



SURFACE VEHICLE INFORMATION REPORT

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(R) Cooling Flow Measurement Techniques

RATIONALE

The contents of this document are judged by the Road Vehicle Aerodynamics Forum Committee to be of value in outlining current and historical techniques for cooling air flow measurements. Common practice for cooling flow assessment has developed significantly since the original issue of this document and this revision brings the document up to date with current approaches; including in particular a new section on the use of Computational Fluid Dynamics (CFD) for cooling air flow assessment.

SAE J2082 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

This report is part of a series of SAE Reports dealing with aerodynamic testing of road vehicles, which are as follows to date:

SAE J2071 199406	Aerodynamic Testing of Road Vehicles - Open Throat Wind Tunnel Adjustment
SAE J2881 201006	Measurement of Aerodynamic Performance for Mass-Produced Cars and Light-Duty Trucks
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1. SCOPE

This SAE Information Report has been prepared at the request of the SAE Road Vehicle Aerodynamics Forum Committee (RVAC), incorporating material from earlier revisions of the document first prepared by the Standards Committee on Cooling Flow Measurement (CFM).

Although a great deal is already known about engine cooling, recent concern with fuel conservation has resulted in generally smaller air intakes whose shape and location are dictated primarily by low vehicle drag/high forward speed requirements. The new vehicle intake configurations make it more difficult to achieve adequate cooling under all conditions. They cause cooling flow velocity profiles to become distorted and underhood temperatures to be excessively high. Such problems make it necessary to achieve much better accuracy in measuring cooling flows.

As the following descriptions show, each company or institution concerned with this problem has invested a lot of time and as a result gained considerable experience in developing measuring techniques that appear to achieve reliable results. There is, however, little uniformity at the present time among the methods used by different companies and no indication at this time of a trend towards a simple and universally acceptable measuring technique.

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3. SYMBOLS

3.1 Basic Symbols

A	area in m ²
C	coefficient
D	Diameter of anemometer rotor, also diameter of intake duct, both in cm
f	Rotational frequency of anemometer in cycles/s
I	Inhomogeneity
M	Mach number
p	Pressure in kPa
q	Dynamic pressure of air stream in kPa
v	Absolute velocity in kph
V	Volume flow rate in m ³ /s
X	x-coordinate, also distance between the anemometer and the radiator exit face, also distance into the intake duct relative to the leading edge of the lip
Y	y-coordinate

3.2 Subscripts

FS	Full Scale
i	Index to resolve different locations over the radiator face
max	Maximum value in any quantity - such as intake diameter or Mach number
n	Number of samples
MS	Model Scale
R	Radiator
stat	Static pressure
tot	Stagnation condition when associated with pressure
VC	Volume Flow Coefficient
ζ	Pressure loss coefficient
∞	Condition far upstream in the approach flow (before any loss has occurred)

3.3 Abbreviations

AC	Air Conditioning
CAE	Computer Added Engineering
CFD	Computational Fluid Dynamics
CFM	Cooling Flow Measurements
FKFS	Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren Stuttgart
FS	Full Scale

MIRA Motor Industry Research Association
 MS Model Scale
 NRC National Research Council of Canada
 NTC Negative Temperature Coefficient

4. COOLING AIR FLOW MEASUREMENTS IN FULL SCALE

Since there are only a few methods to measure the integral value directly and most of these methods are integrating over a number of spatial samples, here, the techniques are subdivided by the measurement technique itself. The respective measurement techniques are either anemometer-based (air vane anemometers or constant temperature anemometers) or pressure based. First, the influence of sample numbers will be discussed.

4.1 Influence of Spatial Sampling

The spatial sampling has to be considered thoroughly, since the discretization of the radiator surface can have a significant influence on the measurement results. The flow inhomogeneity I can be used to analyze the influence of the number of probes [2]. I is defined as:

$$I = \frac{\sqrt{\frac{1}{n}(\sum_{i=0}^n (v_i - \bar{v})^2)}}{\bar{v}} \quad (\text{Eq. 1})$$

and represents the standard deviation of local flow velocities in the radiator v_i with respect to the average velocity $\bar{v}$.

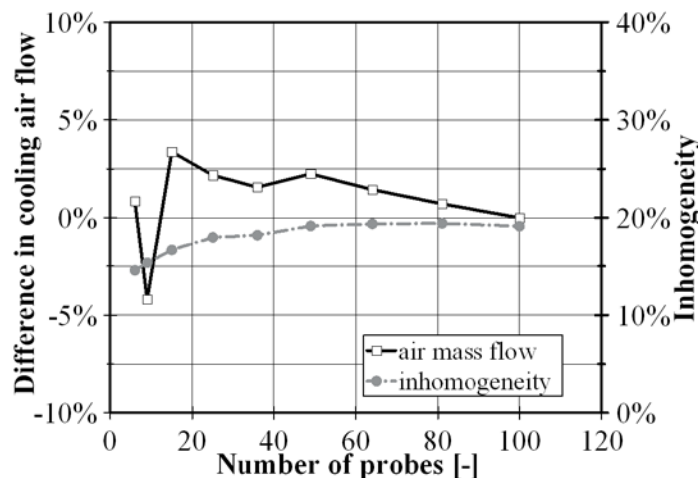


Figure 1 - Difference in cooling air volume flow (left axis) referred to 100 probes and flow inhomogeneity as a function of the number of probes. Results are based on a virtual test case at 140 km/h. [3]

Figure 1 shows the differences in flow inhomogeneity and cooling air flow as a function of the number of probes used - for a virtual test case (CFD results with virtual probes). Evenly distributed probes refer to a maximum resolution of 100 probes. The decrease in flow inhomogeneity (right axis) with smaller probe numbers results from a reduced capability to resolve local gradients. The cooling air flow determined (left axis) with more than 60 spatial samples for a standard passenger car radiator shows a deviation below 3% [3]. Similar results have been published by Kuthada in [2].

4.2 Anemometer-Based Techniques

Based on reports in the literature, the use of different anemometer types for measuring airflow in the vicinity of a radiator will be summarized in the following sections.