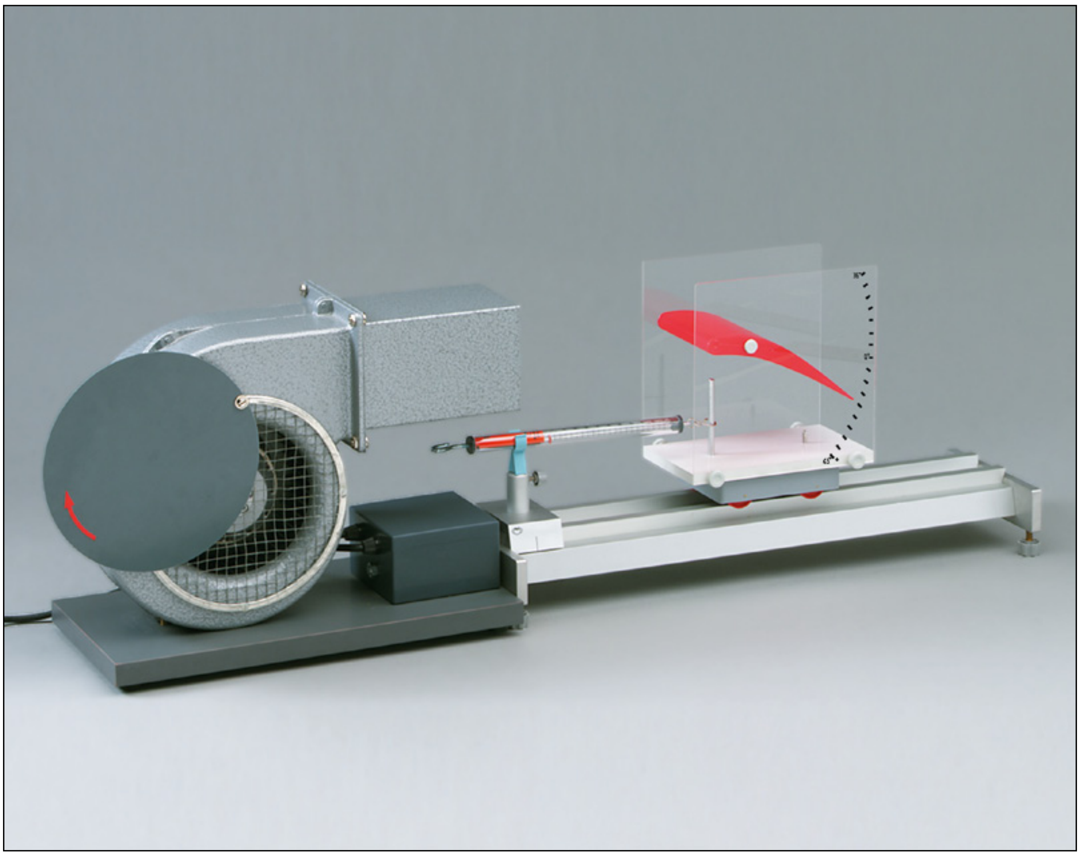
Experiment description/Manual

Demonstration kit

Flight and flying



Cornelsen
EXPERIMENTA

Within the framework of school projects and interdisciplinary instruction many of the federal states in Germany include the subject of 'Flight and Flying' as an elective course in their syllabuses or recommend it for project work.
The proper approach to this subject both visually and in terms of content predisposes this subject for experimentation and includes the practical introduction of models.
The kit 'Flight and Flying' contains a set of equipment and models which permits demonstration experiments or practical group work. Due to the fact that, apart from an air blower, no additional auxiliary equipment is required, the kit can be used outside the instruction rooms or outside of class.
It is recommended that the blower, order no. *29010*, is used. Should other devices be used, it must be pointed out that the attainable flow-velocities have to reach a minimum of 14 m/s.

Demonstration kit

Flight and flying

Order number 29008

Contents

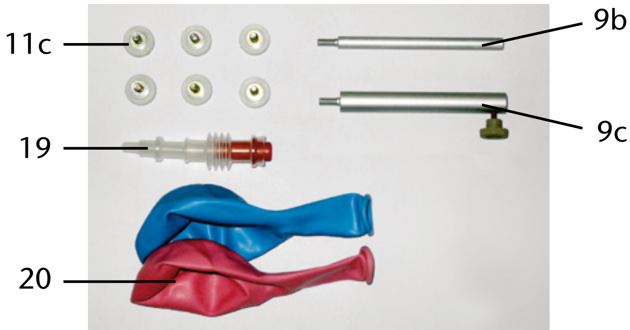
Flight and flying

List of components

Ill. no.	Qty.	Description	Order no.
1	1	Rail, 500 mm	47002
2	1	Pair of feet for rails with adjustable screws	77017
3	1	Rider with clamping tube, 30 mm	47005
4	2	Rider with clamping tube, 75 mm	47006
5	2	Stand rod, 250 mm	40121
6	3	Bosshead	40605
7	1	Dynamometer, 200 mN	41609
8	1	Support clip, 15 mm Ø, on rod	43284
9	1	Carriage (a) with rods (b, c)	43289
10	1	Balance with solar cell	42065
11	1	Lifting power model, *consisting of*: base plate (a), 2 stand plates (b), set (6) screws (c), airfoil model with 1 bore hole (d), support for lifting power experiments (e)	29055
12	1	Stand rod, 100 mm	40131
13	1	Set (4) wind resistant objects	29150
14	1	Thread comb	29180
15	1	Venturi tube with couplings	29091
16	1	Set (3) U-tube manometers	29092
17	1	Support clip, 25 mm Ø, on rod	77040
18	1	Pitot tube with couplings	29081
21	1	Solar zeppelin	45651
22	1	Hot air balloon	47793
23	1	Heat source, *consisting of*: metal base (a), ESBIT burner (b), chimney (c) ESBIT Dry fuel (d)	45623
24	1	Rocket model ROKIT	29200
25	1	Air foil model (a) with support rod (b), probe (c), hose, 400 mm (d)	29051
26	1	Dye, red	12921
27	1	Measuring cylinder, 25 ml	63033
28	1	Airscrew	29056
29	1	Support rod for airscrew	29057
30	1	Pressure gauge setup, *consisting of*: compensation reservoir with couplings and funnel (a), manometer on support rail (b), hose with couplings, 750 mm (c), hose with couplings, 250 mm (d)	29075
31	1	Plastic ball, 38 mm Ø	29121
32	1	Styrofoam ball, 70 mm Ø	29120
33	1	Silicone oil, 10 ml	93377
34	1	Air pump	47628
35	1	Support clip, 45 mm Ø, on rod	77046
–	1	Manual	290086
–	1	Storage plan	290083

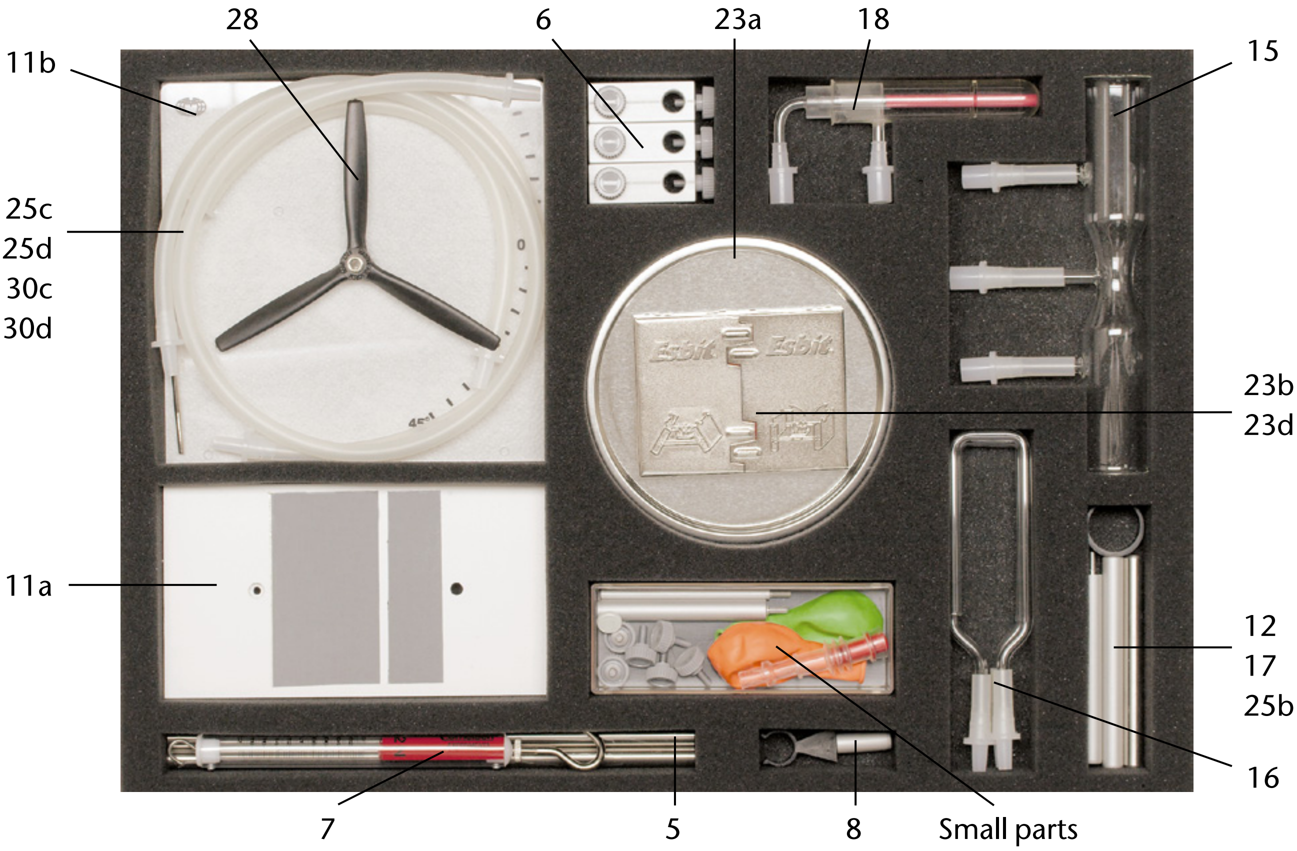
Small parts:

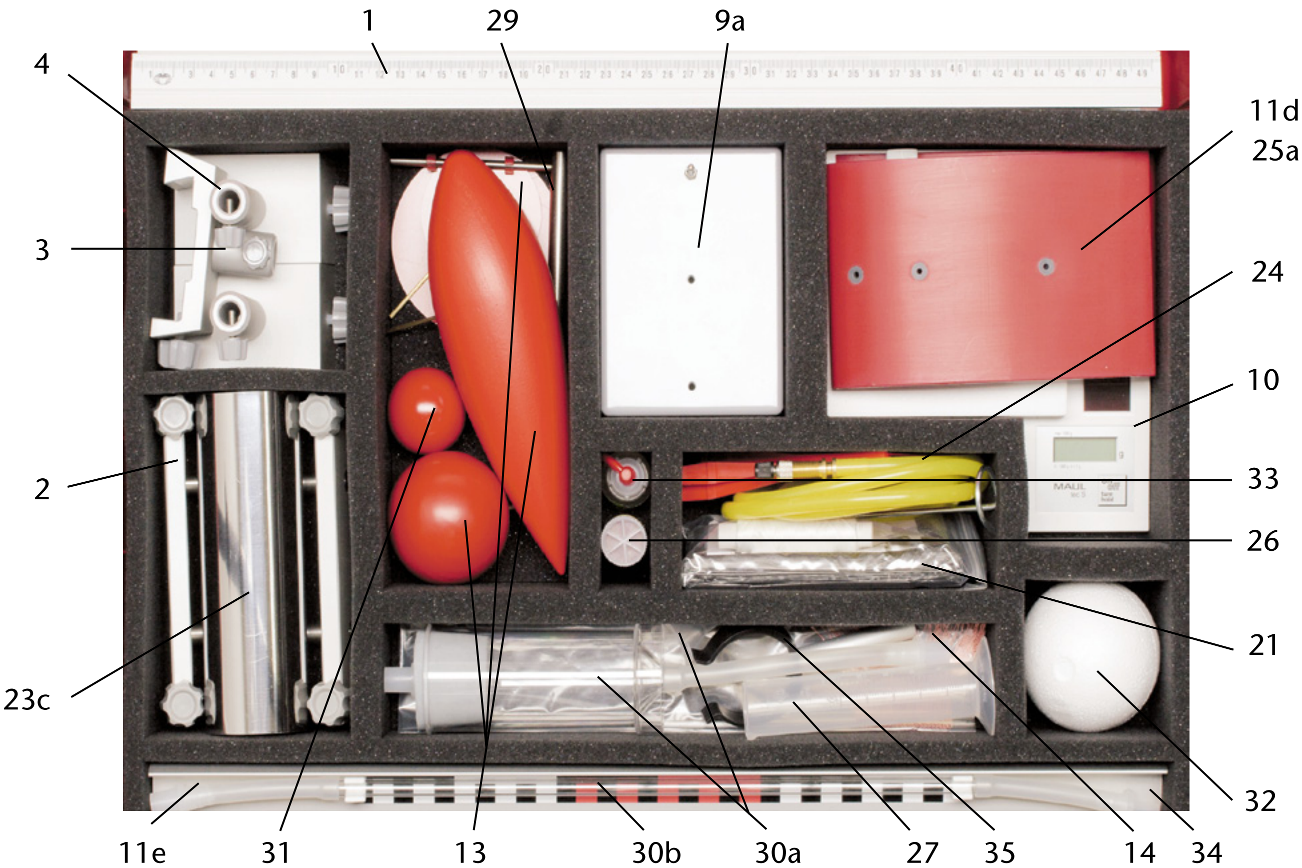
Ill. no.	Qty.	Description	Order no.
9b, c	2	Support rods (for carriage 9a)	43289
11c	6	Screws	29055
19	1	Balloon valve	47660
20	2	Balloons	47725



Storage plan

The *Hot Air Balloon* (22) is stored on the upper foam insert.





