Force Balance for Monash/RMIT Aerodynamic Test Facility

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INTRODUCTION As part of a larger program on vehicle aerodynamic research to be conducted in the new Environmental Wind Tunnel facility at Monash University, a six-component force balance is required to enable the 3 moments and 3 forces to be measured on a vehicle in the test airstream. The facility will be used initially to measure static forces, but will later be developed to measure dynamic forces whilst a vehicle is either being rotated in the airstream, or alternatively, being buffeted by large-scale turbulence. Although specialist companies manufacture force balances for vehicle tunnels price precludes their use.

VEHICLE BALANCE DESIGN Wind-tunnels for full-size car testing use under-floor balances and turntables to yaw both model and balance in order to model the primary (mean) effect of a crosswind. To correctly simulate the ground effects, it is required to move the ground at a similar rate to the test airstream. Most passenger cars and commercial vehicles have relatively high ground clearance and this requirement is relaxed in nearly all commercial testing with care being taken to ensure that the tunnel floor boundary layer has a displacement thickness that is less than about one-tenth of the typical underbody clearance. For the majority of tests undertaken in the Monash/RMIT facility, this will be the case. With a fixed ground representation (and stationary wheels), the logical method of supporting and measuring the loads is via wheel pads.

VEHICLE TESTING A typical force/moment test on a vehicle might involve;

a) setting up of ride height (checking tyre pressures and loading the vehicle with suitable masses);

b) setting the turntable and balance system to zero yaw, then for a symmetrical model monitoring (say) the sideforce output whilst the tunnel is running and rotating the model until no sideforce is generated;

c) testing through a sweep of yaw angles such as -15, -9, -3 -6, 0, 3, 6, 9, 15, 0; and

d) testing at set yaw angles (often 0 and 6 degrees) under a range of airspeeds to examine Reynolds number effects.

It is envisaged that for the Monash/RMIT facility parts c) and d) above would take in the order of half an hour, during which time the temperature may rise several degrees.

BALANCE INTERACTIONS Traditionally, six-component force balances were designed to minimise interactions between the orthogonal force vectors. Each output channel gave a response which only arose from a load applied or resolved in one direction. In recent years balances have been designed that are not interaction free, having typically six outputs that are coupled. These coupled outputs are 'unscrambled' via a six by six inverse calibration matrix. The advantage of the later philosophy lies in the relative ease of balance design and manufacture, whereas non-interacting balances are always mechanically complex and can be less rigid. Disadvantages of interacting balances include more complex calibration (particularly if 2nd order terms are present).

Table 1 Anticipated Vehicle Wheelbase and Track

Item	Wheelbase (m)	Track (m)
Passenger cars	2.2-3.0	1.3-1.6
Light commercial vehicles	2.2-4.0	1.4-2.0
Trains in model scale (1/10-1/5th)	0.6-2.5	0.1-0.3
Motorcycles	1.4-1.6	0
Customer requirements	?	?

When a vehicle is aerodynamically loaded, the tyre patch moves rearward, hence for high accuracy, transducers are needed that are not responsive to the point of application of the load, i.e., they should not be sensitive to a moment interaction.

LOADS AND GEOMETRIES For the Monash/RMIT facility, it is envisaged that the vehicle configurations shown in Table 1 need to be tested.

The mass of the models can vary from a few kilograms for a one-tenth scale train model to about four tonnes for a small truck. Aerodynamic loads range from a few Newtons up to a drag or side load of 5 kN for a yawed small truck at 120 km/hr.

BALANCE LAYOUT A balance layout based on a 3-component force measuring system under each wheel, thereby measuring data directly at the tyre/road interface is proposed. To accommodate variations in wheelbase and track, pads incorporating an eccentric cam arrangement may be used as shown in Figure 1. This layout does not permit all vehicles to be mounted on the system but it covers the main requirements of passenger cars and light vans. Motorcycles can be accommodated by rotating the turntable through 90 degrees and placing the wheels on the pads normally used for the front two wheels of a car.

