

Configuration wt_mk2_full

```

config version : 1.1
chamber model  : Wind Tunnel Mk2

changelog
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1.1: Added ground-truth graph and table of contents.
1.0: Initial version
    
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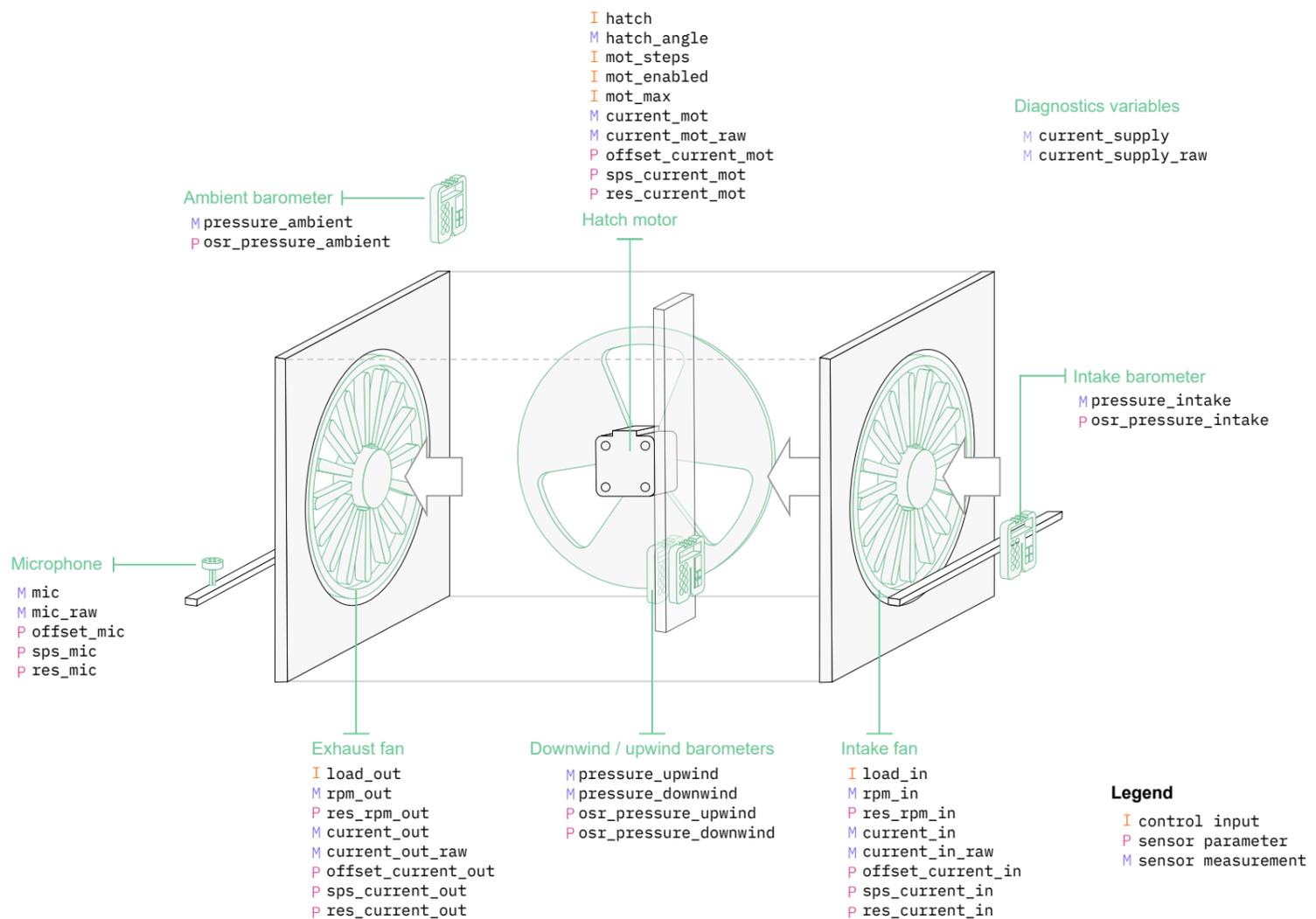
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Description

This configuration exposes all variables of the Wind Tunnel Mk2. The oversampling rates of the barometers (`osr_pressure_*`) and the analog sensors (`sps_*`) can be manipulated, changing the measurement frequency of the complete system; for constant-time measurements, please use the configuration `full_timed`.