Flight and flying

Notes on experiment setup

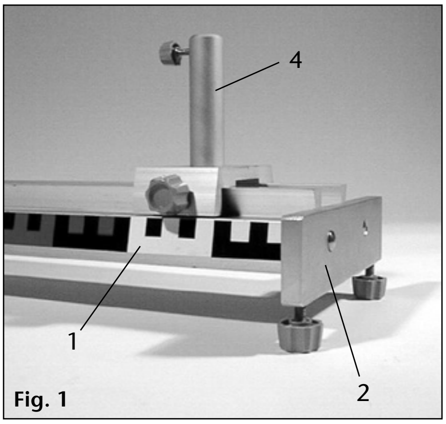


Fig. 1

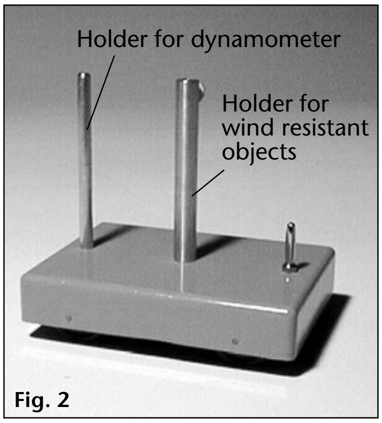


Fig. 2

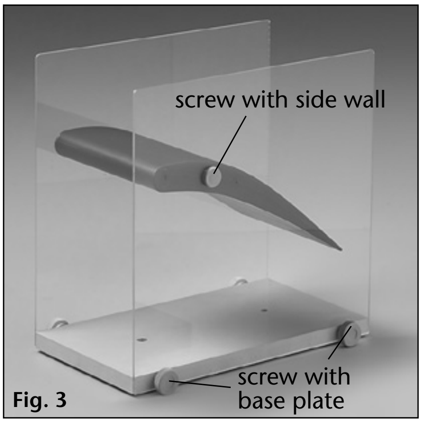


Fig. 3

Fig. 1: The experiment arrangements are primarily assembled on a special multi-purpose rail (1) with attachable side bases (2).
The bases are equipped with adjustable screws so that a height adjustment can be carried out.
Riders (3/4) can be mounted onto the rail and are able to slide into a particular position. They serve for the mounting of stand material.
Fig. 2: The carriage, which can be equipped with screwable rods, is an essential component of many experiments. The **centre** rod (9c) is used as the holder for the wind resistant objects. The **front** rod serves for the suspension of the dynamometer or in conjunction with the 4-mm plug for the mounting of the lifting power model.
Fig. 3: The lifting power model is composed of individual parts (11a–d). To assemble this, first remove the protective foil from the side walls (11b) and then fasten them to the base plate (11a) using the screws. The air foil (11d) model is then inserted between the side walls and tightened with the screws (11c) enough so that it is sufficiently fixed in place.

Do not fasten any of the screw joints too tightly!

Fig. 4: The balance with solar cell is used for the measurement of the lift power. During operation the solar module on the front side may not be covered as otherwise the balance automatically switches off.
Fig. 5/6: The blower (order no. 29010) is your guaranty for the reliable performance of the recommended experiments. It can be setup vertically or horizontally. The air-speed is varied by expanding or contracting the air inlet port.

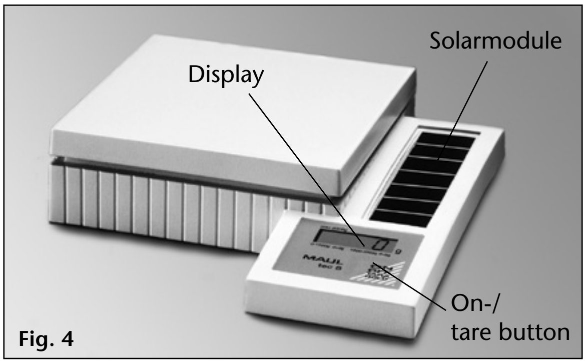


Fig. 4

Adjustable flap for varying the size of the air inlet port

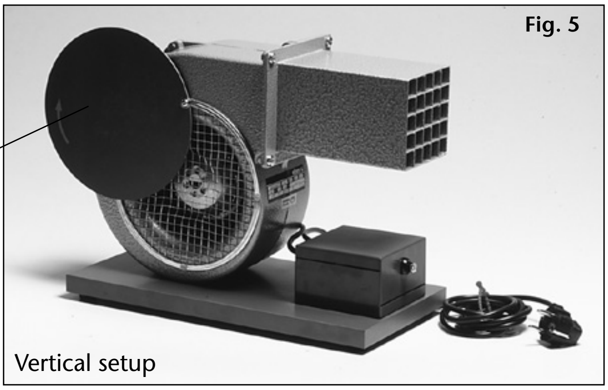
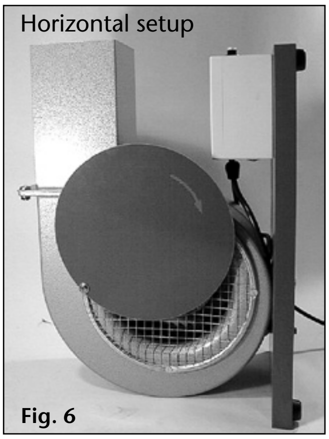


Fig. 5
Vertical setup


Horizontal setup
Fig. 6

Notes on setting up the rocket model

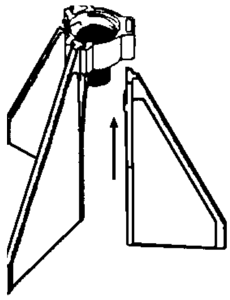


Fig. 1

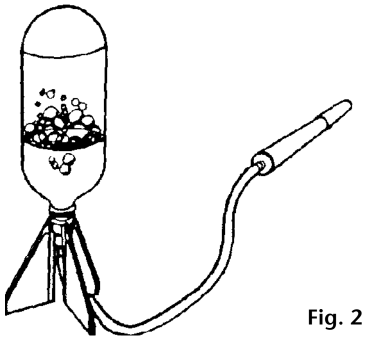


Fig. 2

Safety Instructions

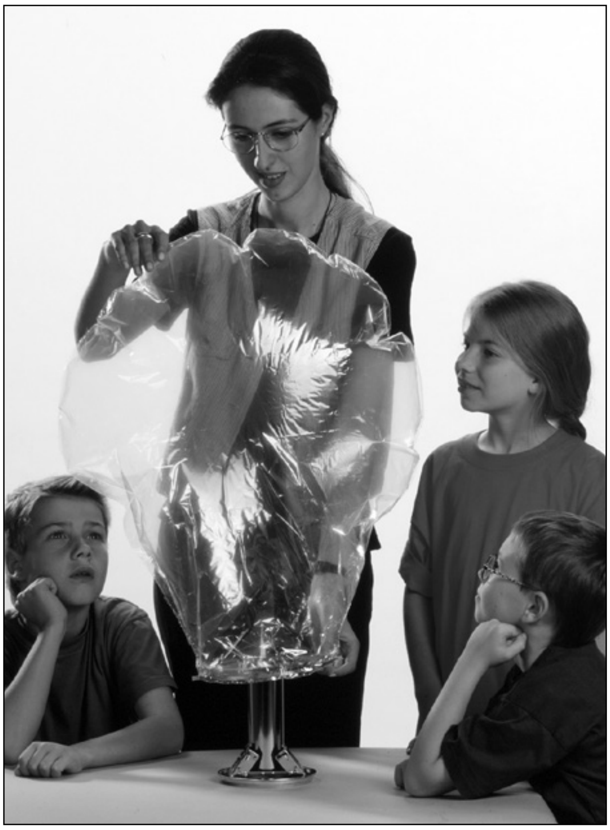
- Warning: This item is not a toy and should only be used under direct supervision of an adult.
- Do not use in confined spaces.
- Do not stand over the rocket.
- Keep a safe distance of 3 m.
- Use on grass for softer landings.
- Use only recommended bottles.
- Should the rocket fail to launch – carefully unscrew bottle from tail unit to release pressure.
- To stop rocket toppling over, if ground is rough or wind is strong, press wire into ground and locate rubber nozzle in loop with fins resting on ground.

Assembling

1. Use an empty 1 lt or 1.5 lt plastic Lemonade or Cola bottle without cap. Quarter fill bottle with water.
2. (See Fig. 1) Assemble black nozzle, white cap and fins to make tail unit – make sure nozzle is retained by groove and rubber ring is located correctly. Finger tight only. **(Important: Overtightening may cause damage to the white cap!)** Screw tail unit on the bottle.
3. Push plug on tube into black nozzle.
4. Place rocket on level ground as illustrated in Fig. 2.

Flight and flying

1 Static lift – hot air balloon



Material

Hot air balloon	22
Heat source	23

Experiment procedure

The skin of the balloon is carefully folded out and the metal clamp bent to create a round opening.
The heat source is setup as follows:
The metal plate is placed on a solid surface. The jaws of the ESBIT burner are folded out and placed in a vertical position. The open burner is positioned on the plate and an ESBIT pellet is dropped in the middle of the bowl and lit. Once the pellet is burning completely, place the chimney over it and fasten it by folding the jaws of the burner against it.
The balloon is filled with hot air by moving the inlet of the balloon back and forth. Use your finger tips to hold the top of the balloon and hold the opening of the balloon approx. 10 cm above the chimney. When a sufficient lifting force is felt, the balloon is released. If the experiment is performed outdoors make sure that there are no obstacles impeding the balloon's lift.

Experiment evaluation

The air inside the balloon expands considerably on account of the heat. As the air escapes from the opening at the bottom of the balloon, it becomes lighter. The balloon lifts up when the weight of the balloon and its skin is less than the weight of the air being displaced by it.

2 Static lift – solar balloon

Material

Solar zeppelin	21

Experiment procedure

The skin of the balloon is carefully folded out and laid out on the ground. One end of the hose-shaped skin is firmly sealed with a piece of thread. The other end is opened and held by a person in such a way that a second person can rapidly fan air into its interior using a large book or a piece of cardboard. Once the balloon is nearly filled with air, the open end is also folded together and sealed with a piece of string. The retaining string is attached to one end.
When the weather is as wind-free as possible the filled solar balloon is positioned directly in the sun and its behavior observed.

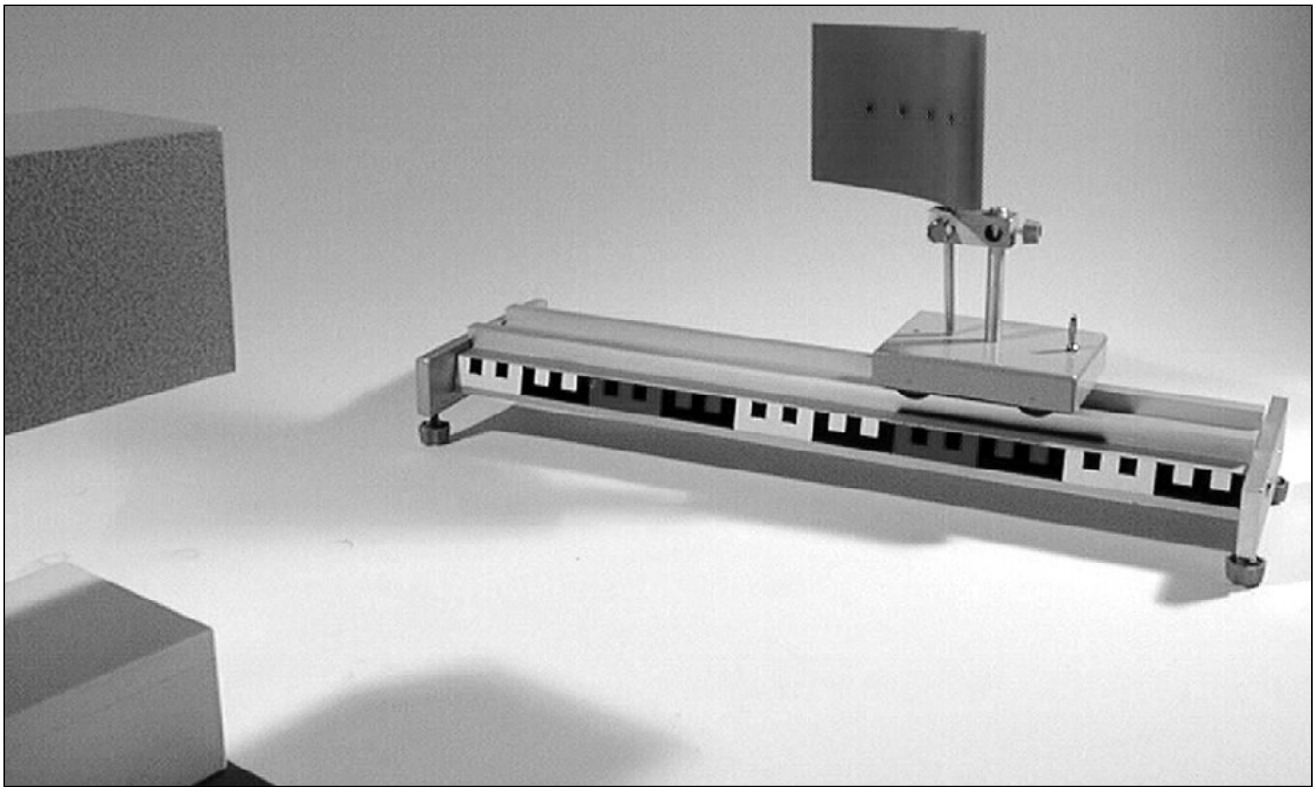
Note: This experiment can only be performed if there are no high-voltage lines or other impediments in the area.

Experiment evaluation

The black skin of the solar balloon is well suited to absorb the heat radiated by the sun. The air inside expands severely, causing the balloon to stretch tightly. Surrounded by the colder ambient air, the warm air brings about static lift in the balloon – it begins to ascend.

