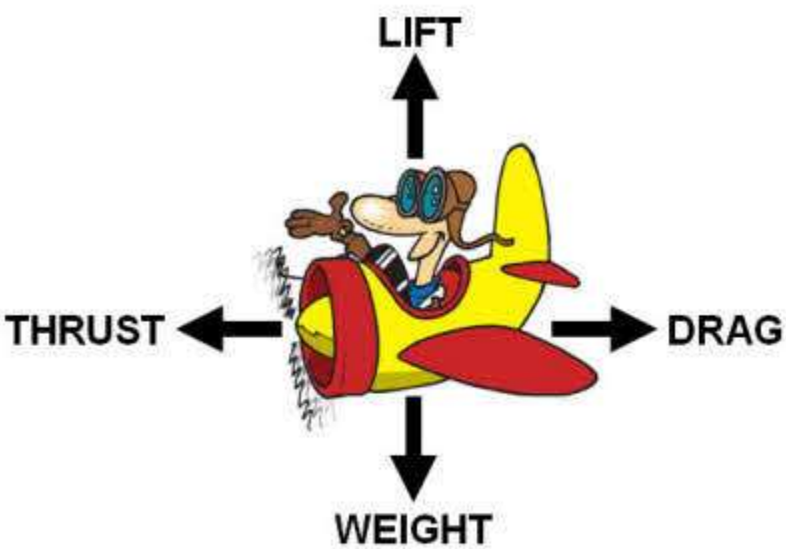
Chapter 3 – Section A – Four Forces of Flight

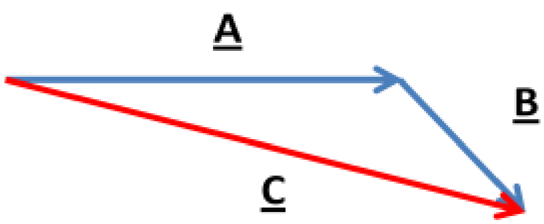


Force Defined: 'any influence to cause an object to undergo a change in position, speed, or direction'

Recall from physics that force has both a magnitude and a direction

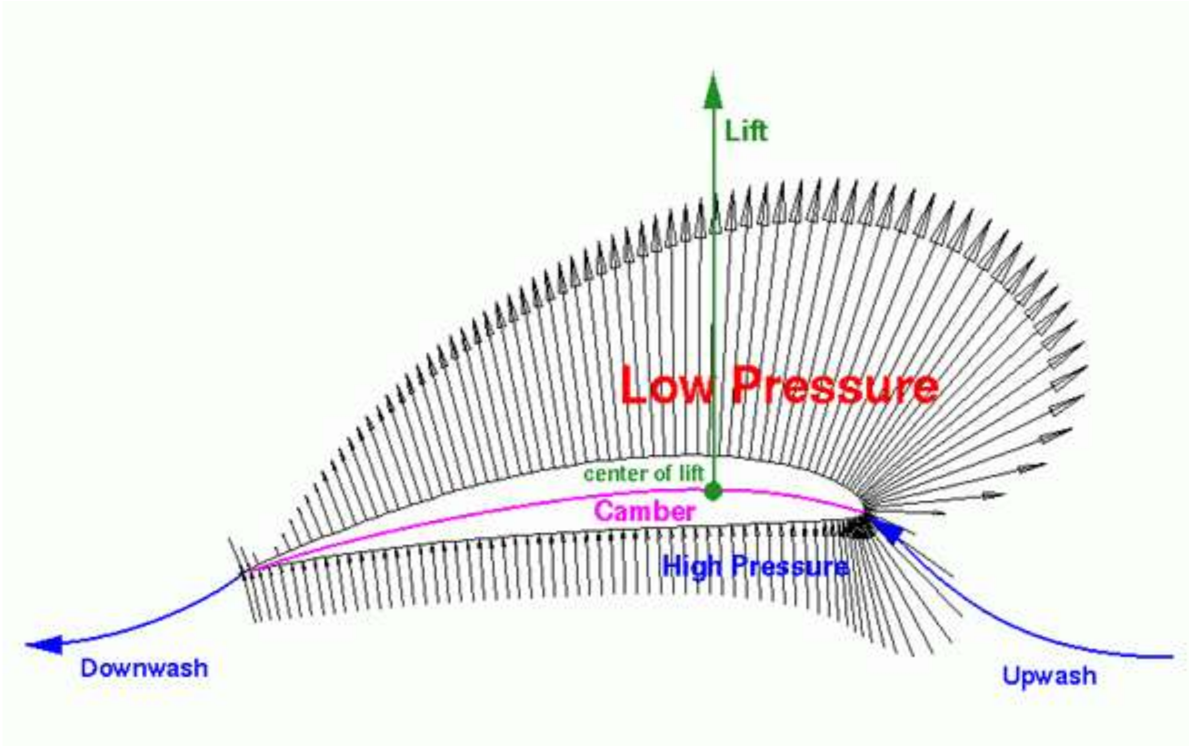
Force **A** is represented by a bold underlined text…

