INVESTIGATION OF THE EFFECT OF CROSS-WINDS ON MOTOR CAR COOLING IN A WIND TUNNEL

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ABSTRACT

The sensitivity of cross-winds in reducing the engine cooling ability on a motor car is shown. Tests on three different motor cars were conducted in the RMIT/Monash full-scale wind tunnel at different yaw angles under different resultant wind speeds. The test results show the motor car cooling ability decreases with the increase of yaw angles and about 13% decrease of the radiator cooling ability was found at a yaw angle of 20 degrees and resultant wind speed of 50 km/h. The effect of yaw angles on the engine cooling also depends on the motor car front-end configuration, but becomes less important with the increase of resultant wind speed.

INTRODUCTION

Lower fuel consumption of cars is one of the major global issues. For the average car, aerodynamic drag takes a large share in useful engine power. The reduction of aerodynamic drag is important to lower the fuel consumption. Since air flow around the car body has been improved, aerodynamic drag caused by air flow through the engine compartment becomes a sensitive factor. Consequently, vehicle grill areas are being decreased in an effort to reduce the vehicle's drag coefficient. The air flow through the radiator and engine compartment is decreasing as a result. The cooling system has also become more sensitive to cross-winds.

Though many papers have been published on the subject of radiator heat transfer and design, relatively few papers have discussed the effect of wind speed and direction on the engine cooling. Schaub and Charles [3] in 1980 investigated the ram air effect on the air side cooling system performance. They found under ram conditions, front-end loss consisted of a basic front-end loss measured at zero approach air speed which depended on the radiator-fan cooling air flow rate; and a ram-air loss which varied with the vehicle speed. Saunders and Kolodziejczyk [2] tested the effect of tailwinds in a modified full-scale car in a wind tunnel. Their tests showed exit hot-air recirculated through the radiator from under the car at a 3.5 km/h tailwind velocity and this reduced radiator heat rejection by 16%. At 25 km/h, the reduction had increased to 28%. Because of the complexity of the wind-tunnel simulation of cooling systems and secrecy for commercial reasons, little information, such as the effect of cross-winds on the engine cooling, has been published. This paper will show that cross-winds in a wind-tunnel simulation can make the car engine cooling worse.

TEST INSTRUMENTATION

The RMIT/Monash wind tunnel is a large full-scale wind tunnel. The vehicle test section is an open jet. Both the jet and collector are about 4 m wide and 3 m high. The maximum wind speed in the front of the jet is about 190 km/h with a turbulence level of about 2%. A turntable provides an opportunity of investigating the cross-wind effect on the engine cooling.

The vehicles used for cooling tests at the RMIT/Monash wind tunnel were three locally-made vehicles (Vehicle A to C). The electric fans were locked. The test set-up is shown in Figure 1. During cooling tests, the test car engine was not operated. The hot coolant through the radiator was provided by a 30 kW heat bench located outside of the wind tunnel. The maximum coolant temperature inside the heat bench was set at 70 °C. The coolant flow rate was measured by an accurate magnetic flowmeter (F & P Mini-Mag 10D1475). The radiator coolant inlet and outlet temperatures and radiator air inlet temperature were measured by six calibrated T-type thermocouples. The velocity ratio between the wind velocity in the front of the car bumper bar and the reference velocity 10 meters upstream of the jet measured by the Pitot tubes was 1.920. Signals from the magnetic flow meter and thermocouples were sent to a Fluke 2620A Hydra Data Acquisition Unit and then recorded by a host computer.

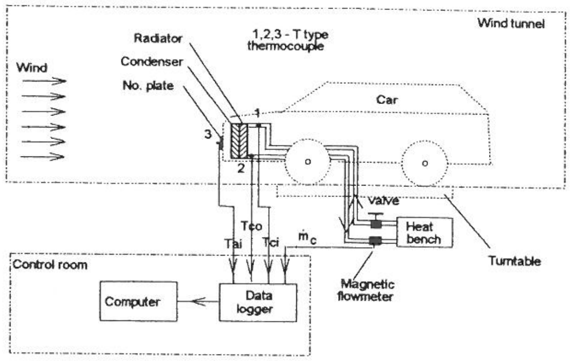

Figure 1 RMIT/Monash Wind Tunnel Car Cooling System Test Layout

TEST RESULTS

During wind-tunnel investigation the cooling system behind the external body work of a test car was unchanged. So the radiator can be used as a transducer to estimate changes in the engine cooling ability at different yaw angles.

