

# Experimental setup for a multiple-fan ventilation system

N.P. Reddy and Y.J. Wang

**Abstract** — This paper describes an experimental setup for multiple-fan ventilation systems at the ventilation laboratory of the West Virginia University Department of Mining Engineering. Housed in a 30-ft x 70-ft room, the experimental setup consists of three 18-in., variable-speed, axial-flow fans; an 18-in.-diam. fiberglass tubing; associated fittings for arranging networks; and a pitot-tube measuring and data-acquisition system. The fiberglass tubing and fans can be organized into non-planar networks of two or three fans. The setup is mainly designed for studying the characteristic curves, operating points and fan stall for multiple-fan ventilation systems.

## Introduction

An important operational problem in using axial-flow fans for mine ventilation has long been recognized as fan stall or aerodynamic stall. In the stalling condition, fan operation is very unstable. "There is considerable throb and pulsation in the air flow, and in rare cases, fans have been damaged by the fluctuating operating conditions. Vibration and noise increase are customary." (Hartman, 1961, p. 179).

To study this problem an analytical and experimental approach was adopted. The analytical part consists of:

- numerical modeling of two- and three-fan networks, and
- development of an algorithm and a computer program for searching and solving multiple network solutions.

The experimental part consists of:

- construction of characteristic curves and observation of the stall condition for individual fans by laboratory pressure-quantity measurements,
- construction of laboratory models for two- and three-fan networks using fans and tubing, and
- laboratory simulation and analysis of fan stall in two- and three-fan ventilation networks.

This paper describes the construction of networks and measurement of fan characteristic curves.

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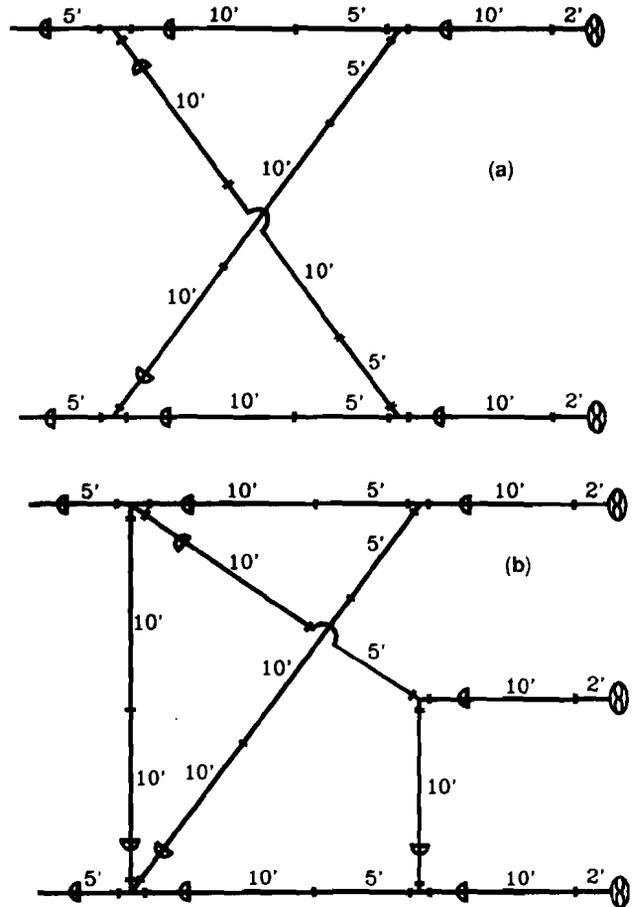


Fig. 1 — The duct networks: (a) a two-fan system, (b) a three-fan system.

## Laboratory equipment

The equipment consists of two networks and three axial-flow fans. One of the systems is a two-fan network about 115 ft long (Fig. 1a), and the other is a three-fan network about 150 ft in length (Fig. 1b).

The networks are constructed using 18-in.-diam RIGIDUCT tubing approved by the Mine Safety and Health Administration Division of Mechanical and Material Safety, under Section 75.302, 30 CFR and the Interim Fire and Toxicity Criteria. The material also meets the ASTM specification E-162 with a flame spread index of less than 25.

The lightweight, fiberglass tubing is made of tough plastic resins that make it highly resistant to attack from acid or alkaline conditions. The tubing is supplied in 10-ft sections unless requested in other sizes.

