TURBULENCE MEASUREMENTS WITH A HIGH RESPONSE PRESSURE PROBE

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1. INTRODUCTION

In turbomachines investigation of the turbulence intensities is important along with the determination of nonsteady velocity vectors. Presently, two procedures are used in this investigation: the hot-wire anemometer and optical anemometers (LDA and L2F). The advantage of the optical anemometers is that they make measurements without contact, and therefore don't disturb the flow. Some of the disadvantages are high device complexity, and therefore higher cost, and the necessity of seeding the flow with reflective particles. The advantage of the hot-wire anemometer is that it has small physical dimensions and therefore practically no influence on the flow. It is also more cost effective in comparison to the LDA or L2F. The disadvantages are that it has a high susceptibility to mechanical destruction and that it's sensitivity varies because of pollution of the hotwire. These two points lead to large difficulties in non-ideal conditions.

These are the foundations for a search of a cost effective and at the same time robust procedure for turbulence measurement. As it has been often demonstrated from various experimentors, pneumatic probes coupled with fast transducers are in a good position to measure the nonsteady velocity vectors. They should then also be able to be used in the determination of the turbulence intensities of a flow.

2. DESCRIPTION OF THE PROBE

The probe is a four hole wedge probe adorned with four Kulite CQ-030 pressure difference transducers which are directly integrated into the probe wedge (Fig. 1). This arrangement guarantees not only a high cutoff frequency, but also protection against mechanical destruction of the transducers. Problems come about in this probe from the low sensitivity of the transducers as a result of its large measurement range of ± 7 bar. This leads to difficulties in the determination of the quasi-steady mean-values of the dynamic pressure oscillations because of an extra voltage superimposed on the signal voltage. This voltage results from temperature dependent variations in the resistances of the Wheatstone bridge and is caused by two effects. The first is a linear effect resulting from changes in the individual resistances, and can be compensated for with appropriate circuits. The second, which cannot be compensated for, is a hysteresis effect probably resulting from mechanical stresses that operate on the pressure transducers in the probe head.

For measurements, therefore, the steady pressure mean-values are determined with a conventional probe built to the same dimensions, upon which the dynamic parts of the nonsteady signal of the fast response probe are superimposed. However, this procedure has disadvantages. In the case of concurrent measurement by the two probes, the flow must be homogeneous in the area around the probes. In the case of sequential measurement with the probes located at the same position, the flow must be steady.

First of all, the principal usability of the probe in turbulence measurements must be demonstrated. Therefore, the evaluation will be carried out in such a way that the pressure oscillations $p'_1 \div p'_4$ are determined for every point in time t. The pressure p(t) can be determined using the mean-value of this pressure (Fig. 2). With this, the velocity vectors U(t), V(t), and W(t) are obtained from the calibration. The oscillation values ($\overline{u'^2}$, $\overline{v'^2}$, $\overline{w'^2}$, $\overline{u'v'}$, $\overline{u'w'}$, $\overline{v'w'}$) can be determined from the deviation of the instantaneous values from the quasi-stationary mean-values.

The advantage of this procedure lies in the real time determination of the individual oscillation parameters. However, in actual practice, the procedure brings many disadvantages along with this benefit. The evaluation in the computer for so many points in time requires a large memory capacity and a lot of CPU calculation, which would make measurements in a rotating system prohibitively impossible. The procedure is therefore only justified in checking the principal appropriateness of the system.

A linearized procedure was tested parallel to this in which the turbulence intensities could be determined from the standard deviations and mean-values of the turbulent pressure oscillations. This linearization permits the effective determination of turbulence intensities even in rotating systems with justifiable computer expenditure and storage.

3. MEASUREMENT SEQUENCE

In a special calibration channel designed as a free jet with an exhaust diameter of 76 mm, a small device was used in which various grid packages could be inserted (Fig. 3). These grid packages were constructed with the help of an L2F measurement so that they gave a turbulence ratio between 2% and 15%. Perforated metal plates with holes of various diameters served to create various amounts of pre-turbulence, after which there was a mesh which realigned the flow if necessary.

With these grids it was possible to create various degrees of turbulence. One can see this in the frequency spectra from a hot-wire signal (Fig. 4). The first curve shows the frequency spectrum for the free stream with a dominant frequency of 460 Hertz. The pre-turbulence is increased by the various grids so that with increasing turbulence intensity, the frequency spectra start to level out.

