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"THE MONASH 1 MW WIND TUNNEL - BILL MELBOURNE'S LEGACY."

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INTRODUCTION

Whilst Professor Bill Melbourne of the Mechanical Engineering Department at Monash University has built many wind tunnels, the three-storey 1 MW wind tunnel built over the last few years will be the crowning legacy - that is if RMIT's testing of high temperature cars, which caught the tunnel on fire or One-Australia's continual testing at maximum speed which sends occasional objects flying down the tunnel doesn't destroy it! So far it has proved a very robust design with many novel features. It is one of the most flexible tunnels built, combining sections for structural, pollution and vehicle research.

It now also boasts a unique vehicle aerodynamics test section that has been designed by the RMIT/Monash team, combining under the banner of "Vehicle Aero-Acoustic Laboratories," to test cars in a turbulent and anechoic environment using a very stiff piezo-electric balance.

Prof. Melbourne or "Bill" as he prefers to be known, has been responsible for the overall wind-tunnel design, and the wind-tunnel balance and turntable have been designed and constructed by the RMIT team. We have specified the needs of the open jet and acoustic facilities and Bill has adapted this specification with many novel approaches. Substantial cost advantages have been achieved by designing and building the facility within the respective Universities with only selected sub-contracting. We would like to overview this facility.

OVERVIEW

Vertical Circulation: The Monash Wind Tunnel is shown by Fig 1 and 2. There are many innovative features of this wind tunnel. Following the tradition of several designs of Professor Melbourne, the wind tunnel circulates vertically. This permits good control of the development of the turbulent boundary layer when required. They are much more difficult to control when the wind tunnel circulates horizontally.

Top Test Section: For wind engineering studies, a reasonably homogeneous turbulent boundary layer is required, necessitating a long fetch before the test section. Instead of having the fan in the furthest leg from the test section, the fan is located in the leg leading to the anechoic test section. Thus the wind tunnel was designed to have a 50 m long top section that can be used to generate a turbulent flow.

The turbulence is started by the use of separations at the start of top section. Turning vanes are avoided in the top corner before the fan by the use of slowly decreasing areas before the fan. This inlet design is used in some designs of "sump" pumps. The advantage of this design is that flat surfaces can be used, which also permit the simple installation of sound absorption material. In addition, this technique has minimised surfaces which might attract noise due to incident turbulence.

Fan Leg: A important technique to reduce fan noise is to ensure that the velocity profile over the face of the fan is uniform which has been achieved. The fan unit comprises two 5 m diameter 500 kW units which have already been shown to be sufficient to generate 190 km/h through the vehicle-testing jet of 4 m by 2.55 m. The 12-bladed fans generate a convenient aspect ratio for both vehicle and wind-engineering/pollution use. The additional use of the top section is for both pollution and the testing of structures. Each fan is belt-driven by two refurbished, mine motors and controlled by thyristor drives permitting infinitely variable control. The fans were designed around the largest blades that could be locally-made. Tip clearances are kept to a minimum consistent with high-speed running, and are surrounded by acoustic treatment of 100 mm depth.

Immediately downstream of the fan are eight 5 m long acoustic splitters which have decreased the wind tunnel noise by 10 dBA at the vehicle aerodynamics test section.

Closed Section: This one of the few wind tunnels that has not only an open jet for testing cars, but also a convenient closed testing section. Immediately downstream of the fan is a 2:1 contraction, contracting only in the horizontal plane. The contraction is kept modest to preserve the turbulence, and if needed it can always be reduced by screens. Thus upstream of the open jet is a high-speed 5 m by 4 m wide closed jet section which can used to test cars as well as other structures and vehicles. It has sufficient length to test for trains, boats, etc. This section can be expanded to 12 m wide to permit slower speed wind-engineering work and has the potential for yawing of long models, such as trains.

Open Jet: The open jet, normally an expensive item, is made from simple shapes and is retractable to change the cross-sectional area. With reference to Fig 3, the section is required for wind-engineering operation in the 12 m wide by 5 m high section. Thus the side walls must be moveable and the nozzle retractable. To ease the ability to retract the nozzle, the open jet is made from a flat plate blending into a curved nozzle section. The top of the nozzle is adjustable vertically which gives a variety of possible jet sizes. A vortex is maintained at the start of the jet, which generates a trivial loss.

