# THE WIND ENVIRONMENT EXPERIENCED BY MOVING VEHICLES

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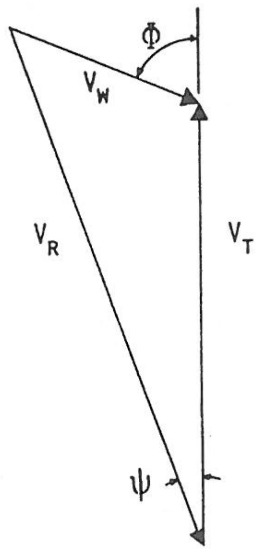
Introduction The relative wind velocity, $V_r$ experienced by surface vehicles is the vector sum of the vehicle velocity relative to the ground, $V_t$ and the velocity of the natural wind relative to the ground, $V_w$. Additionally a yaw angle $\psi$ is generated when the direction of the natural wind is inclined at an angle $\Phi$ to the direction of motion of the vehicle, as shown below in Figure 1.




The first effect of a crosswind is commonly simulated in a wind tunnel by yawing the model at various angles $\psi$ to the oncoming flow and measuring forces which are reduced to coefficient form using the vehicle velocity $V_t$. Frequently the change in relative velocity which can occur in full-size (due to ambient winds) is ignored when interpreting tunnel results.

To take into account both effects when calculating a long-term drag coefficient, Buckley et al (1) suggested a process of wind-averaging tunnel drag coefficients. This is a simple, but useful model for analysing the average primary effects of steady winds on a vehicle´s aerodynamic performance and involves weighting the drag coefficient at various yaw angles to account for the change in relative velocity. It is becoming widely used for interpreting tunnel data from commercial vehicle tests.

It has been shown that for the UK, (2) it is reasonable to assume that the natural wind can approach a vehicle´s direction of motion from any angle $\Phi$ ,ie there needs to be no weighting for wind and route directions. Thus the angle $\Phi$ has equal probability of lying in the range 0 to 360 degrees.

| | NATURAL WIND $V_w$ | WIND DUE TO VEHICLE MOTION $V_t$ |
|---|---|---|
| STEADY EFFECTS | $\overline{V_r} = \overline{V_t} + \overline{V_w}$ ($\overline{V_r}$ varies with height)<br>Generates a yaw angle $\psi$ ($\psi$ changes with height) | Steady component due to vehicle motion $\overline{V_t}$ |
| UNSTEADY EFFECTS | Natural Wind Turbulence<br>Wakes of Stationary Objects | Changes in Speed<br>Changes in Direction<br>Wakes of other moving vehicles |
| | Note : There are sub-sets of the above but their influence is considered minimal | |

However, the natural wind is far from steady. It is turbulent, with continuous fluctuations in speed, and the amplitude and frequency vary in a random manner. There is also a mean variation with height. This paper attempts to document these effects, and to aid this, components of the relative wind sensed by a moving vehicle are separated and presented in Table 1 on the left.

Steady Wind Effects It is commonly known that the natural wind has a mean variation with height. From theoretical

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considerations, the profile can be shown to be a logarithmic function although it is sometimes convenient to fit a power function. This effect has been considered by Buckley (1) and Cooper (3) and shown to produce small changes in yaw angle and relative velocity compared to the magnitiude of the total changes.

Unfortunately there appears to be little data to verify that the velocity profile is close to a log or power fit for the type of terrain and the heights relevant to vehicles. Panofsky (4), and Bradley (5) have studied some of the properties of the wind at heights under 4.3 m (the maximum road-legal height for Victoria), but both studies were over flat landscapes (plains) which had very low associated roughness heights. Most work in this area has been for agricultural purposes. Recent work by Flay (6), has substantially increased the data base on wind effects close to the ground, although problems were experienced from the lowest anemometer (3.2 m) due to flow non-stationarities. It seems likely that for many roads the scale of local roughness (trees, bridges, cuttings etc.) is such that a well-defined velocity profile could be lost, and the unsteady wind effects exert greater influence. Lawson (7) warns against using the power law at the extremities of its fitted range, particularly when the zero plane displacement is large. Considerably more work appears necessary in this area.

Unsteady Effects Rapid vehicle accelerations and changes of direction can change the wind conditions sufficiently rapidly to be viewed as unsteady effects, however this paper is mainly concerned with wind effects that occur on vehicles travelling at highway speeds where these effects are minimal, or may be regarded as quasi-static. For this paper they will be ignored.

Some theoretical work has been done on the effects of natural wind turbulence for vehicle stability studies, Balzer (8) and also Cooper (9) who used data compiled from a variety of sources by ESDU (10). Again there is little experimental work to verify the low-level unsteady effects. There has been some experimental work in the UK by Smith (11) who found that majority of "gusts" measured by a moving car were caused by identifiable local effects. There has also been some work in Japan and France.