Three probes were so arranged that the measurement in a circle with a diameter of 25mm could be carried out at a distance of 2D from the exhaust opening. This arrangement was chosen so that there would be no difficulties in reproducing the results when the grid is changed. With the help of a compressor, the flow was maintained regardless of the grid so that there was a constant Mach number of 0.23.

There are three measurement systems that were compared to each other. The first is a customary Dantec 55 P 91 three sensor hot-wire probe with a subsequent linearizer. In the evaluation, the velocity components U,V,W are determined for every point in time t. From this, the individual oscillation components can be determined. The second measurement system was a Laser Doppler Anemometer which consisted of a 15-Watt Argon-Ion Laser, a 2-color optic with a focal length of 600mm and a computer controlled counter as evaluation unit. Magnesium oxide with an average diameter of 2μm was used for the tracer particles. The pneumatic probe described above was compared with these two systems.

The measurements from the hot-wire and wedge probe were concurrently implemented so that a 100% chronological coherence was given. Unfortunately, measurements with the laser could not similarly be concurrently taken. The hot-wire probe was removed from the stream with the help of a sliding apparatus in order to protect the wire from destruction by the tracer particles. Laser beams were then focused on the volume previously occupied by the hot-wire probe.

4. RESULTS

In the measured behavior of the oscillation amplitude in the z-direction one can see a good agreement between the measured results of the hot-wire and the wedge probe (Fig. 5).

The deviations observed at individual measurement points should be viewed with the knowledge that the results for individual measurement systems are contaminated with variations. For example, one can see the deviation of two measurements taken sequentially by the hot-wire, where the probe is turned 120° around its shaft. Because of the probe architecture, this means that the probe wires are merely being exchanged with each other. There are ,however, really noticeable difference at some of the measurement points. It can be seen that even the smallest deviations in the probe geometry can lead to variations in the measured results.

The development of the velocity oscillation in the main stream direction also gives a satisfying overall agreement. A conspicuous point is the fact that the results of the wedge probe at lower turbulence intensities show much too large oscillations. This comes about from the background noise of the pressure transducers. This, coupled with the low sensitivity of the transducers, leads to problems especially at lower Mach numbers. It appears possible to bring the consideration of this fundamental noise to other measurements in order to achieve satisfying results. Otherwise, it would be possible to solve the problem with the use of other pressure sensors.

The strong deviations in grids 9 and 11 are the most striking. How should they then be explained?

In figure 6 the frequency spectra of grid 9 in comparison to that of grid 10, in which there is good agreement, are shown. The curves of the frequency spectra of the hot-wire-signals reveal no large differences. This appears to confirm the validity of the hot-wire evaluation for grid 9. In contrast, a significant rise in the high frequency pressure oscillations is recognizeable at the total-pressure-hole of the wedge probe. This naturally results in a drastic rise in the calculated oscillations in the main flow direction. The possibility that there is a purely static pressure oscillation can be ruled out because the pressure sensors 3 and 4, which approximately measure the static pressure, show no rise in the high frequency pressure oscillations.

Another explination could be that the necessary fundamental conditions of the given arrangement of the probes in the stream, namely a homogeneous kernel zone, are not guaranteed to the full extent. This point cannot be ruled out with 100% certainty. But if the rise in the total pressure oscillations was only a consequence of the uneven flow, then the convergence of the hot-wire calculations would not fall down to 55% in otherwise unchanged boundary conditions. Because the convergence of the calculations lies otherwise over 98%, we can conclude that the evaluation processes used for the hot-wire do not yield dependable results for extremely strong turbulences.

The wedge probe appears to have a poor resolution for the oscillations in the y-direction. As can be seen in figure 5 for higher grid numbers, the wedge probe shows a relatively flat curve, while the hot-wire displays the rise that is expected under the given conditions. We need further investigation to find out why the wedge probe gives such an inadequate resolution for this plane .

It is, of course, also possible to measure with the wedge probe the shear stresses ($\overline{u'v'}$, $\overline{u'w'}$, and $\overline{v'w'}$), but a reproduceable result could not be realized by any of the measurement systems with the given experimental set-up.

