Problems in wind measurement

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by Dieter von Dreusche

The author questions the accuracy and reliability of current methods of wind measurement. He compares the sophisticated and accurate methods, nowadays used to record and assess the finish of a race, with the less refined methods of assessing wind strength. He explains the problems associated with the use of just one anemometer at one spot and describes experiments being carried out, under the aegis of the German Athletic Federation, to determine whether the use of several anemometers (8), placed at 20m intervals each side of the sprint track, would give a more exact and revealing reading of the wind experienced by the athletes during the whole of the race.

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(Translated from the original German by Jürgen Schiffer)

Doubts about the accuracy of methods of wind measurement have existed since the very first anemometers were brought into use on the athletic track.

Since the replacement of manual by electronic measurement, false results have been eliminated step by step. However, in spite of improvements in wind measuring technique, an objective representation of the effect of adverse and favourable winds on the runners has become even more questionable. The reason for this is that the rules decree that only one wind gauge is necessary. However, the mean value measured by this instrument is expected to be an expression of the wind effects over the whole duration of the run and the rules demand an exactness only in the region of 10-1. Exact measurements – if these are possible at all in view of the problems mentioned above – are rounded up from hundredths to the next higher tenth of a metre per second.

The introduction of photofinish timing systems has made possible an accurate visualization of the athletes as they cross the finish line, which is only 5cm broad. It seems paradoxical, therefore, that the inexactness of such a wind reading is in strong contrast to the accuracy of the timing devices, which can measure values in the area of 10-3, guaranteeing a tolerance of maximally 10-5 in 24 hours. Furthermore it is possible to represent the exactness of 10-2 in the form of a graph instead of a digital sequence.

On the one hand, this uncertainty, when dealing with wind measurement, is caused by the complex "wind" phenomenon. On the

other hand, there are no clear findings as to how much a following wind favours the athletes or how much a head wind hinders them. However, it should be noted that a following wind does not represent a force pushing the athlete because an athlete, running at a velocity of 10m/sec, is moving five times as fast as the legal maximum of the following wind of 2m/sec. A following wind means only that there is a decrease in the aerodynamic drag opposing the athlete's motion.

The way athletes displace the air depends on their body profiles, i.e. their frontal areas, which influence the aerodynamic drag. With a *following wind*, the aerodynamic drag is less than with a *head wind*. Wind measurement in athletics deals only with favourable, i.e. following winds.

When speaking of the athlete's frontal area, one has to imagine the most advantageous (or disadvantageous) streamlined shape. In car construction this shape is expressed by the CW (continuous wave) value, which is constant. In the runner, however, this shape is subject to constant variation. The runner's total CW value could be defined only if each position of the body, i.e. every change of the angular position of arms, legs, head and trunk, were to be measured exactly, in order to calculate each individual CW value during each 1/100 sec of a stride cycle, Reliable findings concerning the athlete's energy balance can be obtained only by using a suitable model of a sprinter, allowing the simulation of all body positions occurring during the run, for the purpose of taking measurements in a wind tunnel.

According to the rules of wind measurement, which are now almost 60 years old, wind forces higher than 2m/sec are considered as favourable. Using a scale from 1 to 12, wind force 2 is described as a light breeze, which can just be felt and which is seen in a rustling of leaves.

We still lack reproducible measurements, clearly showing to what extent a following wind of 2m/sec reduces aerodynamic drag and whether this reduction of drag has any definite effect on the energy output.

Observations which give reason to assume that the wind conditions during the different sections of a sprint and at different points around the track are not at all constant also generate doubt about the reliability of current methods of wind measurement.

Finally, the feeling of uncertainty has been augmented by inadequate regulations about the calibration of wind gauges and the problem of maintaining accurate measurement in spite of mechanical stresses such as set-up, dismantling, transport and storage. Nor is it clear to what extent helpers can be allowed to stay in the area surrounding the wind gauge. And, last but not least, no tests have as yet been made to examine whether the sprinters themselves produce an air movement that is recorded by the wind gauge and thus leads to measurement errors.

There are numerous publications by well-known experts dealing with the problems mentioned above. However, these publications are often based on theoretical assumptions or derive mathematical models from statistical data. They are not based on a systematic investigation of real wind conditions.

The German Athletics Federation (DLV) has initiated a project to examine all Problems in wind measurement. This project is a co-operation of

- the Institute of Thermo and Fluid Dynamics of the University of Bochum,
- the Institute of Aerodynamics and Measurement Technique of the Technical University of Darmstadt,
- the Institute of Athletics and Gymnastics at the German Sport University in Cologne,
- two manufacturers of wind gauges and
- the Federal Institute of Sport Science as co-ordinator.

This investigation, which is supported by the International Athletic Foundation (IAF) has not yet been completed. Therefore, this article deals only with some selected aspects of this ongoing investigation. However, these aspects and approximately

350,000 individual measurements can provide a representative picture.