In order to measure the effect of cross-winds on the motor car cooling, a convenient parameter is required. The parameter used is called Specific Dissipation (SD) which is defined as the total heat dissipated by a radiator divided by the maximum temperature difference across the radiator. SD can be expressed as:

$$SD = \frac{Q}{T_{ci} - T_{ai}} = \frac{\dot{m}_c Cp_c (T_{ci} - T_{co})}{T_{ci} - T_{ai}} \qquad (1)$$

where Q is the heat dissipated by the radiator, $\dot{m}_c$ is the coolant mass flow rate, Cp_c is the specific heat of the coolant, T_{ci}, T_{co} are the radiator coolant inlet and outlet temperatures, and T_{ai} is the radiator air inlet temperature [4].

Thus if a change is made to the yaw angle and all other parameters (e.g., coolant mass flowrate, resultant wind speed and etc.) are maintained constant, SD can measure the effect of cross-winds on the motor car cooling [1].

Tests were conducted at resultant wind speeds of 50, 70, 100, and 120 km/h, and yaw angles varying from 0 to 20 degrees with an interval of 5 degrees. Test results are plotted in Figures 2 to 4.

DISCUSSION

The mean SD values plotted in Figures 2a, 3a and 4a have a repeatability uncertainty of less than 0.5%. The results suggest that Specific Dissipation significantly:

(a) decreases with the increase of yaw angles when other parameters (e.g., wind resultant speed, coolant mass flowrate and etc.) are maintained constant; and, as expected

(b) increases with the increase of resultant wind speeds.

When the percentage change of Specific Dissipation with yaw angle $[100*\left(SD_{yaw=any} - SD_{yaw=0}\right)/SD_{yaw=0}]$ is plotted, Figures 2b, 3b and 4b indicate the effect of cross-winds on the engine cooling:

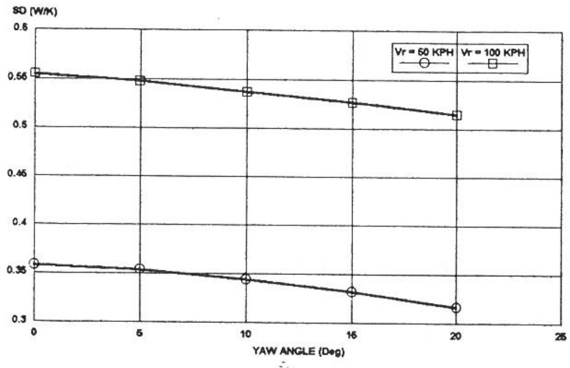

Figure 2a SD at different yaw angles

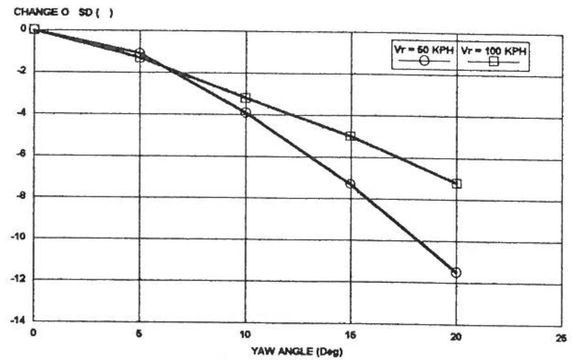

Figure 2b Change of SD with yaw angles

Figure 2 Effect of cross-winds on the motor car cooling for the test car Vehicle A

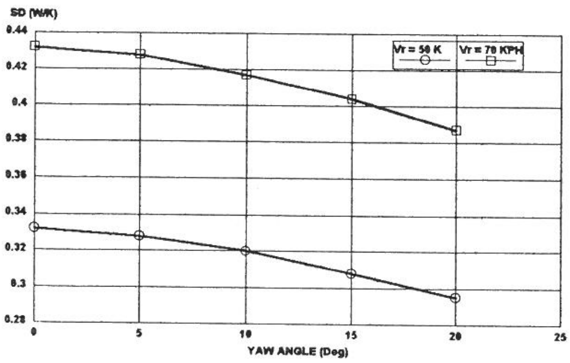

Figure 3a SD at different yaw angles

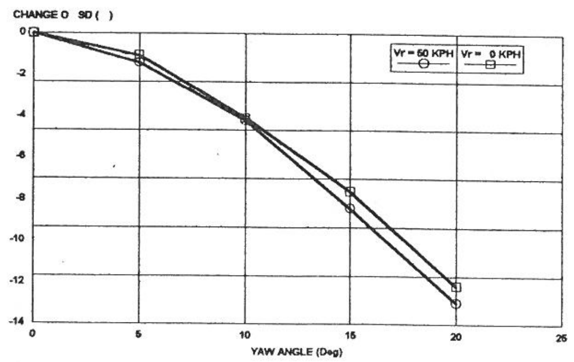

Figure 3b Change of SD with yaw angles

Figure 3 Effect of cross-winds on the motor car cooling for the test car Vehicle B