The linearized evaluation is of interest along with the calculations for each point in time. This results in a good agreement (Fig. 7). At lower turbulence intensities of the oscillation quantity $\overline{u'^2}$, it becomes noticeable that the differences between the hot-wire probe and the wedge probe become smaller. At high turbulence intensities, the variations become larger. This is caused by the fact that at very high turbulence, the linearization becomes no longer valid, and therefore leads to an increase in the calculated values.

In figure 8 one can see the results of the parallel measurements carried out with the LDA. Although these measurements were made by someone with relevent experience in turbulence measurements, no satisfactory agreement could be obtained with the results from the wedge probe and hot-wire probe. One can see that the deviations are noticeable. Because the author is not knowledgeable about Laser-Doppler anemometery, he would not like to explain this deviation, but leave it as an indication that there also exists many sources of errors in standard measuring equipment.

5. SUMMARY

The results just presented should document that it appears possible to implement turbulence measurements with pneumatic probes as long as there does not exist backflow and that the flow shows a preferential direction, such that exists, for example, in turbomachines. There are naturally a lot of questions unanswered, but the intention of this paper is not to present a proven system, but to try and show the limits of pneumatic turbulence measurements. The goal of future measurements should be to determine the limits of application through apropriate research and to extend these limits through compensation techniques.

The probe has perhaps shortcomings, such as blockage effects, background noise, etc., to various degrees, depending on the individual system, but the advantages of a simple and robust operation should not be underestimated, even in comparison to commercially available systems, which display sometimes large tolerance bands in turbulence measurements.

LITERATURE

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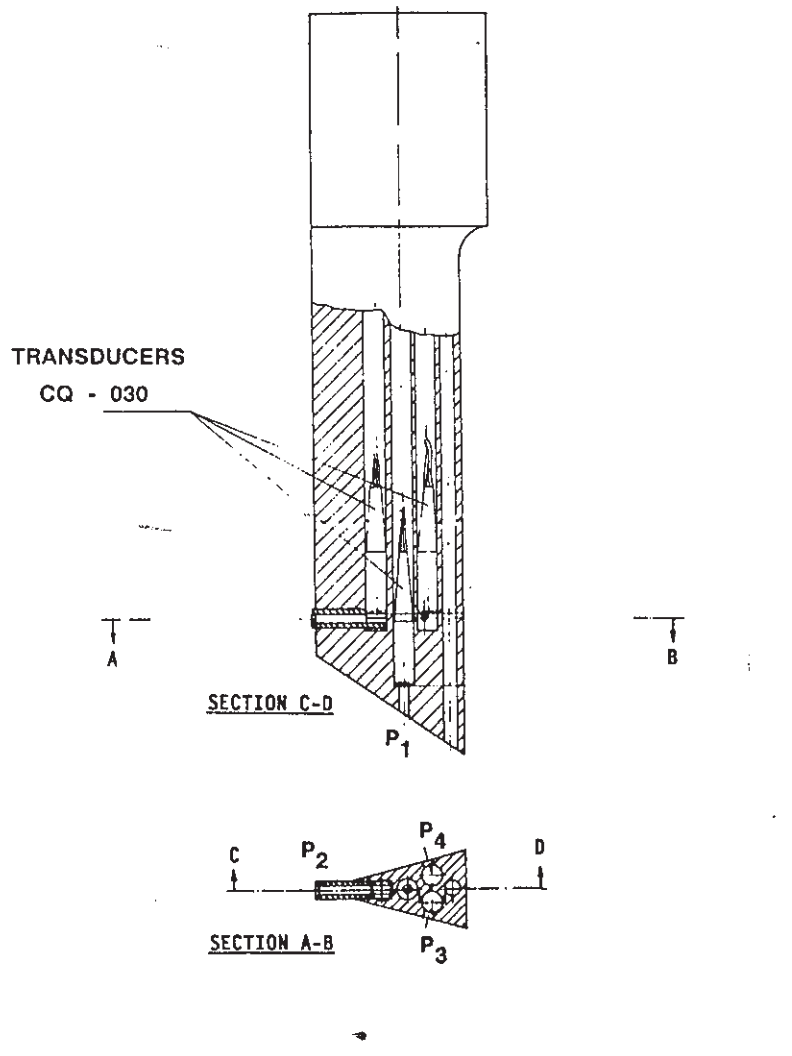


