



Instructions for

**KNIFFELIX online experiment platform with  
wing puzzles**

[www.kniffelix.de](http://www.kniffelix.de)

**&**

**Experiment box  
"Why do airplanes fly?  
Wings & Lift"**

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## Teacher's Guide: Why Do Planes Fly? Airfoil shape and lift

### Goals of the hour:

- Implement work instructions independently.
- Introduce them to trying things out and thinking further with the help of the experiment worksheet.
- Through simple experiments, learn how air flow and buoyancy are related.
- Get to know the phenomenon of buoyancy by comparing different flow bodies and gain your own experience.
- Encourage people to perceive, question and explore phenomena from everyday life.

### 1. Introduction:

 Today, everything will revolve around the topic of "flying". Where can you see airplanes or work in aviation, for example, in Hamburg?

- at the airport, at Airbus, at Lufthansa Technik, at several institutes of the TUHH and in the DLR School Lab

 Around 30,000 people work in the aviation sector in Hamburg, and well-trained people are in great demand. The DLR School Lab was founded at the Technical University of Hamburg-Harburg (TUHH) to get pupils interested in this professional field. This is not an institute where research is carried out, but it was developed especially for schoolchildren, who can carry out experiments on flying, currents in air and water and aircraft construction to get an impression of what aircraft engineers do.

 Why are researchers still working on aircraft construction today? For example, what could researchers invent or improve today?

At the TUHH, researchers are investigating, for example:

- How can aircraft be designed even more reliably and safely?
- How can new aircraft be developed with the help of computer programs?  
This involves a lot of calculations, many different parts that have to fit together, and much more.
- How can noise on the plane be reduced?

 Airplanes are very heavy. Many people can be accommodated in it and transported with it at the same time. So what keeps the plane in the air? (Collect suggestions: How the air flow flows around the wings and the resulting lift.)

 What kind of flying objects have you ever seen in the sky? (airplane, glider, helicopter, hot air balloon, zeppelin, parachute)

 How do they differ? (fast/slow forward movement, air is not heated, with/without motor)

 Today we want to find out why an airplane can fly. All aircraft have wings. How do they have to be shaped? To see what makes them so special, we build wings out of paper and try to make them fly in an air current that we create with a hair dryer. The shape of the wing is very important.

 IF YOU WANT TO EXPLAIN IT EXACTLY: Every flying body needs a buoyancy force that acts upwards and pulls the body upwards. This force is opposed to the force of gravity that keeps it on the ground. The lift force is generated in different ways for different missiles. A hot air balloon can fly because it can carry a large amount of warm air. The warm air is lighter than cold air. She ascends and takes the hot air balloon up with her. Airplanes and helicopters have wings that can be used to generate lift force. To do this, air must flow to the wing. In the case of a helicopter, this is done by the rotational movement of the rotor blades, while an aircraft has rigid wings. During take-off, the aircraft moves forward very quickly, so that the airstream flows around the wings and the aircraft can take off upwards. The air is deflected diagonally downwards by the shape of the wing. In order to deflect the air flow downwards, the wing must exert a force downwards on the air flow. However, since there is no force without opposing force, the air exerts an equally large force in the opposite direction on the wing, i.e. it pushes the wing upwards. That's where the buoyancy comes from. By the way, the same principle can also be found on a sailing ship. Here it is the sail that is flowed by the wind. In line with the LIFT of aircraft, there is a

Sail a PROPULSION that pulls the ship forward and makes it go fast.

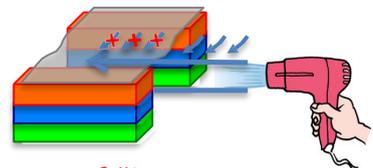
## 2. Attempts:

The group tables are prepared for six groups of 4-5 students each according to the list of materials. Depending on the time and level of knowledge of the students, only attempts 1, or only attempts 2 & 3 or all attempts can be made. The three attempts can be done on one day or on three different days. For experiment 3 you need the materials made in experiment 2. Alternatively, the group can also be differentiated: One group does only experiment 1 or only experiments 2 & 3.

