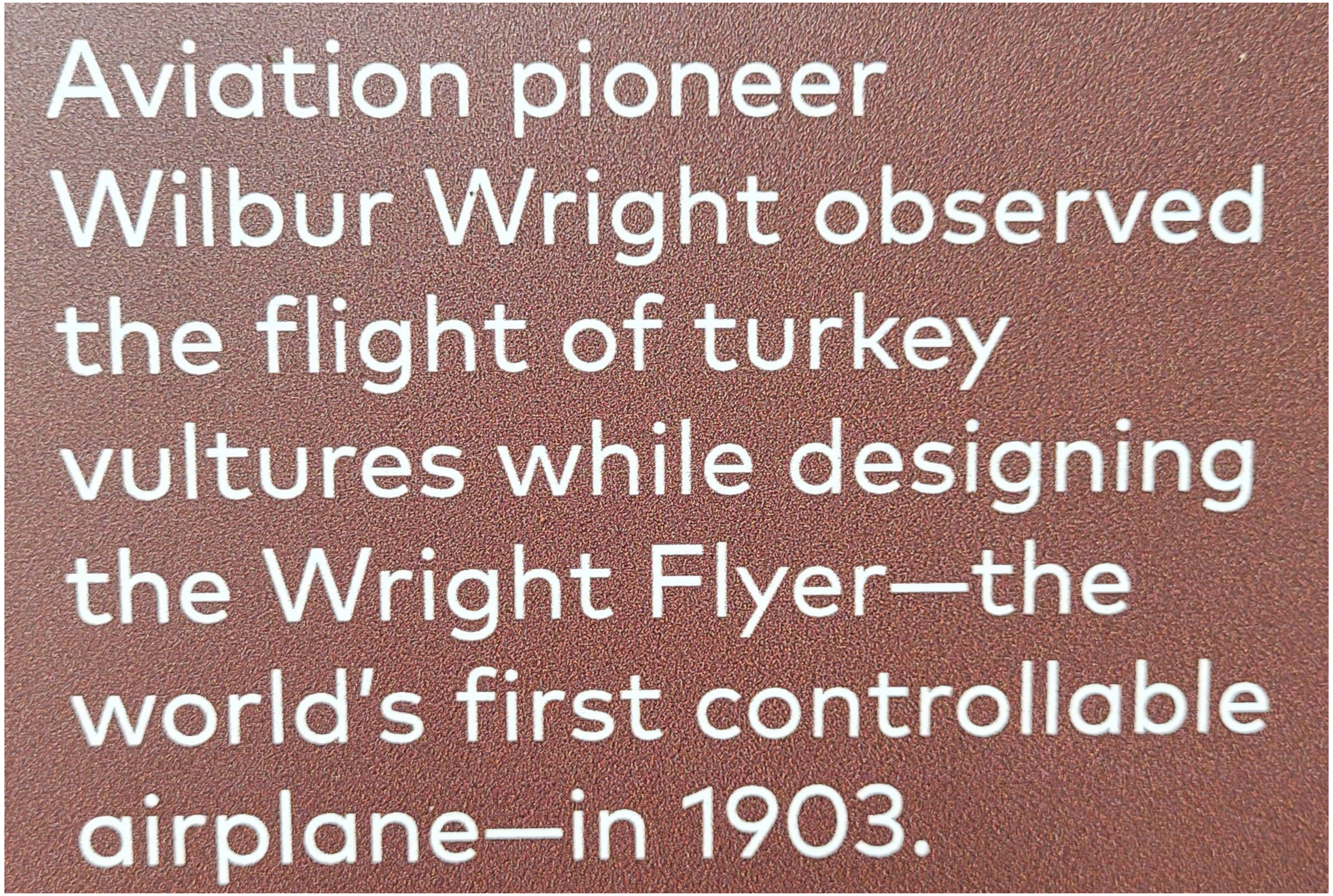
Most airplanes take off against the wind to generate more lift. The speed at which the air moves under an airplane’s wings affects the amount of lift it generates. The faster the air moves, the more lift the wings will generate. By taking off against the wind, air will move faster under the airplane’s wings, resulting in more lift.

If the engine goes out on the takeoff roll, the wind might be a little help to stop before the end of the runway.

