Hot Wire Notes

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1 Resistance Calibration

The resistance calibration is a necessary process in order to determine the voltage delivered by the anemometer to the probe so it maintains a certain overheat temperature T_w which is set to 250^0C.

First, the ambient wire resistances of the probe are determined by subtracting the resistance of cables, probe leads and support equipment from the total measured resistance.

$$R_a = R_{tot} - (R_{cables} + R_{leads} + R_{support}) \tag{1}$$

The overheat resistance R_w is then found from

$$R_w = R_a + \alpha_0 R_0 (T_w - T_a) \tag{2}$$

where

- R_0 is the wire resistance at 20^0C.
- α_0 is the sensor temperature coefficient.
- T_a is the ambient temperature during the calibration.

2 Velocity Calibration

After the resistance calibration and the frequency response adjustment of the anemomenter have been performed, the next task is to obtain the a direct relation between the output voltage and the flow velocities. This is done through velocity calibration which is described below.

2.1 UV-Probe: Center Velocity Calibration - with Nikuradse

This calibration method is outlined in Dantec's practical guide and basically it is about exposing the probe to a set of known velocities and determine the transfer function between the obtained voltage signals and the velocities. This is done by applying a quadratic polynomial expansion

$$U_i = C_0 + C_1 E_{corr,i} + C_2 E_{corr,i}^2 + C_3 E_{corr,i}^3 + C_4 E_{corr,i}^4 \tag{3}$$

where C_0 - C_4 are calibrations constants to be determined and E_{corr} is the temperature corrected voltage output obtained from the probe.

$$E_{corr} = \left(\frac{T_w - T_0}{T_w - T_a}\right)^{0.5} \cdot E_a \tag{4}$$

where

- T_w: Overheat temperature, here 250^0C.
- T_0: Ambient temperature during calibration, here 24^0C.
- T_a: Measured temperature during experiment.
- T_a: Output voltage during experiment.

Dantec recommends to do this calibration procedure using an automatic calibrator which generates a set of known laminar flow velocities. But as this calibrator wasn't at our disposal, we decided to use the pipe flow in order to calibrate the probe. There were two main challenges that we had to deal with:

- The pipe flow is turbulent
- The center line velocity is unknown and has to be approximated

Our solutions:

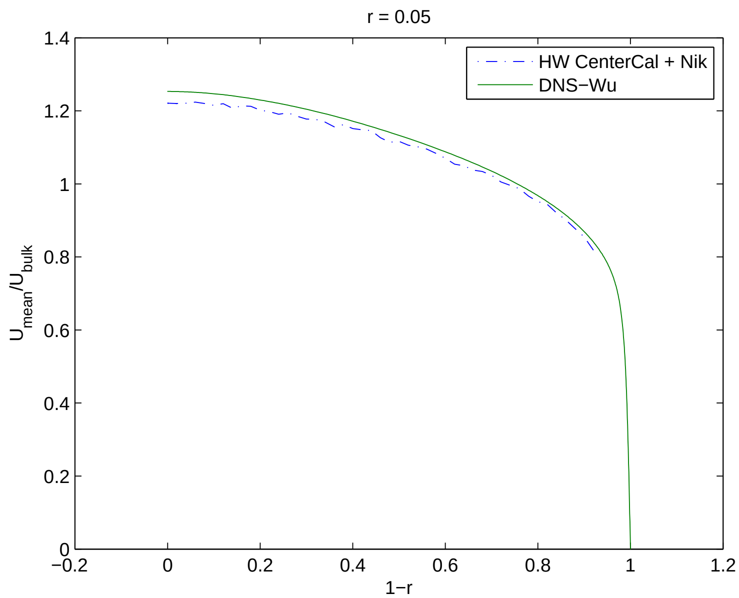
- To make sure the a flow stability criteria was established and use mean values of the voltage output.
- Use the mass flow rate Q measured by the coriolis flow meter to derive a bulk velocity U_b (5) which is used in Nikuradse's equation (6) to find the center line velocity U_c.

$$U_b = \frac{Q}{\rho A} \tag{5}$$

and

$$U_c = \frac{U_b(n+1)(2n+1)}{2n^2}; \tag{6}$$

The problem with the last solution is that Nikuradse's equation underestimates the center velocity. Figure (1) $\bar{U}/U_b$ measured from the center of the pipe and down to the bottom.