- Experiment 1:** The students should recognize that paper is heavier than air and therefore does not fly. However, paper sinks to the ground more slowly when it is spread out than when it has been crumpled. (The weight force is the same for both papers, but the air resistance is different.)

In addition, the students let air flow over a sheet of paper. The leaf is sucked in by the air jet, i.e. it moves towards the air jet. This can be explained by the entrainment of air particles, which is explained on the back of the station sheet. The Bernoulli effect is often found as an explanation: fast flow creates negative pressure, which sucks in the paper. But it's not that simple, because when you blow under the paper, the paper is not sucked in, but blown up, i.e. pushed away.

- If there is enough time, the suction effect of air currents can also be observed in additional test 1.3.



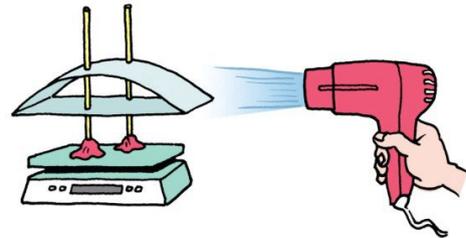
- Experiments 2 and 3:** Show the physical phenomenon of "buoyancy". Each group makes 3 wings, which are then tested with the hair dryer. You could split the work by having two children make the curved wing, which is a bit more difficult, and one child each makes the flat wing (very light) and the triangular profile (a little more difficult). During the experiment, the piece of wood is to serve as a foot. The wings should be able to move freely up and down on the threads, which are stretched vertically upwards with the hands. This should be checked by pushing the wing up by hand before using the hair dryer.

**F** The students are welcome to develop and try out their own wings, e.g. bend the wing up at the end like in the very modern aircraft!

**F** DIVIDED INTO 2 DAYS: Day 1: Try 1 and start with attempt 2 if necessary. Day 2: Attempt 2 (finish if necessary) and attempt 3

**F** **If there is still time:**

Buoyancy can also be measured with the help of a kitchen scale. For example, the wings of the different groups can be compared with each other. For this purpose, the wing is placed on a kitchen scale.



Instead of using the piece of wood as a foot, the straws of the wing are pressed into putty that lies on the scales. Now tare is pressed so that the scale shows 0. As soon as the hair dryer is pointed at the wing, the scale shows negative values. The measured weight is reduced by buoyancy. This makes it possible to read which wing generates a particularly strong lift.

### 3. Debriefing:

**F** How did you cope with the work instructions?

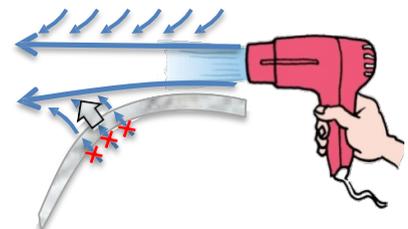
**F** When do air currents occur?

- By wind, blowing, a hair dryer, ...
- Whenever an object moves in the air, air currents are created.

**F** Do air currents also occur in a vacuum?

- No, there is no air in a vacuum.

**F** If you blow OVER a sheet of paper hanging downwards, air particles are carried along on both the top and bottom of the air stream. Because no air can flow in on the underside, as the paper does not allow air to pass through, a vacuum is created below the air flow.



 Where does a sheet of paper move when a fast stream of air flows along the paper?

- Due to the negative pressure on the top of the paper, the paper moves upwards.

 Why does an airplane fly? Where does the buoyancy come from?

- Due to the slight inclination of the aircraft wings and the shape of the wings, the air flow is deflected diagonally downwards. In order to deflect the air flow downwards, the wing must exert a force downwards on the air flow. However, since there is no force without opposing force, the air exerts an equally large force in the opposite direction on the wing, i.e. it pushes the wing upwards. That's where the buoyancy comes from.

 What are the most important characteristics of a wing?

