Second Level Technologies Benchmark TCH 2-09a and TCH 2- 20a Physics of Flight Pt 6

Exploring the science and technology of flight and testing the theory by building models.

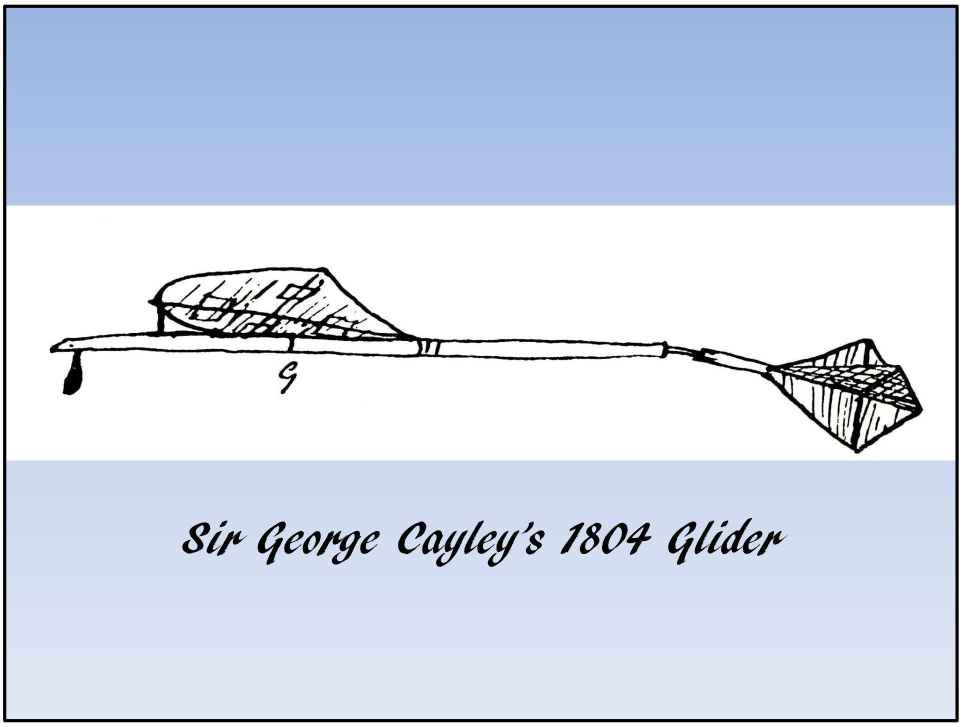
Exploring the configuration of aircraft through historical information and by building flying models to check the validity of the design of three types of aircraft.

We look first at the "Standard" aircraft layout.

This type of layout is by far the most popular in aircraft design.

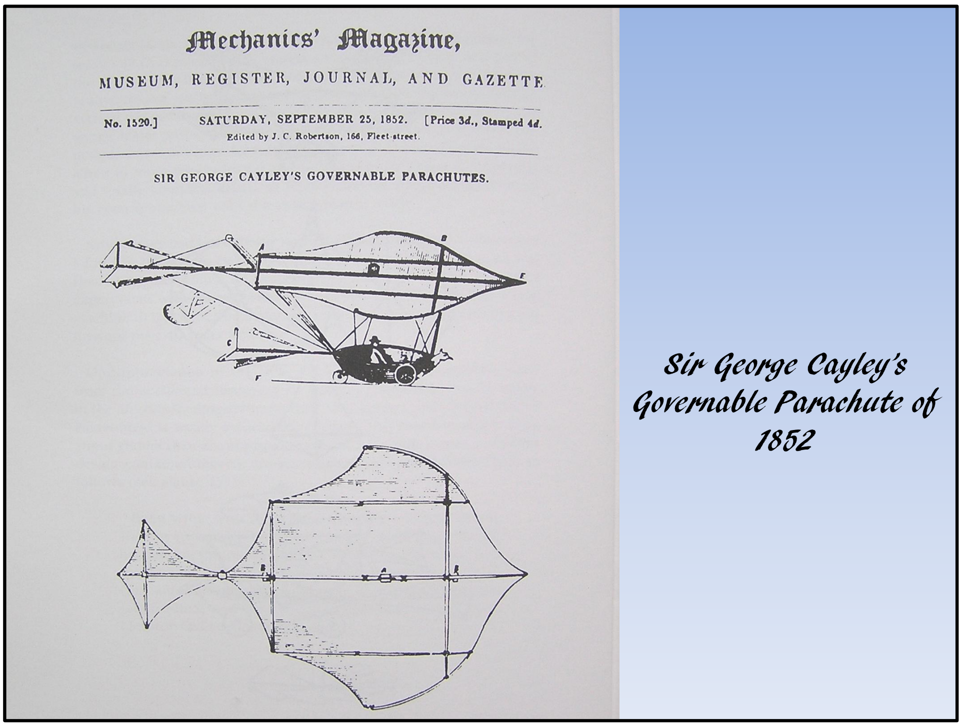
This layout has the wing near the centre of gravity of the aircraft and has the horizontal and vertical stabilising surfaces at the rear of the body.

In the year 1799, Sir George Cayley, proposed that a man-carrying aircraft should have three main elements. A body, to carry the pilot, a wing to produce lift and a tail to balance and steer the aircraft. He, of course, was quite right although it is not quite clear how he came to that conclusion.



Some time later, in 1804, he made a small model glider and discovered that it flew quite well. This is a drawing of George Cayley's model glider which he built and flew in 1804. To our eyes today it looks wrong because the tail unit is bent downwards instead of what we would now expect which would to be bent upwards. However he claimed that it flew well and no doubt it could be made to fly again. But it was to be another 45 years before he decided to try to build a full size glider.

In 1849 Cayley demonstrated that his design did work by launching a full size version of his aircraft down a hill carrying his coachman as the pilot. It is doubtful whether the coachman was ever in control of the aircraft but he did survive, and immediately resigned his post with Sir George.

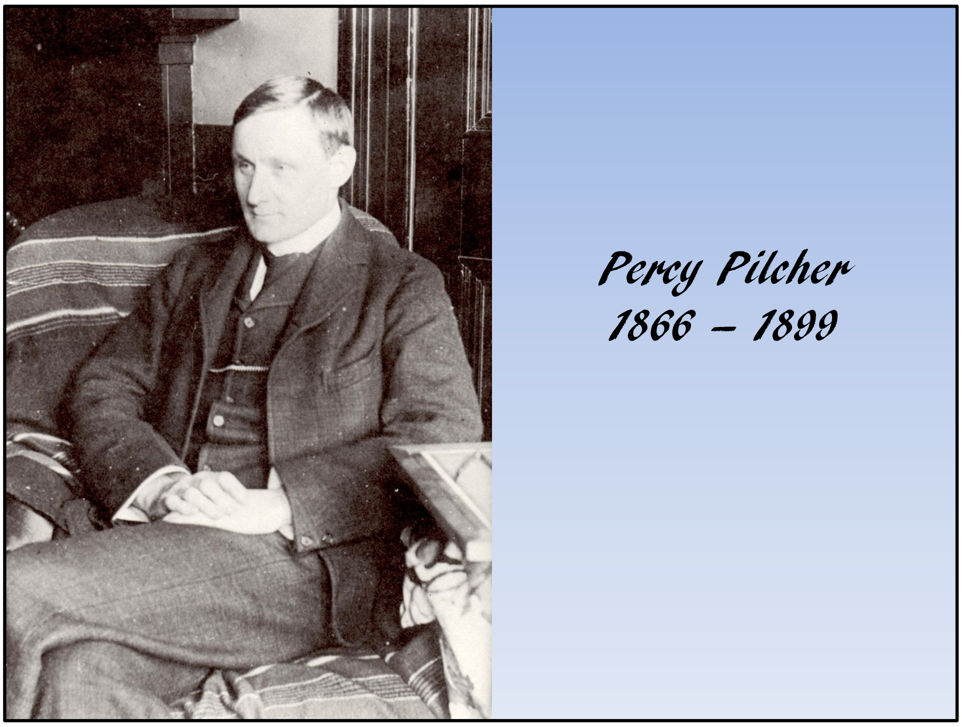


In 1852 Cayley went on to publish a design for his optimum aircraft. He called his flying machine a "Governable Parachute" because the terms "Aeroplane" or "Aircraft" had not yet been invented. George Cayley went on to have an interest in many things and even considered how best to design a helicopter.

