The CIX VFR Club	Flight Training Notes	Exercise 3
For Simulation Purposes only. Not to be used for real World flight	THE AIRCRAFT IN FLIGHT	Issue 1.3 18/01/12

1 INTRODUCTION

This series of tutorials for the CIX VFR Club are based on real world flight training. Each document focuses on a small part only of the necessary skills required to fly a light aircraft, and by echoing real world training, you will be a better Flight Simulator pilot and get more enjoyment out of the hobby as a result.

These tutorials are written specifically for the Flight Simulator Default Cessna 172. Some details will be different for other aircraft.

You should read Exercise 2 before continuing with this tutorial.

2 FLIGHT – A BALANCING OF FORCES

Aerodynamics is significantly more complex than explained here, but this should be sufficient to understand the fundamentals of the Principles of Flight, a subject on which whole libraries of books have been written.

2.1 A Three Dimensional Environment

Because an aeroplane moves in three dimensions, any change in it's attitude must be defined in terms of its rotation about one or more of three axes, which are all at right angles to each other and pass through the center of gravity of the aircraft. Because an aircraft is not constrained by wheels or tracks, when it changes its attitude – the angle relative to one or more of the axes - that motion always takes place about the center of gravity as the pivot point.

The **Normal Axis** is the vertical axis when the aircraft is in straight and level flight. The normal axis passes from top to bottom of the aircraft, through its centre of gravity (and in the case of light aircraft, usually through the cockpit). Motion about this axis is called **yaw**.

The **Longitudinal Axis** is the axis which is parallel to the aircraft's nose and tail. Motion about the longitudinal axis is called **roll**.

The **Lateral Axis** is the axis which is parallel to the aircraft wings. Motion about the lateral axis is called **pitch**.

2.2 Newton's First Law of Motion

A body will continue to move in a straight line at constant velocity unless acted upon by an external force. This fundamental principle was proved by Newton long before man (with perhaps the exception of Leonardo da Vinci) mastered flight.

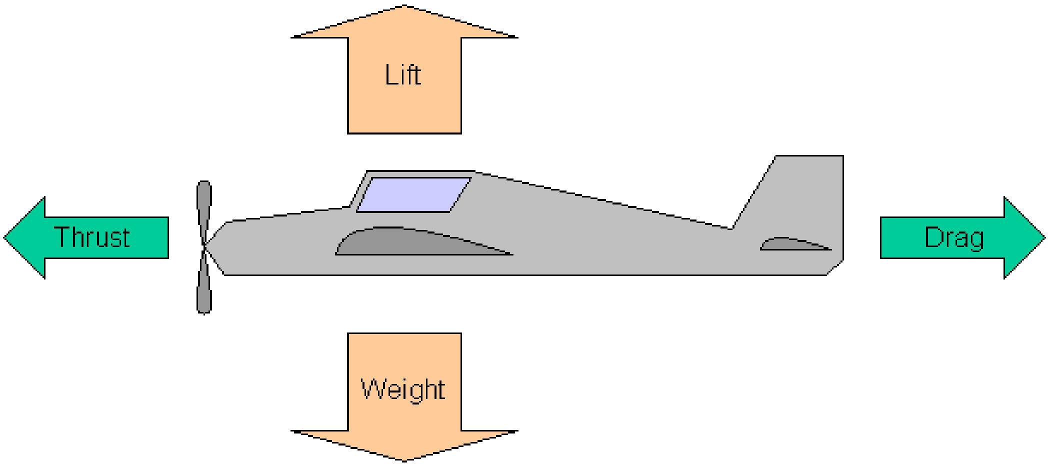
An aircraft in flight is held in equilibrium in the air by the balancing of four forces, Lift, Weight, Thrust and Drag. Any change to the balance of these forces, and the aircraft will change its path through the air in accordance with Newton’s first law.

2.3 The Balancing of Forces

When an aircraft is in straight and level flight at a steady speed, the weight of the aircraft is balanced equally by the Lift generated by the wings, and the Thrust, generated by the propeller, will be in equilibrium with the Drag.

Drag is created by a number of factors including: -

1) The frontal cross-sectional area of the aircraft – profile drag
2) The surface area of the aircraft over which air flows – parasite drag
3) The pattern of airflow over the wings – induced drag



2.4 The Coupling of Forces

An aircraft in level flight at constant speed therefore has two sets of forces counteracting each other in pairs, technically called “couples”. The coupled forces do not necessarily act through the same axis, and consequently can produce a turning force or “moment”.