Forces add both in magnitude and change direction…We will study this more when we see how the wind can impact our flight paths…e.g., **A** + **B** = **C** (see below)



When you study this section, note that many of the forces are notional (we are looking at these from a static and highly simplified perspective) and in reality their direction and magnitude are changing as we change the configuration of the airplane. We will look at more dynamic concepts in sections B and C.

Lift



Pressure vectors and flow over a cambered section.

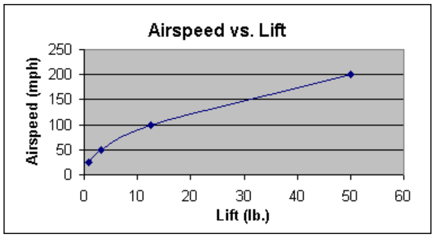
Note that there are two physical phenomena to create lift: First, the Bernoulli principle of increased speed of air over the top of the airfoil creates a pressure differential. Second, Newton's third law of motion shows how the downwash flow (a vector) acts to create an opposite positive component of lift.

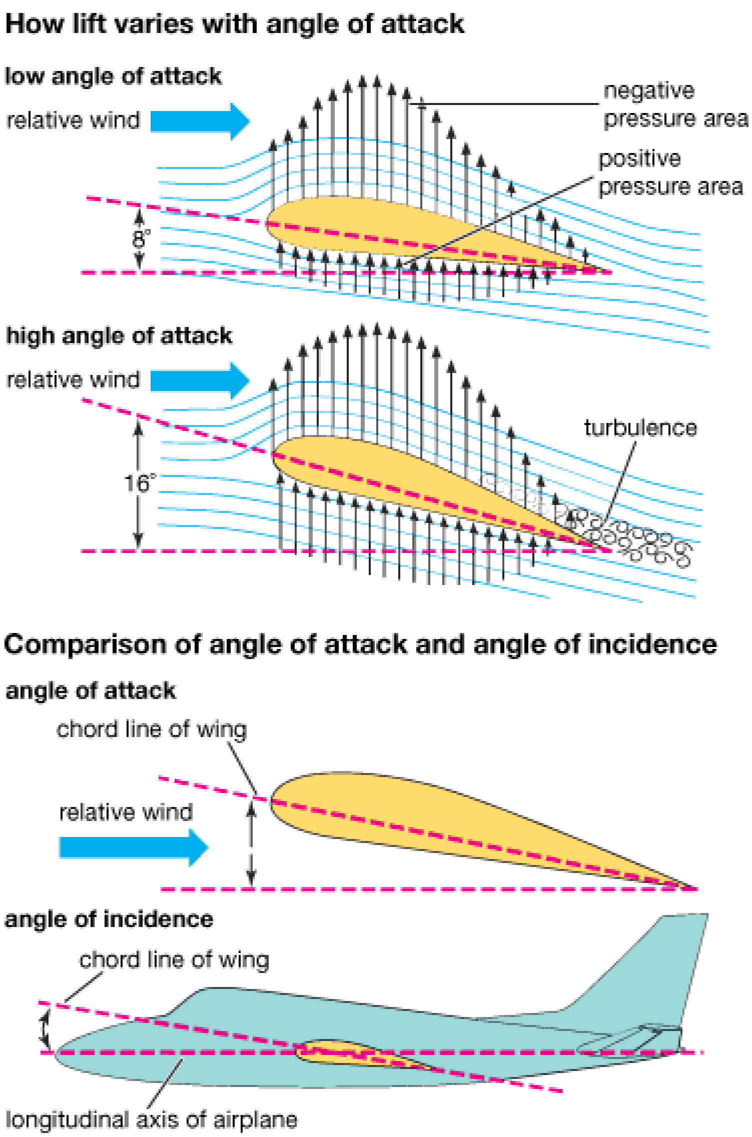
The point at which the upwash first meets the airfoil is called the leading edge, and where the downwash leaves the airfoil is called the trailing edge.