Show the video at http://www.bbc.co.uk/education/clips/zs2xpv4

German Engineer, Otto Lillienthal,
and a photo of him flying one of his gliders in 1894

However it would be another 40 years before a truly successful man-carrying glider appeared. The German engineer Otto Lillienthal had initially experimented with flapping wings, as had others before him, but soon realised that he would be much more likely to be able to control a glider with fixed wings and tail surfaces. He started to glide his first aircraft from the top of a small man-made hill and discovered the method of controlling it in flight. Many photographs were published of these historic flights and these fired the imagination of other experimenters. Two years later, having built and successfully flown many versions of his aircraft, Lillienthal was experimenting with moving flight controls when he lost control of the aircraft and crashed. He died the next day from the effects of a broken spine.

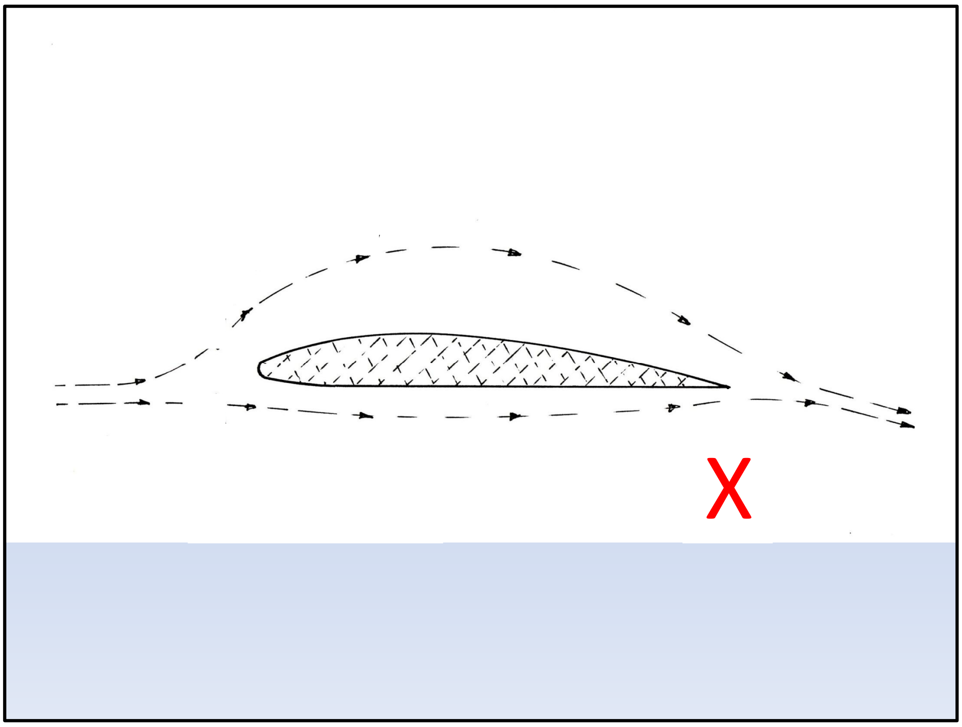


Around this time there was a young Englishman called Percy Pilcher living and working in Glasgow. He had been working in the design department of a Clyde shipyard but was now an assistant lecturer in Glasgow University. Percy had heard of Otto Lillienthal and his gliders and became interested in the idea of flight. Percy had lived and been to school in Germany when he was young and so he wrote to Otto to say that he would also try to build a glider.

Percy Pilcher and his big sister Ella carrying his Bat glider on their way to make a test flight.

Percy's big sister, Ella, had come up to Glasgow to look after her wee brother to make sure that he did not get into trouble but now found that he was going to try to fly. In 1883, Percy built his first glider which he called the Bat. Before he tried to fly it he went to Germany to meet Lillienthal to get some advice on the control of gliders. Lillienthal was surprised to learn that Percy's glider did not have a horizontal tail surface and told Percy that he would not be able to control the aircraft unless one was fitted. Percy returned to Glasgow and despite the advice he tried to fly his Bat. He soon discovered that Lillienthal was right, the Bat could not be controlled, it just kept diving nose-first into the ground.

So what was the important feature of aircraft that George Cayley proposed, and that Otto Lillienthal found out, but that Percy Pilcher did not initially believe?
It was discovered that aircraft with wings need to be **stabilised** by some other aerodynamic force so that they can by controlled by the pilot. To see why this **'stabiliser'** is needed we need to look again at how the wing develops the lift.



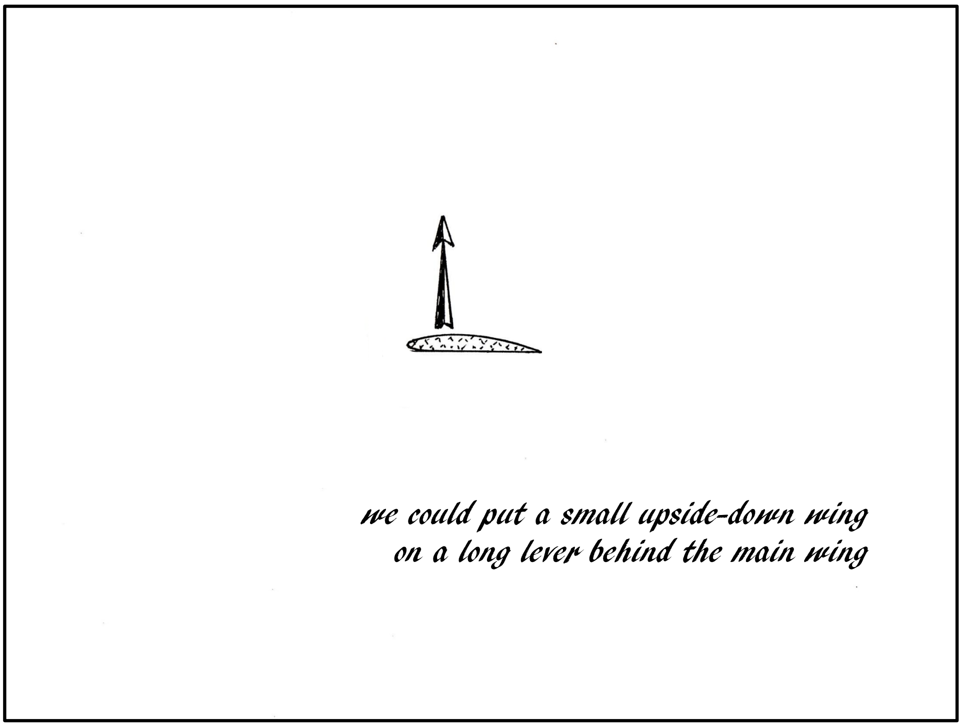
We have already seen that a wing produces the force that we call “lift” by forcing the air that it travels through to rotate upwards and then downwards so that a circular motion is imparted to the air. *(Click)*
In this diagram the air is rotating in a clockwise direction.

Newton said that “for every action there is an equal and opposite reaction” and so, since the air is heavy, the wing is forced to rotate in the opposite direction. *(Click)*
In this diagram the wing is forced to rotate in an anti-clockwise direction.

This is a rather inconvenient fact. It means that if a wing is made to travel through the air at an angle that will produce lift, it is immediately forced to rotate “nose-down” thus destroying the ability to produce lift - just like Percy Pilcher had found.