Flight and flying

3 Forces exerted by air stream



Material

Rail	1	Carriage with centre rod	9a, c
Pair of feet for rails	2	Air foil model	25a
Bosshead	6	with support rod	25b

Additionally required: Blower (Order no. *29010*)

Experiment procedure

The support rod for the wind resistant objects is attached to the carriage. The clamping screw is temporarily removed. The support rod is screwed into the air foil of the air foil model. Using the bosshead the air foil is then attached to the carriage as shown in the figure.
The rail is connected to the feet and setup crosswise in front of the blower at a distance of approx. 50 cm. The carriage is placed on the left edge of the rail and the air foil adjusted so that it forms an angle of approximately 15 degrees with respect to the longitudinal axis of the carriage.
The air flow generator is switched on and the air flow gradually increased while observing the carriage.

Experiment result

The air stream is diverted by the air foil. This generates a repulsion power directed perpendicularly to the direction of the air stream. The carriage is propelled forwards under the influence of this aerodynamic force.

4 Dynamic lift (1)

Material

Rider, 75 mm	4
Air foil model	25a
Styrofoam ball	33

Additionally required:
Blower (Order no. *29010*)

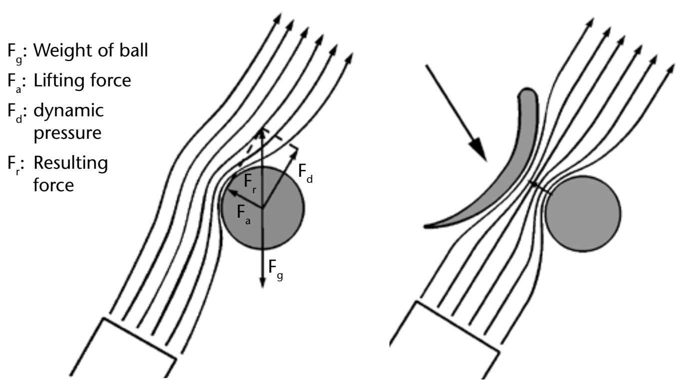
Experiment procedure

The blower is setup vertically. The styrofoam ball is placed in the middle of the output grid when the device is switched off. The air flow is slowly increased until the ball hovers approx. 50 cm above the outlet of the device and has settled into a relatively steady position.
The blower is then slowly tilted to the side while maintaining a view of the ball. The position of the blower is stabilized by inserting the rider underneath it at a tilt angle of approx. 30° (with respect to the vertical position).
The hovering ball is approached from above with the curved side of the air foil and the effects this has on the ball are observed.

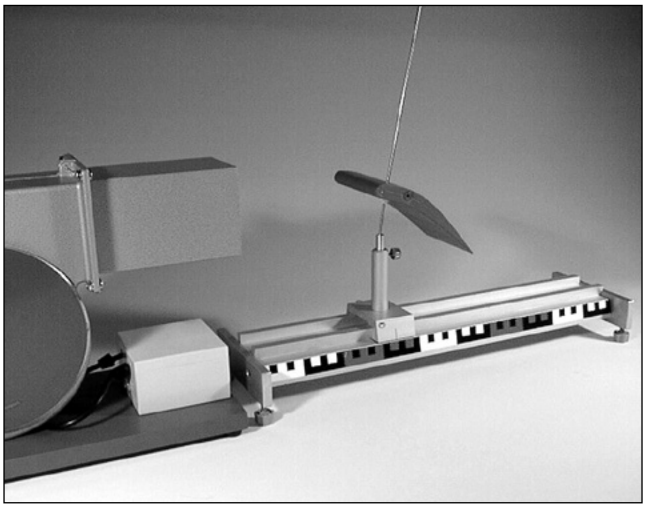
Experiment evaluation

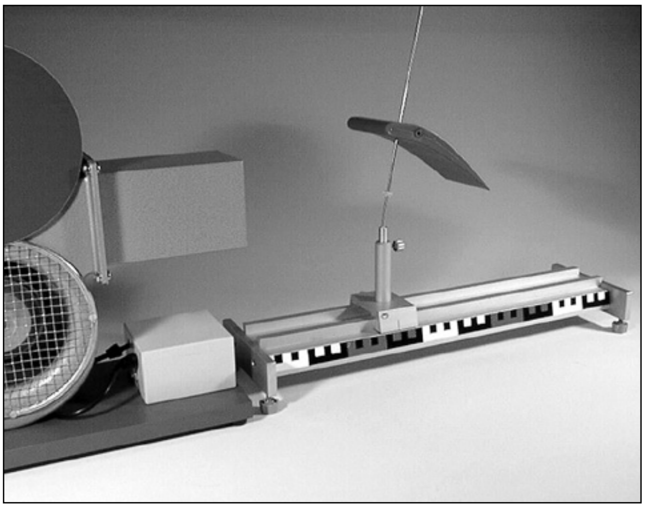
The ball also hovers in the angled air flow, because the air stream flowing over the ball's inward directed surface produces a lifting force which compensates for the weight and air resistance.
This experiment graphically demonstrates the effect of dynamic lift.

When the hovering ball is approached from above with a curved surface (air foil) the flow velocity at this location is increased and the lift strengthened even more. The ball rises in the air stream until it touches the surface. This collapses the air flow and the ball falls back to its previous position. As long as the air foil is held in the air stream, the ball oscillates back and forth.



5 Dynamic lift (2)





Material

Rail	1	Air foil model with one bore hole	11d
Pair of feet for rails	2	Support for lifting power experiments	11e
Rider, 75 mm	4		

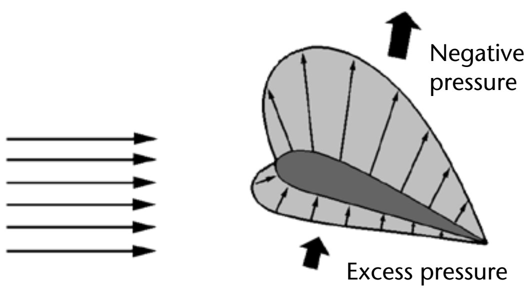
Additionally required: Blower (Order no. *29010*)

Experiment procedure

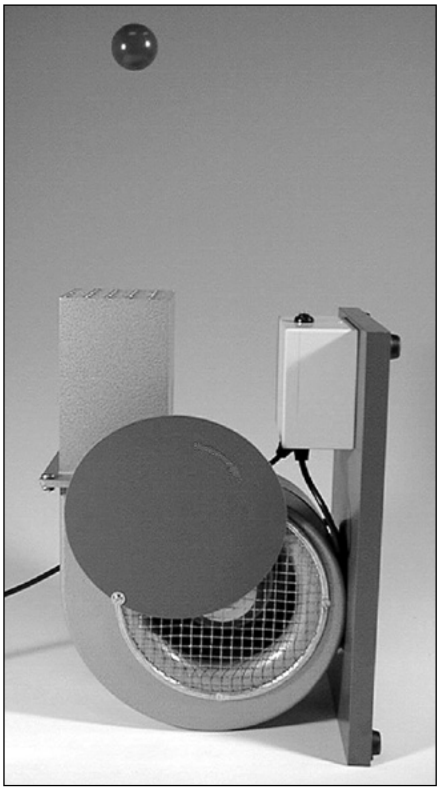
The feet are connected to the rail. The rider is attached and the support for the lift experiments is fastened to the rider. The air foil is connected to the support so that it can glide on the centre socket of the rod. By turning the support inside the rider and by sliding the clamp socket on the rod the air foil is adjusted so that its front edge points to the centre of the output grid of the blower. The distance from the outlet of the blower should be approx. 25 cm.
The blower is switched on and the flow velocity is slowly increased. Observe the air foil at the same time. The blower is switched on and off several times. The effects of this action are observed.
When the blower is switched on, the air foil is kept first in the lower and then in the upper area of the air stream. The behavior of the air foil is observed.

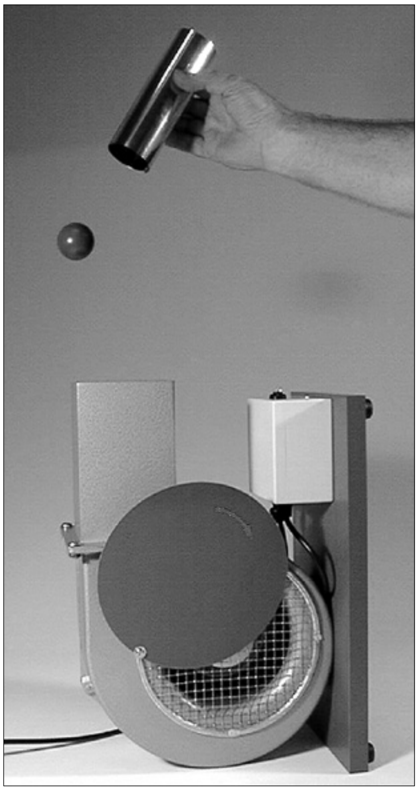
Experiment evaluation

The foil is fixed in the air stream by the support at a setting angle of approx. 30 degrees. The air streaming over the top surface produces a negative pressure there while the air attacking the underside produces an excess pressure. The lift resulting from this exceeds the weight of the air foil – it is lifted upwards.
If the upper air flow is interrupted, the lift force is reduced almost completely and the pressure from below is not sufficient to keep the air foil in the upward position. If the lower air flow is interrupted, then the suction exerted on the upper surface normally suffices to keep the air foil in the upper position.



6 Air-flow velocity





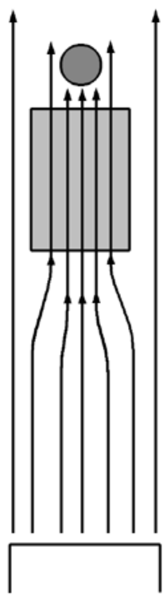
Material

Tube from the heat source	23c
Plastic ball	34

Additionally required:
Blower (Order no. *29010*)

Experiment procedure

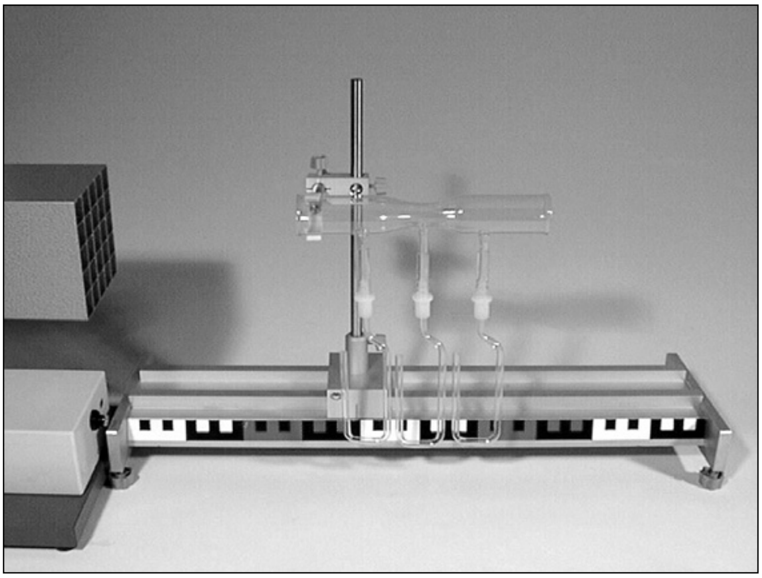
The blower is setup in the vertical position. The plastic ball is placed in the middle of the output grid with the device switched off. The air flow is increased very slowly until the ball hovers approx. 20 cm above the device. This process may have to be repeated several times until the ball achieves a stable position in the air current. Wait until the ball settles into a relatively stable position.
Take the tube from the heat source used for the hot air balloon and use it to approach the ball from above and see how the ball responds.



Experiment evaluation

An equilibrium is established between the weight of the ball and the upward directed air current produced by the blower. Inside the tube a considerably higher air-flow velocity is generated which exerts a greater force on the ball. The ball is pulled upwards and catapulted out of the tube.

7 Air-flow processes (Venturi tube)



Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Stand rod, 250 mm	5
Bosshead	6
Venturi tube	15
U-tube manometers (3x)	16
Clip, 25 mm	17
Dye	26
Measuring cylinder	27

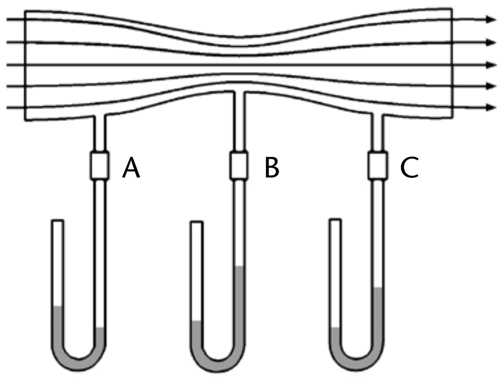
Additionally required:
Blower (Order no. *29010*)

Experiment procedure

The rail is connected to the feet. The rider is mounted and equipped with the stand rod. Using the bosshead and the clip the Venturi tube is arranged so that its aperture is pointed at the centre of the blower as shown in the figure. This is carried out by adjusting the position of the bosshead on the stand rod. The distance to the blower should be approx. 20 cm.
A small amount of colored water is produced in the measuring cylinder using the dye. Carefully fill the three U-tube manometers with the colored water until the fluid is at the same level in all the manometer necks. The U-tubes are then inserted into the couplings on the Venturi tube.
The blower is switched on and the air-flow increased to the maximum level. At the same time observe the level of the fluid in the manometers.

Experiment evaluation

Inside the Venturi tube the air stream generates a total pressure consisting of the pressure in the flow direction (motion pressure) and the pressure exerted towards the sides (static pressure), so-called side pressure.
The side pressure brings about a pressure increase in manometer A.
In the constricted section of the Venturi tube the air-flow velocity increases considerably and the side pressure drops off, while the total pressure remains the same.
The respective pressure levels at points B and C are indicated by the manometer.



