

Development of a Test Apparatus to Determine Optimal Fan Configurations for Haul Trucks and LHDs

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ABSTRACT

Operators of haul trucks and load-haul-dump (LHD) vehicles without cabs used in underground metal and nonmetal mines are frequently exposed to hazardous noise levels, putting them at risk of noise-induced hearing loss. To address this issue, the NIOSH Office of Mine Safety and Health Research (OMSHR) is developing noise controls for these machines. Analysis of field data showed that engine cooling fan noise was the dominant contributor to the sound level at the operator location. Thus, to reduce the operator noise exposure, engine cooling fan noise would have to be reduced. It was determined that a new apparatus would be needed to conduct laboratory noise and air flow testing to evaluate different noise control approaches. This paper documents the development of this test apparatus. This fixture is now being used by NIOSH to develop haul truck and LHD cooling configurations that maintain the required cooling air flow rate while reducing noise emissions.

1. INTRODUCTION

In underground metal/nonmetal mines, haul trucks and load-haul-dump (LHD) vehicles are utilized to move ore from the mining site to a dumping location (Figure 1). In situations where the haul truck or LHD does not have a cab, vehicle operators are frequently overexposed to noise, putting them at an increased risk of noise-induced hearing loss (NIHL). Recent OMSHR mine investigations confirmed that the operators are exposed to sound levels exceeding 95 dB(A) and that engine cooling fan noise was the primary contributor to the sound level at the operator location¹. To reduce the noise exposure experienced by operators', OMSHR sought to develop fan/cooling system-related engineering noise controls.

Meeting this goal required the design and fabrication of a test apparatus for laboratory testing of noise emission—i.e., sound power, and air flow rate. In developing this fan test apparatus (FTA), it was critical to represent the actual engine compartment shape and all of its air flow obstructions, e.g. the radiator, the engine, the portion of the operator compartment that extends

into the engine compartment, etc. The FTA was designed to be versatile enough to allow for multiple fan/cooling system configurations (Table 1).



Figure 1 - Haul truck (upper left) and load-haul-dump (upper right) shown above ground. A load-haul-dump loading a haul truck underground (lower).

Table 1 – List of variables associated with the fan test apparatus, allowing for a wide variety of fan/cooling configurations.

Fan-related variables	Location variables
Type	Fan-to-block distance
Geometry	Fan-to-core distance
Insertion percentage	
Diameter	
Insertion percentage	
Blade angle	
Rotation speed	

THE STOCK ENGINE COMPARTMENT

Because the haul trucks and LHDs in question were similar in size and design with similar fan noise problems, only one was modeled, to develop noise controls to address the noise issue, and then employ similar noise controls for both machines in the field. The initial design was

modeled after a haul truck engine compartment. This required accurate replication of the air flow path into and through the engine compartment. A haul truck grill was fabricated from 19-W-4 carbon steel welded bar grating, just as installed on the haul trucks tested during field studies (Figure 2). A stock fan shroud, fan guard, and radiator were also acquired for the fixture (Figure 3). These were mounted on a sled-like unit that could be moved to change the distances between the fan, block, or core per testing requirements.

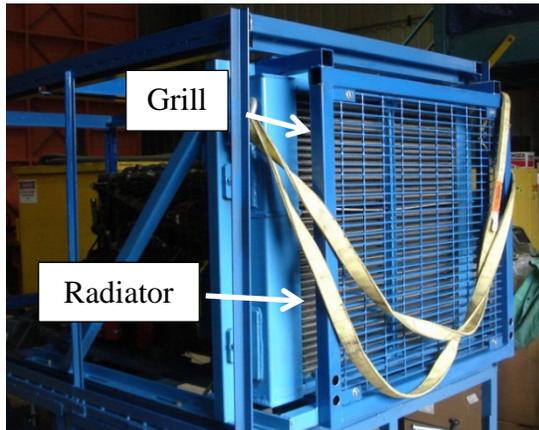


Figure 2 – The front end of the FTA is modeled after an underground haul truck.

