Operating Instructions
HM170 Educational Wind Tunnel

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Operating Instructions
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1 Introduction

The HM 170 demonstration wind tunnel was developed for experimentation and demonstration purposes in the fields of aerodynamics and fluid mechanics. It is a subsonic, open wind tunnel with a square measurement-section profile. The extensive range of available accessories permits the performance of numerous experiments, e.g.:

- Comparison of various methods of velocity and pressure measurement
- Determination of drag coefficients of different bodies (disc, sphere, streamlined object, aerofoil)
- Determination of drag and lift coefficients of aerofoils at different angles of attack
- Effect of aerodynamic aids such as slots and flaps
- Pressure distribution with flow around cylinders and aerofoils
- Instability at an aerofoil, aerodynamic continuous excitation
- Examination of boundary layers

In addition to traditional flow measurement methods, provision is made for computer-aided data acquisition and evaluation using electronic pressure transducers and position sensors. Data can be transferred to a PC via a measurement amplifier with built-in AD converter and serial interface. A special software package permits the generation of lift and pressure distribution curves.
A wind tunnel essentially consists of the following:

- Prechamber with flow straightener (1)
- Jet (2)
- Measurement section (3)
- Diffuser (4)
- Fan (5)

The HM170 demonstration wind tunnel is an open wind tunnel of the so-called Eiffel type, where the air is drawn in from outside and blown back out into the open. The surrounding area returns the air to the inlet. This type of wind tunnel is only suitable for relatively low air velocities ($0 < Ma < 0.2$). The HM170 reaches a Mach number of about $Ma = 0.1$.

As open wind tunnels feature negative pressure in the measurement section, the section must be closed.

On the other hand, if higher velocities are required, then a closed wind tunnel can be used. Since in these wind tunnels the measurement section represents the ambient pressure, the measurement section can be open. Closed wind tunnels have an advantage in that less energy is required than in an open wind tunnel due to the closed-circuit air routing. However, they need more space to accommodate and higher cost to produce.
2.1 Function of the wind tunnel

The air is drawn in from the atmosphere via the streamlined **funnel** (1).

Any transverse flow components are filtered out in the **flow straightener** (2). It is made of a tubular honeycomb structure. The air exits from the flow straightener as a parallel flow and is accelerated to roughly 3.3 times its original velocity in the **jet** (3).

The static pressure (4) is measured downstream of the jet at the entrance to the measurement section. Based on the assumption of virtually loss-free flow, the flow velocity can be determined from the pressure difference with respect to ambient pressure (total pressure at zero velocity).

The air then flows through the **measurement section** (5) which has a constant cross-section.

After the measurement section the flow is decelerated in a **diffuser** (6) and part of the pressure drop required to accelerate the air in the jet is recovered. The diffuser angle is designed in a way to prevent flow separation.

An **axial fan** (7) with downstream guide (8) draws the air out of the diffuser and conveys it into the open.
A guard (9) in front of the fan prevents damage caused by foreign matter or models, whereas the guard (10) behind the fan prevents contact with the fan when it is in operation.
Funnel (5), jet (3) and diffuser (6) are made of glass-fibre reinforced plastic.

To provide access to the closed measurement section, the sliding guide (12) permits adjustment of jet and funnel (3, 5) together with the measurement section (2).

The flow straightener (4) has a tubular honeycomb structure.

The measurement section (2) is made of perspex glass.

The axial fan (7) is provided with a downstream guide which makes it highly efficient and producing
low noise. The fan is driven by a three-phase AC motor. A frequency converter (11) permits infinite adjustment of rotational speed and thus air velocity. The fan is rigidly connected to the diffuser and both are attached to the laboratory trolley using rubber elements. This effectively provides a shielding of vibrations and guarantees extremely smooth running.

The switch box (11) contains main switch, emergency stop, speed control and fan switch are located in .

The models (1) are attached to the electronic two-component force transducer (8). The values for drag and lift are displayed digitally on the measurement amplifier (9) with two sensitivity settings.

