ANIPROP
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GbR

Large Wind Tunnel
ANIPROP GWK 3

Setup, operating modes, control
Instructions for using the wind tunnel balance
Accuracy of the measurements

Version 4.4 / 2018 en

Preliminary version still subject to language modifications

The layout of the GWK3 may be subject to minor modifications.

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Content

Note. Clicking on the page number accesses the page.

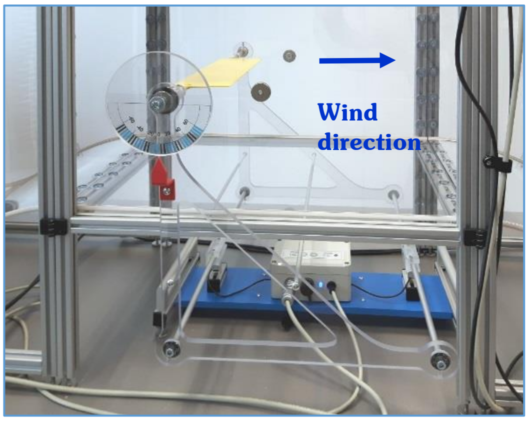
1. Description of the Wind Tunnel

1. General properties

(1) Operating principle and properties

The tunnel is technically a so-called Eiffel Tunnel. The air is taken in from the environment via the inlet and blown back into the environment after the working section. Therefore, the uniformity of the incoming air also influences the quality of the flow in the working section. At full speed of 20 m/s, i.e. 72 km/h, and thus in the range of wind force 8, almost 2.5 m^3/s of air are transported through the laboratory. The tunnel should therefore be set up on a fixed, freestanding table whose distance from the nearest walls is at least 1 m to all sides.

The tunnel is a new development of ANIPROP GbR in its dimensioning. A special feature is the short contraction segment of 0.5 m in length, which narrows or widens the airflow to ¼ of its cross-section. Thus, despite the measuring cross section of 0.35 mx 0.35 m, the tunnel still operates in a normal laboratory room. A laboratory area of 4 m x 3 m is the lower limit for installation.



Design as a genuine Eiffel tunnel in suction mode (left), balance with force sensors

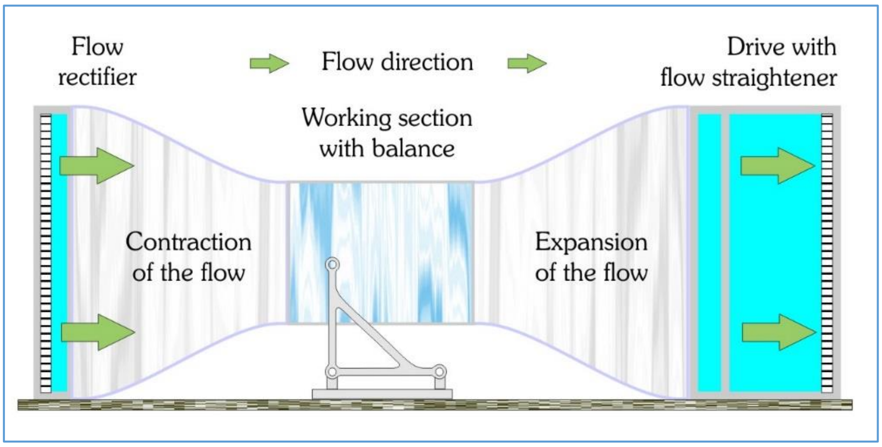
The tunnel operates in two operating modes: suction mode S and pressure mode D. In the picture above, the flow is sucked in by the drive and comes from the left. The wind tunnel balance with an airfoil (a flat plate) as the measuring object in the version with force sensors is shown enlarged on the right. In the pressure mode, the drive forces the flow through the contraction segment and narrows the cross-section of the drive to 1/4 of the entry surface. The balance can stand free in front of the flow outlet.

(2) Modules and operating modes

The wind tunnel consists of five self-supporting modules with the same cross section.

- **Cross-section of the modules.** The square cross-section of all large segments is 0.774 m x 0.774 m plus 15 mm height through the feet under all segments.
- **External dimensions** Width x Height x Length 0.8 m x 0.8 m x 2.0 m.
- **(1) Drive unit with flow straightener** Length 0.4 m.
- **(2) and (4) Contraction segments** Length je 0.5 m.
- **(3) Working section** Length 0.5 m.
- **(5) Flow straightener** Length 0.09 m.

Between the segments, silicone seals are inserted in the T-slots of the frame. In suction mode, all five modules adjoin in the order 1 to 5, which results in a total length of about 2.0 m.

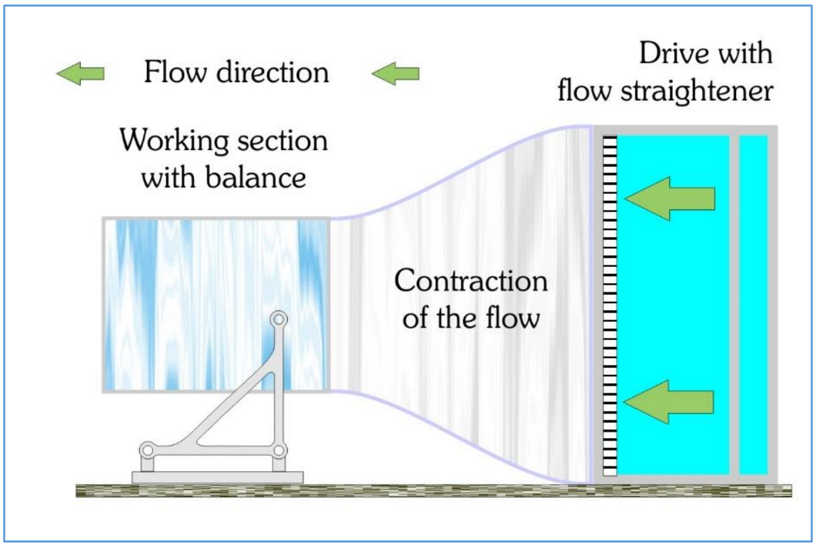


Functional schematic of the tunnel in suction mode S

In principle, the symmetry of the structure allows it to use all five modules in pressure mode. But the purpose of the suction mode design is precisely to eliminate the turbulence from the four drive motors from the flow.

- Access to the measuring object takes place in the suction mode through an opening of 250 mm at the top side of the working section.

The usual structure in pressure mode shows in the following picture.



Functional schematic of the tunnel in pressure mode D

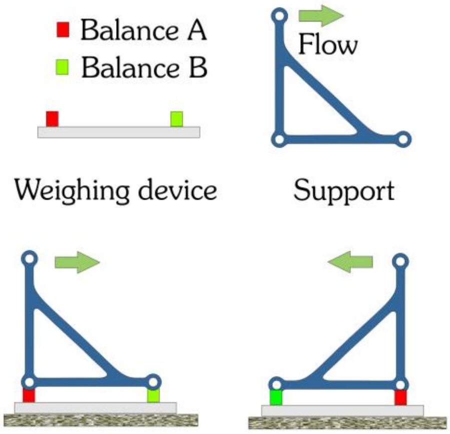
The pressure mode allows unrestricted access to measuring objects and in many cases is sufficient for determining the air forces acting on the measuring object.

- The suction mode, especially at low speeds, results in a well layered, laminar flow, which visualizes streamlines pretty well.
- Turning the drive unit changes the layout from the suction mode to the pressure mode and vice versa.

In the pressure mode, the contraction segment, including the flow straightener, is not used.

(3) Wind tunnel balance

The supplied wind tunnel balance determines the force of the flow on the measuring object. From its measuring principle, it measures the force component in flow direction, the flow drag, and the force component perpendicular to the flow, the (dynamic) lift. The wind tunnel balance is used in both operating modes suction mode and pressure mode. It should be noted that the measuring device, referred to for short as the wind tunnel balance, consists of two parts, which can be separated from one another. These parts are the actual weighing device, which consists of two laboratory balances or two force sensors, and the support, which carries the measuring object. The two balances or force sensors are named A and B.



Whole weighing device reversed

Changing the operating mode

In principle, the measurements with laboratory balances or force sensors do not differ. The support for the measuring object remains the same. The two weighing devices differ significantly in the number of possible measurements per second (scan rate). The laboratory balances allow a maximum of two to three measurements per second, while the force sensors have a high temporal resolution of up to 500 Hz. These are therefore suitable for dynamic measurements.

It is recommended to turn the entire wind tunnel balance when changing the operating mode, as shown in the picture above. Then the balance A or the dynamometer A always remains below the object to be measured, which is attached to the vertically upstanding arm.

(4) Control and measuring equipment

Display of the windsensor
(„ns“ stands for „m/s“)

From 2017 on, all versions of the tunnel are equipped with a control unit. The wind speed is set on a control panel with digital input via push buttons and then held by a controller (PID controller). The measured input value for the controller is received from a hot wire anemometer suitably positioned in the airflow. The adjoining image shows the display of the measuring device, in which at the same time the temperature of the airflow is determined. The following quantities are available on the control unit at an output socket:

- the control voltage for the motors (0 … 10 V)
- the wind speed, pictured on 0 … 10 V
- the temperature, imaged on 0 … 10 V

As standard, the weighing device consists of two laboratory balances with a measuring range of 1 kg and a display field. The force sensors have a measuring range of 20 N. Data can be recorded from both weighing devices. For the version with force sensors, the display of the data is possible only on the PC.

2. Technical layout of the wind tunnel

(1) Drive and control

The drive is equipped with four FN030 motors each with 0.42 kW power within the FE2owlet ECblue series from Ziehl-Abegg. The series is very quiet and therefore well suited for operation in a laboratory with further workplaces. A description with the technical data can be found on the attached CD (see attachment). The drive is controlled via the UNIcon control panel from Ziehl-Abegg. In addition to controlling the drive, the unit allows numerous other operations. With the digital input of the desired wind speed via keys, individual operating points can precisely be reproduced.

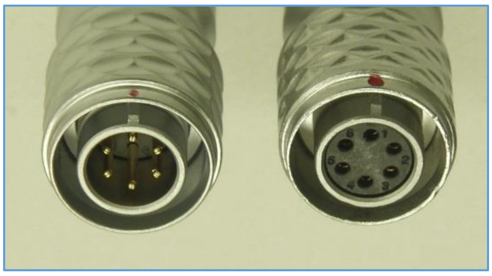
Drive motors of the GWK3

Connection of the controller of the GWK3 in the version for laboratory balances, until 2016 still without further sockets for sensor elements (connection power 1.68 kW).

(2) Electrical connection

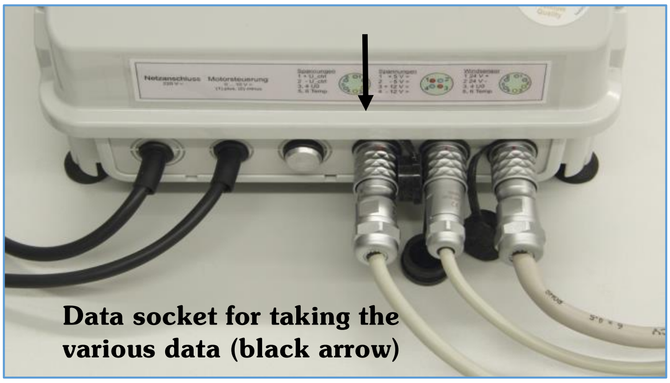
The electrical connection to the grid is seen on the left side of the tunnel. The supplied cable with cold plug is connected to 220 V ~. The built-in power switch is additionally equipped with a 10 A miniature fuse. Next to the connection socket for 220 V ~ are the connections for the control panel. The two cables of the control panel serve for its power supply and the forwarding of the control voltage to the motors. The plug for the control voltage has a red dot, which must match the associated socket. The plug is pressed into the socket until the holding ring audibly locks ("push-pull"). The connection is released by lifting the ring and pulling out the plug. Included is another plug, which can be connected to the socket for access to the control voltage and other values. For measurements with a data acquisition system, the control voltage can be obtained for recording.

The data socket on the control panel has six poles, the meaning of which is listed below.



Plugs and sockets are clearly marked by consecutive numbers next to each contact. On closer inspection you can see that pin 1 is below the red dot. When you look at the socket, the count continues in the clockwise direction, the plug left accordingly counter-clockwise.

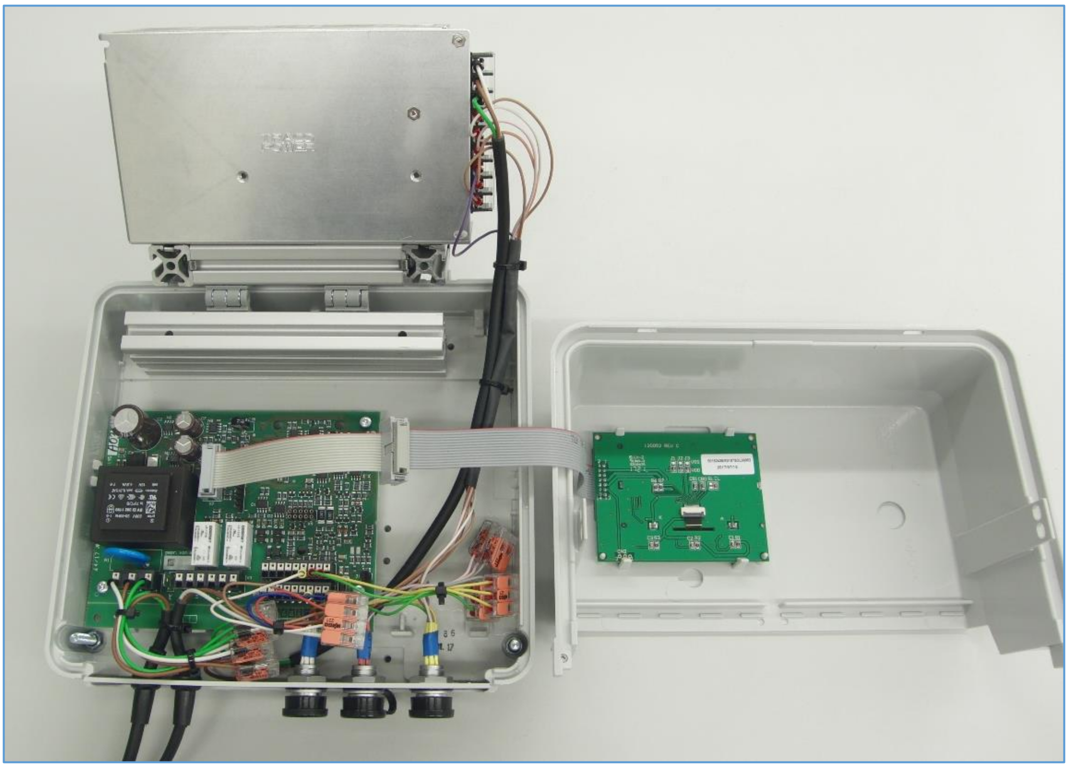
An additional power supply is built into the control panel to supply the wind sensor and the force sensors, which can be opened.



Data socket for taking the various data (black arrow)

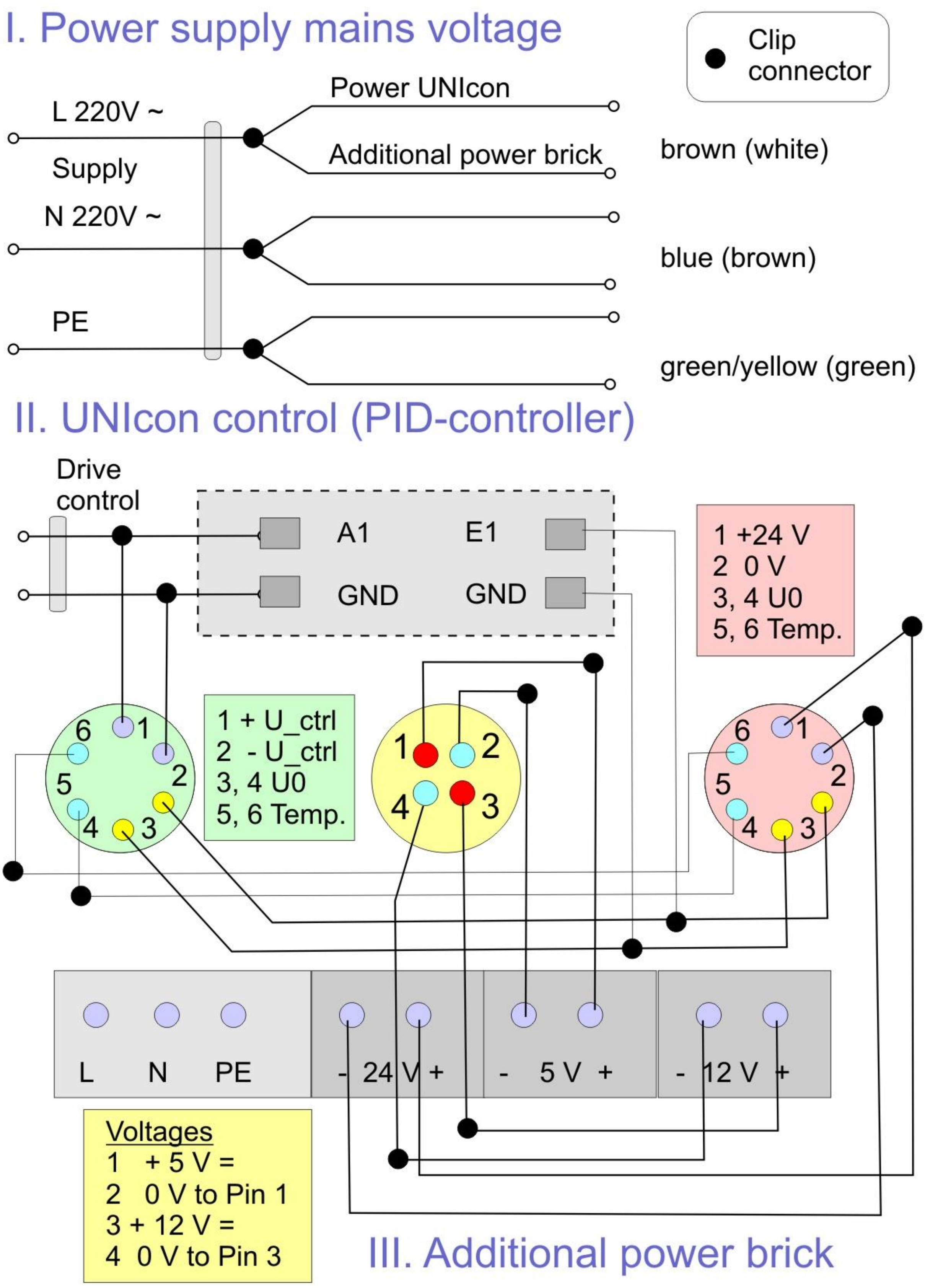
Connections on the control unit (control panel) are from the right wind sensor, power supply of the force sensors and the forwarding of the data control voltage and wind sensor (from the right).

Pin	Data socket on the control panel	
1	red	motor control 0 bis 10 V
2	blue	motor GND
3	yellow	signal wind sensor
4	green	wind sensor GND
5	pink	signal temperature sensor
6	grey	temperature sensor GND

[1]

The inside of the control panel UNIcon with the connections for the sensors.

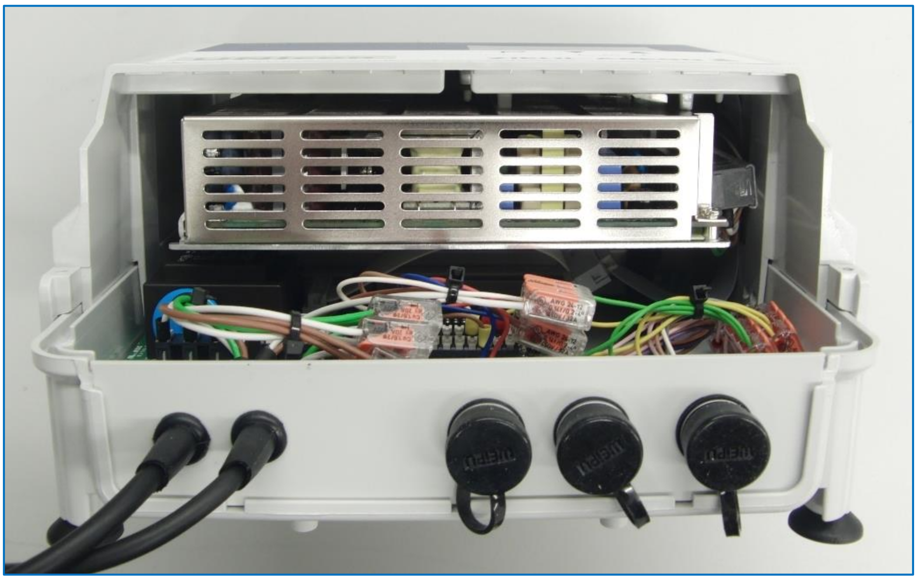
[1] Push-Pull circular connector SF12 from WeiPu. http://www.weipuconnector.com/



Circuit diagram of the control panel UNIcon with additional power supply

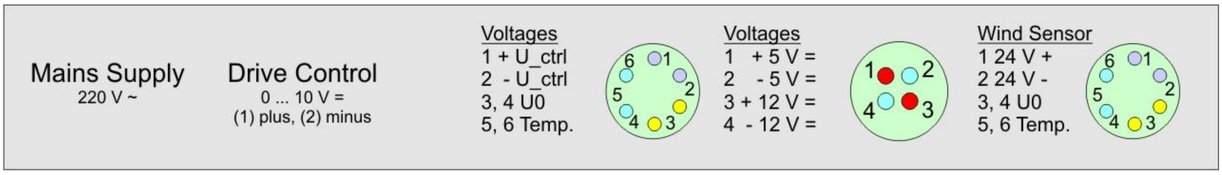
The picture on the previous page shows the inside of the control panel. Access is achieved by loosening the two screws on the left and right of the front cap (not in the picture), which closes off the control panel. On the left is the supply of the mains voltage from the terminal box on the drive. In the picture, the marking of the cable wires for the mains voltage instead of the colors brown, blue and yellow / green exceptionally is white, brown and green.

In addition, the control cable leads to the motors of the drive with the colors white for "+" and brown for "GND". Both lines are connected to the drive unit during operation. The following picture shows the control unit without the front cap.