Presumably this is the first time that several calibrated wind gauges, together with a computer programme especially developed for such measurements, have been used to examine the behaviour and possible measurement of air movements in stadiums.

In the framework of this investigation, four wind gauges were placed on the left and right side of the running track and measurements were made during

- the World Championships in Stuttgart in 1993,
- the Duisburg Gala Meeting in 1994,
- the South German Championships in Konstanz in 1994.

Research was also conducted, under non-competition conditions, in the university stadium in Freiburg and in the stadium of Villingen-Schwenningen.

During the World Championships in Stuttgart in 1993, a new Ultrasonic anemometer was used as the official wind gauge. The results of the measurements taken were integrated into the data records stemming from the eight measuring tubes. The measuring devices were arranged as shown in *Figure 1*. For technical reasons, the data acquisition system had to be moved to the start area; consequently, because of the prepared length of the cables, devices 8 and 4 had to be placed in the start area while devices 1 and 5 had to be moved to the finish area. During all later measurements the arrangement of the devices was the other way round. This means that the measuring tubes 1 and 5 were always placed in the start area and devices 4 and 8 were placed near the finish area. The distance between the start and the first measuring tube, between each measuring tube and between the last measuring tube and the finish was 20 metres. Therefore, the official wind gauge at the 50m point was always between the 6th and the 7th tube in Stuttgart and between the 2nd and 3rd measuring tube during the measurements at the other meetings. The following wind conditions have been arbitrarily selected from the data recorded in Stuttgart

In two of the men's 200m heats time segments could be observed, during which there were relatively windy conditions while, on August 16 and 17, 1993, the days of the other test measurements, there were extraordinarily windless conditions. *Figures 2a and 2b* give an overview of the measurements recorded by all the tubes. In each case the official record has been printed on the top right side of the figure; this measurement record is the mean value of *one* measurement over a 100m course and the corresponding time. The mean values of all eight measuring tubes in the test sequence deviate from this official value to the same extent as the mean

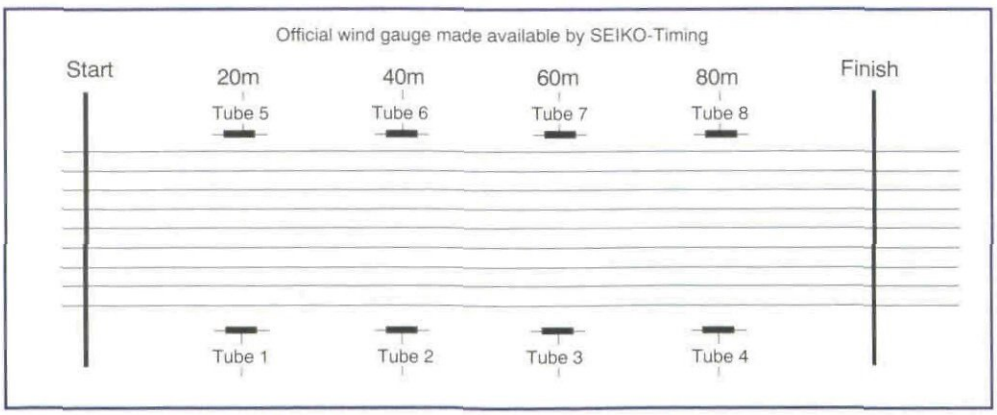


Figure 1: Arrangement of wind measurement devices along the track

3rd Heat 200m Men								Seiko measurement: +1.6m/sec	
Time	Tube1	Tube2	Tube3	Tube4	Tube5	**Tube6**	**Tube7**	Tube8	
11:24:43	0.43	1.25	1.11	0.35	-0.75	**1.60**	**1.08**	0.21	
11:24:44	0.43	1.60	1.13	0.33	-0.76	**1.66**	**1.15**	0.16	
11:24:45	0.46	1.50	1.22	0.30	-0.79	**1.71**	**1.18**	0.14	
11:24:46	0.49	1.32	1.19	0.26	-0.82	**1.71**	**1.22**	0.13	
11:24:47	0.52	1.30	1.13	0.23	-0.79	**1.65**	**1.15**	0.38	
11:24:48	0.56	1.34	1.09	0.23	-0.81	**1.62**	**1.03**	0.46	
11:24:49	0.61	1.39	1.04	0.22	-0.85	**1.51**	**0.92**	0.51	
11:24:50	0.66	1.37	1.01	0.21	-0.85	**1.52**	**0.93**	0.60	
11:24:51	0.66	1.33	0.93	0.18	-0.87	**1.69**	**0.86**	0.70	
11:24:52	0.61	1.30	0.91	0.15	-0.92	**1.72**	**0.74**	0.71	
Mean	0.54	1.37	1.07	0.24	-0.82	**1.64**	**1.02**	0.40	**0.68**
Mean						**1.64**	**1.02**		**1.33**