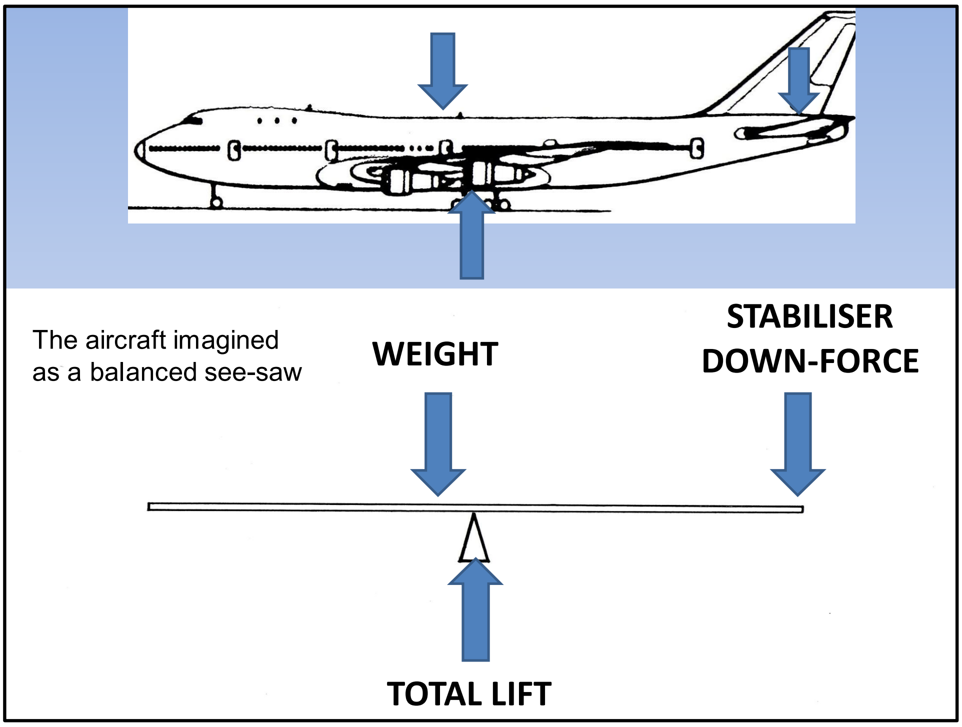
So the trick is now to find a way to hold the wing at the same angle all the time - a second force has to be added to the system to balance the nose-down rotation of the wing.

We could add a counterbalancing weight behind the wing *(Click)* but the problem with that is that the wing lift varies with speed whereas the counterbalancing weight will remain constant.
So that will not work. *(Click)*



What is needed is another aerodynamic shape like a wing which will not only provide the counterbalancing force but will also vary if the speed changes. Here we have a wing producing lift, *(Click)* but also being forced to rotate nose-down thus causing it to lose lift.

A solution would be to have a small upside-down wing on the end of a lever that would produce a down force to stabilise the wing. *(Click)*



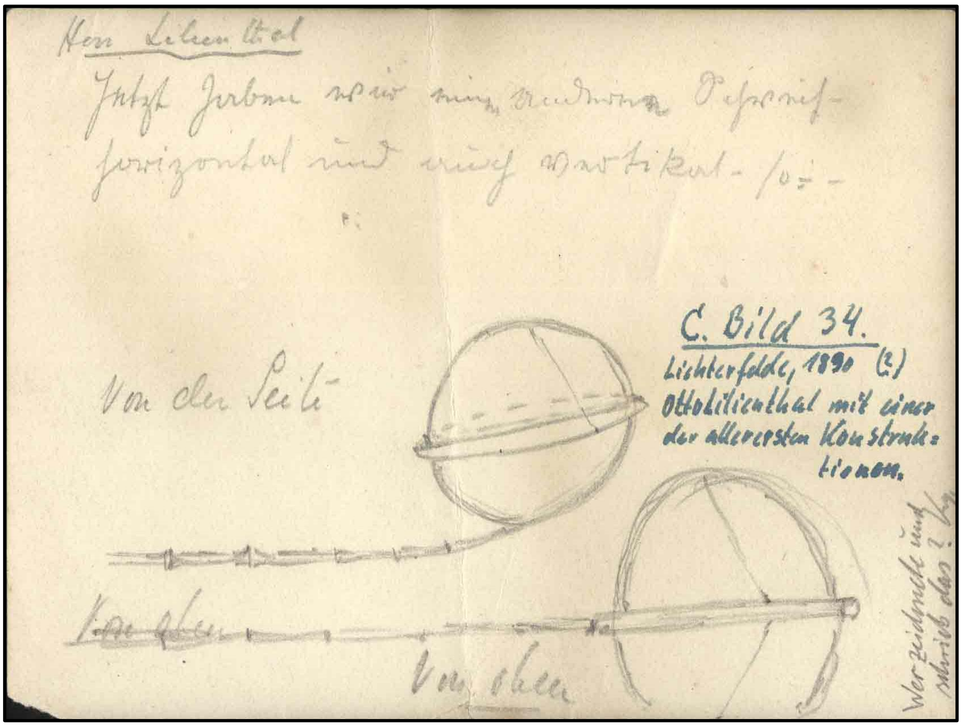
Now we know what we can do to balance the aircraft aerodynamically but that still leaves a problem.

There is another force acting on the aircraft that we can not ignore and that is the force of gravity. Any aircraft that we devise will have weight due to the force of gravity so now we need to know how to distribute that weight so that it acts at a point that does not upset the aerodynamic balance of the aircraft.

In fact we can arrange to position the centre of gravity of the whole aircraft so that it enhances the stability of the aircraft.

If we imagine the aircraft as a giant see-saw and position the centre-of-gravity just ahead of the centre of the lift we can see that the weight of the aircraft will always tend to move the aircraft nose down. Now, if the aircraft flies too slowly, the lift loads on the wing and stabiliser reduce to the point where they can not balance the aircraft, the weight causes the nose to drop. This condition is safe since the aircraft will dive and the speed will increase to the point where the balance is restored. Most aircraft are arranged to be balanced this way.

The diagram shows an aeroplane balanced with a small wing ‘pressing down’ behind the main wing.



Percy Pilcher now fully realised why his original design was faulty and immediately set about rebuilding the tail unit of the Bat to have a horizontal stabilising surface. He sent a letter to Lillienthal explaining the change to the design and included a small sketch of the new circular tail unit. Note that the letter is written in German – Percy Pilcher had spent some time at school in Germany.

So now Percy had an aircraft where all the forces were in balance as the aircraft flew through the air but, **and this is a big but**, the forces are only balanced at one speed. So Lillienthal and Pilcher now had stable aircraft that would be able to glide downhill but only at a constant speed and only in a constant direction.

This of course is not what was wanted so both men had to find a way of controlling the aircraft in flight.

The problem of flight control had to be solved.

Lillienthal had assumed that he would be able to move his weight backwards, forwards and sideways by swinging his body around while supported on his arms. This movement of his weight would then upset the balance of the aircraft and cause it to speed up, if he swung his body forward, and cause it to slow down if he swung his body backwards, also by moving sideways he proposed to turn the aircraft to point in another direction. Lillienthal found that this type of “weight shift” control did actually work but the control was very limited.

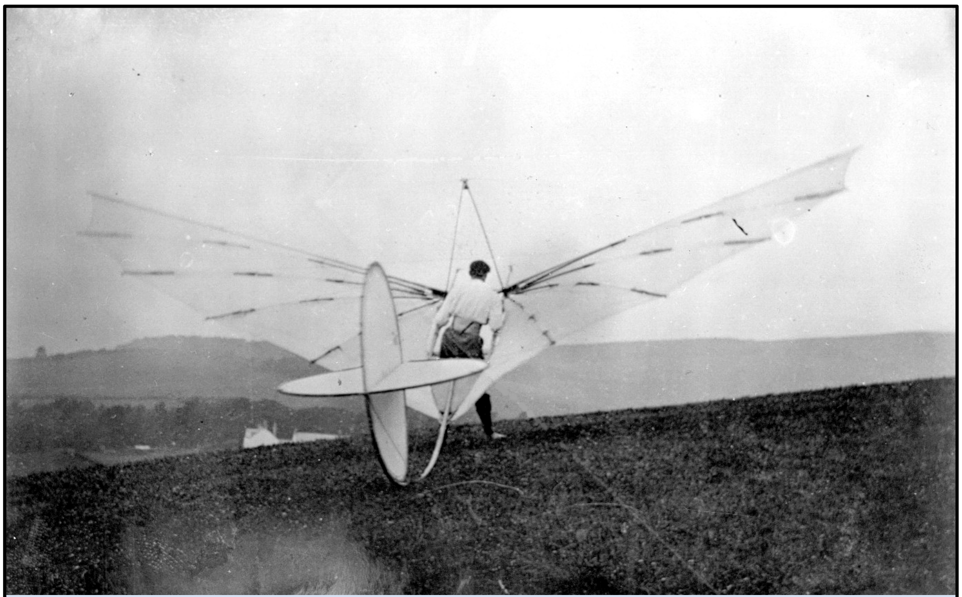
Percy Pilcher intended to control the Bat in the same way.