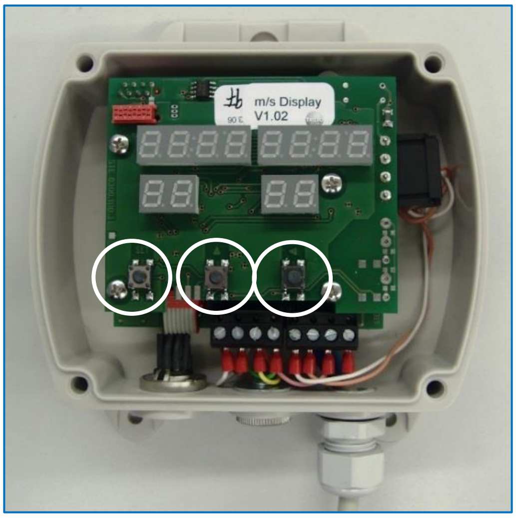


There is no need to open the control panel during normal operation. However, if this is necessary for a different configuration of the connections, please note:

Disconnect mains connection before opening.



Label on the cover of the control unit



Pin	Socket wind sensor control unit	
1	white	supply +24 V
2	brown	supply 0 V
3	yellow	signal wind sensor
4	green	wind sensor GND
5	pink	signal temperature sensor
6	grey	temperature sensor GND

Pin assignment of the wind sensor (right-hand socket on the control unit). Wind sensor open. Keypad for individual setting of data acquisition visible (white rings).

Changing the wind sensor settings is not required during normal operation.

The middle of the three connection sockets on the control unit only serves for the voltage supply of the force sensors. The adjacent table shows the allocation. The additional power supply provides the three supply voltages 5 V, 12 V and 24V.

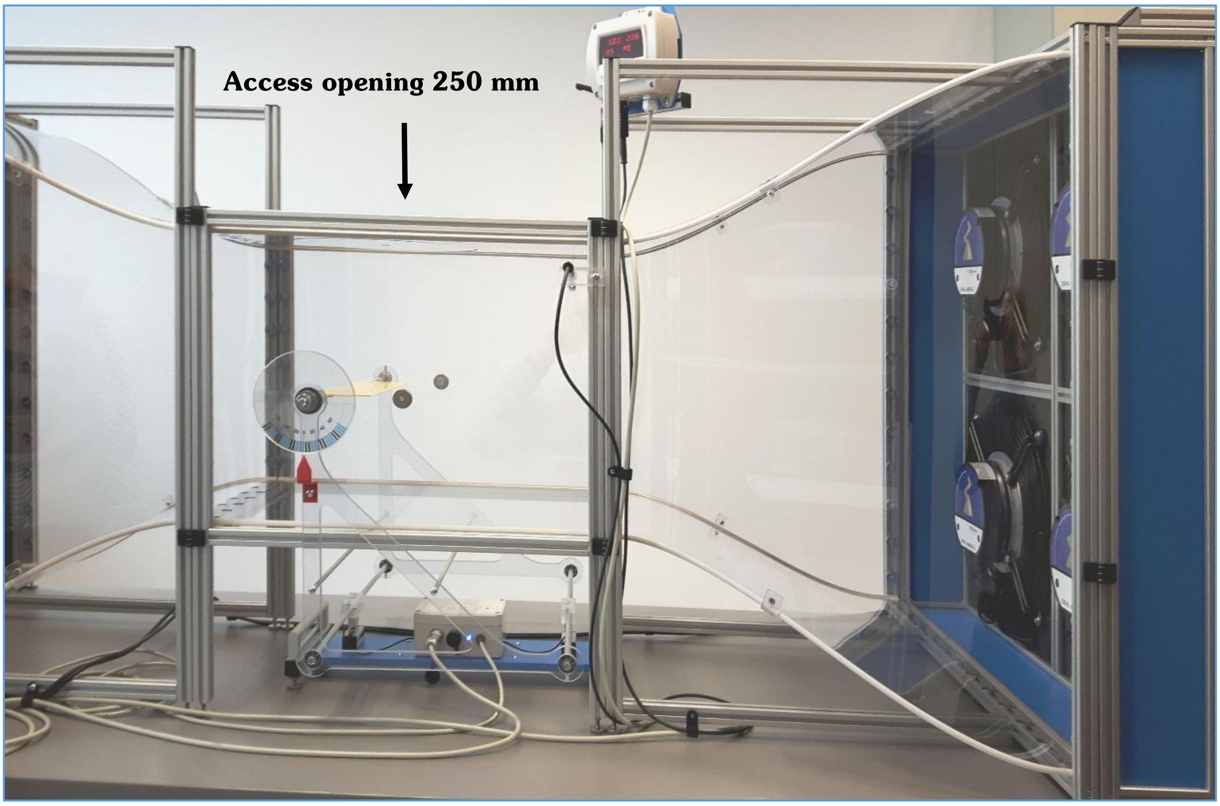
Pin	Low voltage socket on the control panel	
1	violet	+5 V =
2	pink	0 V at Pin 1
3	dark brown	+12 V =
4	light brown	0 V at Pin 3

The installation of the additional power supply in the previously practically empty UNIcon control unit has taken place without additional ventilation slots. This is not necessary for the electrical load generated by the connected sensors. The power supply can actually deliver higher power. But then, the control panel has to be rebuilt and ventilated. Therefore:

- The low-voltage connections of the control panel must not be loaded with other consumers which require significant power. The heating of the interior of the control panel is to be checked in case of doubt with a temperature sensor and should not exceed 40° C in continuous operation of a laboratory day. **Maximum permissible continuous temperature for UNIcon: 55 ° C**

(3) Working section and wind sensor

The segment called working section fulfills the dual purpose of guiding the flow out of the contraction segment (mode D) and in the opposite direction as the space for the measurements (mode S). The inside dimensions are 0.35 m x 0.35 m x 0.5 m. The sidewalls are like all other walls 3 mm thick windows, made of polycarbonate (Bayer Makrolon©).



Working section with wind sensor in suction mode, wind tunnel balance with force sensors

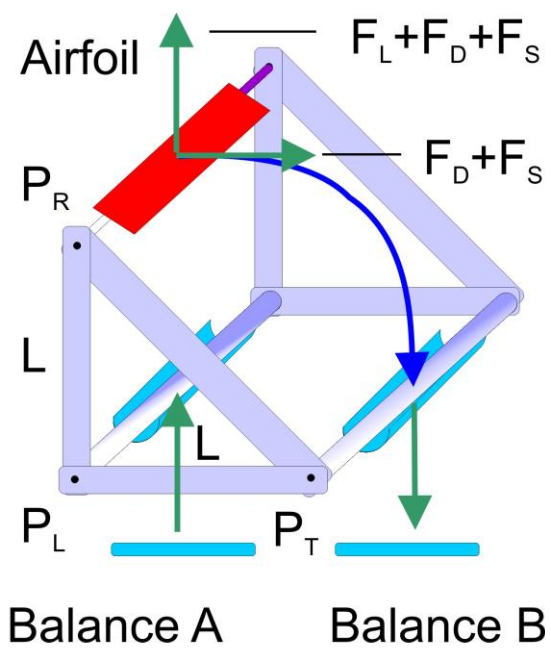
In the side walls opposite two openings with 15 mm in diameter are embedded, which are closed to the inside in the pressure mode flush with the wall. Through these openings the measuring object is connected to the wind tunnel balance, when the tunnel is operated with a closed working section (suction mode).

Access to the working section for accessing the objects to be measured takes place via the 250 mm diameter passage, which can be closed with a lid (not visible in the picture on the previous page). The holder of the test object is led out in operating mode S through the two openings on both sides of the working section to the support (next section).

(4) Wind tunnel balance - Support and measuring principle

Wind tunnel balance is the abbreviation for the unit, which consists of two elements:

Weighing device with two balances or two force sensors for the measurement of the components lift F_L and drag F_D of the air's force acting on the object to be measured if the flow is present.



Principle of measurement

Support for the object to be measured, whose characteristic is the L-shaped, isosceles construction over which the test object rests on the two balances. Between the two side parts of the support is the suspension for the test object. The suspensions are axles (diameter d = 6 mm) with angle indication for the inclination against the flow (angle of attack).

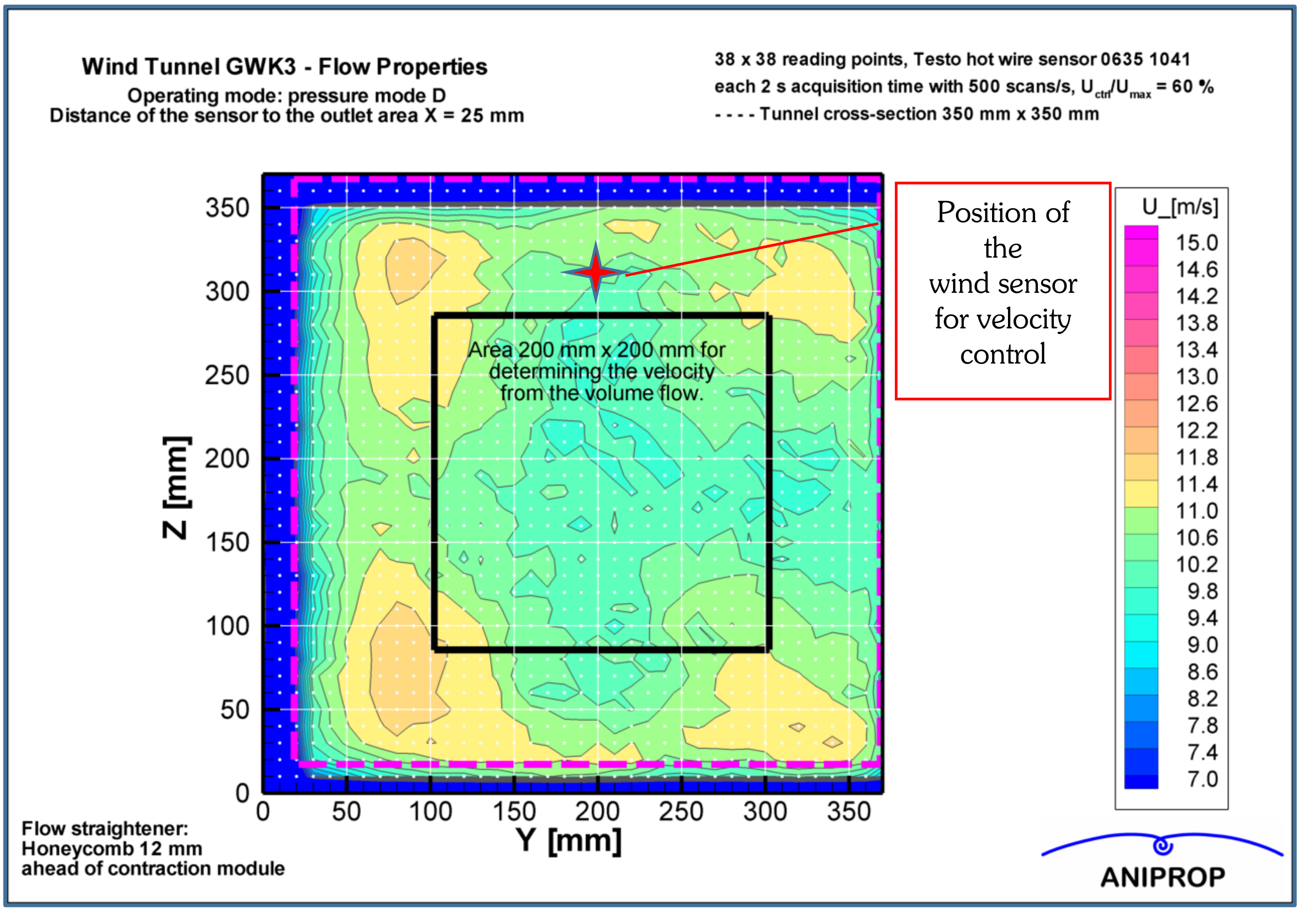
The support is connected to the two balances via two brackets. Its own weight together with the weight of the measuring object acts as a force F_S. This force is distributed on both balances, the front for the weighing oft lift and drag and the rear for the weighing drag only. The picture shows the measuring principle of the support with which the components lift and drag of the air's reaction force can be measured on an airfoil or on another object to be measured. The construction consists of two triangular, right-angled side parts, which are connected to one another at the corner points by axes transverse to the direction of flow. One of the two arms connects the front (P_L) and rear bearing axis (P_T), the other faces the flow and carries the object to be examined. This can be rotated about an axis parallel to the bearing axes (P_R). If a force acts on the object to be examined, the force component parallel to the wind direction acts on both axes, the component perpendicular to the wind direction acts only on the front bearing axis. For an object that only experiences drag, the front bearing force decreases by the same amount by which the rear bearing force becomes larger. The bearing shells are in real execution ball bearings on both sides of the support.

- As a result, the front balance or front force sensor measures lift and drag, and the rear balance or rear force gauge only measures the drag. So one always has to subtract the drag from the front measurement to calculate the lift.

2. Flow Measurements

1. Flow pattern of the measuring cross section in pressure mode

Operation of the wind tunnel in pressure mode is the easiest way to determine the air force on a measuring object. The short and simple design of the wind tunnel means that little influence can be exerted on the generation of a high-quality laminar flow. The following figure shows the velocity distribution in the measuring cross-section at the end of the working section, which only has the function of a wind guide in this experiment.



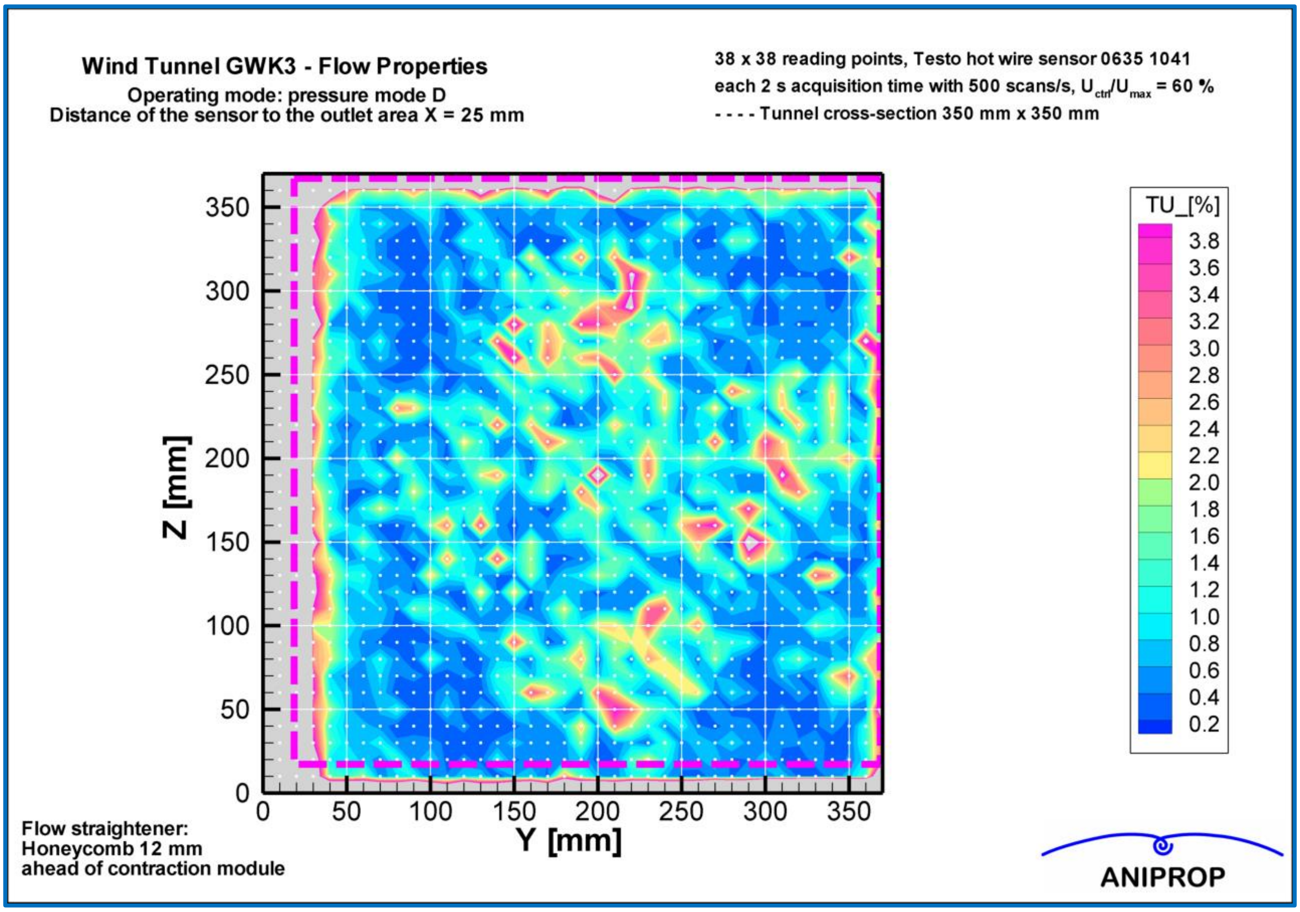
The measurement was carried out with the traversing device ANIPROP TRV1. One can see the signature of the four drive motors in the four corners. The data are the first measurements performed on the GWK3 using this technique. The wind sensor is guided automatically and line by line over the outlet surface of the air flow. The grid is 10 mm x 10 mm. At each position, the sensor remains short - in the above case for 2 s - and takes 500 readings per second. During evaluation, these values are averaged over time. Each individual measuring point includes an average, which the graphical evaluation program combines to form contour lines of the average speeds.

The question of the "correct" indication of the speed arises with the local fluctuations of the speed. The answer results from the determination of the volumetric flow rate, the amount of air that flows in total through the measuring cross section per second. If this volume flow, measured in m^3/s, is divided by the measuring surface, then the correct average speed is obtained in m/s. However, since the slightly higher velocities in the corners give too high a value for the area in which the measurements take place, instead of the measuring cross section of 350 mm × 350 mm, mm, a central area of 200 mm × 200 mm has been selected for the determination of the volume flow and the corresponding flow velocity.

Of course, this effort cannot be made for every measurement. It only serves the purpose of finding the right position for the wind sensor. Already optically one recognizes that approximately in the middle between the core ranges with higher speed the speed field comes very close to the central area in the middle. There, the wind sensor is positioned and determines the local measured value when the desired speed is reached. A more precise determination of the speed for the control of the drive is not possible.

2. Turbulence level in pressure mode

The measurement frequency of 500 Hz already allows a statement about the degree of turbulence for the low-frequency fluctuations in the flow. Only these are of interest for evaluating the flow characteristics of the tunnel in pressure mode. The following figure shows that the turbulence level of the tunnel in pressure mode is about 2%.