Chamber Diagram

See the variables table for a detailed description of each variable.



Variables Table

Variable	Settable	Values	Default	Description
timestamp	No	float	–	The timestamp of the measurement, in seconds with respect to the system wall-clock.
counter	No	$\{i \in \mathbb{Z} : i \geq 0\}$	–	Measurement counter.
flag	Yes	float	0	User-defined flag.
intervention	No	$\{0,1\}$	–	Intervention flag. Has a value of 1 if this is the first measurement after a SET instruction, and 0 otherwise.
hatch	Yes	float $\in [-45.0, 45.0]$	0	The set position of the hatch, in degrees. The hatch is closed at 0° and fully open at 45°.
hatch_angle	No	float	–	The position of the hatch, in degrees, as measured by the encoder of the motor.
mot_steps	Yes	$\{3200, 1600, 800, 400, 200\}$	3200	The steps-per-revolution of the stepper motor controlling the hatch. Higher values mean a higher motor resolution, i.e., more precise positioning. At low current levels <code>mot_max</code> and/or step values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position <code>hatch</code> and the actual hatch angle.
mot_enabled	Yes	$\{0,1\}$	1	Enables (1) or disables (0) the motor controlling the hatch. If the motor is disabled (0), setting <code>hatch</code> will have no effect on the actual position of the hatch.
mot_max	Yes	$\{0, \dots, 4095\}$	3000	Regulates the maximum current drawn by the motor controlling the hatch. At low current levels and/or <code>mot_steps</code> values below 800, the motor may lose torque and start missing steps, resulting in a mismatch between the set position <code>hatch</code> and the actual hatch angle.
current_mot	No	float	–	The measurement (in Amperes) of the electric current drawn by the motor controlling the hatch.
current_mot_raw	No	$\{-32768, \dots, 32767\}$	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement <code>current_mot</code> .
offset_current_mot	Yes	$\{0, \dots, 4095\}$	0	The reference voltage (offset) of the ADC producing the <code>current_mot</code> and <code>current_mot_raw</code> measurements. The actual reference voltage (in Volts) is given by $5 \times \frac{\text{offset_current_mot}}{4095}.$
sps_current_mot	Yes	$\{0, \dots, 7\}$	7	Because the signal from the current sensor is passed through an inverting amplifier, higher values of <code>offset_current_mot</code> result in lower values of <code>current_mot_raw</code> . The data rate of the ADC producing the <code>current_mot</code> and <code>current_mot_raw</code> measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) 8, 16, 32, 64, 128, 250, 475 and 860 samples per second.
res_current_mot	Yes	$\{0, \dots, 5\}$	0	The resolution of the ADC producing the <code>current_mot</code> and <code>current_mot_raw</code> measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767 , if the input voltage exceeds the set range.
load_in	Yes	float $\in [0.0, 1.0]$	0.01	The load of the intake fan, corresponding to the duty cycle of the pulse-width-modulation (PWM) signal that controls its speed. At higher values, the fan consumes more power and turns faster. At 0, the complete fan is powered off, including the tachometer; the measurement of fan speed (<code>rpm_in</code>) remains constant at the last measured value.
rpm_in	No	float	–	The speed of the intake fan in revolutions per minute.
res_rpm_in	Yes	$\{0,1\}$	1	The resolution of the tachometer that measures the speed of the intake fan, where 1 corresponds to microseconds (higher resolution) and 0 to milliseconds (lower resolution).