This is the field that Percy used for his first flights.

In the summer of 1895, Percy and Ella went off on for a summer holiday complete with the Bat. They went to a farm called Auchensail on the north bank of the River Clyde just up the hill from the small town of Cardross. One of the farm fields was ideal for flying since it had a good slope and faced into the prevailing southwest wind. Also the farm had space in an old barn to allow Percy to work on the Bat.

This is the field that Percy used for his first flights. He flew down the slope towards the big single tree that grows beside the road that leads to the farm. Percy could only fly on days when the wind was blowing quite strongly up the hill since he could not carry the glider, which weighed about 20 Kg, and run downhill to get up to its flying speed of about 25 mph. Not even an Olympic sprinter could do that.

Percy now discovered that if he swung his body weight forwards and backwards he could slightly alter the position of the centre-of-gravity of the whole aircraft and this altered the trim of the aircraft which caused the aircraft to fly slower or faster. This was the start of understanding flight control.



Percy and the Bat ready to take-off

Here is Percy and the Bat ready to take-off down the hill. The new tail unit shows up well in this photo. Many flights were made down the slope of this field.

Percy bringing the Bat back up the hill

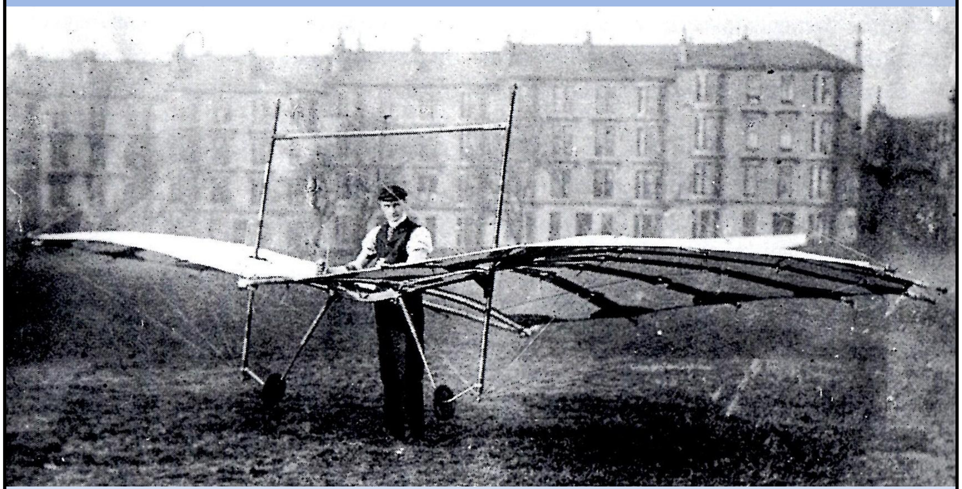
This is how Percy brought the Bat back up the hill. He simply let it fly ahead of him and guided it by holding onto the front of the body.

Pilcher Bat replica at Prestwick

One hundred years after Percy Pilcher made the first controlled flights in a heavier-than-air aircraft in Britain, it was decided that this important aviation first should be marked by building a reproduction of the Bat. A small team at Prestwick built the aircraft…

Pilcher Bat replica in the Riverside Museum, Glasgow

….and it was presented to the new Riverside Museum in Glasgow where it can be seen today.

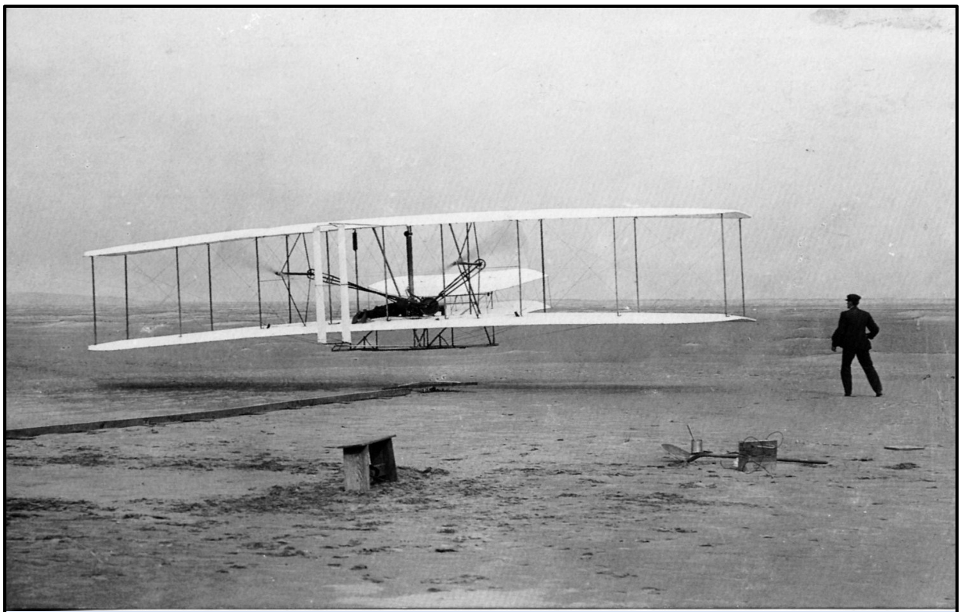


Percy Pilcher and his Hawk glider at Glasgow University

Percy went on to build two more gliders, the Beetle and the Gull but both were unsuccessful. The beetle was too heavy and the Gull was too big. He then built his most efficient glider, the Hawk, and when he moved back to England, he flew this glider many times. It was also flown by his niece, the first woman to fly in Britain.

This picture shows Percy Pilcher and his Hawk glider on Glasgow University playing fields just before he moved back to England to fly it there. This aircraft still exists and is in the National Museum of Scotland in Edinburgh. The Hawk is the oldest surviving aircraft in Britain.

Pilcher also started to develop a powered aircraft and designed and built an engine to suit. Unfortunately, in 1899, just before he tried to fly the powered aircraft he was killed in a flying accident in the Hawk.

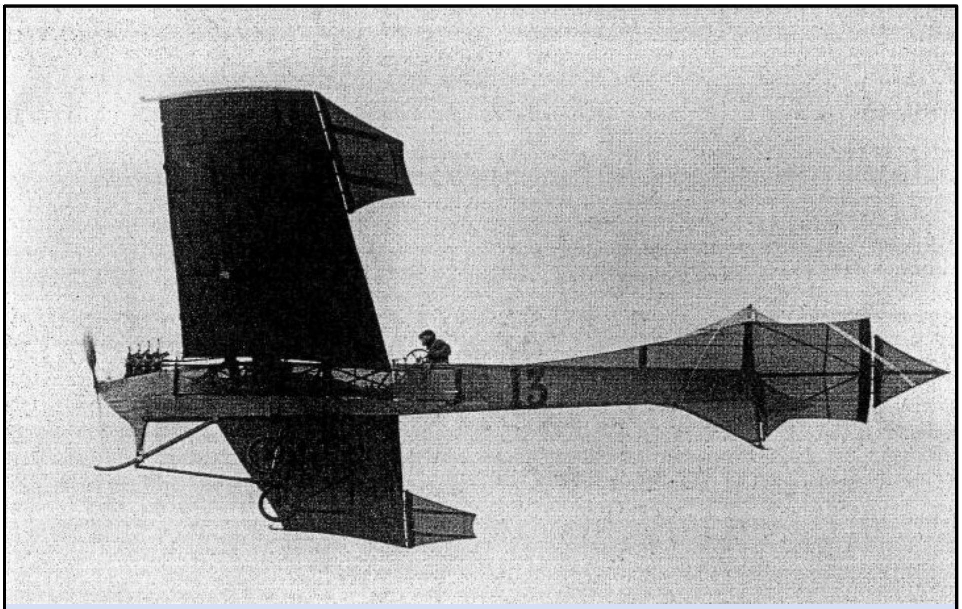


The Wright Brothers first flight. 17th December 1903.
This flight lasted 12 seconds, the fourth flight of the day lasted for 59 seconds.