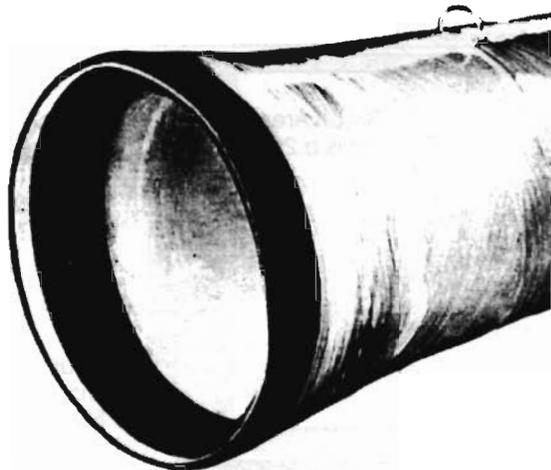


Fig. 2 — Black color-coded bell end with internal rubber gasket internally wound in the fiberglass rovings (Peabody ABC, 1983).

Each section is supplied with a tapered bell coupling at one end and a spigot coupling at the other, designed to minimize air leakage. The couplings have fiberglass-fabric-reinforced ends to reduce breaking or fraying as the tubing is handled. The bell end is color coded black for quick and easy identification. The bell and spigot couplings provide a push-fit joint between adjacent tubes. Antistatic, fire-resistant, neoprene "Rigiseals," attached to the bells, efficiently seal the joints from leakage (Fig. 2). The overall tubing network for a three-fan system is shown in Fig. 3.

The two- and three-fan networks consist of eight and eleven branches, respectively. These networks are non-series-parallel and non-planar. Each of the fans is connected to the network by a 2-ft-long, 18-in.-diam adapter. The adapter is the section of the network that establishes a connection between the fan and the fiberglass tubing.

Each of the branches has a graduated damper (air regulator) installed in it. These dampers are used to adjust the branch resistances. Figures 1a and 1b show the two- and three-fan systems, including the dimensions and damper locations.

The three axial-flow fans are Joy Series 1000, model 18-14. They can be operated at variable speed and blade angle. The blade setting index is numbered from 0 to 16, where 0 is the highest angle of attack and requires the greatest horsepower. As the setting index number is moved toward 6 or 16, the flow pressure and horsepower are reduced. The manufacturer-recommended setting is between 6 and 16. The setting for the fan characteristic curve measurement, which will be described in a later section, was at 6, which is the lowest setting recommended by the manufacturer.

### Laboratory instrumentation

Instrumentation hardware included an IBM PS/2 model 30 microcomputer, an IBM 8513 color display, an Epson LQ-1000 printer, a DAS-8 MetraBytes data acquisition board (internal), an STA-08 screw terminal connector board, a C-1800 connector cable, eight model 264 Setra Systems differential pressure transducers, six Davis Instruments pitot tubes, and tubing for connections between the pitot tubes and pressure transducers. The connections between different hardware are as shown in Fig. 4.



Fig. 3 — The overall experimental setup for a three-fan system.

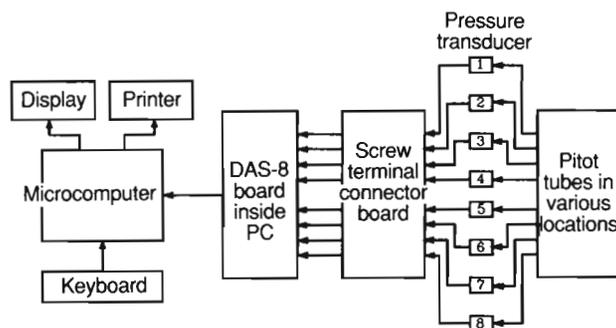


Fig. 4 — Schematic of the instrumentation connections.

The DAS-8 data acquisition board is an 8-channel, 12-bit, high-speed, successive approximation A/D converter and timer/counter for the IBM microcomputer. The DAS-8 is 5 in. long and is fitted in a "half" slot. Using a universal expansion multiplexer and instrumentation amplifier board, 16 differential inputs can be output to one input channel of DAS-8. Up to eight of these boards can be cascaded together on a single DAS-8 for a total of 128 channels of analog input.

All I/O connections between the transducers and the DAS-8 board are made through miniature screw terminal connectors on the screw terminal board. The digital I/O port lines are monitored by seven LEDs, of which four red LEDs are used to monitor the output bits and three yellow LEDs are used to monitor the input bits. A small bread-board area is provided with  $\pm 12$  V power from the computer buss. This offers an easy access to all I/O lines. The eight transducers are hardwired to the eight screw terminals. All connections are made through a standard 37-pin D male connector that projects through the rear of the computer. The I/O connections between the screw terminals and the DAS-8 are established by the C-1800 cable.