Table 1: Description of the variables produced by the chamber configuration `wt_mk2_full1`. Settable variables can be manipulated by calling `.set(<variable>, <value>)`. “float” corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
load_out	Yes	float ∈ [0.0, 1.0]	0.01	The load of the exhaust fan, corresponding to the duty cycle of the pulse-width-modulation (PWM) signal that controls its speed. At higher values, the fan consumes more power and turns faster. At 0, the complete fan is powered off, including the tachometer; the measurement of fan speed (<code>rpm_im</code>) remains constant at the last measured value.
rpm_out	No	float	–	The speed of the exhaust fan in revolutions per minute.
res_rpm_out	Yes	{0,1}	1	The resolution of the tachometer that measures the speed of the intake fan, where 1 corresponds to microseconds (higher resolution) and 0 to milliseconds (lower resolution).
pressure_intake	No	float	–	The air pressure, in pascals, measured by the barometer placed at the tunnel intake.
osr_pressure_intake	Yes	{0,1,2,3}	0	The oversampling rate of the intake barometer, which determines how many consecutive readings are averaged to produce a single measurement. The values correspond to 1, 2, 4 and 8 readings, respectively.
pressure_ambient	No	float	–	The air pressure, in pascals, measured by the outer barometer. This is the ambient pressure outside the chamber.
osr_pressure_ambient	Yes	{0,1,2,3}	0	The oversampling rate of the ambient barometer, which determines how many consecutive readings are averaged to produce a single measurement. The values correspond to 1, 2, 4 and 8 readings, respectively.
pressure_downwind	No	float	–	The air pressure, in pascals, measured by the barometer inside the tunnel placed facing away from the airflow.
osr_pressure_downwind	Yes	{0,1,2,3}	0	The oversampling rate of the downwind barometer, which determines how many consecutive readings are averaged to produce a single measurement. The values correspond to 1, 2, 4 and 8 readings, respectively.
pressure_upwind	No	float	–	The air pressure, in pascals, measured by the barometer inside the tunnel placed facing into the airflow.
osr_pressure_upwind	Yes	{0,1,2,3}	0	The oversampling rate of the upwind barometer, which determines how many consecutive readings are averaged to produce a single measurement. The values correspond to 1, 2, 4 and 8 readings, respectively.
current_in	No	float	–	The measurement of electric current drawn by the intake fan, in Amperes.
current_in_raw	No	{-32768, ..., 32767}	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement <code>current_in</code> .
offset_current_in	Yes	{0, ..., 4095}	0	The reference voltage (offset) of the ADC producing the <code>current_in</code> and <code>current_in_raw</code> measurements. The actual reference voltage (in Volts) is given by $5 \times \frac{\text{offset_current_in}}{4095}.$ Because the signal from the current sensor is passed through an inverting amplifier, higher values of <code>offset_current_in</code> result in lower values of <code>current_in_raw</code> .
sps_current_in	Yes	{0, ..., 7}	7	The data rate of the ADC producing the <code>current_in</code> and <code>current_in_raw</code> measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) 8, 16, 32, 64, 128, 250, 475 and 860 samples per second.
res_current_in	Yes	{0, ..., 5}	0	The resolution of the ADC producing the <code>current_in</code> and <code>current_in_raw</code> measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range {-32768, 32767}. The voltage ranges are, respectively, ±6.144, ±4.096, ±2.048, ±1.024, ±0.512 and ±0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.
current_out	No	float	–	The measurement of electric current drawn by the exhaust fan, in Amperes.
current_out_raw	No	{-32768, ..., 32767}	–	The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement <code>current_out</code> .

Table 1: Description of the variables produced by the chamber configuration `wt_mk2_full1`. Settable variables can be manipulated by calling `.set(<variable>, <value>)`. “float” corresponds to a 32-bit float.