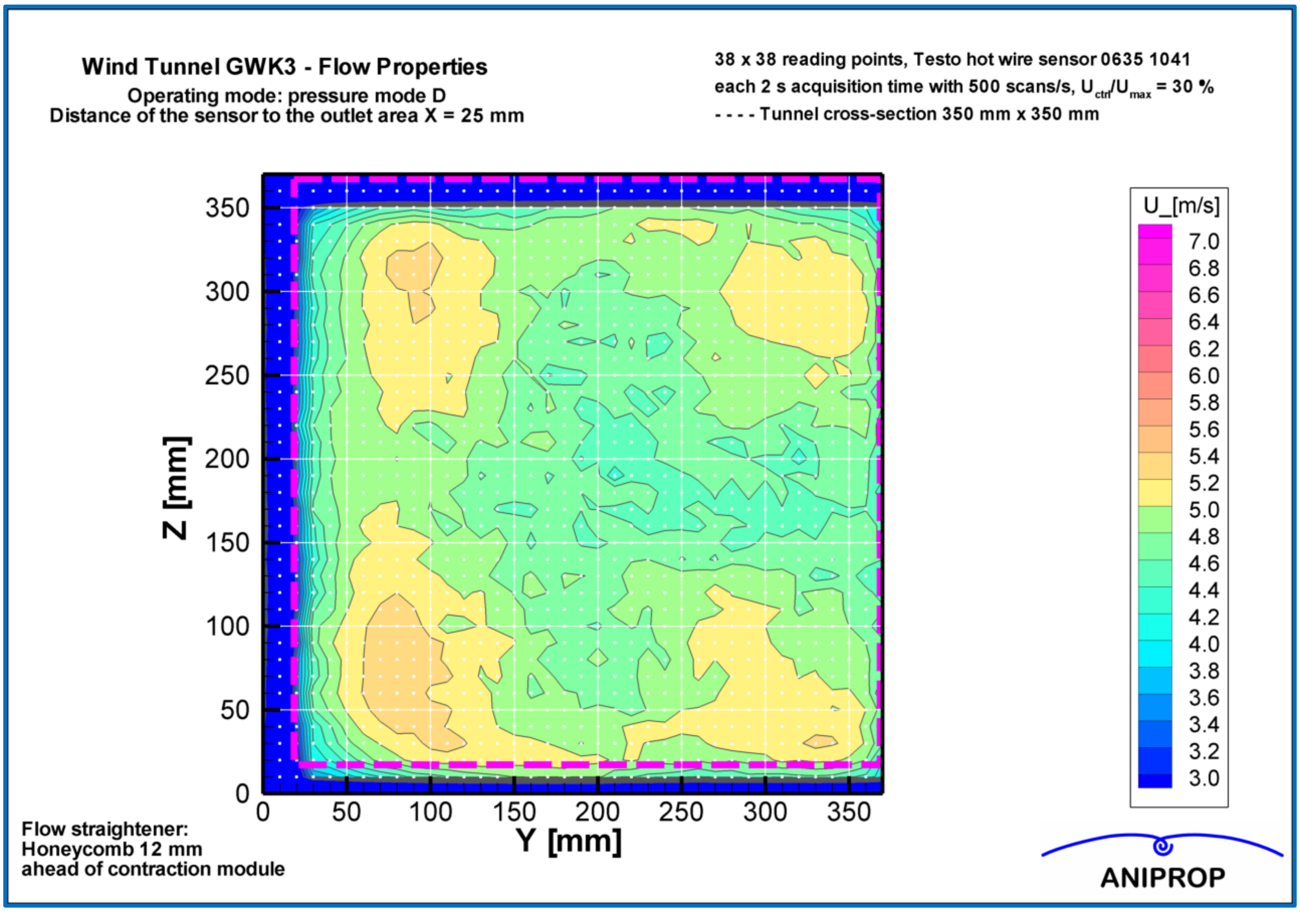


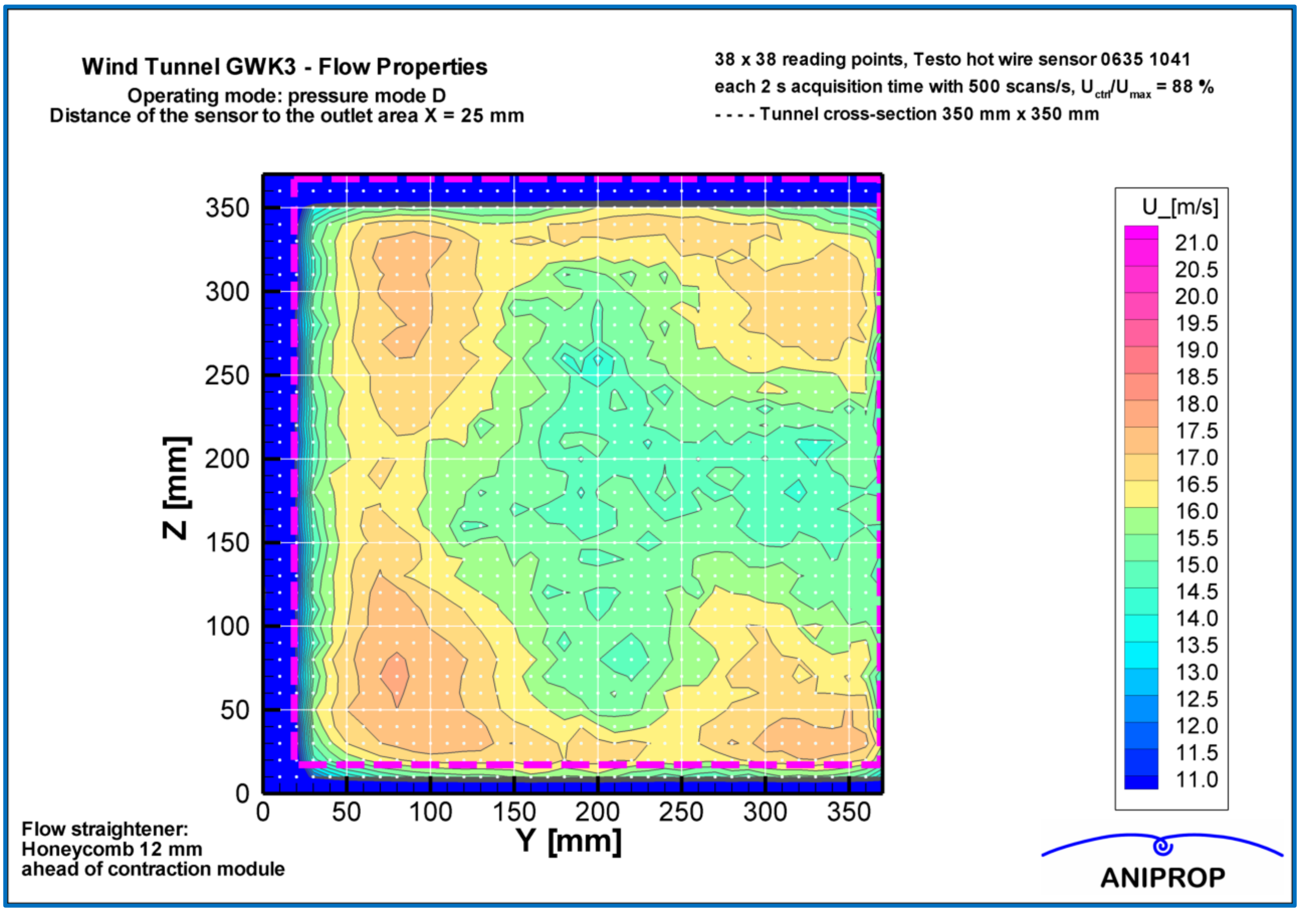
The two preceding figures apply to the middle operating range around 10 m/s. It turns out, however, that the topology of the contour lines does not change significantly over the entire speed range of the tunnel.

3. Overview of the entire speed range

On the following page, the contour lines of the speed are indicated for two further speeds 5 m / s and 15 m / s. The degree of turbulence does not change much, but is not shown here. At higher speeds, it decreases somewhat.

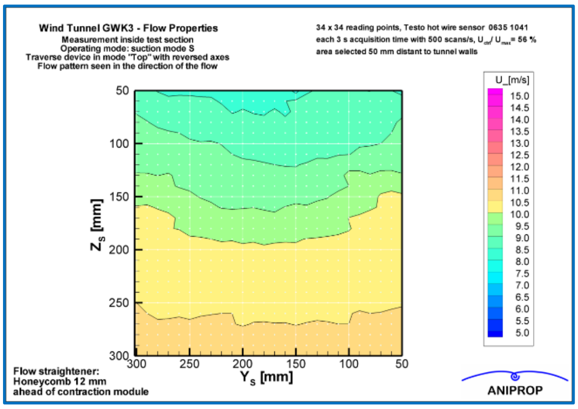
Annotation. The sensor used for these measurements indicates too low a speed. The calibration curve gives a value about 10% higher. The correction has been omitted here.


Wind Tunnel GWK3 - Flow Properties
Operating mode: pressure mode D
Distance of the sensor to the outlet area X = 25 mm
38 x 38 reading points, Testo hot wire sensor 0635 1041
each 2 s acquisition time with 500 scans/s, U_{ctrl}/U_{max} = 30 %
- - - - Tunnel cross-section 350 mm x 350 mm
Z [mm]
Y [mm]
U_[m/s]
7.0
6.8
6.6
6.4
6.2
6.0
5.8
5.6
5.4
5.2
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
Flow straightener:
Honeycomb 12 mm
ahead of contraction module
ANIPROP

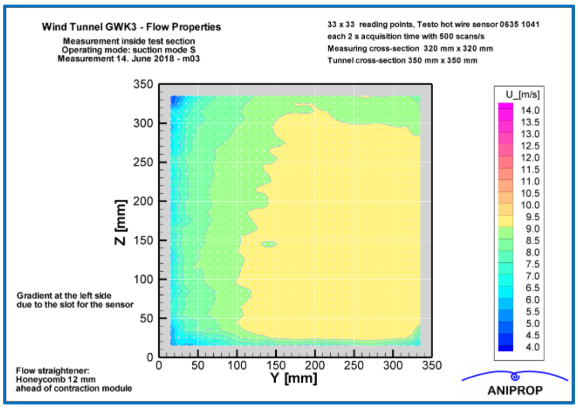

Wind Tunnel GWK3 - Flow Properties
Operating mode: pressure mode D
Distance of the sensor to the outlet area X = 25 mm
38 x 38 reading points, Testo hot wire sensor 0635 1041
each 2 s acquisition time with 500 scans/s, U_{ctrl}/U_{max} = 88 %
- - - - Tunnel cross-section 350 mm x 350 mm
Z [mm]
Y [mm]
U_[m/s]
21.0
20.5
20.0
19.5
19.0
18.5
18.0
17.5
17.0
16.5
16.0
15.5
15.0
14.5
14.0
13.5
13.0
12.5
12.0
11.5
11.0
Flow straightener:
Honeycomb 12 mm
ahead of contraction module
ANIPROP

4. Velocity and degree of turbulence in suction mode

In the previous versions of this description the problem of a gradient in the velocity field of the working section was mentioned. The assumption that the cause could be the measurement procedure itself has now been confirmed by re-measurements. Below are two measurements that took place with different measuring layouts.



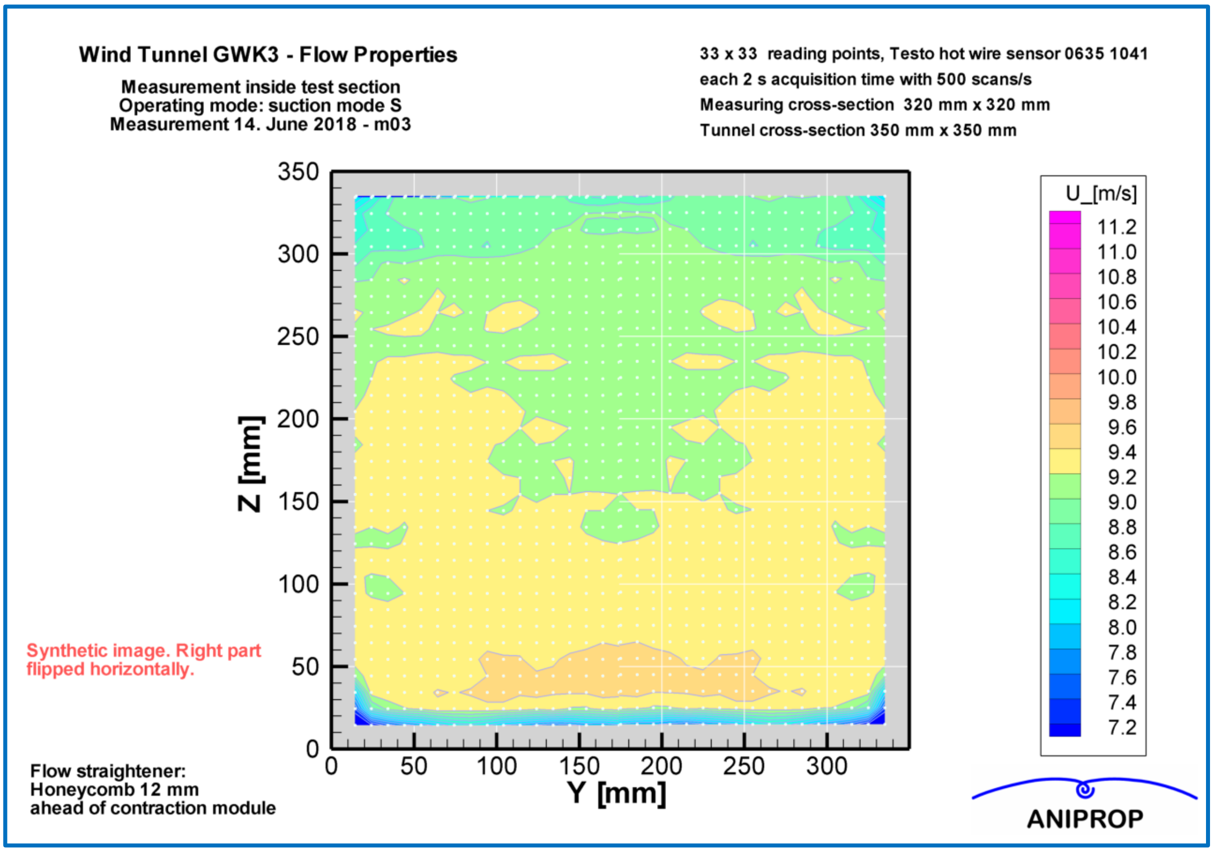
Measurement with slot for the probe at the top.



Measurement with slot for the probe on the left side.

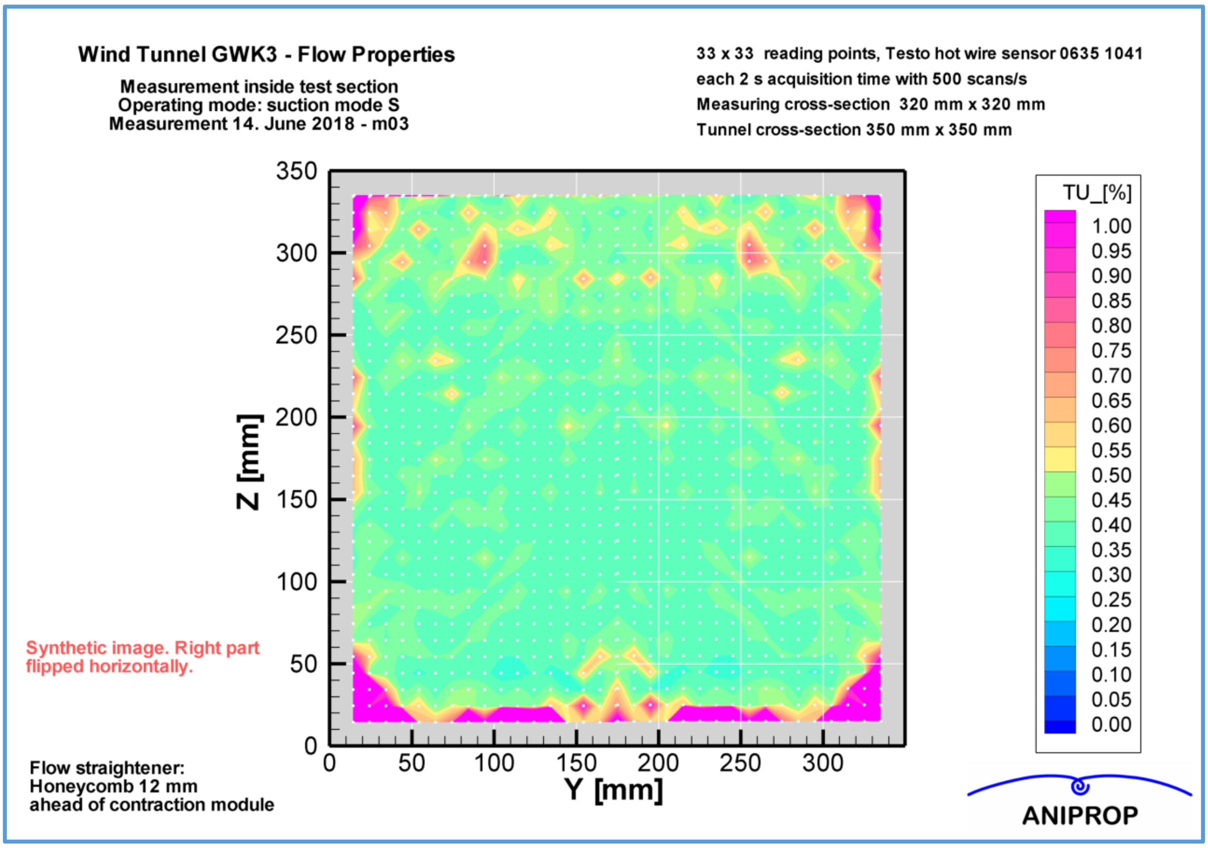
A suitable measurement technique must be such that the sensor measures significantly upstream of the point at which the probe is inserted into the wind tunnel.

The following is a synthetic image with the right side of the measurement above right flipped horizontally. The increment of the contour lines was lowered from 0.5 to 0.2.



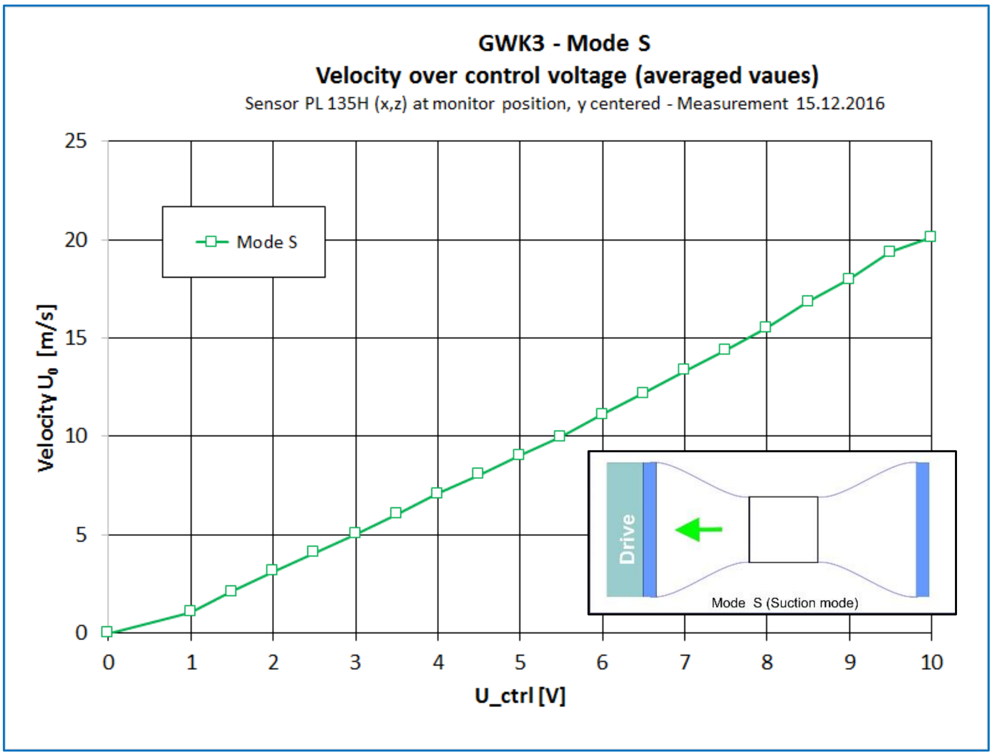
The following page shows the test setup, in which the probe is inserted laterally into the working section.

GWK3 with traversing device ANIPROP TRV1 - Existing measuring technology



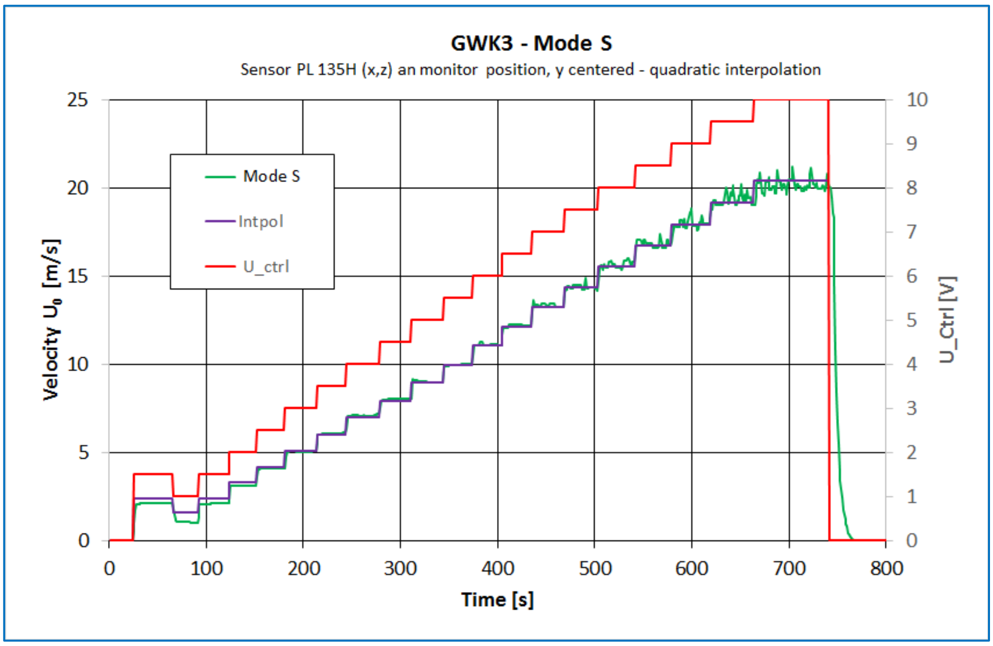
Turbulence level at 4 m/s is around 0.4% (suitable for streamline surveys).

5. Speed via control voltage in suction mode



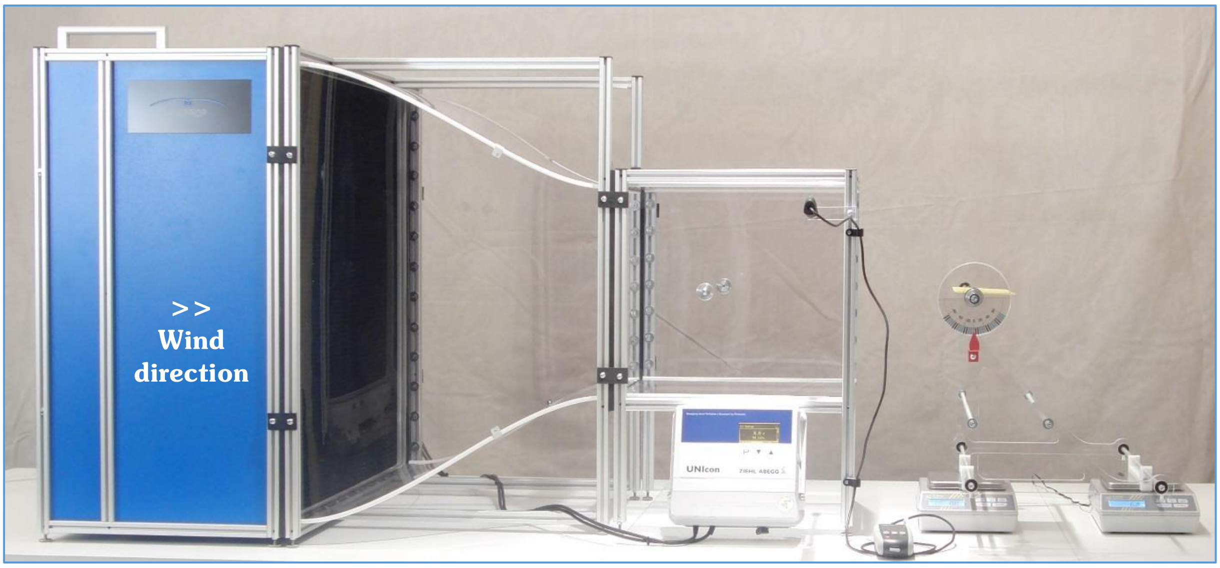
U_ctrl	[V]	0.0	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
<U0>	[m/s]	0.0	1.1	2.1	3.1	4.1	5.0	6.0	7.1	8.0	9.0	10.0	11.1	12.2	13.4	14.4	15.5	16.8	18.0	19.4	20.1

The graph above shows averaged results obtained with another flow sensor. The sensor was positioned in the upper side of the test section during these measurements. The lower graph shows the measurement series as it has developed over time. From the data for a fixed control voltage, the respective mean value was formed. At higher speeds, there are larger flow fluctuations, whose low-frequency peaks indicate disturbances in the incoming air.



