1 INTRODUCTION

This tutorial is specifically designed for Microsoft Flight Simulator pilots flying VFR flight in the UK. It explains in fuller detail than does FS itself, the meaning and application of the basic performance data provided in the program, plus some additional information from the real world which is applicable to Flight Simulator.

The aircraft described in this tutorial is the FSX Cessna 172SP, but the principles apply to all light aircraft.

2 FSX SPECIFICATIONS

The following table is taken from FSX. Some of the figures don't compare with real world experience, namely the claimed normal cruise speed and the claimed service ceiling. The metric equivalent of Basic Empty weight is also incorrect. More likely values are included later.

	Imperial	Metric
Maximum Speed	126 knots	234 km per hour
Cruise Speed	105 knots	192 km per hour
Engine	Textron Lycoming IO-360-L2A 180 bhp	
Propeller	Macauley Fixed Pitch Two Blade	
Maximum Range	638 nm	1,183 km
Service Ceiling	14,000 feet	4,267 meters
Fuel Capacity	56 gallons	212 litres
Empty Weight	1,665 pounds	757 kilograms
Maximum Gross Weight	2,550 pounds	1,157 kilograms
Length	27 feet, 2 inches	8.2 meters
Wingspan	36 feet, 1 inches	11 meters
Height	8 feet, 11 inches	2.72 meters
Seating	Up to 4	

3 PERFORMANCE LIMITATIONS

Although not mentioned in the documentation or Flight Lessons, the FSX default Cessna 172SP can be assumed to have similar demonstrated performance limits as a real world Cessna 172.

3.1 Take off Performance:

Ground Roll...805 feet 245 metres

Total Distance over a 50-FT Obstacle.................1440 feet 440 metres

3.2 Landing Performance:

Ground Roll...550 feet 168 metres

Total Distance over a 50-FT Obstacle.................1295 feet 395 metres

3.3 Stall Speed (KCAS):

Flaps Up, Power Off 51 knots

Flaps Down, Power Off 47 knots

The McGraw-Hill Dictionary of Aviation gives take off distance as follows:

The horizontal distance required to accelerate from a standing start with all engines operating to achieve a safety speed at a height of 50 ft above the takeoff surface, determined for a level, short, dry surface.

ICAO Standards and Recommended Practices (SARPS) define the term 'Landing Distance' as "*the horizontal distance traversed by the aeroplane by the aeroplane from a point on the approach path at a selected height above the landing surface to the point on the landing surface at which the aeroplane comes to a complete stop*" (ICAO Annex 8 Part IIIA Paragraph 2.2.3.3. and Part IIIB Sub-part B Paragraph B2.7 e).

3.4 V-Speeds

Another important system of performance definitions is called V-Speeds. For the Cessna 172SP the table below is the usually accepted list.

V-Code	Description	Value
V_{ne}	Never-exceed speed	163 knots
V_{no}	Maximum normal operating speed	127 knots
V_x	Best angle of climb	62 knots
V_y	Best rate of climb	74 knots
V_a	Manouevring Speed (at 2,550 lbs all-up weight)	105 knots
V_a	Manouevring Speed (at 1,900 lbs all-up weight)	90 knots
V_{fe}	Maximum flap extension speed	85 knots

V_s	Stall speed without flaps	51 knots
V_{so}	Stall speed with full flaps extended	47 knots

The V-speeds are normally indicated on the airspeed indicator as coloured arcs, e.g. the flap operating range is coloured white.

3.5 Demonstrated Crosswind Limit

The real world Pilot Operating Handbook for most Cessna 172 models states: "The maximum allowable crosswind velocity is dependent upon pilot capability rather than airplane limitations. With average pilot technique, direct crosswinds of 20 MPH can be handled with safety." So – for Club purposes, we will assume 17 knots.

The crosswind component of the wind is proportional to the cosine of the angle between the wind direction and the runway direction.

There is a quick reference for crosswind calculations for take off and landing

Wind Direction	Headwind	Crosswind
Up to 30 degrees off the runway direction	Full	Zero
From 30 degrees to 45 degrees off runway direction	50%	50%
45 degrees to 60 degrees off runway direction	30%	70%
More than 60 degrees off runway direction	Zero	Full

E.g. a 30 kt wind 30 degrees off the runway track is 15 kts across; 45 degrees off is 21 kts across; 60 degrees off is 27 kts across.