Variable	Settable	Values	Default	Description
<code>offset_current_out</code>	Yes	{0, ..., 4095}	0	<p>The reference voltage (offset) of the ADC producing the <code>current_out</code> and <code>current_out_raw</code> measurements. The actual reference voltage (in Volts) is given by</p> $5 \times \frac{\text{offset_current_out}}{4095}.$ <p>Because the signal from the current sensor is passed through an inverting amplifier, higher values of <code>offset_current_out</code> result in lower values of <code>current_out_raw</code>.</p>
<code>sps_current_out</code>	Yes	{0, ..., 7}	7	<p>The data rate of the ADC producing the <code>current_out</code> and <code>current_out_raw</code> measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) 8, 16, 32, 64, 128, 250, 475 and 860 samples per second.</p>
<code>res_current_out</code>	Yes	{0, ..., 5}	0	<p>The resolution of the ADC producing the <code>current_out</code> and <code>current_out_raw</code> measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.</p>
<code>mic</code>	No	float	–	<p>The measurement of the sound level captured by the microphone, in Volts.</p>
<code>mic_raw</code>	No	$\{-32768, \dots, 32767\}$	–	<p>The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement <code>mic</code>.</p>
<code>offset_mic</code>	Yes	{0, ..., 4095}	0	<p>The reference voltage (offset) of the ADC producing the <code>mic</code> and <code>mic_raw</code> measurements. The actual reference voltage (in Volts) is given by</p> $5 \times \frac{\text{offset_mic}}{4095}.$ <p>Because the signal from the current sensor is passed through an inverting amplifier, higher values of <code>offset_mic</code> result in lower values of <code>mic_raw</code>.</p>
<code>sps_mic</code>	Yes	{0, ..., 7}	7	<p>The data rate of the ADC producing the <code>mic</code> and <code>mic_raw</code> measurements. Lower values mean the ADC accumulates more readings to produce a single measurement, reducing noise but also lowering the measurement speed. The actual data rates are (respectively) 8, 16, 32, 64, 128, 250, 475 and 860 samples per second.</p>
<code>res_mic</code>	Yes	{0, ..., 5}	0	<p>The resolution of the ADC producing the <code>mic</code> and <code>mic_raw</code> measurements. Higher values mean a higher resolution, where a smaller voltage range is mapped to the ADC output range $\{-32768, 32767\}$. The voltage ranges are, respectively, $\pm 6.144, \pm 4.096, \pm 2.048, \pm 1.024, \pm 0.512$ and ± 0.256 Volts. The reading will saturate, i.e., clamp at -32768 or 32767, if the input voltage exceeds the set range.</p>
<code>current_supply</code>	No	float	–	<p>The current drawn by the chamber and all its components, including the onboard computer and server. Used for diagnosis.</p>
<code>current_supply_raw</code>	No	{0, ..., 1023}	–	<p>The uncalibrated measurement, i.e., the raw ADC output, corresponding to the measurement <code>current_supply</code>.</p>

Table 1: Description of the variables produced by the chamber configuration `wt_mk2_full1`. Settable variables can be manipulated by calling `.set(<variable>, <value>)`. “float” corresponds to a 32-bit float.

Causal Ground Truth

The graph below can be interpreted as a causal ground truth, where an edge $X \rightarrow Y$ signifies that an intervention on X will change the distribution of subsequent measurements of Y . This causal interpretation is formalized in Gamella et al. [2025, Appendix V]. Note that the absence of an edge between two variables does not preclude the existence of a causal effect between them. As with most real systems, effects between observed variables may exist beyond what we know or can validate through experimentation, e.g., due to a lack of statistical power. Furthermore, there may be confounding effects where unmeasured external variables simultaneously affect some of the variables in the chamber, such as ambient pressure or lighting conditions. For more details, we refer the reader to Gamella et al. [2025, Appendix V].

