Anemometer System Review

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Introduction

The majority of laboratory and engineering applications of hot-wire anemometers put a relatively modest demand on the anemometer circuit. In addition, the increasing interest in examining the dynamics of the large-scale structures in turbulent flows has led to an increased demand for large multi-channel systems. This in turn has led to the development of new anemometer systems by both researchers and commercial manufacturers that provide reasonable capabilities at more modest prices, \$100-\$2000 USD per channel, as opposed to the conventional commercial systems that are typically \$5,000-\$8,000 USD per channel. The objective of this investigation is to compare the performance of these systems in a low speed axisymmetric shear layer with speeds up to Mach 0.15, which provides the turbulent flow conditions typical of a variety of basic applications.

This review compares the performance of two all purpose commercial systems, the DISA 55-M (Dantec) and AA Labs AN2000 systems with the new Dantec MiniCTA and two custom designs, one based on the simplest Perry [2] design and a second based on his more sophisticated design. The simplest design by Citriniti [1] et al, at the University at Buffalo, TRL UB, has a flat frequency response with no bridge loop frequency compensation. The design developed at the Thermo and Fluid Dynamics Department at Chalmers University of Technology, TRL CTH, incorporated high quality instrumentation amplifiers, frequency compensation and cable inductance compensation making this system the most similar to commercial systems. These systems range in cost from \$100-\$250 USD per channel to build. The performance of these systems is compared using measurements from the axisymmetric shear with a standard single hot-wire (Dantec 55P01, 5 μm x 1.25 mm). The ease of use and stability of each system is also reported and discussed.

Anemometers

Perry's [2] basic design, diagrammed in figure (5), was chosen for the TRL UB anemometer because of its simplicity and thorough documentation. It requires only two operational amplifiers, a power transistor to drive the Wheatstone bridge and the bridge itself. The design, described in detail by Citriniti[1], lends itself readily to large channel count applications and the dynamical characteristics of this design are more than sufficient for low frequency measurements. The bridge is tuned with an offset adjustment of the second stage amplifier. The slightly more sophisticated TRL CTH design substitutes the first stage amplifier with an adjustable high gain instrumentation amplifier, adds a second stage frequency dependent feedback filter and adjustable inductance for cable compensation. The only commercial system with published circuit diagrams, the DISA 55M, adds adjustable capacitance for cable compensation and a third stage active adjustable high frequency filter. Other features beyond the scope of interest here make this system highly stable and robust. The DISA 55M systems have provided almost 30 years of exceptional service, but are now unfortunately approaching the end of their serviceable life. The new Dantec MiniCTA has a published frequency response of 10 kHz making it an attractive choice for low frequency applications. The AN2000 was intended as a high end benchmark system.

Experimental Procedure

Each anemometer system was set for an overheat ratio, $R = R_w/R_g$, of 1.7. After tuning the frequency response for $20m/s$, a calibration was performed from 1 to $40m/s$. With the jet exit velocity, U_0, at $20m/s$ an 80 kHz bandwidth spectra, equation 1, was taken at the jet exit and a profile of 8 kHz bandwidth spectra were subsequently taken at $x/D = 3$ with $r/D = 0, .25, .5$ and .65.

$$u^2 = \int_{-\infty}^{+\infty} fuu(f)\mathrm{d}f \qquad (1)$$

The frequency response was then tuned at the jet exit with $U_0 = 40m/s$ and $5m/s$. A second wide bandwidth spectra was taken with $U_0 = 5m/s$. Finally a second calibration was performed to check for drift over the approximately 3 hour experiment.

Measurements

The frequency response, $1/(1.3\tau)$, see table (1), was calculated by measuring the time, τ, from the rising edge of the square wave response to the return to 3% of the peak response. The first negative overshoot was set to 15% of the peak response. We were unable to reduce the gain sufficiently on the MiniCTA to avoid a 20% overshoot. At maximum damping the pulse wave response of the AN2000 resulted in a 30% overshoot. This may explain why the spectra taken in the shear layer rise slightly above a -5/3 slope.

The turbulence intensity measurements taken at the jet exit showed a standard deviation of 0.05% between the anemometers for a given jet velocity. This variation is due in part to the slight change in the exit velocity from experiment to experiment, the level of the noise floor and the frequency response function of the particular bridge.