When the jet is in place, it presents a 2.55 m high by 4 m wide section which currently generates 190 km/h and starts the plenum hall surrounded with acoustic wedges to reproduce the semi-anechoic environment required for vehicle and building tests.

Plenum Hall: The plenum hall, turntable location, size of the jet and collector size has been designed largely on the work of Wiedemann, (1992) along with modelling work at Monash, within the physical constraints of an existing wood-shop and the up-stream needs of sufficient fetch for wind engineering boundary-layer development.

Collector: The collector is currently being designed and built. The jet behaviour without the collector is not satisfactory for aerodynamic coefficient measurements on vehicles located on the turntable and is currently only used for aero-acoustic work. All aerodynamic coefficient work is currently undertaken in the closed section.

The collector will be retractable to permit various opening sizes of the collector including the full-width use of the tunnel in a wind engineering mode.

The various sizes of jet and collector were also designed to permit maximum facility for tuning the jet and pressure distribution around the car.

Downstream Leg: The turning and diffusing leg consists of splitters which Professor Melbourne tested at model scale. The splitters are flat (to ease construction) and filled with 100 mm of acoustic material. As is seen in the side-view of Fig 3, the flow would normally separately fairly rapidly in the expansion. A key part of the design is the corner vortices which permit the flow to remain substantially attached to close to the top corner.

Top turning vanes: The top turning vanes complete the circuit. Currently screens are used for low turbulence applications.

Temperature control: The tunnel is not temperature controlled. Refrigeration is expensive. However, the vertical design of the wind tunnel will permit limited control by simple venting through the ceiling. In the meantime, rapid data acquisition minimises the effects of temperature variation.

High Stiffness Balance And High-speed Turntable: Fig 5 shows the high-stiffness balance and high-speed turntable. The turntable balance measures aerodynamic force and moment coefficients. Underneath each wheel there are three-component Kistler piezo-electric force transducers. The transducers are compact and have high accuracy with very high stiffness combined with high sensitivity - ideal for dynamic as well as static measurements. The Kistler charge amplifiers have trivial drift.

RESULTS

Velocity Profiles: The boundary layer height in the closed section is under 40 mm and with the suction fans on in the open jet, it is below 100 mm. The turbulent intensities are 4% and 2% respectively, which is typically what is required for car applications.

Acoustic Tests: An Aachen "Head" was used to record the wind tunnel out-of-flow noise levels without a car present, but in a reverberative field (the wedges are not currently installed). Fig 6 shows a Variable-Frequency-Resolution (VFR) spectrum of the noise levels at 112 km/h. The Head software scans through the frequency band balancing the time and frequency resolution and sequentially evaluates the spectrum up to increasing higher frequencies. It thereby substantially improves the FFT estimates at lower frequencies. From 339 averages, the software pieces together an improved estimate of the FFT, particularly at lower frequencies.

Fig 7 shows a 500 Hz to 6 kHz 4th-order Butterworth Notch Filter results. The notch filter results are for the frequency regime where most of the annoying aerodynamic noise occurs. Fig 8 shows the A-weighted spectrum. The overall noise level was measured at 78 dBA and 100 dBA linear.

The Head was positioned about one metre from the jet shear layer, level with the centre of the turntable with the left ear facing towards the oncoming jet and about 5 m from the nearest edge of the open jet. Line of sight was to the upstream wind-tunnel wall. There was not a clear line from any part of the left ear to either the acoustic splitters or the fans. The right ear was about 7 m from the downstream splitters.

The graphs show two signals. The slightly lower signal was for the ear facing the on-coming jet. The higher signal shows noise coming from the downstream splitters. The noisy spike was from a loose panel on the downstream acoustic splitters (since rectified).

The typical noise levels in the car were about 65 dbA with the 500 Hz to 6 kHz Notch Filter. The controlled environment with the relative low noise levels is already proving useful even though the wedges had not been installed at that stage. In combination with the Head, it has been useful in evaluating the annoying frequency components of various mirrors, which may give similar overall SPL's.

Currently the out-of-flow measurements are comparing very well with overseas aero-acoustic tunnels. Measurement of inflow spectra will be available shortly.

Buffeting: Initial tests were undertaken by yawing several local production cars at 15° in 4% turbulence intensity showing quite discernible levels of buffeting. As the ability to vary turbulence evolves, so the quantification of the effect of turbulence will evident. Observers in the cars who had experience the effect of similar yaw angle in other tunnels had not experienced the same buffeting effects.