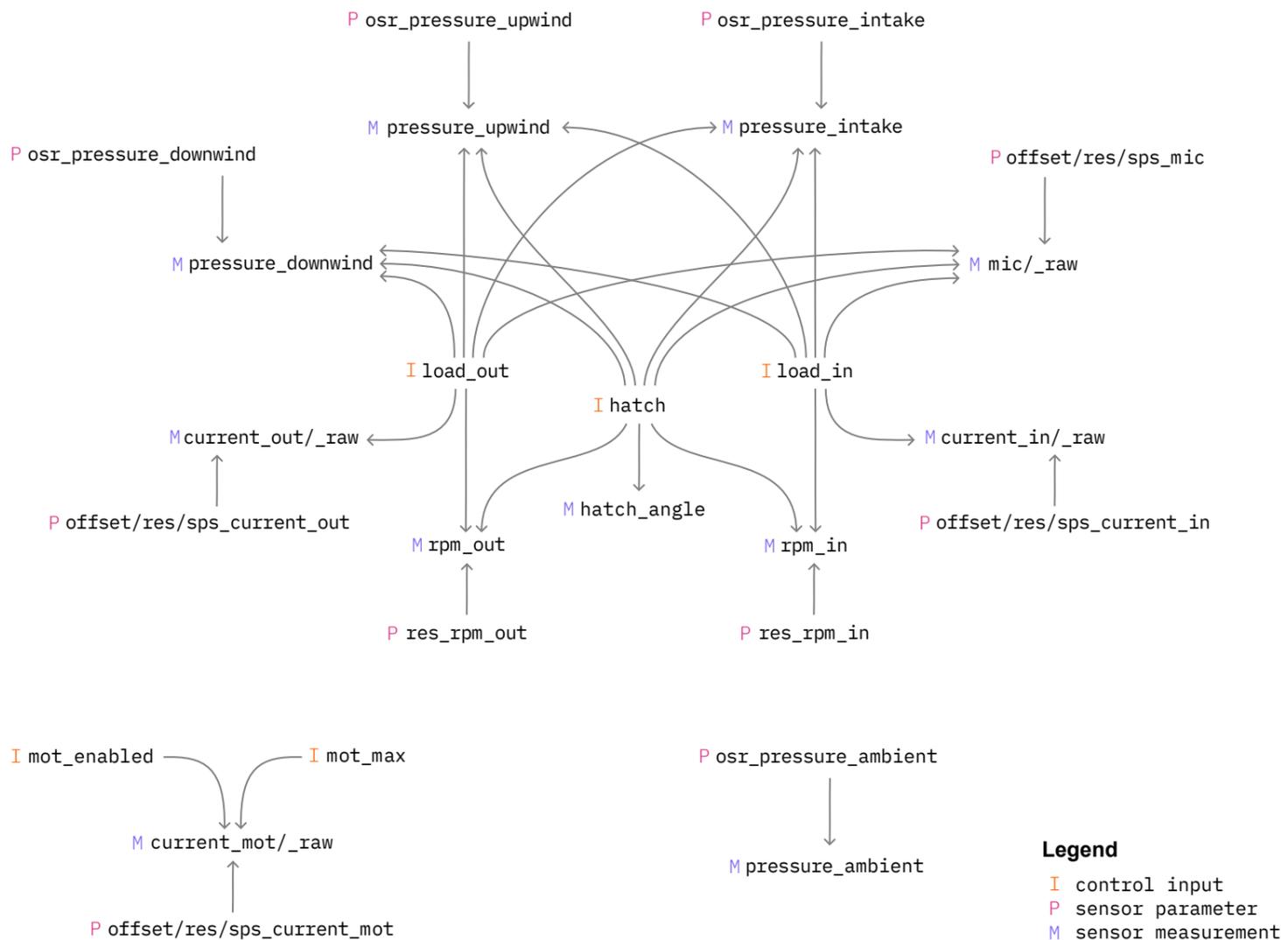


Figure 1: Graph representation of the known effects between the variables of the chamber. We use some shorthand notation to simplify the graph: node labels separated by a comma correspond to independent nodes with the incident edges, e.g., a node *var_1, var_2* corresponds to two separate nodes *var_1* and *var_2*. Similarly, a node *a/b/c_var* is shorthand notation for the separate nodes *a_var*, *b_var*, and *c_var*.

References

Juan L. Gamella, Jonas Peters, and Peter Bühlmann. Causal chambers as a real-world physical testbed for AI methodology. *Nature Machine Intelligence*, 2025. doi: 10.1038/s42256-024-00964-x.