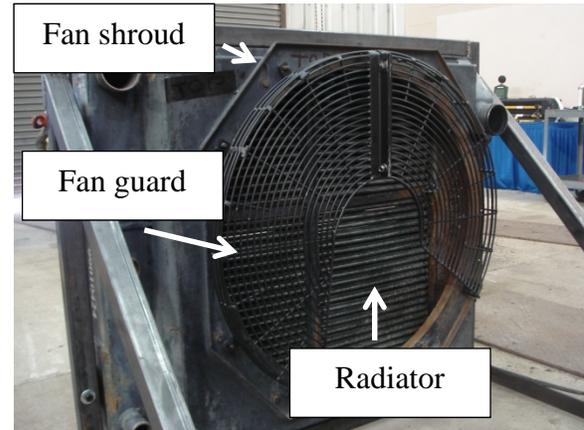


Figure 3 – The radiator is mounted on a movable sled to allow for re-positioning.

The haul truck engine is a significant obstruction to the flow of air through the engine compartment. For lab testing purposes, OMSHR used Deutz haul truck engine of the similar model used on the haul trucks in the field testing was acquired (Figure 4). Assorted hoses and pipes for the radiator coolant, charge air, etc. were also purchased and installed (Figure 5). The frame of the FTA is 50 mm x 50 mm steel tubing. The skin is 5 mm-thick clear polycarbonate panels, chosen for its scratch resistance and ability to withstand impacts. The side panels are roughly 89 cm wide by 117 cm high and are secured by steel tabs and toggle clamps to allow for easy access to the interior. The FTA is mounted on wheels so that it can be rolled into and out of the test facilities. Six jacks are installed to level the FTA during testing.



Figure 4 – The Deutz haul truck engine prior to installation.

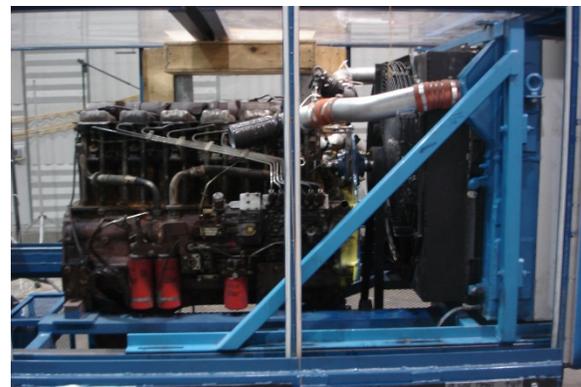


Figure 5 – The Deutz haul truck engine installed in the FTA.

FAN DRIVE SYSTEM

The test objective was to replicate a haul truck engine compartment and address fan noise and air flow rate. Inclusion of the engine and its placement were key, as it needed to serve as an air flow obstruction near the fan. However, unlike in field conditions, there was no need to have the haul truck engine actually drive the fan. An alternative method was selected for this. This approach had the additional benefit of alleviating concerns about engine diesel fuel or engine exhaust. A review of the fan curves for the stock Multi-Wing 76 cm diameter airfoil fan showed that a 22 kW motor would be required for operation. To accommodate for this and fans that would have additional power requirements, a Dayton 29.8 kW motor was selected for this application (Figure 6, Table 2). Supplying power for the motor was a Fuji variable frequency drive (VFD) (Figure 7, Table 2). Fan rotation speeds were controlled via the VFD.



Figure 6 – A 29.8 kW Dayton motor to drive the fan.



Figure 7 – A Fuji VFD to provide power for the Dayton motor and control the fan rotation speed.

Table 2 – Motor and variable frequency drive specifications

Motor		Variable Frequency Drive	
Manufacturer	Dayton	Manufacturer	Fuji
Power (kW)	29.8	Power (HP)	37.3
Voltage (VAC)	208-230/ 460, 3-phase	Voltage (VAC)	380-480
Frame	NEMA 324TS	Output current (A)	75
Rotation speed (rpm)	3,555		

The motor was connected to a 1.83 m, 51 mm diameter precision drive shaft via three V-belts and three sheave pulleys with taper lock inserts. The drive shaft is secured by three base mount ball bearings. The drive shaft is coupled to the fan shaft with three bearings, an idler pulley, and a timing style drive belt. A turnbuckle served to tension the drive belt. The fan shaft is 41 cm in length, 38 mm in diameter and keyed to mate with the fan hub (Figure 8).

