English description of a proposed
ON-STAGE ACTIVITY

We Make Wind!

Understanding the principles of flying – Experimental lecture

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c/o ANIPROP GbR Felix Scharstein und Dr. Wolfgang Send

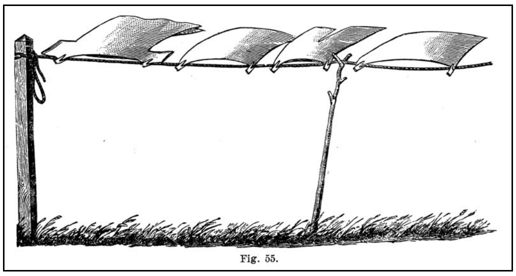


Fig. 1. Otto Lilienthal (1848-1896), *Der Vogelflug als Grundlage der Fliegekunst*, Berlin 1889 – Translated 1911.

I. Getting on and motivation. A fine sketch from Otto Lilienthal's book *Birdflight as the Basis of Aviation* shows clothes on a line fluttering in the wind, which also displays the solution of an optimisation problem (Fig. 1). The surface is cambered in the direction of the wind. This shape exposes the least drag to the wind, and it most lifts the clothes. A thin and yielding material like a towel bears force only in the direction of its fibres, whereas a thin board also bears a load perpendicular to its surface. The more the wind blows, the more it carries of the clothes's weight on the line. In a sufficiently strong wind, the clothes pegs merely hold the parts, while the current's force completely lifts them.

Fig 2. Otto Lilienthal, pioneer in aeronautics, with glider.

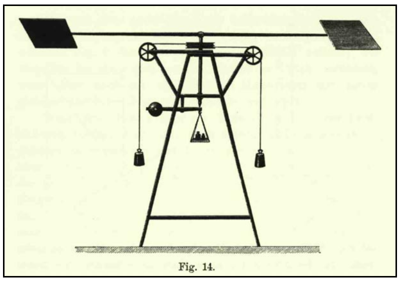
This picture also focusses on the two key tasks, aeronautical research was faced with since its beginning. Otto Lilienthal wanted to fly like a bird (Fig. 2). To manage this as human beings, we have to solve to tasks:

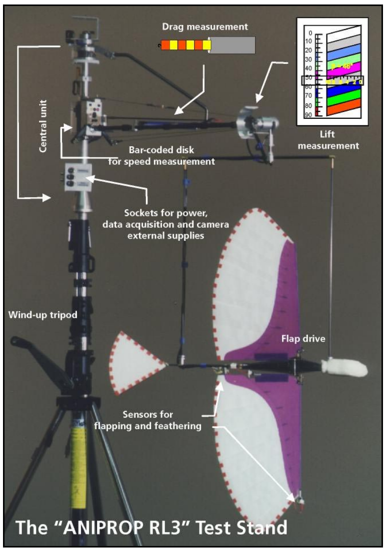
- Our air vehicle needs to carry us in the air flow.

The face of the lifting surfaces, also named wings, has very much to resemble the towels on the clothesline. At the same time, the wings must have the strength to carry their weight and also a payload, as there is no line in the air to hold on to. Therefore, the second important task reads as follows:

- We have to move forward relative to the wind fast enough, and we have continuously raise the force which overcomes the drag of the onset flow.

To find the best solution fort these two tasks, we have to carry out experiments and to perform measurements. The solution of the first task requires that we have to determine the wing with the best performance for carrying load and, at the same time, with the lowest drag. There are several options to plan the set-up of the experiments. We might take our test stand and drive along a straight road, or we find a good place with strong winds awaited, or we provide a facility, where the air blows relative to our lifting surface. All of these different options have been tried and applied in the past. In our experiments, we decide on “we make wind!”.





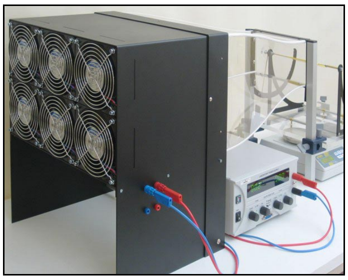


Fig. 3, above. Rotating apparatus by Otto Lilienthal for investigating the force on lifting surfaces (flat plates with angle of incidence).

Fig. 4, middle. Test stand ANIPROP RL3 by Felix Scharstein and Wolfgang Send for investigating flapping flight.

Fig. 5, upper right, Fig. 6 lower right. Drive and test section of the wind tunnel ANIPROP KWK2 for schools and undergraduate physics courses by Felix Scharstein and Wolfgang Send (white area: see below).

II. Experiments on lift and drag. It has to be proved that already a flat plate with an increasing *angle of incidence* versus the wind flow experiences an increasing force perpendicular to the flow, the so-called *lift force*. A cambered thin plate yields significantly more lift. At the same time, such a plate also experiences a force in the direction of the flow, the so-called *drag force*. The drag force also gains in strength with increasing angle of incidence. But the drag force does not totally disappear even if the plate experiences no more lift force at all. The remaining part is the *friction force* of the flow particles along the surface of the wetted body. A quick look at the professional background sketches the origin of the lift force:

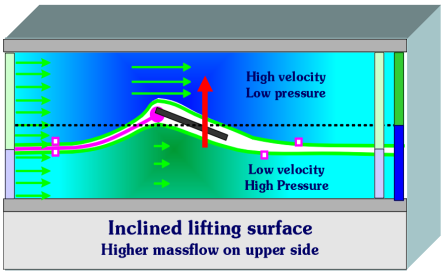


Fig 7. The lift force (red arrow) is caused by a higher mass flow around the upper side, if the plate is inclined. For zero angle, equal mass passes the plate above and below.