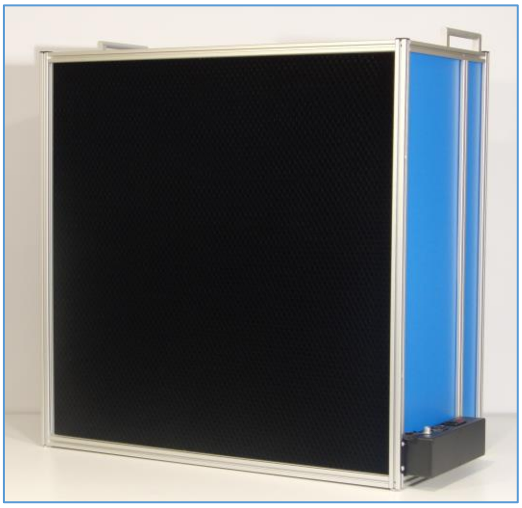
3. Operating Modes

1. Mode D – Drive pushes the air through the contraction segment



Layout of the wind tunnel GWK3 in operating mode D (pressure mode)

The picture above shows in oblique view the built-in drive unit straightener. The adjacent picture shows the front. The flow straightener is a 50 mm deep aluminum honeycomb structure designed to remove the swirl from the flow created by the four drive fans. The individual honeycombs have an edge length of approximately 12 mm and are powder-coated to dampen the natural vibrations of the structure. In mode D, the working section serves only as a wind alignment and at the same time allows the measurement of the speed with the wind sensor. At the outlet, the flow impinges on the wind tunnel balance.



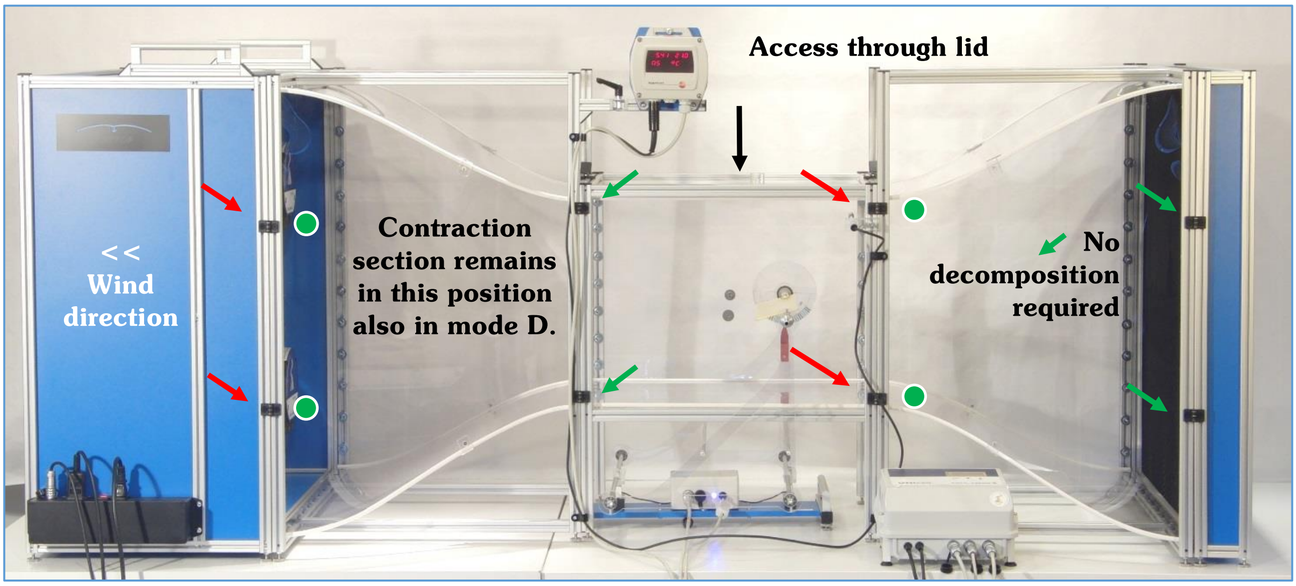
Flow straightener of the drive

2. Mode S – Drive sucks in the air through the contraction segment

The layout is a closed air duct with measuring objects within the closed working section. Access to the test objects takes place through a ceiling opening with 250 mm diameter.

For this operating mode, the drive has to be turned over in relation to the D mode. The air is sucked in via the second flow straightener on the right side of the image, and is contracted to the cross section of the working section. Also the wind tunnel balance should be rearranged, now pointing towards the drive.

The figure below shows the layout in mode S. The airfoil (a flat plate) points to the right, as seen by the viewer of the image. The operation of the two balances is then carried out from the rear side.



Construction of the wind tunnel GWK3 in operating mode S (suction mode) - split points

Important note: The drive unit weighs 42 kg and should therefore only be carried or turned by two adults.

Assembly and disassembly in mode S. In the above picture of mode S, the red arrows show where the tunnel has to be put together or disassembled. The bolds which tighten the joints are loosened at the side marked by the red arrow and, after turning the joints away, have to be re-inserted into the existing T-slot nut with a slight twisting. The joints remain fastened on the side with the green dot ●. The green arrows point to assembly points, which are joined together once and remain fixed.

The **advantage of mode S** is the significantly higher flow quality. The air is not curled by the fans. The mode S is also the one with which Gustave Eiffel built the tunnel type named after him at the beginning of the 20th century[2].

- A measuring object, including the supplied wing, can be removed and installed via the access on the top of the working section. Disassembly of the tunnel is not required.

[2] The wind tunnel is still in use. Images may be found on the following link: http://www.aerodynamiqueeiffel.fr/index.php
Advice: on the front page index.php automatically appears a slide show which is worth to wait for.

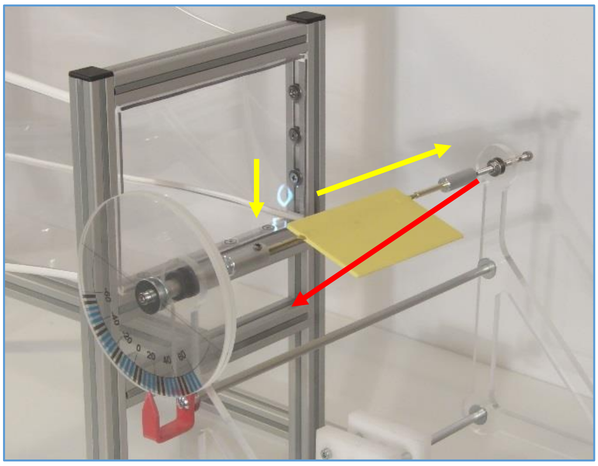
3. Notes on changing the operating modes

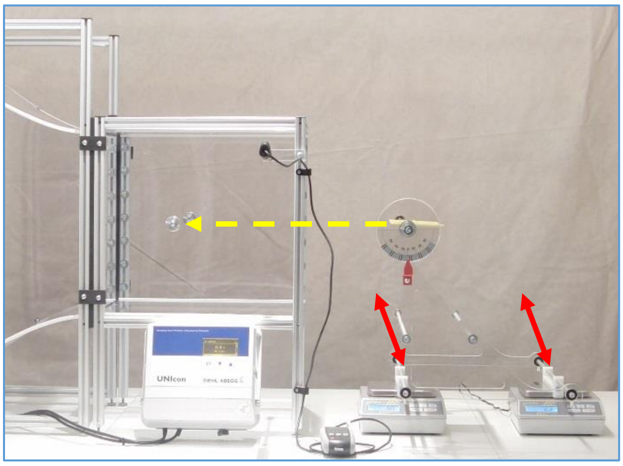
The second (in the picture on the previous page the right) contraction segment and also the flow straightener are not required in the D mode. The two segments are expediently placed only for the operating mode S on the laboratory bench.

For handling and space reasons the following procedure is recommended.

- For the change from D to S first the drive unit is rotated, then the second contraction segment with straightener is assembled.
- For the change S to D, first remove the second contraction segment and the straightener, then turn the drive.

If the test object is measured in the closed working section (mode S), the wind tunnel balance must first be placed under the working section without the test object. Then the object is mounted through the lid in the ceiling.





Removal of the measuring object — Moving the wind tunnel balance

To do this, unlock the stud (vertical yellow arrow on the left) and push the holding axis of the object to the right into the through bushing until the retaining axis is no longer in the bearing bush on the left (yellow arrow on the left). Then carefully pull the holding axis to the left out of the bearing bush, leaving the left-hand side of the axle next to the bearing bush with a stud screw (motion along the red arrow to the left).

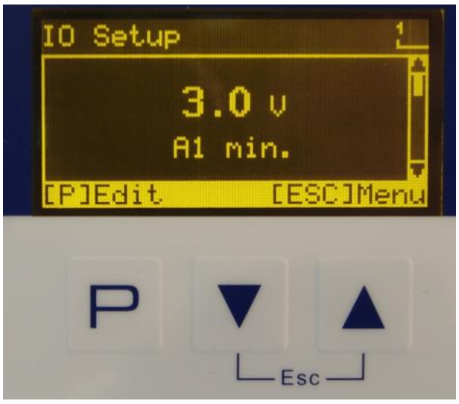
The clear width of the two arms of the wind tunnel balance is sized to 400 mm, so that the entire device can be positioned exactly in front of the two openings of the working section.

- The two closures must of course be removed beforehand!

Important. Lift the two balances first (red arrows right picture) and then move them (yellow, dashed arrow on the right). When lifting, you notice that the transverse axles are mounted in bearings, so the balances begin to oscillate immediately and smoothly. After the exact positioning of the two balances, the measuring object is inserted in the reverse order. The circular **reading device** for the inclination of the measuring object (angle of attack) is scaled in degrees. The line across the entire scale serves to align the measuring object with the horizontal orientation of the balances. Only after aligning the stud is tightened.

4. Control of the wind tunnel and wind tunnel balance

1. Control of the drive motors in manual mode



If the wind sensor is not connected, the wind tunnel can also be controlled manually.

Here are just the important steps. Further information can be found in the operating instructions.

1. Switch on the power supply
   Display top left info and in the frame **0% modulation**

2. **Press both ESC keys ↓ and ↑ simultaneously.**
   Display top left **main menu** and highlighted under Start
3. With the left Cursor ↓ go to **IO Setup** .
4. Press **P**. The **1. control signal** shows in the frame.
5. Press the left Cursor ↓ . The above picture appears with **0.0 V / A1 min.** A1 is one of the two analogue outputs of the UNIcon controller for voltage regulation in the range 0 - 10 V.

   In this window, the entire engine control takes place.
6. Press **P**. Display 0.0 V starts to flash. With the right Cursor ↑ go tot he higher value **3.0 V**.
7. Press P. The flashing disappears. The wind speed changes.
8. For further changes, first press **P**, then use ↓ or ↑ to set a different value. Then press **P** again.

   The wind speed changes.

   Note 1. Lasting pressing of ↓ or ↑ changes the value automatically until release.

   Note 2. Further pressing of Cursor ↓ like in 5. leads to higher values of A1.

2. Operation with presetting of the wind velocity

The controlled operation with presetting of the velocity takes place in the operating mode 6.01 of the universal control module UNIcon of the company Ziehl-Abegg. The module supplies the control voltage for the drive motors. The company issues the printed instruction for the control panel, which is part of the delivery. The document is also available on the accompanying CD under the following name:

UNIcon_MODBUS_Master_L-BAL-E250-GB.pdf[3]

Picture of the manufacturer of the control module UNIcon

Operating mode 6.01 assumes that the wind speed is supplied by a sensor as a measured variable between 0 and 10 V. This voltage is given to the input E1. The user sets the desired wind speed as the setpoint in the range 0 to 20 m/s. Output A1 now provides the control voltage that matches the wind speed. The controller, a so-called PID controller, ensures in a control loop that the measured wind speed, the actual value, approaches the setpoint.

[3] The instructions offered by Ziehl-Abegg: https://www.ziehl-abegg.com/de/en/downloads/file/get/11305/

3. Weighing device with laboratory balances

(1) Program Kern Balance Connection

Virtually all laptops and PCs used in laboratories no longer have physical serial ports, only USB (Universal Serial Bus) ports. Such a serial port is physically a 9-pin Sub-D connector, which is often used for the interface with the RS232 standard. The balances from the Kern 440 series used by ANIPROP GbR have such a RS232 interface, the connection of which cannot simply be converted to a USB connection. Such simple adapters available in trade must not be used, even if their pins physically fit.

Since 2017, the GWK3 is equipped with two balances with new software *Kern Balance Connection* developed by the Kern company[4], which can manage two so-called virtual COM ports (VCP) at the same time. The software can of course also manage real COM ports, if a computer should be equipped with two such serial ports. This is usually no longer the case with newer computers.

The RS232 interface with the 9-pin Sub-D connector is converted to a USB port via an electronically active adapter[5] (see next page). The driver of this adapter from the company FTDI establishes on the computer a so-called virtual COM port (VCP) whose port number one must query in the list of installed devices. The driver is offered by the company FTDI for download for all common operating systems[6].

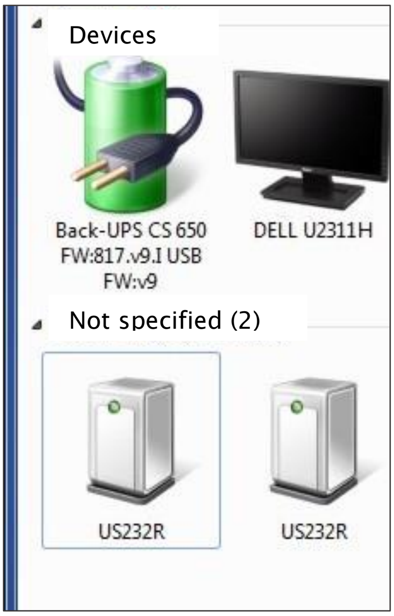
Important note: Always carry out assembly work with the balances switched on in order to detect overloading.

[4] Demo version: Full range of functions, usage is limited to 10 days. https://www.kern-sohn.com/shop/en/software/BalanceConnection/

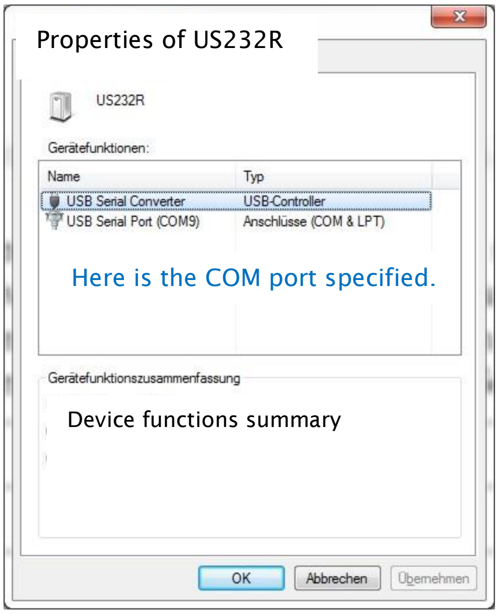
[5] Information on the adapter: https://www.ftdichip.com/Support/Documents/DataSheets/Cables/DS_US232R-10_R-100-500.pdf

[6] https://www.ftdichip.com/Drivers/VCP.htm

VCP adapter for two Kern balances

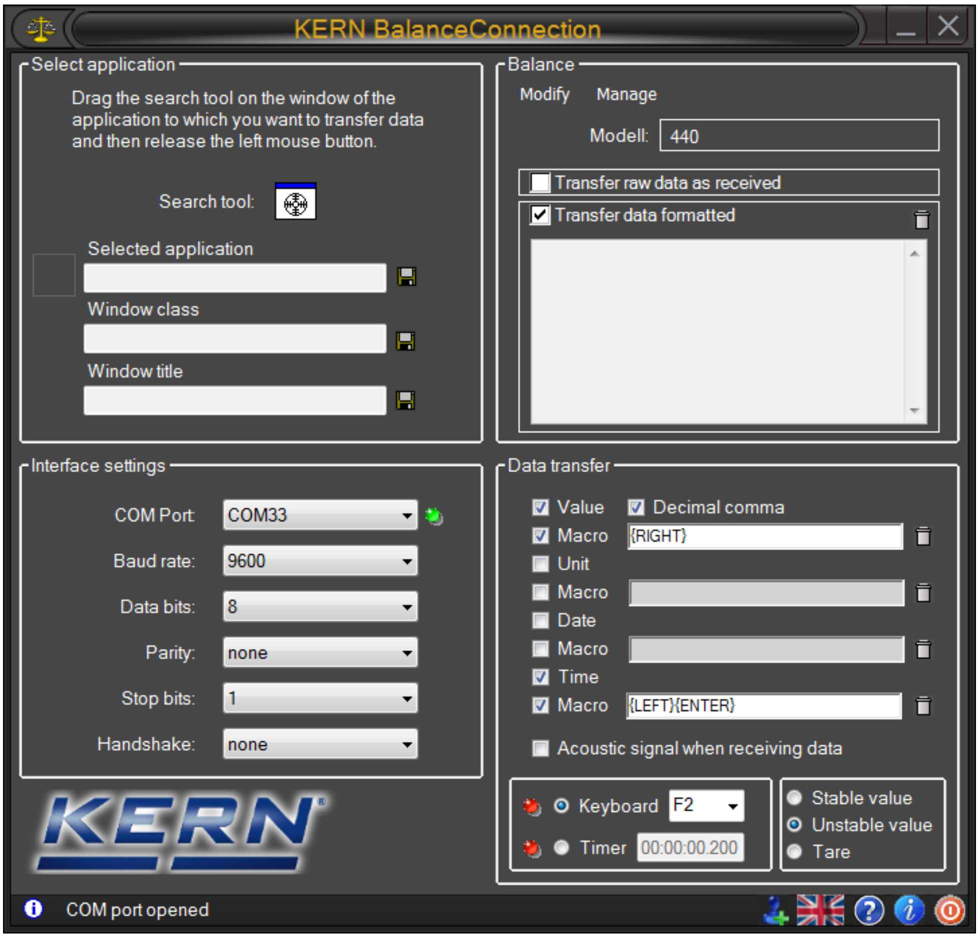


Display of the adapters in the device list (Windows 7, 64bit)



Associated COM port found under the properties of device US232R

Main window of the Software *Kern Balance Connection*[7]:



The picture shows the main window of the software, which offers a number of possibilities to automate the acquisition of data. It is highly recommended to open an Excel spreadsheet right

[7] The actual description as PDF: http://balanceconnection.kern-sohn.com/manual.pdf

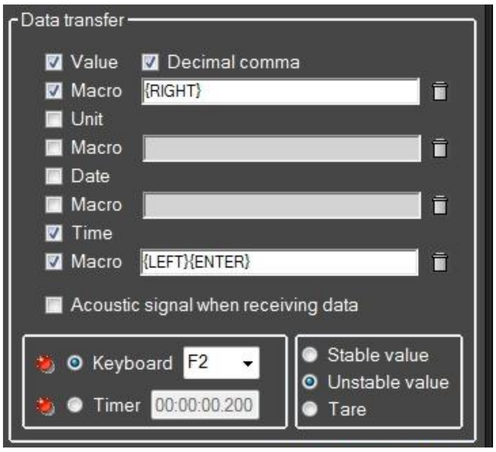
at the beginning in order to write the data there. The link is very user-friendly organized. Clicking on the icon to the right of the search tool in the upper left field and dragging it to the opened window with the Excel file establishes the link. The name of the file then automatically appears in the third field from the top below the term window text. This simple way is described at first.

(2) Simple mode (measurements one after the other)

In the “Interface settings” pane, “COM Port” is a drop-down menu that displays all active COM ports on the computer. You select the port, which has been previously determined for the respective device US232R. Each key press with the function key F2 now writes a measured value in the cell, which was selected with the cursor in the Excel file.

If two balances with two adapters are connected, then the respective balance must be selected by selecting the COM connection. You can also automate this manual assignment. The data from two balances are simultaneously retrieved and enter into an Excel file. This requires the use of the software in expert mode and is explained in the following section.

Value	Date
224.4	18:20:21
224.4	18:20:21
224.4	18:20:21
224.4	18:20:22
224.4	18:20:22
224.4	18:20:22
224.4	18:20:23
224.4	18:20:23
224.4	18:20:23
224.4	18:20:24



COM9	COM10
balances 1	balances 2
193.4	41.1
193.4	41.1
193.4	41.1

Data from two balances

It is also possible to record the data at the maximum readout speed by selecting the “Timer” option instead of pressing the button F2 on the keyboard. The time is set to 00: 00: 00.200. The value 0.2 seconds is the smallest value, otherwise an error message appears to the right of the field. This selction is useful if you want to determine a value by averaging over some individual measurements.

- The setting of the macro commands for formatting the output is done by pressing the respective key on the keyboard of the computer, not by writing in the field!

These settings create the left table above. The acquisition terminates after switching back to “Keyboard”. The data collection shows that the scan rate is actually 3.3 scans/s. Setting the timer is a bit awkward. The following way works:

1. *Timer* is clicked and then *Tare*.

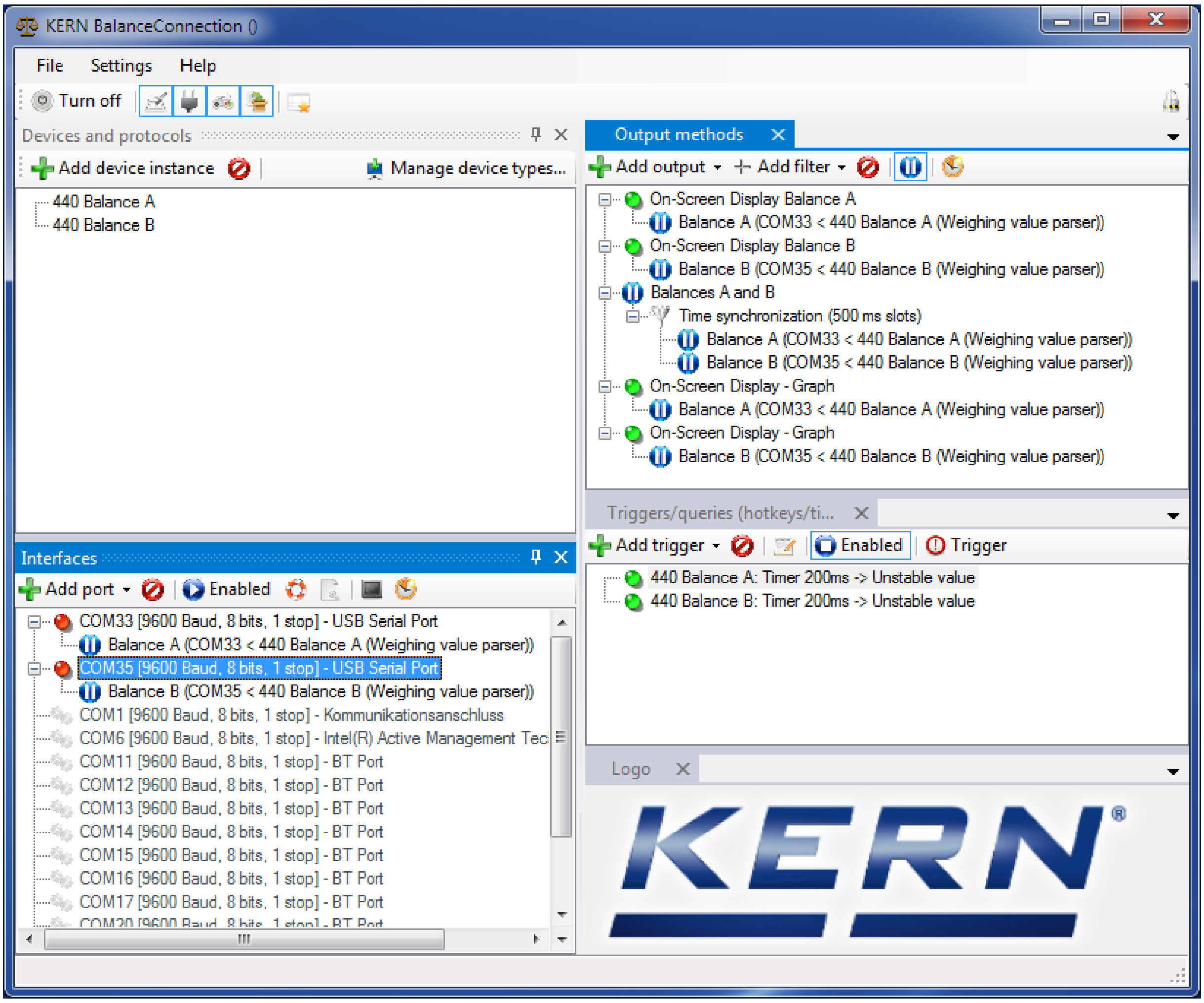
Now the numbers can be accessed and 00.200 set.