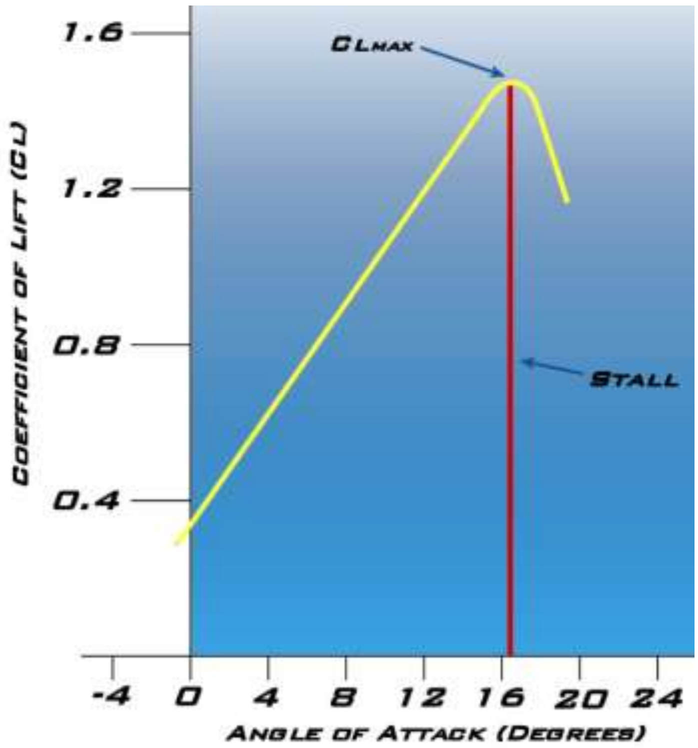
Lift is a function of both the relative wind velocity and angle of attack. As the angle of attack increases to the critical angle of attack, **Lift** increases. As it approaches this critical angle, the airflow becomes turbulent, separating from the airfoil, and less **Lift** is created. Once the airflow becomes separated, **Lift** drastically is reduced, and we say the airfoil has stalled.

As the relative wind increases over an airfoil, the **Lift** increases. In fact, it increases such that the **Lift** increases by the square of the airspeed.

Review the following three figures. Note that angle of incidence refers to how the wing (airfoil) is placed with respect to the longitudinal axis of the airplane.


Airspeed vs. Lift
Airspeed (mph)
250
200
150
100
50
0
0
10
20
30
40
50
60
Lift (lb.)


How lift varies with angle of attack
low angle of attack
relative wind
negative pressure area
positive pressure area
8°
high angle of attack
relative wind
turbulence
16°
Comparison of angle of attack and angle of incidence
angle of attack
chord line of wing
relative wind
angle of incidence
chord line of wing
longitudinal axis of airplane



An airplane can be stalled at any airspeed, attitude, and weight. It only requires that the critical angle of attack be exceeded. In most general aviation (GA) aircraft, the critical angle of attack is about 17 degrees.