4 THE EFFECT OF ALTITUDE

The atmosphere is thinner at high altitude and it isn't too hard to appreciate that aircraft performance will be affected. If the air is thinner, then as well as the engine struggling to get enough air to run, the wings struggle to generate enough lift and thus we have the aircraft's performance "ceiling" the highest altitude to which it can climb.

Although the claimed service ceiling is 14,000ft, and it possibly is the absolute maximum if you have all day to wait, but in practice the FSX C172SP really struggles to reach even 10,000ft., flying with a low airspeed (60-65 knots IAS) and a rate of climb around 200ft/minute.

Remember though that at high altitude, indicated airspeed is considerably less than true airspeed for the same reason – the air is thinner. The dynamic pressure on the pitot head at a given airspeed is less than at lower altitudes, so the differential pressure with the static vent is less and therefore the indicated airspeed is less. For an explanation of how the airspeed indicator works with air pressure, see http:/www.cixvfrclub.org.uk/training/TrainingManual/Aircraft_Systems.php

It is useful to know the true airspeed, in order to calculate the groundspeed and therefore progress through the flight, but indicated airspeed remains critical, for the stalling speed is the indicated airspeed. So eventually, if you keep on going up, the indicated airspeed, even at maximum power, will equal the stall speed, assuming you haven't run out of lift first. The calculation of true airspeed from indicated airspeed is covered in Exercise 16 of the Cix VFR Club Training Manual.

4.1 The Standard Atmosphere

The International Standard Atmosphere (ISA) has a temperature of 15^{o} Celsius and a Barometric Pressure of 1013 hectopascals at sea level, but the actual atmospheric temperature and pressure varies from day to day. The performance figures given in the Pilots Operating handbook are for a day when the barometric pressure is "Standard", and if an aircraft is flying in conditions other than Standard its performance will be affected, perhaps for the better, perhaps for the worse.

The effect can be calculated, which is particularly important when the aircraft's performance is likely to be affected adversely.

4.2 Pressure Altitude

Pressure Altitude has a complicated definition, but this can be simplified to "Pressure altitude is the altitude displayed on the Altimeter when 1013 is set on the Kollsman sub-scale." In other words, it is the altitude relative to the ISA pressure datum. For VFR pilots, it is important mainly for helping to determine an aircraft's performance when the barometric pressure is very low, particularly take off performance.

Let us take an airfield at 825 feet above sea level when the Barometric pressure (QNH) is 980 hectopascals (hPa).

If the altimeter Kollsman scale is advanced from 980 to 1013 to display pressure altitude, 33 hPa will be added, equivalent to 33 x 30 feet = 990 ft.

So the pressure altitude will be 825+990 = 1815 feet above sea level on that day. That can make a difference if the runway is very short.

4.3 Density Altitude

The temperature of air affects its density – cold air is denser than warm air – and density affects pressure. The Altimeter will over read on a cold day and under read on a warm day. When flying from warmer air to colder air at a constant indicated altitude, therefore, the aircraft will actually descend. If terrain clearance is an issue, this could be important.

On a day when the temperature at sea level is 15°C, (ISA temperature) the temperature at a pressure altitude of 3000 feet will be 6 °C less; 9 °C, because the temperature decreases by 2 °C per thousand feet as explained above. So at 3000 feet, 9 °C may be called the "ISA temperature" for that altitude. Similarly, on a day when the temperature at 3000 feet is 18 °C, because the ISA temperature is 9 °C, the temperature can be described as "ISA+9". The temperature at sea level will be 24 °C, and you should be able to calculate why.

The density altitude can be determined in three ways:

1) By calculation from Pressure Altitude and temperature
2) Graphically (there are usually graphs in aircraft Manuals)
3) By using an aeronautical slide rule or calculator.

Method 1) uses the pressure altitude correction factor of 1 °C per 120 feet, and is the method used in the calculation below.

Let us take an airfield at 825 feet above sea level on a blistering hot July day - 28 °C at the airfield, and the QNH is 999 mb. First calculate the pressure altitude

If the altimeter Kollsman scale is advanced from 999 to 1013 to display pressure altitude, 14mb will be added, equivalent to 14 x 30 feet = 420 ft.

So the pressure altitude will be 825+420 = 1245 feet on that day.

The ISA temperature at that pressure altitude will be

15 °C – (2 x 1245/1000) = 12.5 °C, but the actual temperature is 28 °C

The density altitude correction to the pressure altitude value is therefore

(28-12.5) x 120 feet = 1860 feet

The density altitude on that very hot day is therefore 3,105 feet, a significant difference from the airfield elevation of 825 feet. What is important here is that the aircraft and its engine will perform as if the airfield were at 3,105 feet in ISA conditions.