2. Click on *Unstable value* for acquisition.
3. Terminate acquisition by clicking on *Keyboard*.

(3) Expert mode (measurements simultaneously)

The expert mode can be reached by clicking on the icon with the "+" on the left of the flag on the footer. The following description explains how to write the data on two balances simultaneously in an Excel file. This must happen in due brevity. When purchasing a new GWK3, learning the handling is part of the one-day training.

- The software in expert mode requires a thorough training for independent handling. The design possibilities are so varied that only one specific way, which has proven useful in the laboratory of ANIPROP GbR, is described below.



There are four main panes and the pane with the logo of the company:

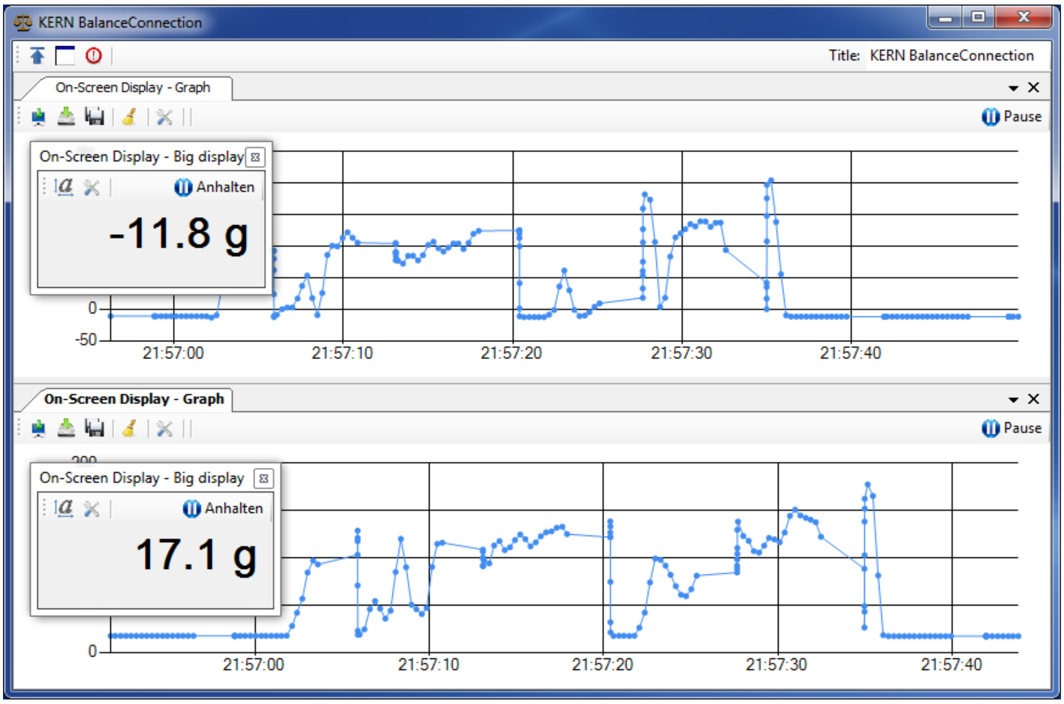
- Devices and protocols
- Interfaces
- Output methods
- Trigger (for the data flow)

Set up as appliances, called device instance, are the two 440 type balances labeled *Balance A* for lift and drag and *Balance B* for drag. The protocol with the abbreviation 440 belonging to these balances is part of the software and only has to be activated. The interfaces require two COM ports, which are assumed to be set up. The numbers COMnn differ from computer to computer.

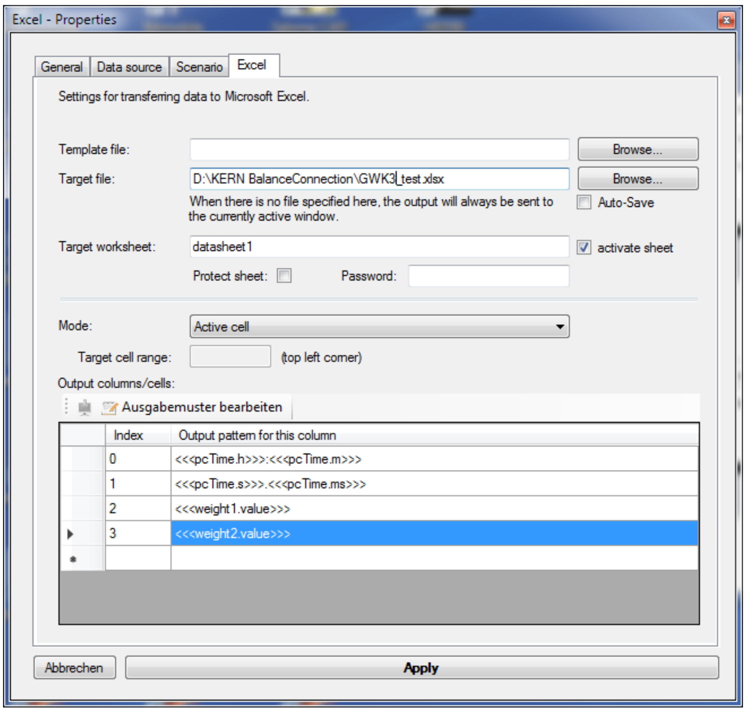
It is advisable to assign the connection with the lower number to balance A. In the example, balance A belongs to COM33 and balance B to COM35. There are various possibilities with the protocol parser of analyzing and decomposing the incoming data stream. Selected is the "weight parser", in which only the measured values of the weighing are filtered out and displayed.

Among others, the **output methods** are a large display for each balance and the graphical representation of the measured values over time. These are set up separately for each balance.

The output methods appear as separate windows and can freely be arranged:



Unfortunately, the name for the individual windows is not included in the display. The most important output method for storing the data is the "Excel workbook" method. This option is explicitly specified in the pop-up menu, which appears when you click on the green plus when adding.



In the "General" tab, enter the freely selectable name "Balances A and B", under "Data source" you can now find the two devices behind COM33 and COM35. The entries are already complete. For “Excel” the above window appears. Only the “Target file” is needed. It should already be open and have the “Target worksheet” with the specified, but freely selectable name *datasheet1*.

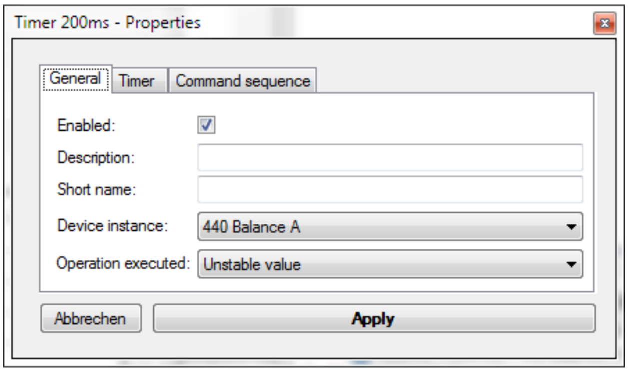
The table is activated with the checkmark to the right of the name. The “Mode” *active cell* is convenient because the data block then is written into the cursor-clicked cell and the columns to the right according to the **output pattern** Then, if the timer for the respective COM port is set to continuous output, the following row in the same columns will be described after each line with the specified columns. The query when specifying an existing Excel file is somewhat irritating: “The file already exists. Shall it be replaced?” The answer is “Yes”. But only the name is taken over and the file is not re-established. Existing data are retained. The output pattern with the index 0, 1, 2, 3 describes for each column, which data is written out in which format. The term "index" refers to the data columns. The numbers are generated automatically. "0" is the current column in *datasheet1* in which the cursor is located. The output pattern indicated is:

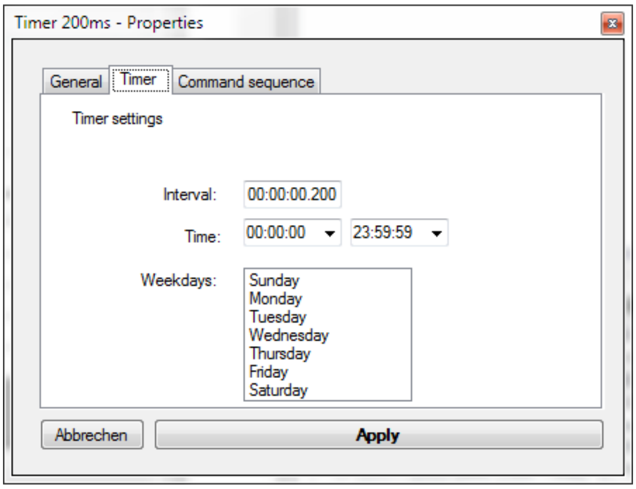
Index	Output pattern for this column
0	<<<pcTime.h>>>:<<<pcTime.m>>>
1	<<<pcTime.s>>>.<<<pcTime.ms>>>
2	<<<weight1.value>>>
3	<<<weight2.value>>>

The corresponding result in *datasheet1* of the Excel file looks like this:

Time	Time	Balance A	Balance B
hh:mm	s	-(L+D) [g]	D [g]
alfa_S deg	12		
U0 [m/s]	8	Values	Values
14:44	51.351	-15.50	9.32
14:44	51.741	-15.51	9.32
14:44	52.151	-15.37	9.23
14:44	52.501	-15.34	9.29
14:44	53.341	-15.43	9.39
14:44	53.541		9.39
14:44	54.771	-15.61	9.30
14:44	54.891	-15.54	9.35
14:44	55.301	-15.61	9.35

The yellow and green shaded fields are optional pre-registered explanations to the data. The cursor was at the beginning of the transmission in the field highlighted in red. The blue highlighted fields are the automatically entered data. The first column "0" shows the hour (h) and minute (m) of the PC time, while the second column shows the second (s) with fractions in milliseconds (ms). You see that the data are transmitted on average twice a second. This is due to the set times for the "synchronous" acquisition, which has a certain amount of time slip between the individual data inputs. The last two columns show the values of the two balances. Now the **triggers** for the data streams have to be set up in the main menu. With "Add" you can choose between "Timer" and "Hotkey". The data curves for lift and drag measurements always combine several data to form an average, "Timer" is the right choice. With the button "Enabled" one can stop the entire data flow of an input stream. For each data input, a separate timer must be set up:

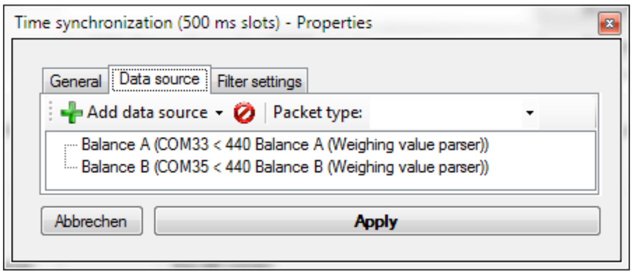


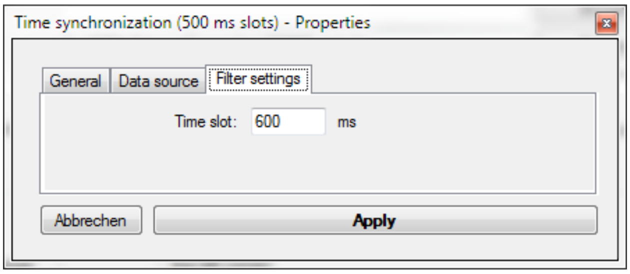


For balance B, the analogue setting is made. The triggered command that is sent continuously is "Unstable Value". This is a feature of the balances: they require a longer acquisition time for a stable value. Since, however, a constant stable load on the balances does not occur anyway due to the vibrations of the test objects in the airflow, "Stable Value" would not provide any data in the worst case. The timer runs "24/7" as it says and sends a request for data every 0.2 s. The balances are not working much faster anyway.

- The setting of the “Trigger” as Timer causes the data stream to be interrupted only if it is stopped by clicking on "Enabled". Repeated clicking again starts the data stream.

Finally, the data should enter a row in the Excel file synchronously. This is achieved by activating a *hold on* function with the “Add filter” option in the “Output methods” pane:



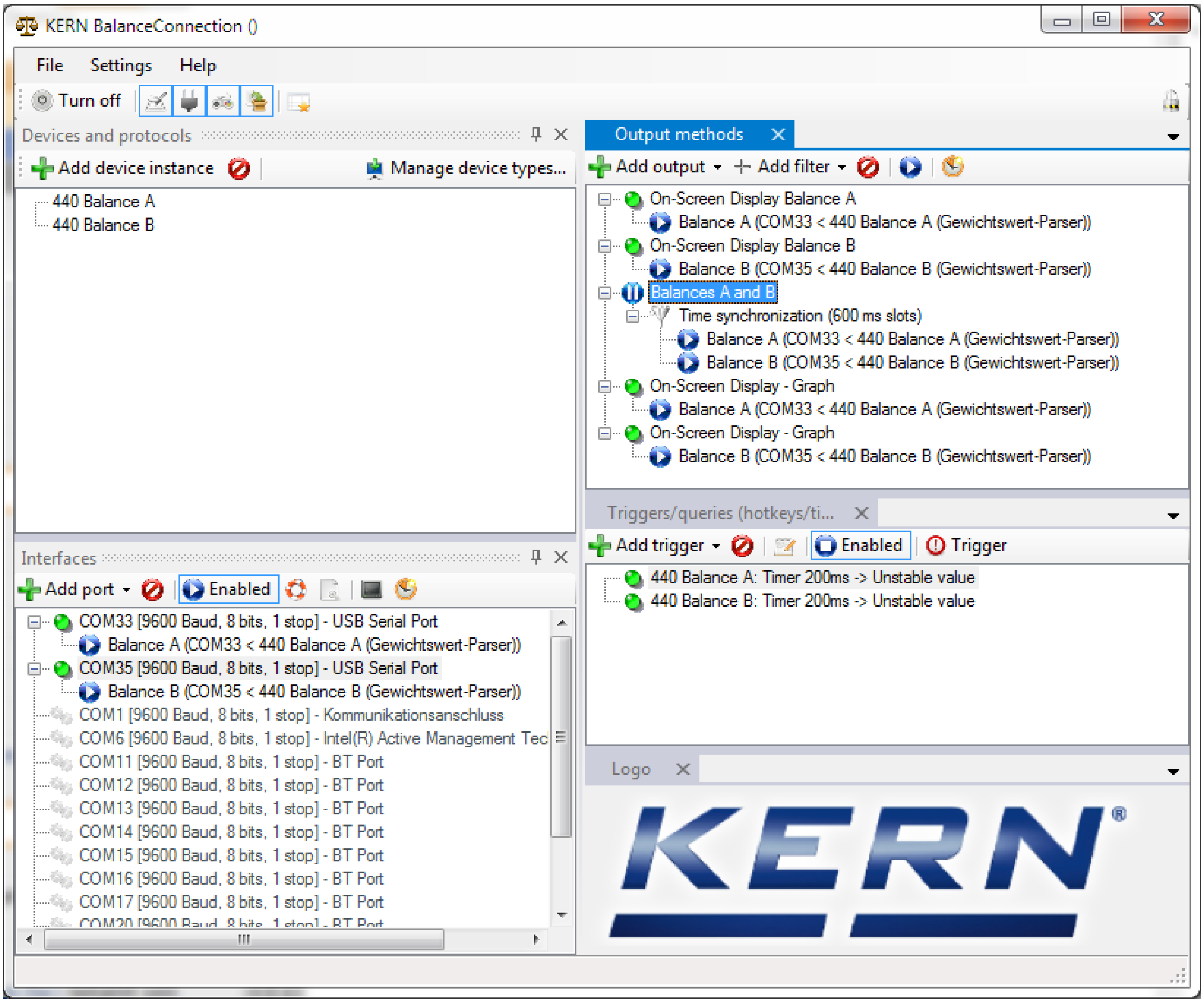


The time synchronization option with the 500 ms time slot (on the right pane before set to 600 ms with “Apply” as shown in the window on the next page) causes signals within this time window to be considered as simultaneous and written into one line. If this is not the case, then one value is missing in one line (see the example on the previous page).

Even if the data streams are open, any output method can be stopped individually. This is important for writing the data to the Excel spreadsheet. For a measurement e.g. at various angles of attack, the acquisition keeps running, and only the data flow to the table is paused until a new angle of attack is set and a new cell is selected to start writing. Then, as many lines of values are retrieved, as one would like to have for averaging. Practically, you can always write out a few more lines than you need for averaging.

(4) Settings in summary

In summary, the settings discussed give the following picture:



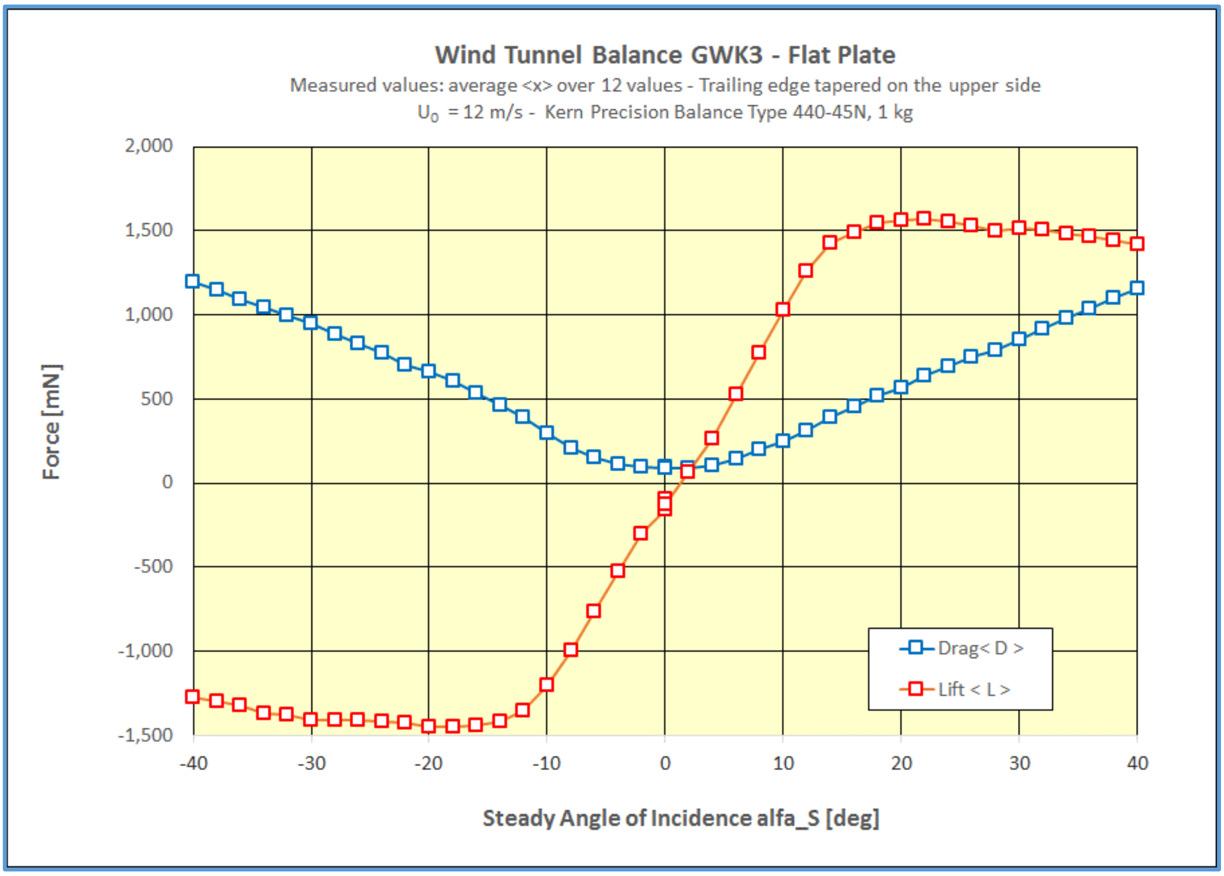
All data inputs are activated, writing to the Excel sheet is paused.

