

On-System Engine Cooling Fan Measurement as a Tool for Optimizing Cooling System Airflow Performance and Noise

2011-01-1169

Published
04/12/2011Michael Sortor
Robert Bosch LLC

Copyright © 2011 SAE International

doi:10.4271/2011-01-1169

ABSTRACT

When designing the vehicle cooling system, accurate knowledge of the required airflow through the heat exchangers is necessary for proper specification of the cooling fan, the heat exchangers, and the associated electrical loads. The simplest method of expressing the engine cooling fan performance requirement is based on the “open air” performance curve measured on the airflow test chamber, excluding effects of the heat exchangers and vehicle environment. However, the difference between open air and on-system airflow performance and noise (installed on the heat exchangers) can be significant due to the influence of the heat exchangers, fan shroud, and downstream blockage on the airflow through the fan. If these factors are neglected in the evaluation of the cooling fan, incorrect specification of the fan performance can result.

In this paper, two case studies are presented in which different fan modules, designed for the same vehicle applications, are compared both in open air and installed on the heat exchangers. In both cases, open air test results lead to erroneous conclusions concerning power consumption and noise for a given on-system airflow rate. Misleading comparison results such as these could lead to incorrect selection or specification of the cooling fan, resulting in inadequate cooling, excessive power consumption, or excessive noise. Accordingly, it is recommended that cooling system designers specify cooling fan performance using on-system test conditions. A list of factors which should be considered in specifying on-system performance is presented.

INTRODUCTION

The cooling system of a motor vehicle must be designed to achieve the required heat dissipation from the engine, climate control, and other vehicle systems while minimizing the cooling system's energy consumption. The cooling system weight and installation space also influence the vehicle energy consumption and CO₂ production indirectly. Finally, fan noise must be considered in terms of customer acceptance and, in some regions, regulatory requirements. It is necessary that a fan component specification guarantees at least the minimum heat rejection performance required by the vehicle at all driving conditions. However, it is also important not to over-specify performance at the expense of adding unnecessary weight, size, power consumption, or noise.

COOLING SYSTEM REQUIREMENTS - AIRFLOW AND PRESSURE

For a given system of heat exchangers and vehicle operating conditions (air and coolant temperatures, for example), heat rejection is a direct function of the airflow through the heat exchangers. For each driving condition, then, a minimum airflow requirement can be defined. In order to specify the fan requirements, it is necessary to define not only the airflow but also the pressure rise to be developed at each vehicle operating condition. The required pressure rise will depend on two sets of factors, one related to the overall resistance of the heat exchangers and vehicle environment, and the other related to the distribution of airflow across the heat exchanger faces. The first set includes the resistances of the individual heat exchangers, their relative size and positions, any sealing between them, the contribution of the “ram air” entering through the front of the car if it is moving, and the resistance presented by the engine compartment and underbody air

exhaust. The second group depends mostly on the size and position of the fans relative to the heat exchangers, and to a lesser extent the distribution of the ram air through the front end openings.

AIRFLOW REQUIREMENTS

In-vehicle measurement of the cooling system airflow rate requires complex instrumentation and techniques. Williams [1] describes a system of anemometers which is mounted between the radiator and the fan shroud and traversed across the rear face of the radiator. One drawback of this system is that the installation of the anemometers requires an increase in the clearance between the radiator rear face and the fan shroud, which affects the interaction between the heat exchangers and the fan. Also, anemometer systems in general introduce blockage to the airflow through the cooling system and thereby affect the overall system performance. In-vehicle measurements also generally need to be taken in a wind tunnel in order to provide adequate control over the operating environment.

Another factor which needs to be taken into account in establishing the cooling airflow requirement is that the heat rejection of the heat exchangers can be affected by the nonuniformity of the flow velocities induced by the fan, shroud, and upstream disturbances. Chiou [2] developed a method to calculate the magnitude of this effect and found that, for large degrees of nonuniformity, the loss of heat transfer performance can be significant. Fellague et. al [3] applied a similar method using a flow field calculated by CFD for a typical automotive cooling system installation and found that the predicted deterioration of heat transfer was in the range of 4-6%.