Other airfoil terms:

Aspect ratio = wing span / average chord, e.g. 40 feet / 4 feet = 10
(As aspect ratio increases, there is generally less drag)

Planform, refers to shape of wing when looking down, or up, the vertical axis of the airplane

Chord, line between leading edge and trailing edge of airfoil – this, when measured against the relative wind, determines the angle of attack.

Changing **Lift** – by three methods:

- Increase/decrease relative wind velocity
- Increase/decrease angle of attack
- Change shape of airfoil

Flaps: The most common means to change an airfoil is by means of flaps.

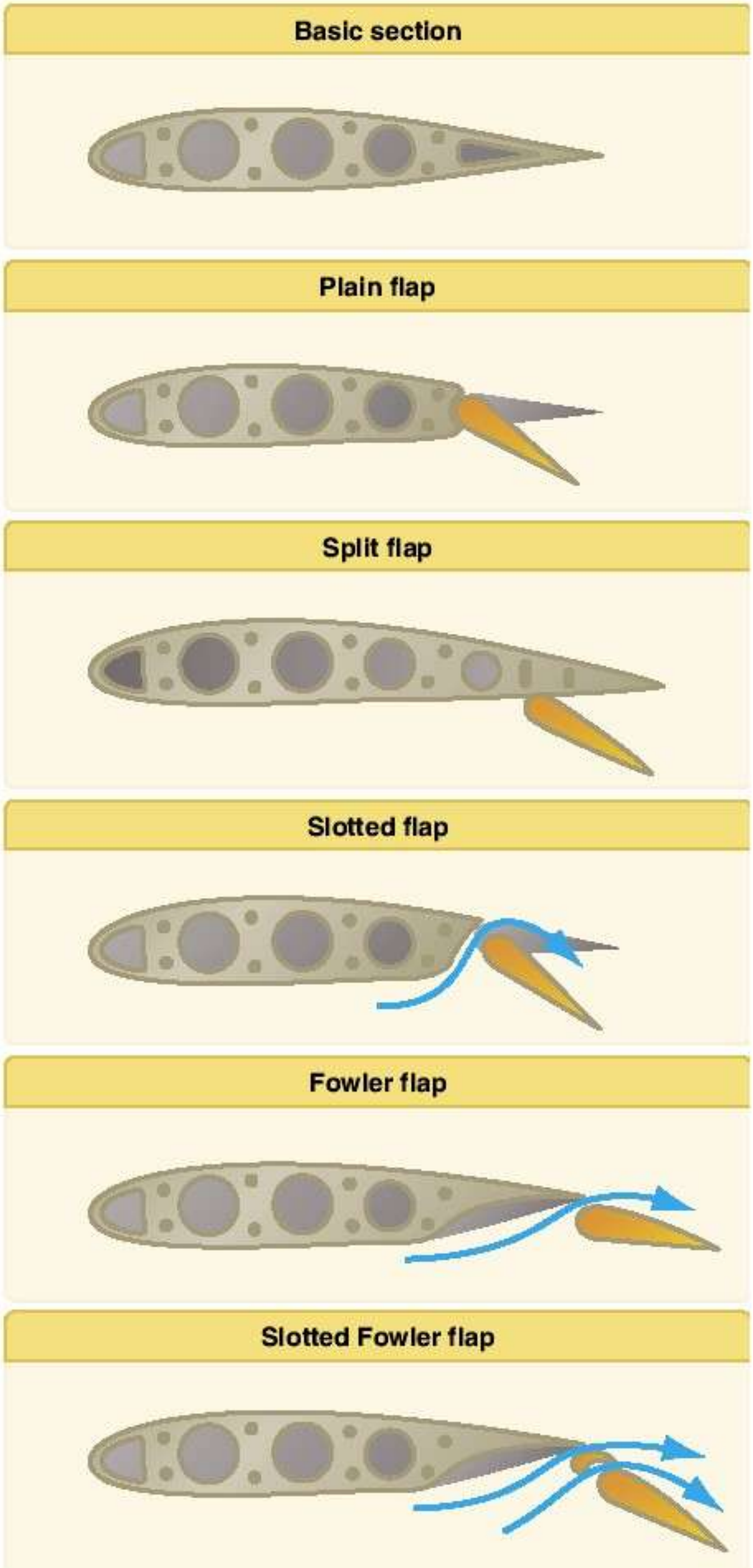
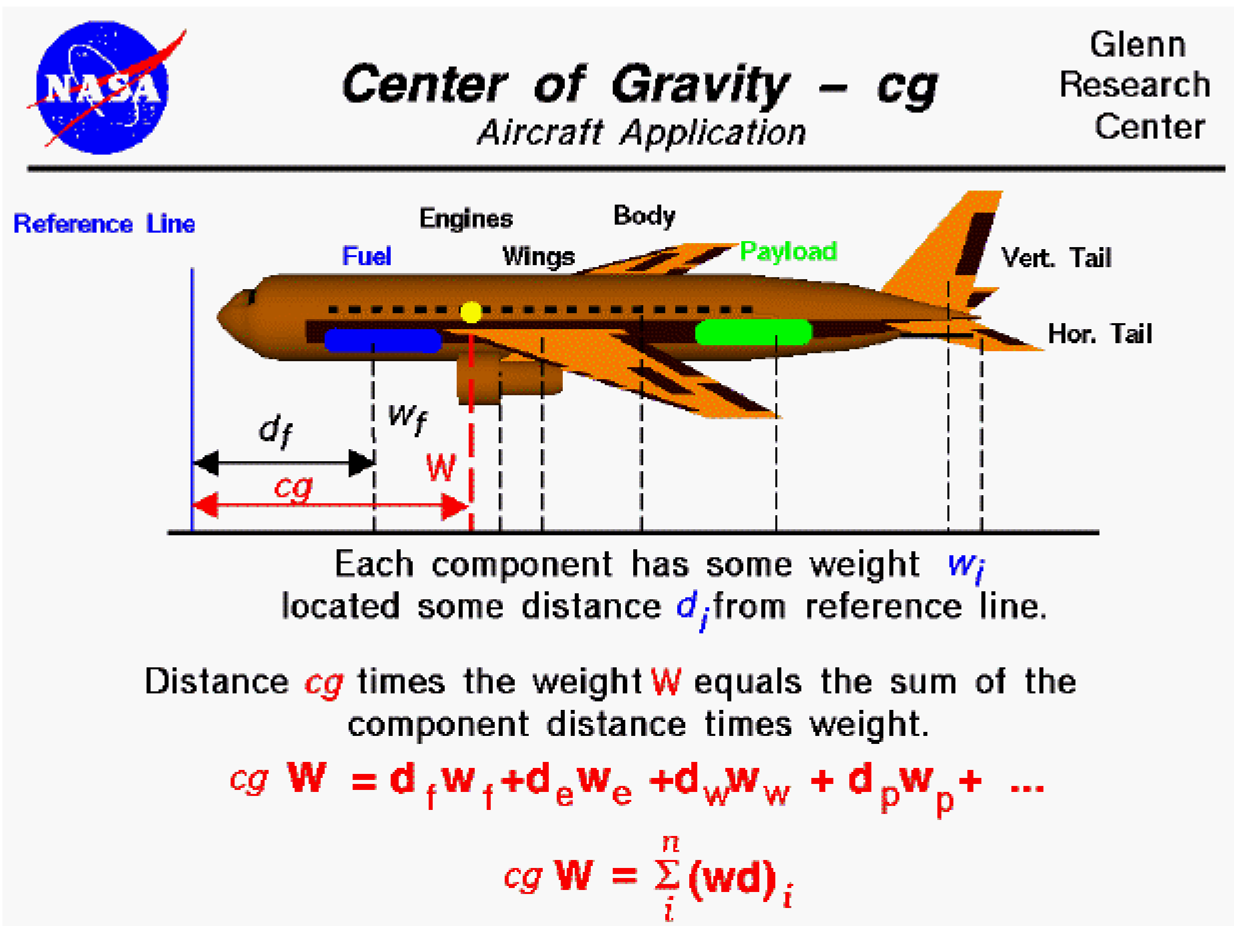