Cooling: Tests have been performed measuring both the radiator top-tank air-to-boil temperatures and the heat rejection. Both were found to be significantly reduced at yaw angles of 15°. Rear-end flow was found to also reduce the cooling capacity of a stationary car. Future developments include a dynamometer that has been proposed which will have the facility to yaw as well as interchange rollers to investigate ride-quality.

CONCLUSIONS

The Monash 1 MW wind tunnel will generate a large amount of path-finding research in wind engineering, pollution and vehicle testing. It will be a long-standing credit to Professor "Bill" Melbourne.

ACKNOWLEDGMENTS

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REFERENCES

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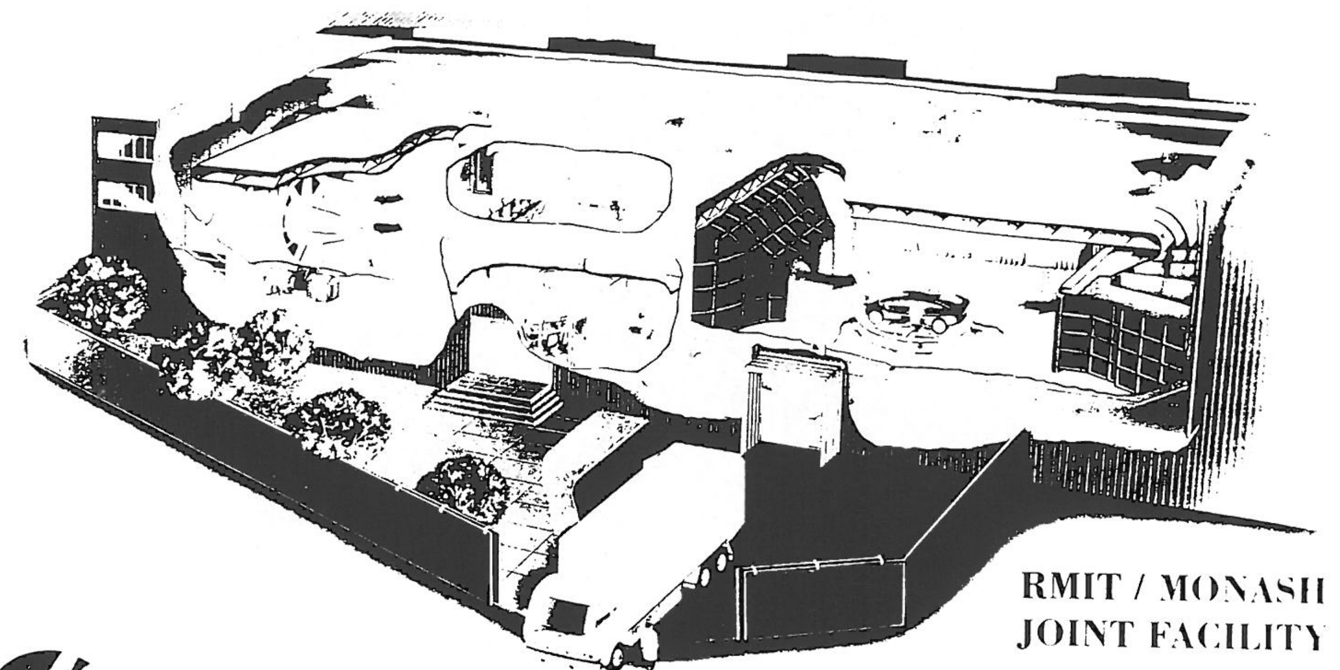

