



SURFACE VEHICLE RECOMMENDED PRACTICE

J1390™

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Engine Cooling Fan Structural Analysis

RATIONALE

Corrections have been made to punctuation, grammar, and spelling where needed. Section 5.2.2.3 has been expanded to include Power Take Off (PTO) mounted parking brakes. Clarifying statements have been added where needed.

FOREWORD

This SAE Recommended Practice is intended as a guide toward standard practice but may be subject to frequent change to keep pace with experience and technical advances, and this should be kept in mind when considering its use.

1. SCOPE

Three levels of fan structural analysis are included in this practice:

- a. Initial structural integrity.
- b. In-vehicle testing.
- c. Durability (laboratory) test methods.

The initial structural integrity section describes analytical and test methods used to predict potential resonance and, therefore, possible fatigue accumulation.

The in-vehicle (or machine) section enumerates the general procedure used to conduct a fan strain gage test. Various considerations that may affect the outcome of strain gage data have been described for the user of this procedure to adapt/discard depending on the particular application.

The durability test methods section describes the detailed test procedures for a laboratory environment that may be used depending on type of fan, equipment availability, and end objective.

The second and third levels build upon information derived from the previous level. Engineering judgment is required as to the applicability of each level to a different vehicle environment or a new fan design.

This SAE Recommended Practice is applicable to any engine cooling fan application including medium and heavy-duty trucks, buses, construction equipment, industrial, and agricultural equipment. Some sections are more applicable to engine-driven fans than to hydraulic-driven or electric-motor-driven fans, especially with respect to speed control. Fan failure modes, however, are generally the same regardless of driving modes.

The usage of non-metallic construction necessitates areas of evaluation not required by metallic designs. Chief among

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these are temperature extremes, moisture content, impact resistance, chemical attack, material purity/homogeneity, and aging/weathering. Areas of evaluation affecting both metallic and non-metallic fans, but requiring somewhat different approaches with non-metallic parts, include natural frequency determination and durability testing.

1.1 Purpose

The purpose of this document is to identify the general methodology for the structural analysis of engine cooling fans, and to provide expanded information on subset practices within the general methodology, such that a user of this practice can adapt specific subsets related to a vehicle¹ class.

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 J1099 Technical Report on Low Cycle Fatigue Properties, Ferrous and Non-Ferrous Materials

SAE J1116 Categories of Off-Road Self-Propelled Work Machines

SAE J1234 Specification Definitions - Off-Road Work Machines

SAE J/ISO 6165 Earthmoving Machinery - Basic Types - Vocabulary

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D618 Standard Practice for Conditioning Plastics for Testing

3. DEFINITIONS

3.1 NON-METALLIC FANS

Non-metallic fans can be constructed from a variety of thermoplastic and thermosetting resins, with or without any of the following: reinforcing fibers, fillers, stabilizers, modifiers, and pigments. Non-metallic fan materials in common use include but are not limited to polypropylene, nylon, polyester, and vinyl ester.

3.2 WELD-LINE or KNIT-LINE

The area of a molded non-metallic part formed by the union of two or more streams of thermoplastic flowing together during an injection molding process.

3.3 STRESS WHITENING

An effect noted in non-metallic materials under stress loading occurring as a result of molecular orientation, visible as a white area due to the change in the refraction index of the material.

4. INITIAL STRUCTURAL INTEGRITY

¹ The term "vehicle" as used in this practice is defined as an all-inclusive term.

4.1 Scope

It is necessary to identify and attempt to evaluate the characteristics of an application which can have an effect on fan durability. Failures almost always occur in fatigue, so careful attention should be paid to avoid resonance or forced vibration of the fan. This section considers vibrational inputs, fan natural frequencies, and operating speed as part of the initial structural integrity analysis. A fan application fact sheet (Figure 1) is recommended as a form to communicate between user and fan supplier.

