GONE WITH THE WIND:

Attenuation of turbulent velocity in **hot-wire anemometer** measurements

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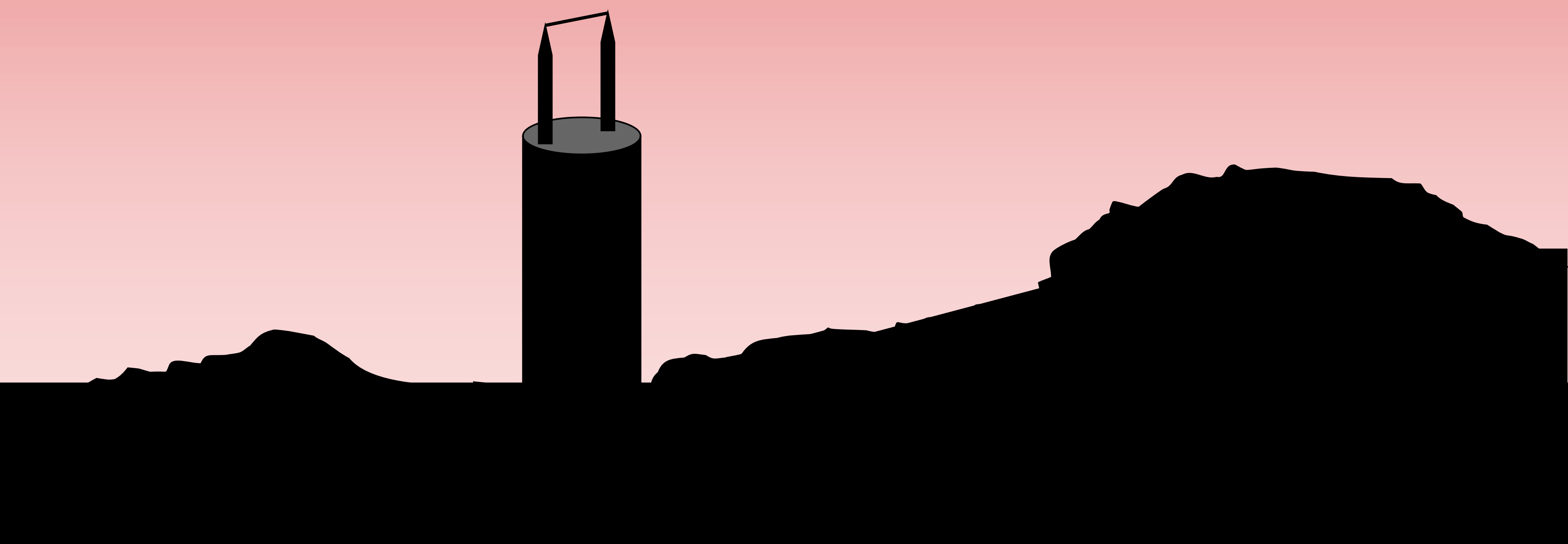
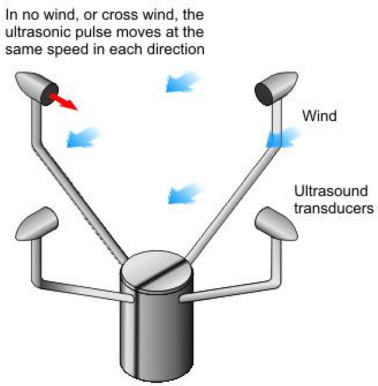
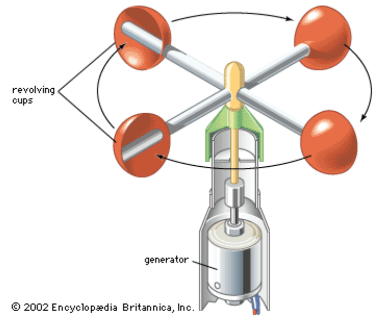