Figur 1: Center to Bottom HW with center line calibration and nikuradse vs Wu's DNS

2.2 UV-Probe: Profile Integrated Calibration - without Nikuradse

The calibration procedure that finally proved to work is the profile integrated calibration. This method provides us the apportunity to avoid the use of the Nikuradse approximation. The calibration procedure envolves measuring velocity profiles at different flow rates and using the integrated voltage output to compare with the known bulk velocities given by the flowmeter.

The relation between the bulk velocity U_b and the in situ velocity U is given by

$$U_b = \frac{1}{A}\int_0^{2\pi}\int_0^R U r dr d\theta = \frac{2\pi}{A}\int_0^R U_c r dr \tag{7}$$

The quadratic expansion then becomes

$$\frac{A}{2\pi}U_{b,i} = \int U_i r dr = C_0\int r dr + C_1\int E_i r dr + C_2\int E_i^2 r dr + C_3\int E_i^3 r dr + C_4\int E_i^4 r dr \tag{8}$$

where the index i indicates a given flow rate and E is of course the temperature corrected voltage output and should have been denoted E_{corr}.

The profile integrations are performed by measuring the flow at a set of uniformely distributed points along the pipe diameter and using the Simpson's composite integration rule to approximate the integrals in eq.(8).

$$\left[\int (E_j)^n r dr\right]_{ik} \approx [(E_j)^n r w_j]_{ik} \tag{9}$$

where w_j is the Simpson weighting vector $w_j = [1, 4, 2, 4, 2, ..., 4, 1]$ and j indicates the uniformely distributed points in the pipe.

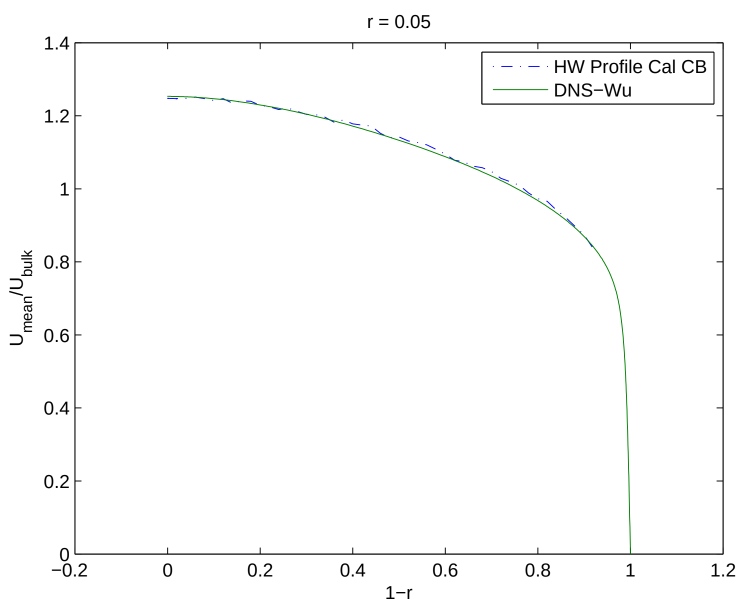
The result of this procedure is a linear system

$$\frac{A}{2\pi} U_{b,i} = \left[E_j^n r w_j\right]_{ik} C_k \tag{10}$$

and the coefficient vector can be found by solving this equation

$$C_k = \frac{A}{2\pi} \left[E_j^n r w_j\right]_{ik}^{-1} U_{b,i} \tag{11}$$

The results from this calibration procedure, see fig (2) turned out to be pretty accurate proving that the avoidment of the use of Nikuradse's approximation was a necessity.



Figur 2: Center to bottom HW with profile integrated calibration vs Wu's DNS