The Physics of Gliding

Gliding is the sport of flying gliders, also known as sailplanes. Gliders are light aircraft designed to fly without an engine. Gliding first became a sport after the First World War due to the Treaty of Versailles which restricted German use of small powered aircraft. Pictured (right) is an ASK13. The ASK13 first flew in 1966 but has remained a common training glider due to its easy-to-control flight characteristics [1].

Glider design

Structure

Originally, gliders were made of wooden frames with cloth stretched over them [2]. This allowed them to be both strong and light. However, the skins of these gliders are thin and easily torn, and the wood can warp. For this reason, fiberglass is used in most modern gliders as well as metal frames.

Fiberglass is a glass fiber reinforced plastic. It is very strong for its weight and can be made to have a very smooth surface which is an obvious requirement for aircraft. Most fiberglass gliders use fiberglass made from glass cloth (woven glass fibers) and epoxy resins such as Epikote 162 [3]. 'Rovings', string-like bits of glass fiber, are also used to reinforce joints.

On their own the materials are not sufficient to make a glider, the glass cloth is too flimsy and the resin actually comes as a liquid. The resin is hardened by an amine hardener such as Laromin C260 [4]. The resin on its own has a young's modulus of approximately 3.5GPa whereas an S-Glass composite (a composite designed to maximize stiffness) has a young's modulus of around 89GPa [5] [6] [7]. This is important because when a glider is flying it must withstand the various forces during flight.

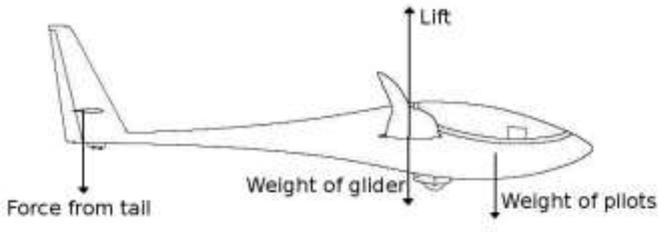
The glider is also constructed to distribute the forces and make them stronger. For example the wings have cross sections of wood and glass fiber to keep them from breaking (see right).

Controls

A glider is controlled by moving the stick and rudder pedals (pictured right). These controls pull various wires that are connected to control surfaces. This allows the pilot to easily feel what is happening on the aircraft and so gives a greater level of responsiveness. It also means that, in dual-control aircraft, both pilots use the same control system and so there is no confusion with who is in control since the pilots can feel if the other is doing something with the controls.

Limitations

In preparing for flight the pilots must check the weight limitations of the aircraft. An extremely heavy pilot may not be able to fly whereas a light pilot may need ballast (weights, often lead, designed to increase the mass in the cockpit). This varies depending on the aircraft. There are several key forces that are used to determine the weight limitations of a glider (see above). If we take moments around the centre of lift (in this diagram the centre of lift (CoL) and mass of the glider are approximately equal) we can see that (weight of the pilots) x (distance from CoL) must be equal to (force from tail) x (distance from CoL). For this reason, two person aircraft have a weight limitation placard that is used to determine how heavy each person must be to balance correctly. This is because, depending on who sits where, the weight of the pilots will be acting in different places.



Gliders also have limitations on their velocity. As the glider goes faster the lift forces on the wings increase as well as the drag forces, if these forces get too high then the wings can be overstressed or even break off. An instructor once said “if the wings start shaking, you have around 3 seconds to slow down before they fall off”.

Glider launching

Gliders can get into the air in a variety of ways; winch launching, aerotow, self-launch, bungee launch and car launch.

- Aerotow is the most well known, a powered aircraft tows the glider into the air and to a specified height, most often 3000-4000ft
- Bungee launching is almost obsolete now but was used often in the early days of gliding, a glider is attached to a bungee rope and a group of people stretch the rope, the glider is then let go and so is launched. Bungee launching is restricted to hillsides or cliffs due to its inability to launch gliders very high.
- Self-launching is also uncommon, it is essentially launching using a built-in engine, often a propeller that folds away into the tail fuselage of the glider.
- Winch launching is the most commonly used way to launch a glider. Winch launching uses a large stationary engine which pulls in a cable that is attached to a glider; this pulls the glider up into the air. These launches are mostly around 1300ft but can be higher depending on conditions and the length of the airfield.
- Car launching is essentially winch launching except, instead of a stationary engine pulling the glider in, a car is used to pull the glider along.

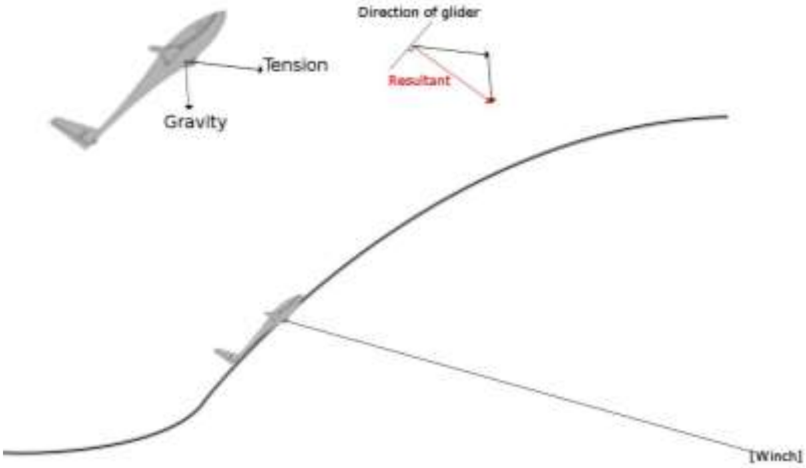
Winch launching

During a winch launch the forces required are extremely high, thus the materials used must be strong.