Lift acts through the Centre Of Pressure, and weight acts through the Centre Of Gravity. If these are not the same, then any turning force will manifest itself about the pitch axis. In other words the nose of the aircraft will want to lift or to drop depending on the direction of the turning force. The purpose of the aircraft’s tailplane is to create lift at a point remote from the centre of gravity, to counteract any turning moment. It is the same as balancing a ruler across your finger, (which is the pitch axis in this example). A big weight near your finger may be counterbalanced by a small weight further away.

A stable aircraft design is one in which the nose naturally drops as the forces on it reduce, (for reasons which don’t matter here). This means that in practice, the tailplane of most aircraft is used to keep the nose UP, and therefore the "lift" generated by a tailplane acts downwards, not upwards.

3 GOING UP AND COMING DOWN

3.1 Level Flight

The lift generated by the wings acts perpendicularly to the wings through the Centre of Pressure. If the lift is equal to and opposite in direction to the total weight of the aircraft acting through the Centre of Gravity, the aircraft will fly level. It will neither climb nor descend. The lift generated by the wing is a function of the speed and direction of the airflow over the wing.

The direction of airflow reaching the wing is called the **Angle of Attack**. If the speed of the air passing over the wing increases, and the angle of attack remains the same, then the lift will increase, and vice versa. If the angle of attack increases, but the speed of the air passing over the wing remains the same, then the lift will increase, and vice versa. In level flight, the angle of attack for most light aircraft is between 1 and 3 degrees. However, if the angle of attack becomes too high (around 10 degrees) the airflow over the wing ceases to be smooth, and the lift effect is lost. The wing is then said to be **stalled**.

3.2 Climbing

If the lift generated by the wings is greater than the total weight, because of increased airflow over the wing surface, (created by an increase in speed for instance) and the aircraft started from level flight, it will now climb. Alternatively, if the nose is raised, so that the angle of attack is increased, the aircraft will also climb. However, in this case because there is no increase in energy in the system, the climb will result in a reduction of speed. This will reduce the lift, so that the aircraft climbs more slowly than the initial rate.

3.3 Descending

If the lift generated by the wings is less than the total weight, because of decreased airflow over the wing surface, and the aircraft started from level flight, it will now descend. Similarly, if the nose is lowered, so that the angle of attack is decreased, the aircraft will descend. The descent will result in an increase in speed which will increase the lift, so that the rate of descent reduces from the initial rate.

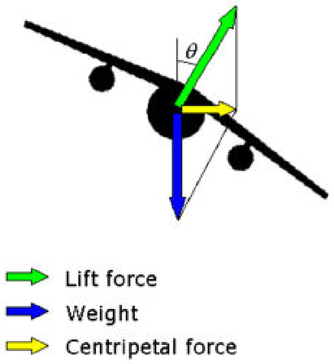
3.4 The Effect of Power

In a propeller driven aircraft, though not in a jet engined aircraft, increasing power increases the airflow over the wings without any increase in airspeed. Consequently an increase in power will make the aircraft climb. Similarly, decreasing power decreases the airflow over the wings and the aircraft will descend.

4 TURNING

Note that because mass always acts vertically downwards, but lift acts perpendicularly to the wing, then if the aircraft is not level, the forces are not in balance. An aircraft banking for instance generates less total lift at an angle to the vertical, so the vertical component of the lift will be less than the total lift. A banking aircraft will therefore always tend to descend if all other forces are unchanged. An aircraft flying without any pilot input (it has been known) will eventually enter a spiral dive to earth.

In a turn, the aircraft banks so that a horizontal force is introduced (yellow arrow) which generates the turn. Without that horizontal fore, Newton's lawa of Motion again state that the aircraft would continue to fly in a straight line. When the aircraft banks, however, it loses lift, because the maximum lift (green arrow in the image below) is no longer equal and opposite in direction to the weight (blue arrow) of the aircraft.



Unfortunately, the effect is rather exaggerated in FS, and back pressure on the yoke is required to maintain a level turn. In the real world, an aircraft with a bank angle of up to about 15° – 20° shows little tendency to descend, making it easier to fly than its FS brother.

4.1 Normal Turns

"Normal" turns are made at 30 ° angle of bank, as this is the optimum for a tight turn without introducing the adverse effects of out of balance forces. In FS, apply some back pressure to restore the lost lift and prevent the aircraft simultaneously descending.