None of the anemometer systems were found to have unacceptable drift. The variations seen in table (2) are within our calibration uncertainty. High precision measurements of the calibration air properties and low speed pitot tube pressure would be required to further quantify these variations.

The noise floor of the high end commercial systems measured at the jet exit, shown in figure (6), are 1-2 orders of magnitude

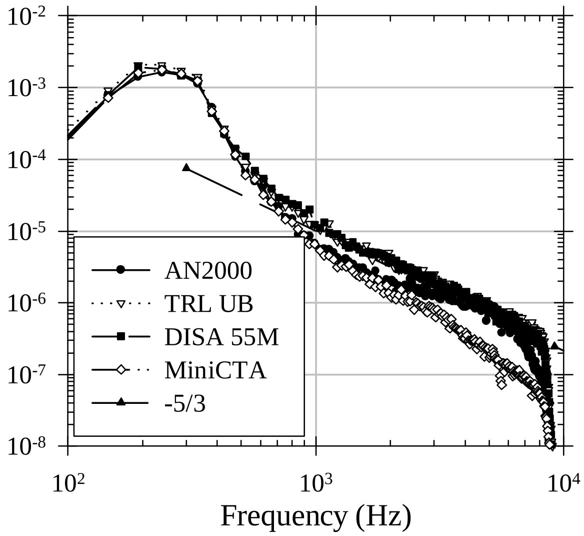

Figure 1: Shear Layer Power Spectra in m^2/s at $r/D = 0$, $x/D = 3$, $U_0 = 20m/s$, $\overline{u} = 19.6m/s$

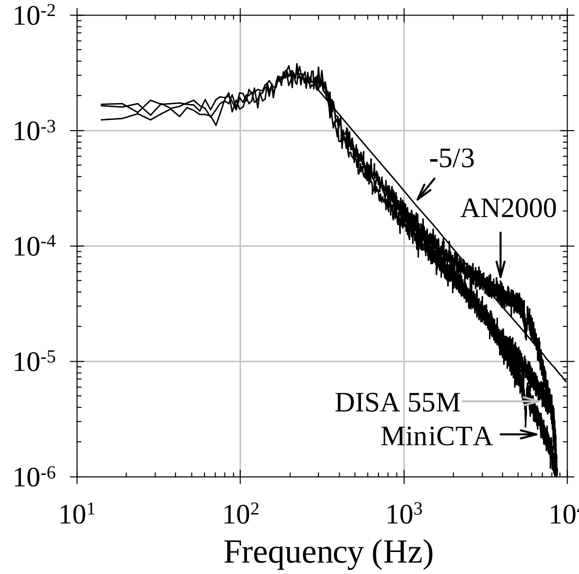

Figure 2: Shear Layer Power Spectra in m^2/s at $r/D = 0.25$, $x/D = 3$, $U_0 = 20m/s$, $\overline{u} = 19.5m/s$

lower than the other systems. This may reveal some further insight into the variations in the turbulence intensity.

Discussion

Both of the non-commercial anemometers show the expected hump in figure (6) as described by Perry for an anemometer with a flat gain versus frequency response. Although the CTH version has frequency compensation circuitry intended to remove this further tuning is needed. The DISA 55M exhibited the greatest susceptibility to electronic noise, probably due to the aging of its transistors. The Dantec MiniCTA and the TRL CTH anemometer where not susceptible to the 5 kHz interference found on the other anemometers. All the anemometers picked up the strong broad brand 30 kHz inverter drive noise from the motor controller. This type of electronic noise is common in most laboratories and considerable efforts might be required to eliminate it if your anemometer system is susceptible to such interference. As the signal to noise ratio decreases the effect of these subtle differences becomes increasingly more important.

