9th AUSTRALASIAN
FLUID MECHANICS CONFERENCE,
AUCKLAND, 8-12 DECEMBER 1986

Aerodynamic Improvements to Car Radiator Performance Using a Wind Tunnel Facility

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ABSTRACT

A 3m x 2m wind tunnel, designed basically for scale model vehicle aerodynamics experimentation, has been successfully used to improve air flow rates through a full scale motor car radiator assembly.

The investigation was performed to further improve the cooling system performance of a typical locally-produced 6-cylinder motor car equipped with air conditioning.

It was discovered that very small changes in vehicle geometry resulted in significant improvements in heat rejection from the radiator. Attempts to monitor changes to the velocity profile behind the radiator core were largely inconclusive because of the low values of velocity, however improved techniques are expected to produce more information in this important area.

INTRODUCTION

The first experiments in this project were performed as a result of a technical enquiry from a major motor car manufacturer in the State of Victoria. The primary objective was to improve the heat rejection performance of the radiator, in series with an airconditioning condenser, by air flow modifications.

Road tests were performed with a full-scale vehicle to establish the centre-line approach air flow geometry. The forward end of a full-scale body (as far as the A-pillar, and incorporating production suspension units and wheels, but using a timber and foam engine block to save weight) was subsequently mounted in the RMIT Industrial Wind Tunnel.

The approach air geometry in the wind tunnel was compared with that obtained at full scale and was found to be sufficiently similar to proceed. With the wind tunnel tests, hot water was piped to the radiator at a measured rate from an external source and the radiator complex was then instrumented to measure air and water inlet and outlet temperatures as well as a 64-point total head traverse immediately downstream of the radiator core.

A baseline heat rejection parameter was established and compared to those for other vehicle front-end configurations. The other configurations involved were mainly small geometry modifications to the front bumper assembly and licence plate position.

After an initial series of tests, a baseline was established which enabled a searching evaluation of the performance of the air side of various aerodynamic configurations. It was found that the local body geometry was critical to the performance of the radiator.

Subsequent tests improved the quality of the instrumentation applied to this problem, and gave good indications of the areas in which cooling performance improvements were likely to be obtained.

WIND TUNNEL TESTS

The wind tunnel tests were performed in the RMIT 3m x 2m Industrial Wind Tunnel, Hird (1979). See Figure 1.

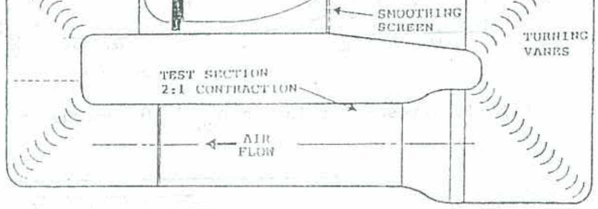


Figure 1: The RMIT Industrial Wind Tunnel, working section is 3m x 2m.

It had been anticipated that the use of part of a full-scale motor car would cause blockage problems in a wind tunnel test. In an attempt to justify the use of a wind tunnel, a full-scale test was organised at a vehicle proving ground. In this test, a chase truck was employed to provide a long wool-tuft ahead of the test vehicle. The truck was separated by three vehicles widths from the test vehicle and the two vehicles were together motored at 100 km/hr. The tests were arranged to provide photographic evidence of the streamline identified by a wool tuft, emanating from known heights above the ground. In this way, the flow field approaching the vehicle was established. In particular the original height of the approach flow resulting in the stagnation point was determined. The evidence was carefully recorded through the use of video equipment. Further front-on tests were recorded, using video, of the position of the stagnation point on a typical vehicle.

In the wind tunnel, tests were performed on the front end of a full-scale vehicle, Pitt(1985). Original body work was used along with fully representative wheels and suspension. A wooden/foam engine block with all normal accessories was installed for weight saving purposes. The vehicle was cut off horizontally at a position which left one half of the windscreen in place in an attempt to create a reasonably representative wake and the associated base pressure. Since flows through the engine bay were so important, the influence of the base pressure on static pressures in the engine bay needed the closest possible modelling.