One can immediately see that take off at an airfield 7,000 feet above sea level when the pressure is low and the ambient temperature is high, could result in a very long take off run being required to get airborne. In some conditions, the aircraft's performance capability could be exceeded.

5 GENERAL HANDLING

Some pilots fly by instinct, some "by the numbers", the best, - by a combination of the two. But what numbers should be used? The following "numbers" are appropriate for normal flight in Flight Simulator. They may vary slightly according to payload and weather conditions. Correct trimming is assumed.

Configuration	Power	Performance
Normal Cruise	2300rpm	105 knots
Cruise Climb (200-500ft/minute)	2300rpm	100 knots
Cruise Descent (500ft/minute)	2000-2100rpm	100 knots
Best Rate of Climb (Vy)	2400rpm	76 knots
Best Angle of Climb (for obstacle clearance) (Vx)	2400rpm	59 knots
Normal approach with 2 stages of flap	2100rpm	70 knots
Short Field Landing with full flap	2100-2200rpm	60 knots
Short Field take off 10 degrees flap	2300rpm	60 knots
Practical Service Ceiling with appropriate mixture control (70 knots IAS)	2300rpm	10,000ft.

N.B. Aerobatic manoeuvres are outside the scope of this document.

6 FUEL MANAGEMENT

6.1 Endurance

If a pilot in the real world runs out of fuel and lands safely in a field, you may feel he did well, was lucky, or has got away with having to make an insurance claim for his bent aeroplane. You may be surprised to know that he or she will also be prosecuted for negligence by the Civil Aviation Authority. Cix VFR Club pilots, like their real world counterparts, therefore do not run out of fuel.

The Cessna 172SP holds 56US gallons, according to FS, 212 litres in French, so if the fuel consumption is 8 US gallons/hour (about 30 litres/hr), then the aircraft has enough fuel for 7 hours flight. This is known as the aircraft's "endurance". However, UK Aviation Law requires that pilots of light aircraft, flying under VFR, should plan their flights so that they have at least 45 minutes of fuel remaining on landing, so the maximum safe planned flight duration is 6 hours 15 minutes.

An aircraft burns 30 litres of fuel per hour and cruises at 110 knots. A pilot plans to make a flight of 180 miles and from the weather forecast he expects to encounter a 10 knot headwind throughout the flight. What is the minimum useable fuel he must depart with? Assume that you must have a minimum of 45 minutes of fuel remaining on landing.

The groundspeed is going to be 100 knots, subtracting the headwind of 10 knots from the airspeed of 110 knots. So 180 miles will take 180/100 = 1.8 hours or 1 hour 48 minutes. Add 45 minutes reserve to this to obtain the amount of fuel required expressed as time – 2hrs 33 minutes. If the fuel is consumed at 30 litres per hour, then the fuel required on take off will be 76.5 litres.

6.2 Which Fuel Tank?

In most aircraft, most if not all of the fuel is stored in the wings. The Cessna 172 is a "high wing" aircraft – the wings are above the engine, and all its fuel is stored in the wings, so fuel flows by gravity to the engine. A selector valve in the cockpit allows the pilot to select the left wing tank, the right wing tank, or both (or neither, when shutting down at the end of a flight). Mostly, FS pilots will fly with both tanks selected, which simplifies fuel management significantly.

However, if you choose to fly using fuel from only one tank (and many aircraft do not have a "both" option), you should keep both tanks with roughly the same amount of fuel in each by flying for 30 minutes on one tank, then changing tanks and flying 30 minutes on the other tank, then again changing. The exception to this is that when taking off and landing, the fullest tank should be selected.

Low-wing aircraft need a fuel pump to pump the fuel from the tanks to the engine. There are normally two fuel pumps; one driven by the engine, and one electrically driven. During take off and landing, the electric pump is switched on in case the engine-driven pump fails during these crucial phases of flight.

Some aircraft have several fuel tanks, and these are normally used in a sequence, set out in the operating notes, which eliminates or minimises any out-of-balance forces.

6.3 Economy or Speed?

An aeroplane can be flown economically or as fast as possible. You will recognise from car driving, that that choice will affect fuel consumption. The table below gives some comparison figures, although the figures are not taken from real world or from FS.