The spectra measurements taken across the jet shear layer shown in figures (1 - 4) extenuate the subtle differences of these systems as well. The lower frequency roll-off in the MiniCTA spectra is evident at all locations becoming less significant as the mean velocity (and the probe roll-off frequency) drops. Similarly the rise in the AN2000 spectra becomes less obvious at the outer edge of the shear layer, figure (4). While it was not the particular intention of this review to evaluate the effectiveness of these systems for dissipation or high frequency measurements, it is clear that considerable care must be used when performing low turbulence intensity measurements, or for that matter any measurements at high frequency. The wide variation of the spectra at high frequency in our low turbulence in-

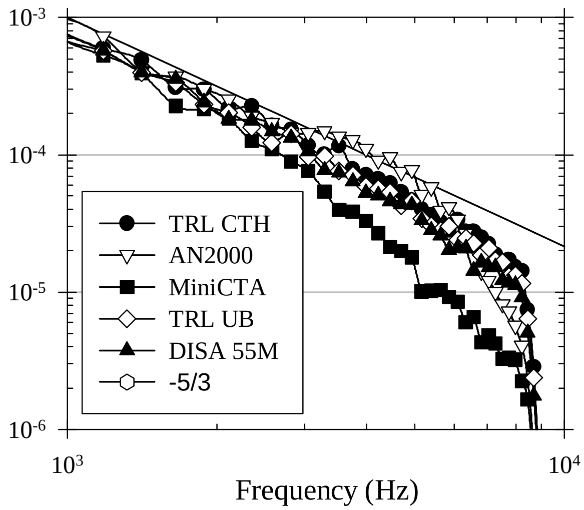

Figure 3: Shear Layer Power Spectra in m^2/s at $r/D = 0.5$, $x/D = 3$, $U_0 = 20m/s$, $\overline{u} = 13m/s$

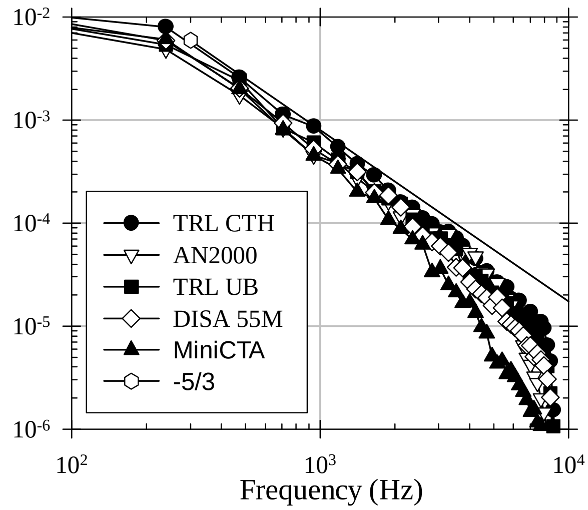

Figure 4: Shear Layer Power Spectra in m^2/s at $r/D = 0.25$, $x/D = 3$, $U_0 = 20m/s$, $\overline{u} = 7.5m/s$

tensity flow as shown in figure (6) should be an immediate flag to researchers interested in the dissipation range of turbulent spectra or in higher order moments of quantities depending on it. Obviously the customary method for setting up the anemometer is not adequate, and a full frequency response measurement is required, either by injecting a sine wave over the range of frequencies of interest or white noise.

In conclusion there was little evidence found that the simple anemometers built following the basic Perry design did not perform adequately at low frequencies. In fact these simple anemometers show considerable promise at modest frequencies when large channel counts make the commercial systems unrealistic.

Acknowledgments

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References

[1] Citriniti, J. H., K. D. Taulbee, S. H. Woodward, and W. K. George. *Design of multiple channel hot-wire anemometers*, Fluid Measurement and Instrumentation 1994, pages 67-73, ASME FED-Vol. 183, 1994.

[2] Perry, A. E., 1982, *Hot-Wire Anemometry,* Oxford University Press, Oxford.

Velocity	MiniCTA	DISA 55M	TRL CTH	AN2000	TRL UB
5	76.9	41.6	38.5	19.2	12.5
20	76.9	51.3	48.1	23.7	15.5
40	76.9	51.3	54.2	26.1	22.3

Table 1: Frequency response in kHz versus velocity in m/s.

MiniCTA	DISA 55M	TRL CTH	AN2000	TRL UB
0.75%	0.23%	0.90%	0.64%	0.64%

Table 2: Standard Deviation of the Calibration drift from start to finish of the experiment.