Figure 5-17. *Five common types of flaps.*

Lift Quiz:

- If the relative wind is zero, and angle of attack is positive, there is a positive **Lift**?
- For the same relative wind velocity, an increase in angle of attack results in a decrease of **Lift**?
- For the same angle of attack, an increase in relative wind from 100 knots to 200 knots results in a 4 times greater amount of **Lift**?

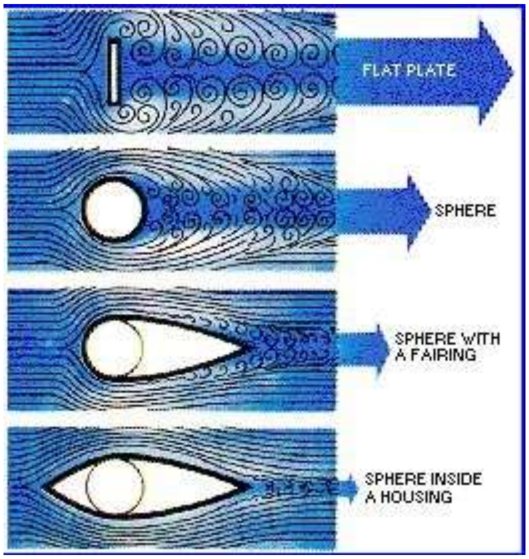
Weight is the downward force due to gravity acting in the center of gravity of the airplane. We will study this later when we do weight and balance as part of aircraft performance exercise.



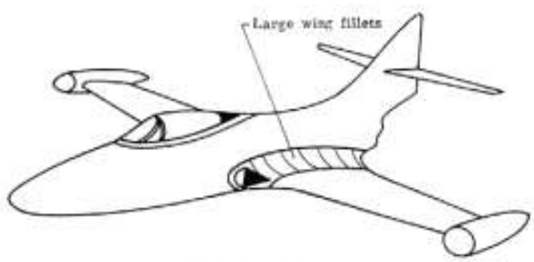
Drag

Two types:

1. Parasitic (a byproduct of faster airspeed)
   a. Form Drag

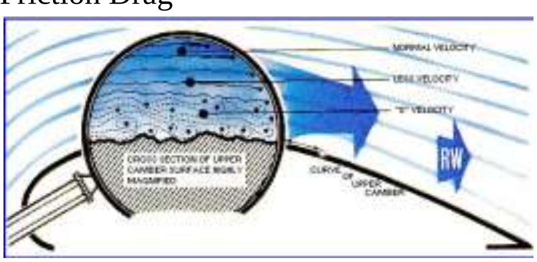


   b. Interference Drag

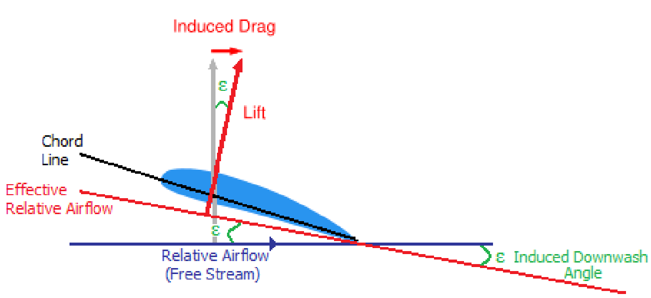


F9F Panther Jet

   c. Friction Drag

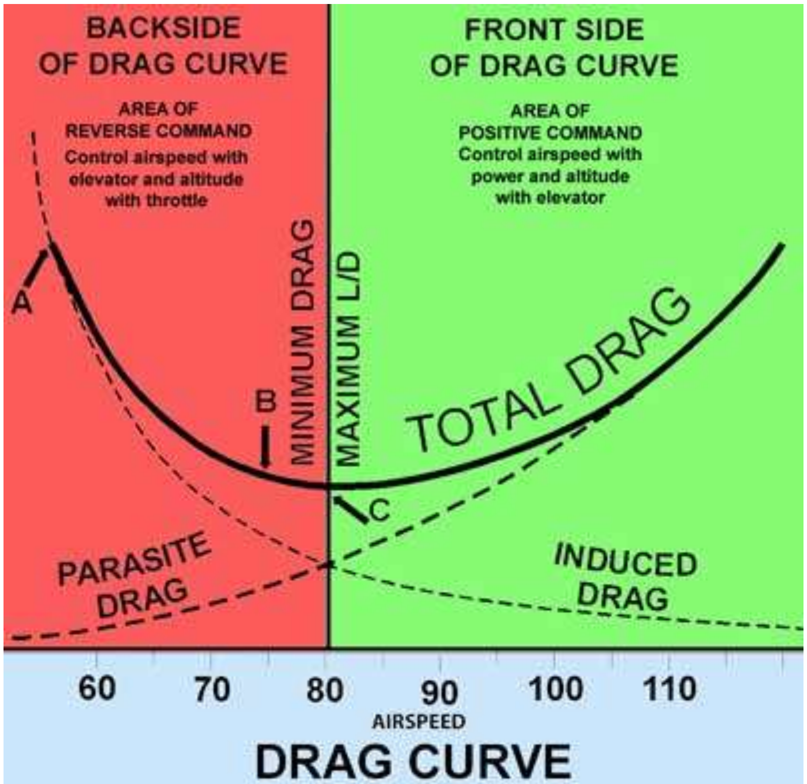


2. Induced Drag (a byproduct of creating lift at lower airspeed)



(Induced drag increases inversely to the square of the airspeed)