The inclined-tube manometer (10) is used to indicate the current air speed at the entrance to the measurement section.

The wind tunnel is installed on a laboratory trolley (13) that is easy to move. The trolley is provided with shelves and lockable drawers for storing measuring instruments, models and other materials.
2.2.2 Force measurement

The flow forces at the model are measured electronically in this wind tunnel.

For this purpose the wind tunnel is provided with a permanently installed electronic two-component force transducer beneath the measurement section.

The forces are converted via the lever arm of the model holder (1) into proportional moments which deform a bending and torsion beam (2). The deformation is measured with a strain gauge (3) and displayed digitally as force on a two-channel measurement amplifier (7).

There is relatively little deformation, so that the position of the model in the flow is scarcely influenced. The angular position of the model (angle of attack at aerofoil) in the flow is set by means of a graduated dial (6).

The flexible measuring beam on the model holder form an oscillatory system that may generate unwanted vibrations of the measuring device. The model holder is equipped with a piston-shaped shoulder (4) located beneath the measurement beam and dipped into a viscous-oil-filled vessel (5). Damping of unwanted oscillations is generated by trapped flow in the gap between the piston and the vessel.
3 Safety

**DANGER of electric shock**
Pull mains connector before opening switch box. Switch box is only to be opened by qualified personnel.

**DANGER of electric shock**
Pull mains connector before opening measurement amplifier. Housing is only to be opened by qualified personnel.

**DANGER OF INJURY caused by rotating impeller**
Never operate wind tunnel without guards at fan inlet and outlet.

**ATTENTION**
Never place moveable objects in front of wind tunnel inlet and outlet. **Strong suction!**
Inflow and outflow of air must not be hindered in order to achieve rated performance.
On installation, comply with following **minimum distances** from walls or other objects:
- Intake: 1 m
- Fan outlet: 2 m

**ATTENTION**
Lock rollers of laboratory trolley. Wind tunnel may develop thrust of up to 100 N.
ATTENTION: Lock jet properly with the catch (1) during operation. Jet may otherwise abruptly open forwards due to the negative pressure at the inlet.

ATTENTION: Close lower opening in measurement section with slide. Entry of secondary air will otherwise prevent achievement of rated wind tunnel performance.

ATTENTION: Do not overload force transducer. Measuring ranges:

- Lift $F_A$: 10 N
- Drag $F_W$: 3 N

ATTENTION: Programming of frequency converter must not be altered without consulting G.U.N.T.
4 Commissioning and operation

4.1 Installation

Rated performance is only possible if there is an unhindered inflow and outflow of air. As the air in the installation area flows from outlet to inlet, a sufficiently large space (> 150 m$^3$) must be selected in order not to influence the flow conditions.

The following minimum distances from walls or other objects are to be ensured on installation:

- Intake: min. 1 m
- Blower outlet: min. 2 m

The wind tunnel has a considerable suction effect. Lightweight, loose objects should not be positioned in front of the inlet.

The wind speed at the outlet reaches up to 100 km/h. Lightweight or loose objects are thus not to be positioned in the vicinity of the outlet.

As the wind-tunnel thrust may reach 100 N, the brakes on the laboratory trolley rollers are to be applied to stop the wind tunnel rolling away.

Appropriate fusing is to be provided for the mains connection. (e.g. 16A for 230V)
4.2 Commissioning

4.2.1 Checking inclined-tube manometer

- Align manometer horizontally using spirit level.
- Fill manometer with the supplied red liquid provided up to the zero mark on the scale.
- Finely adjust zero mark by moving the scale in the slots.
- Check hose connection between end of inclined tube and measurement socket at wind tunnel.

4.2.2 Removing the transport safety device

The transport safety device prevents the jet from opening during transport.
Remove green transport safety device (1) at the jet-guide shafts.

4.2.3 Opening and closing measurement section

To have access to the interior of the measurement section, push the measurement section with the jet forwards. The measurement section is locked in the closed position with a pin.