6th Heat 200m Men								Seiko measurement: +0.6m/sec	
Time	Tube1	Tube2	Tube3	Tube4	Tube5	**Tube6**	**Tube7**	Tube8	
11:46:39	1.41	0.76	1.58	-1.82	-1.42	**1.99**	**-0.62**	-1.01	
11:46:40	1.20	0.68	1.55	-1.82	-1.43	**2.03**	**-0.37**	-0.78	
11:46:41	1.06	0.63	1.38	-1.70	-1.24	**1.94**	**0.08**	-0.60	
11:46:42	0.93	0.58	1.20	-1.59	-1.10	**1.87**	**0.72**	-0.55	
11:46:43	0.86	0.53	1.14	-1.42	-0.97	**1.65**	**1.06**	-0.46	
11:46:44	0.85	0.46	1.06	-1.27	-0.89	**1.34**	**1.00**	-0.42	
11:46:45	0.90	0.42	0.96	-1.10	-0.84	**1.00**	**0.93**	-0.39	
11:46:46	0.88	0.39	0.85	-1.00	-0.81	**0.86**	**0.95**	-0.38	
11:46:47	0.75	0.34	1.01	-0.96	-0.74	**0.74**	**1.03**	-0.34	
11:46:48	0.70	0.26	1.14	-1.01	-0.69	**0.66**	**1.11**	-0.29	
Mean	0.95	0.50	1.18	-1.37	-1.01	**1.41**	**0.59**	-0.52	**0.22**
Mean						**1.41**	**0.59**		**1.00**

Figures 2a and 2b: **Samples of measuring results of all tubes (1-8) in comparison to the official measuring result, 200m men, heat 3 and 6**
(bold: tubes 6 and 7 next to the official device)

values of tubes 6 and 7, which have been considered separately and between which the official measurement tube was placed. However, these results are distorted because all values fail to take into account the runners' movements. The runners reach tubes 8 and 4 after 20 metres, tubes 7 and 3 after 40 metres, tubes 6 and 2 after 60 metres and tubes 5 and 1 after 80 metres. The wind acting on the runners would have been measured only at these points. Therefore, it is not surprising that these mean values do not at all correlate with the official wind readings.

Figures 3a and 3b show the data of the respective time periods and make possible the reconstruction of what happened on the track. Although, from a mathematical point of view, the averaging out of already determined mean values is questionable, it should be clear that a mean value from four already calculated mean values can be expected to be more exact than the values measured over a total period of 10 seconds and recorded in the form of one mean value.

Although the air currents observed during the 12 hours of measurement were extremely light, the measuring data demonstrate the very different wind conditions at the individual measuring tubes.

Figures 4a and 4b show the respective maximum values of tail and head winds. The tables selected were derived from the data measured by tubes 6 and 7, between which the official wind gauge was placed. The wind conditions are shown for certain points in time (seconds) rather than for the whole period. It is interesting to observe that, apart from the maximum values at tubes 6 and 7, very different measurements were recorded at all other tubes.

Time	metres	Tube 1/5	Tube 2/6	Tube 3/7	Tube 4/8	Mean
11:24:42	0	0.44/-0.79	0.91/1.42	1.31/0.96	0.36/0.39	
11:24:43	10	0.43/-0.75	1.25/1.60	1.11/1.08	0.35/0.21	
11:24:44	20	0.43/-0.76	1.60/1.66	1.13/1.15	0.33/0.16	T1/T5 -0.16
11:24:45	30	0.46/-0.79	1.50/1.71	1.22/1.18	0.30/0.14	
11:24:46	40	0.49/-0.82	1.32/1.71	1.19/1.22	0.26/0.13	T2/T6 1.52
11:24:47	50	0.52/-0.79	1.30/1.65	1.13/1.15	0.23/0.38	
11:24:48	60	0.56/-0.81	1.34/1.62	1.09/1.03	0.23/0.46	T3/T7 1.06
11:24:49	70	0.61/-0.85	1.39/1.51	1.04/0.92	0.22/0.51	
11:24:50	80	0.66/-0.85	1.37/1.52	1.01/0.93	0.21/0.60	T4/T8 0.41
11:24:51	90	0.66/-0.87	1.33/1.69	0.93/0.86	0.18/0.70	
11:24:52	100	0.61/-0.92	1.30/1.72	0.91/0.74	0.15/0.71	
Mean		0.53/-0.82	1.33/1.62	1.10/1.02	0.26/0.40	0.71

Seiko: +1.6 m/sec; mean between T6/T7: 1.32 m/sec; mean of all means: 0.68m/sec
blue: data when the runners passed the respective pairs of tubes