Most cable in recent history has been made of steel because it has a tensile strength of approximately 0.92GPa. However, the steel cable is quite heavy at around 7.7KG per 100m [8]. For this reason materials such as Dyneema are used as replacements. Dyneema has a tensile strength of approximately 1.05GPa and is relatively light at 1KG per 100m [9].

Dyneema is a polymer fiber made of UHMWPE (Ultra-high-molecular-weight polyethylene) [10]. UHMWPE is a thermosetting polyethylene and has very long molecular chains. These long chains transfer load effectively to the molecular backbone. This is because the long chains have a lot of surface area that can come into contact with other molecules (see left) and so there are many Van der Waals forces. Since Van der Waals are relatively weak, the molecules can slip along each other which allows the material to stretch a bit before starting to break the strong covalent bonds within the molecules. This results in a high impact strength and high toughness because the molecules do not immediately break [11]. Dyneema is made of fibers of this made into a rope. It is useful for winch launching because it is extremely abrasion resistant (up to 15 times as resistant as carbon-steel) [12] which means that it can be towed around and used without fear of damage.

However, when launching, if a glider is overstressed the wings could break off. For this reason, a weak link is built into the cable. This takes the form of a piece of metal in a bracket between the glider and the cable (see right). This weak link is required when launching gliders unless the cable used has a tensile strength less than the maximum tensile force on the glider.



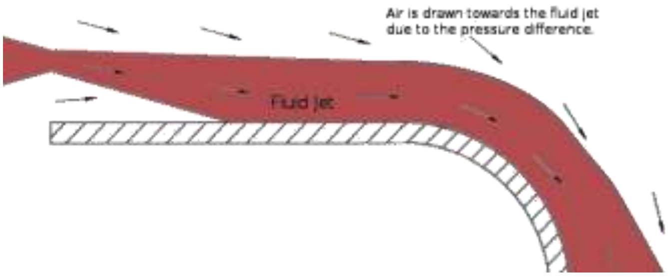
During the launch the glider uses circular motion to gain height.
In the first part of the launch the glider is pulled along the ground to gain speed. The glider then ‘rounds out’ into the climb. During the climb, the resultant force from gravity and the tension from the winch acts perpendicularly to the velocity of the glider. This means that there is no work done in the direction of the velocity and so there is no acceleration. This is the main part of the launch where the glider gains the most height. Once the glider gets to the top of the launch it releases and continues in flight.

To ensure that the glider doesn’t get stuck attached to the winch, a variety of safety release mechanisms are built in.
- The pilot first attempts to release using their controls.
- If that fails then there is a back-release, where the cable is pulled from the back of the release mechanism.
- Then there is the weak link, mentioned earlier, that will break.

- If all of those mechanisms fail then the winch driver has a cut-off that simply severs the cable from the winch. This isn't preferable as the glider ends up trailing a length of cable.

Lift

The Bernoulli Principle states that if there is an increase in velocity of an inviscid fluid (a fluid with no viscosity) will occur simultaneously with a decrease in pressure [15] [14]. Hence, a jet of air will be lower pressure than the surrounding air. This causes something called the Coanda Effect. The Coanda Effect is the tendency of a fluid jet to stick to a nearby surface [16]. As in the diagram (below) a jet of air will stick to a nearby surface. On an aerofoil the Coanda effect can generate lift. When the air flow sticks to the wing it follows the curve of the aerofoil and is turned downwards. Since the air is pulled downwards, the wing must be pulled upwards, thus causing a lift force.



The Bernoulli Principle is named after Daniel Bernoulli, a Swiss mathematician and physicist who is well known for his work on fluid dynamics in the 18th Century.

The Coanda Effect is named after Henri Coanda, a Romanian inventor and aeronautics pioneer. He discovered the Coanda Effect in the early 20th Century.

This is also applied to the control surfaces of the glider, when they are deflected it turns the flow and causes a force on the aircraft.

Soaring

Once launched, gliders use various air flows to gain height. The most well known of these are thermals; thermals are columns of warmer air (hence the name), since hot air is less dense, it rises and forms updrafts that can carry a glider upwards. Another commonly used soaring mechanism is a ridge; wind hitting a ridge cannot go around the ridge and so must go up and over it. This causes strong upwards currents that can give a glider lift. The final key source of lift is called 'wave', wave happens when fast wind passes over a high place and starts to move up and down. The gliding height record was set in wave and currently stands at 50700 feet [13].

Obviously, as the altitude increases the pressure decreases. This makes absorbing the oxygen in our lungs significantly harder since our lungs work by pressure difference. To counteract this glider pilots have to carry oxygen when flying above 10000 feet and some gliders (such as those setting records) will often have fully pressurized cockpits.

Conclusion

Flight is a huge area of physics; a lot of it remains a mystery that researches strive to solve. Gliding is an ongoing sport, despite the practical uses of gliders being limited. This could mean that they will continue being used for a long period of time but will there ever be another breakthrough, or are we just going to continue refining the same designs?

Images

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Significant portions of this essay are based on physics learned at school and principles learned whilst learning to fly gliders at Bicester Gliding Centre.

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