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"ENGINE COOLING - DYNAMOMETER SIMULATION IN A WIND TUNNEL"

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INTRODUCTION: Testing of car cooling needs much closer attention to the wind environment of cars. This applies both to on-road testing and in environmental wind tunnels.

Australia has had uniquely difficult conditions. It has been the only country where customers want an aerodynamic car (rather than a pick-up truck) to tow a caravan or trailer in 40 °C ambient temperature at high speed on poor quality roads and expect all facilities to work well, particularly the air-conditioner! However, many developed and developing countries are suffering temperature problems with their cars in their local environment. Recent information also suggests that buyers in the United States are starting to demand similar levels of "robustness" in their passenger cars.

Traditionally, engine work for cars has been undertaken in climatic wind tunnels. The development of climatic wind tunnels with their associated dynamometers has evolved from the traditional needs of an engine in association with an engine-dynamometer and air-conditioning and cold-start requirements of cars. The cost of the dynamometer, refrigeration equipment and solar panels in these climatic wind tunnels has meant that in very scant attention is paid to the aerodynamic environment of the car. Indeed to significantly increase the size of an environmental wind tunnel would significantly add to its cost.

Often the aerodynamic blockage in the climatic wind tunnel generated by the car is high and the nozzle in front of the car is small so generating a poor pressure distribution of the car.

Cooling research on cars has previously been preformed with little attention to the quality of the airflow that is the normal environment of most cars.

WIND CONDITIONS: On average, the wind blows at about 14 km/h in Australia (and the USA) from some direction. Accordingly, a cross-wind is the norm and this wind will be turbulent with an RMS longitudinal turbulence component of 15-35%. For an average car road-speed of say 90 km/h, this produces an annual average RMS turbulence of 3-5% at a non-zero yaw angle of 3-4 deg, (Watkins, et al, 1992). On occasions, the wind environment of a car is substantially more turbulent with much greater yaw angles.

With the tendency of modern cars subjected to cross-winds to generate significant side forces, sensitivity of the cooling to incident yaw angles is expected. However, normally a dynamometer cannot be yawed into the wind to simulate a cross-wind condition.

RMIT/MONASH VEHICLE AERO-ACOUSTIC WIND TUNNEL: Figures 1, and 2 show the new joint RMIT/Monash Vehicle Aero-Acoustic Wind Tunnel at Monash. This national facility is the only wind tunnel in the world that can start to more closely model the turbulent on-road wind environment experienced by cars. In addition, the car could be yawed in an full scale open-jet tunnel in a turbulent environment. However a dynamometer was not available.

At Royal Melbourne Institute of Technology, our traditional means of evaluating the heat rejected by the radiator was to use an external heat bench (Hird et al, 1986, Saunders et al, 1991, 1992a & b). This testing only has a hot radiator and does not simulate the many other hot components in an engine.

It was decided to attempt to more realistically simulate the temperature pattern inside the engine bay. The question was how to increase the load on the engine without crankshaft loading through a dynamometer.

From Adler and Bazlen (1978), for 100% fuel energy into a water-cooled spark-ignition engine, the approximate energy distribution to the exhaust gas is 35% of the fuel energy. The large amount of energy exiting via the exhaust pipe suggested scope for trends where what was expected.

Car companies normally "sign-off" cars during "hot-trips". The cross-wind sensitivity shows that on-road testing results are likely to be highly irregular once the wind is blowing and the direction of the car is changing relative to the natural wind.

Thus duplication of road results in a conventional climatic tunnel without any yawing facility can only be achieved for a zero cross-wind condition. On-road, the cooling problems will be greater when a cross-wind blows, but a simulation in an climatic wind tunnel at zero yaw angle will under-estimate the cooling problems.

The quest for lower aerodynamic drag has resulted in the planform of a modern motor car becoming a reasonable airfoil. Consequently, any yaw angle of the incident wind will be result in significant side-force. The resultant circulation around the car will accentuate the movement of the stagnation point. This amplified movement of the stagnation point will increase the sensitivity of the cooling system of "aerodynamic" cars to cross-winds.

CONCLUSIONS : 1. A technique was evolved whereby the exhaust of engine was restricted whilst the engine was brought up to road speed without driving the wheels. This effectively changed the compression ratio, reduced the efficiency of the engine and permitted the heat rejected by the engine to be tuned to level consistent with on-road conditions at 100 km/h. Thus heat rejected by the engine was simulated without using a dynamometer.

2. A hot car radiator appears significantly more likely to boil when the car is at an angle to the wind. Engine compartment testing should be undertaken at yawed conditions in the wind tunnel. This should include testing at a yaw of 180°, because a stationary hot car subjected to rear-end flow also appears significantly more likely to boil.