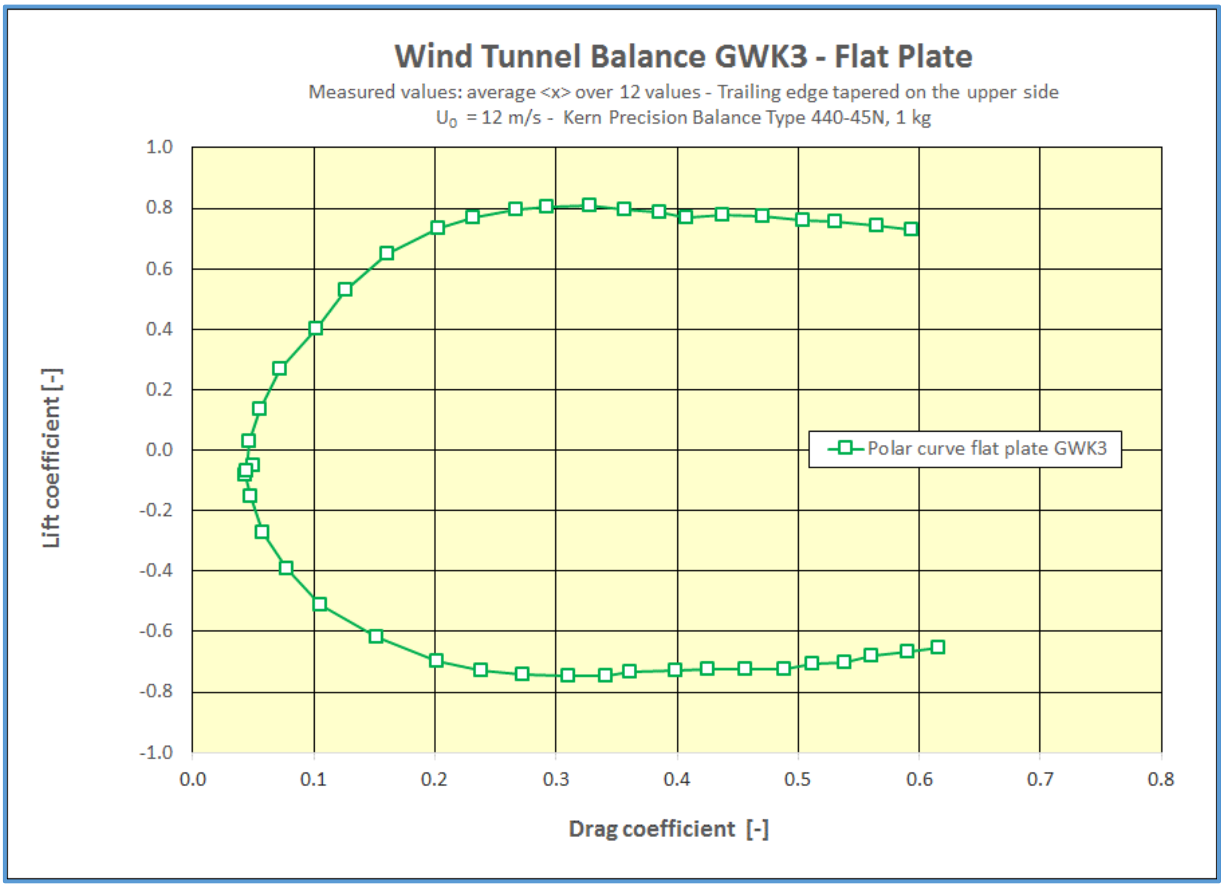
Note. Unfortunately, English notation sometimes switches back to German. *Gewichtswert-Parser* means *Weighing value parser.* In a previous image *Anhalten* means *Pause*.

As already noted, the assignments of COM ports differ from computer to computer. As an example, the output to the Excel file has been paused. By clicking on the white triangle on a blue background, the data flow starts again.

(5) Example measurement: lift and drag of a flat plate

On the pages of aniprop.de is an Excel file specified, in which the measurement of a polar with all measured data and the evaluation is completely contained. Measurement data and evaluation are also available as PDF files. The following page shows the aerodynamic coefficients of a flat plate for the speed 12 m/s versus the angle of attack. The data also are shown as polar diagram.

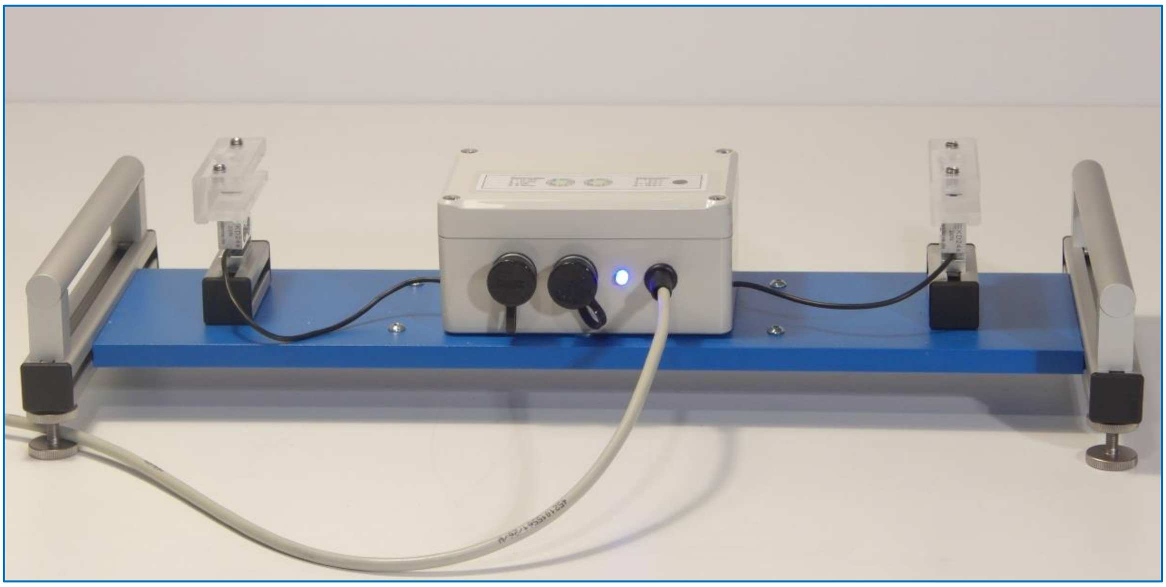

Wind Tunnel Balance GWK3 - Flat Plate
Measured values: average <x> over 12 values - Trailing edge tapered on the upper side
U0 = 12 m/s - Kern Precision Balance Type 440-45N, 1 kg
Force [mN]
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-40
-30
-20
-10
0
10
20
30
40
Drag< D >
Lift < L >
Steady Angle of Incidence alfa_S [deg]

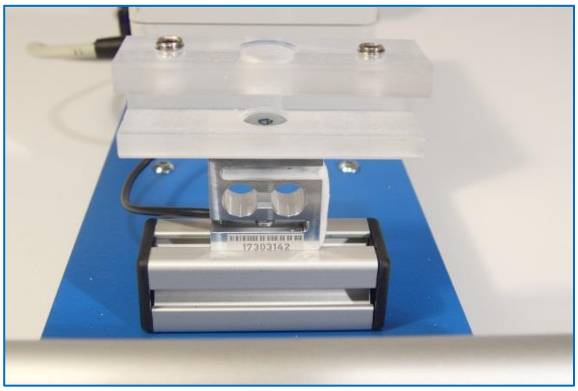

Wind Tunnel Balance GWK3 - Flat Plate
Measured values: average <x> over 12 values - Trailing edge tapered on the upper side
U0 = 12 m/s - Kern Precision Balance Type 440-45N, 1 kg
Lift coefficient [-]
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Polar curve flat plate GWK3
Drag coefficient [-]

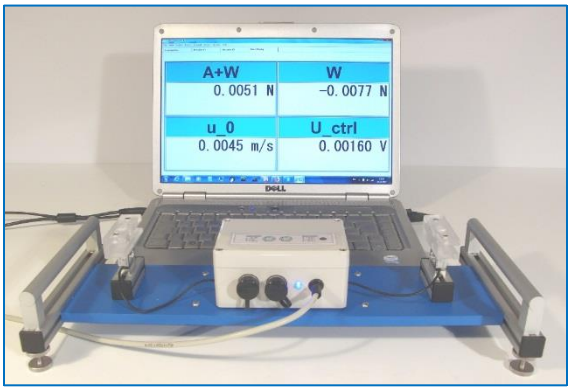
4. Weighing device with force sensors

(1) Mechanical structure of the weighing device

The weighing device with two force sensors differs from the weighing device with two laboratory balances in its design, but not from the measuring principle. The support with the measuring object fits both weighing devices.







The upper picture shows on the left the leading force sensor A and the trailing force sensor B, each of which with a measuring range 20 N, on the base plate of the weighing device. The cable leads to the control unit of the wind tunnel for the voltage supply with 5 V DC. It powers the type of force sensor used and the wireless communication unit. The box contains the measuring amplifier for the two force sensors. The data are sent via Bluetooth to a PC. The lower left image shows the front force sensor, the lower right image the display of the data acquired with the software GSVmulti. The software is described in the following section.

Important note: Always carry out assembly work with the load sensors with indication of the load in order to detect overload.

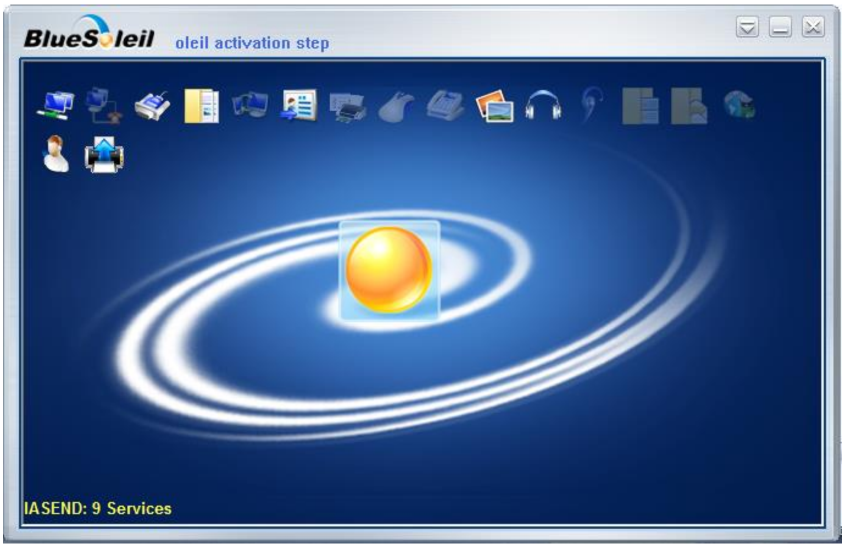
The communication software must first be installed and started.

(2) Start the connection with Bluetooth (Software BlueSoleil)

The communication software is supplied together with a Bluetooth USB dongle from LogiLink. The use of the supplied USB stick is important because its use makes the BlueSoleil software automatically licensed.

- During the installation, the BlueSoleil cPhone software will also be installed if the installation is not disabled by deactivating the corresponding tick. This part of the software is not needed.

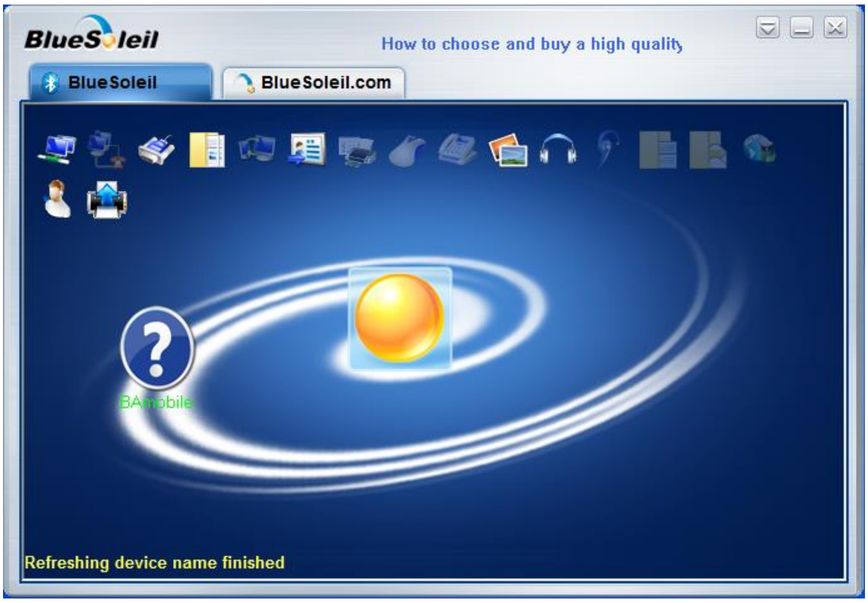
Image of the software when all connections are deleted:



Right-click on the sun in the middle (as a symbol for your own computer). The selection window below appears. Select device search.

- **Search Devices**
- Turn on Bluetooth
- Properties …

The measuring amplifier must already be switched on. Then you will find the following information (picture below left), after the program has started search for devices.

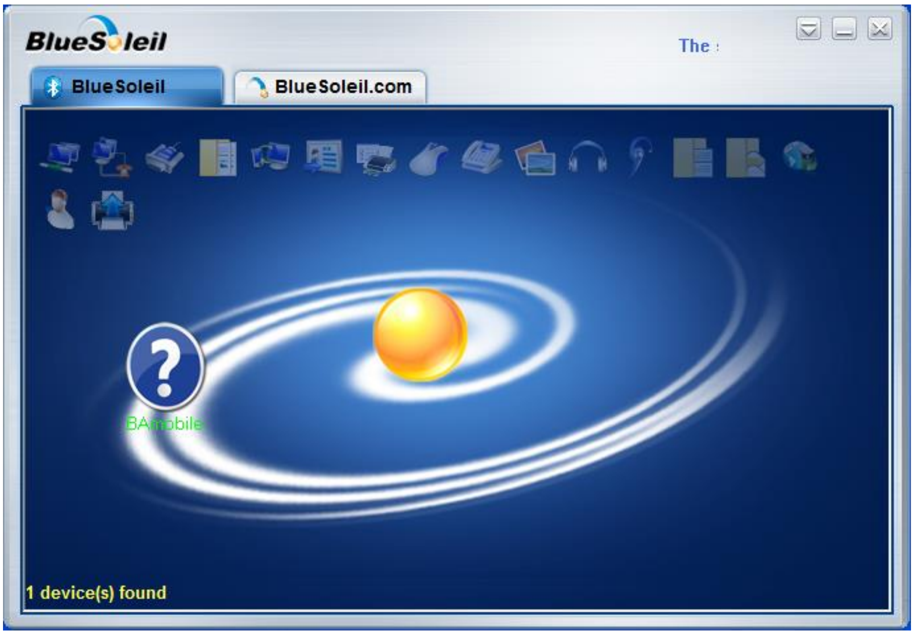


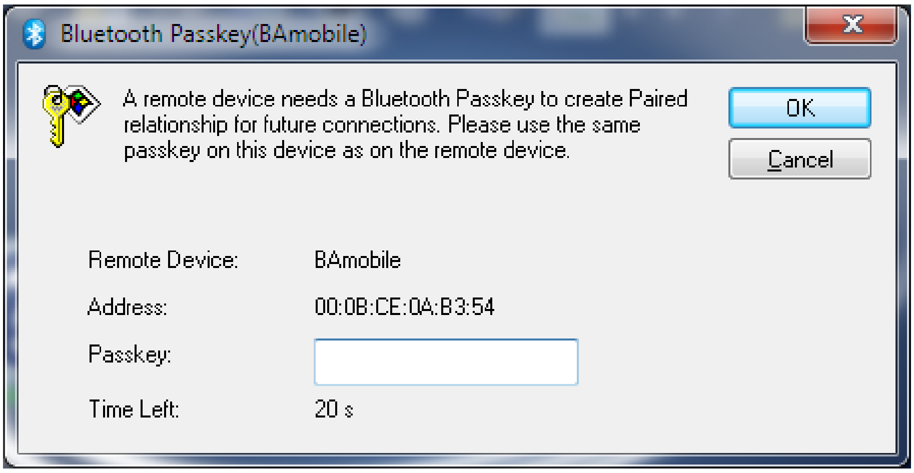
- **Search Services**
- Pair
- Delete
- Properties …
- Rename
- More bluetooth devices

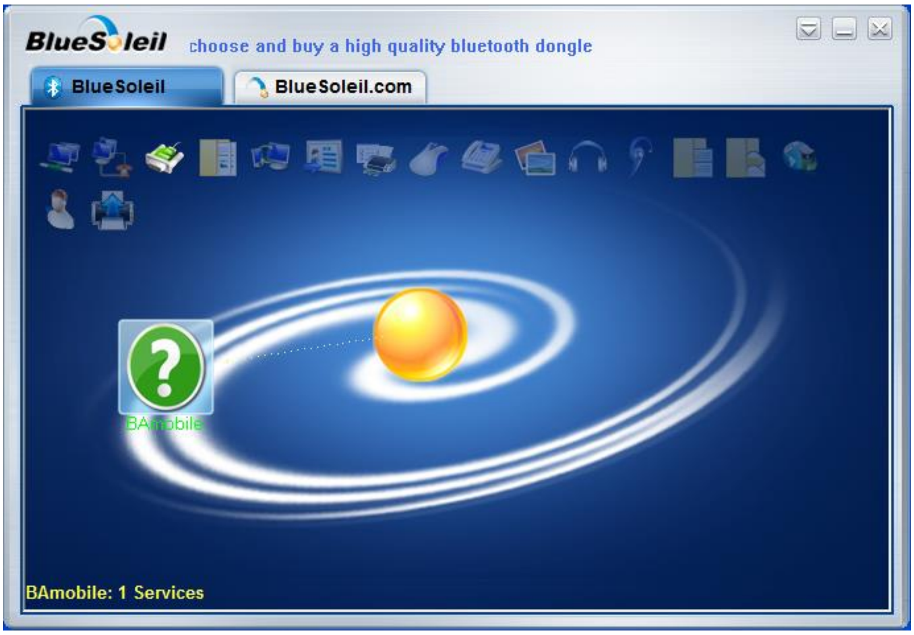
It might be necessary to click on the question mark and to press the right mouse button also for calling up the device name. In this case:

Press **Call up device name.** The result shows the name BAmobile. Now **Search Services**.

The window below appears. Now select the option “Pair”.







Enter the **password 0000** here. Right mouse button again for options.

This time, a slightly changed list appears.

Search Services

“Connect Bluetooth Serial Port”

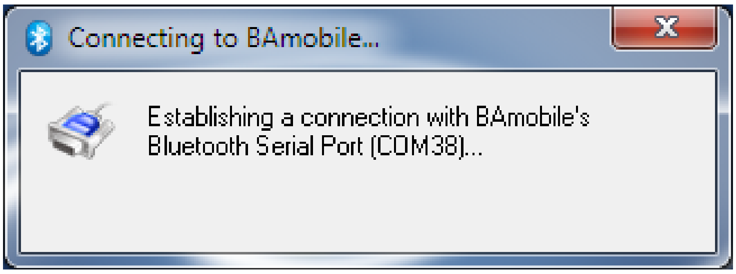
A dotted line appears between the device and the sun, on which a red dot moves along the line (image lower left corner).

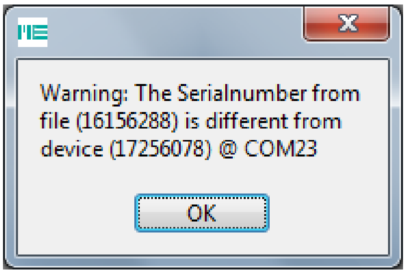
This means that the connection is made. If you now press the right mouse button on the external device, a new selection menu will appear:

- **Search Services**
- **Disconnect Serial Bluetooth-Port (COM23)**
- Delete
- Properties …
- Rename
- More bluetooth devices …

The specified COM port is given as a connection in the software GSVmulti.

If different GSV-4BTs are called in succession, a warning similar to the one shown on the next page may appear. The warning can be ignored. But the calibration data of the sensors have to be checked.



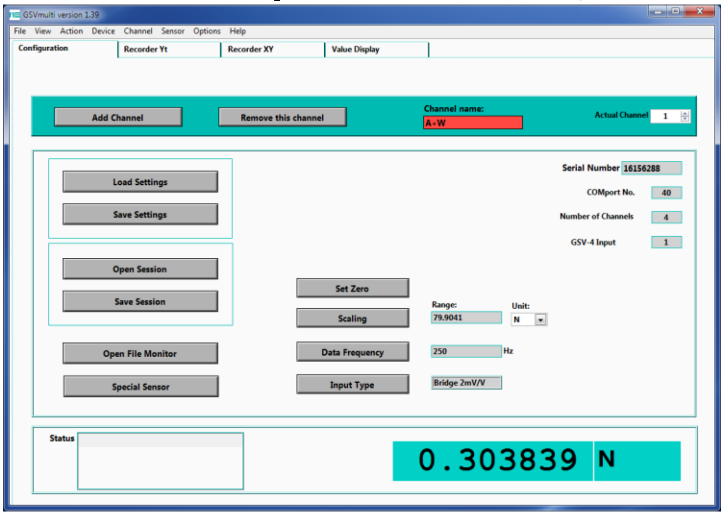


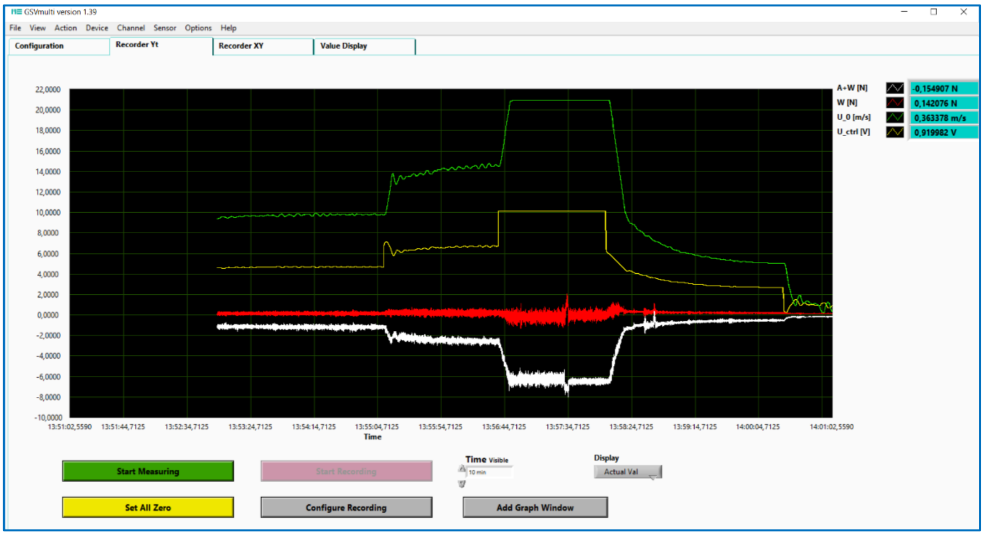
Once the connection data has been stored in a session within GSVmulti, the software automatically opens the connection to the measurement amplifier when it is called up.