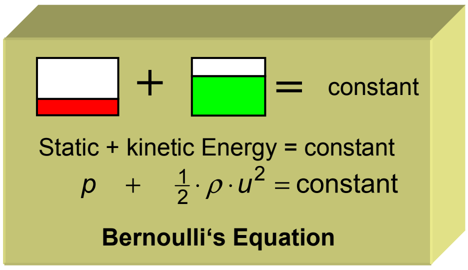


Fig. 8. Higher velocity u results in lower pressure p and vice versa (ρ density). The reason is the conservation of the sum of static and kinetic energy in a flow. The pressure difference effects the lift force in fig. 7.

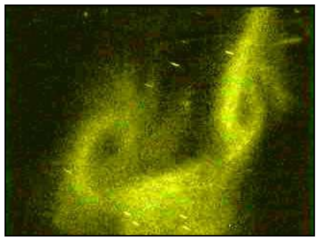


Fig 9. Tip vortices behind an inclined lifting surface, visualized by an experiment with the wind tunnel ANIPROP KWK2.

That portion of drag which increases with increasing angle of incidence is named *pressure drag*. It is true that the *pressure difference* between upper and lower side of the wings of airplanes and flying animals carries their weight, but, at the end of the wings at the wing tip, the balance of the pressure difference is unavoidable, and one has to pay for. There, the fluid particles streaming along the lower side force their way to the upper side and roll up to the so-called *tip vortex* at both wing tips. While flying, a huge amount of kinetic energy continuously is required for the air which initially was at rest. The consumption of energy for the tip vortices is in no way inferior to the amount of energy which is needed to balance the *friction drag*. An experiment has been developed in particular for teaching purposes which reveals this phenomenon of a curling flow. The demonstration is of high importance for understanding the physics of flying. Fig. 6 shows the location of the light sheet behind the trailing edge where fig. 9 displays the flow particles. The light sheet is created with a slide projector housing a slide with a small slot. The light is scattered from harmless steam particles with which the flow is seeded upstream.

III. Experiments on thrust. Until now, the question still remained open how the thrust for balancing the drag can be provided. For Lilienthal's glider and its successors, sailplanes and paragliders, the question easily is answered. Paragliders are carried on a high mountain, sailplanes are lifted with an air tow winch. If they cannot gain altitude from rising air, they glide down to ground along a more or less extended stretch. Potential energy is converted into kinetic energy until the lowest possible point is reached, like any simple paper plane demonstrates.

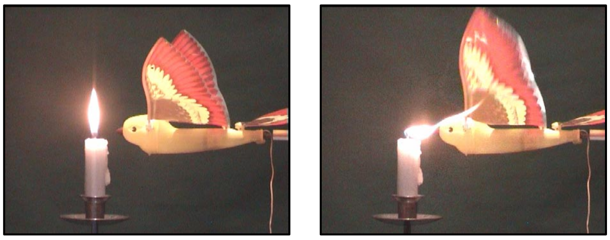


Fig. 10,11. The artificial bird shows how the air is taken in during the flapping motion.

Fig. 12,13. Airplane turbines take in the air and push it downstream. In the lecture, a small propeller airplane demonstrates the thrust.

Airplanes with engines and birds have more in common then one usually might think of: they both "make wind". For large airplanes, their "wind" easily reaches the strength of a hurricane. The air is taken in by turbines or propellers and pushed downstream. Thereby, a counter-reacting force develops. The mechanism of flapping flight in nature acts in the same way. The motion of the wings pushes on the air, and the air pushes back on the flyer, creating thrust. The ingenuity lies in the fact that the both properties carrying weight and producing thrust are accomplished with one and the same device, the wing.

More about the author and the experiments on www.aniprop.de

Professional hints. The lecture condenses the subject "Physics of Flying" to the length of a 45 minutes lesson with the handy title "We Make Wind!". The content addresses young children in the age of nine to twelve years, however parts of the lecture exceed that level and are enriched by elements, the knowledge and understanding of which is desirable when teaching the subject.

The lecture with this subject is intended to be held at Göttingen's Children's University during the next winter term 2008/09, adapted to the aptitude of children at the age of nine to twelve years und within the time frame of 45 minutes[1].

Technical hints. The experiments which will be seen are those with the wind tunnel, the thrust experiment (Fig. 10,11) and its comparison with a model airplane of similar size (without picture). The experiments require two tables of ordinary size of about 0.8 x 1.2 m². Besides the VGA connection for the laptop, a video socket (PAL composite signal) is necessary for the video camera which displays the details of the experiments for the audience.

If the vortex experiment is desired to be demonstrated in a *live* show, the lecture room has to be completely darkened. Except that the depth of the stage has to be about 2.5 m for the space the slide projector needs.

Sources. Figures 1,3, III. Edition of Lilienthal's book *Der Vogelflug als Grundlage der Fliegekunst* from 1889, Göttingen 1938. - Figure 2, Courtesy of Lilienthalmuseum Anklam. - Figure 12,13, Boeing Company Seattle (U.S.A.), „Building the Dream", released for publication. – All other figures ANIPROP GbR.

[1] **Added in December 2008**. The lecture was held in German. The contents (PDF in German and a report by the *Göttinger Tageblatt*) may be found among the references of the Childrens's University which is affiliated to the University of Göttingen: www.uni-goettingen.de/de/79794.html