	Airspeed	Fuel Burn
Best Economy	80 knots	27 litres/hr
Best Range	90 knots	30 litres/hr
Normal Cruise	100 knots	35 litre/hr
Best Speed	120 knots	50 litres hour

It is entirely the pilot's choice which he prefers for a given flight. For 120nm flight at 90 knots, the flight will take 120/90 x 60 = 80 minutes (I hour 20 minutes) and the fuel used will be 30 x 80/60 = 40 litres. At 120 knots the flight will take 1 hour and the fuel consumed will be 50 litres. It is cheaper to go more slowly, but can you afford the longer flight time? Pilot's choice, as stated at the beginning.

Of course, because virtual aviation fuel is free, you may think that this isn't of great relevance to Flight Simulator, but how much fuel you carry directly affects your payload – how many virtual passengers you can carry. You might one day take part in a competition to fly as far as you can with a known payload on a given amount of fuel, so now you know where to start your planning.

7 ENGINE MANAGEMENT

Aircraft engines are hugely expensive and the prudent pilot really looks after it. Maintaining the correct fuel/air ratio, cylinder and oil temperatures and oil pressure, and avoiding carburettor icing are vitally important. It is of course less critical in Flight Simulator, although software exists which can mimic engine failures due to mismanagement. In the default Cessna 172, the temperatures and pressures (known to pilots as Ts and Ps) can be mismanaged without any effect, but Flight Simulator does mimic the fuel/air mixture dynamics. The Cessna 172 in FS9 and FSX has a fuel injected engine in which the mixture is controlled electronically, and has no carburettor. Therefore it does not, cannot even, suffer carburettor icing.

7.1 Mixture Control

The mixture control (push-pull lever with a red knob next to the throttle) reduces the amount of fuel which passes to the cylinders. The volume of air being drawn into the cylinders is constant, so as the red knob is pulled out, the ratio of fuel to air is reduced – the mixture becomes "leaner". Ultimately, when the mixture control is pulled all the way out, the fuel flow is reduced to near zero and the engine stops. This is of course the correct way to stop most aircraft piston engines. It is dangerous to stop the engine by switching off the magnetos, because this leaves the cylinders charged with fuel, and an inadvertent switching on of a magneto can cause a cylinder to fire when it would be most undesirable for it to do so, such as if an Engineer is turning over the propellor by hand. Amputations have happened. Of course this is not relevant to FS, but we like to do things properly, so we always stop the engine using the mixture knob, don't we?

At sea level, a fully-rich mixture setting (the mixture control pushed fully forward) produces a perfectly acceptable ratio of fuel to air for combustion in the cylinders. In practice the sea-level mixture is deliberately set rich, so that the unburn fuel remaining after combustion aids in engine cooling at high power settings, such as take off and climb.

As the aircraft climbs higher, the air becomes thinner. If the mixture setting remains constant, the engine will receive the same amount of fuel, but much less air. It receives the same volume of air, but it is less dense – fewer molecules per cubic inch, and it is the correct number of molecules which matters. So because there's so much more fuel compared to air, this mixture becomes too “rich” and will not burn efficiently. It is possible for the mixture to be so rich that combustion fails and the engine stops – the so called “rich cut”.

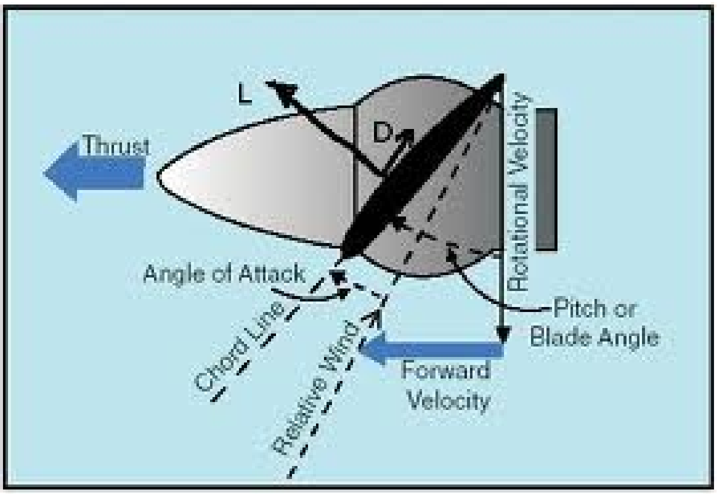
This fuel/air combustion algorithm is fully modelled in FS and we have to manage it. As the aircraft climbs, and as the air becomes thinner, the pilot "leans" the mixture (i.e. reduces the amount of fuel being introduced to the engine) so that the ratio of fuel to air is maintained at the optimum, and the engine keeps running smoothly.

