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Laboratory Testing of Light-Duty Vehicle Electric Cooling Fan Assemblies for Airflow Performance		

RATIONALE

SAE Five-Year Review.

1. SCOPE

This SAE Recommended Practice is intended for use in testing and evaluating the performance of electric cooling fan (ECF) assemblies typically used for vehicle engine cooling. Conducted in a laboratory environment with intended heat exchangers, the performance measurement includes fan output in terms of airflow and pressure and fan motor input in terms of voltage and current. This information can be used to calculate the efficiency of the assembly, including aerodynamic efficiency of the fan and shroud, and electrical efficiency of the motor. The electric power consumption can be used to estimate electrical charging system sizing and fuel economy.

The performance of a given fan assembly depends on the installation details of the application, including the effects of system resistance and geometries of the grill, heat exchangers, engine and other underhood components, and front end components. This document provides guidance for duplicating such details in the test setup for accurate performance measurement.

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Figure 1 - Single light-duty ECF assembly using a brushless motor

NOTE: Includes fan, motor, shroud, stators, electrical connector, and pressure-relief flaps for high vehicle speed applications.

1.1 Purpose

The primary purpose of this recommended practice is to provide a standard test method such that airflow performance data can be accurately compared between ECF suppliers and Original Equipment Manufacturers (OEMs), taking into consideration different motor technologies and methods of speed control.

1.2 Field of Application

This document applies mainly to light-duty truck and passenger car OEMs, although any vehicle that uses an ECF assembly can benefit from the information provided. ECFs are typically purchased as complete assemblies, consisting mainly of the fan(s), motor(s), and shroud (see Figure 1). This recommended practice will only consider such complete assemblies. Some purchased ECF assemblies using brush-type motors may also include digital control devices such as power resistors or pulse width modulation (PWM) electronics or local interconnect network (LIN) for speed control. In the case of brushless motor technology, the controller is an integral part of the motor, where it also performs the commutation process electronically.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1339 Test Method for Measuring Performance of Engine Cooling Fans

2.1.2 ANSI Accredited Publications

Copies of these documents are available online at <https://webstore.ansi.org/>.

American National Standard Laboratory Methods of Testing Fans for Aerodynamic Performance Rating

ANSI/AMCA Standard 210-2016

ANSI/ASHRAE Standard 51-2016

3. TEST PROCEDURE

3.1 Equipment and Facilities (see Figure 2)

- 3.1.1 An airflow measurement structure with minimum length, width, and height of 200% of the largest dimension of the ECF shroud assembly, which includes a suitable plenum chamber. A calibrated flow measurement nozzle (one with experimentally determined coefficient k_n) should be coupled to this structure. The plenum chamber should preferably contain perforated “settling” screens to dissipate jets of air and provide uniform air movement (also known as “flow straighteners”).
- 3.1.2 An auxiliary blower and shutters (or other restrictive device) of appropriate shape and diameter to vary the plenum pressure.
- 3.1.3 A method for mounting the ECF test component and the representative heat exchangers to the airflow measurement structure. A plywood end-wall of the plenum is typically used for this purpose. Actual heat exchangers, such as a radiator, A/C condenser, charge air cooler (CAC), and air/oil cooler, are preferred in order to approximate the in-vehicle airflow restriction.
- 3.1.4 A method of mounting rough shapes of plywood or other materials at an appropriate distance behind the ECF to simulate the airflow restriction of underhood components, such as an engine that is downstream of the ECF. These obstructions may vary in size, shape, and distance from the ECF and are not shown in Figure 2.
- 3.1.5 A calibrated variable-voltage DC power supply capable of powering the ECF motor(s) through their entire design range. The power supply should have ability to provide accurate output voltage (V) and current (A) such that these values can be recorded and electrical power (W) calculated.