- A wing provides lift when flying.
- From below, the wing is flat or slightly curved inwards. Due to the inclination of the wing, the air is deflected diagonally downwards.
- The top is curved: the air is also deflected diagonally downwards here. The curvature must not be too strong and must not have any edges, so that the best possible flow without turbulence is created.
- The position of the wing in relation to the direction of movement (angle of attack) plays an important role in lift. The stronger the wing is set, the greater the lift until the flow breaks off at some point (so too much is also harmful).

4. Distribute knowledge box.

## 5. Further information for teachers



In the DLR School Lab, the students are divided into several small groups and work with supervisors at various stations on the topics of air and water currents, sound insulation in aircraft construction and flying. (By the way: The School Lab can also be visited on the subject of ships!) More information about the DLR School Lab at [http://www.dlr.de/schoollab/desktopdefault.aspx/tabid-1732/10608\\_read-23753/](http://www.dlr.de/schoollab/desktopdefault.aspx/tabid-1732/10608_read-23753/)



Further teaching materials can also be found on [www.skyfuture.de](http://www.skyfuture.de) in the "Future Pilots" programme for schools. (Young talent initiative with competition of the German Aerospace Industries Association (BDLI))



Other experiment kits on the topics of aerospace:

-  Does the aircraft fly?: Center of gravity and flight behavior of a wood-foam plane
-  Helicopter: From model to drawing
-  The Juri magazine Experiment: Bionics & Helicopters
-  The Juri Magazine Experiment: Rocket Propulsion & Space

## Material list for teachers

### Why do airplanes fly? Wings & Lift

1 CAMERA (in "General Box" if supplied for project)

1 box "Why do airplanes fly? Wings & Lift"

1x Teacher's manual with all documents in a blue folder 25x

Student worksheet: "Why do airplanes fly" Lift

25x Knowledge Box: "Why do airplanes fly?"

6x laminated solution to the student worksheet: "Why do airplanes fly lift"

3 different finished sample wings (flat, curved, triangular profile)

**Each of the six groups: (4-5 children):** (There are enough wing cut-out sheets and straws that all children in the group can make all the wings. The best ones can then be tested with the hair dryer.)

#### **For experiment 1:**

1 laminated instruction manual for experiment 1

2 small sheets of paper (DIN A6)

2 DIN A4 sheets of paper (80g paper)

1 hair dryer with rejuvenating attachment

**2 stacks of books, each at least 3 cm high** (or e.g. 2 packs of copy paper, or similar)

#### **For experiment 2+3:**

1 laminated instruction for experiment 2 and 3

1 template sheet each for crafting the flat wing, curved wing and the triangular profile

3 drinking straws without a bend with a diameter of 5 mm (or cut off a crease)

1 prepared piece of wood with 2 threads to which straws are attached for easier threading

1 scotch tape

1 hair dryer (from experiment 1)

1 punch pliers

1 pair of scissors

#### **If there is still time: (material for the entire large group):**

1 digital kitchen scale putty

Extra paper for self-developed wings  
Extra straws for self-developed wings

**Red text = not in the experiment box, must be placed by yourself (one stack is also sufficient if the groups take turns)**

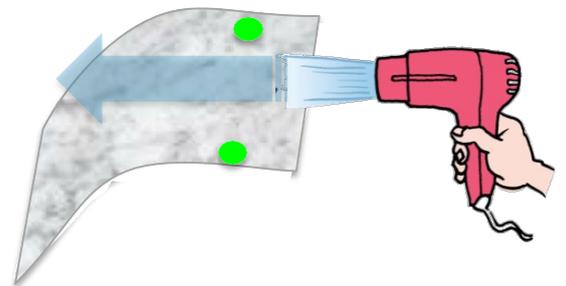
## Instructions for Attempt 1 Air resistance, air flow & buoyancy

1. You have two sheets of paper of the same size and weight. Crumple one of them into a ball, then drop both from the same height. What do you observe? Which one takes longer to land? Why?