The FS Cessna 172 has an instrument that displays the exhaust gas temperature (EGT). The pilot leans the mixture until the engine RPM reaches a peak. At this point he should note the EGT and then richen the mixture until the EGT is 50°C lower. This gives you the "Best Power" mixture. If you want "Best Economy" then you leave the mixture at the max EGT.

Some FS aircraft don't have an EGT instrument. The technique for correct leaning then is to note the max RPM and then lean until the RPM just begins to fall. Then richen the mixture a fraction to gain that cooling effect of the excess fuel.

8 THE PROPELLOR

The propellor blade is a rotating wing, and therefore is an aerofoil section. As it rotates, the air flowing over it comes partly from the blades rotating and is therefore moving in the plane of the propellor disk; and partly at right angles to the plane of the propellor disk due to the forward travel of the aircraft. The total airflow, the “relative wind” when the aircraft is at cruising speed, is at about 60° to the axis of the propellor, as shown in the diagram below. The propellor blades are angled so that the “lift” the propellor blade produces is parallel to the propellor axis and is called “thrust”, a term you are already familiar with because it is thrust which powers the aircraft to make it move through the air.



8.1 Fixed Pitch Propellor

A fixed pitch propellor is fitted to most small aircraft because they are simple in construction and operation. In a dynamic environment the fixed blades are only able to produce optimum thrust over a narrow range of rotational speeds and airspeeds. They are not ideal for any one thing, yet they're in many ways best for everything. They represent a compromise between the best angle of attack for climb and the best angle of attack for cruise. When the aircraft is stationary on the ground, a propellor turning at maximum r.p.m. is in fact almost stalled but, by design, its efficiency is at a maximum at cruising speed and power setting. The propellor r.p.m. is the same as the engine r.p.m., measured by the Tachometer, or r.p.m. gauge, because there is no gearbox. The propellor is bolted directly onto the engine crankshaft. In Flight Simulator that is about all you need to know about fixed pitch propellers.

8.2 Constant Speed Propellor

The other type of propellor is a constant speed propellor, more commonly known as a variable pitch propellor. This type of propellor is fitted to the default Beech Baron among other aircraft. The former describes its operation, the latter describes its construction. Constant speed propellers can be operated efficiently over the full power range of the aircraft, so allow more power to be converted into thrust than a fixed pitch propellor.

Each blade of the propellor can rotate about its longitudinal axis by a certain amount in order to vary the angle of attack of the blade to the airflow – known as the pitch of the propellor. The pilot has a pitch control lever (with a blue knob) with which he adjusts – not the pitch directly – but the speed of revolution of the propellor. This is why it is more accurately called a constant speed propellor, and that speed is regulated by a governor within the propellor gearbox. The governor will adjust the propellor to whatever pitch it needs to maintain the r.p.m. as long as the propellor blades are not at the coarse or fine limit of their range of pitch.

When the propeller is set to fine pitch, there is less torque load on the engine, so it can rotate more quickly and it delivers maximum thrust. When the propeller is set to coarse pitch, there is a greater torque load on the engine, and it rotates more slowly so it delivers less thrust.

The propeller control is set to fully fine (normally the lever is fully forward) for maximum r.p.m. and maximum power. Full throttle and maximum r.p.m. are used for takeoff and climb. As power is reduced for the cruise, the propellor r.p.m. can be reduced (the propellor pitch coarsened) to develop sufficient power for the cruise, but save fuel because of the lower r.p.m.

A similarity is often drawn with a simple machine screw. Screws with a coarse thread (coarse pitch) need fewer turns of the screwdriver to drive them home, but the effort required to turn them is higher in a given material. Screws with a fine thread (fine pitch) require more turns to drive them home, but are easier to drive home. They can also take a greater load than a coarse pitched screw, which is why they are used in such applications as cylinder head bolts.

Another parallel can be drawn with a car gearbox. Low gear is needed for starting off, high engine r.p.m. and high power, with high gear for "cruising" with a lower engine r.p.m..

In some aircraft, the engine can overspeed when the propellor pitch is fully fine with full power, as the governor is on its stops and there is still power to spare. The propellor can no longer provide sufficient load for the engine, so it overspeeds (similar to revving up a car engine when it is in neutral. Where this is an issue, the rule for safe constant speed propellor management is

"Rev up, throttle back".