In 1903 the American Wright brothers showed that it was possible to fly a powered aircraft. By doing so they stole a march on all other aircraft designers. However, the Wright brothers had designed an aircraft that had very little natural stability on the assumption that this would make the aircraft easier to manoeuvre in flight. This was found to be the case but the system was not without its problems. The pilot had to actively control the aircraft at all times.

The Europeans, particularly the French, aircraft designers decided that the future of flight lay with aircraft that had some inherent stability to make flight control less demanding for pilots. They were worried that having an unstable aircraft, that had to be flown constantly by the pilot, would cause many aircraft to crash due to a combination of tiredness or distraction of the pilot.

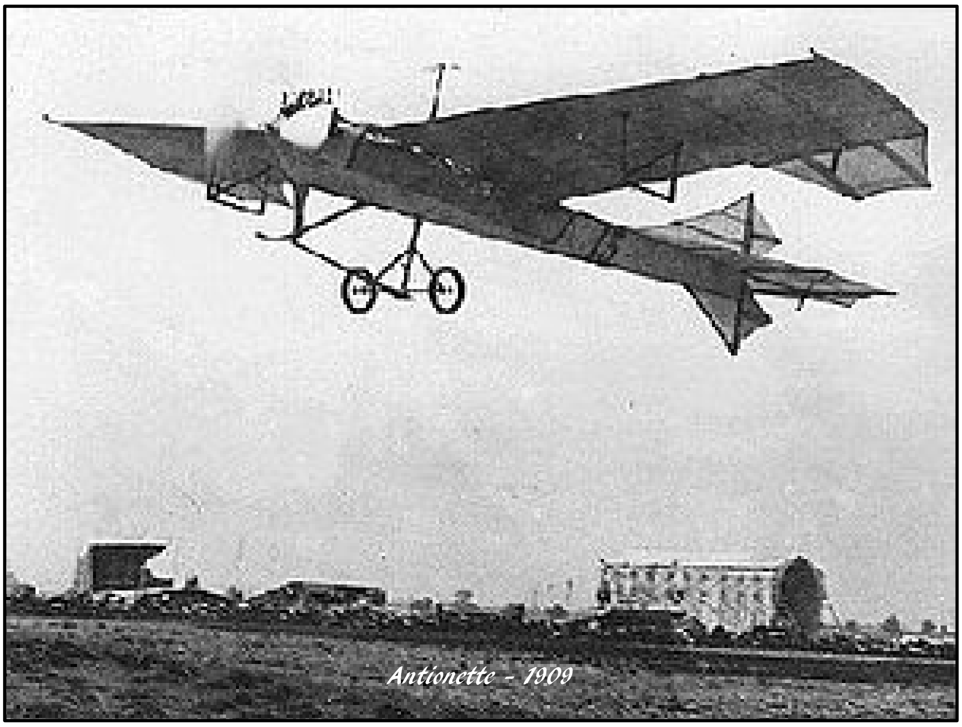
So the design of most aircraft continued down the route pioneered by Cayley, Lilienthal and Pilcher.



The influential Antionette aircraft of 1909

European aircraft designers, particularly the French, devised various ways to make aircraft stable in flight. The trick was to find a level of stability that would make the aircraft relatively easy to fly but not so stable that it could not be manoeuvred in flight. They also decided that the best place to mount the stabilising surfaces was at the rear of the aircraft in what is commonly called a tail unit, in fact just as Cayley had proposed over one hundred years earlier. The other important change that the French designers discovered was to angle the wings slightly up towards the tips since it was found that this angle, now called the dihedral angle, gave the aircraft stability both laterally and directionally.

At first the stabilising surfaces were relatively crude flat structures but as aircraft increased in speed and weight these structures became symmetrical aerofoils shapes which were much more efficient. These early aircraft set the standard of aircraft layout which is used on the greatest majority of modern aircraft.



Here is another view of the French Antionette aircraft that set the standard in 1909. It has vertical surfaces above and below the rear fuselage and a horizontal surface.

In time of war the pace of development of technology accelerates as each of the combatants tries to outdo the performance of the weapons of the enemy. During the 1914-1918 war Britain, France, Germany and the USA developed many fighting aircraft which improved rapidly in performance and sophistication. Just 15 years after the Wright Brothers showed that powered flight was possible, the warring nations were fighting each other in the sky with technically advanced aircraft and laying waste to enemy territory with long range heavy bombers. This photo shows the Sopwith Camel fighter aircraft of the First World War. The horizontal and vertical stabilising surfaces are at the rear.

At the end of the war there were about 60,000 military aircraft in service and almost all of them were designed to have the “standard” layout with stabilising surfaces at the rear.

In the years after the First World War the pace of aircraft development slowed. However, some important changes happened in aviation technology.

The aircraft manufacturers in the USA saw that there could be a future in civil aircraft and, because the USA was such a large and wealthy country, it could support long range air transport. Also in Britain it was seen that air transport could be used to link with the distant outposts of the British Empire.

Long range aircraft and flying boats were developed to meet that market. These aircraft were designed as all-metal structures and this was to become an important point in the next few years.

The Second World War again promoted the very rapid development of military aircraft and when the USA entered the war it already had a head start in the production of aircraft including, crucially, efficient transport aircraft. The above photo is of the famous Douglas DC3 aircraft. Some 16,000 of them were built before and during the war including Russian and Japanese versions built under licence. This aircraft set the standard for future transport aircraft and many are still flying 80 years later. The horizontal and vertical stabilising surfaces are at the rear of the fuselage.

Many nations became involved in the war with many producing aircraft of all types and nearly all of the “standard” layout.

During the Second World War the USA and Britain produced thousands of long range heavy bombers to take the war to the heart of Germany. This photo shows the Boeing B17,called the Flying Fortress. Note the relatively large horizontal and vertical stabilising surfaces at the rear.

It was American long range bombers loaded with atomic bombs that entirely wiped out two Japanese cities, Hiroshima and Nagasaki, and brought the war with Japan to an end.

Towards the end of the Second World War, Britain had developed this twin engine jet fighter, the Gloster Meteor. This aircraft was capable of nearly 600 mph.

The German Air Force also had a twin engine jet fighter, the me 262, which was even more advanced than the Meteor. Again, the stabilising surfaces are at the rear.

Hughes H-4 'Spruce Goose' – 1947

The Howard Hughes Spruce Goose that flew briefly in 1947, had very large stabilising surfaces at the rear.   No aircraft built since that date has ever had a larger wing span.

Saunders-Roe Princess flying boat - 1952

This huge Saunders Roe Princess flying boat, built in 1952 had very large tail mounted stabilising and control surfaces. The control surfaces were so large that the pilot had to have mechanical assistance to move them, just like the servo assisted brakes and steering on modern cars.

Scottish Aviation Limited Bulldog – c.1973

This is the Bulldog, a small pilot training aircraft built at Prestwick. The horizontal and vertical tail surfaces show up well.

This Jetstream 41 aircraft, also built at Prestwick, has its horizontal stabilising surface mounted halfway up the vertical surface.

Airbus A350 - 2013

This modern Airbus A350 still has the standard layout at the tail but it relies entirely on powered systems to move the horizontal surfaces to achieve stability at all speeds.