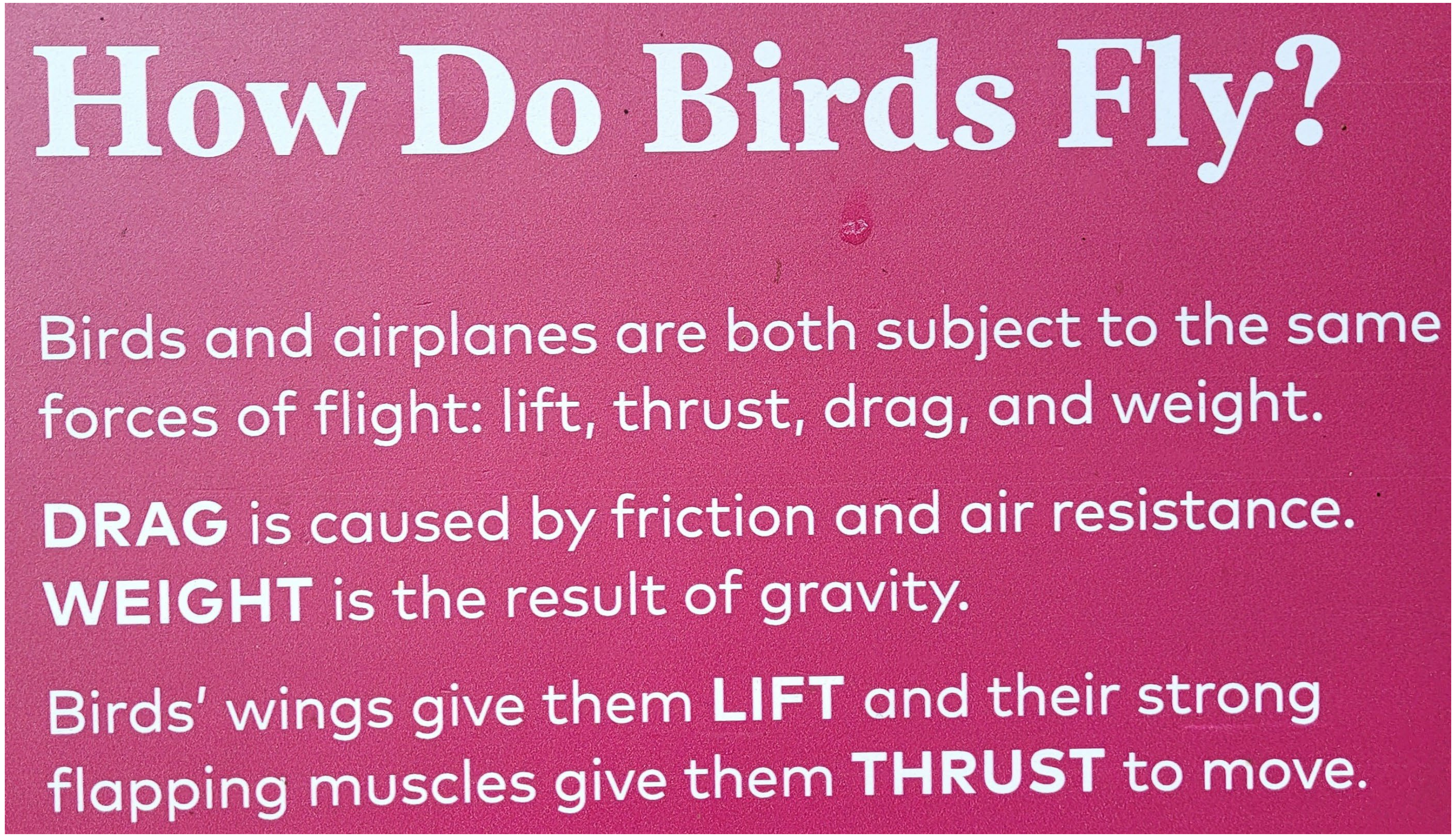
Click here to open in YouTube

The Fours in Takeoff and Landing

Birds and Planes



Birds and Planes



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