This means that when adding power, lead with the propellor lever, reducing r.p.m. a little as power is fed in. When reducing power, bring the power lever back first, followed by moving the propeller lever towards the "fine" end of its range. Typical maximum r.p.m. values are between 2500 and 2700.

When starting from a standstill, power must be fed in gradually, with a sharp eye on the r.p.m. (tachometer) coarsening the prop. Lever as necessary. Once the aircraft is moving and full throttle is achieved the r.p.m. can often be increased again (blue lever forward) as the propellor begins to "bite".

Normal climb technique is at full power to altitude and then reduce the r.p.m. to the cruise setting. If you level off at an altitude below 7,000 feet, you may wish to reduce the manifold pressure to a cruise setting. Above 7000 feet, most engines will be run at full throttle.

Most engines have r.p.m. limits for a given manifold pressure. For example, on some engines, you can use any r.p.m. down to 2200 with a manifold pressure of 24 inches. Below 2200 RPM, the manifold pressure must be reduced. As a rule of thumb, cruising with the power and prop. settings “all square”, or 24/24, for example, (24 inches manifold pressure and 2400 r.p.m.) will be reasonably correct, but if you want to fly by the book in FS, then download the Pilots Operating Handbook, or similar document from the web. All the engine management information will be in there.

For the approach and landing, you will need to reduce power. Landings are always made with the propellor fully fine, in case of a go around, so reducing manifold pressure initially to around 17 inches and moving the prop. lever fully forward is a good starting point. Adjust power as you add the drag of the lowered undercarriage and flaps.

8.3 Manifold Pressure

Manifold pressure, which is read in inches of mercury or “in hg”, is one of the best methods to determine just how much power is being developed by the engine.

The more air and fuel that is drawn into the cylinders, the more power the engine can develop, and the air pressure in the induction system, just before the air / fuel mixture enters into the cylinders, gives a good idea of how much power is being developed.

In normally aspirated engines (non turbo-charged), the manifold pressure gauge has a range of between 10 – 40 in. hg (or inches of mercury). In a turbocharged engine, the manifold pressure is allowed to go as high as the engine manufacturer allows. When the engine is shut down, the manifold pressure gauge should indicate the current atmospheric pressure setting as there is no pressure difference between the inside and the outside of the induction manifold.

On a variable pitch propellor driven aircraft, the manifold pressure gauge provides an indication of "how much throttle" you have selected. So, 24" MP might be the cruise setting, 20" might be selected for descent, and 17" for the circuit.

The phrase “manifold pressure” needs a little explanation. The manifold pressure gauge is measuring absolute pressure, where zero would be a complete vacuum! The engine is actually creating a vacuum inside the intake manifold as air is sucked into the cylinders. That’s why at idle power the manifold pressure gauge might read 10 or 12 inches when the outside ambient atmospheric pressure is 30 inches, and as the throttle is opened the vacuum is reduced. At full throttle, the manifold pressure is close to the ambient atmospheric pressure as the restriction of the butterfly throttle valve in the inlet manifold is at a minimum. When the engine is stopped, the manifold pressure gauge indicates the ambient atmospheric pressure.

9 WEIGHT AND BALANCE

9.1 Weight

The safe way to avoid running out of fuel is to fill the tanks completely and fly no more than 3-4 hours, say, but that isn't the whole story. If you wish to take four 15 stone adults and their luggage on a 4 hour trip to the south of France, you might find that you can't, because if you uplift enough fuel for the trip, the aircraft will be too heavy to take off safely.

Let's do the sums – add up all the component weights.

Firstly, what is the calculation with full fuel?

Item	US Units	Metric
Aircraft basic empty weight (BEW)	1665lbs	757Kg
Four 15 stone adults	840lbs	382Kg
Luggage	80lbs	36Kg
Full fuel	336lbs	153Kg
Total	2921lbs	1328Kg
Maximum All-up Weight (MAUW)	2550lbs	1159Kg
Overweight	371lbs	169Kg

This weight calculation must be done real world before every flight, and also in FS, if you want to do things properly. So if you are more than 2-up in a Cessna 172, you should do the maths. The humble Cessna is not a load carrier. The seven hours theoretical endurance is probably only possible with no pilot!

So let's see if we can still go if we uplift less fuel. The aircraft is overweight by 371lbs and full fuel weighs 336lbs. A moment's thought reveals that the aircraft is too heavy, even with NO fuel! You will have to draw lots as to who you leave behind.

Three 15 stone adults and their luggage weigh 690 lbs. That looks more promising. Also, you have calculated that the trip will take three and a half hours. So you only need upload four and a quarter hours-worth of fuel.