In no wind, or cross wind, the ultrasonic pulse moves at the same speed in each direction
Wind
Ultrasound transducers


revolving cups
generator
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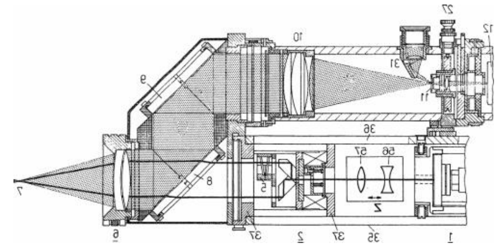
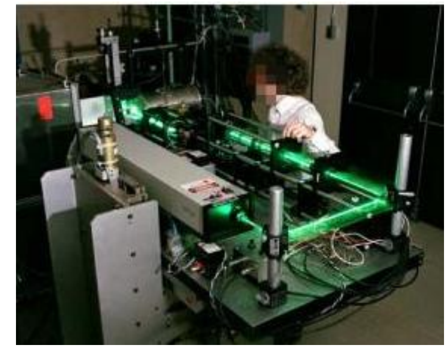
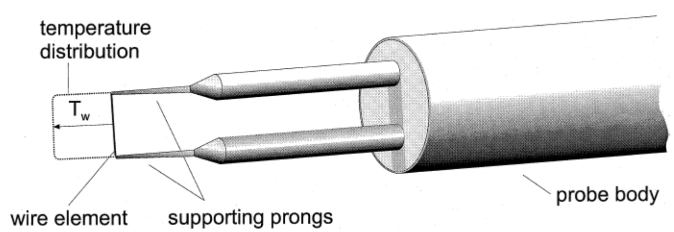
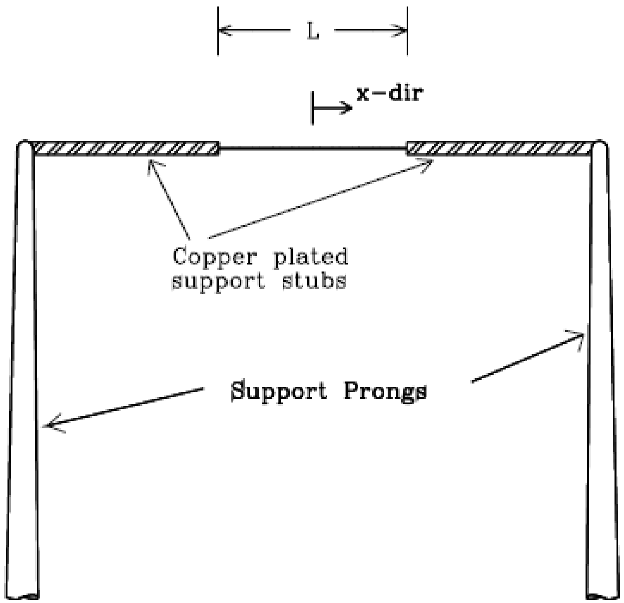


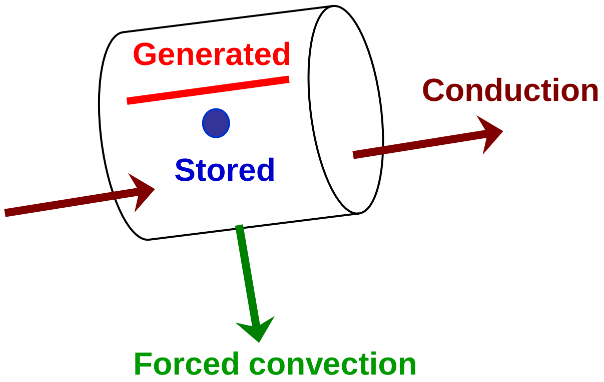



temperature distribution
T_w
wire element
supporting prongs
probe body

MARX
Anemometer
12,70
Windmesser
0-12 m/s

Hot-wire anemometer





$$dQ_{generated.} = dQ_{forced-convection} + dQ_{conduction} + Q_{stored}$$

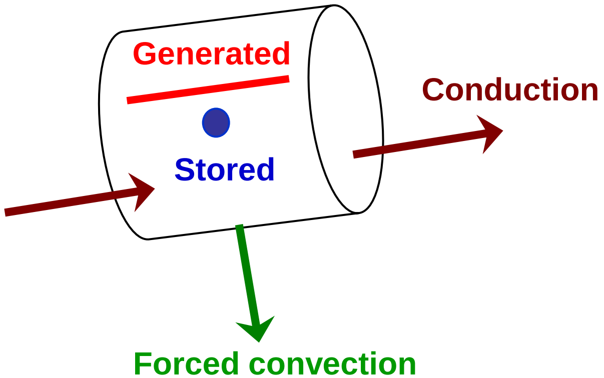
$$I^2 \frac{\chi_w}{A_w} = \pi d h(\theta_w - \theta_a) - k_w A_w \theta \frac{\partial^2}{\partial x^2}\theta_w + \rho_w C_w A_w \frac{\partial}{\partial t}\theta_w$$

Motivation

- What limits the frequency response and the size of the eddies that can be accurately measured with a hot-wire anemometer?