4.2 Rate One Turns

A “Rate One” turn is a turn which completes 180° in one minute. This of course is a function of airspeed, lift and bank angle, and is a complicated mathematical equation. Oddly, an empirical formula works very well, though it has no apparent scientific basis. To achieve a rate one turn in any aircraft, the bank angle required is the airspeed divided by 10, plus 7. In the Cessna 172, for instance, with an airspeed of 100 knots, the angle of bank required to achieve a rate one turn is 100/10+7 = 17° . Using fifteen degrees is therefore a reasonable approximation.

4.3 Steep Turns

If the required turn is greater than 30° angle of bank, then adding power will restore the lost lift. In the extreme, a 70° bank will require full power to maintain level flight, and the stall speed is increased substantially, (don’t ask why) such that it is possible to stall the aircraft at 90 knots in a steep turn. I haven’t tested this in FS, but a steep turn stall tends to affect the upper wing first, and the dramatic effect is that the aircraft suddenly rolls wings level. In some aircraft, the lower wing will stall first, and the aircraft will flip inverted. Not fun. Generally, steep turns, definitely those with more than 60° of bank, are best avoided unless deliberately undertaking aerobatics.

4.4 Climbing Turns

In the climb, airspeed is low, and maximum lift in a vertical direction is needed, so the angle of bank needs to be minimised whilst achieving the required change of direction. In practice climbing turns should be limited to “Rate One” or 15° of bank in most circumstances.

4.5 Descending Turns

In a descending turn, the rate of descent will tend to increase for a given airspeed. It is not a hazard, but pilots need to be aware that their descent rate will increase in a turn. This can be used to advantage if an approach to land is too high, when a series of gentle ‘S’ turns on final approach can significantly reduce excess height.

At low airspeed, such as when turning onto final approach, the bank angle must be kept to a maximum of about 15°, otherwise the loss of height as explained in 3.0 above becomes excessive. The instinct is then to apply back pressure on the yoke, reducing airspeed further (you are already slow) and you are in great danger of a stall or worse a spin during the final turn. It has happened many many times in real life, and is rarely survivable, so it is a major no-no to make your final turn steeper than 15° (in the Cessna 172).

5 OTHER FORCES

5.1 Torque Roll

This force isn't going to worry the Cessna driver, but is a consideration for a Spitfire pilot. Applying full power very rapidly in a very powerful aircraft can produce a torque reaction in the opposite direction of the rotation of the propeller, resulting in a sudden roll (banking) of the aircraft which can catch the pilot unawares. It used to catch the unwary WWII pilot when doing a low pass and then powering away into the climb. More than one wingtip has struck the ground, resulting in no climb!

5.2 The Coriolis Force

The final complication of an aircraft flying in its 3-dimensional medium is that the engine and propeller form a gyroscope. The main property of a gyroscope is that when spinning at high speed, its axis of spin remains constant. Any attempt to change the axis of spin requires a significant force to be applied. If that force is applied, then due to a phenomenon called the Coriolis Force, the direction of turn of the spin axis is at right angles to the direction of application of the force. Another effect of Coriolis force is that if a gyroscope is accelerated or decelerated, then the axis of spin tries to rotate.

You can see this effect for yourself if you hold a bicycle wheel by its axle, one hand at each end, with the wheel itself between your arms as if your arms were the front forks of the bicycle. Get someone to spin the wheel quite quickly, and then move your left hand towards you. It will actually be forced up or down (depending on the direction of rotation of the wheel), and not towards you at all. A more painful experiment may be made by riding slowly and suddenly turning the handlebars. The tendency is always to fall off away from the direction in which the front wheel is pointing!

If you turn the aircraft, then the gyroscopic effect of the engine and propeller and the associated Coriolis force makes the nose want to rise or lower, depending on the direction of turn and the rotational direction of the engine. If you accelerate the engine, then a turning effect to right or left is produced, again depending on the direction of rotation of the propeller.

Fortunately, in modern aircraft the effect is scarcely noticed, except in one circumstance, and that is when starting the take-off roll. Then, the rapid acceleration of the engine tends to swing the aircraft, and that swing has to be checked with rudder. In a Cessna 172, with a clockwise rotating propeller as seen from the cockpit, that swing is to the left, and right rudder is needed to check it. Like many things in life, the experienced pilot will hardly know he is doing it, the rudder input being automatic when opening the throttle on take off.