Item	US Units	Metric
Aircraft basic empty weight (BEW)	1665lbs	757Kg
Three 15 stone adults	630lbs	286Kg
Luggage	60lbs	27Kg
Fuel for 4.25 hours @8 gals/hr*	196lbs	89Kg
Total	2551lbs	1159Kg
Maximum All-up Weight (MAUW)	2550lbs	1159Kg
Within limits by	-1lbs	0Kg

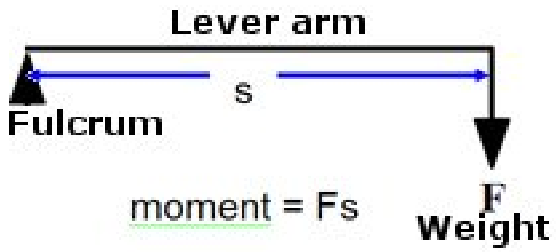
**Aviation gasoline (AVGAS) weighs 5.76lbs per US gallon, so you need 4.25 x 8 x 5.76 lbs of fuel = 219lbs*

Rounding errors result in the pounds to kilograms conversion not being exactly accurate. Anyway, you will normally only work in one set of units, depending on your preference. Using the pounds column, you can see that you would be 1lb overweight, but that will be burned while taxying, so that's OK.

Where did the fuel consumption figure of 8 gallons/hour come from? FS doesn't mention this anywhere, but there are many references to the real world aircraft on the Internet which provide such data. One has to assume that a similar value is correct within FS.

9.2 Balance

The other loading factor which affects an aircraft's performance is where the loads are placed. You can easily imagine that if all the heavyweights were in the back with their luggage, the aircraft would want to pitch up and flight would be difficult if not impossible. This is due to the principle of "moments". A moment is a turning force created by a weight F acting at the end of a "lever arm" S about a fixed "fulcrum". Calculating moments is important in maintaining an aircrafts longitudinal stability.

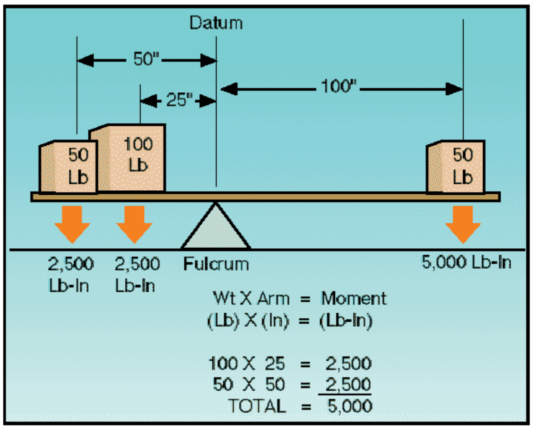


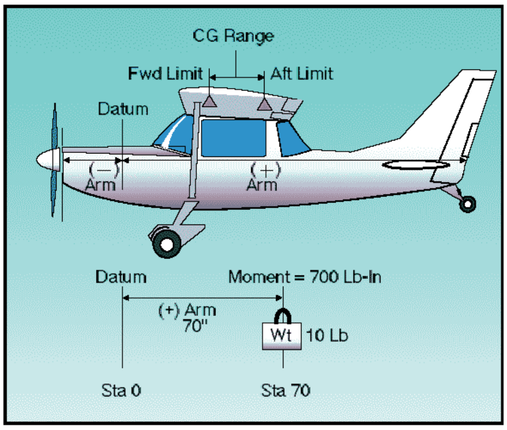
Every moment due to an element of the weight of an aircraft has to be balanced, within certain limits, by an equal and opposite moment on the other side of the centre of gravity if the aircraft is to remain with its longitudinal axis horizontal in cruising flight. It must be neither nose heavy nor tail heavy. (Actually, it needs to be a tiny bit nose heavy for reasons we don't need to go into.)

An empty aircraft is designed with that longitudinal stability. The weight of the aircraft body and engine forward of the Centre of Gravity (CofG), must be balanced by the weight of the fuselage and empennage aft of the CofG. The aircraft structure aft of the CofG, however, is much lighter than the aircraft structure and engine forward of the CofG. To maintain the necessary balance, the tailplane exerts a downward acting lift force as shown in the diagram below. The wings and fuel tanks in the wings are positioned at the CofG, so do not affect the longitudinal stability. However, adding payload – fuel, passengers and luggage, DOES affect that stability.