8 Principle of the inclined tube manometer

Material

Rail	1
Pair of feet for rails	2
Rider, 75 mm (2x)	4
Stand rod, 250 mm	5
Bosshead (2x)	6
Stand rod, 100 mm	12
Dye	26
Measuring cylinder	27
Pressure gauge setup	30
Clip, 45 mm	35

Experiment procedure

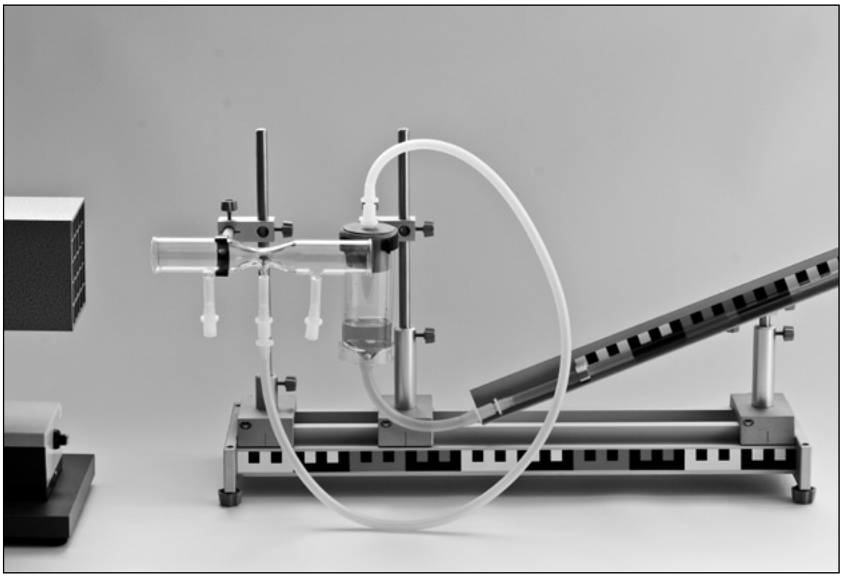
The rail is connected to the feet. The riders are mounted onto the rail as shown in the figure and each one is equipped with a stand rod. The manometer tube is fastened to the 100 mm stand rod with the aid of a bosshead. The manometer tube should be tilted at an angle of 20° with respect to the rail.
The compensation reservoir is fastened to the 250 mm stand rod using a bosshead and the clip as illustrated. The lower connection of the compensation reservoir is connected to the left terminal of the manometer tube by means of the coupling.
The measuring cylinder is filled with water and coloured dark red using the dye. By means of the funnel the compensation reservoir is slowly filled through its right-sided connection until the fluid level in the manometer tube just about reaches the middle of the tube. In the reservoir the fluid level is then approx. 3 cm high. The shorter hose connected to the terminal of the lid. The open end of the hose is pressed closed using your fingers and the hose is squeezed together several times. Meanwhile observe the fluid level in the manometer tube.

Note: Under no circumstances may the fluid level in the compensation reservoir reach the rubber stopper as otherwise there is not enough room for the air above the fluid.

Experiment evaluation

The inclined tube manometer differs from the U-tube manometer primarily on account of its greater display sensitivity and is thus better suited for the measurement of the small pressure differentials found in the subsequent experiments.
The pressure changes which effect the fluid surface in the compensation reservoir are transferred to the manometer tube. The inclined fluid column has a longer displacement distance than the U-tube manometer for the same pressure changes. Thus small pressure differentials can be made more visible.

9 Measuring the flow velocity



Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Rider, 75 mm (2x)	4
Stand rod, 250 mm (2x)	5
Bosshead (3x)	6
Stand rod, 100 mm	12
Venturi tube	15
Clip, 25 mm	17
Dye	26
Measuring cylinder	27
Pressure gauge setup	30
Clip, 45 mm	35

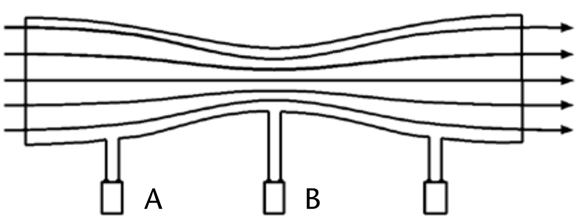
Additionally required:
Blower (Order no. *29010*)

Experiment procedure

The rail is connected to the feet. The setup for the pressure gauge is carried out as described in experiment 8.
Using the rider 30 mm, a stand rod 250 mm is mounted on the left end of the rail. This is used to attach the Venturi tube using a bosshead and the clip 25 mm as illustrated. The distance from the Venturi tube opening to the centre of the blower should amount to approx. 20 cm. The longer hose is attached to the lid of the compensation reservoir whose end initially remains unconnected.
After switching on the blower (maximum power) first establish the connection of the manometer reservoir to terminal A and then to terminal B of the Venturi tube. In both cases the changes occurring in the fluid column from the initial level are read off and recorded in mm.
The experiment is repeated at lower flow velocities (1/2 and 1/3) and the results recorded.
Afterwards terminal A is connected to the compensation reservoir of the manometer by means of the short hose and the long hose is used to connect terminal B to the previously unconnected end of the manometer tube opening. When the blower is switched on the level of the fluid column is recorded beginning with the starting fluid level. Changes regarding this reference point are noted at 1/3, 1/2 and full air speed.

Experiment evaluation

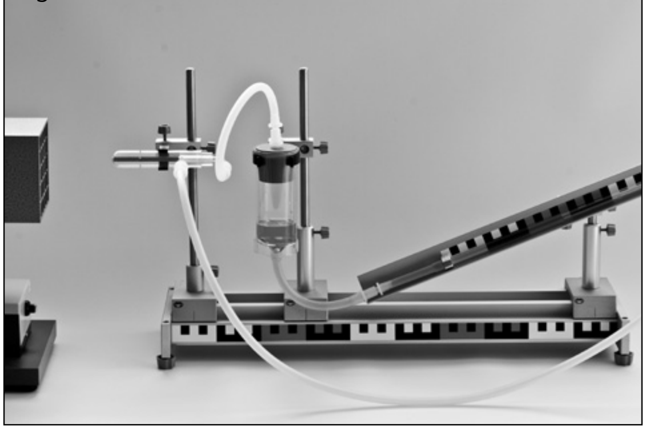
Flow velocities can be determined using the Venturi tube. This employs the difference in static pressure at points A and B of the manometer. The flow velocity can be obtained from the measured pressure differential using Bernoulli's equation.



10 Principle of the Pitot tube

Fig. 1

Fig. 2



Material

Rail	1	Pitot tube	18
Pair of feet for rails	2	Dye	26
Rider, 30 mm	3	Measuring cylinder	27
Rider, 75 mm (2x)	4	Pressure gauge setup	30
Stand rod, 250 mm (2x)	5	Clip, 45 mm	35
Bosshead (3x)	6		
Clip, 15 mm	8	*Additionally required:*	
Stand rod, 100 mm	12	Blower (Order no. *29010*)	

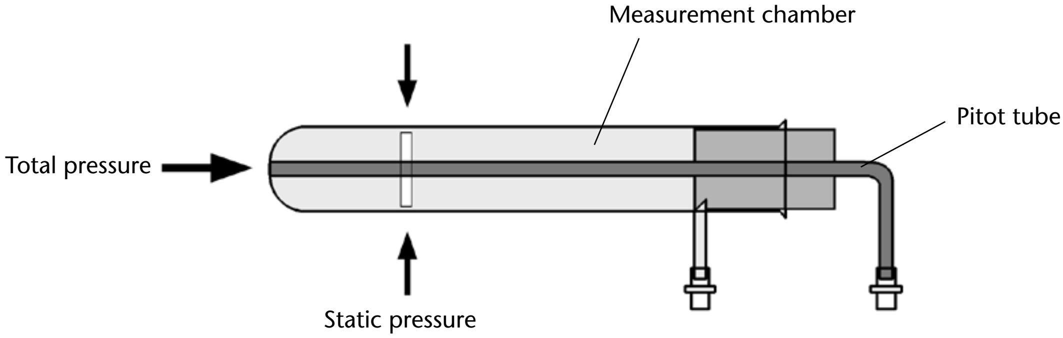
Experiment procedure

The rail is connected to the feet. The setup for the pressure gauge is carried out as described in experiment 8. Using the rider 30 mm, a stand rod 250 mm is mounted at the left end of the rail. The pitot tube is attached by means of a bosshead and the 15 mm clip as shown in the figure.
By sliding the bosshead, the height of the pitot tube is positioned in the middle of blower's output grid. The distance from the head of the pitot tube to the air blower should be approx. 15 cm. The initial position of the fluid in the manometer is noted.
By means of the short hose the red tube in the pitot tube is connected to the manometer reservoir and the effect of full air flow is recorded (Fig. 1). Afterwards the manometer reservoir is connected to the measurement chamber of the pitot tube. And finally connect the terminal on the red tube to the compensation reservoir and the measurement chamber terminal to the open end of the manometer tube by means of the longer hose (Fig. 2). For each setup the indicated pressure changes are recorded at full air speed.

Experiment evaluation

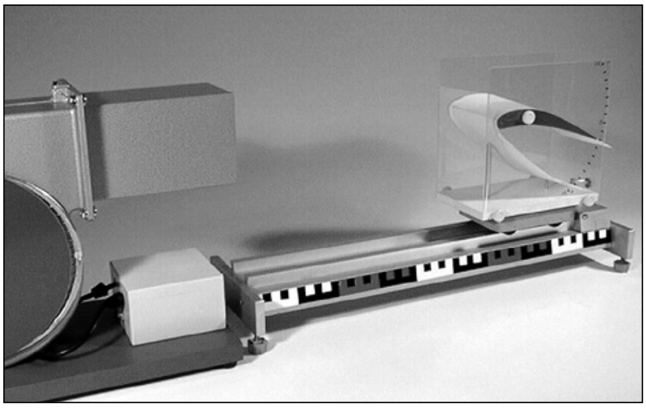
The pitot tube records the total pressure being exerted in the flow direction at its tip (red tube). The total pressure is composed of the dynamic and static pressures. The static pressure level influences the resulting dynamic pressure. The static pressure measured along the side slits of the measurement

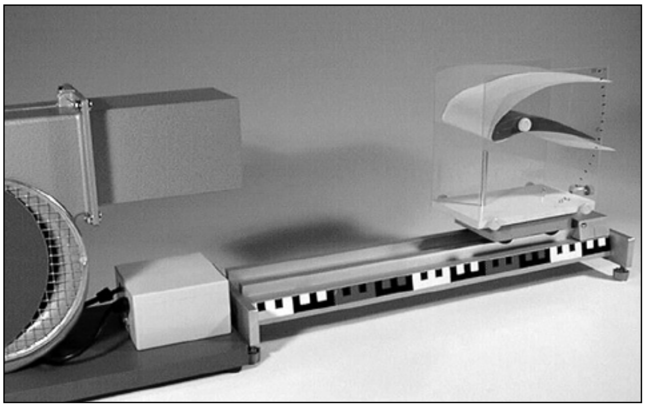
chamber of the pitot tube is subtracted from the dynamic pressure, when applied to the open side of the manometer.
When measuring the total pressure with an open manometer, the existing atmospheric air pressure acts as the static pressure. The measurement produces a differential, the dynamic or impact pressure at the tip of the pitot tube.



Note: Due to the fact that the static pressure frequently differs only slightly from the atmospheric pressure, direct measurement of this phenomena may lead to no visible change in the manometer!

11 Pressure differences at the air foil





Material

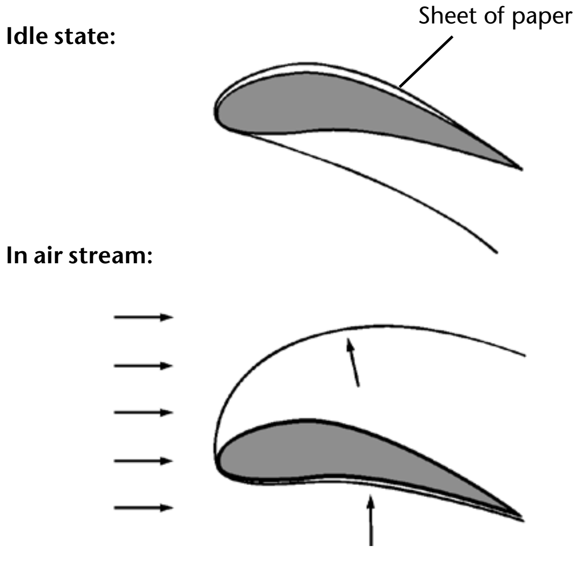
Rail	1	Lifting power model	11a–d
Pair of feet for rails	2		
Rider, 30 mm	3	*Additionally required:*	
Cariage with front rod	9a,b	Blower (Order no. *29010*)	

Experiment procedure

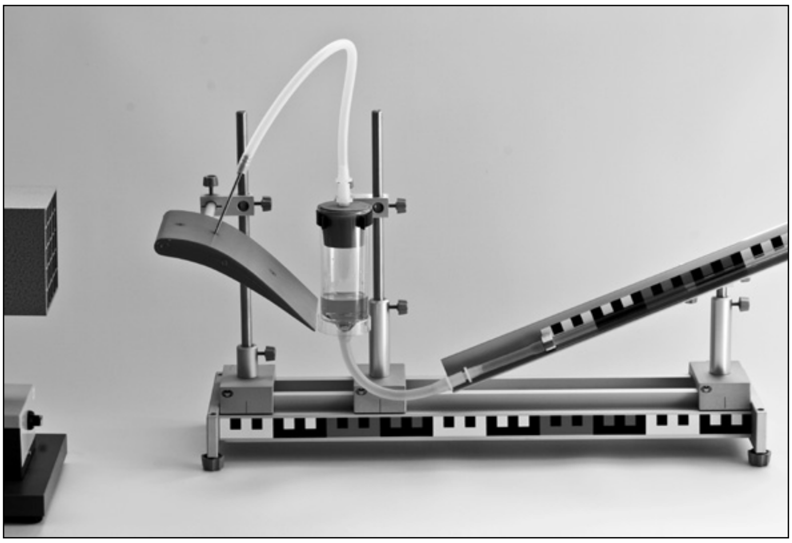
The rail is connected to the feet. The side walls of the lifting power model are connected to the base plate.
The airfoil is attached between the side walls as shown in the figure.
The carriage is equipped with the front stand rod to mount the model onto the carriage. Here it is important to make sure that the 4-mm plug is located underneath the back end of the foil.
The carriage with the model is placed on the rail and fastened with a rider. The airfoil is set to an angle of +20°. A strip of newspaper is cut twice the length of the airfoil and with somewhat less width. The paper strip is bent somewhat and placed over the airfoil as shown in the figure. Press on it so that it conforms to the shape of the airfoil. The rail is positioned in front of the air blower and the air flow is set to medium speed. Observe what happens to the paper strip.