- Model the system (temperature distribution along the wire) and simulate the dynamic response of the filament for different wire dimensions and flow conditions

Hot-wire FILAMENT



$$\theta = \frac{\theta_w - \theta_a}{\theta_a}$$
$$\eta = \frac{x}{\ell}$$
$$Q = \frac{4I^2 R_{0x}}{\pi k_w} \left(\frac{\ell}{d}\right)^2$$
$$Z = \frac{4I^2 R_{0x}}{\pi k_w \theta_a} \left(\frac{\ell}{d}\right)^2$$
$$\xi = 4Nu \frac{k_f}{k_w} \left(\frac{\ell}{d}\right)^2$$
$$\tau = \rho_w C_w \frac{\ell^2}{k_w}$$

$$I^2 \frac{\chi_w}{A_w} = \pi dh(\theta_w - \theta_a) - k_w A_w \theta \frac{\partial^2}{\partial x^2} \theta_w + \rho_w C_w A_w \frac{\partial}{\partial t} \theta_w$$

$$\tau \theta_t = \theta_{\eta\eta} + (Q + \xi)\theta + Z$$

Solve coupled flow and heat conduction equations to find contributions of conduction and convection.

…Or, assume steady-state

$$\theta = \overline{\theta} \qquad \overline{\theta} = 0 \qquad at \quad \eta = \pm 1 \, (x = \pm \ell)$$
$$\overline{\theta_\eta} = 0 \qquad at \quad \eta = 0 \quad (x = 0)$$

$$\overline{\theta}(\eta) = \frac{\overline{Z}}{Y^2}\left[1 - \frac{\cosh(Y\eta)}{\cosh(Y)}\right]$$

Integrating along the wire:

$$\theta_m = \theta_a + \frac{\overline{Z}}{Y^2}\theta a\left[1 - \frac{\tanh(Y)}{Y}\right]$$

Uniform temperature distributions if

$$\frac{2\ell}{d} \geq 200$$

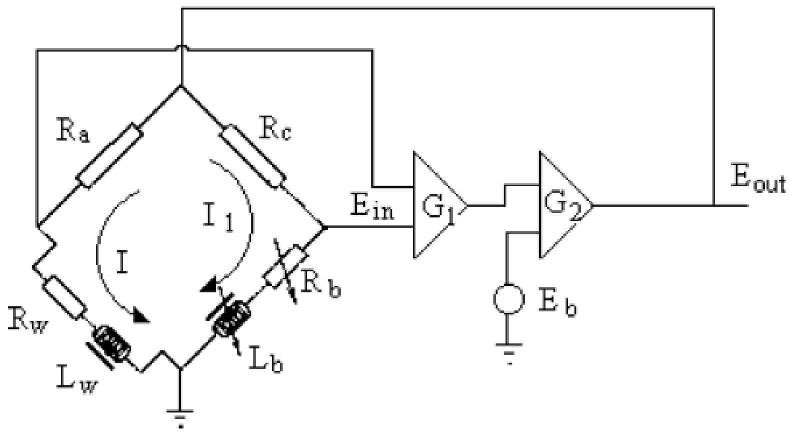
[Lange, 1999]

Hot-wire ANEMOMETER

$$R_x = R_0\,[1 + \alpha(\theta_w - \theta_a)]$$

$$R_x = 2\int_{-\ell}^{+\ell} R_x dx$$

$$Ew = IR_w$$



Keep Rw constant by driving a differential amplifier that creates a variation in the heating current I that compensates for the fluctuations in velocity

$$e_w = S_u(\theta, Rw)u' + S_\theta \theta'$$

Hot-wire FILAMENT

$$r'_w = R_0 \alpha \ell \theta_a \int_{-1}^{+1} \theta' d\eta \qquad \theta' = \frac{\theta'_w}{\theta_a}$$