Fig. 1: 4-HOLE WEDGE PROBE

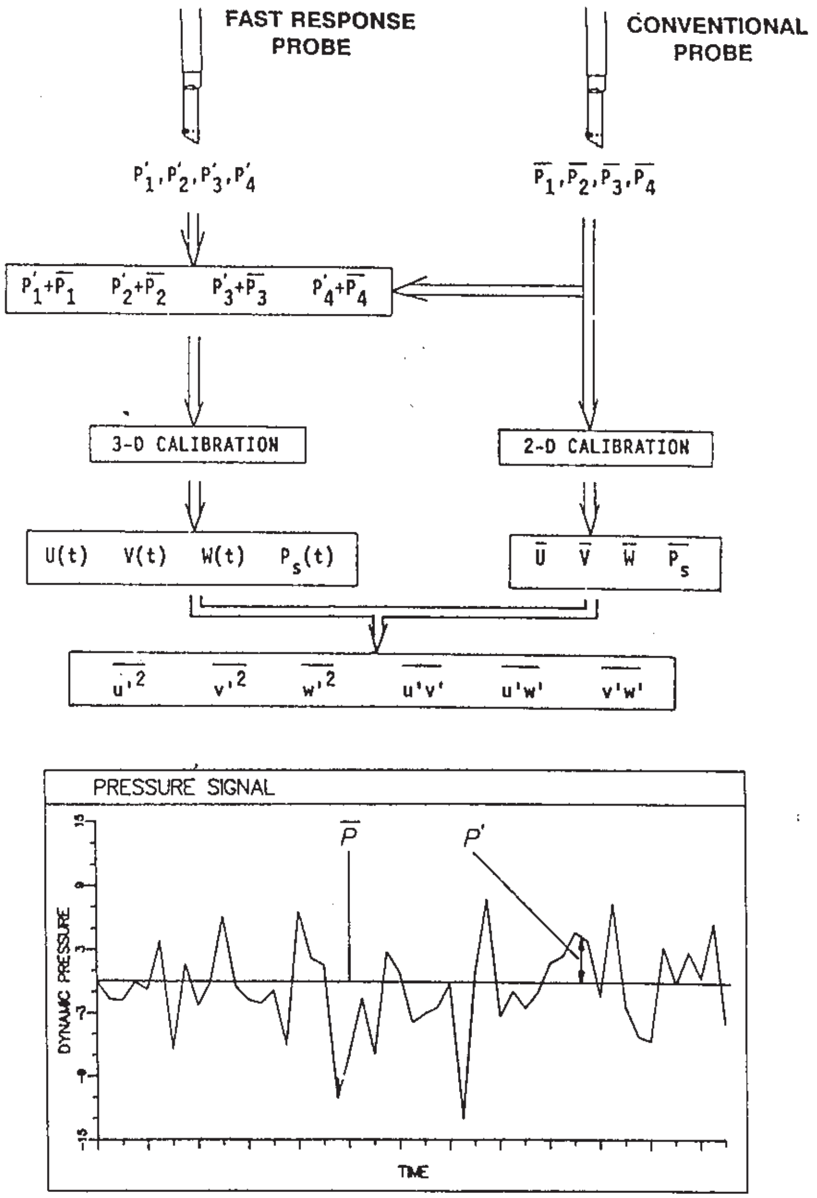


Fig. 2: EVALUATION SCHEME

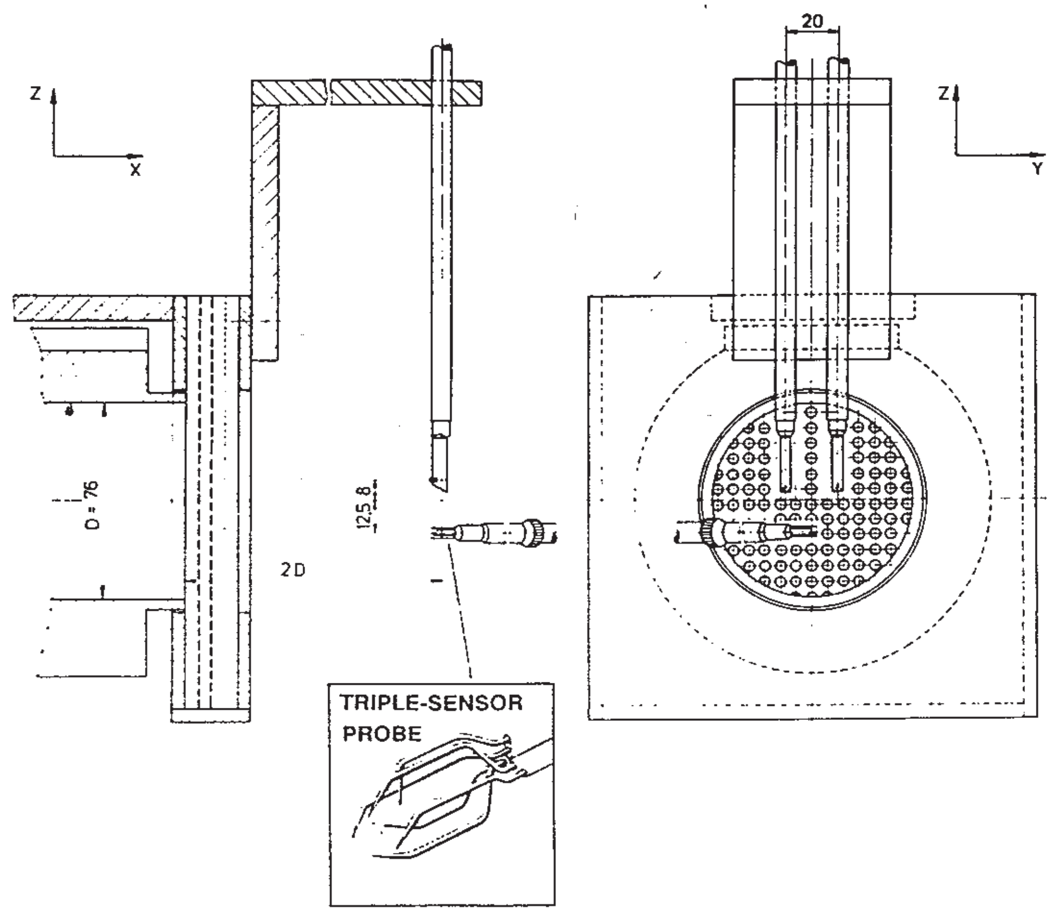