- 4.1.1 A resonant condition may occur when the natural frequencies of the fan as determined from 4.3 is coincident with either of the vibrational input frequencies or their harmonics, as calculated in 4.2, or with the effects of airflow obstructions near the fan.
- 4.1.2 It is desirable to separate these frequencies, including the upper and lower harmonics, whenever possible. In addition, torsional vibrations, auxiliary equipment, driveline vibrations, etc., may cause vibratory inputs to the fan which cannot be predicted in equation form.
- 4.1.3 Vibratory inputs to the fan caused by the fan tips rubbing against a shroud should be avoided. Such rubbing is generally accompanied by much noise but can also be easily identified by visual inspection of the fan and shroud. Engine movement and vehicle frame flexure are two conditions that can cause rubbing.

PART ONE - FAN USER INFORMATION

Customer: _____ Location: _____

Contact Person: _____

Phone Number: _____ E-mail Address: _____

Performance Required

Volumetric Flow Rate: _____ Air Density: _____

Speed: _____ RPM Static Resistance Pressure: _____

Max Fan Power: _____

Limitations

Max Fan Diameter: _____ Max Over-Speed: _____ RPM

Max Projected Width: _____ Max Fan Power: _____

Other: _____

Application (Vehicle) Description

Model Number: _____ Engine: _____

Rated Power: _____ at Engine Speed: _____ RPM

Fan Drive Type: _____

Fan/Engine Speed Ratio: _____ Fan Mounting Location: _____

Fan Rotation: _____ Belt Tension: _____

Pilot and Bolt Circle: _____ Maximum Run-Out: _____

System

Shroud (& Type): _____ Shroud Diameter: _____

Fan Position: _____

Clearance to Obstructions: Front: _____ Rear: _____

Required Testing

Airflow: _____ Spin Burst: _____ Shaker Scan: _____ Impact: _____

Strain Gage: _____ Endurance (Bench Test): _____ Dimensional Check: _____

Material Properties: _____ Other: _____

PART TWO - FAN SUPPLIER INFORMATION

Manufacturer: _____ Location: _____

Contact Person: _____

Phone Number: _____ E-mail Address: _____

Proposal

Manufacturer's Part Number: _____

Drawing and/or Model File Attached: _____

Fan Weight: _____ Max Fan Imbalance: _____

Fan Rotational Inertia: _____ Fan Transverse Inertia: _____

Other: _____

Test Results Attached

Airflow: _____ Spin Burst: _____ Shaker Scan: _____ Impact: _____

Strain Gage: _____ Endurance (Bench Test): _____ Dimensional Check: _____

Material Properties: _____ Other: _____

Figure 1 - Fan application fact sheet

4.2 Vibrational Inputs

4.2.1 Frequency Prediction

Without verification by in-vehicle testing, the potential critical speeds and frequencies that can affect the fan can only be predicted. Two potential frequencies of vibration are the harmonics of the piston firing frequency Equation 1 and the harmonics of the fan rotational frequency associated with obstructions that cause a non-uniform or pulsating flow as the fan rotates (Equation 2). Both full-order and half-order harmonic frequencies should be considered.

$$\text{Piston Firing Frequency} = \frac{(\text{No. of Cylinders})(\text{Engine rpm})}{(30)(\text{No. of Cycles})} \quad (\text{Eq. 1})$$

where:

number of cycles refers to two or four stroke engine

$$\text{Fan Rotational Harmonic Frequencies} = \frac{(n)(\text{Fan rpm})}{60} \quad (\text{Eq. 2})$$

where:

n = 1,2,3, ... obstructions encountered per revolution

4.2.2 Air Pressure

The cooling fan operates with a working pressure gradient across the fan swept area. Local obstructions, side-members, and core (or stacked core) air restrictions all affect fan blade deflections and strain levels.

4.3 Fan Natural Frequencies

4.3.1 The resonant frequencies and location of the node lines of the fan should be measured for each mode of vibration. This can be done by using a shaker table, accelerometers, strain gages, or by observation. The resonant frequencies may be for both rectilinear and torsional modes of vibration. Each resonant frequency of a fan can be affected by the following:

4.3.1.1 The shape of the fan mounting surface, which may affect the relative spring constant of the system and should be duplicated as closely as possible.