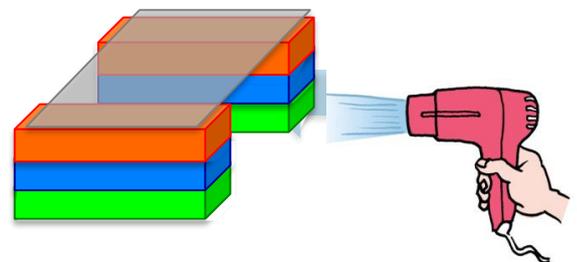
2. What do you think happens when you blow with your mouth or a hair dryer OVER a piece of paper?

Hold a sheet of paper by its short side (the green dots on the drawing) and blow smoothly OVER the paper as the hair dryer does in the drawing. What do you observe?



3. **Additional experiment:** What do you observe when you blow with a hair dryer through a tunnel consisting of two stacks of books and a sheet of paper as a tunnel cover?

Why? Change the book spacing, the height of the hair dryer and the distance of the hair dryer in front of the tunnel.



## Good to know!

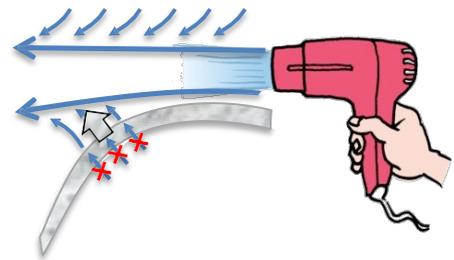
**F** Whenever an object moves in the air, air currents are created. If an object moves in a vacuum, i.e. in a vacuum, these are not created.

**F** A flat blade falls more slowly than a crumpled one, as it has more air resistance due to its larger area.

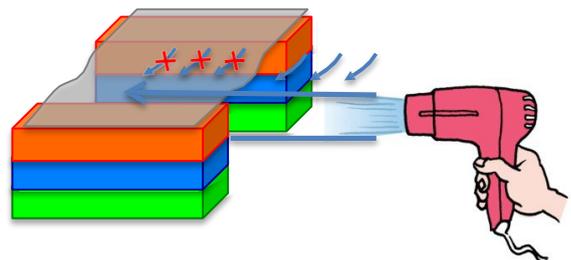
**F** Air currents carry still air with them.

**F** If you blow OVER a sheet of paper hanging downwards, air particles are carried along on both the top and bottom of the airflow (small blue arrows).

Since no air can flow in on the underside (red crosses), because the paper does not allow air to pass through, a negative pressure is created below the air jet. This vacuum sucks the paper upwards (thick gray arrow).

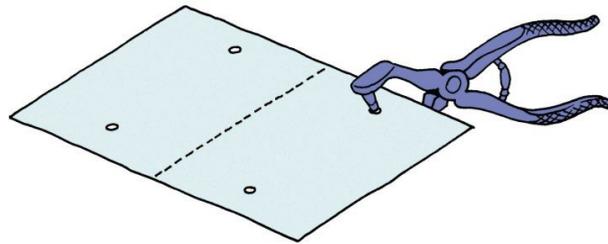


**F** In the tunnel test, the blade is sucked downwards, as the foehn air also carries away air particles in the vicinity. Since not enough air can flow in the tunnel, a negative pressure is created that sucks the paper downwards. (The books also feel this negative pressure, but are too heavy, so they don't move.)



## Attempt 2 Crafting Three Different Wings

Punch holes in the paper at the circles you draw with the punch pliers.