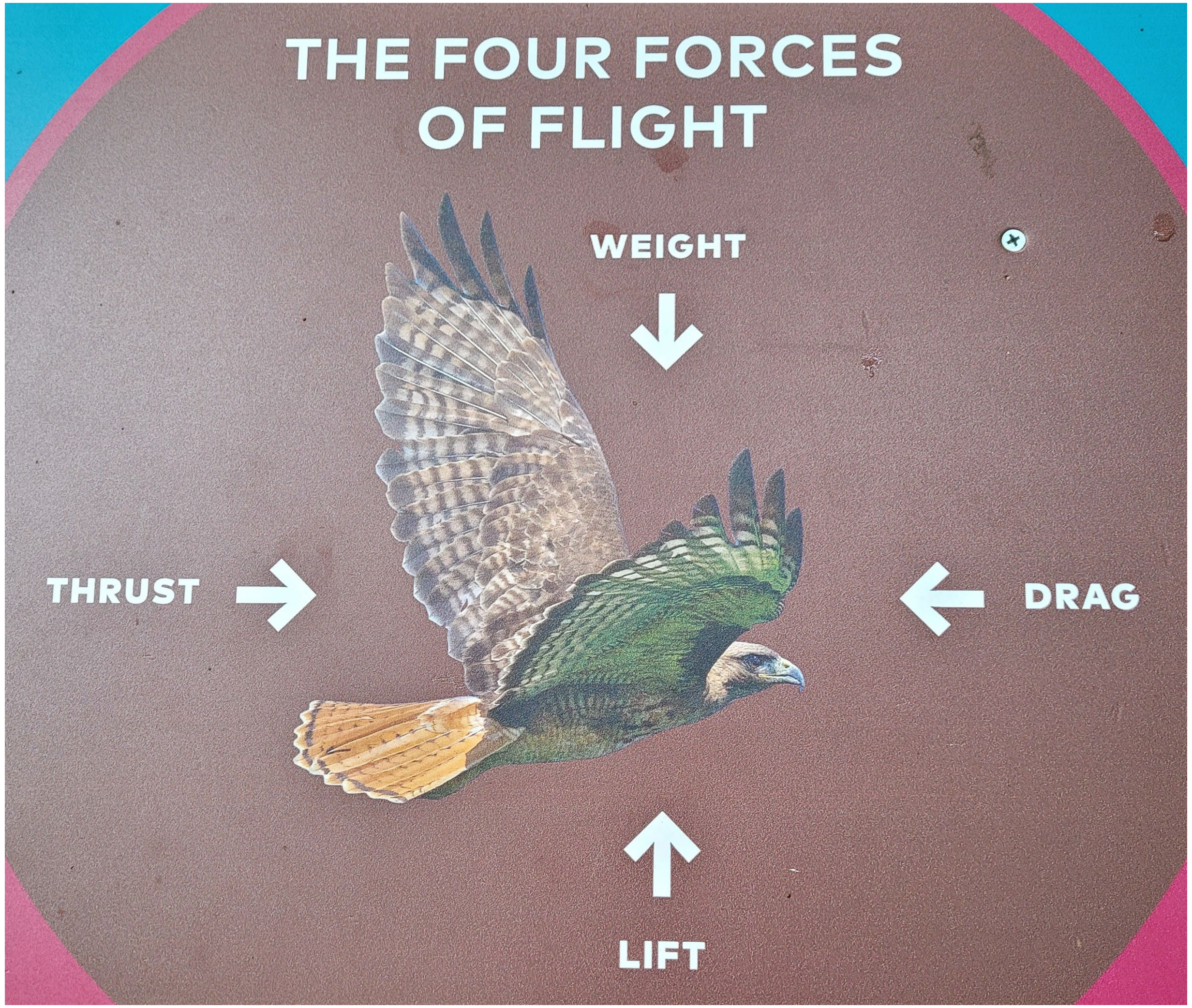

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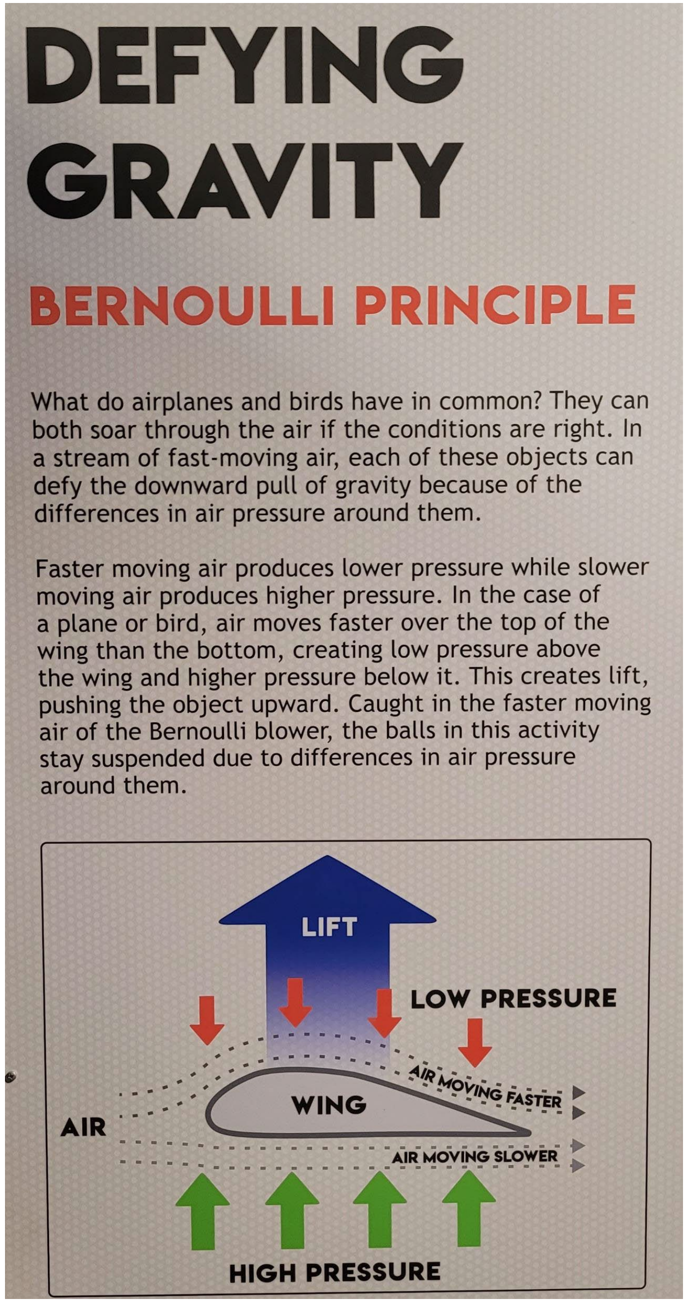

Any questions I can answer or follow up later on?