For small perturbations, the heat balance equation can be written:

$$\theta' = \frac{\theta'_W}{\theta_A}$$

$$\tau \theta'_t = \theta'_{\eta\eta} + (Q' + \xi)\overline{\theta} + (\overline{Q} - \overline{\xi})\theta' + Z'$$

$$\tau \theta'_t = \theta'_{\eta\eta} + (\overline{Q} - \overline{\xi})\theta' + 2(\overline{Z} + \overline{Q\theta})i + \chi \overline{\theta} u$$

$$\mathcal{L}\left[\tau \theta'_t = \theta'_{\eta\eta} + (\overline{Q} - \overline{\xi})\theta' + 2(\overline{Z} + \overline{Q\theta})i + \chi \overline{\theta} u\right]$$

$$\frac{d^2}{d\eta^2}\widetilde{\theta'} - \left[\tau_s + (\overline{\xi} - \overline{Q})\right]\widetilde{\theta'} = -2(\overline{Z}+\overline{Q\theta})\widetilde{i} - \chi\overline{\theta}\widetilde{u}$$

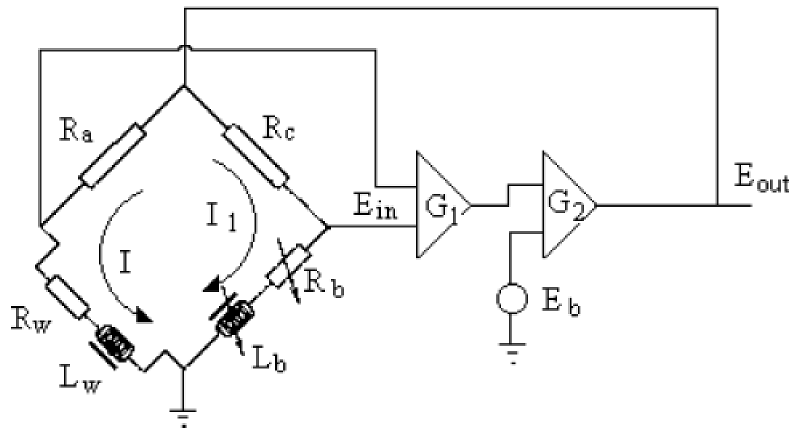
$$\widetilde{r}_w = R_0 \frac{\alpha\theta_a}{2Y_s^2}\int_{-1}^{+1}\left[\frac{\cosh(Y_s\eta)}{\cosh(Y)} - 1\right] M(\eta)\, d\eta$$

$$\widetilde{u} = u_1(s)\cos(\beta\eta)$$

$$\widetilde{r}_w = P\widetilde{i'} + A\widetilde{u'}$$

$$\frac{\widetilde{i'}}{\widetilde{u'}} = -\frac{A_1}{P}$$

Hot-wire ANEMOMETER



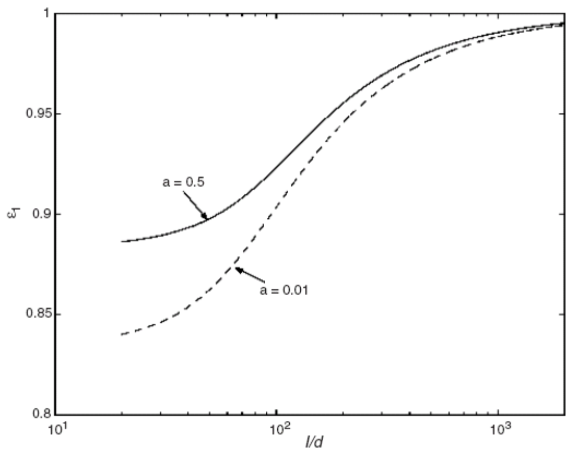
$$(M_1 M_2)\frac{d^2}{dt^2}e_{out} + (M_1 + M_2)\,\frac{d}{dt}e_{out} + e_{out} = Ke_{in}$$

$$\widetilde{e}'_{out} = \frac{A_1}{B_1 - C_1}\widetilde{u'}$$

$$\frac{\widetilde{e}'_{out}}{\widetilde{r}'_w}$$

Attenuation: Hot-wire filament

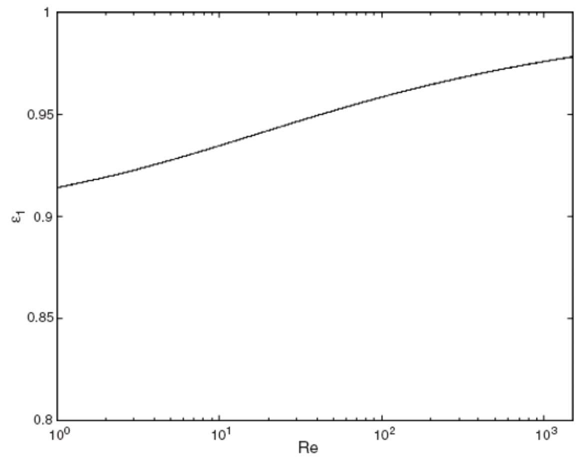
[Li, 2004] [Freymuth, 1977]