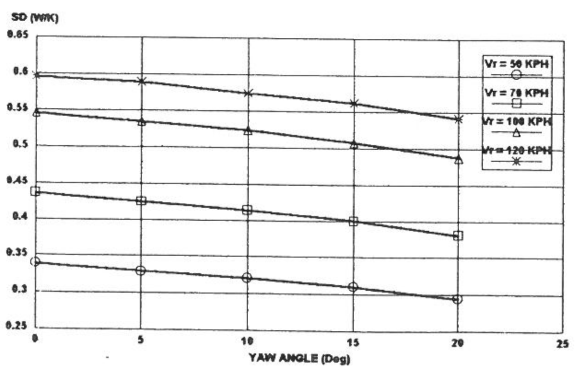

Figure 4a SD at different yaw angles

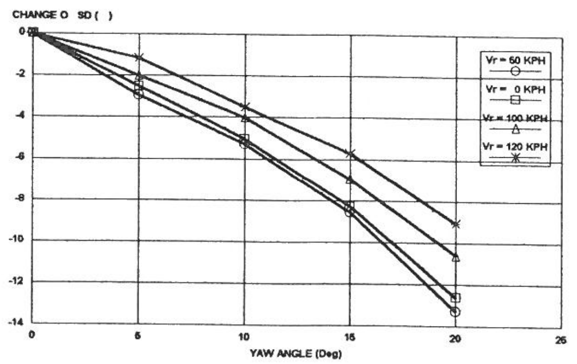

Figure 4b Change of SD with yaw angles

Figure 4 Effect of cross-winds on the motor car cooling for the test car Vehicle C

(a) increases with the increase of yaw angles and about 13% decrease of the radiator cooling ability is shown at a yaw angle of 20 degrees and resultant wind speed of 50 km/h;
(b) depends on the car front-end configuration; and
(c) becomes less important when the resultant wind speed increases.

In terms of determining percentage changes of the radiator cooling ability caused by cross-winds at different yaw angles, tests at full-scale wind tunnels can give sensitive results enabling the automotive cooling engineers and stylists to evaluate the ranking of their designs. These results need on-road validation.

CONCLUSIONS

Within the restrictions of full-scale wind tunnel investigation on three locally-made motor cars, the following conclusions can be made:

1. Cross-winds can significantly reduce the motor car cooling. The reduction increases with the increase of yaw angle. An about 13% decrease of the radiator cooling ability was found at a yaw angle of 20 degrees and resultant wind speed of 50 km/h.
2. As expected:
   (a) at the same yaw angle, the effect of cross-winds will decrease with the increase of resultant wind speed; and
   (b) the effect of cross-winds will vary with the motor car front-end configuration.

These results need on-road validation.

ACKNOWLEDGMENTS

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NOMENCLATURE

Q	- the heat dissipated by the radiator, W	SD	- Specific Dissipation, W/K
$\dot{m}_c$	- coolant mass flow rate, kg/s	T_{ai},	- radiator air inlet temperature, K
Cp_c	- specific heat of the coolant, J/kg K	T_{ci}, T_{co}	- radiator coolant inlet and outlet temperatures, K

REFERENCES

1. Lin C. H., Experimental Simulation on Passenger Car Engine Cooling, Ph.D. Thesis, in Preparation.

2. Saunders J. W. and Kolodziejczyk E., 1992, Car Radiator Response - Front-end air Management - Tailwinds Sensitivity, Proc. 3nd ATA Int. Conf. on Innovation and Reliability in Automotive Design and Testing, Florence, Italy.

3. Schaub U. W. and Charles H. N., 1980, Ram Air Effects on the Air Side Cooling System Performance of a Typical North American Passenger Car, SAE Paper 800032.

4. Stratton D. G., Stringer R. E., and Taylor S. R. G., 1965, Engine Cooling System Design and Development, Proc. Instn. Mech. Engrs, Vol. 180, Pt 2A, No. 8, pp. 221-235.