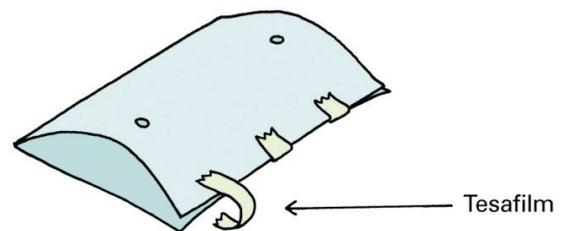


### 1) Making a flat wing

1. Fold the paper at the stroke line.
2. Tape the long open side with scotch tape.

### 2) Making a curved wing

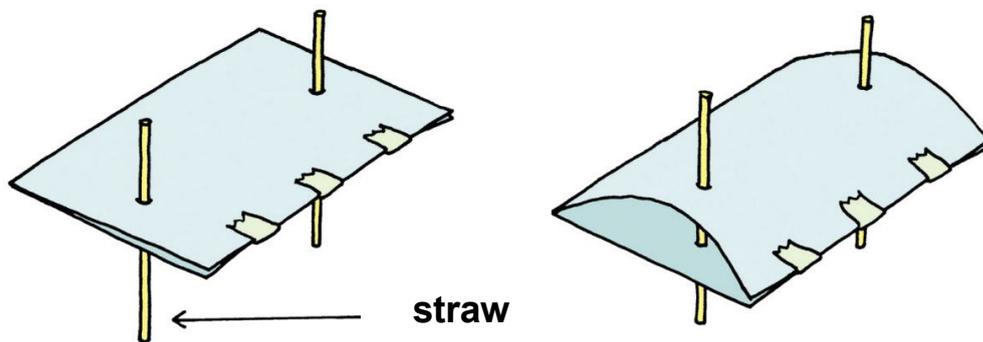
1. Fold the paper at the stroke line.
2. Place the longer side up. Gently push them back so that the longer end bulges (don't bend!).
3. If it hits the other end, glue the two edges together with scotch tape. Let them help you if it's difficult on your own.



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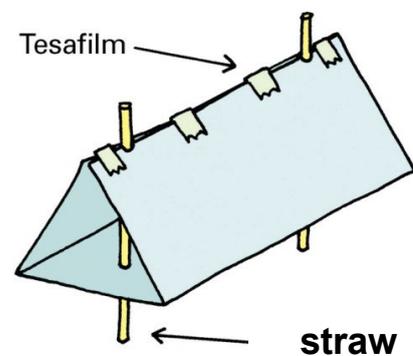
### 3) Putting the wings on drinking straws

1. Cut two straws in half.
2. Stick a piece of drinking straw through each hole on both wings and attach it with some scotch tape.



### 4) Making a triangular profile

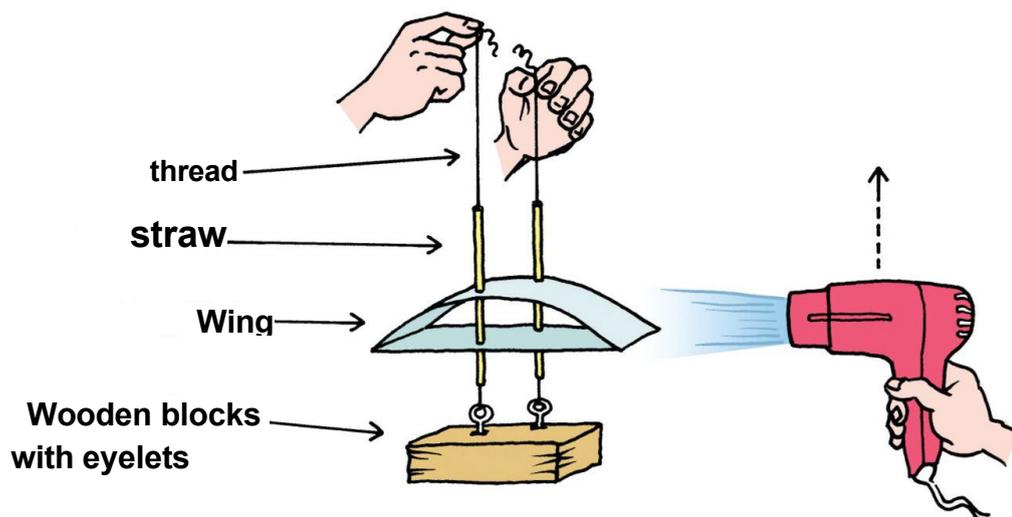
1. Fold the paper at the stroke lines. Glue it together with scotch tape to create a triangle shape.
2. Put half a straw through each hole in the wing and secure it with some scotch tape.