Fig. 3: EXPERIMENTAL SETUP

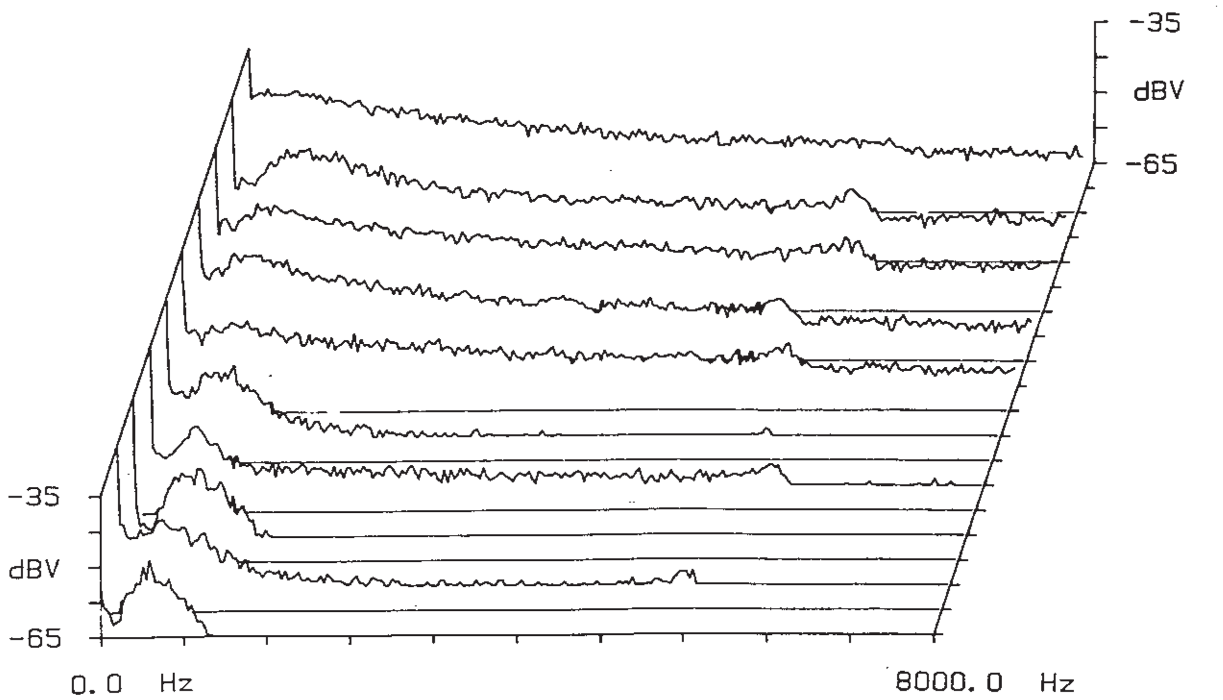


Fig. 4: FREQUENCY SPEKTRA OF A HOT-WIRE SIGNAL FOR VARIOUS GRIDS