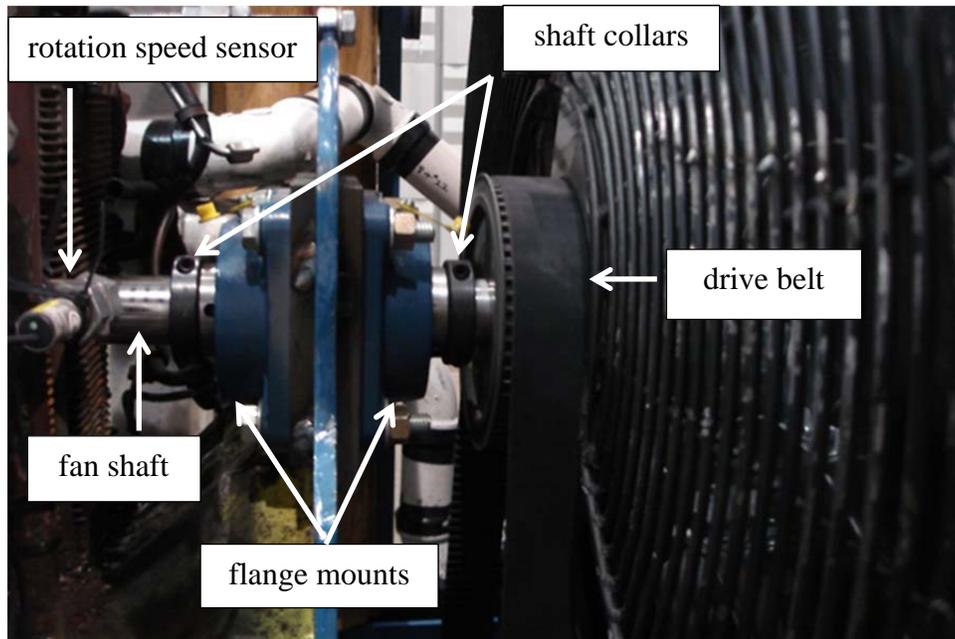


Figure 8 – Close-up of the fan shaft and associated hardware.

AIR FLOW SYSTEM

Maintaining adequate air flow is a concern when changing the cooling package components of a vehicle. Therefore, it is important to be able to document the air flow entering the FTA. This prompted the purchase of an Air-Flow Technologies Fan Evaluator Probe Assembly (Figure 9, Table 3) and the associated Veltron II differential pressure/flow transmitter with an LCD display. The Probe Assembly is a multi-point self-averaging traverse station with an integral air straightener-equalizer honeycomb cell. The unit provides an average air flow rate through its cross section. This rate and differential pressure are displayed on the transmitter. The Probe Assembly is installed midway through ducting that mate with the FTA (Figure 10). The ductwork was designed in-house per the Air Flow Technologies requirements for Probe Assembly installation. The ductwork and the Probe Assembly are mounted on a steel frame with wheels.



Figure 9 – The Air-Flow Technologies Fan Evaluator Probe Assembly.

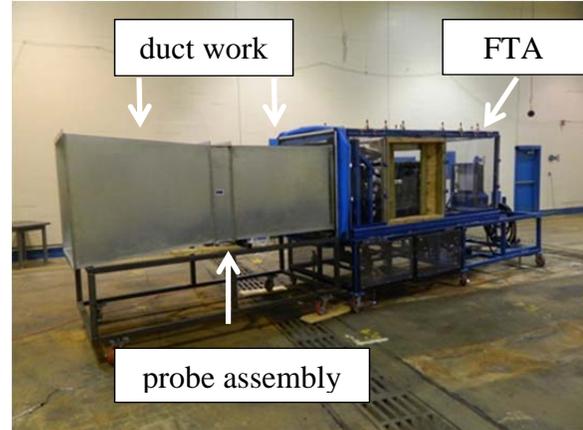


Figure 10 – The FTA and air flow system in a testing laboratory.