In comparison to in-vehicle testing, the system airflow rate is more easily measured with the cooling system (heat exchangers with fans) installed on an airflow chamber, or in a calorimeter for simultaneous verification of the system heat rejections. For a given size and installation of fans on the heat exchangers, we can assume that the effect of the airflow distribution on the heat exchanger thermal performance will be essentially constant. Thus, cooling system airflow, as measured on a test chamber, can be directly correlated with the in-vehicle heat rejection for a given application.

FAN PRESSURE REQUIREMENTS - FOOTPRINT EFFECT AND SYSTEM ADAPTATION

Measurement of the system pressure loss (or required fan pressure rise) presents additional challenges, in both the in-vehicle condition and in the airflow chamber. It is difficult even in the simplest case, when the vehicle is standing at idle and the static pressures at the inlet to the heat exchangers and at the outlet of the fan are approximately zero. In this case,

the pressure loss of the heat exchangers is approximately balanced by the pressure rise of the fan, but it is difficult to correctly evaluate these two components separately. The cooling fan and shroud impose a spatially nonuniform airflow and pressure drop through the heat exchangers ("footprint effect") as illustrated in [Figure 1](#). This nonuniform distribution makes the fan pressure rise difficult to measure and characterize when installed on the heat exchangers. Williams [4] describes an addition to the anemometer system used in [1] for measuring the pressures at an array of locations inside the shroud while the fan is operating in vehicle. He also proposes a procedure for estimating the fan performance in the installed condition (with shroud and heat exchangers) by measuring the components separately and inferring different loss effects. However, Williams reports difficulties in correlating the measured pressures with expected values from CFD simulation using this technique. Also, as with the in-vehicle airflow measurement, this process requires extensive instrumentation on-vehicle and testing in a wind tunnel.

The footprint effect in turn results in a higher pressure drop through the heat exchangers than what is measured with uniform flow for the same velocity, due to the nonlinear relationship between the air velocity and the pressure drop. This effect is illustrated in [Figure 2](#). As a result, the operating pressure of the fan with the heat exchangers cannot be specified simply comparing the heat exchangers' uniform flow pressure loss against the fan open air performance.

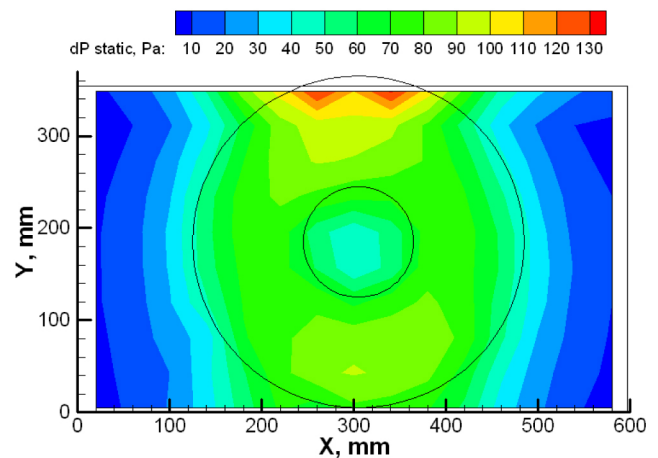


Figure 1. Example of footprint effect. Distribution of pressure drop through radiator with fan assembly