Figure 3a: Research on wind measurement in athletics at Stuttgart 200m men, heat 3

Choosen time segment: 10sec between 11:24:42 - 11:24:52

Time	metres	Tube 1/5	Tube 2/6	Tube 3/7	Tube 4/8	Mean
11:46:38	0	1.67/-1.47	0.88/2.14	1.69/-0.67	-2.03/-1.20	
11:46:39	10	1.41/-1.42	0.76/1.99	1.58/-0.62	-1.82/-1.01	
11:46:40	20	1.20/-1.43	0.68/2.03	1.55/-0.37	-1.82/-0.78	T1/T5 -0.116
11:46:41	30	1.06/-1.24	0.63/1.94	1.38/0.08	-1.70/-0.60	
11:46:42	40	0.93/-1.10	0.58/1.87	1.20/0.72	-1.59/-0.55	T2/T6 1.225
11:46:43	50	0.86/-0.97	0.53/1.65	1.14/1.06	-1.42/-0.46	
11:46:44	60	0.85/-0.89	0.46/1.34	1.06/1.00	-1.27/-0.42	T3/T7 1.03
11:46:45	70	0.90/-0.84	0.42/1.00	0.96/0.93	-1.10/-0.39	
11:46:46	80	0.88/-0.81	0.39/0.86	0.85/0.95	-1.00/-0.38	T4/T8 -0.69
11:46:47	90	0.75/-0.74	0.34/0.74	1.01/1.03	-0.96/-0.34	
11:46:48	100	0.70/-0.69	0.26/0.66	1.14/1.11	-1.01/-0.29	
Mean		1.02/-1.05	0.54/1.47	1.23/0.47	-1.43/-0.58	0.3625

Seiko: +0.6 m/sec; mean between T6/T7: 0.97 m/sec; mean of all means: 0.21m/sec
blue: data when the runners passed the respective pairs of tubes

Figure 3b: Research on wind measurement in athletics at Stuttgart 200m men, heat 6

Chosen time segment: 10sec between 11:46:38 - 11:46:48

Figures 5 and 6 illustrate these different measuring results with regard to another period of time during the World Championships in Stuttgart. These figures make clear that wind movements do not follow any logical structure.

The results of the measurements conducted at the Gala Meeting in Duisburg on June 12, 1994, the South Germany Championships in Konstanz on July 23 and 24, 1994 and in the Freiburg and Villingen-Schwenningen stadiums (where measurements were made only for scientific purposes) confirm the finding that there is no constant air movement on a 100m course during a period of 10 seconds (*Figures 7 and 8*). This leads to the conclusion that wind measurements using only one wind gauge do not provide a representative or even an exact, let alone, a just result. We must wait and see whether this will eventually lead to a change in the rules. It should, however, be emphasized that the current rules of wind measurement are extremely questionable.

Earlier publications dealing with this subject compared wind readings in a stadium closed by stands at all four sides (but without a roof) with those in stadiums with openings between the stands, through which the wind could enter in varying degrees of strength.

These measurements were conducted in

- the Daimler stadium in Stuttgart, which is enclosed by identically high stands at all four sides. Furthermore, a roof over the stands at all four sides causes identical wind flow conditions;
- in the Wedau stadium in Duisburg, where there is one stand of a lower height, the main stand facing the finishing straight has a roof and the stand along the back straight is roofless;
- in the stadium in Konstanz, which is open on one side;
- in the Freiburg University stadium and in the Villingen/Schwenningen stadium, where the stands are not so high, so that the wind can enter to some degree.

Measurements were taken in five different stadiums and, although the wind conditions were different, there were identical results.

On a course of 100m length the wind does not move at all in a regular or even predictable way.

The multitude of data confirms the finding that all buildings in the environment of the stadium lead to significant wind swirls, which disperse only after long distances free of obstacles.

During the measurements in Freiburg the wind gauges were supplemented by smoothly moving wind flags made of a rigid plastic material. *Figure 9* shows the wind direction readings, the wind forces determined by the measuring device using laminar streamlines and the computed real wind forces and directions.

Against this backcloth, the following observation becomes significant: Wind is met not only on the straight sections of the track but at every other section of the oval running track and the interior space of the stadium.

Agenda to Figure 5

x-axis = time.
In this case: Aug. 16, 1993, 18:33:15 – 18:33:24. This time interval is 10sec and thus corresponds to the duration of a 100m race.

y-axis = wind force in m/sec.

Wind velocity was continuously measured and recorded, regardless of the competitions so that, apart from the competition periods, which were given special marks, more than 5,000 states (1 state = 1sec with one measuring value each at 8 gauges) were recorded.