Work at RMIT To investigate unsteady wind effects, a car instrumented with a GILL propeller-vane anemometer and a TSI hot film anemometer, recorded data along the Geelong Road. A typical trace is shown below. The wind relative to the ground (at a height of 3.3 m) averaged 2.2 m/s and this data was recorded near the 40 km marker (from GPO Melbourne). This windspeed appears close to the average Australian daily windspeed, Giang (12).

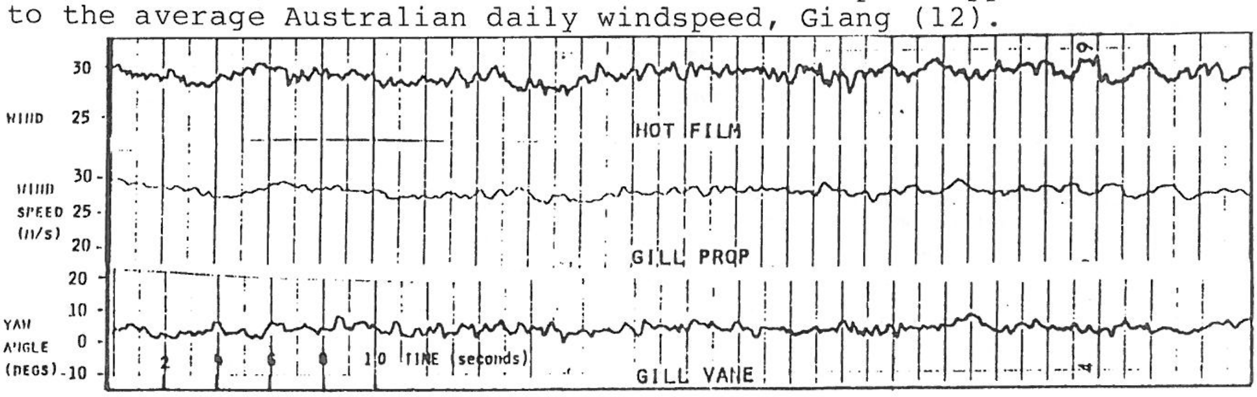

Figure 3 below, was obtained from the same vehicle, but the measurements were made along the Hume Highway approximately 60 km south of Sydney. The data was filtered at 1 Hz and sampled every 8 s. Roadside obstructions differ markedly from the Geelong Road as the tree cover is far more dense and there are many more cuttings and forested areas close to the highway.

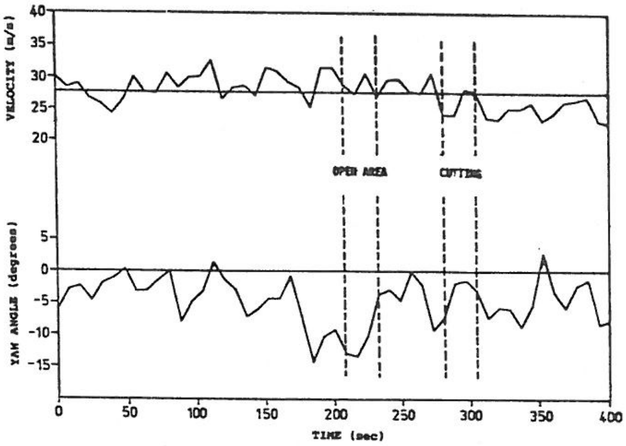


FIGURE 3 WIND DATA-N.S.W.

For all runs the car speed was held constant at 100 km/h (27.8 m/s) to within $\pm$ 1 km/h. The mean windspeed relative to the ground was 3.1 m/s and it was orientated at a mean angle $\Phi$ of 30 degrees to the direction of motion. 10 degree variations of yaw angle within a period of 20 seconds were frequently encountered, accompanied by changes in relative wind velocity of the order of 5 m/s. This is thought to be typical of roads which have intermittent roadside tree cover.

Further work has been undertaken on the Geelong Road test route and a summary of some of the parameters is shown below. Data were recorded at sites along the roadside and the car was positioned upwind of the road to ensure that the effects of moving vehicle wakes were not recorded. Data was also recorded with the vehicle moving (denoted by asterisk) at 100 km/h and all runs were made immediately after the preceding stationary run. To calculate the turbulence intensity for the moving vehicle, it was desired to remove the effects of slow changes in vehicle speed. This was done by high-pass filtering all the data at 0.1 Hz, which corresponds to a road distance of 280 m or approximately 17 articulated vehicle lengths. All data were recorded on analogue tape. The output from the GILL propellor was low-pass filtered to remove only discrete fluctuations from the tach-generator output, hence the maximum frequency response was dictated by the inertia of the instrument. The output from the hot film was low-pass filtered at 50 Hz. Measured intensities for the moving vehicle range