(3) Software GSVmulti and Hardware GSV-4 BT for force sensors

Channel	Measured variable	Unit
1	Force sensor A (L+D)	N
2	Force sensor B (W)	N
3	Wind velocity U_0	m/s
4	Control voltage U_ctrl	V

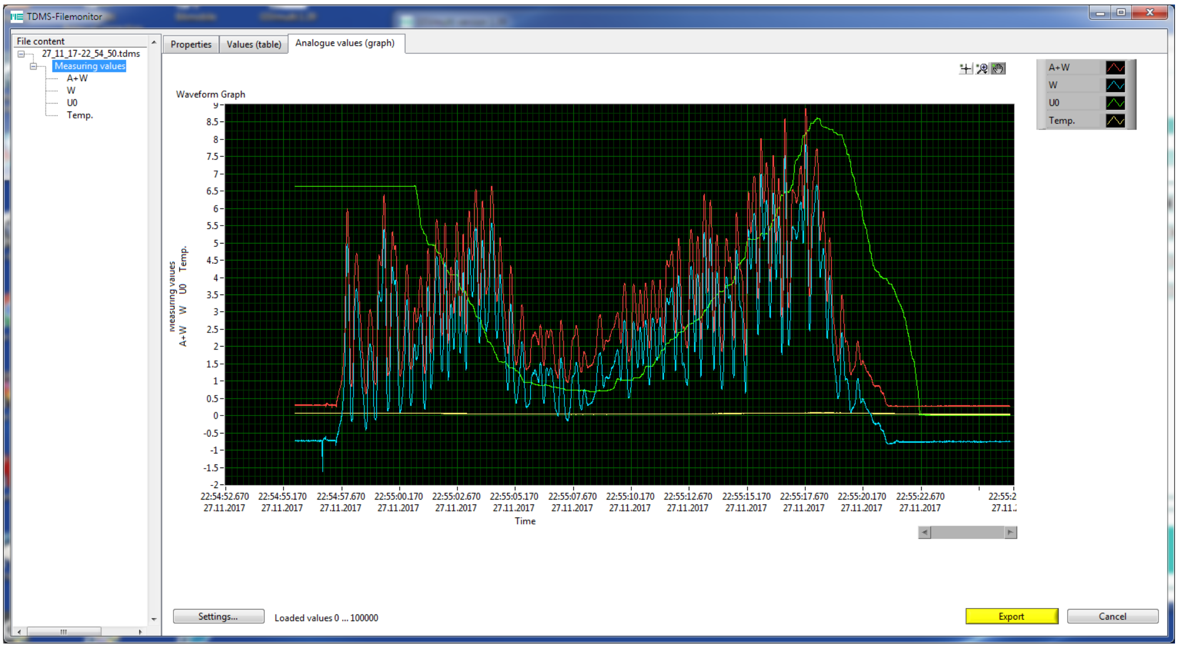
The hardware is a four-channel measuring amplifier, which is configured for the wind tunnel ANIPROP GWK3. L + D refers to the measuring priniple of the balance. The front sensor A measures lift L and drag D are measured, the rear sensor measures D only. Channel 3 indicates the output to the wind sensor, which maps the measuring range 0 ... 20 m / s to 0 ... 10 V. Channel 4 represents the control voltage for the motors. The adjoining configuration window allows the adjustment of the channels. The scan rate is up to almost 1000 Hz. A typical measurement on the tunnel shows the following picture. The wind speed indicator is already balanced and shows the actual wind speed, which is also indicated by the wind sensor on the display. The wind tunnel has been raised in three steps from 0 to 20 m/s. The measuring object is a plane plate with a varying angle of incidence:





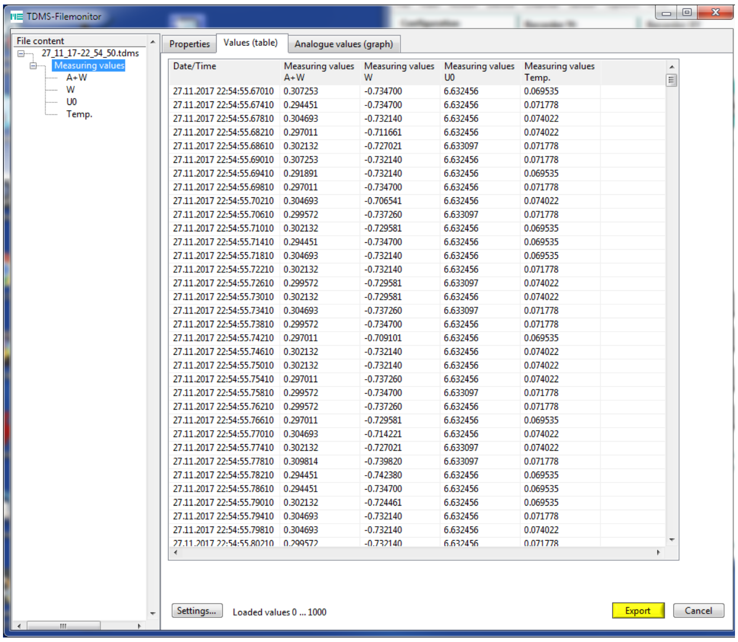
The following figure shows the main window for measurements[8]. However, the data do not come from an experiment. The control voltage is not displayed in the two following graphs.

The acquired data have been recorded simultaneously and given a systematic name, in this case 27_11_17-22_54_50.tdms. With "Open File Monitor" you can look at the file.

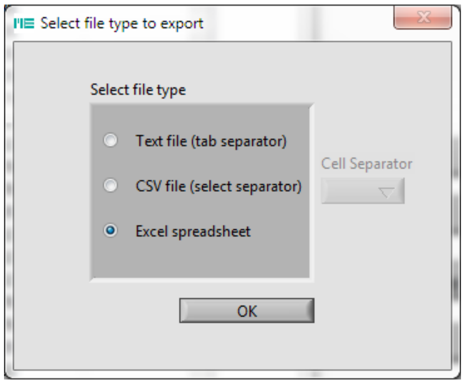


Since the GVSmulti software is based on Labview, you can see Labview's typical data analysis options by selecting and expanding data areas.

[8] These figures are taken from the German version of the user manual. L corresponds to A and D to W.



The first drop-down menu in picture to the left "Properties" provides some technical information about how the spreadsheet was generated. The second menu shows the data as array. The amount of data that you want to see can be chosen with Settings … underneath the graph. The option "Export" leads to the selection



The data can be exported to an Excel file, which offers numerous possibilities for graphical representation.

- But you can also directly open the * .tdms file with the Microsoft Excel Importer[9]. This way has the advantage that the file information is also included in the file.

File information includes the full date from the beginning to the end of the measurement and the scan rate. The file contains two sheets. The first sheet is named with the systematic name of the file, the second sheet contains the full-resolution measurement data:

Root Name	**Title**	**Author**	**Date/Time**
06_01_18-20_17_01_Test_GWK3			
Group	**Channels**	**Description**	*Decimation*
Measuring values	4		Not used. every value from device recorded.
Measuring values			
Channel	**Datatype**	**Unit**	**Length**
L+D	DT_DOUBLE	N	340
D	DT_DOUBLE	N	340
U0	DT_DOUBLE	m/s	340
U_ctrl	DT_DOUBLE	V	340

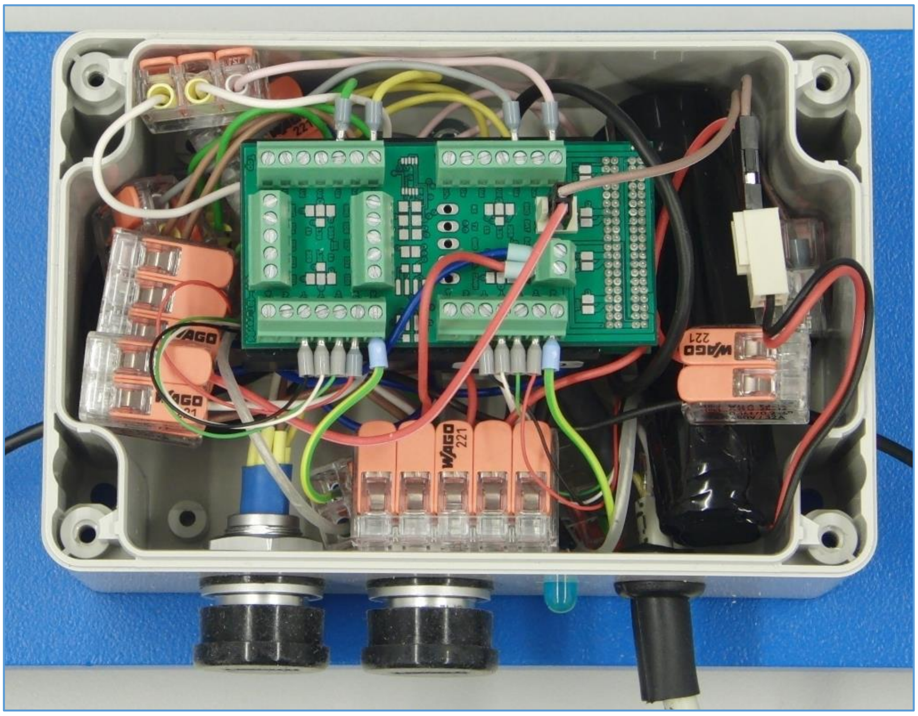
The information in the *root* sheet extends over a longer column area, and therefore is not fully mapped.

Link: https://www.me-systeme.de/en/software/gsvmulti

[9] The Excel Importer is a free add-in by National Instruments: http://www.ni.com/example/27944/en/

(4) Electrical construction with measuring amplifier GSV-4BT

The measuring amplifier GSV-4BT from ME-Systeme[10] is located on the weighing device and is connected to the two force sensors. The supply voltage is obtained from the control unit UNIcon via a cable permanently connected to the weighing device. The additional measurement data are supplied via a 6-pin cable, which connects the two parts, the weighing device and the control unit. The following figure shows the opened terminal box on the weighing unit.



On the front are two sockets for the data cable, which are identically assigned. The free socket serves the possibility of connecting other devices for data acquisition or, if appropriate, alternatively to feed other data for transmission with the measuring amplifier.

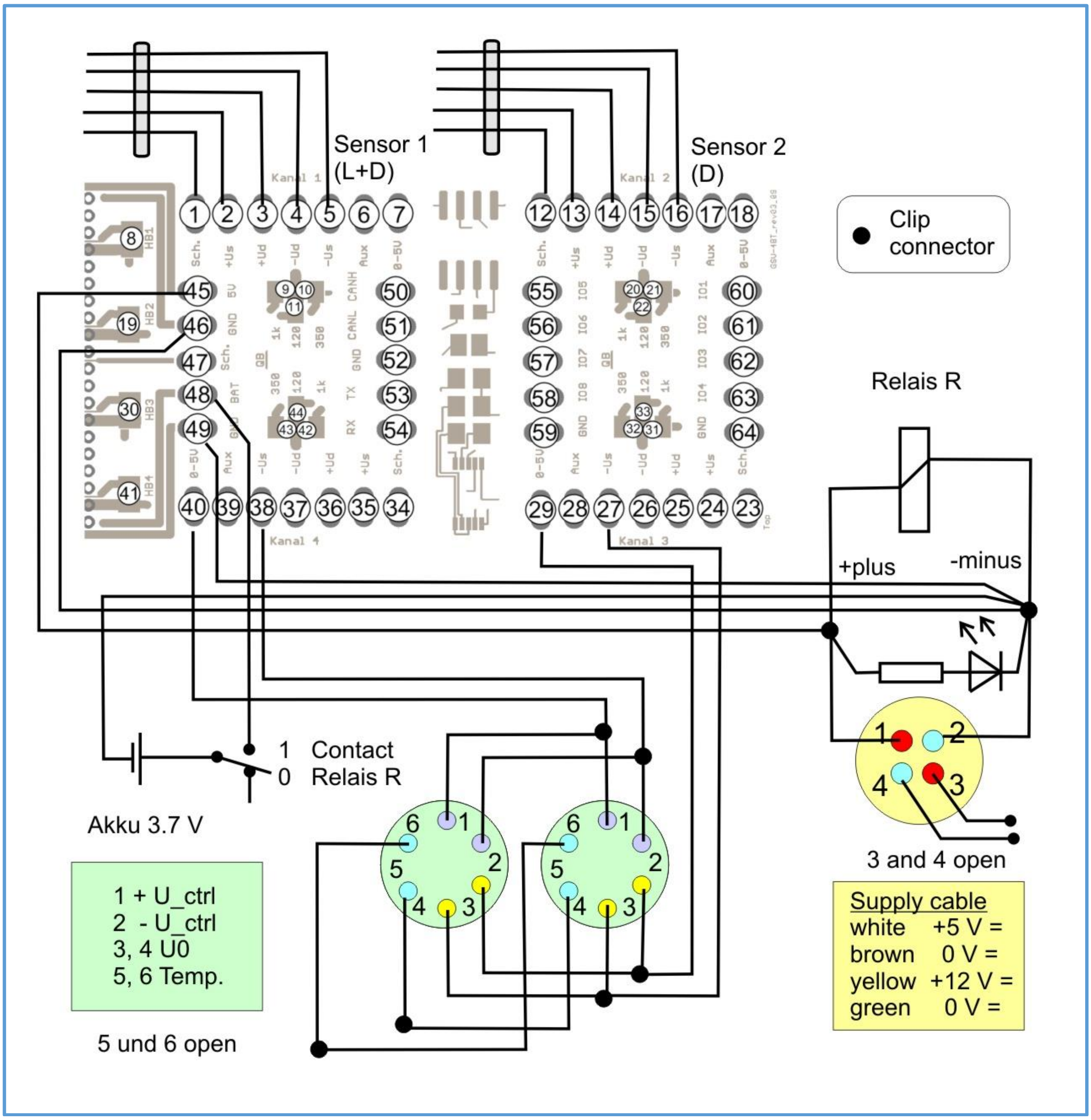
- All connections in the connection box are clip-on connectors so that the connections can easily be changed for individual configuration.

The picture shows in the middle not the measuring amplifier itself with Bluetooth transmitter, but the corresponding adapter MSTB with screw connections. The measuring amplifier is located underneath and is plugged onto the adapter. The four 7-pin connections in the longitudinal direction are the inputs of the measuring amplifier or the supply lines for data transmission. The four channels start in the lower row from right to left in a clockwise direction. Channels 1 and 2 each have four connections for the supply voltage (red / black) and the bridge voltage (green / white) of the force sensors in addition to the shield, while tunnels 3 and 4 transmit the voltages for the wind sensor (yellow / green) and the control voltage (pink / gray). The colors refer to (+ plus / -minus).

The measuring amplifier with Bluetooth transmitter is powered by a lithium accumulator 3.7 V. The battery is supplied via a standard plug whose connections (red / brown) do not lead directly to the battery. The battery serves as a buffer for the 5 V supply voltage from the UNIcon control unit, which is fed to the screw connections in the middle (red / blue).

[10] The manual gives more information.
https://www.me-systeme.de/produkte/elektronik/gsv-4/anleitungen/ba-gsv4_en.pdf

The supply voltage supplies a relay, which turns on the voltage supply for the amplifier under voltage. A blue control diode indicates the existing voltage supply for the weighing device. The circuit diagram of the junction box can be seen below. For details of the amplifier please refer to the supplied description of the GSV-4BT.



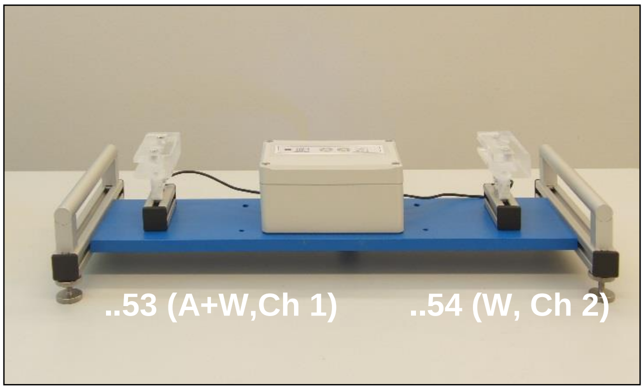
Wiring diagram “Connection Box” of the weighing device with sensors

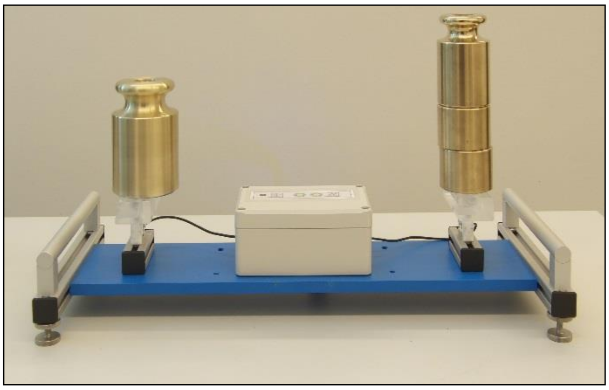
5. Check and calibrate the wind tunnel balance

1. Sensitivity of the force sensors

For the use of force sensors for the weighing device (serial number 1516304) of the wind tunnel balance of the GWK3, first some explanations are given below. The check is done by way of example with installed components. The two sensors KD24s 20 N - 18100053 and 18100054 from ME-MessSysteme are used in conjunction with the measuring amplifier GSV-4BT. The measuring amplifier can be operated with two input sensitivities s_M, s_M = 2 mV / V and s_M = 10 mV / V. The data of the measuring amplifier are sent via Bluetooth to a PC and evaluated with the software GSVmulti Version 1.39.

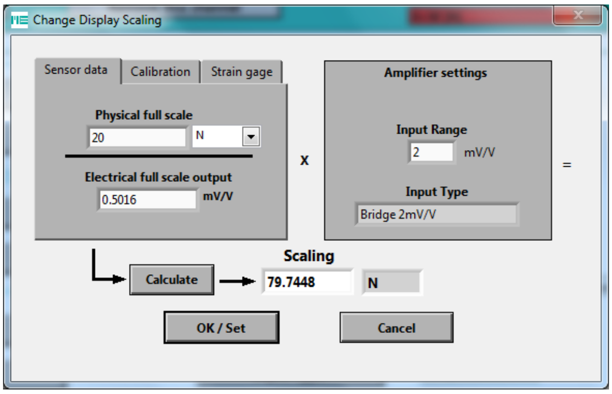
The two pictures below show the weighing device without and with weights of 2 kg each, which just reach the intended nominal load of F_S = 20 N. The force exerted by the weights is F = 19.6133 N. The weights stand on the holder for the support, which in turn carries the test object during measuring operation.

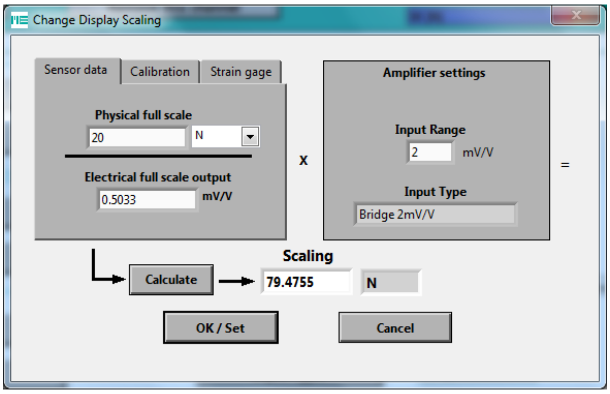




The sensors have the following properties according to the test protocol:

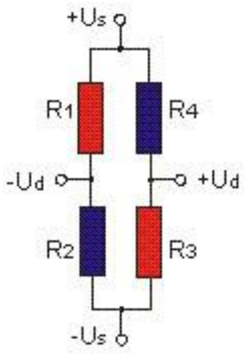
Sensor	Zero signal [mV/V]	Characteristic k_S [mV/V/ F_S]	Resistance [Ω]	Scaling factor f_S [N]
18100053	-0.0218	0.5016	481.45	79.7448
18100054	0.0133	0.5033	425.18	79.4755





Sensor 53 (left) Sensor 54 (right)

The scaling factor f_S results from the set sensitivity of the amplifier of 2 mV/V (see below). In each of the two windows for the scaling, the characteristic value k_S is determined as *Electrical full balance output*. This value must be entered manually. Use the *Calculate* key to calculate the *Scaling*. Only this - gray highlighted - scaling factor is stored in the amplifier.



Us: Bridge supply voltage
Ud: Bridge output
ε : Strain
k: k-Factor (ca. 2,0)
Ud/Us = 1/4 · (ΔR1/R1 - ΔR2/R2 + ΔR3/R3 - ΔR4/R4)
Ud/Us = 1/4 · k · (ε1 - ε2 + ε3 - ε4)

With a k-Factor k=2,0 follows:
500 µm/m corresponds to 1 mV/V

The full bridge with 4 active strain gages is the preferred standard circuit in sensor construction. The strains of R1, R2, R3, and R4 are equal in magnitude. The strains of R1 and R3 are respectively opposed to the strains of R2 and R4.
Source: https://www.me-systeme.de/en/technology-first/strain-gauge/strain-gauge-bridge-circuit

The characteristic value k_S describes the sensitivity of the force sensor and is defined as the bridge voltage of the force sensor at rated load and per volt bridge supply voltage U_S. Their value is at the measuring amplifier GSV-4BT U_S = 2.5 V.

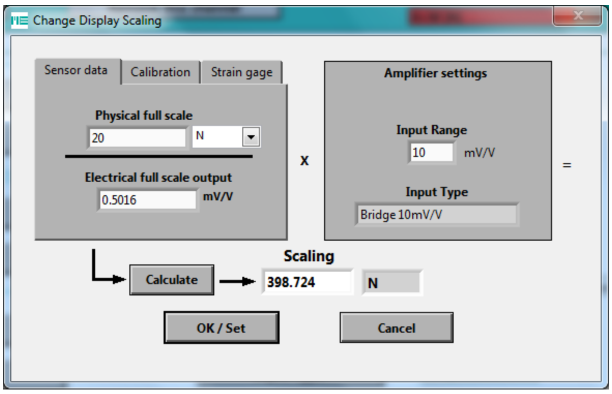
Numerical example: With a nominal force of 20 N and a characteristic value k_S = 0.5 mV/V, a bridge voltage U_D of 1.25 mV results. A final measurement confirmed this value within the measurement accuracy of the voltage meter used.