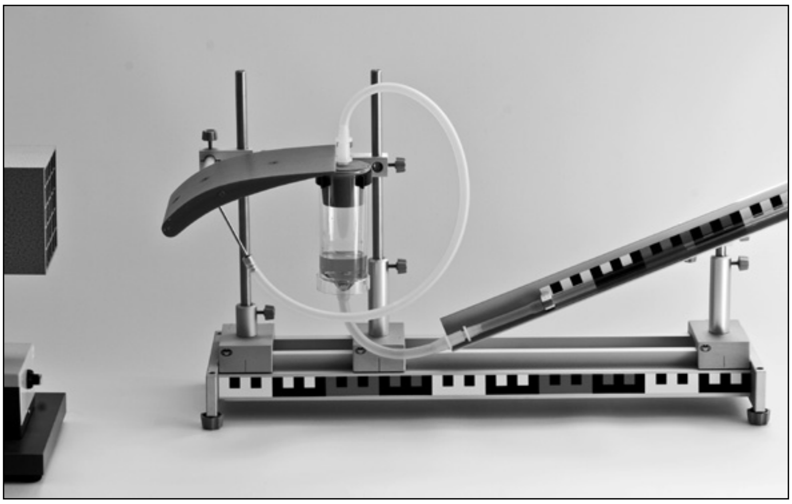
Experiment evaluation

The paper strip is pressed against the underside of the airfoil while the upper side is lifted into the air.
There is a pressure zone at the bottom of the air foil while a suction zone exists along the upper side of the air foil.



12 Pressure distribution along the surface of the airfoil





Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Rider, 75 mm (2x)	4
Stand rod, 250 mm (2x)	5
Bosshead (3x)	6
Stand rod, 100 mm	12
Airfoil model with support rod, probe and hose	25a–d
Dye	26
Measuring cylinder	27
Pressure gauge setup	30
Clip, 45 mm	35

Additionally required:
Blower (Order no. *29010*)

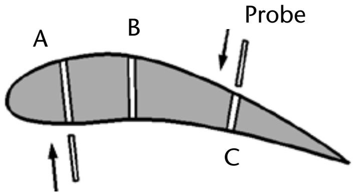
Experiment procedure

The rail is connected to the feet. The setup for the pressure gauge is carried out as described in experiment 8. On the left-hand side of the rail the rider 30 mm is mounted and a stand rod 250 mm inserted into it.
The support rod is screwed into the side of the airfoil model. Using a bosshead the air foil is attached to the stand rod as shown in the figure. By sliding the bosshead the airfoil is adjusted so that when placed horizontally its face is located in the centre of the air blower's output grid. The distance to the air blower should amount to approx. 15 cm.
The hose with probe is connected to the compensation reservoir. The air blower is set to maximum speed. The initial level of the fluid column in the manometer tube is noted. The probe is inserted in sequence into the appropriate drill holes for the various setting angles (see table) and the respective fluid column deviations are measured in mm and recorded.

Make sure here that when inserting into the underside the measurements are performed on the pressure ratios existing on the upperside and vice-versa, when the sensor is inserted into the upperside the measurement is for the pressure ratios on the underside.

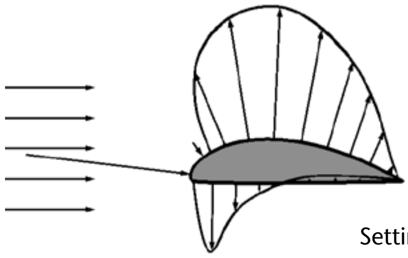
Measurement Point		Setting angle		
Upperside	A	–15°	0°	+15°
	B			
	C			
Underside	A			
	B			
	C			

+ = Pressure – = Suction Changing with respect to initial level

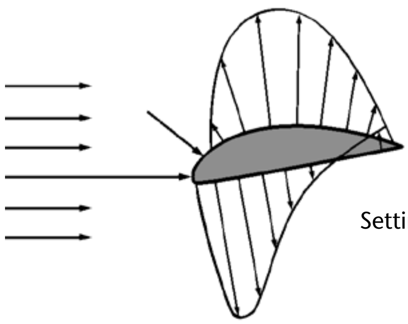


Experiment evaluation

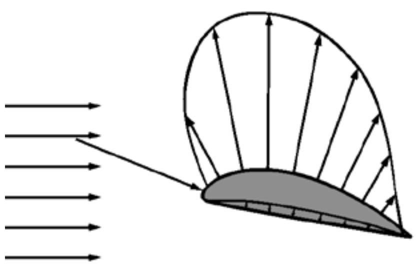
The total aerodynamic lift of the foil consists of the suction forces exerted on the upperside (negative pressure) and the pressure forces exerted on the underside (excess pressure).
These forces are extremely dependent on the setting angle of the airfoil. As the setting angle increases in the positive range the suction on the upperside rises and occurs primarily on the forward section of the airfoil. In the case of negative setting angles the pressure ratios on the underside also develop into a suction effect.



Setting angle: 0°

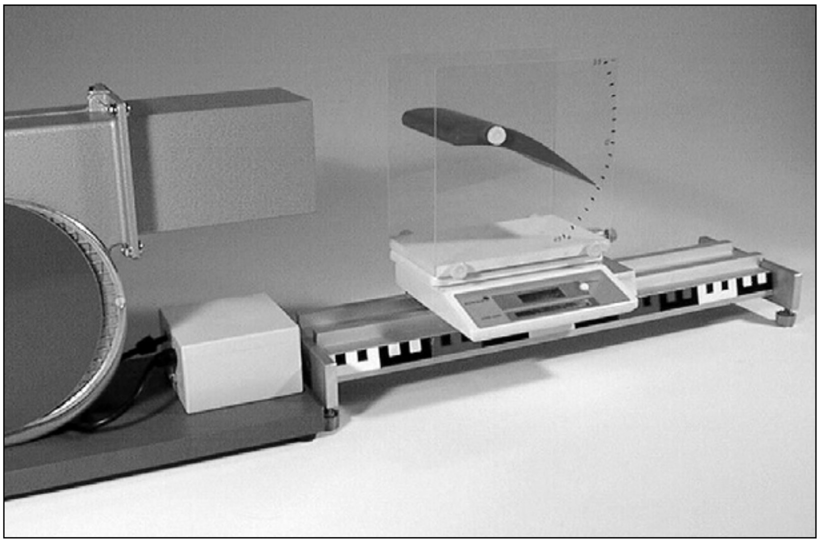


Setting angle: –15°



Setting angle: +15°

13 Measuring the dynamic lift



Material

Rail	1
Pair of feet for rails	2
Balance with solar cell	10
Lifting power model	11a–d

Additionally required:
Blower (Order no. *29010*)

Experiment procedure

The rail is connected to the feet. The rail is positioned directly in front of the air blower. The balance with solar cell is placed in such a manner on the rail as seen in the figure so that its display is parallel to the rail. The side sections of the lift model are connected to the base plate. The airfoil is clamped between the sidewalls so that the setting angle can still be varied. The balance is switched on and the model is placed onto the balance only after the calibration process has been completed (display shows 000). The weight of the lift model G_1 is determined. By adjusting the screws on the rail feet the height of the lift model is set so that the front edge of the plate points to the middle of the air blower output grid in the horizontal position.
Subsequently the changes in weight G_2 are determined on the balance for the following setting angles a (air-speed 8 m/s - the air blower flap half opened):

α [°]	–30	–25	–20	–15	–10	0	+10	+15	+20	+25	+30
G_1 [g]											
G_2 [g]											
$\Delta G = G_2 – G_1$ [g]											

The same experiment procedure is repeated but at maximum air-speed:

α [°]	–30	–25	–20	–15	–10	0	+10	+15	+20	+25	+30
G_1 [g]											
G_2 [g]											
$\Delta G = G_2 – G_1$ [g]											

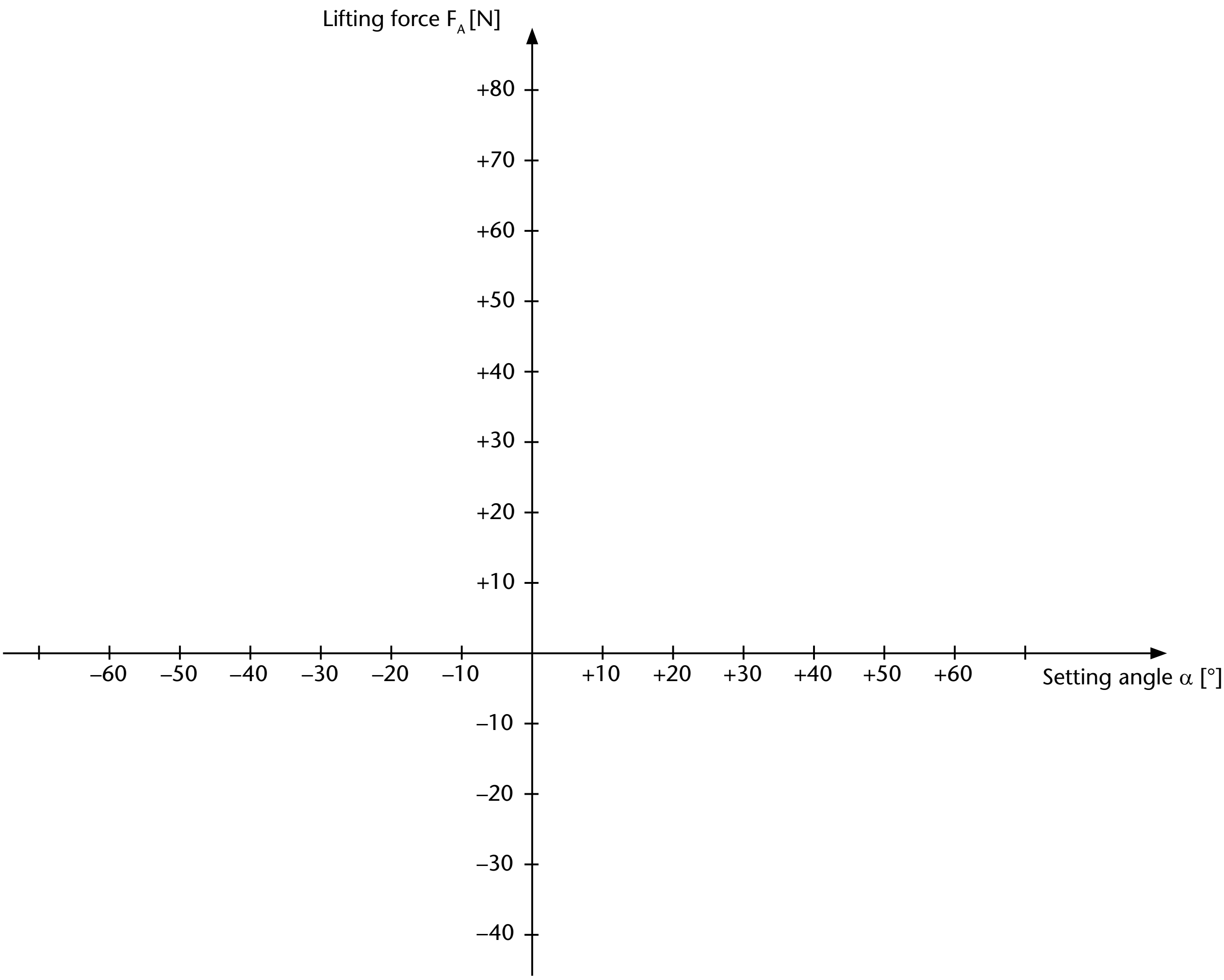
Both experiment sequences are repeated using the airfoil on the lift model.
The differential values determined are converted into Newtons.
Subsequently, the setting angle with the greatest lift is set to the airfoil on the model. The base of the model is loaded down with a weight (500 g) or similar.

The air blower is switched on and the weight difference is compared to the result obtained under the same conditions but without using the weight to load down the model.

Note: The solar module of the balance with solar cell has to be illuminated sufficiently during the experiment!

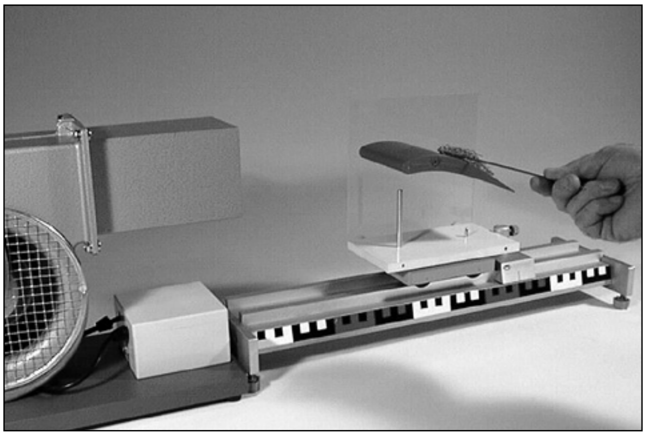
Experiment evaluation

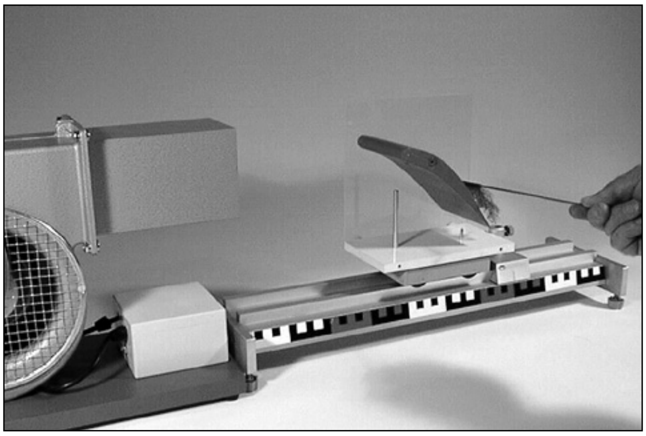
The air stream brings about an aerodynamic lift at the airfoil. The strength of the lifting force is dependent on the setting angle, the speed or velocity and the air resistance.
Based on the difference between the initial weight (G_1) and the weight (G_2) measured in the experiment, the effective lift force can be determined. Depending on the setting angle, the model becomes "lighter" or "heavier" under otherwise identical conditions.
With the same airfoil setting angle and the same air speed the lifting force is independent of the weight of the model.
The results obtained in the experiment with the airfoil should be transferred into a graph:



A maximum lifting force is produced at a certain setting angle. With negative setting angles the weight experiences an apparent increase – the model is "pressed" down on the balance.