In the present case the official wind measurement would have taken place at the location of the experimental wind gauges 2 and 4. The mean value of these measurements would have been above the limit value of 2.0m/sec although all other wind gauges produced significantly lower values; the mean value of all gauges, measured over the complete 10sec interval, would have been around 0.31m/sec.

Maximum measurement results at tube 6

Time	T1	T2	T3	T4	T5	T6	T7	T8	Mean of tubes 1-8
12:07:24	0.97	0.06	-0.66	-1.05	-1.18	**-2.18**	-1.57	-1.63	-0.91
12:07:25	1.03	0.10	-1.19	-1.19	-1.24	**-2.02**	-1.69	-2.00	-1.03
12:07:37	0.55	-0.75	-0.99	-0.91	-0.31	**-1.88**	-2.19	-1.24	-0.97
12:07:36	0.58	-0.75	-1.09	-0.97	-0.34	**-1.87**	-2.02	-1.21	-0.96
18:52:01	*-0.46*	*-2.20*	*-0.32*	*-0.29*	*-1.04*	***-1.85***	*-0.39*	*0.03*	*-0.82*
12:07:38	0.51	-0.76	-0.94	-0.90	-0.27	**-1.76**	-2.10	-1.19	-0.93
18:38:17	1.62	2.73	-0.10	-0.64	0.18	**2.08**	-0.60	-1.01	0.53
11:46:38	1.67	0.88	1.69	-2.03	-1.47	**2.14**	-0.67	-1.20	0.13
18:38:18	1.71	2.70	-0.22	-0.88	0.12	**2.18**	-0.85	-1.18	0.45
11:46:37	1.98	1.02	1.85	-2.20	-1.51	**2.18**	-0.74	-1.23	0.17
18:38:19	1.57	2.58	-0.32	-1.10	0.05	**2.21**	-0.99	-1.23	0.35
11:46:36	2.34	1.12	1.95	-2.06	-1.55	**2.23**	-0.68	-1.40	0.24

Maximum measurement results at tube 7

Time	T1	T2	T3	T4	T5	T6	T7	T8	Mean of tubes 1-8
12:07:29	0.97	-0.15	-1.60	-1.19	-0.83	-1.08	**-2.67**	-1.63	-1.02
12:07:28	*1.00*	*-0.14*	*-1.63*	*-1.22*	*-0.90*	*-1.18*	***-2.56***	*-1.85*	*-1.06*
12:07:30	0.94	-0.32	-1.45	-1.26	-0.71	-1.03	**-2.56**	-1.57	-1.00
12:07:27	1.04	-0.07	-1.46	-1.18	-1.02	-1.37	**-2.42**	-1.97	-1.06
12:07:32	0.79	-0.69	-1.21	-1.51	-0.50	-1.08	**-2.37**	-1.30	-0.98
12:07:31	0.88	-0.57	-1.32	-1.55	-0.61	-1.04	**-2.30**	-1.44	-0.99
18:07:50	-0.71	-0.15	0.00	0.05	0.05	0.12	**1.66**	0.26	0.16
11:59:31	-0.45	0.39	1.30	0.25	0.59	0.20	**1.66**	0.98	0.62
18:04:33	0.99	0.59	0.96	-0.09	1.21	1.48	**1.68**	-0.87	0.74
18:04:25	0.74	0.53	0.54	0.13	0.37	1.12	**1.78**	-0.32	0.61
18:04:27	0.89	0.67	0.61	0.11	0.62	1.26	**1.78**	-0.75	0.65
18:04:26	0.86	0.62	0.59	0.13	0.50	1.13	**1.84**	-0.57	0.64

Figures 4a and 4b: **Samples of measuring results of all tubes (1-8) in comparison to the official measuring result** (bold: tubes 6 and 7 close to the official device)