VEHICLE AERO-ACOUSTIC LABORATORIES

Fig 1 - Cut-away illustration of the Monash Wind Tunnel

RMIT

Fig 2 - Photograph of the Monash Wind Tunnel

Fig 3 - The Open Jet

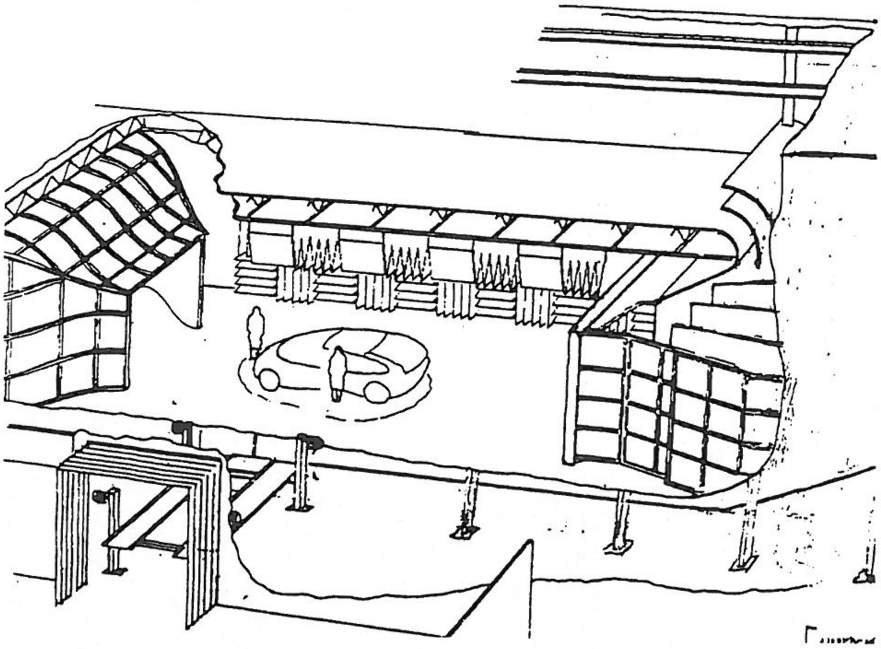

Fig 4 - Plenum Hall (concept cut-away)