Eight differential pressure transducers (six 0-10 in. water and two 0-5 in. water) are factory calibrated. These transducers sense the pressure difference and convert it to a proportional electrical output that ranges from 0 to 5 VDC. The zero and span adjustments are accessible on top of the casing. However, these adjustments are not recommended by the manufacturer because they are done by trained technicians under a controlled environment at the manufacturer's site.

Pressure connections are provided on top of the casing by

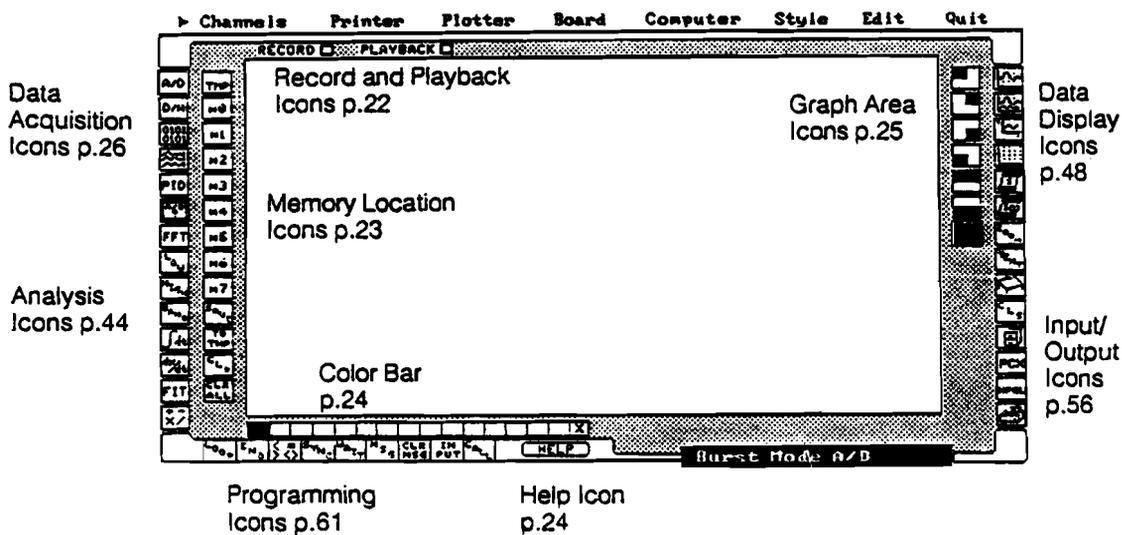


Fig. 5 — Icon classification and location on the Easyest screen.

a 3/16-in. OD, barbed brass pressure fitting for 1/4 in. push-on pitot tubing. Electrical connections are also provided on top of the casing by screw terminal strips.

The pressure transducers work on 12 VDC power provided by the computer bus through the screw terminal board. The effects of resolution, repeatability and thermal changes are negligible on the accuracy of the data.

The pitot tubes are manufactured by Davis Instruments, Inc. in compliance with the Air Movement and Control Association, Inc. (AMCA) and American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) specifications. All tubes are 8 in. long and are graduated in inches to show depth of insertion into the duct during measurements.

The digital psychrometer is manufactured by Vista Scientific Corp. It is a microprocessor-based electronic instrument that provides fast and accurate measurements of relative humidity, dry bulb, wet bulb and dew point temperatures. Temperatures can be read out in either Fahrenheit or Celsius.

The direct reading type aneroid barometer is manufactured by Airflow Developments, Ltd. Although less sensitive than the Askania microbarometer, it is widely used for its convenience and rigid construction. Aneroid barometers should be calibrated periodically against a mercury barometer, since their thermal compensation characteristic changes, and a definite zero shift or drift can continue with time.

### Data acquisition software

Fan curve measurement data were acquired using the Easyest data acquisition software — an icon-driven data acquisition, analysis and graphics package. System requirements include an IBM or compatible microcomputer with at least 640 KB RAM and 1 MB free space on hard disk, a graphics card and monitor, a Microsoft compatible mouse driver, a math coprocessor, and a Keithly Asyst-supported data acquisition board (DAS-8) and a DAS driver.