Total **Drag**



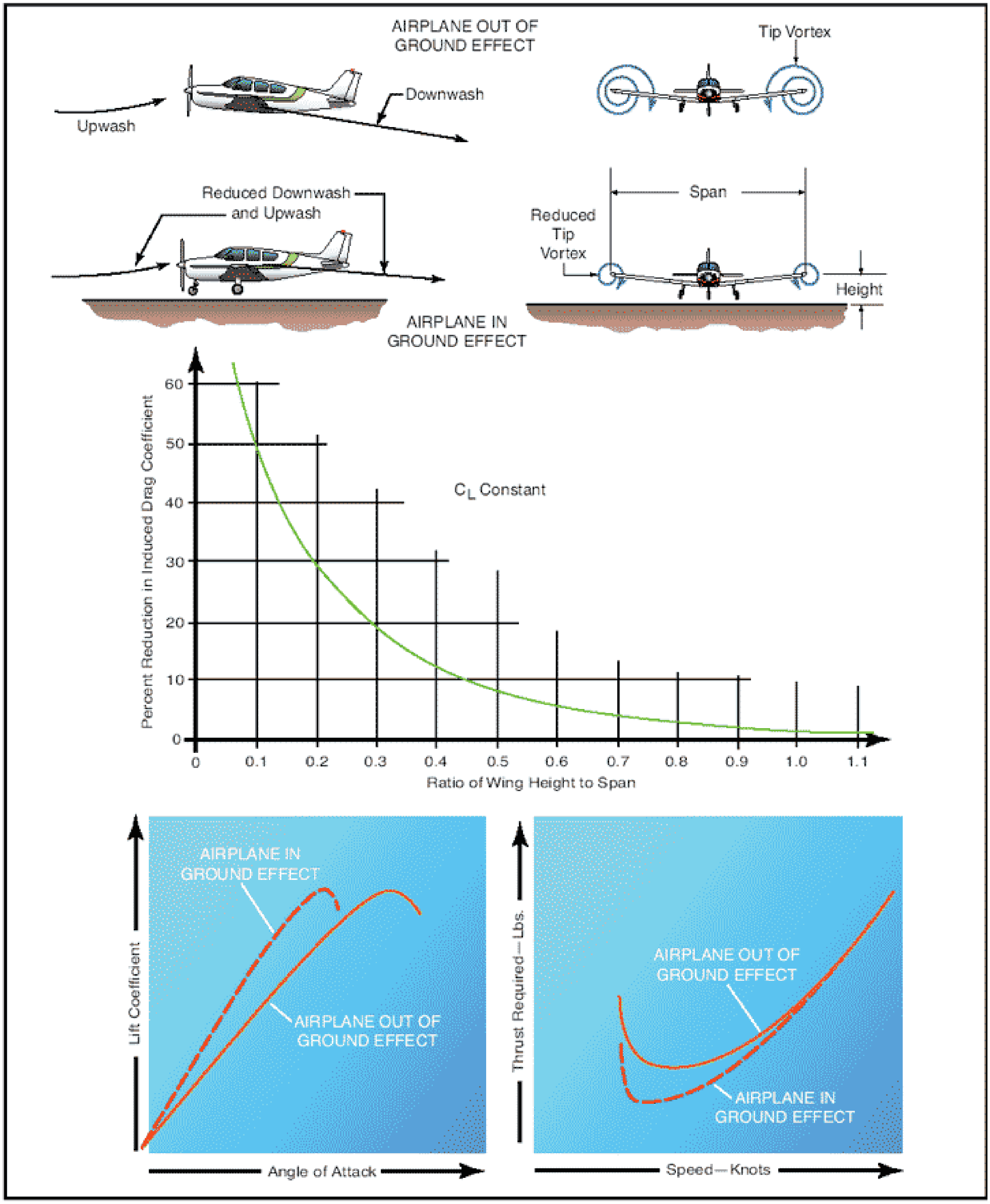
A special point on this curve, L/D_{max}, indicates where the maximum glide ratio is achieved, or, if the engine can still produce power, the airspeed for the lowest power necessary for maximum range. (Lowest power means best fuel economy)

Drag, for a given airspeed, is also sometimes called the required**,** since that is the power necessary to maintain a constant airspeed.

Thrust is the forward force generated by the engine to oppose drag. What if the engine quits? There is still forward thrust created by the weight of the airplane during a glide. More on this later.

One error in the book, there is a statement that if you reduce thrust, and decelerate the airplane, drag decreases, that is true only if you are in the airspeed region above L/D_{max} (see above curve).

Ground Effect A phenomena where operating an airplane within 1 wingspan it alters airflow, reduces downwash and wingtip vortices, hence reducing induced drag, causing plane to fly more efficiently at a reduced airspeed.


AIRPLANE OUT OF
GROUND EFFECT
Upwash
Downwash
Tip Vortex
Reduced Downwash
and Upwash
Span
Reduced
Tip
Vortex
Height
AIRPLANE IN
GROUND EFFECT
Percent Reduction in Induced Drag Coefficient
60
50
40
30
20
10
0
C_L Constant
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Ratio of Wing Height to Span
Lift Coefficient
AIRPLANE IN
GROUND EFFECT
AIRPLANE OUT OF
GROUND EFFECT
Angle of Attack
Thrust Required—Lbs.
AIRPLANE OUT OF
GROUND EFFECT
AIRPLANE IN
GROUND EFFECT
Speed—Knots

Ground effect factoids:

- During takeoff, if you climb at too slow of an airspeed, when you leave ground effect it may cause the airplane to sink (perhaps abruptly) back to the runway
- During landing, excess speed in flare may cause floating, the Diamond is particularly susceptible to this.
- More noticeable in low-wing aircraft
- Diminishes/increases as airplane goes higher, lower

Section B (DVD) – review book

Section C (DVD) – review book