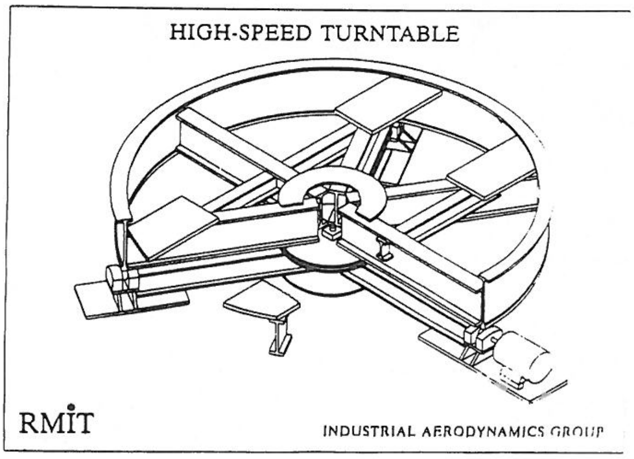

Fig 5 - Schematic of the high-speed turntable at the new facility

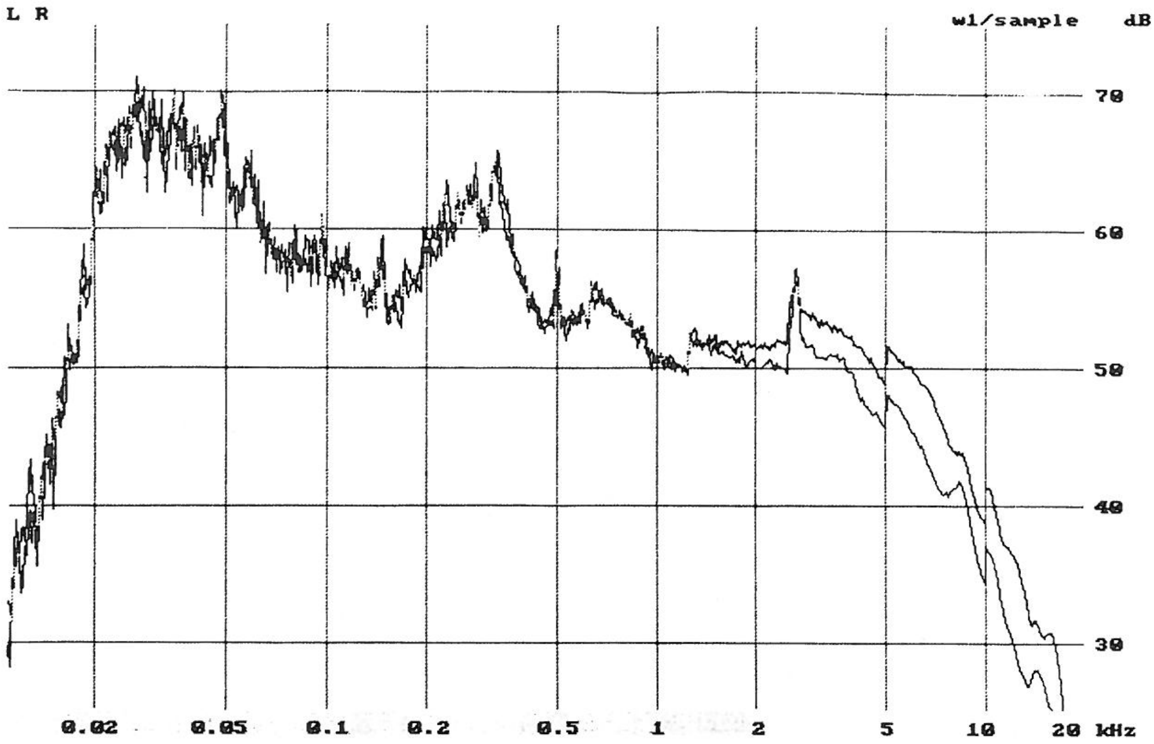

Fig 6 - Linear Variable Frequency Resolution FFT of the out-of-flow noise in the VAL Monash wind tunnel at 112 km/h

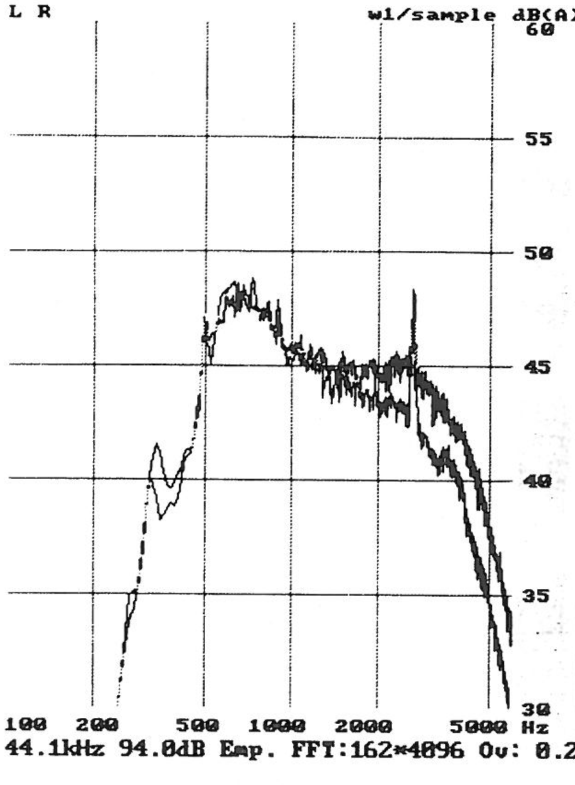

Fig 7 -
500 Hz to 6 kHz
Notch Filter Spectrum.

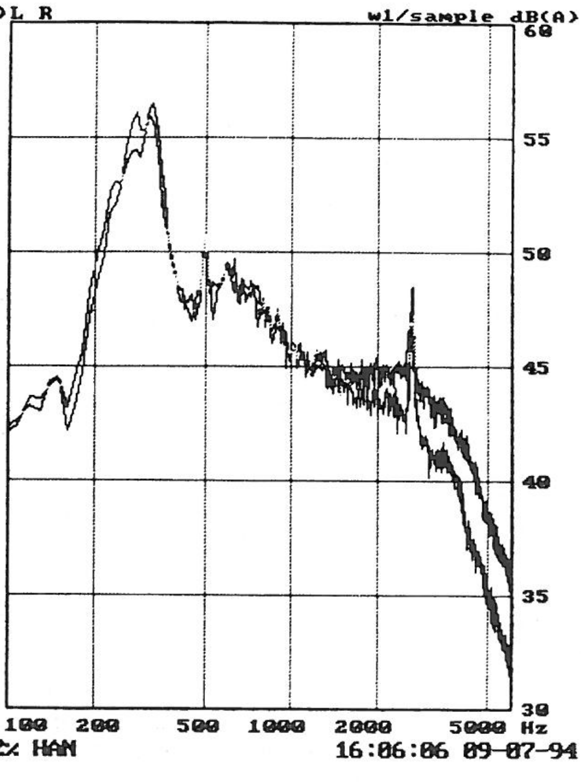

Fig 8 -
A-weighted spectrum
of the out-of-flow