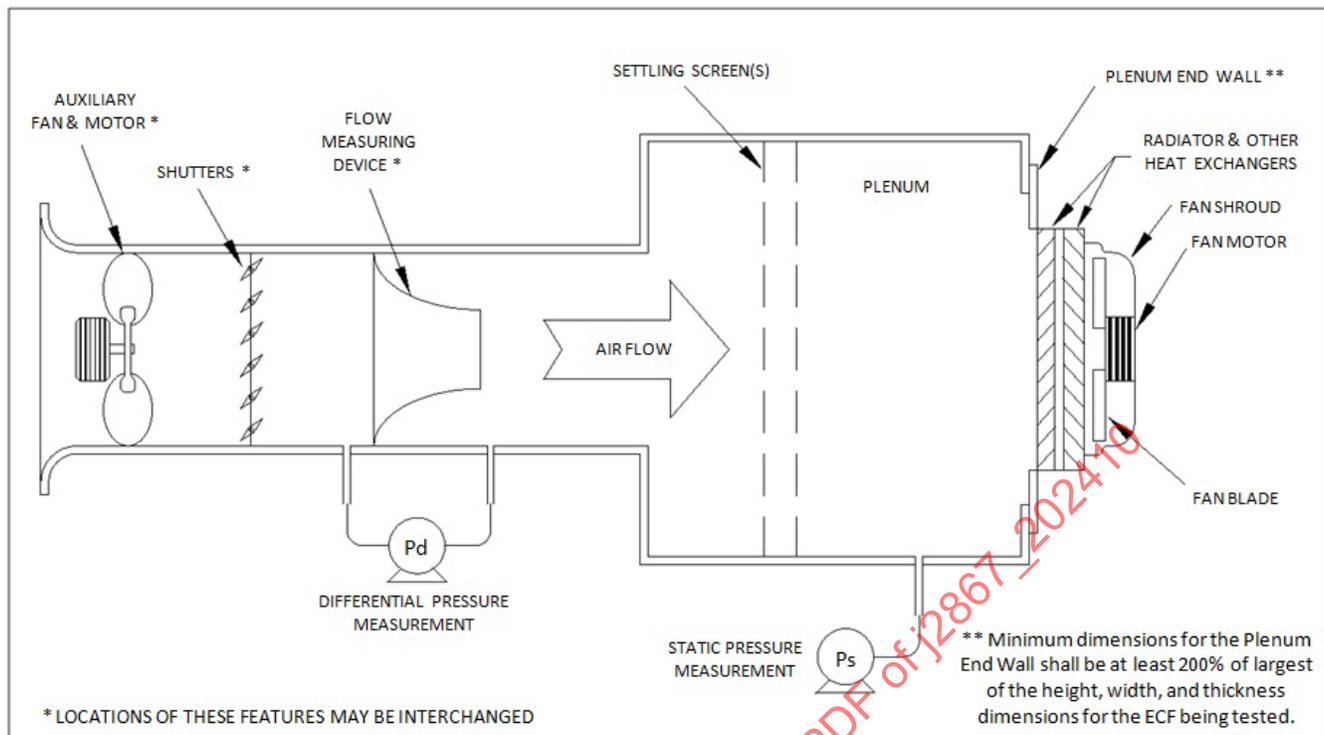


Figure 2 - Fan performance test setup

- 3.1.6 A method for measuring fan rotational speed (rpm). This can be a photoelectric device reading reflective tape applied to one fan blade, a magnetic pickup reading metal clips appropriately placed on the fan, or a manual method using a photo tachometer.
- 3.1.7 A controller device to send duty cycle demand to a PWM or LIN fan controller (when applicable).
- 3.1.8 Equipment necessary for measurement of air temperature, barometric pressure, differential pressure across the flow nozzle, and the pressure inside the plenum chamber.
- 3.1.9 The ANSI/AMCA Standard referenced in 2.1.2 provides guidance on preferred flowmeter construction, instrument accuracy, and alternative airflow calculations. Although it is primarily for fans with integral housings, its guidelines are applicable for non-ducted fan performance, such as ECFs.
- 3.2 Test Conditions
- 3.2.1 The ECF, including its motor(s) and shroud, should be mounted to the airflow measurement structure in a manner that is representative of the vehicle installation. At a minimum, the correct heat exchangers (radiator, A/C condenser, CAC, air/oil cooler) should be included to provide representative pressure restrictions. The heat exchangers will influence the air loading of the fan and therefore its speed for a given electrical power and pressure drop condition.
- 3.2.2 The ECF and heat exchangers should be securely fastened to the airflow measurement structure to prevent the components from being pulled into or blown out of the structure during testing.
- 3.2.3 The ECF and heat exchangers should be sealed with duct tape (or similar methods) to prevent air from bypassing the units and to maintain a serial flow path.
- 3.2.4 Mount rough shapes of plywood or other materials an appropriate distance behind and ahead of the ECF to simulate the airflow restriction of underhood components, such as the engine and vehicle grill. If possible, actual components should be used up to, and including, the complete vehicle front end.

3.2.5 Tests should be conducted at room temperature. Specify exact test conditions used on the fan test report, plots, and/or tabulated data.