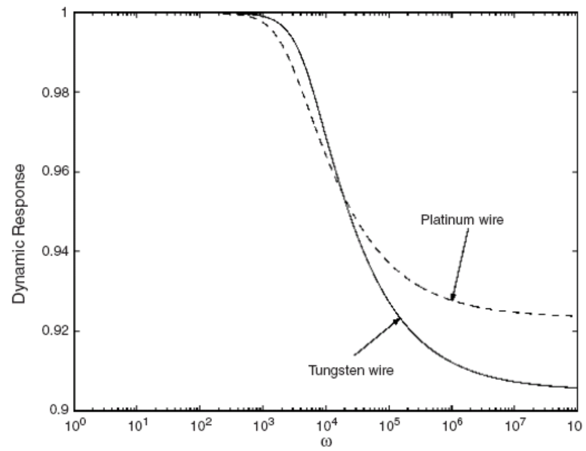


[Teo, 2001]

[Experimental: Khoo]

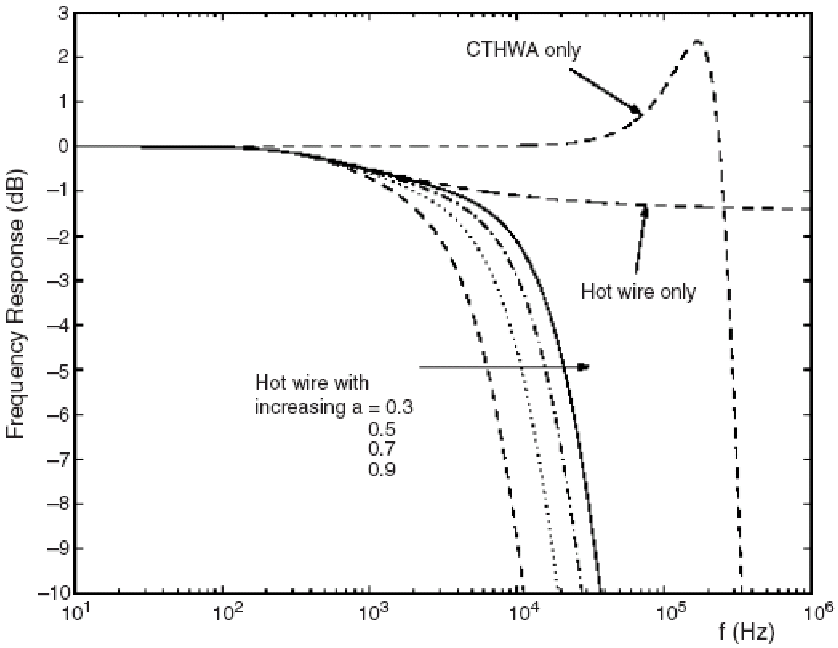
[Chew, 1998]