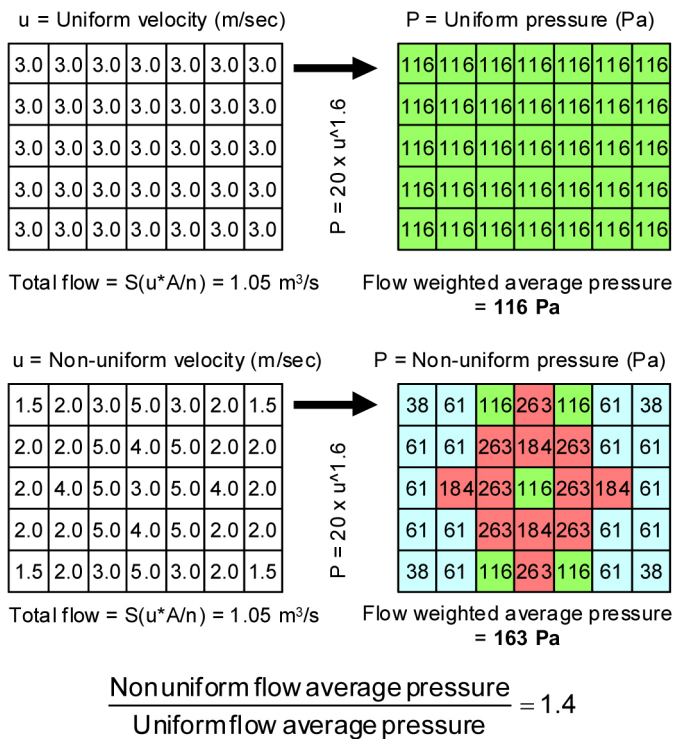


Figure 2. Example of footprint effect. Calculation of additional heat exchanger pressure drop due to flow nonuniformity

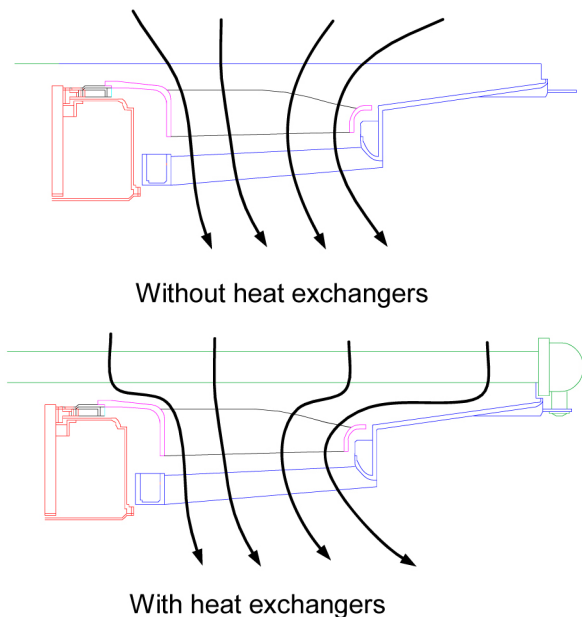


Figure 3. Influence of heat exchangers on fan operation

A further difficulty in estimating fan static pressure arises when an attempt is made to correlate the fan's on-system performance with its open air performance (the performance of the fan measured without the heat exchangers installed). The presence of heat exchangers influences the velocity and pressure distribution as well as turbulence of air entering the fan (Figure 3.) For this reason, a fan which operates efficiently in open air may work poorly when installed on-system. The reverse may also be true. A given fan at a given airflow rate and rotation speed may produce different average pressure rise in open air than on-system. We refer to this as the fan's "system adaptation".

CORRELATING ON-SYSTEM AND OPEN AIR FAN PERFORMANCE

Traditionally, the required pressure rise of the fan has been estimated by intersecting either the heat exchanger resistance curve or the on-system fan airflow rate with the open air performance curve of the fan measured at the same rotation speed and air density (sometimes referred to as the head-capacity or P-Q curve). The setup of the fan for open air and on-system performance measurement is shown in Figure 4.

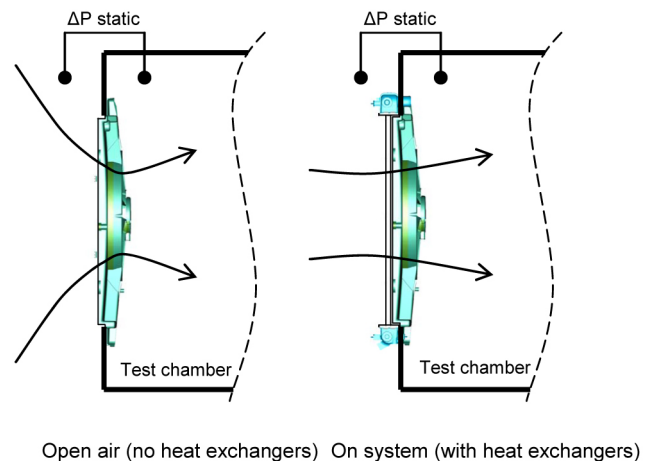


Figure 4. Open air and on-system fan testing

In Figure 5, point A represents the operating point found by the intersection of the fan open air performance curve with the heat exchanger resistance, and point B represents the operating point inferred from the on-system airflow. In general, point B will tend to indicate lower airflow and higher pressure requirement than point A.