Opening measurement section
- Pull pin (1) upwards and push measurement section (2) forwards.
- With model fitted, lower closure plate (3) is pushed backwards out of slot by model holder (4).
Closing **measurement section**
- Insert closure plate (3) in slot of measurement section (2) and pull measurement section backwards until pin (1) engages.

- With model fitted, first pull measurement section backwards until model holder (4) is at start of lower slot. Then insert closure plate (3) and completely close measurement section (2) until pin (1) engages.

**ATTENTION:** Measurement section must be properly locked in position by **engagement of pin**. Otherwise there is a danger of sudden opening of the measurement section during operation.

### 4.2.4 Operation of fan

All fan controls are located in the switch box.
- Emergency stop switch (1)
- Main switch (2)
- Fan switch (3)
- Fan speed control (4)

**ATTENTION:** Before starting the fan first check the following:
- **No loose objects** (models, fastening screws, covers etc.) in jet, measurement section or diffuser
- **Closure plate** inserted
- **Measurement section closed** and **locked**
- **Emergency stop switch** released (pull red knob)
- **Speed control** on zero
- Turn the unit on using the main switch (2)
- Switch on fan (3)
- Use speed control (4) to increase slowly fan speed. Observe inclined-tube manometer and set desired speed.
- Speed control setting 10.0 (max.) should produce 28 m/s.

**ATTENTION:** Secondary air caused for example by absence of closure plate will reduce wind-tunnel performance.
Then max. speed would not be reached.
4.3 Speed measurement

4.3.1 Measurement with built-in instrument

The air speed is measured at the entrance to the measurement section. The static pressure $p_s$ in the duct is tapped by means of four holes distributed around the periphery of the duct.

The difference in pressure between total and static pressure corresponds to the dynamic pressure $p_d$ and is proportional to the square of the flow velocity.

Assuming negligible pressure losses, the total pressure $p_g$ in the duct is equal to the total ambient pressure $p_u$. This raises the need for pitot tubes in the duct which would influence the flow field.

With density $\rho$ of air, speed is thus:

$$v = \sqrt{\frac{2 \ p_d}{\rho}} = \sqrt{\frac{2 \ (p_u - p_s)}{\rho}} = \sqrt{\frac{2 \ \Delta p}{\rho}}.$$

Height $h$ of liquid column in inclined-tube manometer gives

$$\Delta p = \rho_l \ g \ \Delta h.$$

where $\rho_l$ is the density of the liquid.

$$v = \sqrt{\frac{2 \ \rho_l \ g \ \Delta h}{\rho}}.$$

Direct speed readings can be taken by means of a scale calibrated in m/s on the manometer.
4.3.2 Measurement with Prandtl tube

If available, a Prandtl tube may also be used to measure the speed.

Such a tube is a combination of a pitot tube for measuring the total pressure and a measurement point for measuring the static pressure. The two pressures are transferred to a differential pressure gauge (3) by means of a double-walled tube.

The measurement point (1) for the total pressure is on the end face of the probe to which the flow is applied. Further measurement bores (2) are uniformly distributed around the periphery for measuring the static pressure. Taking the mean value of the peripheral points will minimize a possible oblique flow.

The speed is calculated as follows

\[ v = \sqrt{\frac{2 \rho_f g \Delta h}{\rho}}. \]

The probe should be parallel to the flow when Prandtl tube is used for measurement.
4.3.3 Calibration of speed measurement

The built-in speed measuring device can be calibrated if a Prandtl tube is available.

Due to pressure losses in the inlet, the flow straightener and the jet, the total pressure at the measurement point does not exactly correspond to the ambient pressure. Allowance for the resultant measurement error can be made by a correction factor.

The current air density must be known for precise measurement. This is taken from tables on the basis of known atmospheric pressure, relative humidity and temperature, e.g.