The tunnel was run at an approach airspeed of 78 km/h, the highest that the blockage would allow. A series of 2m long wool tufts was streamed from a vertical post situated on the tunnel (and vehicle) centre line. The flow was further visualised using a hand-held probe with a wool tuft attached. Visual comparison was made of the resultant flow pattern in the wind tunnel and that obtained full-scale. Video recordings were used in both cases. The comparison showed that the flow patterns were substantially the same for flow over and under the vehicle leading edge and, more significantly, that the position of the stagnation point was the same in each case. Incidentally, the stagnation point coincided with the centroid of the number plate.

The demonstration of similarity of the on-road and wind tunnel flow patterns enabled the tests to proceed further in the confidence that, at least on the centreline, the entering cooling air was being well modelled in the wind tunnel. Subsequent tests were performed with no modification to the flow in the working section.

THE RADIATOR CONFIGURATION AND INSTRUMENTATION

In response to the initial requirements of the manufacturer, the tests were performed with both a standard engine cooling radiator and, ahead of that, an air-conditioning condenser; the cooling fan was removed, see Figures 2 & 3. The radiator was fed with hot water from a metered laboratory supply at approximately 1 l/s and a temperature of approximately 70°C. With the heating capacity available it was not possible to match the temperatures encountered in on-road usage. However the major object of the exercise was to determine whether aerodynamic alterations to the front end of a vehicle could improve radiator heat rejection rates. The primary objective was to rank the performance of different configurations, rather than to obtain absolute values of the heat rejection parameters.

The two fluid end state temperatures were measured using thermocouples. The approach air thermocouple was mounted on the wool tuft mast previously mentioned whilst the downstream air temperature was mounted on the front end of the engine block. The water temperatures at inlet and outlet were measured by thermocouples mounted in the inlet and outlet hoses. A rake of eight pitot tubes was mounted downstream of the radiator core surface with a clearance of 10mm.

Four open plastic tubes were taped at various points within the engine bay with locations chosen to provide static pressure information with minimum velocity pressure components.