3.3 Test Procedures

3.3.1 Fan Speed

Operate the test fan over a range representative of the intended use. Select sufficient discrete speeds to establish performance for the speed range available per the vehicle speed control strategy. Choice of fan speed depends upon several factors, including the type of control system:

3.3.1.1 Fan motors with fixed speed controls typically have three speeds (off, low, and high), achieved by using relays and a resistor (for single fans).

3.3.1.2 Dual fan units have the additional modes of series/parallel operation.

3.3.1.3 Digitally controlled (PWM or LIN) fan motors are capable of infinitely variable speeds. At a minimum, measurements at minimum power, 50%, 80%, and at full power are recommended (most PWM devices are calibrated to full power at less than 100% PWM; consult the PWM manufacturer to determine appropriate signal input required).

3.3.1.4 Many applications may require measurements above and below normal vehicle voltage; i.e., for a 12-V system, data may be taken at voltages from 9 to 16 V.

3.3.2 Test Setups

3.3.2.1 Run 1: Flow Nozzle and End-wall Loss. As described in 3.1.3, mount an end-wall on the plenum with an opening sized to heat exchanger core width (W_{hx}) and height (H_{hx}).

3.3.2.2 Run 2: Flow Nozzle + Heat Exchangers. Install radiator to end-wall of Run 1 as described in 3.2, as well as all heat exchangers of interest (condenser, transmission oil cooler, CAC, etc.).

3.3.2.3 Run 3: Flow Nozzle + Heat Exchangers + ECF Assembly (Fan Powered). Install ECF assembly to heat exchangers and set power level as desired (minimum power, various PWM or LIN levels, different voltages, etc.).

3.3.2.4 Note that Run 3 may be conducted many times if different speeds and/or power levels are studied, but Run 1 and Run 2 will typically only need to be conducted once per heat exchanger setup.

3.3.3 Data Acquisition

At each discrete test speed and setup condition, vary the plenum pressure to various test points by using the auxiliary fan and/or shutters. The first point should be at a flow rate of Z , where Z is defined as the maximum flow rate that the air measurement structure can sustain without damage to the test components or facility. Reduce auxiliary fan speed and/or shutters opening to attain additional plenum pressure points. Plenum pressures should be both positive and negative. Typically, a minimum of five discrete plenum pressure points should be sufficient to define fan performance or the system restriction curve. At each plenum pressure point, measure and record the following variables (see Table 1 for preferred units):

3.3.3.1 Fan speed, N .

3.3.3.2 Fan motor voltage, V .

3.3.3.3 Fan motor current, i .

3.3.3.4 Plenum pressure, P_p . (Use care to record proper sign as pressure within plenum can vary from negative to positive during a test.)

3.3.3.5 Nozzle differential pressure (Delta P), P_d .

- 3.3.3.6 Barometric pressure, B. (May be acquired once per test if value does not change during test.)
- 3.3.3.7 Ambient air temperature, t. (May be acquired once per test if value does not change during test.)
- 3.3.3.8 Relative humidity, RH. (Optional; collect if used in calculating air density.)

4. COMPUTATIONS AND RESULTS

4.1 Definition of Symbols

Table 1 lists definitions and units of acquired data and subsequent calculated results.

Table 1 - Definition of symbols

Symbol	Definition	Units SI	Units English
A	Absolute temp conversion factor	273 °C	460 °F
B	Barometric pressure	kPa	in Hg
C	Air density correction factor	None	None
D	Air density	kg/m ³	lbm/ft ³
D _{sa}	Standard air density	1.20 kg/m ³	0.075 lbm/ft ³
d _n	Nozzle diameter	m	inches
E _s	Fan static efficiency	%	%
i	Fan motor current ⁽¹⁾	A	A
K	Density conversion factor	$\frac{3.487 \text{ kg}^\circ\text{C}}{\text{m}^3 \text{ kPa}}$	$\frac{1.325 \text{ lbm}^\circ\text{F}}{\text{ft}^3 \text{ in hg}}$
k _f	Flow conversion constant	2100	5.97
k _n	Nozzle flow coefficient	Function of nozzle geometry	
N	Fan speed	r/min	r/min
Q	Airflow	m ³ /min	ft ³ /min
P _{wr}	Fan motor power (actual)	W	hp
P _{wrth}	Theoretical static air power	W	hp
P _{CRFM}	CRFM static pressure	kPa	in-H ₂ O
P _d	Nozzle pressure (Delta P)	kPa	in-H ₂ O
P _p	Plenum pressure	kPa	in-H ₂ O
P _s	Static pressure	kPa	in-H ₂ O
RH	Relative humidity	%	%
t	Ambient temperature	°C	°F
U	Air power conversion factor	0.06	6356
V	Fan motor voltage ⁽¹⁾	V	V
Y	Power conversion factor	1.0	0.00134 HP/W
Z	Maximum facility airflow	m ³ /min	ft ³ /min
Subscripts			
c	Corrected to standard air density		