14 Air-stream distribution around the airfoil





Material

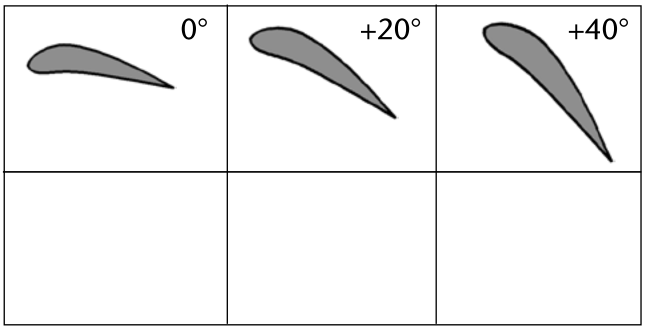
Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Carriage with front rod	9a, b
Lifting power model	11a–d

Additionally required: Blower (Order no. *29010*)

Experiment procedure

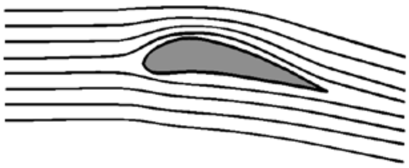
The rail is connected to the feet. The lifting model is mounted so that the airfoil is fastened to only one wall, the other side remains free. The model is mounted onto the carriage with the rod and fastened to the rail with a rider as shown in the figure. The distance to the air blower should be approx. 20 cm. Switch on a medium speed (approx. 8 m/s) at a setting angle of 0°.

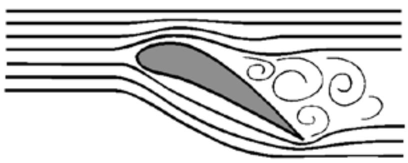
The comb of threads is held above the airfoil at the setting angles depicted and the flow pattern determined by observing how the threads move. This procedure is also used to find out the flow pattern at greater setting angles.



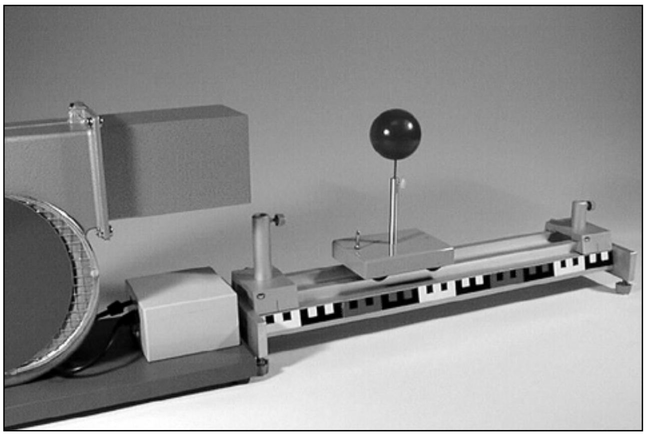
Experiment evaluation

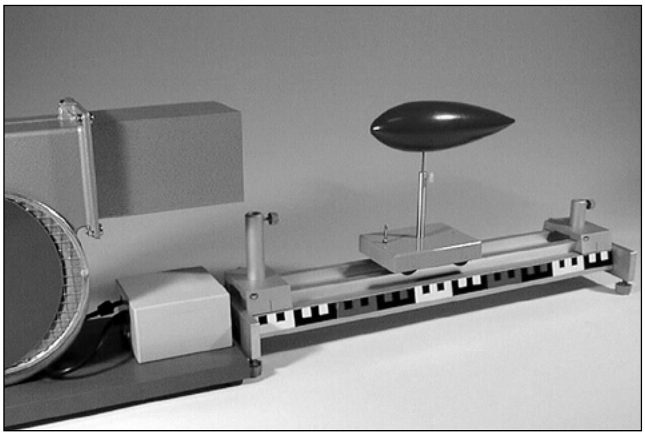
At small setting angles the threads conform to the flow lines and demonstrate a steady or laminar flow. At a large angle setting the air stream separates from the surface at the back of the airfoil, the threads demonstrate a whirling effect. The air stream becomes turbulent. In the experiment it is possible to determine the model's critical angel setting.





15 Comparing wind resistant objects





Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Rider, 75 mm	4
Carriage with centre rod	9a, c
Set of wind resistant objects	13

Additionally required:
Blower (Order no. *29010*)

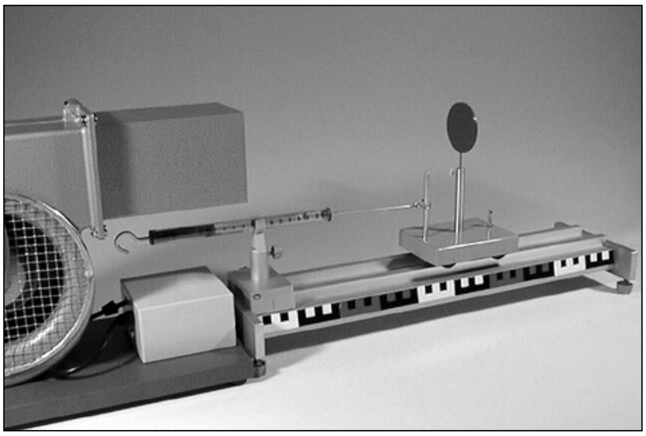
Experiment procedure

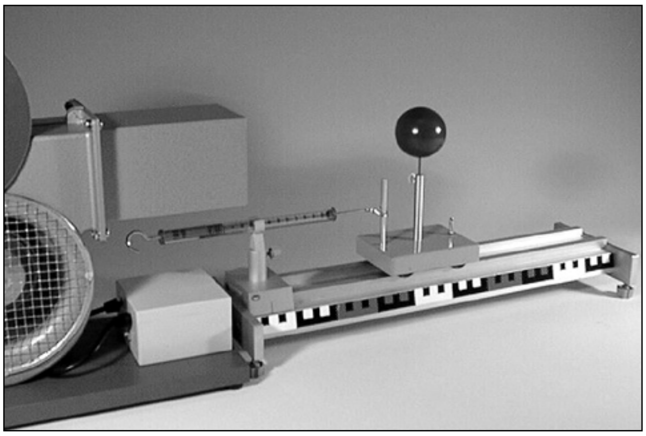
The rail is connected to the feet. The riders are mounted at the two ends of the rail. The support rod with the clamping screws is fastened to the middle of the carriage. The carriage is placed on the rail at the far left stop.
First take the small plate from the set of wind resistant objects and fasten it onto the support rod so that it is located in the centre of the air stream. The rail is positioned directly in front of the air blower. The carriage is held in the end stop position and the blower set to maximum air speed. The carriage is released and its response observed.
The experiment procedure is repeated at the same air speed and the same initial carriage position using the ball and the streamlined wind resistant object.

Experiment evaluation

The streaming air exerts a force on the wind resistant object causing it to move. Under identical conditions the force effect is severely dependent on the shape of the object. Although all three objects have the same diameter, the streamlined object shows hardly any effect and barely moves.
Air resistance can be reduced considerably by employing the appropriate object form.

16 Measuring the air-stream resistance





Material

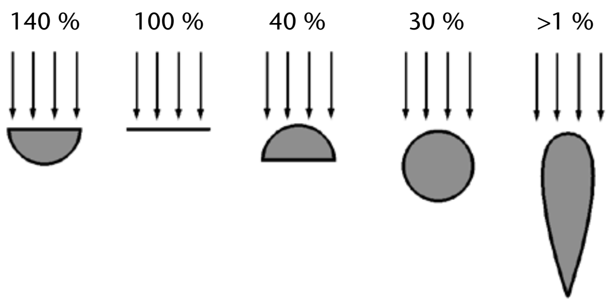
Rail	1	Carriage with rods	9a, b, c
Pair of feet for rails	2	Set wind resistant objects	13
Rider, 30 mm	3		
Kraftmesser	7	*Additionally required:*	
Clip, 15 mm	8	Blower (Order no. *29010*)	

Experiment procedure

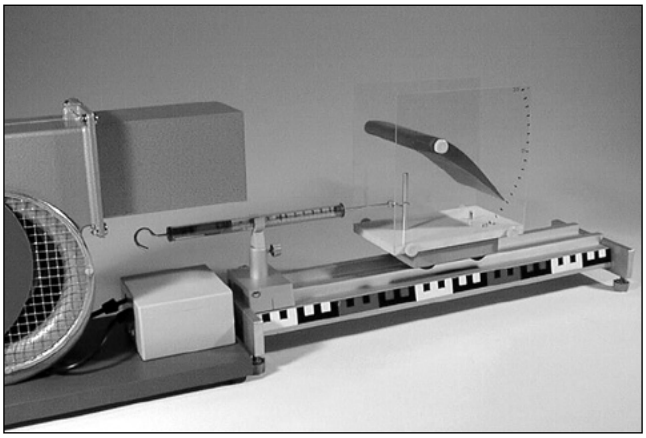
The rail is connected to the feet. The rider is arranged on the left side. The clip with rod is clamped into the rider and the dynamometer is clamped in as shown in the figure so that it is placed parallel to the rail. By turning the upper hook of the dynamometer this is set to zero in the horizontal position.
The rods are mounted to the carriage and the small plate is the first wind resistant object inserted into the centre rod. The carriage is placed onto the rail and the dynamometer is suspended from the forward rod. The initial position of the carriage should be set so that its forward edge is approximately 15 cm from the rail end (adjust the dynamometer correspondingly using the clip).
Use your hand to hold the carriage and then carry out another zero-point correction of the dynamometer by sliding the clip.
Air speed is set to approx. 11 m/s on the air blower (flap is opened to two-thirds). The carriage is released and the force effect of the air-flow on the wind resistant object is determined on the dynamometer.
The experiment procedure is repeated under the same initial conditions (air blower distance, air speed) but using the ball and the streamlined object. At the same time it is possible to briefly increase the air speed to maximum.

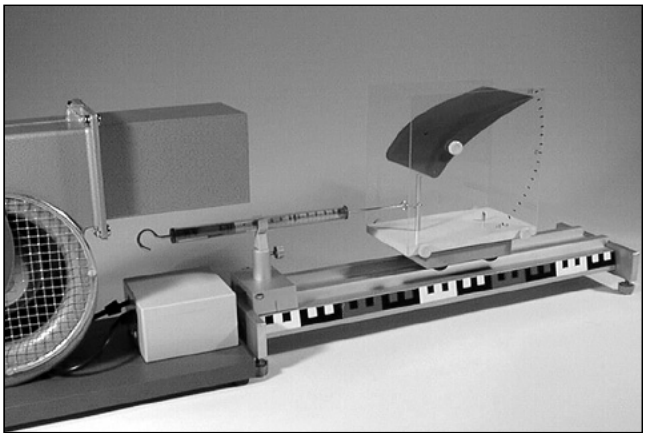
Experiment evaluation

The wind resistance of an object is severely dependent on its shape.
In the case of the ball, it is approx. 30 % with respect to the plate and less than 1 % for the streamlined object.



17 Measuring the air flow resistance at the air foil





Material

Rail	1	Carriage with front rod	9a, b
Pair of feet for rails	2	Lifting power modell	11a–d
Rider, 30 mm	3		
Dynamometer	7		
Clip, 15 mm	8		

Additionally required:
Blower (Order no. *29010*)

Experiment procedure

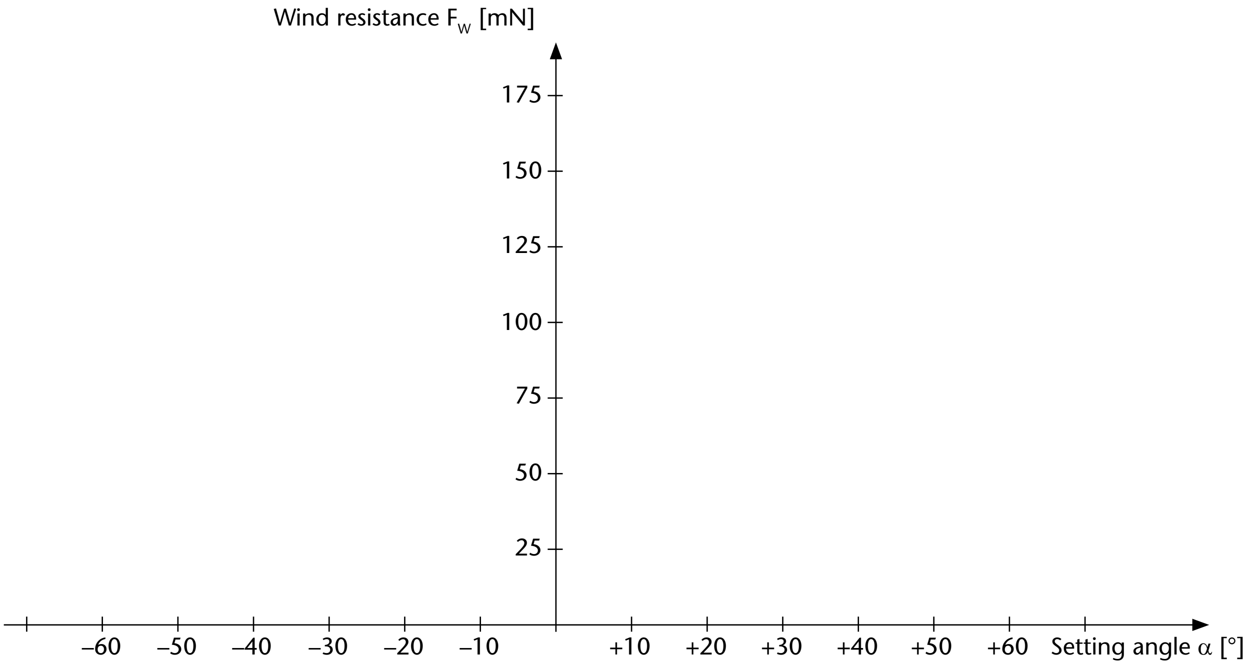
The rail is connected to the feet. The rider with the clip and the dynamometer clamped inside is arranged on the left side. The rail is placed directly in front of the air blower. The lifting model is assembled and tightened using the screws. The airfoil is fastened between the sidewalls so that it can rotate. The carriage is equipped with the front rod and the model is mounted on it. By turning the upper hook of the dynamometer this is set to zero in the horizontal position. The carriage is placed on the rail and the dynamometer is suspended on the rod of the carriage.
The dynamometer is screwed onto the clip so that there is a distance of 14 cm between the rod on the carriage and the rail edge on the left-hand side.
The angle is set initially to 0°.
The air flow speed is initially set to approx. 8 m/s (flap half opened) and subsequently to approx. 11 m/s (flap opened 2/3).
The force F_w [N] is determined for the following angle settings and entered into a table:

Air Speed \ Angle	–30°	–25°	–20°	–15°	–10°	–5°	0°	+5°	+10°	+15°	+20°	+25°	+30°
8 m/s													
11 m/s													

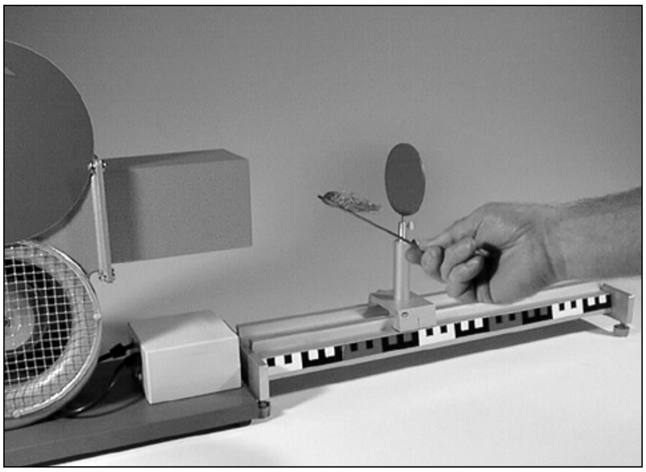
Note: When changing the angle setting switch off the air blower or close the flap.

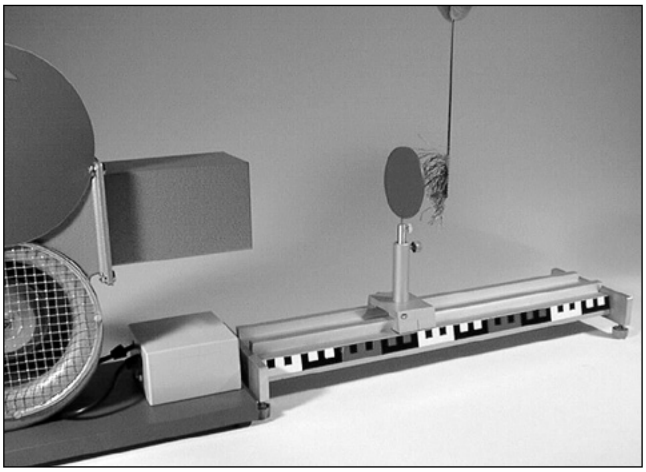
Experiment evaluation

The wind resistance of the airfoil is dependent on the set angle. An increase in the air speed also brings about an increase in the wind resistance.
The dependency of the wind resistance on the angle setting can be depicted in a graph, in which the values determined in the experiment are entered:



18 Air-stream processes at wind resistant bodies





Material

Rail	1
Pair of feet for rails	2
Rider, 75 mm	4
Rod for mounting wind resistant objects (carriage)	9c
Set of wind resistant objects	13

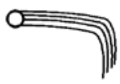
Additionally required: Blower (Order no. *29010*)

Experiment procedure

The rail is connected to the feet. The rider is mounted as shown in the figure. The distance from the edge of the rail should be approx. 20 cm. The rod is fastened into the rider. The large plate, the ball and then the streamlined object are inserted one after the other and fastened tightly.
By adjusting the support rod in the rider they are positioned into the centre of the air stream. At medium air speed (flap half opened on the air blower) the thread comb is held in the air stream in front of (position A), above (position B) and behind (position C) the respective object. A sketch is made of how the threads respond (thread pattern).

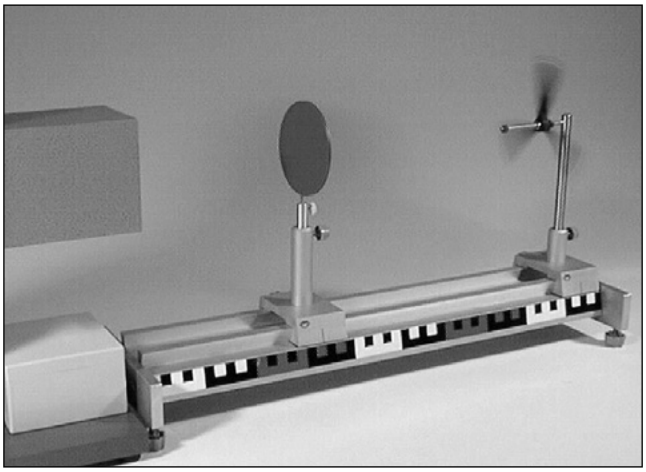
Experiment evaluation

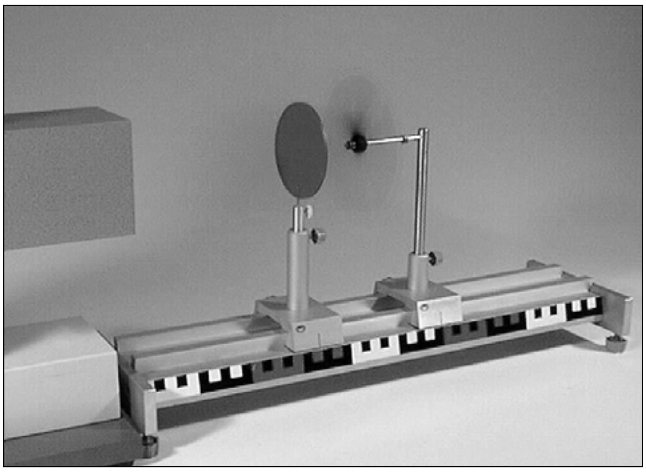
When the experiment is performed, the following air stream patterns are obtained:

Object	A	B	C
Plate			
Ball			
Streamlined object			

A laminar air flow without turbulence only occurs with the streamlined object.

19 Turbulence formation





Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Rider, 75 mm	4
Rod for mounting wind resistant objects (carriage)	9c
Set of wind resistant objects	13
Airscrew	28
Support rod for airscrew	29
Silicone oil	33

Additionally required: Blower (Order no. *29010*)

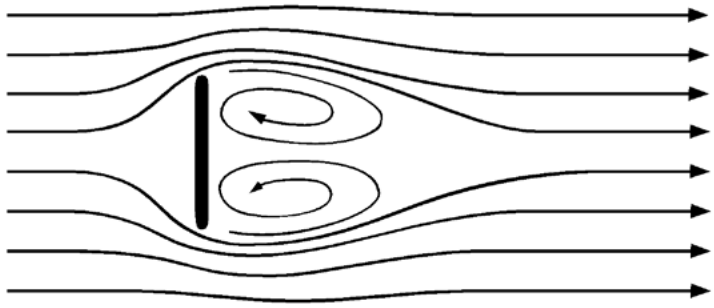
Experiment procedure

The rail is connected to the feet. The riders are arranged as shown in the figure. Using the support rod of the carriage the large plate from the set of wind resistant objects is fastened onto the higher rider. The rider is tightened in this position.
In the rider on the right-hand side the support for the airscrew is mounted. The airscrew is inserted and locked on using the clamp. It should be slidable over the entire length of the support rod's shaft. The rider with the airscrew should also slide smoothly over the rail. The rail is set directly in front of the air blower.
At first, the rider with the airscrew is slid to the far right-hand side and the air blower is switched on with an air speed of approx. 8 m/s (flap is half opened). When the airscrew begins rotating, the rider is very slowly moved towards the plate. At the same time the airscrew is observed. It might prove necessary to increase the air speed so that the airscrew is able to overcome the frictional resistance of the shaft.

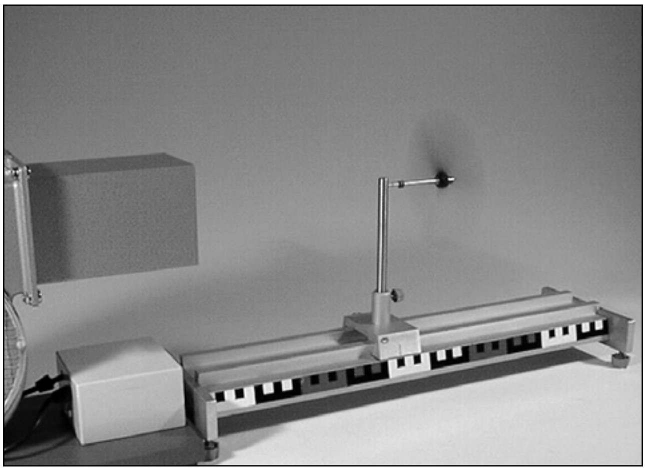
Experiment evaluation

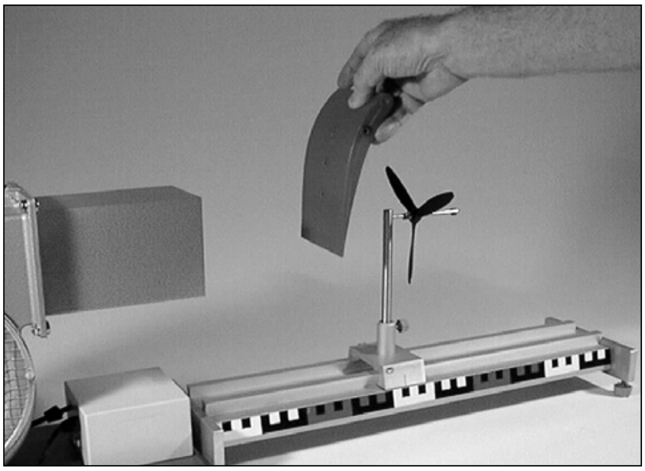
The airscrew is caused to rotate by the air stream and is displaced to the far right. If you move the rider with the airscrew closer to the plate, at a certain distance the rotation direction is reversed. The airscrew now begins moving on the shaft towards the plate.
This response is brought about by the reverse flow caused by turbulence behind the plate. If you move the rider with the airscrew away from the plate again, it comes to a standstill and then begins turning in the same rotation direction as it did initially. It is then located outside of the turbulent zone.

Note: The slidability of the airscrew should be enhanced using a drop of silicone oil.



20 Principle of the airscrew





Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Plate or airfoil of the lifting model	11a, d

Airscrew	28
Support rod for airscrew	29
Silicone oil	33

Additionally required: Blower (Order no. *29010*)

Experiment procedure

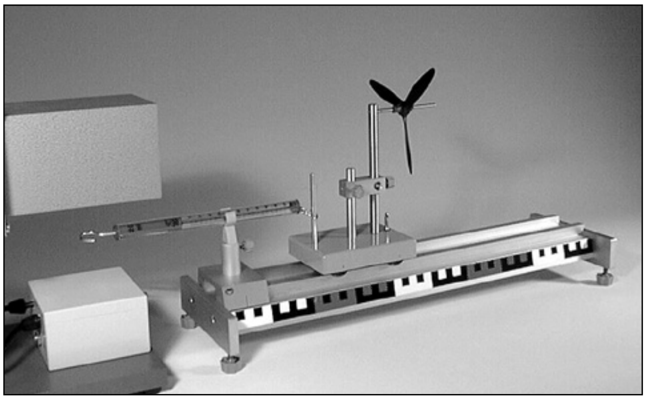
The rail is connected to the feet. The rider is mounted onto the rail and the support rod for the airscrew is attached. The airscrew is inserted onto the shaft and fastened with the clamp so that it can slide over the entire length of the shaft. The rail is positioned directly in front of the air blower. The air speed is increased until the airscrew begins rotating rapidly and is displaced to the right end of the rail.
The plate or airfoil of the lifting model is held between the air blower and the airscrew so that the air stream is interrupted abruptly. The response of the airscrew is observed.

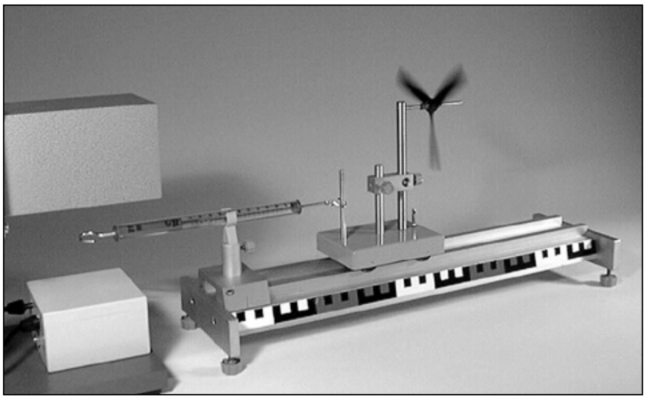
Note: The slidability of the airscrew should be enhanced using a drop of silicone oil.