| RUN NO | LOCATION | SAMPLE (mins) | WIND SPEED (m/s) | WIND D'ION | TURBULENCE INTENSITY GILL | TURBULENCE INTENSITY HFA | COMMENTS ON TERRAIN |
|---|---|---|---|---|---|---|---|
| 1 | 30 km | 12 | 1.9 | SW | 26.4 | 34.5 | In tree wake |
| 2 | 50 km | 12 | 2.5 | SSW | 9.1 | 13.4 | Short bushes |
| 3 | 70 km | 12 | 4.6 | SSW | 8.2 | 12.2 | Short grass |
| 4 | 90 km | 12 | 8.3 | SSW | 8.4 | 12.4 | Short grass |
| 5 | 50 km | 12 | 6.5 | S | 11.5 | 16.4 | |
| 6* | 50-40 km | 6 | 29.1 | S | 3.0 | 4.0 | Passed one truck |
| 7 | 30 km | 12 | 5.8 | S | 11.6 | 20.2 | |
| 8* | 30-50 km | 12 | 33.1 | S | 2.8 | 3.0 | Light traffic |
| 9 | 70 km | 12 | 6.8 | S | 7.8 | 11.8 | |
| 10* | 70-90 km | 12 | 27.4 | S | 2.8 | 2.9 | Light traffic |
| 11 | 90 km | 12 | 4.5 | S | 12.7 | 15.7 | Fine rain |
| 12 | 70 km | 12 | 6.5 | S | 9.6 | 15.1 | |
| 13* | 70-90 km | 12 | 25.6 | S | 2.4 | 2.6 | Light traffic |
| 14 | 90 km | 12 | 5.5 | S | 9.6 | 15.0 | |
| 15 | 30 km | 8 | 1.2 | SE | 13.9 | - | |
| 16* | 30-50 km | 12 | 30.2 | SE | 1.5 | 1.7 | Light traffic |
| 17 | 50 km | 10 | 2.2 | SE | 13.8 | 34.6 | |
| 18* | 50-30 km | 12 | 27.7 | S | 1.9 | 2.5 | Light to medium traffic |
| 19 | 30 km | 12 | 2.7 | S | 12.7 | 28.9 | |
| 20 | 70 km | 5 | 2.6 | S | 11.3 | 20.6 | |
| 21* | 70-90 km | 12 | 25.0 | S | 2.4 | 2.4 | Light traffic |
| 22 | 90 km | 3.5 | 2.6 | S | 13.5 | 21.5 | |
| 23* | 90-70 km | 12 | 27.1 | S | 2.0 | 2.1 | Light traffic |
| 24 | 70 km | 2 | 1.4 | S | 16.2 | 38.0 | Short run (tape ran out) |

Table 2 Stationary and Moving Wind Data - Victoria Test Route

from the lowest value of 1.5 % rms from the GILL to a maximum of 4.0 % rms for the hot film, with windspeeds varying from 1.2 to 6.8 m/s. Other work undertaken during periods of stronger winds (≈10 m/s) resulted in turbulence intensities of up to 6 %.

To investigate the frequency distribution, power spectral density functions are currently being calculated.

Concluding Remarks  Currently major vehicle tunnels have turbulence levels of less than 1 % and none have the ability to investigate possible velocity profile effects. With increasing pressure being put on vehicle manufacturers to reduce drag coefficients, it may become necessary to improve the wind tunnel's simulation of the on-road flow conditions. For this to occur further knowledge of the wind environment of the moving vehicle is necessary.

## References


1. Buckley F.T., Marks C.H., Walston W.H. — A Study of Methods for Improving Truck Fuel Economy. Prepared for the National Science Foundation, University of Maryland, USA, 1978.

2. Ingram K.C. — The Wind-Averaged Drag Coefficient Applied to Heavy Goods Vehicles. TRRL (UK) Supplementary Report 392, 1978.

3. Cooper K.R., Campbell W.F. — An Examination of the Effects of Wind Turbulence on the Aerodyanamic Drag of Vehicles. J. Wind Eng. & Ind. Aero. 9, (1978), 167-180.

4. Panofsky H.A. — Scale Anaylsis of Atmospheric Turbulence at 2 m. Qt. Jl. Royal Met. Soc. 88, 1962.

5. Bradley E.F. — Private Communication. CSIRO., July, 1984.

6. Flay R.G.J. — Structure of a Rural Atmospheric Boundary Layer Near the Ground. PhD. Thesis, University of Canterbury, New Zealand, 1978.

7. Lawson T.V. — Wind Effects on Buildings, Vol 2. Applied Science Publishers Ltd., 1980.

8. Balzer L.A. — Atmospheric Turbulence Encountered by High-Speed Ground Transport Vehicles. Jl. Mech. Eng. Sci. Vol 19, No 5, 1977.

9. Cooper R.K. (sic) — Atmospheric Turbulence with Respect to Moving Ground Vehicles. J. Wind Eng. & Ind. Aero., 17 (1984).

10 ESDU — Engineering Science Data Unit. Data Sheets 74030, 74031 and 75001.

11 Smith N.P. — Wind Gusts Measured on High-Speed Roads. Motor Industry Research Association (UK), Report 1972/7.

12 Giang N. — Computer Simulation of the Effect of Climatic Winds on the Performance of Trucks in Australia. Final Year Thesis, Department of Mechanical and Production Engineering, RMIT, Dec 1984.