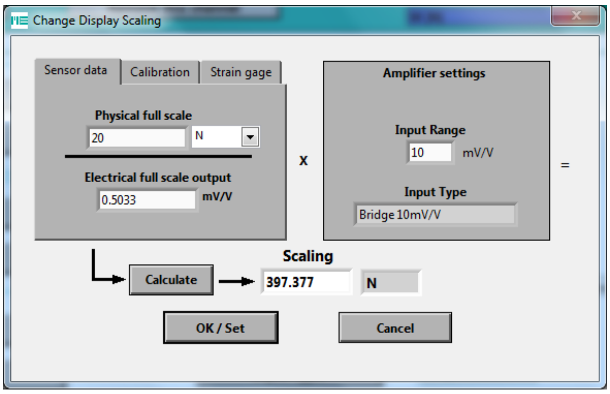
Once the "OK / Set" button has been pressed, the scaling factor is calculated and the next time the window is called, only the input range appears. Then you must not press the "OK / Set" button again.

The scaling factor f_S is the quotient oft the input sensitivity s_M of the amplifier and the value k_S

$$f_S = s_M / k_S\text{; in numbers } f_S = (2\text{ mV/V}) / (0.5\text{ mV/V}/20\text{ N}) = 80\text{ N}$$

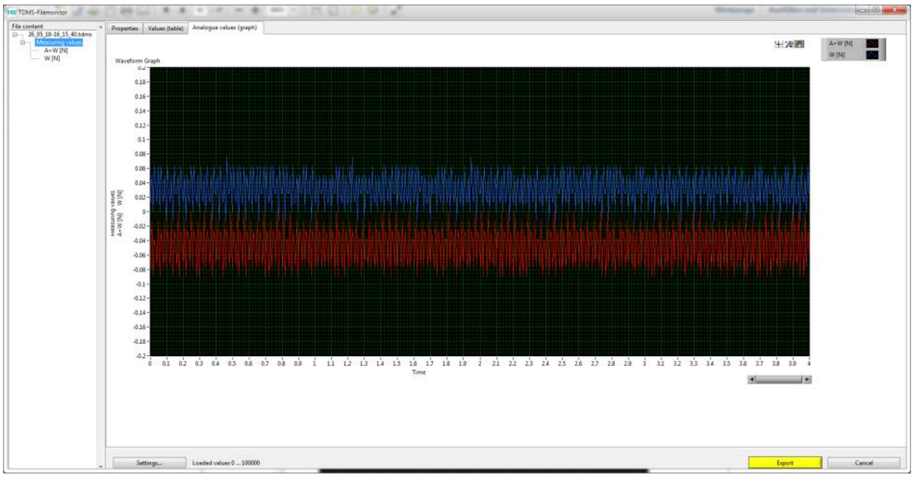
The numbers actually shown differ slightly from the simplified example. If you change the input sensitivity to 10 mV/V, the scaling factor increases fivefold to 400 N:



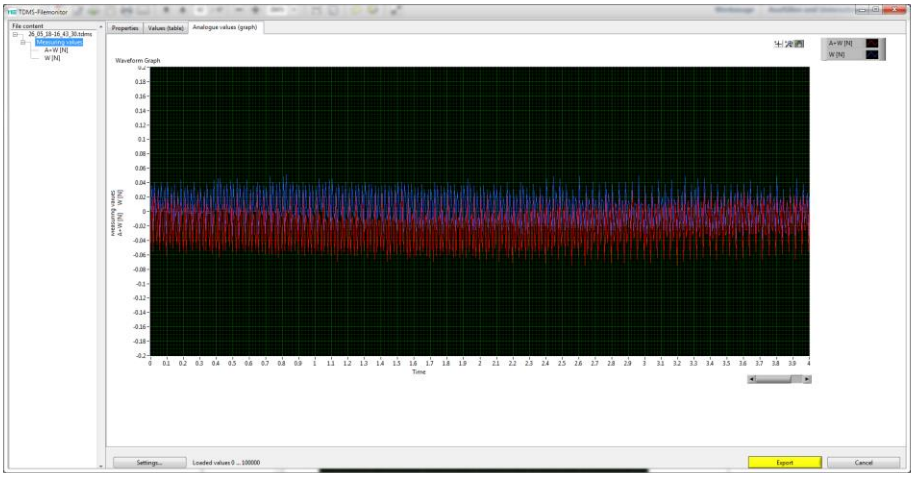


Subsequently, the data of the two sensors were first recorded at a measuring frequency f = 125 Hz for the two different input sensitivities. It can be seen that the values for 10 mV/V fluctuate around a zero value, which is slightly higher than specified in the test report. The set zero button was pressed before the measurement each time. The mean values below are among the graphs below.

Measurement with input sensitivity 10 mV/V:



Measurement with input sensitivity 2 mV / V:

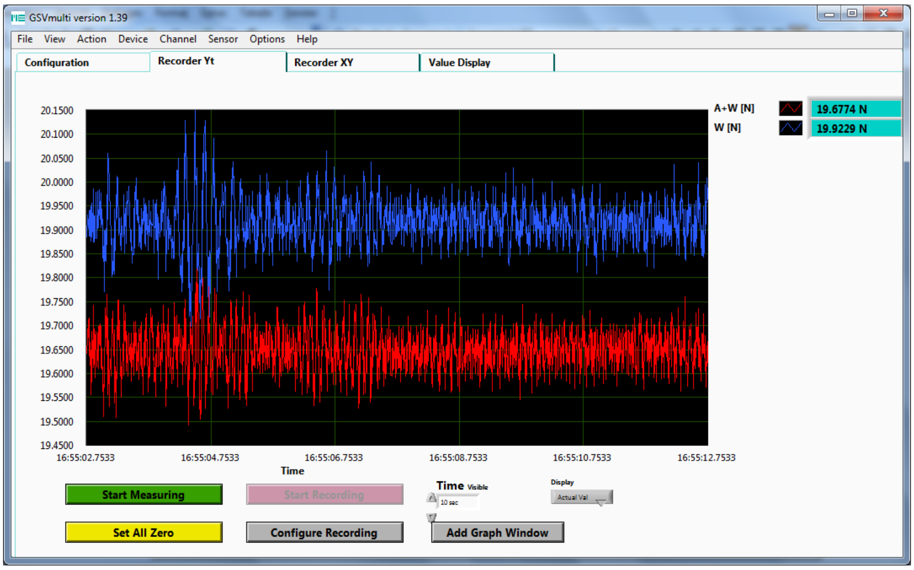


Sensor	Zero signal [mV/V]	Measured at 10 mV/V	Measured at 2 mV/V
18100053	-0.0218	-0.0475	-0.0213
18100054	0.0133	0.0305	0.0061

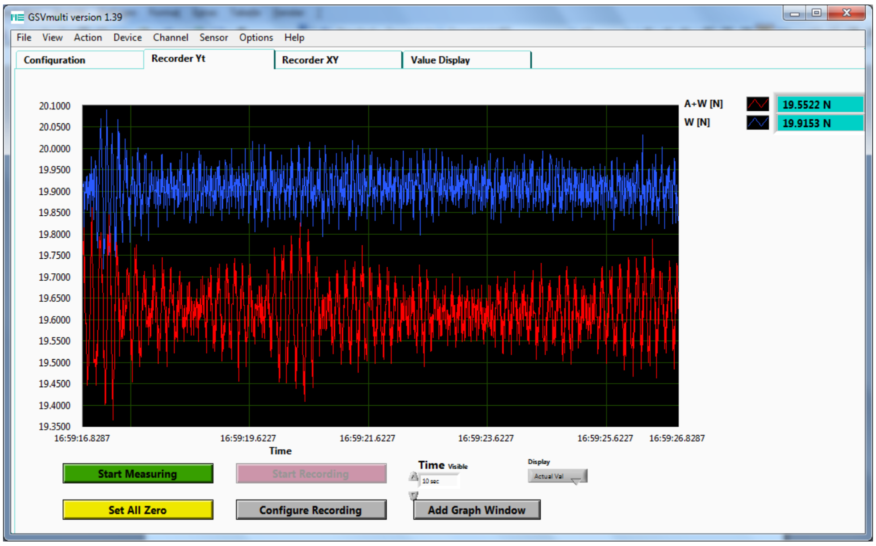
If the weights shown at the beginning are put on, there is no coincidence between the values. The following image series shows various placement attempts, which were carried out as well as possible. First the results at k_S=2 mV/V:

Sensor Set 19.6133 N	Layout 1 Averaged values	Error %	Layout 2 Averaged values	Error %
18100053	19.648	+0.18	19.620	0.03
18100054	19.920	+1.56	19.910	1.51

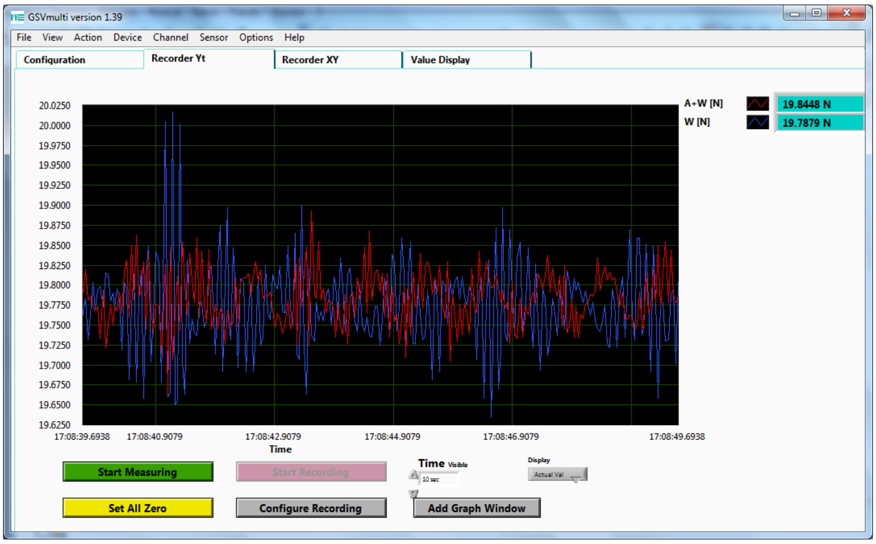
Measurement with layout 1: 2 kg weight at L + D, combined weight 2 kg at D.



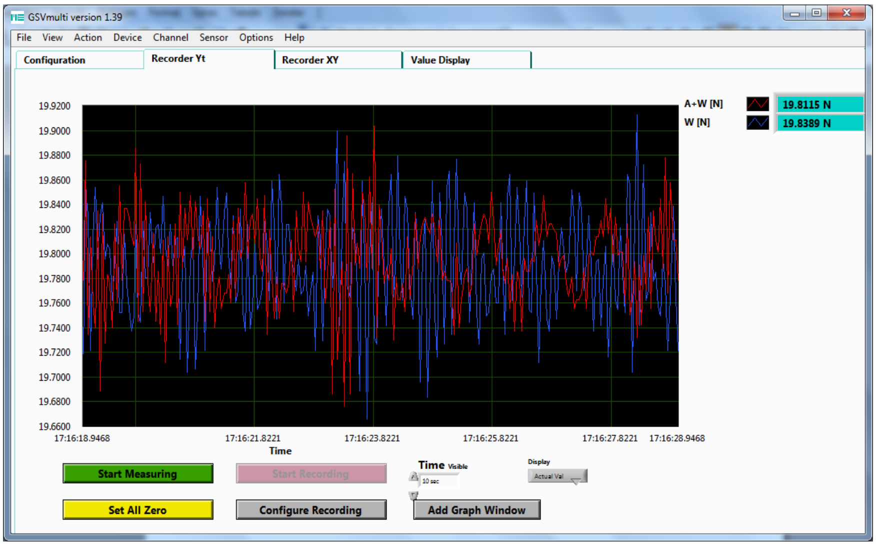
Measurement with layout 2: 2 kg weight at D, combined weight 2 kg at L + D.



Now the measuring frequency has been reduced from 125 Hz to 25 Hz. The signals clearly move together. With k_S=2 mV/V the measurement according to layout 1:



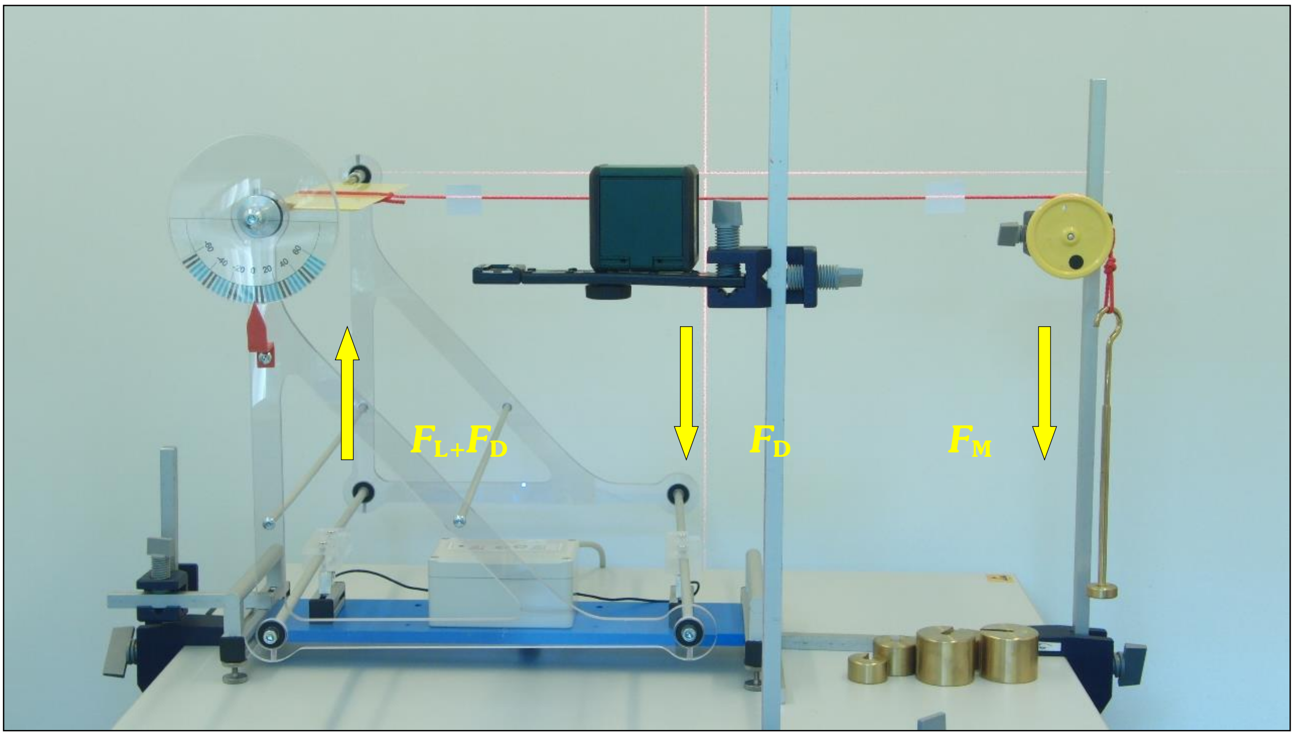
Measurement according to layout 2:



Sensor Set 19.6133 N	Layout 1 Averaged values	Error %	Layout 2 Averaged values	Error %
18100053	19.784	+0.87	19.796	+0.93
18100054	19.774	+0.82	19.792	+0.91

2. Measuring principle as the basis for determining the accuracy of the balance

The calibration measurements are carried out with the support and the measuring object inserted. The following picture shows the used configuration.



The flat plate (yellow) is pulled at the angle of attack 0 ° in the middle via a traction cable with variable force F_M. F_M corresponds to the drag F_D in the wind tunnel. The force arises from the load of a vertically suspended weight M, which exerts the horizontal force F_M via a deflection roller. The rope is leveled. On the left and right of the leveling device, white pieces of paper are attached to the rope. It can be seen that the red laser line lies on both sides on the extension line of the rope. The design of the balance in this case - the load alone with a horizontal force - causes the force F_M to raise the front left load sensor by the same amount that the rear right sensor is pushed down.

F_M for the left sensor corresponds in the wind tunnel the sum of lift and drag $-(F_L+F_D)= F_M$. In the theoretical ideal case, the measured values are in line. The deviation indicates the error of the balance during measuring operation.

3. Accuracy of the balance

In the diagram on the next page, the error is + 2% for the sensor L+D and -2.2% for the sensor D. The mirror-image errors indicate that despite the care taken when setting up the measurement still setting errors have occurred. However, with every load, there is also a slight deformation of the support, which also contributes to an error in the measurements.

- The expected measured values must correspond exactly to the respective load generated with calibration weights of high accuracy.

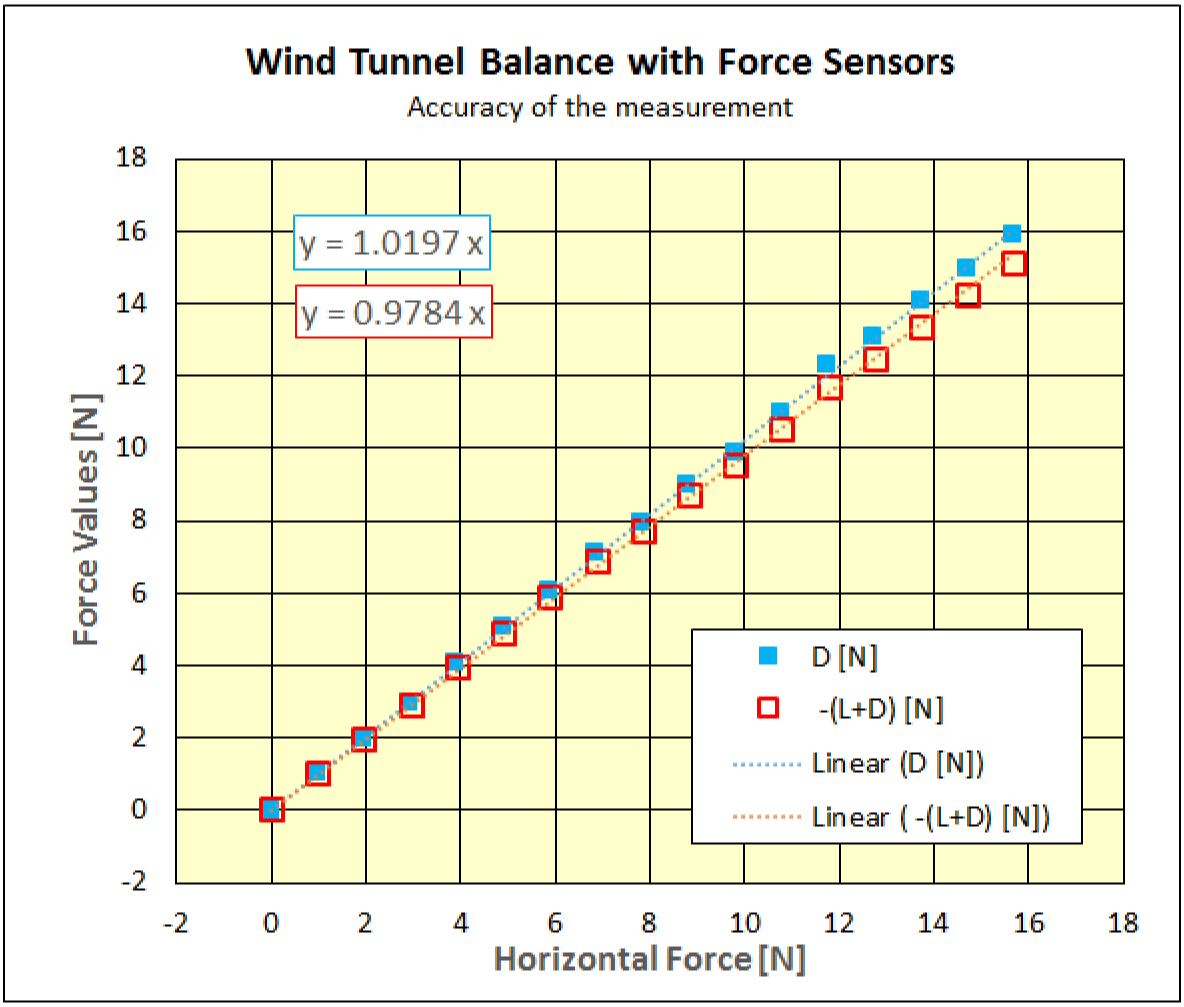
In each case, data from 200 measured values, which were recorded at a measuring frequency of 25 Hz, were averaged for the evaluation.

- **In practical measuring operation, measurement results might contain an error of up to +/- 2.5%.**

Measurement	Content
31_05_18-15_20_08	Set zero both channels
31_05_18-15_21_26	100 g
31_05_18-15_22_26	200 g
31_05_18-15_23_30	300 g
31_05_18-15_24_24	400 g
31_05_18-15_27_04	500 g
31_05_18-15_27_53	600 g
31_05_18-15_29_03	700 g
31_05_18-15_29_51	800 g
31_05_18-15_30_37	900 g
31_05_18-15_31_31	1000 g
31_05_18-15_39_27	1100 g
31_05_18-15_40_28	1200 g
31_05_18-15_41_37	1300 g
31_05_18-15_42_18	1400 g
31_05_18-15_43_07	1500 g
31_05_18-15_43_49	1600 g
31_05_18-15_45_58	Zero offset adjustment
31_05_18-15_47_47	Set zero for both channels

The load of 16 N does not occur during a regular measuring operation with the wind tunnel. There, values of up to about 5 N occur when the plane plate is set perpendicular to the flow, and the highest wind speed of 20 m/s is set. However, the balance is still functional up to three times this operating load. The accuracy of measurements can further increase by using the determined systematic deviation to correct the measurement results. The values have been linearly interpolated and the slope for both sizes L + D and D given. The scaling factor is the reciprocal of the respective slope. For L+D with the slope 0.9784 of the linear interpolation the scaling factor 1.022 results, for D with the slope 1.0197 the value 0.981 follows.

The file numbers of the measurements are listed for purposes of internal documentation.



Accuracy of the balance with the measuring amplifier GSV-4BT, serial number 1516304.

Theoretically, the measured values must be identical to the horizontal force.

■■■■■

6. Attachments

1. Separate printed manuals
    - Motor control UNIcon
    - Balances Kern 440-45N
    - Kern Balance Connection (including license key)

   Included as printed documents. Also to be found on the CD.
2. Documents on CD
    - Kern software on a separate CD

3. PDF files on CD

    - User manual: Large Wind Tunnel ANIPROP GWK 3
    - UNIcon_MODBUS_Master_L-BAL-E250-GB.pdf
    - KernBalance-440-45N_en.pdf
    - Testo BAL StrömungsMUF.pdf
    - Ziehl-Abegg_FE2owletECblue_FN030.pdf

■ ■ ■ ■ ■

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