3. When a car is tested on-the-road, the cross-winds should be monitored.

FUTURE RESEARCH : Tests should be repeated over a greater range of operating conditions. Some modelling of the turbulent natural wind should be considered. Using a representative car or car shape, the principal areas to be investigated are: (a) Correction factors for variation from operating conditions, particularly be incident airflow and top-tank temperatures; (b) Influence of natural turbulence on cooling and underhood temperatures; (c) Optimising airflow through radiator and condenser; (d) Influence of yaw and outside surface shapes on radiator and cooling air flows. (e) Factors affecting airflow other than frontal area of heat exchanger, including the design of effective air dams under vehicle, the use of baffle around the heat exchanges. (f) Factors affecting underhood temperatures in area of battery, alternator under engine cover, engine air intake and inlet manifold, and how to reduce underhood temperatures.

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redirection of that energy. That an internal-combustion engine is pumping fluid immediately also offered scope for loading engine by restricting the exhaust. This would immediately reduce the compression ratio which would increase the heat rejected by the engine, (Adler and Bazlen report a 40% increase in wasted energy when the compression ratio decreases from 8 to 4).

DYNAMOMETER SIMULATION: The heat load on the radiator was achieved by the following technique (see Fig 4). A 4.2 litre V8 family sedan was used. The car tested has a 560 mm wide by 35 mm slot above the bumper bar. It was set up and operated as follows. The thermostat was removed. The engine management controls associated with air and coolant temperatures were locked out. The air-conditioning set at maximum load by setting the lowest cabin temperature; leaving both rear windows 50 mm open; and the blower set at maximum blower speed. The coolant flow essentially constant due to the constant engine RPM, but was tuned via a valve on a Fisher and Porter Magnetic flowmeter. A clear section of glass was installed to monitor any gas intrusion into the coolant The exhaust pipe was throttled via valve which was kept constant. The car engine speed was kept constant at 2800 RPM and the car's mechanical fan was locked on to the crankshaft. T-type thermocouples were installed in the coolant at least four pipe diameters from any sharp bends. The coolant was 15% glycol mix and the thermocouples were electrically isolated from the coolant The wind-tunnel speed was kept constant at 100 km/h. The turbulent intensity was 4% The top-tank temperatures were run at 10 °C below boiling to ensure no boiling occurred. The ATB was determined (Air-To-Boil temperature was defined as the coolant boiling point - top tank temperature + ambient air temperature).

RESULTS: Yaw Angle = 0 °: The heat rejected by the radiator was measured and it was that by tuning the exhaust restriction, that 40 to 60 kW could easily be rejected. The initial ATB was measured. The top slot was then closed, the ATB was measured once stability was achieved after about 10 minutes. The bottom slot was then re-opened. It was found that the initial ATB could be repeated within ± 5 °C. On-road tests undertaken by the car company on this vehicle reported that closing the top slot decreased the ATB by about 4-5 °C. Simulating the same conditions in the wind tunnel gave a decrease of 6 °C.

Yaw Angle = 15 °: A strong cross-wind was simulated by setting a yaw angle of 15 °. This reduced the ATB for an open top slot condition by 13 °C, substantially reducing the boiling safety margin. With the slot closed, the ATB reduced a further 9 °C.

Yaw Angle = 180 °: The engine was idled at 800 RPM. The car was rotated through 180 °. The effect is shown on Fig 4. It is evident that for an idling engine, that flow from the rear can reduce the ATB by 12 °C. Slot closure reduces the ATB by a further 3 °C.

DISCUSSION: Providing the throttling of the exhaust is kept constant and changes to the engine air temperature are kept minimal, this work suggests a useful technique to test the effects of improved pressure distribution, cross-wind and turbulence simulation in aerodynamic wind tunnel which may not have a dynamometer.

The reason that this technique appears to have worked so well is the effect on the compression ratio. The lower the compression ratio of an engine, the lower the thermal efficiency - a larger combustion space means the cylinder is evacuated more inefficiently and the fresh cylinder will have more non-combustible residual gas. During the compression stroke, the fuel and air particles will not be so densely compressed and will not get so hot and so fuel atomisation will be slower and not be so complete. During the power stroke, the reduction in the pressure of hot gas will not be so great, so reducing the Carnot efficiency, with hotter exhaust gases dissipating more heat.

The power output of an engine will vary directly with increase in atmospheric pressure and decrease with the increase in ambient temperature to the half power. Thus comparison between test configurations can only be reasonably undertaken at constant conditions of temperature and pressure. A 10 °C increase in temperature will give a 2% reduction in power output. Thus tests to determine the effect of changes in geometry are best performed "back-to-back."