## Experiment 3

### Check lift of three different wings

1. Select a wing. With the curved wing, the flat side must point downwards!
2. Thread a thread from the piece of wood through each of the two straws. One of you now holds both threads tightly vertically upwards.
3. Another child turns on the hair dryer and blows on the wing from the front (not from below!). How does the wing behave?



4. Repeat the experiment with all 3 forms! Examine which wing rises with you when you move the Föhn upwards: the flat, the curved or the pointed?
5. **Additional experiment:** What changes if you blow lightly against the wings from below?

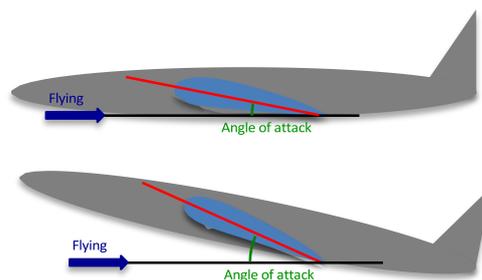
## Good to know!

**F** Only with the right shape does a wing that is flowed in from the front rise upwards. It must be curved at the top and flat or slightly curved inwards at the bottom.

You can find a detailed explanation of why only the curved wing rises upwards when blowing from the front in the knowledge box that you get at the end of the lesson.

**F** As an additional test: If you blow diagonally from below against the curved wing, it rises better upwards. You can also make the other wings rise in this way.

Unfortunately, a pilot cannot wish for the wind to come from below, but by tilting the aircraft with the help of the elevator, he can ensure that the wind flows more towards the wings from below.



With a larger angle of attack, the aircraft has more lift. It's rising.

**F** In a real airplane, the wings are slightly tilted. This increases buoyancy.

The strength of the buoyancy force depends on:

- ▶ The wing shape: Some wings are better lifters than others.
- ▶ The wing area: Large wings generate more lift than small ones.
- ▶ The Speed: Je faster the air flow, the stronger the buoyancy.
- ▶ The angle of attack of the wings: Angle between the wing and the air flow.

**F** For more information, please visit: [www.luftfahrtarchiv.eu](http://www.luftfahrtarchiv.eu)

Flat wing



Flat wing



Buckling



Buckling



Arched wing



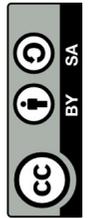
Arched wing



Buckling



Buckling





Triangular profile

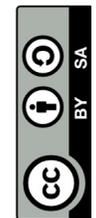
Triangular profile

Buckling

Buckling

Buckling

Buckling



## Worksheet: Why do airplanes fly? (buoyancy)

### Experiment 1: Drag & Buoyancy



You have two sheets of paper of the same size and weight. Crumple one of them into a ball, then drop both from the same height. What do you observe?

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Which one takes longer to land? Why? \_\_\_\_\_

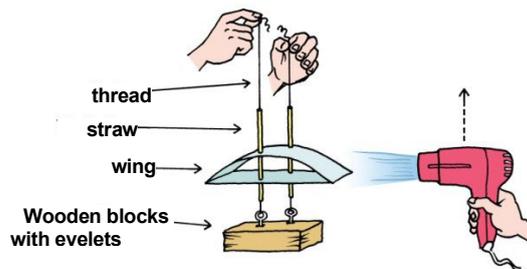
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When air flows quickly over a bent sheet of paper, in which direction does the sheet of paper move? Why? \_\_\_\_\_

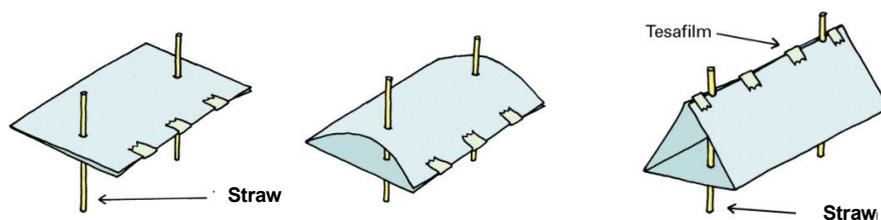
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### Experiment 2 & 3:

#### Check lift of three different wings



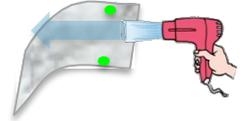
Which wing rises with you when you move the foehn up: the flat, the arched or the tip? \_\_\_\_\_



# Worksheet: Why do airplanes fly? Buoyancy

## SOLUTION

### Experiment 1: Drag & Buoyancy

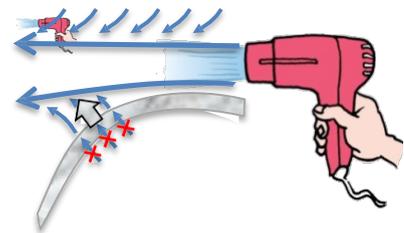


You have two sheets of paper of the same size and weight. Crumple one of them into a ball, then drop both from the same height. What do you observe? **The flat sheet falls more slowly than the crumpled paper.**

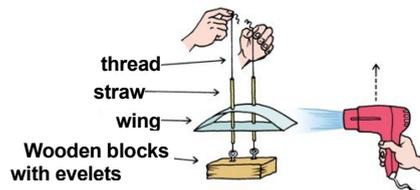
Which one takes longer to land? Why? **The flat blade falls more slowly because it has more drag due to its larger area. (In a vacuum, both blades would fall at the same speed, because there is no air, so there is no air resistance.)**

When air flows quickly over a bent sheet of paper, in which direction does the sheet of paper move? Why?

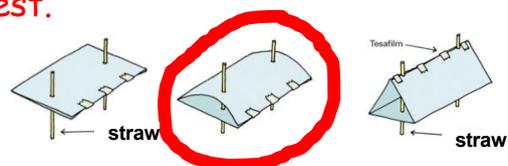
**When the air jet flows over the paper bent downwards, air particles are carried along on both the top and bottom. Since no air can flow in on the underside because the paper does not allow air to pass through, a vacuum is created below the air jet, which sucks the paper upwards.**



### Experiments 2 and 3: Checking the lift of three different wings



Which wing rises with you when you move the Föhn upwards: the flat, the curved or the tip? **The arched wing rises best.**



## Knowledge box: Why do airplanes fly?

It is not so easy to understand that airplanes can fly, because their weight pulls them to the earth. In order for them to fly, there must be a force that counteracts this **weight force**, i.e. that pulls the aircraft upwards. This force is called **buoyancy force**.

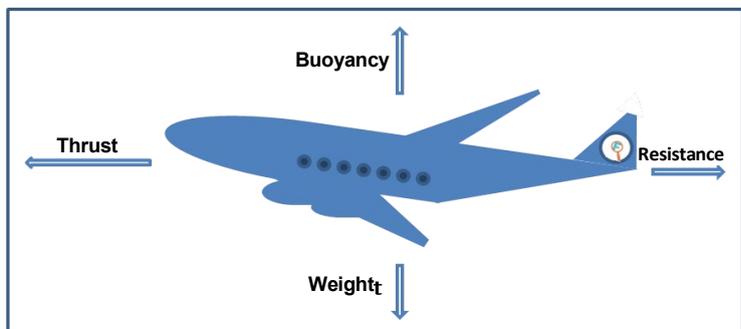
But what can cause this buoyancy?



You can hardly imagine that air has power on a windless day, but you notice it in a storm. But you can also feel the power of the wind when there is no wind, but you are moving quickly, e.g. when you hold your hand out of the window while driving, as shown. Then you will feel two forces that are also important when flying: **air resistance**, which

Hand pushes back and the buoyancy that pushes the hand up.