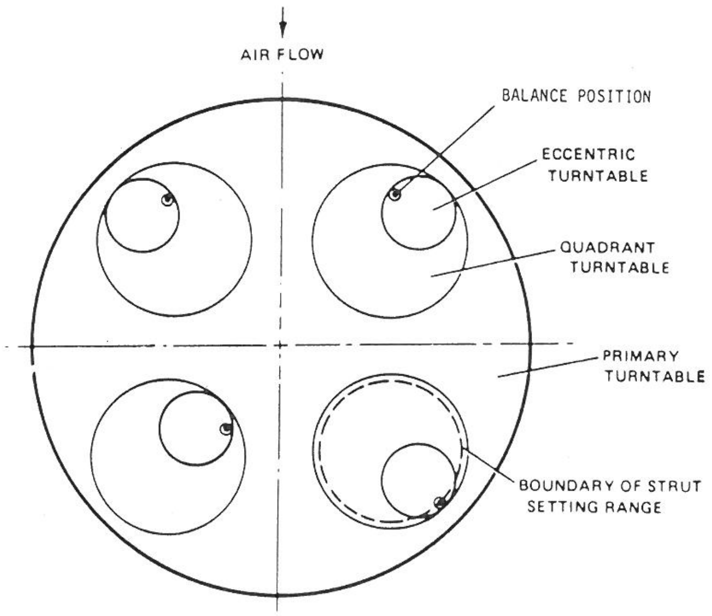

Figure 1 Possible Turntable Layout, after Kelly et al, 1982

Trains pose particular problems regarding wind-tunnel testing due to their length, and it is normal to measure only the drag of one 'live' wagon (i.e., connected to a balance) buried in a length of dummy wagons. This can place the live wagon further downstream of the test section than would normally be the case, precluding the use of the road vehicle balance. Separate balances are needed, probably using the 3-component modules removed from the road vehicle balance.

TRANSDUCER TYPES From the loading requirements it is clear that a high static load can be imposed by the vehicle weight. The balance needs to be relatively stiff since for passenger vehicles, and perhaps racing cars, stability tests will be undertaken which can involve either rapid rotation of the vehicle or generation of large-scale turbulence by active and/or passive methods upstream.

Options for each 3-component system include commercially-available triaxial strain gauges, or piezoelectric load cells, or manufacture of 3-component load cells, either from scratch, or using single-component load cells.

COMMERCIALLY-AVAILABLE UNITS To date no commercially-available strain-gauge units were found in Australia that could offer triaxial measurements in the desired loading capacity, although units up to 500 N are available and some engineering companies will make one offs. However, Kistler make 3-component piezoelectric load cells that are compact and have high accuracy with very high stiffness combined with high sensitivity. Traditionally these crystals have only been used in dynamic work since the charge produced when they are deformed leaks away through the measuring electronics. With advances in electronics, it now becomes possible to have very low leakage rates, hence forces can be measured that reach equilibrium conditions within about one minute. Also since the leakage rate is linear, it becomes possible to apply a correction to the force-time drift. A balance incorporating these elements has been successfully used at the Building Research Establishment in the UK (Cook, 1983).

IN-HOUSE DESIGNED UNITS Whilst various designs have been considered, Figure 2 shows a possible layout utilising flexural elements operating in sway mode which is designed to minimise interactions. This seems a preferable mode rather than a cantilever mode since for any given surface strain level the displacement is minimised, (see for example Ono and Hatamura, 1986). This will be the subject of an initial study, probably using a finite-element approach to work out the optimum geometry to maximise sensitivity and stiffness whilst minimising interactions.

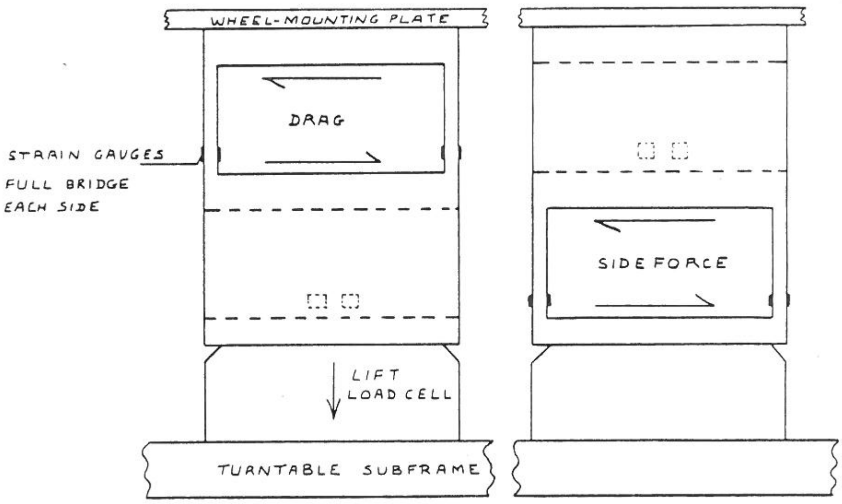

Figure 2 Configuration for Triaxial Load Cell

CONCLUSIONS The force balance will incorporate four separate triaxial modules that will measure lift, drag and sideforce loads at each wheel with, hopefully, minimal interactions between component forces and moments. This will provide a system that gives direct road/tyre interface data and allows modules to be relocated in the tunnel to suit a range of requirements. It is too early to predict the final module design since more information is required on commercially-available units and detailed design is needed to evaluate modules designed in-house.

REFERENCES

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