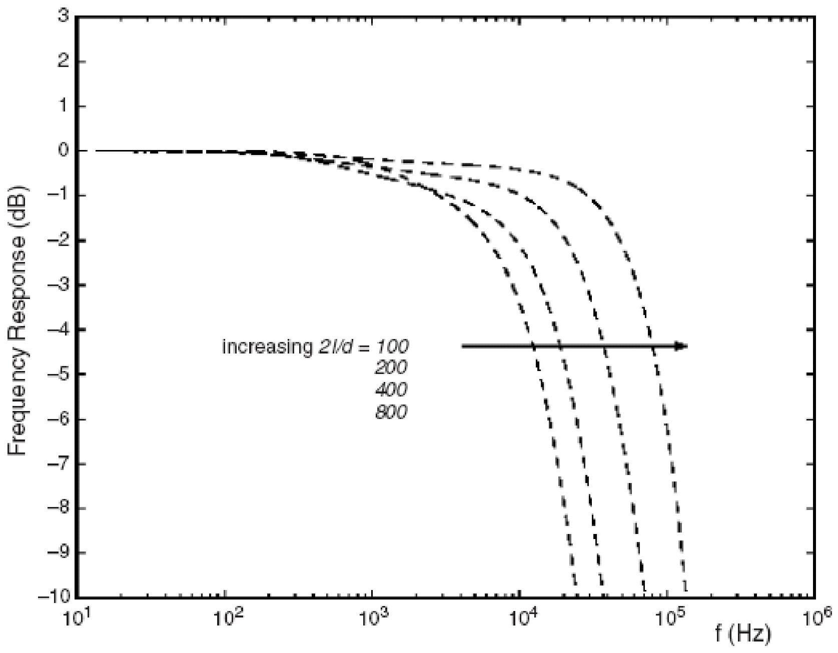




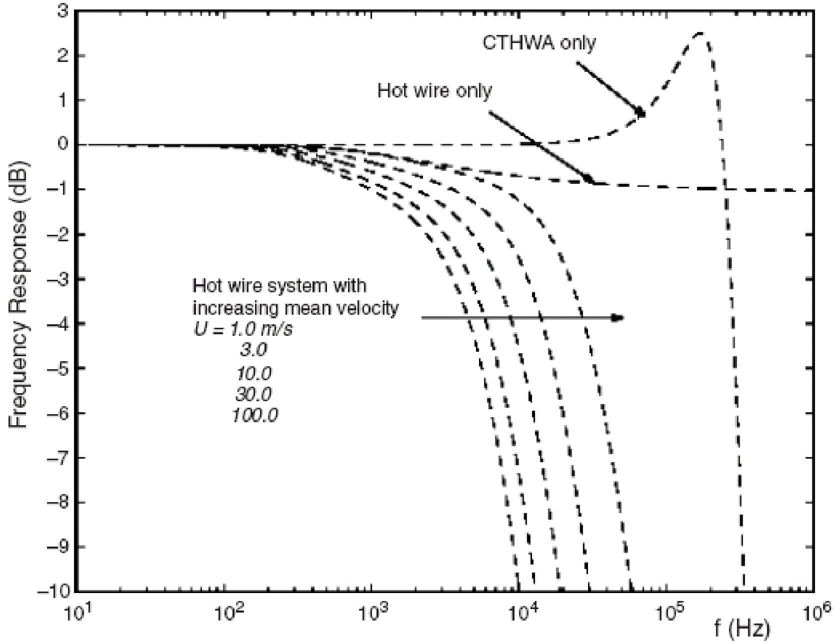
[Morris, 2001]

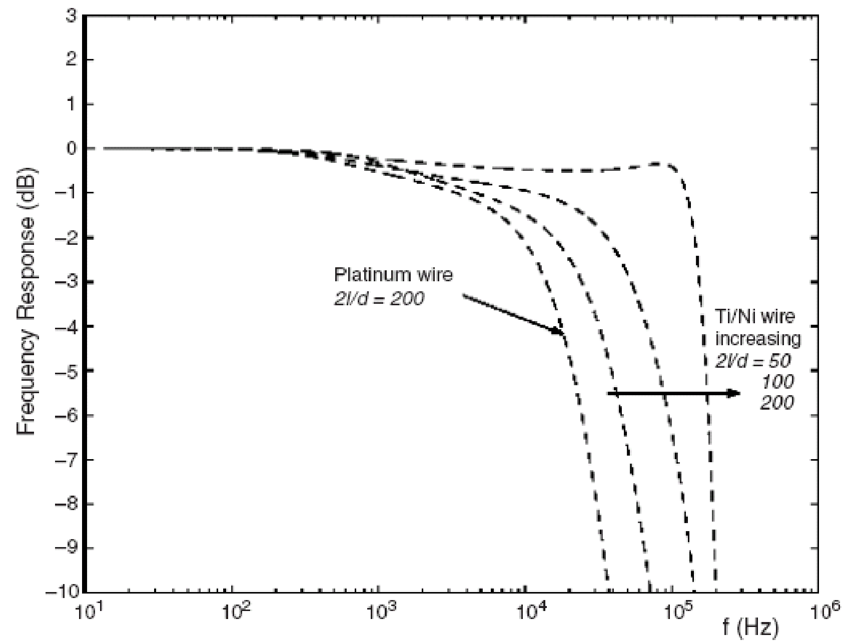
Attenuation: hot-wire with anemometer CTHWA





Attenuation: hot-wire with anemometer CTHWA





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