4.3.1.2 The torque of the mounting bolts may also affect the relative spring constant.

4.3.1.3 Dimensional variations from fan to fan, including material tolerances, may affect both the relative spring constant and the vibrating mass.

4.3.1.4 When using means other than the actual installation for driving the vibrating mass, caution should be exercised with the excitation level as the natural resonant frequencies can be masked by the high excitation levels of an over-driven forced vibration.

4.3.1.5 Temperature and moisture content of a non-metallic fan, since tensile modulus and flexural modulus vary with both temperature and moisture content.

4.3.1.6 Orientation of reinforcing fibers of a non-metallic fan (if present).

4.3.1.7 Material homogeneity of a non-metallic fan due to molding process variations.

4.3.2 The maximum stress may not occur at the resonant frequency. It may occur at a frequency between the resonant frequencies of two different modes of vibration, i.e., a combination of rectilinear and torsional excitation.

4.3.3 Finite element analysis methods may be used as a supplement to the previous test methods. Mode shapes and frequencies, and relative stress gradients can be numerically predicted and compared to vehicle vibrational inputs.

4.4 Operating Speed

4.4.1 As fan operating speed increases, so does stress due to centrifugal force. Also, a broad speed range increases the exposure of the fan structure to potential resonant frequency input whether from engine shake inputs or airflow disruption. While it may be desirable to keep the fan operating speed as low as possible to minimize stresses, fan speed is dictated by vehicle cooling requirements.

4.5 Log Sheet

4.5.1 The fan user and supplier may wish to establish a fan application fact sheet. This can be used to identify design parameters that affect fan performance for their particular application and to record the basic fan characteristics. It must be remembered, however, that one cannot anticipate all of the factors that will affect fan durability while early in the design stage. No itemized list will be all-inclusive, and no algorithm is possible. A sample fact sheet is provided as Figure 1. Users and suppliers should feel free to modify it as mutually desired.

5. IN-VEHICLE TEST

5.1 Scope

In-vehicle tests can be used to complement the Initial Structural Integrity section of this document because the forces on a fan are determined by a combination of the fan's operating environment and the engine/vehicle operational duty cycle conditions. A fan designed for a specific vehicle application and having satisfactory structural strength in its intended application may have unsatisfactory durability in a different application. The following sections will aid in the selection of a suitable test vehicle, in the preparation and instrumentation of the vehicle for test, and in conducting the actual test.

5.2 Test Vehicle Selection

This subsection considers the kinds of standard and optional vehicle equipment which can impose forces, vibrations, and frequencies on the subject fan. The vehicle equipment environment influences the fan by three different methods. First, equipment obstructions ahead of, behind, and around the fan disturb the air flow passing through the fan. This air flow disturbance imposes forces and vibrations on the fan. Second, the engine and other equipment are sources of mechanical vibrations. These vibrations can propagate and be transmitted to the fan through its mounting attachment. Third, the fan drive that determines the plane-of-rotation, the center-of-rotation, and the rotational speed directly affects inertial forces and vibrations in the fan. Consideration of these factors will permit the tester to specify the appropriate optional equipment for the test vehicle.

5.2.1 Package Obstructions

Equipment located in the near vicinity of the fan that restricts and obstructs the fan air flow.

5.2.1.1 Radiator Core

Consider the variation in air flow restriction due to optional radiator cores with a different number of tube rows, core depth, fin densities, and fin designs. Radiator tanks, side structures, and cross-reinforcing rods can be significant obstructions if the fan partially "sweeps" any of these items.

5.2.1.2 Heat Exchanger Core

Any finned core located ahead or behind the fan will restrict air flow. Examples are air conditioning condenser and coolers for engine lubricating oil, power steering fluid, automatic transmission fluid, hydraulic PTO fluid, and charge air coolers.

5.2.1.3 Shroud

Optional fan shroud or hand guards. As with radiator tank obstruction, fan shroud design relative to the fan sweep path may significantly impact air loading of the fan structure.