Table 3 - Selected specifications for the AirFlow Technologies Probe Assembly

Parameter	Specification
Measurement accuracy	2%
Duct height (cm)	91
Duct width (cm)	107
Duct length (m)	1.22 / section
Maximum air flow rate (m ³ /hr)	42,500

With this fixture, it is now possible to conduct a wide range of testing to determine the noise emission and air flow rate of a given cooling system configuration. Initially, air flow rate and noise emissions can be determined for a stock fan configuration to establish a baseline for both. Then, a variety of combinations of cooling system configurations can be tested and compared to the baseline to document the noise reduction and the effect on the flow of air.

SOUND POWER TESTING

NIOSH OMSHR maintains two acoustics laboratory facilities suited for sound power level testing². The first is large reverberation room, the acoustic test chamber (ATC). Testing is typically conducted in the ATC per an engineering method acoustics standard for sound power testing, the ISO 3743-2³. The second OMSHR test facility is the OMSHR hemi-anechoic chamber (HAC). In the HAC, OMSHR conducts fan configuration sound power testing per the ISO 3744⁴ and employs a parallelepiped measurement surface (6.8 m long x 5.5 m wide x 4.1 m high) (Figure 11). Nineteen Type 1 microphones are employed and the sound pressure data is collected with a Bruel and Kjaer Pulse system. At each test configuration, three sound power levels are calculated and these are averaged to determine the mean sound power for the test configuration.



Figure 11 – The FTA in the hemi-anechoic chamber for sound power testing.

AIR FLOW TESTING

Air flow testing is conducted separately from sound power testing. During sound power testing, the air flow system is stored outside the test laboratory. After the cooling package has been configured and sound power testing conducted, the air flow system is wheeled into the laboratory and the air flow testing is conducted, following the same test plan as for the sound power level testing.

TESTING RESULT DISCUSSION

The FTA has been used to test a variety of axial fans to assess their ability to generate the required air flow rate while generating less noise⁵. A summary of fan configuration variables tested to date are listed in Table 4. Thus far, OMSHR has tested three types of Multi-Wing America axial fan designs, an airfoil, a high pressure airfoil, and a sickle fan. Two fan diameters have been tested, 76 cm airfoil and high pressure airfoil fans and 76 cm and 81 cm sickle fans.

Table 4 - Fan configurations laboratory tested with the FTA

Parameter	Tested
Fan type	airfoil, high pressure airfoil, sickle
Fan diameter (cm)	76, 81
Insertion %	0, 25, 33, 50, 67, 75, 100
Pitch angle (degrees)	35, 40, 45
Rotation speeds (rpm)	2,000, 2,200, 2,450, 2,600

The following is an example of how cooling package configurations and their parameters could be varied for testing purposes. Initially, a series of sound power and air flow tests are conducted at the stock or baseline condition. From this, a baseline sound power emission and air flow rate are established. This air flow rate is the target—i.e., the required air flow rate that must be met or exceeded with the implementation of noise controls. Next, an additional series of tests will be conducted changing the fan geometry, fan type, or fan diameter, and other parameters to

determine their effect on the sound emission and air flow rate. This will generate a data matrix of sound power and air flow rate data, delineated by test configuration. An example of this is shown in Table 5. In the first column is the stock, or baseline configuration for the FTA. This is the configuration that most accurately met the actual haul truck cooling package configuration. The most successful results have been increasing the fan diameter, from 76 to 81 cm (30" to 32") and changing from a Multi-Wing America airfoil fan to a Multi-Wing America sickle fan. Note that the fan insertion percentage, blade angle, rotation speeds, etc. for the stock condition and the larger diameter fan are the same.