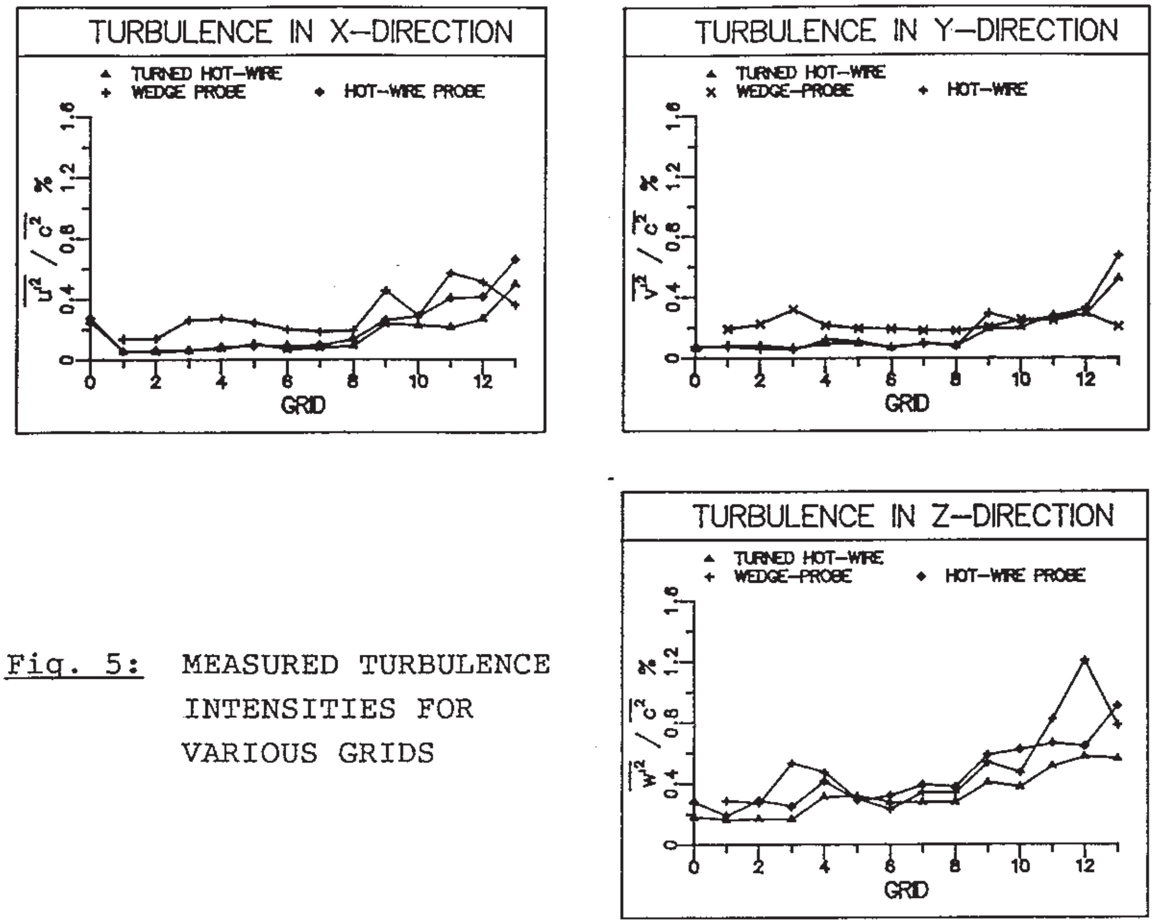


Fig. 5: MEASURED TURBULENCE INTENSITIES FOR VARIOUS GRIDS

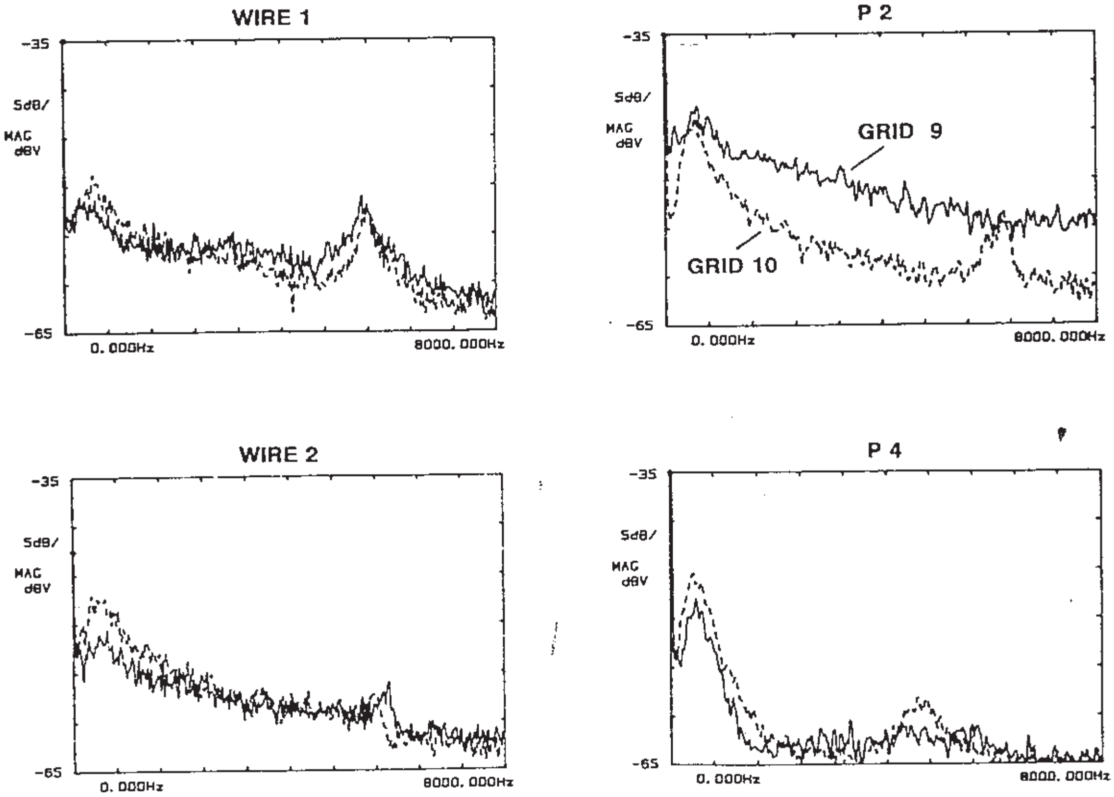