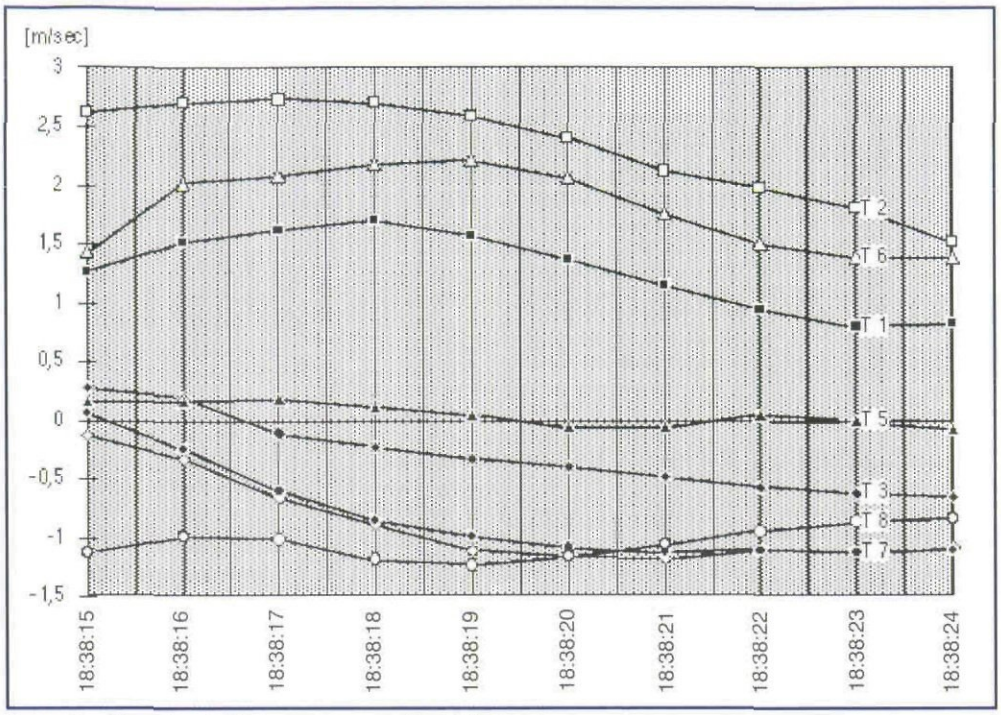


Figure 5: Sample of wind measurements at Stuttgart

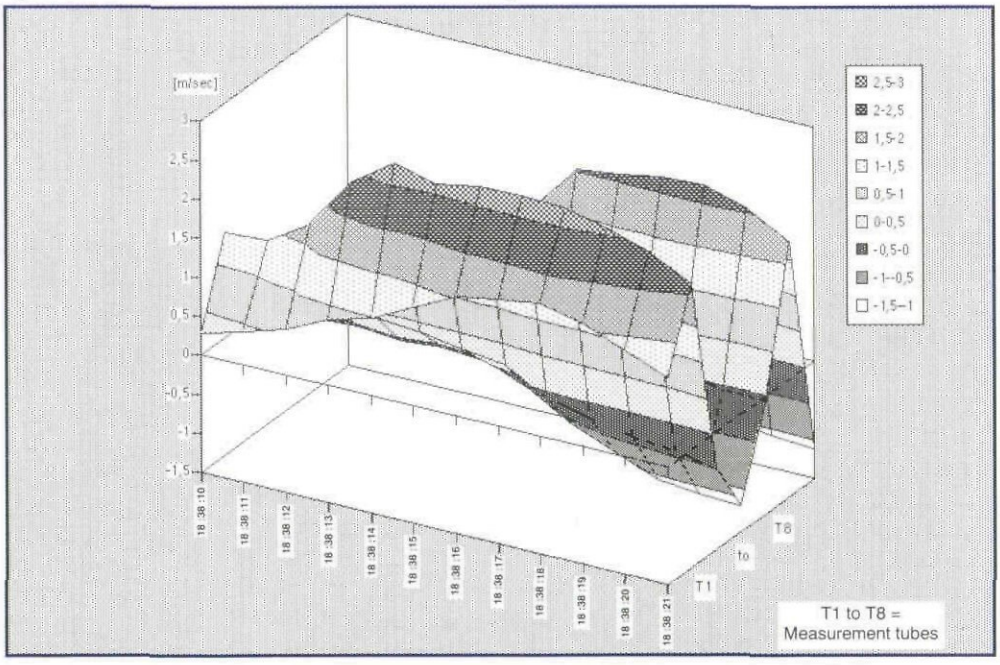


Figure 6: Sample of wind measurements at Stuttgart

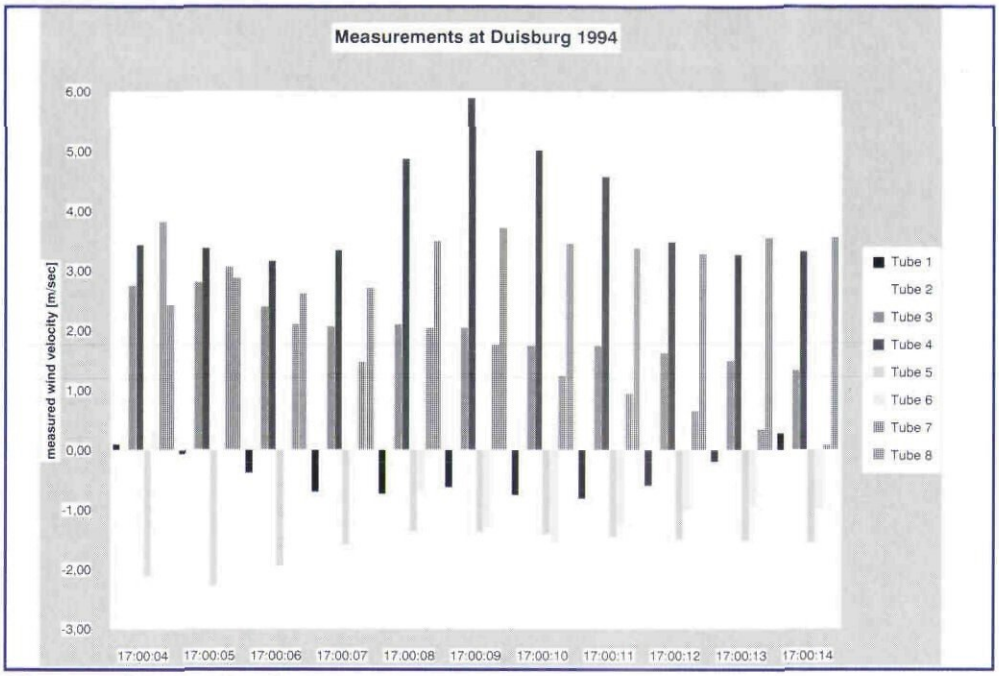