- Atmospheric pressure: 1013 mbar
- Rel. humidity: 60%
- Temperature: 20 °C
- Density: 1.199 kg/m$^3$

Measurement is to be performed as follows:
- Remove any models from the measurement section.
- Close off lower slot of measurement section (1) with slide (5).
- Close and lock measurement section.
- Connect Prandtl tube (2) to second inclined-tube manometer (3).
- Align the manometer (3) horizontally and set zero point.
- Set wind-tunnel speed at 20 m/s.
- Insert Prandtl tube (2) into measurement section through 13mm-hole (4) on its side.
- Use Prandtl tube to take measurements at various points in flow cross-section and note down pressures. Ensure sufficient wall clearance (min. 50 mm). Do not take measurements in the vicinity of fastening holes.

- Make sure Prandtl tube is aligned in parallel to the flow.

- Using the mean values displayed and determine with current density the speed

\[ v_0 = \sqrt{\frac{2 \rho_{fl} g \Delta h}{\rho}}. \]

- Calculate correction factor at speed \( v \) of the built-in instrument

\[ k = \left( \frac{v_0}{v} \right)^2. \]

Corrected speed is thus

\[ v_{corr} = \sqrt{k \cdot v^2}. \]

Repeat measurement for other speeds and check correction factor.
4.4 Installation of models

Aerodynamic models for which a force measurement is to be performed must have a model holder with a shaft diameter of Ø4 mm.

To obtain the correct lever arm for the force measurement, the length of the holder should be 190 mm measured from the centre of the model. This simultaneously positions the model in the centre of the measurement section.

- Before inserting model in two-component force transducer, set angle scale to zero.

- Insert model and carefully secure with upper knurled screw.

In doing so, set model to a distance of exactly 302 mm between centre of bending beam and centre of model. The force measuring device is calibrated to this lever arm.

- Set desired angle of attack by loosening the lower knurled screw and turning the angle scale. Re-tighten knurled screw.
Other models and devices, such as instability model for aerofoils, models for investigating boundary layers or different measurement probes can be attached to the holes in the measurement section.

Side

Top

HM 170 Educational Wind Tunnel

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4 Commissioning and operation
4.5 Force measurement

4.5.1 Force transducer

The flow forces at the models are measured by an **electronic two-component force measuring device**.

This device consists of a force transducer and a measurement amplifier with display.

The forces $F_A$ (Lift) and $F_W$ (Drag) are converted by means of the lever arm $a$ of the model holder into proportional moments $M$, which deform a bending and torsion beam.

The deformation is measured with a strain gauge and displayed digitally on the two-channel amplifier as force.

Lever arms other than $a=302$ mm involve correction of the displayed force $F$.

$$F_{corr.} = \frac{F \cdot 302}{a} \text{ with } a \text{ in mm}$$

The following force directions are conventionally-defined as positive (top view):
4.5.2 Measurement amplifier

The measurement amplifier contains two bridge amplifiers with variable gain. These amplifiers take their input from the strain-gauge full bridges in the force transducer.

The output voltages are directly indicated on two digital displays as lift (1) and drag (2) in N. Zero calibration of the displays can be performed with two offset potentiometers (3, 4). Tare setting is thus also possible. Sensitivity can be altered by a switch (5) by a factor of 10.

The measurement amplifier is connected to the force transducer via a 8-pole cable.

The mains switch (6) is on the back.

The unit should be allowed to warm up for roughly 30 min. prior to measurement. Zero calibration of the display is then performed.

4.5.3 Error due to influence of dead weight

In the case of models with support outside the centre of gravity, there is an additional error indication caused by the effect of weight \( G \cdot s \).

As this error is static, compensation can be provided by means of zero balancing in stationary condition with model fitted.
4.5.4 Error caused by model holder

The drag of the model holder may bias the measurement.

As the error is a function of speed, it does not occur in stationary condition and cannot be equalised by means of offset balancing.

Compensation involves the following steps:

- Fit **holder without model**.
  If holder is permanently connected to model, fit substitute holder with same geometric dimensions.
- When the measurement speed is reached, measure the drag.
- Fit **model** and repeat measurement at same speed.

The difference between the two measurements gives the net drag force at the model.

\[ F_W = F_G - F_H \]
A simple experiment is outlined here. Other interesting experiments are contained in the instructions for G.U.N.T. accessories.