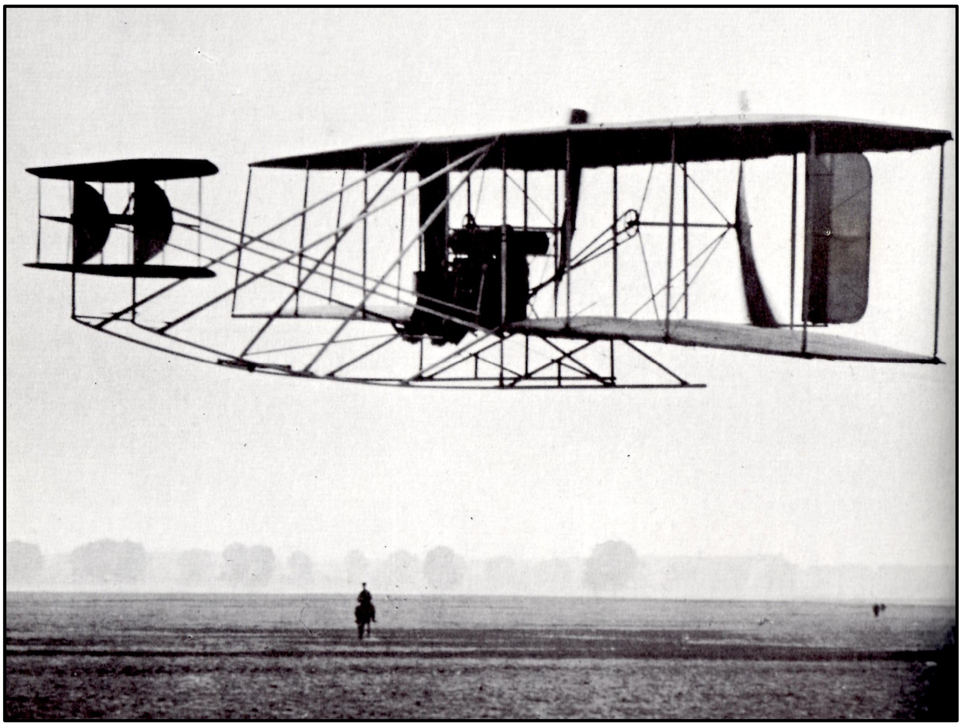
DG Flugzeugbau DG-1000S glider - 2003

This high performance sailplane has the same standard layout with horizontal and vertical stabilisers at the rear.
These type of gliders are the most efficient aircraft ever made by man.

We now look at the "Canard" aircraft layout.

This type of layout is not common but it is still used in the design of specialised aircraft.

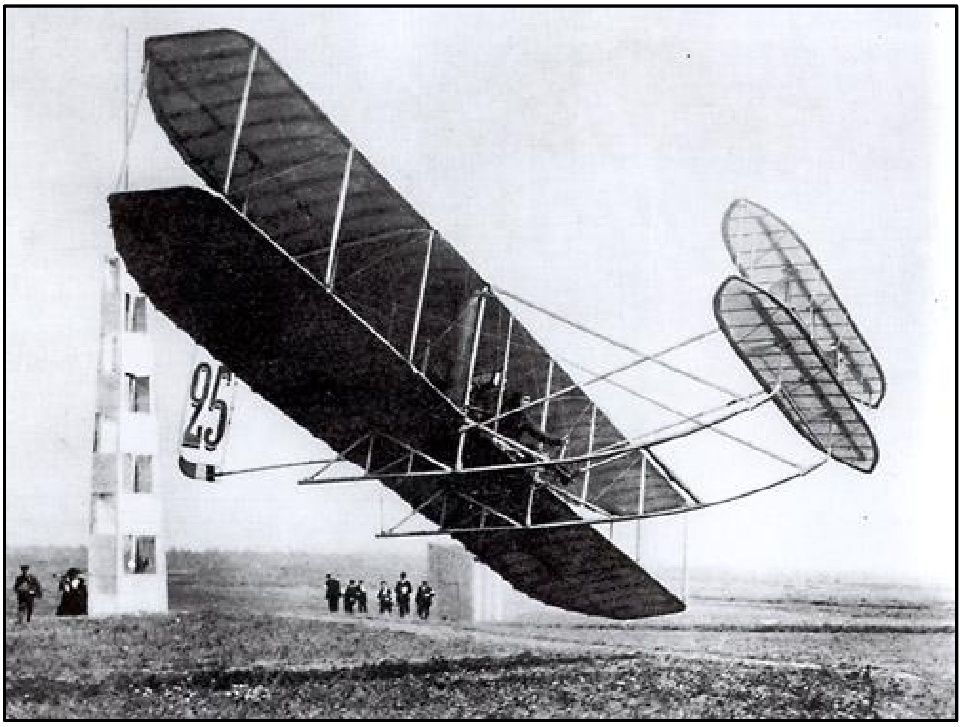
This type of layout has the main wing positioned a bit behind the centre of gravity of the aircraft and horizontal stabiliser positioned at the front of the body. This stabiliser is deigned to always supply an upward lifting force.



Some aircraft designers said that the Wright Brothers knew how to do things and pointed out that they had mounted the pitch stabilising and control surfaces at the nose of the aircraft. They argued that it was stupid to have a stabilising surface at the rear of the aircraft that pushed down to stabilise the wing when you could have a surface at the front of the aircraft that not only stabilised the wing but also created lift upwards so that it assisted the wing in supporting the aircraft.

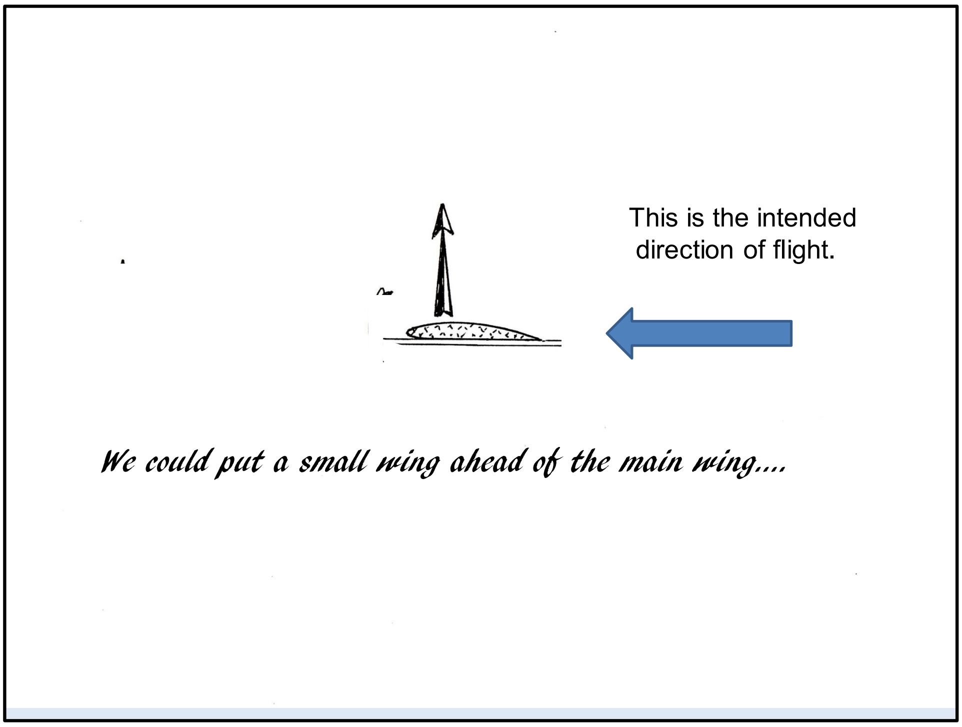
Over the years a number of aircraft have been designed that had stabilising and control surfaces at the front. The French called these type of aircraft "canards" since they looked like ducks when they were flying.

These type of aircraft are not easy to design and work best on aircraft that are basically rather unstable just like the Wright Brothers Flyer of 1903.



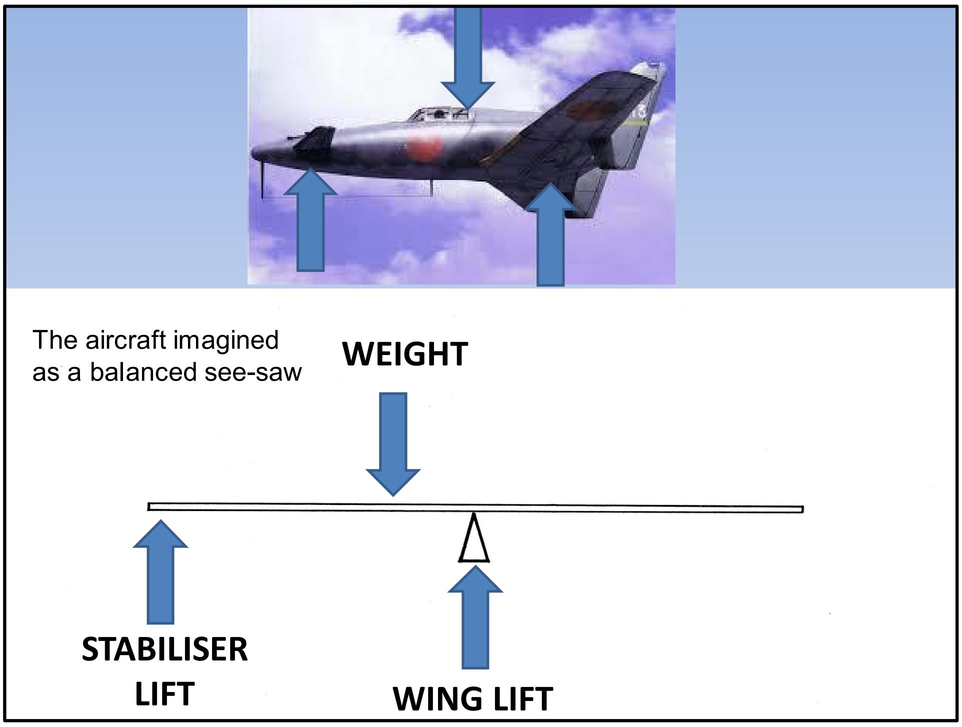
The Wright brothers aircraft were built under licence in Britain and France and many pilots were able learn to fly the aircraft. In 1909 at Reims in France, an air race was held with all the latest European aircraft competing. This photo of the French pilot Lefebvre flying a French built Wright biplane shows just how accurately the aircraft could be flown close to the ground as it rounded one of the course marker pylons.