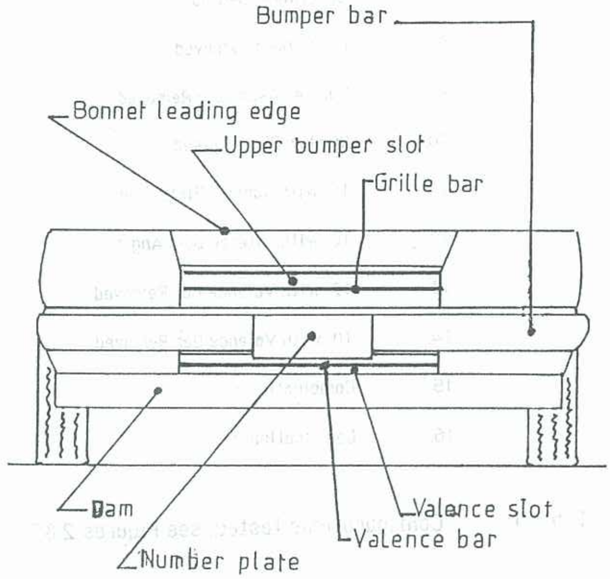


Figure 2: Geometry of vehicle front end viewed from upstream

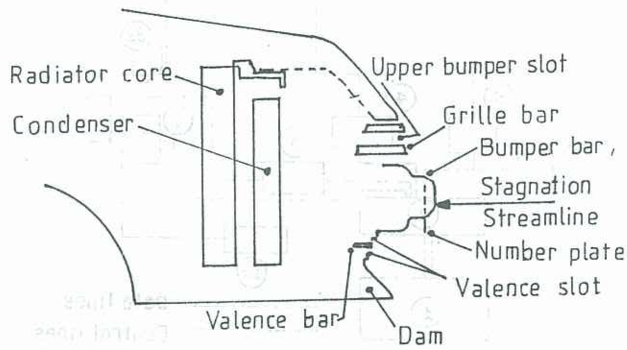


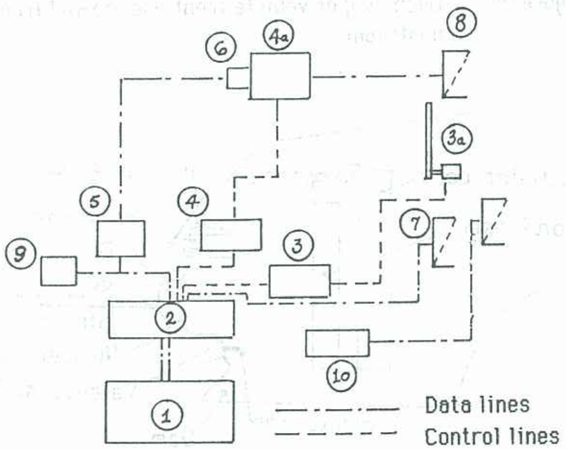
Figure 3: Front end schematic showing possible air paths to radiator

AN INDIVIDUAL TEST

An individual test, for each of the configurations listed in table 1 below consisted of running the tunnel at 78 km/h and the heat bench at 1 l/s until the water inlet and outlet temperatures had stabilised. A traverse was then performed with the pitot-static rake. This process was semi-automatically controlled, and the data stored, by a Hewlett Packard 85 microcomputer. The complete system is shown in Figure 4.

1.	Baseline Model
2.	Upper Bumper Slot Covered
3.	Side Covers (Blinkers)
4.	Upper Bumper Radiused
5.	Lower Bumper Radiused
6.	Valence Slot Covered
7.	Baseline Repeated
8.	Grille Bars Removed
9.	Bumper Assembly Removed
10.	Number Plate Raised
11.	10. with Number Plate Cover
12.	10. with Altered Dam Angle
13.	12. with Valence Bar Removed
14.	10. with Valence Bar Removed
15.	Combination 1
16.	Combination 2

Table 1: Configurations tested; see Figures 2 &3



1 - HP 85 Computer
2 - HP 3421A Data Acquisition Unit
3 - Lead Screw Controller
3a - Lead Screw
4 - Scanivalve Controller
4a - Scanivalve
5 - Output Box
6 - Druck Pressure Transducer
7 - Seven Thermocouples
8 - Pitot-Static Tube Rake
9 - Digital Voltmeter (Optional)
10 - Digital Thermometer (Optional)

Figure 4: Data acquisition system

During the traverse, inlet and outlet water and air temperatures were monitored and mean values established. From the water flow rate, water temperature change and known physical properties of water, a heat rejection parameter was established.

HEAT REJECTION PARAMETER

With the complex cross-flow and finned geometry of a typical vehicle radiator, overall heat transfer performance is commonly related to a mean temperature difference between water and air through an equation which incorporates factors allowing for heat transfer area, heat transfer coefficients and heat exchanger geometry. For the simple configuration-ranking objective of the experiments described using one particular radiator, a heat rejection parameter was defined as the rate of heat loss from the water divided by the temperature difference between the entering water and air streams. Changes in that parameter were attributable to the only aspect of the process which was substantially varied - the air flow through the cooling system.

VEHICLE GEOMETRY MODIFICATIONS

Following a given test, the external geometry of the vehicle was altered to modify the possible paths of incident air into the radiator assembly (see again table 1 and Figures 2 & 3). A further test was then conducted to establish the appropriate heat rejection. Each geometry change was small and recognised that gross changes, causing stylishly unacceptable appearance of the vehicle, would not yield information helpful to the manufacturer. By this process it was established (see Table 2) that minor local geometry changes could give significant improvement to the heat rejection rates from the radiator. Furthermore the tests were performed at realistic values of local Reynold's Numbers, often the stumbling block for wind tunnel tests. The major geometry change to influence heat rejection was in the siting of the number plate, the position of which is closely controlled under Victorian Statutes. In lifting the number plate some 50mm associated with marginal under-bumper radiusing, an improvement of heat rejection of 10% (conservatively estimated) over the baseline condition, could be achieved.

VELOCITY PROFILES

At the commencement of the tests it was hoped that some useful data would emerge from the velocity traverses. Particularly, it was hoped that the integration of velocity profiles would give good correlation in volume flow to figures deduced from the radiator heat rejection and the overall rise in air temperature. Throughout, the deduced figure exceeded the measured value. With the condenser/radiator complex, the downstream velocities were too low to be accurately determined with a pitot-static traverse. In addition, local density variations were not taken into account. (See Figure 5). Downstream temperarure fluctuations across the core were also not taken into account, affecting calculations of mass flow rate.