Figure 7: Sample of wind measurements at Duisburg
(stadium with high stands at the home straight and lower stands opposite)

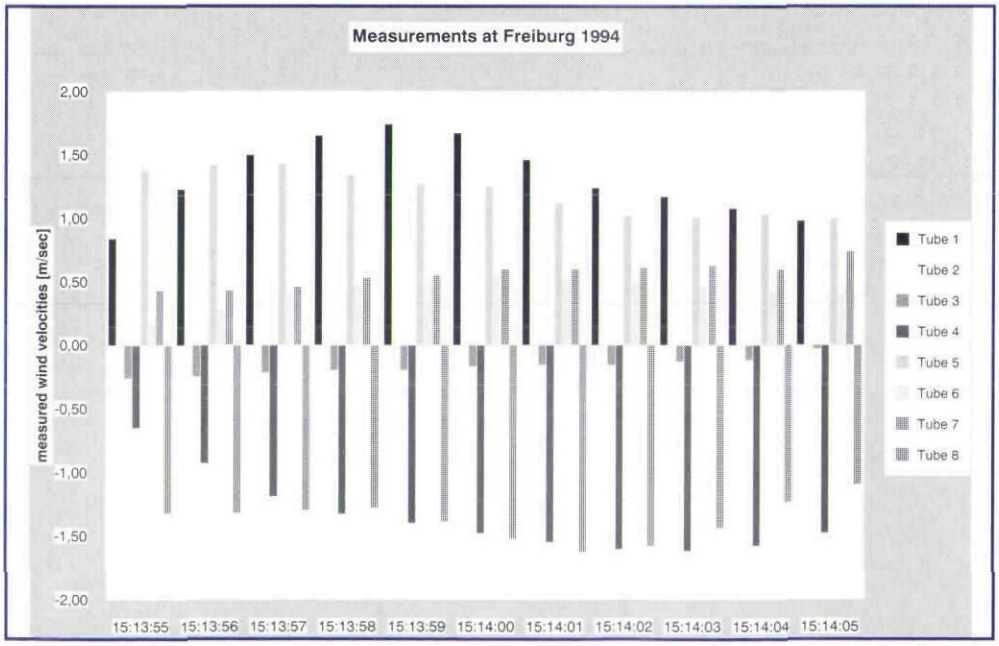


Figure 8: Sample of wind measurements at Freiburg (stadium with low stands)