Following the calibration tests after the experiments, an intermittent fault in the data-logger gave concern as to the absolute accuracy of the incremental changes, although the

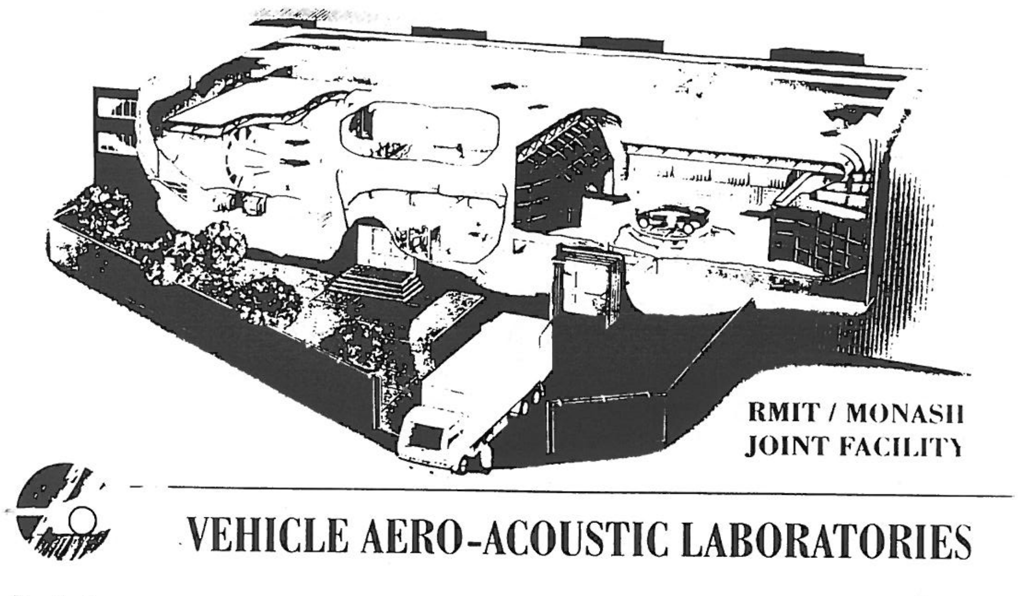

Fig 1 - Cut-away illustration of the Monash Wind Tunnel

Fig 2 - Photograph of the Monash Wind Tunnel

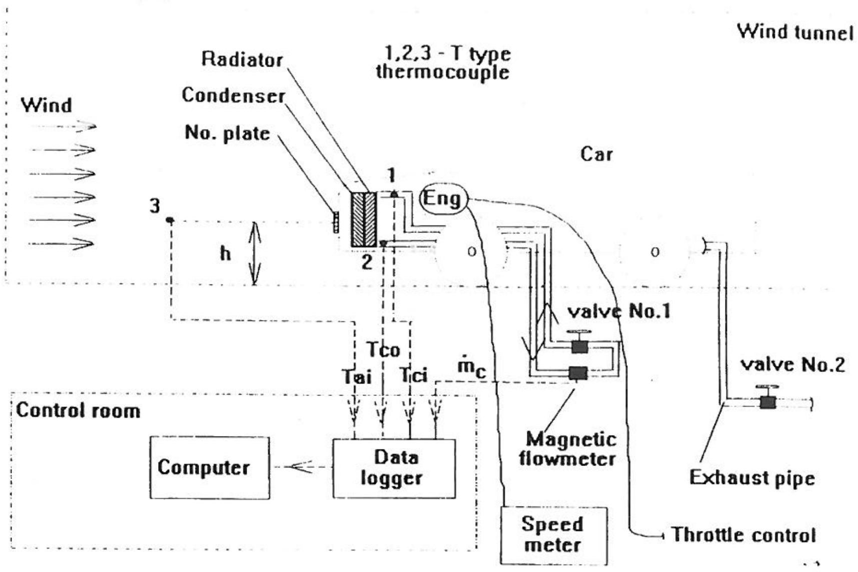

Fig 3 - Wind Tunnel Car Cooling System Test Layout

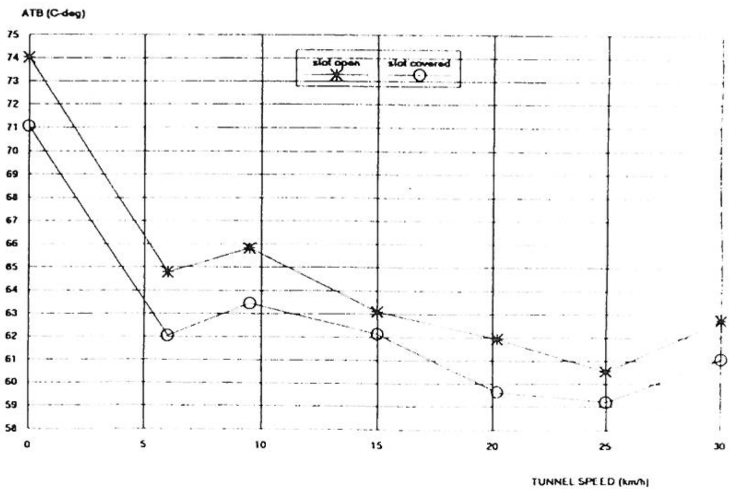

Fig 4 - Effect of tailwind on the Air-To-Boil temperature