The experiment involves determination of the drag coefficient \( c_w \) on a simple circular disc.

The drag on an object subjected to flow can be calculated using the following equation

\[
F_w = \frac{1}{2} \rho c_w A v^2 .
\]

Drag increases with the square of the velocity.

Furthermore, it is governed by the density \( \rho \) of the air, the projected area \( A \) of the object and the drag coefficient \( c_w \), which reflects the influence of the object’s shape, but is independent of its size.

If \( c_w \) is known, drag can be calculated in advance for any body. The drag coefficient can be determined from the drag at given velocity

\[
c_w = \frac{2 F_w}{\rho A v^2} .
\]

A circular disc of 80 mm diameter is installed in the measurement section at right angles to the direction of flow.

The drag is measured at 25 m/s

\[
F_w = 2.23 \, \text{N} .
\]

The projected area of the end face is

\[
A = \frac{d^2 \pi}{4} = \frac{0.08^2 \pi}{4} = 5.02 \times 10^{-3} \, \text{m}^2 .
\]
With $T = 18^\circ\text{C}$, $p = 1026$ mbar and a relative humidity level of 60% the air density is

$$\rho = 1.225 \text{ kg/ m}^3 .$$

The drag coefficient can be thus calculated

$$c_w = \frac{2 F_w}{\rho A V^2} = \frac{2 \cdot 2.23 \text{ N}}{1.225 \text{ kg/m}^3 \cdot 0.00502 \text{ m}^2 \cdot 25 \text{ m}^2 / \text{s}^2}$$

$$c_w = 1.16 .$$

This value is comparable to the value (1.10) found in the literature.
Appendices

6.1 Technical Data

**General data**

Dimensions
L x W x H : 2850 x 750 x 1700 mm³
Weight: 250 kg
Power supply: 230 VAC, 50 Hz, 1ph
Alternatives optional, see type plate

**Measurement section**

Cross section: 292 x 292 mm²
Length: 450 mm

**Force measurement**

Model holder, dia. 4 mm
Model holder, length to centre of model: 225 mm
Lever arm, centre of model to bending beam of force transducer: 302 mm
Measurement ranges:

Lift: 10 N
Drag: 3 N
Resolution: 0.01 N
Display: 3 1/2 digit
Switchable gain: x1, x 10
Offset adjust: ± 50 % FS

Air flow

Air velocity (adjustable): 0 to 28 m/s
Irregularity of velocity ± 2 %
(for a measurement section of 200 x 200 mm²)

Velocity distribution across the working section
Fan
Head: 500 Pa
Max. air flow: 2.5 m³/s
Blower wheel dia.: 400 mm
Motorpower: 2.25 kW
Speed (variable frequency control):
0 to 2800 RPM
## 6.2 List of symbols

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<th>Symbol</th>
<th>Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>a</td>
<td>Length of lever</td>
<td>m</td>
</tr>
<tr>
<td>A</td>
<td>Area</td>
<td>m²</td>
</tr>
<tr>
<td>(c_w)</td>
<td>Drag coefficient</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>Diameter</td>
<td>m</td>
</tr>
<tr>
<td>F</td>
<td>Force</td>
<td>N</td>
</tr>
<tr>
<td>(F_w, F_A)</td>
<td>Drag, Lift</td>
<td>N</td>
</tr>
<tr>
<td>g</td>
<td>Acceleration due to gravity</td>
<td>m/s²</td>
</tr>
<tr>
<td>G</td>
<td>Weight</td>
<td>N</td>
</tr>
<tr>
<td>h</td>
<td>Head</td>
<td>m</td>
</tr>
<tr>
<td>k</td>
<td>Velocity correction coefficient</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Moment</td>
<td>Nm</td>
</tr>
<tr>
<td>p</td>
<td>Pressure</td>
<td>N/m²</td>
</tr>
<tr>
<td>s</td>
<td>Distance to centre of gravity</td>
<td>m</td>
</tr>
<tr>
<td>(\rho)</td>
<td>Density</td>
<td>kg/m³</td>
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