For any element of the aircraft, the moment due to that element is its weight multiplied by its distance (the lever arm) from the "Datum" (which, in the case of the Cessna 172, is the firewall between the engine compartment and the cabin.

In the diagram below left, the moments due to the weights on the left of the fulcrum must be in balance with the moments due to the weight on the right of the fulcrum. In the diagram below right, the principle is applied to an aircraft. The 10lb weight, 70 inches from the aircraft's datum exerts a moment of 10 x 70 = 700 lb-in about the aircraft's Datum – the fulcrum. The commonly used imperial unit of measurement for moments in weight and balance calculations is "pounds inches" symbolised as lb-in. In metric units it is kilogram-metres.





We need to calculate the moment of each element (taking the empty aircraft with no fuel as one element) from the datum and add them all together.

Then we divide the total moment by the total weight, to get the "resultant" lever arm. This lever arm length – measured from the Datum, defines where the overall centre of gravity of the **loaded** aircraft lies, and it **must** lie within the forward and aft "C of G limits"

Simple aircraft with fuel tanks only in the wings are designed so that the centre of gravity of the fuel tanks, at any stage of emptiness, is coincident with the centre of gravity of the whole aircraft. The pilot and front seat passenger are also designed to be coincident with the centre of gravity. So what we are concerned with in our balance calculation is actually only the rear seat passengers and the luggage.

9.3 Why Is This All Important?

Any item aboard the aircraft which increases its weight degrades performance. An overloaded aircraft may not be able to leave the ground, or if it does become airborne, it may exhibit unexpected and unusually poor flight characteristics, and the initial indication of poor performance usually takes place during takeoff – just when you don't want it.

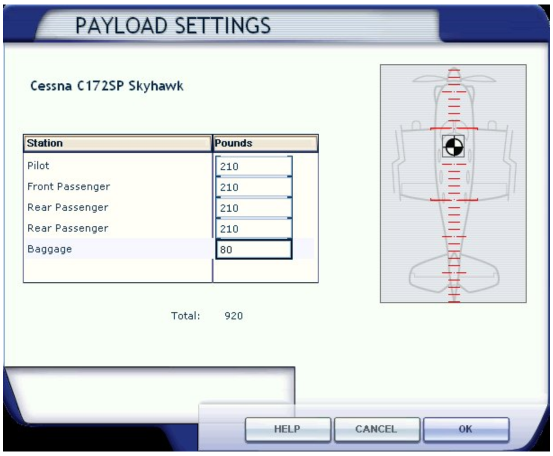
An overloaded or badly loaded aircraft will suffer:

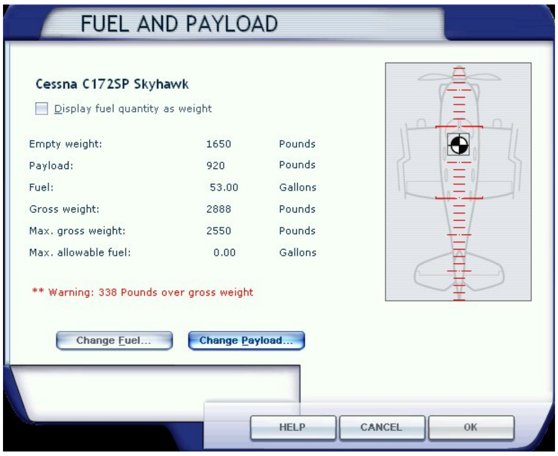
- Higher takeoff speed,
- Longer takeoff run,
- Reduced rate and angle of climb,
- Lower maximum altitude,
- Shorter range,
- Reduced cruising speed,
- Reduced maneuverability,
- Higher stalling speed,
- Higher approach and landing speed,
- Longer landing roll,
- Excessive weight on the nosewheel or tailwheel.

9.4 Off the hook

Having taken you through the whole issue of weight and balance, and strained your rusty maths to the limit, there are two pieces of good news.

4) It is almost impossible to load a Cessna 172 such that its centre of gravity is out of limits. That is one of the reasons why it is the safest aircraft in the world.
5) Flight Simulator does the weight and balance calculations for you. Open the Aircraft/Fuel and Payload section of FS, enter the loads you wish to carry and it will tell you whether you are too heavy, whether the C of G is out of limits, or both.





The two illustrations above show the effect in FSX of our four 15 stone passengers and their luggage with full fuel tanks. Note that although significantly overweight, the centre of gravity remains well within limits.

Remember – for good practice in Flight Simulator, don't overload the aircraft and don't run out of fuel.