Table 5 - Tested cooling package configurations and their parameters

	Stock condition	Larger diameter sickle fan
Fan type	axial	axial
Fan geometry	airfoil	sickle
Fan diameter (cm)	76	81
Insertion (%)	67	67
Blade angle (degrees)	35	35
Fan-to-block-distance (cm)	10.2	10.2
Fan-to-core-distance (cm)	7.6	7.6

Shown in Figure 12 are data collected using the stock 76 cm diameter airflow fan and an 81 cm diameter sickle fan. For this example, the required air flow rate is 27, 900 m³/hr and the sound power emission is 116.1 dB(A). At the required flow rate, the 81 cm fan sickle fan emits 113.5 dB(A). In the laboratory, this was accomplished to reducing the rotation speed when using the 81 cm sickle fan. Thus, by changing the fan geometry (axial to sickle), increasing the fan diameter (76 cm to 81 cm) and reducing the rotation speed, a configuration was determined that meets the air flow rate requirement while generating less noise. To this point, this is the optimal configuration.

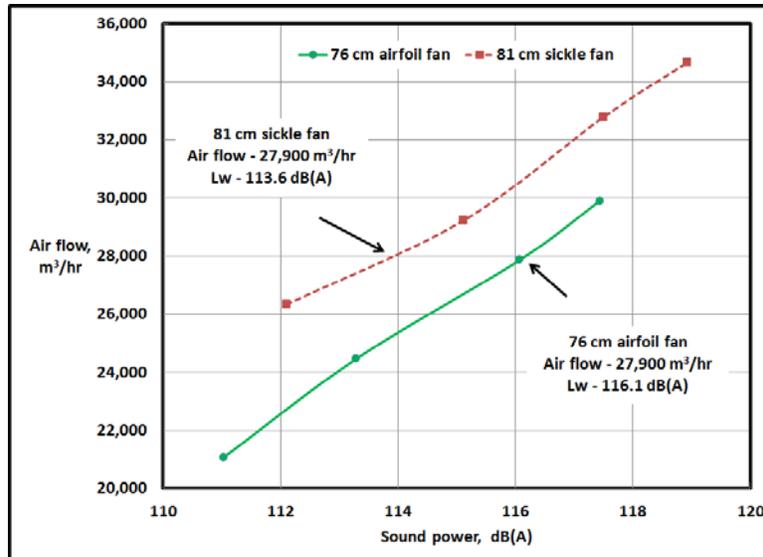


Figure 12 – Graph showing that the 81 cm sickle fan met the air flow rate requirement of 27,900 m³/hr and emitted less noise.

Additional examples of test data are shown in Figure 13. Here, sound power and air flow rate data collected using a 76 cm airfoil fan collected with the fan at its stock 35 degree blade pitch angle, at 40 degrees, and at 45 degrees. Fan insertion settings ranged from 0 % (fan leading edge at the shroud trailing edge) through 100 % (fan fully inside the shroud). Fan noise emission is at its minimum and air flow rate at its maximum when the fan insertion is 67 or 75%. However, increasing the blade pitch angle alone did not produce the desired objective of reduced noise emission while maintaining airflow.

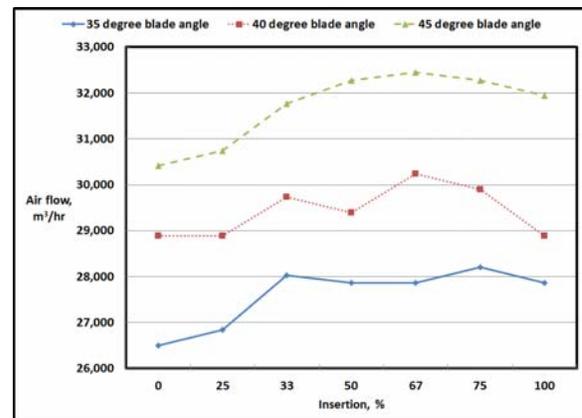
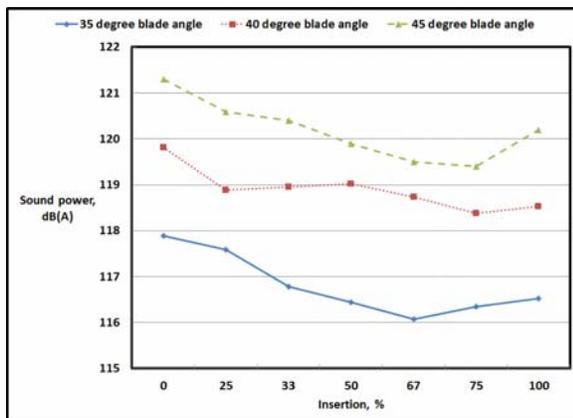


