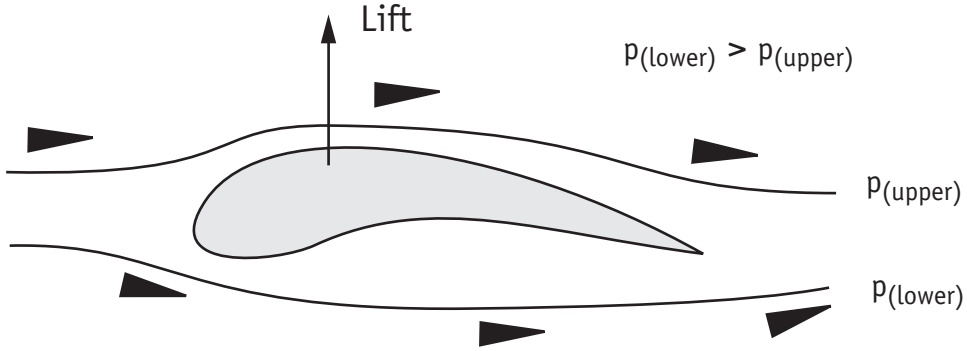
## Activity II: Physics of Flight

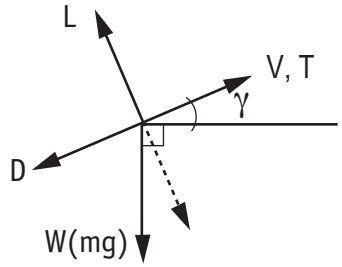
### Introduction

In order for air traffic controllers and other pilots to monitor and predict where airplanes are flying, pilots must fly within a flight path, as proposed in their flight plan. To ensure safety, air traffic controllers sometimes ask pilots to make adjustments to their course, altitude, or air speed. Changing speed requires an understanding of the physics of flight, which is explained (in its most simplified form) below.

A general wing with air flow above and below it.:




Lift of the wing occurs because the pressures below and above the wing differ. $p_{upper} < p_{lower}$, allowing lift to occur.




$\angle\gamma$ = flight path angle

L = Lift, V = Velocity, T = Thrust, D = Drag, W = Weight,
m = mass, g = gravity

We can combine these vectors to determine the net force on the airplane.

$$T - D - W\sin\gamma = F_{net}$$

$\dot{V}$ denotes the rate of change of speed.

Because $W = mg$ and $F_{net} = m\dot{V}$,

$$T - D - (mg)\sin\gamma = m\dot{V}$$

In order to determine the rate of change of speed, we solve the equation for $\dot{V}$.

$$\dot{V} = \frac{T - D}{m} - g \cdot \sin\gamma$$

1. Using the following values, simplify the equation for the rate of change of speed ($\dot{V}$) to be a function of just the flight path angle ($\gamma$).

$T = 1.80 \times 10^4$ N

$D = 1.12 \times 10^4$ N

$m = 6.00 \times 10^3$ kg

$g = 9.8$ m/sec$^2$

$$\dot{V} = \frac{T - D}{m} - g \cdot \sin\gamma$$

$$= \frac{(1.80 - 1.12) \times 10^4 \text{ N}}{6.00 \times 10^3 \text{ kg}} - 9.8 \text{ m/sec}^2 \cdot \sin\gamma$$

$$= \frac{0.68 \times \cancel{10^4} \text{ N}}{0.60 \times \cancel{10^4} \text{ kg}} - 9.8 \text{ m/sec}^2 \cdot \sin\gamma$$

( Remember: 1 N = 1 kg • 1 m/sec$^2$ )

$$= 1.13 \frac{\cancel{\text{N}}}{\cancel{\text{kg}}} \cdot \left(1 \frac{\cancel{\text{kg}} \cdot \text{m/sec}^2}{\cancel{\text{N}}}\right) - 9.8 \text{ m/sec}^2 \cdot \sin\gamma$$

$$\dot{V} = 1.13 - 9.8 \cdot \sin\gamma \text{ m/sec}^2$$

2. Solve for the rate of change of speed ( $\dot{V}$ ) for the following values of the flight path angle ($\gamma$):

a.) $\gamma$ = 0º (level flight)

$$\dot{V} = 1.13 - 9.8 \cdot \sin(0^\circ) \ m/sec^2$$

$$= 1.13 - (9.8 \cdot 0) \ m/sec^2$$

$$= +1.13 \ m/sec^2$$

Q: What do you notice about the effect of gravity when the flight path angle is 0º (level flight)?

A: Because the coefficient of the gravity term is 0 ( sin 0º = 0 ), there is no effect of gravity.

b.) $\gamma$ = +90º (straight up flight)

$$\dot{V} = 1.13 - 9.8 \cdot \sin(90^\circ) \ m/sec^2$$

$$= 1.13 - (9.8 \cdot 1) \ m/sec^2$$

$$= -8.67 \ m/sec^2$$

Q: What do you notice about the effect of gravity when the flight path angle is +90º (straight up flight)?

A: Because the coefficient of the gravity term is +1 ( sin 90º = 1 ), gravity has the greatest negative effect.

c.) $\gamma$ = -90º (straight down flight)

$$\dot{V} = 1.13 - 9.8 \cdot \sin(-90^\circ) \ m/sec^2$$

$$= 1.13 - (9.8 \cdot (-1)) \ m/sec^2$$

$$= +10.93 \ m/sec^2$$

Q: What do you notice about the effect of gravity when the flight path angle is -90º (straight down flight)?

A: Because the coefficient of the gravity term is -1 ( sin (-90º) = -1 ), gravity has the greatest positive effect.

d.) $\gamma = +10^{o}$ (climb out)

$\dot{V} = 1.13 - 9.8 \cdot \sin(10^{o})$ m/sec$^2$

$= 1.13 - (9.8 \cdot 0.17)$ m/sec$^2$

$= 1.13 - 1.67$ m/sec$^2$

$= -0.54$ m/sec$^2$

Q: What do you notice about the effect of gravity when the flight path angle is 10º?

A: As expected, gravity has a small negative effect (-1.67).

e.) $\gamma = -3^{o}$ (approach)

$\dot{V} = 1.13 - 9.8 \cdot \sin(-3^{o})$ m/sec$^2$

$= 1.13 - (9.8 \cdot (-0.05))$ m/sec$^2$

$= 1.13 + 0.49$ m/sec$^2$

$= 1.62$ m/sec$^2$

Q: What do you notice about the effect of gravity when the flight path angle is -3º?

A: As expected, gravity has a small positive effect (+0.49).