⁽¹⁾ These are valid where the fan motor is directly driven by vehicle voltage; however, common practice where a PWM control is included is to measure system input current and voltage, thus including PWM losses.

4.2 Computations

4.2.1 Air Density

The density of dry air varies directly with absolute air pressure and inversely with absolute air temperature and the universal gas constant R. For simplicity, the conversion factor K combines these factors so that the equation for air density is:

$$D = K \cdot B / (t + A)$$

NOTE: Other sources, such as the ANSI publication in 2.1.2, provide computations for using relative humidity to obtain more accurate values of air density. At 20 °C, relative humidity affects density by ±1.2%.

4.2.2 Air Density Correction Factor

$$C = D_{sa} / D$$

4.2.3 Fan Airflow

$$Q_c = k_f \cdot k_n \cdot d_n^2 \cdot (P_d / D)^{0.5}$$

4.2.4 Fan Power

$$P_{wr} = Y \cdot V \cdot i$$

4.2.5 Corrected Fan Power

$$P_{wr_c} = P_{wr} \cdot C$$

4.2.6 Fan Static Pressure

Fit a second order polynomial whose y-intercept is zero on an x-y plot of plenum pressure P_p (y-axis) versus airflow (x-axis) to the Run 2 - Flow Nozzle + Heat Exchangers data. Plot the polynomial with the Run 3 - Flow Nozzle + Heat Exchangers + ECF assembly data. The fan static pressure curve Q_c versus P_s is computed by subtracting the Run 2 pressure from the Run 3 pressure. Care must be taken to ensure proper signs of resulting fan static pressures. Plenum pressures in Run 2 will be positive, but Run 3 plenum pressures can be both positive and negative.

4.2.7 Corrected Fan Static Pressure

$$P_{sc} = P_s \cdot C$$

4.2.8 CRFM Static Pressure

Fit a second order polynomial whose y-intercept is zero on an x-y plot of plenum pressure (y) versus airflow (x) to the Run 1 - Flow Nozzle data. Plot the polynomial with the Run 3 - Flow Nozzle + Heat Exchangers + ECF assembly data. The CRFM pressure curve Q_c versus P_{CRFM} is computed by subtracting the Run 1 pressure from the Run 3 pressure. Care must be taken to ensure proper signs of resulting CRFM static pressures. Plenum pressures in Run 1 will be positive, but Run 3 plenum pressures can be both positive and negative.

4.2.9 Corrected CRFM Static Pressure

$$P_{CRFM_c} = P_{CRFM} \cdot C$$

4.2.10 Theoretical Static Air Power to Produce Q_c Airflow at P_{sc} Static Pressure

$$P_{wr_{th}} = Q_c \cdot P_{sc} / U$$

4.2.11 ECF Static Efficiency

$$E_s = P_{w_{th}} / P_{w_c}$$

NOTE: This measure of fan efficiency combines the efficiencies of both the fan and the electric motor.

4.2.12 System Resistance Curve

Subtract the Run 1 data from Run 2 data. That difference is the system resistance, including the heat exchangers and the ECF assembly.

4.2.13 Presentation of Results

4.2.14 The fan flow (Q_c), fan static pressure (P_{sc}), and fan power (P_{w_c}) shall be plotted at each fan speed N , as shown in Figure 3.

NOTE: Fan static pressures are generally plotted as positive values, so P_s (and P_{sc}) calculated in 4.2.6 (and 4.2.7) should have their signs changed before plotting (i.e., positive values become negative and negative values become positive).

4.2.15 For ease of use and greater applicability, it is recommended that the fan flow (Q_c), fan static pressure (P_{sc}), and fan power (P_{w_c}) also be presented as tabulated data as shown in Figure 4.

4.2.16 The ECF model designation, test conditions, heat exchangers, flow obstructions, air density, fan speed, and any special conditions should be noted on both plots and tabulated data pages.

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