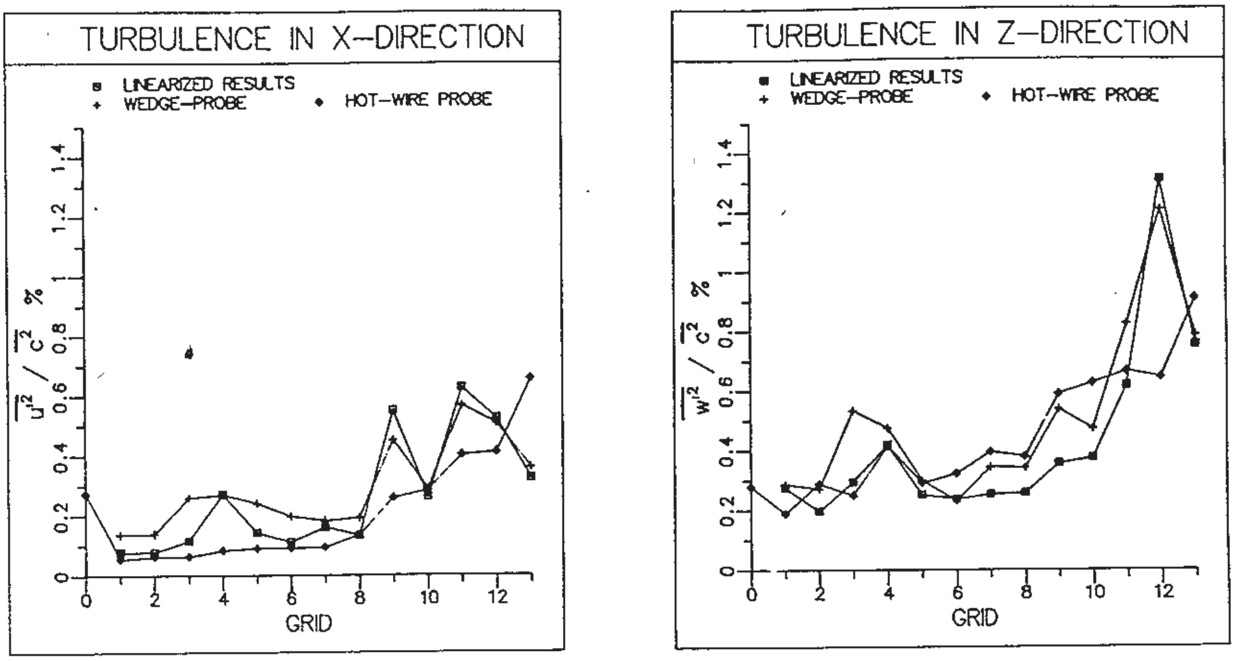
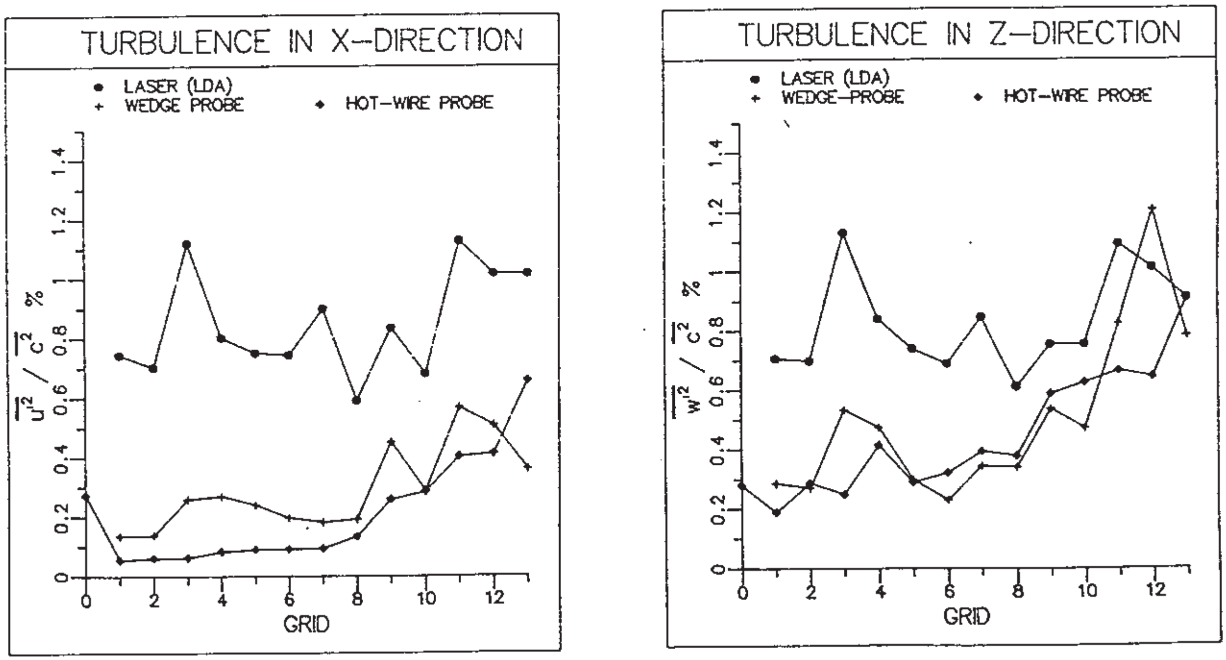


Fig. 6: COMPARISON OF FREQUENCY SPEKTRA


TURBULENCE IN X-DIRECTION

TURBULENCE IN Z-DIRECTION

Fig. 7: RESULTS OF LINEARIZED EVALUATION


TURBULENCE IN X-DIRECTION

TURBULENCE IN Z-DIRECTION

Fig. 8: RESULTS OF LDA-MEASUREMENT