The Wright brothers aircraft was deliberately designed to have almost no inherent stability to allow it to be easily manoeuvred in the air. It is interesting to note that modern fighter aircraft are designed in the same way to make them more agile when in combat. These aircraft are so unstable that they no longer can be flown by pilots and need high powered fast computers to operate the flight controls.



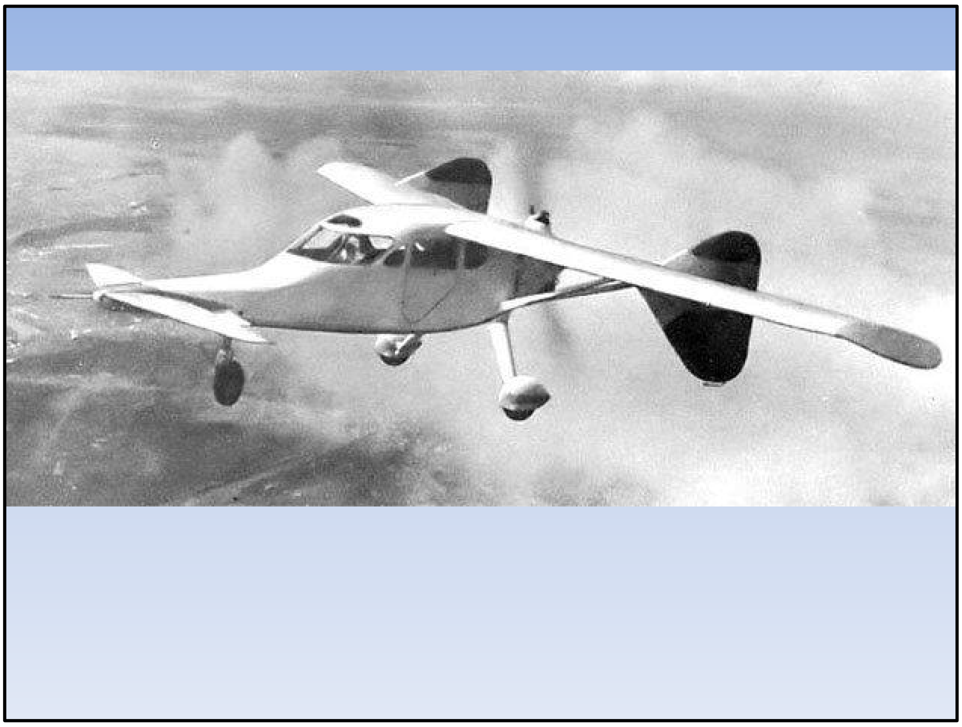
What is needed is another aerodynamic shape like a wing which will not only provide the counterbalancing force but will also vary if the speed changes. Here we have a wing producing lift, *(Click)* but also being forced to rotate nose-down thus causing it to lose lift.

The Wright Brothers' solution was to have another wing on the end of a lever ahead of the main wing to develop an upward lift force to stabilise the wing. *(Click)*



Here is another “canard” type aeroplane which is stabilised by a small wing ‘pushing up’ ahead of the main wing.

Hugh Lorimer, an Ayrshire school teacher, designed and built this aircraft called the Iolaire [the Eagle]. It has a horizontal stabiliser at the front and two vertical stabilisers at the back.



This slightly bigger, but very similar looking aircraft, is the Russian Mig 8. This aircraft was an experiment to see how well an aircraft with a stabilising surface at the front would perform.

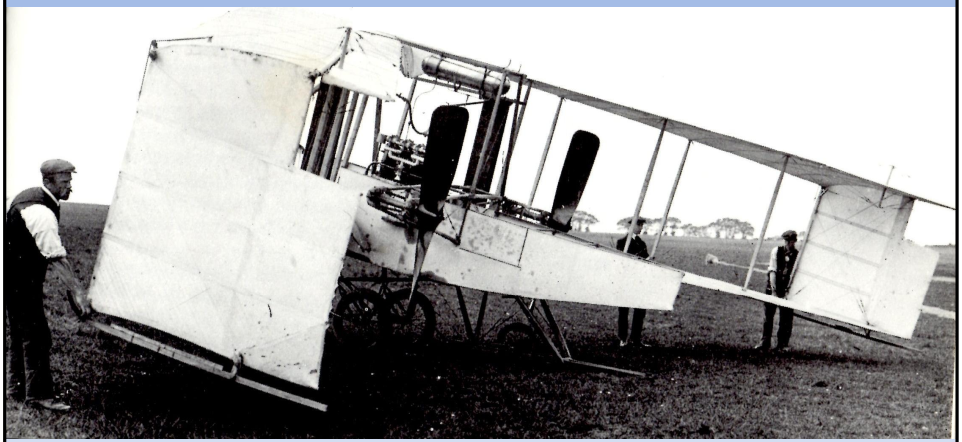
This small aircraft, called the Quickie, designed by the American Burt Rutan, uses the engine out of a Volkswagen Beetle car. It can fly twice as fast and twice as far on the same amount of fuel as the original car. A very efficient light aircraft.

The Gossamer Albatross man-powered aircraft was pedalled across the English Channel in 1979. Note the relatively small forward wing. This extremely light aircraft flew at about 10 mph.

At the other end of the speed range is this Royal Air Force Typhoon aircraft, capable of 1,500 mph. It also has forward horizontal surfaces but the aircraft is deliberately designed to be unstable so that it is very manoeuvrable. So the "canard" forward surfaces are more to do with control. This aircraft, and other fighter aircraft, are so unstable that a human pilot can not react quickly enough to control it. The aircraft is controlled by computers that move the powered controls under the direction of the pilot.

We now look at the “Tailless” aircraft layout.

This type of layout has been around since the beginning of aircraft design and, although not common, is still used in the design of specialised aircraft.

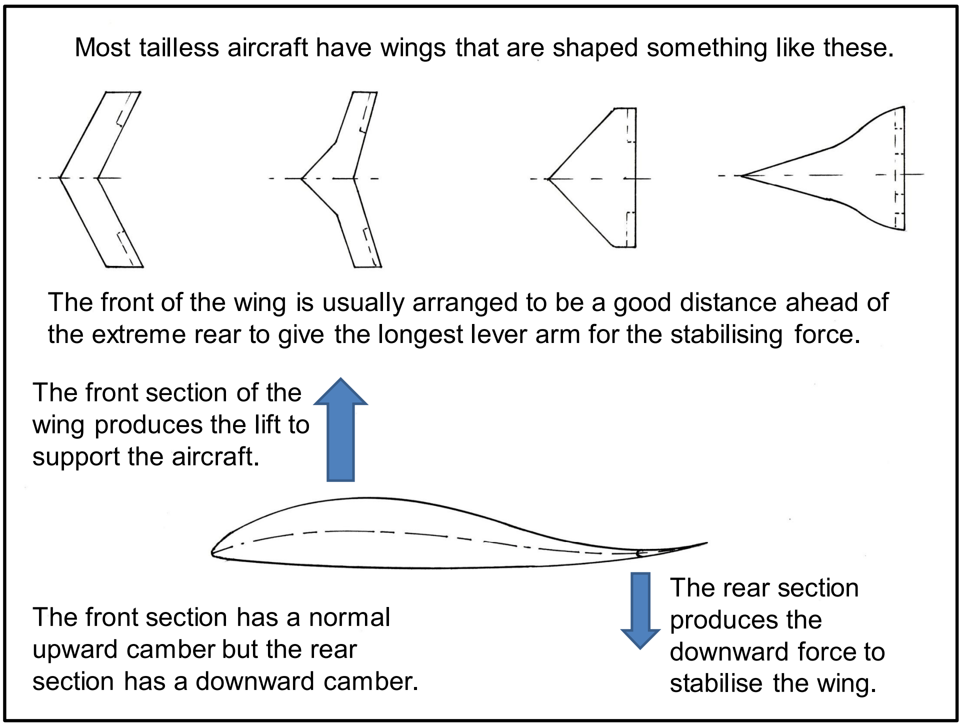


Dunne D5 Tail-less Aircraft, 1910

This type of aircraft, the so-called “tailless” or “flying wing”, have been around for as long as aircraft have flown. As the name implies these aircraft have no separate horizontal stabilising surfaces at the front or the rear of the aircraft, they just have a wing.