Figure 13 – Airfoil fan testing, 76 cm diameter. Increasing the blade angle increases the noise emission and air flow rate.

In Figure 14, data collected during 76 and 81 cm diameter sickle fan testing is shown. Here, the data is delineated by rotation speed. As one would expect, increasing the sickle fan diameter or the fan rotation speed resulted in an increased sound emission and air flow rate. As compared to the stock 76 cm airfoil fan, there was a 2 dB reduction in sound power at the required air flow

rate when utilizing a 76 cm sickle fan. Employing a larger, 81 cm sickle fan, increased the reduction to 2.6 dB.

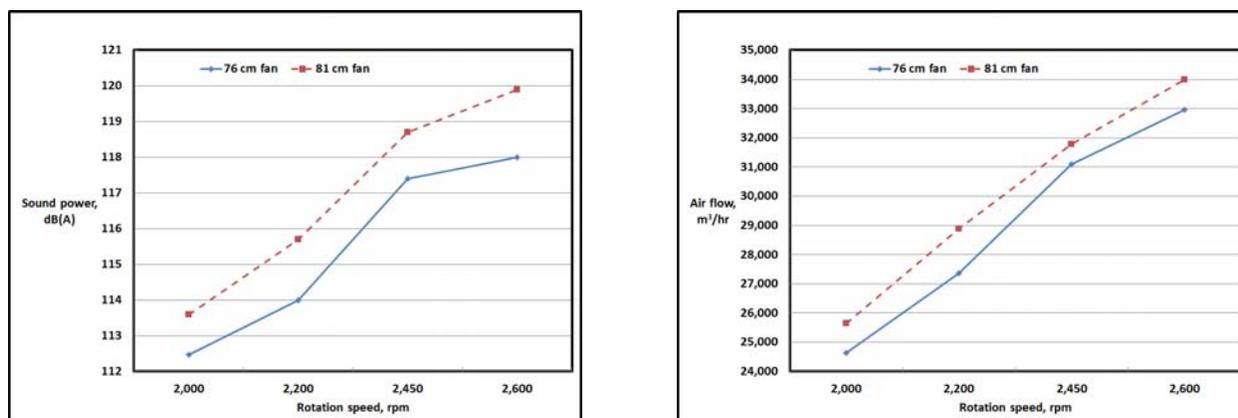


Figure 14 – Sickle fan testing, diameters of 76 and 81 cm. Increasing the fan diameter or rotation speed increases the noise emission and air flow rate.

SUMMARY

As part of its noise control program, NIOSH OMSHR has designed and fabricated a fan test apparatus for the development of haul truck and LHD fan/cooling system noise controls. The FTA is used to determine optimal fan/cooling system configurations that maintain the required cooling air flow rate while emitting less noise than the stock or baseline cooling system. Laboratory testing has determined that while fan geometry, fan size, blade angle, rotation speed, etc. all individually affected the noise emission and air flow rate, it was a combination of changing the fan geometry, increasing the fan diameter and reducing fan rotation speed that yielded the best results to date. Future plans for the research project include underground testing at a collaborating mine. This will be conducted using a larger diameter sickle fan than is normally used and rotating at a reduced rotation speed relative to the stock condition. The objective will be to document the effect on operator noise exposure and ensure that the required cooling is maintained.

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