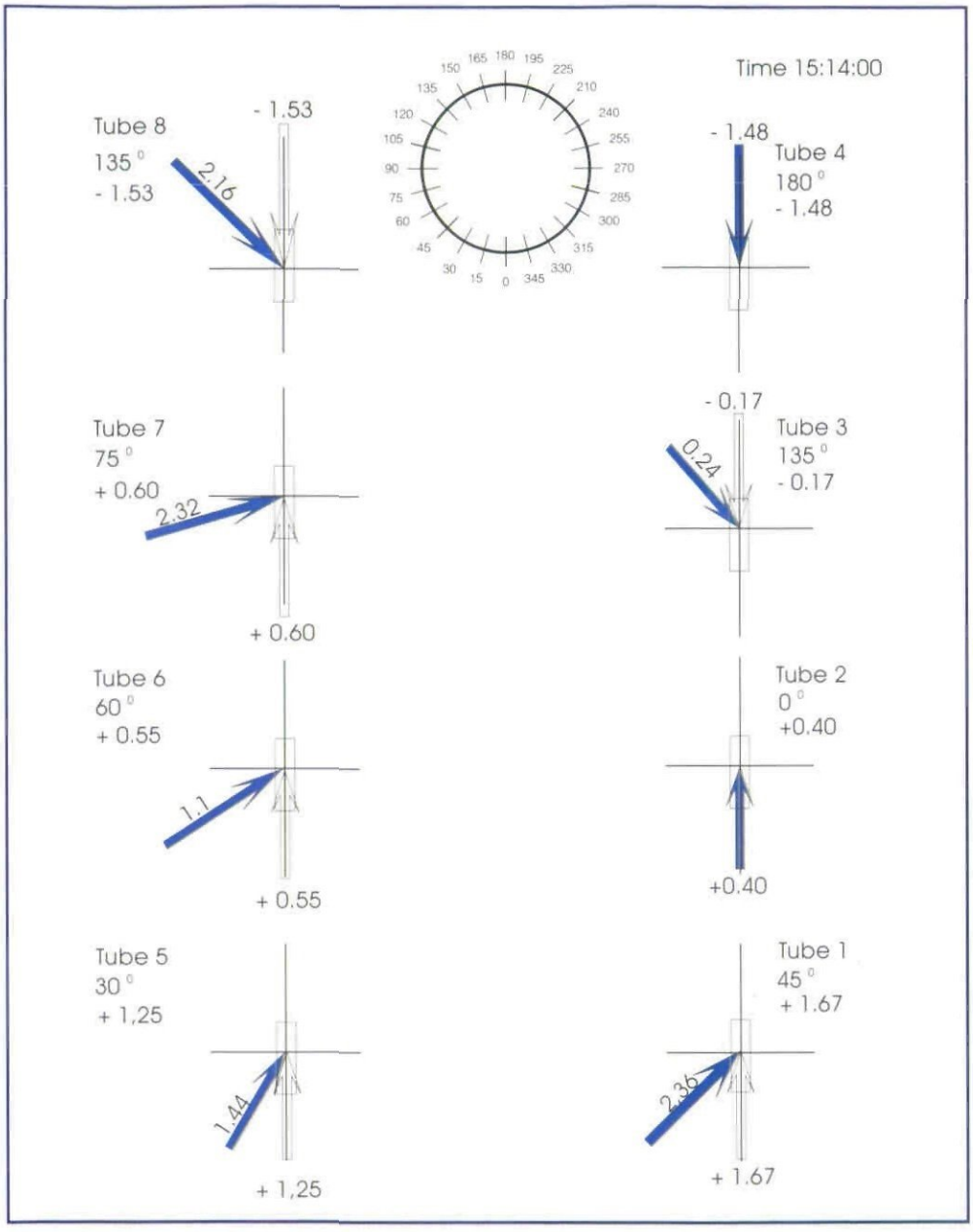


Figure 9: Wind directions and wind forces measured by laminar streamline devices (tubes 1 to 8) and the real wind directions and forces

The fact that the rules demand wind measurement in long and triple jump competitions, even if they take place on the back straight, proves that it is assumed that the wind effects the athlete at every other place in the stadium. However, if that is the case, it

is hardly understandable why no wind measurement is taken in the relays and in the 400m run or in the javelin and discus throw especially as, in the two latter events, positive wind effects have been known for a very long time.

This should be enough to say about conditions which can be shown in an exact and reproducible way by using repeated measurements.

It is difficult and expensive to develop a model of an athlete, in such a way that all movements during a stride cycle can be realistically simulated and computed in a wind tunnel, using different angles of attitude, so that a balance of results can be obtained. A first test using a model in the wind tunnel at the University of Bochum gives reason to assume that, in the case of a tail wind of 2m/sec, the aerodynamic drag is reduced by about 4 N, as compared to a windless situation. Whether the athlete physically perceives these 400 g can be computed. However, it is not possible to compute the psychological effect of the wind on the sprinter. For instance, during the Duisburg meeting, a triple jumper was allowed to have a look at the ongoing measurement and was assured that the head wind, which he felt to be very disturbing, existed only during the starting phase and dispersed in the area of the take-off board or even turned into a tail wind. This was only partly accepted by the triple jumper, who still maintained that he was hindered by the head wind which was "programmed into his head".

In conclusion, some remarks should be made on the measurement devices. Indisputably, the time has come to break with the mass-containing impeller (or rotor) devices, because ultrasound technology has made the building of mass-free devices possible, although these devices will be somewhat more expensive than the traditional impeller devices. However, ultrasound devices can be useful only if they are capable of measuring in three dimensions, so that the real wind condition and the very complex swirls can be measured. It is important to realize that the athletes are submitted to these swirls to a much greater extent than to the air movements acting parallel to the running track.

There is no getting around the fact that measuring the wind only at one point of the track does not give a valid representation of the wind conditions. However, this also means that much higher costs must be expected because exact wind readings will only be possible if several wind gauges are used at the same time. Presumably this will lead to a decrease rather than an increase in the number of non-recognized performances.

(Editors' note: Research for this study was done for an IAF and DLV -German Athletics Association- project on wind measurement. When the project is completed, NSA will give a summary report on the results.)