Airplanes also need such airstream. Nozzles or propellers generate the **thrust** that moves the aircraft forward. Only when the aircraft has enough thrust on the runway, it can take off - and of course the pilot must also provide enough thrust in flight so that there is always enough lift, otherwise the aircraft will sink. In the illustration you can see the four forces on the aircraft.



However, flowing air alone is not enough to make an aircraft fly. As you could see when experimenting with the hair dryer, the secret lies in the special **shape of the wings**. They are usually slightly curved at the top, flat at the bottom or curved inwards and are placed at a slight angle to the air flow.

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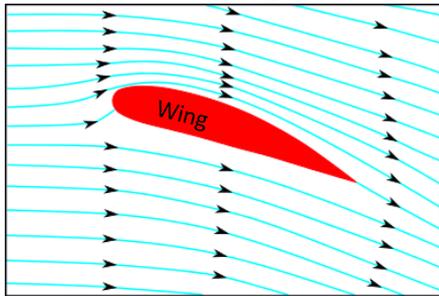


## Why is the curvature important?



The air flow nestles against curved surfaces, i.e. changes its original direction. This will result in you being able to blow out a candle that is behind a bottle, as the current will flow in an arc around the bottle. It is important that the curvature is not too strong, otherwise the air will continue to flow straight ahead and vortices will form behind the curvature.

When flying, the airflow in front of the wing is divided in such a way that one-part flows over the wing and the other underneath it. The part of the air that flows along the top of the wing surface contributes the most to lift. Actually, the



Air flows straight ahead, but due to the effect described above, the flow follows the wing, i.e. flows downwards in an arc. As you can see in the picture, the arrows behind the wing point diagonally downwards. The airflow under the wing also follows the shape of the wing and is thus deflected diagonally downwards.

## Now you need to know the following:

In order to deflect the air flow downwards, the wing exerts a downward force on the air flow. So it pushes the air under the wing down, and it also sucks the air above the wing down. However, as a famous researcher named Newton discovered, there is no force without an opposing force - this is called the "recoil principle". This means that the air exerts an equally great force on the wing in the opposite direction: it sucks from above and pushes the wing upwards from below. That's where the buoyancy comes from.

### Example of Newton's law of force and opposing force:

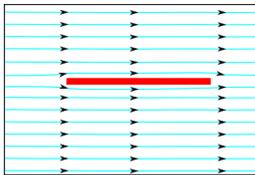
If two boats are lying next to each other on the water and someone from one boat pushes off the other boat, both boats will diverge in opposite directions. If someone pushes off the jetty in a boat, only the boat is moving, but the jetty also feels the force, only it does not move because it is anchored in the ground.

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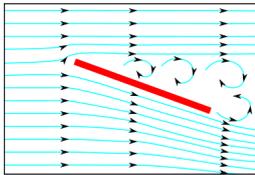


Maybe you'll find other explanations for why planes fly. Some only say that a vacuum is created above the wing, which sucks the aircraft upwards like a vacuum cleaner, while below it there is an overpressure that pushes the aircraft upwards. We have also tried to explain to you here what causes this negative pressure. For the super researcher: Sometimes it is claimed that the air flowing above the wing must arrive at the end of the wing at the same time as the air flowing under the wing and must therefore hurry because it has the longer path. But there is no reason for this claim. In fact, the air that flows above the wing arrives at the end of the wing even earlier than the air that flows under the wing, even though it has the further path.

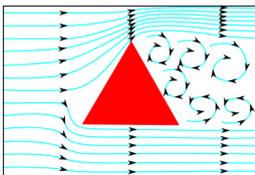
## Why don't the other tested wings work?



If the wing is flat and horizontal in the air, the air is not deflected and there is no lift.



If it is tilted, the air flow does not follow the wing, but breaks off at the sharp upper edge and continues to flow straight ahead, while air vortices form behind the edge. On the underside, however, the air flow is diverted downwards, creating some lift. This allows kites, for example, to fly.



With the wing with a triangular profile, the air is hardly deflected at the bottom. At the upper edge, the kink is so strong that the air cannot follow the curvature, but tears off and vortices form.