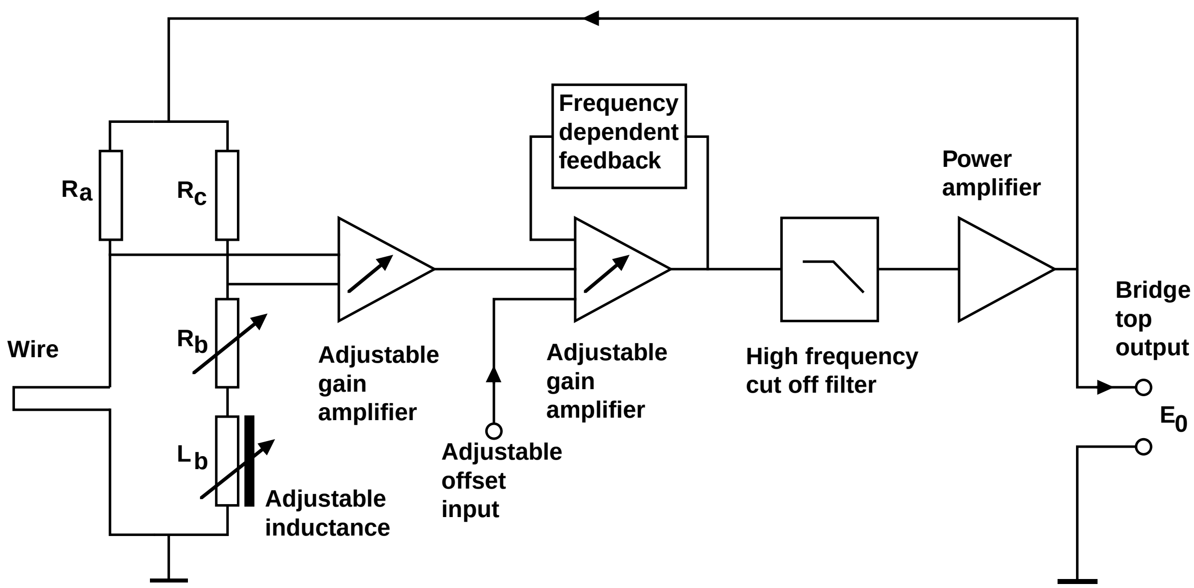

Figure 5: ANEMOMETER SYSTEM BLOCK DIAGRAM

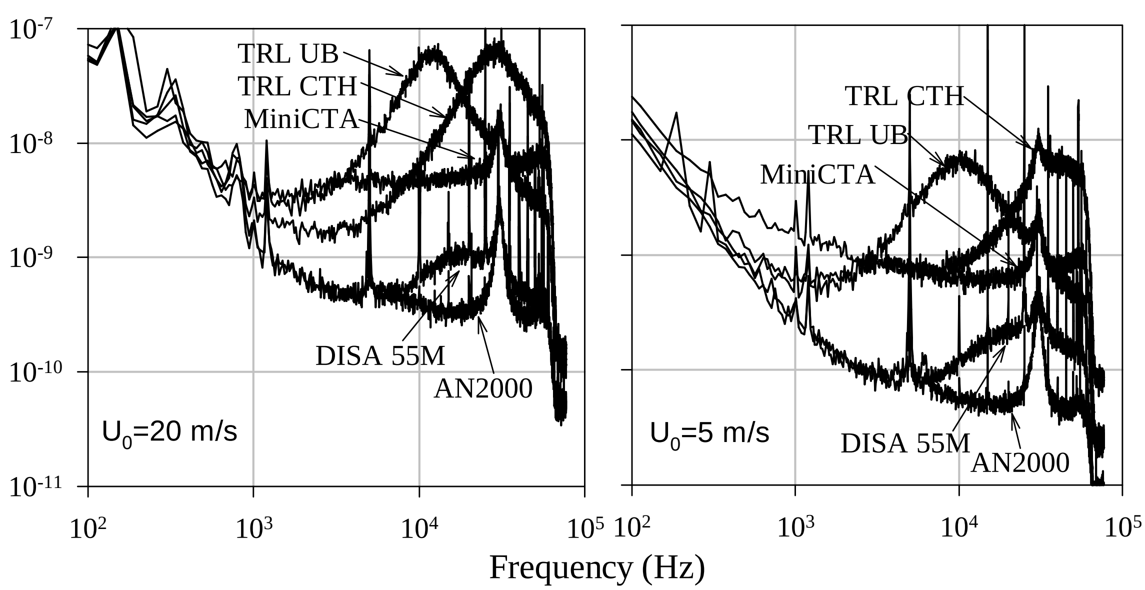

Figure 6: Spectra in m^2/s at Jet Exit.