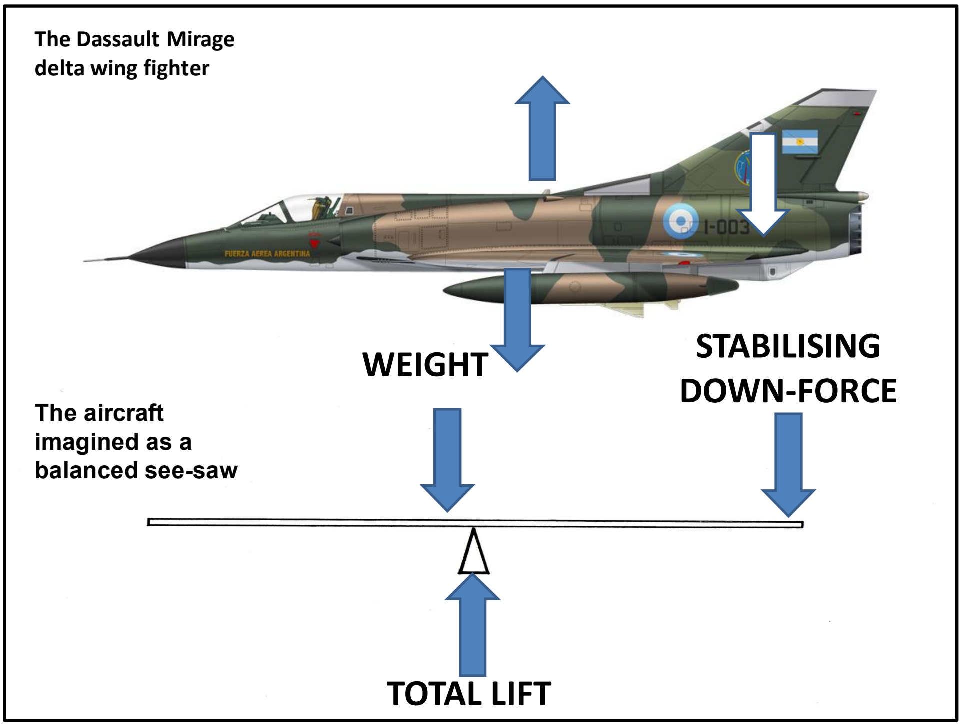
Back in 1910 an Irish engineer called John William Dunne decided that he could design a very stable aircraft without having to use a separate tail unit or forward stabilising surface. His aircraft, the Dunne D5, was a biplane with steeply swept wings and it flew quite well. Note how the bi-plane wing tips are filled in with panels that act as the vertical stabilisers and rudders. The aircraft was tested at the estate of the Duke of Atholl in Scotland. The aircraft was indeed exceptionally stable, in fact so much so that pilots could quite happily leave the controls alone and the aircraft would continue to fly on its own.

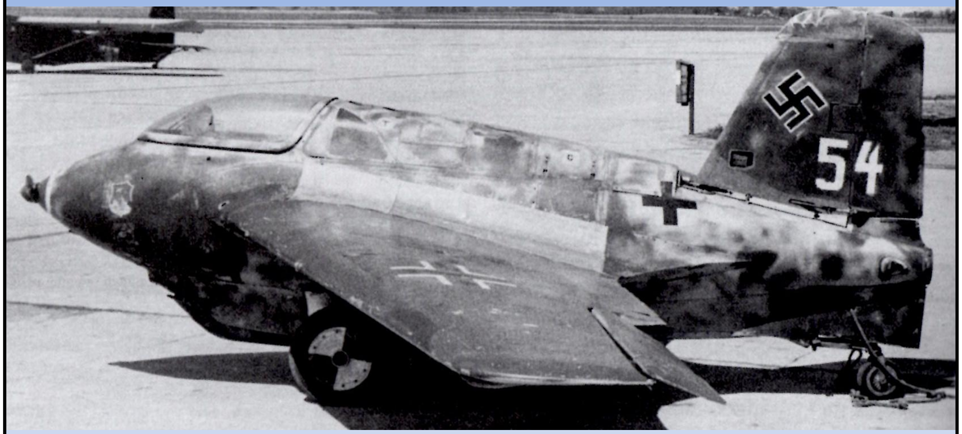
There are plenty of other examples, some have a fuselage to carry crew, passengers and equipment ….



So how was this stability achieved? Tailless aircraft all have one thing in common, they either have wings that are swept back or are triangular in shape - known as a “delta” wing shape.

The reason for this is that the aerodynamic section of the wing is not simple. The front part of the wing generates the lift to support the aircraft but the rear part of the wing has an upside-down camber so that it generates lift downwards to stabilise the wing. So in fact the rear part of the wing does exactly the same as a horizontal stabiliser at the rear of the aircraft would do. So that is why the wing has to have more length from front to back to allow the rear surface to be far enough back to stabilise the front section of the wing.


The Dassault Mirage
delta wing fighter
WEIGHT
STABILISING
DOWN-FORCE
The aircraft
imagined as a
balanced see-saw
TOTAL LIFT



Messerschmitt Me-163, 1943

In 1943, during the Second World War, the Germans designed this very fast rocket powered interceptor the Me 163. It had no horizontal tail surfaces.

Avro Vulcan B2, 1960

In 1960, during the Cold War with Russia, the British company Avro designed this Vulcan Mk 2 Nuclear Bomber. The Vulcan has a vertical stabiliser but no separate horizontal stabiliser.

BAC-Aerospatiale Concorde

This is probably the most beautiful of all the tailless aircraft. The BAC-Aerospatiale Concorde capable of cruising at 1,350 mph.

The design of the Concorde was a challenge for the design engineers in almost every way. One of the problems was trying to stabilise a wing on an aircraft that was designed to fly at twice the speed of sound. As the aircraft reached the speed of sound the shock wave alters the airflow over the wing which moves the centre of lift backwards. This made the aircraft very nose heavy and would have needed very large stabilising and control surface area to be able to keep the nose up. This would have produced a large amount of drag which was unacceptable.

The designers solved the problem by doing what Lillienthal and Pilcher had done 100 years before by moving the centre of gravity of the aircraft backwards to re-balance the aircraft. On Concorde this was achieved by pumping a large amount of fuel from the front of the aircraft to the rear of the aircraft as it accelerated past Mach 1, the speed of sound.

It seems strange that this most modern high speed aircraft had to use a very basic weight-shift method of stabilisation.

Try making and flying the models described in “Exploring the Configuration of Aeroplanes”.

The last landing of the beautiful Concorde in 2003

All of the so called “tailless” aircraft that we have looked at so far still have a vertical stabilising surface, so they do actually have part of a tail.

The future?

Will the tailless layout be developed to the point where we will all fly in aircraft like this some day? However, all of the so called “tailless” aircraft that we have looked at so far still have a vertical stabilising surface, so they do actually have part of a tail.

Northrop Grumman B2, c.1990

Some 30 years later the Northrop Grumman company in America designed this B2 stealth bomber. Note that it has neither horizontal nor vertical stabilising surfaces. It has to be flown by computers since it is so unstable that a human pilot can not react quickly enough to fly it.