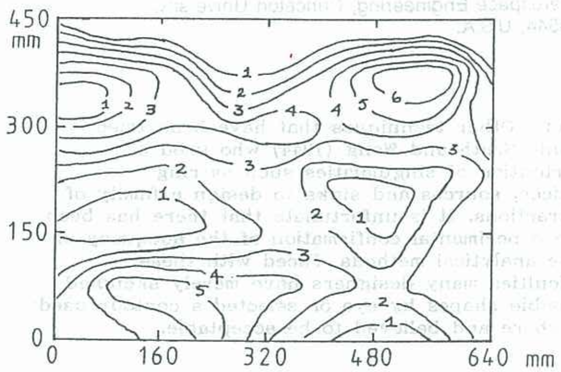


Figure 5: Typical velocity contours behind radiator viewed from downstream

RESULTS

Thermodynamic Considerations: Referring to Table 2, it is noted that the heat rejection parameter for the baseline case was reproduced within 3% after several intermediate configuration changes. The largest changes measured were reductions in heat transfer associated with blocking the major inlet slots and with changing the dam angle. The largest improvement was associated with the removal of the the entire bumper assembly, but consistent with the other constraints on vehicle front-end geometry, the raised number plate combined with modified under-bumper radius provided the more acceptable increase of over 10% in the heat rejection parameter. The changes in air mass flow rate computed from the velocity traverses correlated with the measured changes in the heat rejection performance, although the air flow measurements can only be viewed qualiltatively. It is also of interest that the static pressure values also correlate with the heat rejection parameter and provide a readily measured indication of the desired aerodynamic performance.

Aerodynamic considerations: It is felt that considerations of aerodynamic principles can lead to optimisation of current radiator inlet situations and, more importantly, can assist in the future design of vehicle front-end geometry as the thrust for reduced aerodynamic drag results in the ever lowering of forward leading edges. This lowering has serious implications to the engineers involved in engine cooling. Any method which assists in reducing core size requirement by aerodynamic optimisation is worth pursuing.

Test No.*	Config	Heat Rej kW/C	% change in H.R.	Air Mass from H.T kg/s	Air Mass from VT kg/s	Static# Pressure Pa
1	Baseline	0.653	-	1.309	0.894	-44.5
2	Top Slot	0.418	-35.9	0.661	0.281	-27.2
3	Blinkers	0.692	+6.1	1.446	0.888	-50.1
4	UBR	0.670	+2.7	1.431	0.901	-58.9
5	LBR	0.679	+4.1	1.456	0.870	-51.5
6	Valence	0.496	-23.9	0.853	0.326	-32.8
7	Base Rep	0.670	+2.7	1.364	0.792	-42.4
8	Grille	0.708	+8.6	1.654	1.230	-41.5
9	No Bumper	0.760	+16.6	2.021	1.554	-60.4
10	Plate	0.705	+8.1	1.616	0.961	-46.3
11	Plate Cover	0.712	+9.2	1.583	1.008	-40.3
12	Dam	0.509	-21.9	1.083	0.877	-37.7
13	12 + Val	0.684	+4.9	1.426	0.792	-57.6
14	10 + Val	0.703	+7.8	1.504	0.949	-54.5
15	Combin 1	0.549	-15.8	1.200	0.877	-44.1
16	Combin 2	0.740	+13.5	1.662	1.119	-64.3

* See Table 1 #relative to free stream

Table 2: Radiator Performance data

CONCLUSIONS

Despite difficulty in obtaining accurate under-bonnet air velocities, a test procedure has been developed that gives useful information to motor vehicle designers and the engineers who implement the designs. The tests were performed in a manner which generated a realistic flow to the engine cooling region of a vehicle.

Further work is planned to refine the test method following interest and support by CSIRO, Cooper and Chan (1985). In particular, efforts will be made to improve the data acquisition and processing and to measure more accurately the downstream velocity profiles. Discarding the air-conditioning condenser, an original test requirement, would lead to higher downsteam velocities with an associated improvement in measurement acccuracy.

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