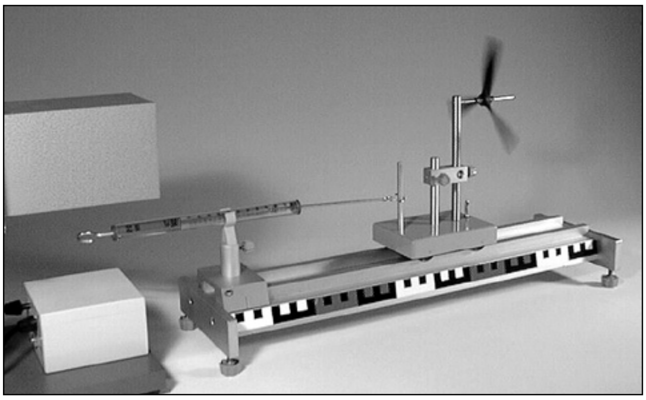
Experiment evaluation

The airscrew begins to rotate and is displaced along the shaft because of the wind resistance. If the air stream is interrupted the airscrew rapidly moves in the opposite direction.
The airscrew initially absorbs energy in the air stream – the kinetic energy of the air stream is converted into rotating energy of the airscrew. When the air stream is interrupted the rotation energy is converted back into kinetic energy which takes the form of a suction force.

21 Propulsive power of an airscrew







Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Bosshead	6
Dynamometer	7
Clip, 15 mm	8
Carriage with rods	9a, b, c
Airscrew	28
Support rod for airscrew	29
Silicone oil	33

Additionally required:
Blower (Order no. *29010*)

Experiment procedure

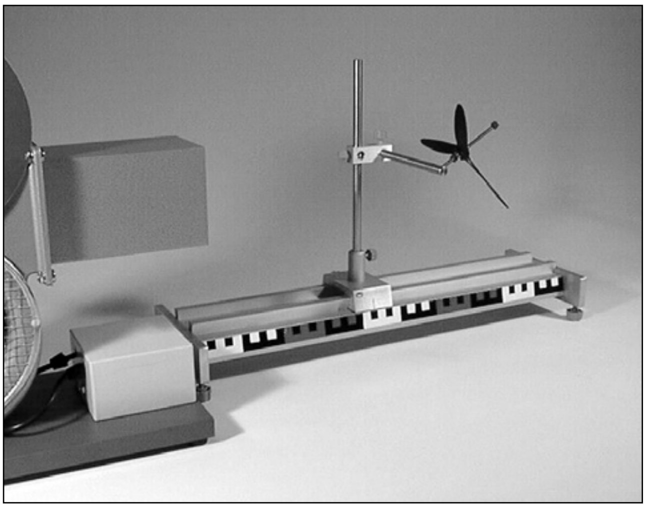
The rail is connected to the feet. The rider is mounted onto the left end of the rail. The dynamometer is attached to the rod using the clip as depicted in the figure. The carriage is equipped with the two rods. The side fastening screws on the support rod for the wind resistant objects are temporarily removed. The support rod for the airscrew is mounted on the carriage as shown in the figure using the bosshead. The airscrew is inserted onto the shaft and fastened using the clamp so that it can rotate smoothly without displacing. The carriage is set onto the rail and the front rod is suspended in the hook of the dynamometer. The dynamometer is to be previously calibrated so that it is set to zero in the horizontal position.
The rail is placed at a distance of approx. 8 cm from the air blower. The air speed is slowly increased. At the same time observe the airscrew and the indicator on the dynamometer.

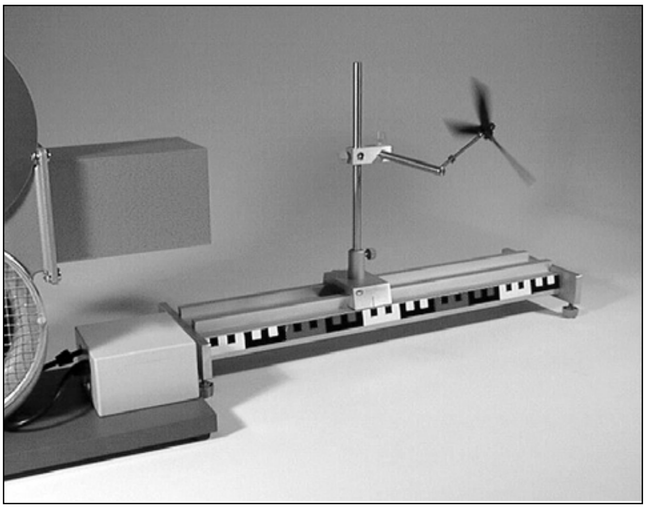
Note: The slidability of the airscrew should be enhanced using a drop of silicone oil.

Experiment evaluation

The kinetic energy from the streaming air flow causes the airscrew to rotate. The rotation energy of the airscrew brings about propulsive force which is a function of the rotation speed and which causes the carriage to move. The result is not a linear relationship because the wind resistance of the airscrew is considerably higher when rotating than at rest.

22 Principle of the gyroplane





Material

Rail	1	Airscrew	28
Pair of feet for rails	2	Support rod for airscrew	29
Rider, 30 mm	3	Silicone oil	33
Stand rod, 250 mm	5		
Bosshead	6		

Additionally required: Blower (Order no. 29010)

Experiment procedure

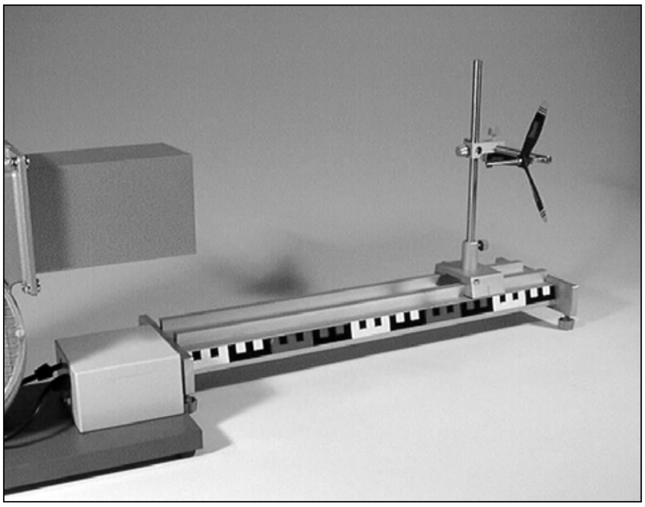
The rail is connected to the feet. The rider is mounted onto the rail as shown in the figure and equipped with the standing rod 250 mm. Using the bosshead the supporting rod for the airscrew is arranged at a right angle to the rail so that the shaft has an angular setting of approx. 30°. The airscrew is fastened onto the shaft using the clamp so that it can slide over its entire length. The rail is offset to the side but in front of the air blower so that the shaft holding the airscrew is positioned in the middle of the air stream (see the figure).
The air speed is slowly increased and the airscrew simultaneously observed.

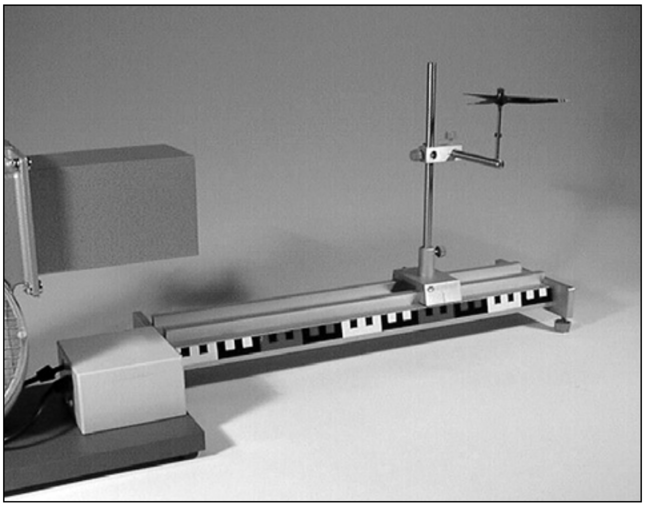
Note: The slidability of the airscrew should be enhanced using a drop of silicone oil.

Experiment evaluation

The airscrew begins to rotate and is lifted upwards in the air stream. A rotating airscrew located in a streaming air flow effects a lifting force. This principle is referred to as a gyroplane.
In the case of a gyroplane, a large airscrew, whose shaft is tilted against the flight direction, takes on the function of a wing. When the airplane moves forward, the gyroplane is driven generating an aerodynamic lifting force.

23 How the helicopter propeller works





Material

Rail	1
Pair of feet for rails	2
Rider, 30 mm	3
Stand rod, 250 mm	5
Bosshead	6
Airscrew	28
Support rod for airscrew	29
Silicone oil	33

Additionally required: Blower (Order no. 29010)

Experiment procedure

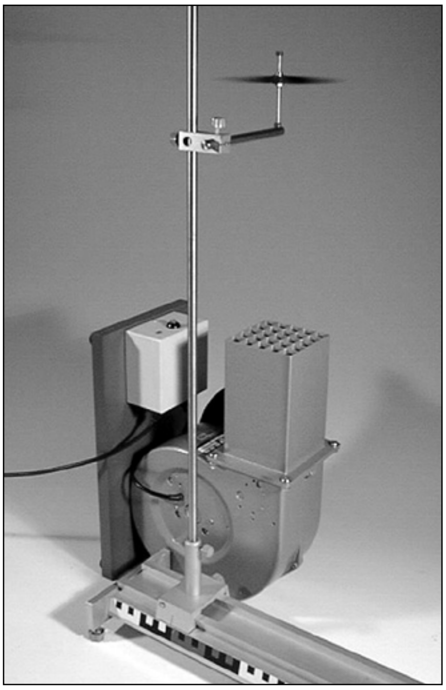
The rail is connected to the feet. The rider is mounted onto the rail as shown in the figure and equipped with the standing rod 250 mm. Using the bosshead, the supporting rod for the airscrew is arranged at a right angle to the rail so that the shaft is pointing into the middle of the air blower. The airscrew is inserted onto the shaft and fastened there using the clamp so that it can slide over its entire length. Make sure that the unlabeled side of the airscrew is pointing in the direction of the air stream.
The air blower is operated at medium air speed. It is set up so that the shaft of the airscrew is located in the centre of the air stream (can be adjusted by moving the stand rod!).
Once the airscrew has reached a high rotation speed, the clamp of the support rod on the bosshead is loosened, and the rod is quickly swiveled 90° upwards by hand so that the shaft of the airscrew is now positioned vertically. This experiment procedure is repeated several times.

Note: The slidability of the airscrew should be enhanced using a drop of silicone oil.

Experiment evaluation

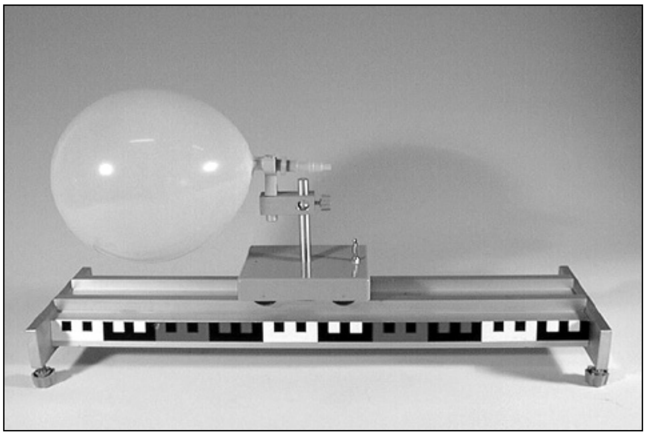
The energy generated by the air-flow causes the airscrew to rotate. When the supporting rod is swiveled the airscrew quickly lifts upwards.
As a helicopter propeller the stored rotation energy effects a propulsive force upwards. When the copter begins falling the helicopter propeller begins rotating through autorotation caused by the air streaming up from below, thus producing a lifting force even without motor generation.

In an actual helicopter the adjustment of the rotor blades achieves both a lifting force as well as a forward propulsion.
An interesting supplementary experiment on the response of the airscrew in an air stream can be performed in accordance with the following figure:



However, to perform this you need an additional stand rod of 50 cm length, which is not contained in the experiment box. However, you can also hold the support with the airscrew in the air stream with your hand. Using the bosshead the support is adjusted on the stand rod so that the airscrew is located in the middle of the air stream approx. 20 cm above the vertically positioned air blower. The air speed is increased and the response of the airscrew observed.
By varying the height of the airscrew at medium air speed a location is found at which the airscrew assumes a hovering state in the middle of the axis.
The same result can also be achieved by varying the air speed. At this position the wind resistance of the rotating airscrew is great enough to prevent any further ascent at the same air speed.

24 Principle of repulsion



Material

Rail	1
Pair of feet for rails	2
Bosshead	6
Clip, 15 mm	8
Carriage with centre rod	9a, c
Balloon valve	19
Ballon	20

Experiment procedure

The rail is connected to the feet. The support rod for the wind resistant object is attached to the carriage. The side fastening screw is temporarily removed. With the aid of the bosshead the clip is attached to the rod as shown in the figure.
The air balloon is connected to the balloon valve and fully blown up. By pinching the diaphragm together the valve is closed. The valve with the blown-up balloon is clamped shut in the clip. The carriage is placed on the rail and rolled to the left. The valve is opened and the carriage released.

Experiment evaluation

When the balloon contracts, the energy stored in the balloon via pressure creates a force which is converted into kinetic energy. The carriage is put into motion by the repulsion generated. But the amount of energy only suffices for a small impulse as not only the weight but also the friction of the carriage has to be overcome.

25 Rocket model

Material

Rocket model	24

Also required:
PET-bottle

Experiment procedure

The rocket is assembled as shown on page 7. The valve of the loose hose end is attached to an cycle pump und air is pumped into the rocket until the air pressure inside the rocket disconnects the coupling between the hose and adaptor automatically and the rocket takes off.

Experiment evaluation

The air is pressurized and severely compressed when pumped into the empty space above the water inside the PET-bottle. After the hose connexion is pressed out the air expands and propels the water out of the rocket opening at a high velocity. The weight of the rocket is overcome by the force of the repulsion and is launched.

Experiment description/Manual
Demonstration kit 'Flight and flying'
Order number 29008 6

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