Easyest's screen displays a command menu along the top of the screen and icons along the other three sides. The large center portion of the screen displays data or dialog boxes for

configuration before data are acquired. These menu items, icons and dialog boxes are used to communicate with the Easyest program (Fig. 5). Detailed information can be obtained from Asyst Software Technologies, Inc. (1990).

### Measurement preparation

Initial measurements were carried out to construct the fan characteristic curves for each of the three fans. The blade tip-to-tip diameter of the fan is 18 in. The fan blades were set at a setting index number of 6 for this particular measurement. A 2-ft fan adapter establishes the connection between the fan and the tubing. The duct tubing was 18 in. diam, and the cross section for differential pressure measurements was located 10 ft from the fan rotor.

The direct reading aneroid barometer was calibrated against a vertical, fixed-position mercury barometer. This calibrated barometer was used to read the atmospheric pressure during fan curve measurements.

The digital psychrometer was calibrated using the digital voltmeter and the thermometer. After filling the wet bulb reservoir, the instrument was turned on. The sensors were allowed to attain equilibrium for about three minutes, and then the measurements of relative humidity, dry bulb, wet bulb and dewpoint temperatures were noted.

### Measuring technique

After a few measurements, it was decided to locate the circular cross section for measurement 10 ft away from the fan rotor. Therefore, for measuring purposes, the fan was considered to be the fan proper, the adapter and the 8-ft duct tubing at which the cross section for measurements are located.

The tubing network is laid on the ground. Therefore, the original classic method of locating traverse lines 90° apart was modified to three traverse lines 120° apart (Fig. 6). Five concentric rings of equal area were constructed, and the intersections of alternate ones with the centerlines were located.

The radii of the equal-area rings were calculated. The

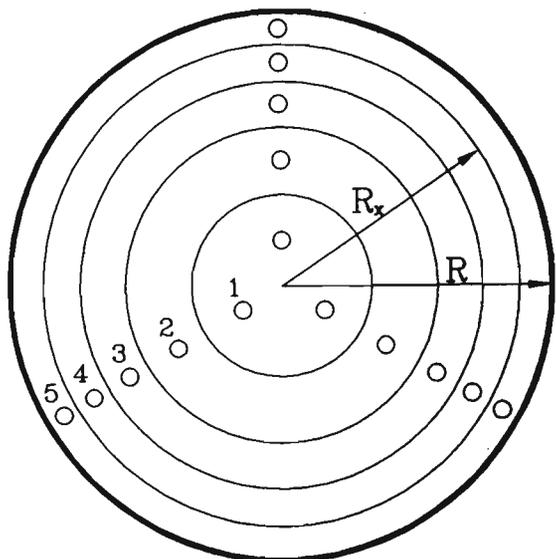


Fig. 6 — Five equal-area concentric rings of the duct tubing cross section. The small circles at the centerlines of the equal-area rings are the pitot tube locations during measurements.

radius distance for alternate rings was calculated to take readings along the centerlines at the intersections with alternate concentric rings. The radii of the first through fifth rings  $r_1, \dots, r_5$  were, respectively,  $0.316r, 0.548r, 0.707r, 0.837r$  and  $0.949r$ , where  $r$  is the radius of the duct.

Once the concentric rings of equal-area were established and centerlines were located, measurements were taken by placing the three pitot tubes at these intersections along the three lines located  $120^\circ$  apart (Figs. 6 and 7). In total, along each line, five measurements were made at the center of each of the five concentric equal-area rings. The total number of measurements along all three lines equaled 15 (5 measurements along each of three lines).

The pressure at the center of these concentric rings through the pitot tube was detected by eight pressure sensors. Along two of the three lines, three sensors each were used to measure the total, static and velocity pressures. For the third line, the total and static pressures were measured but not the velocity pressures because only two sensors were available for this line. The velocity pressures on this line were calculated from the corresponding total and static pressure measurements.

The atmospheric pressure, saturation pressure, temperature, absolute temperature and relative humidity were noted by reading the appropriate instrument. The hardware and software were prepared, and data acquisition was started by pressing any key on the keyboard. After the data were acquired by the eight transducers, they were automatically saved in the eight memory folders M0 to M7.

The data display icons were used to display the data and confirm that the data were correct. Then using the I/O icons and the I/O dialogue box, the data in all of the memory holders were saved under a single file name.

For the fan curve shown in Fig. 8., measurements were made for a total of 25 different positions of the damper. At each position, as mentioned earlier, there were 15 measurements for five equal-area rings.



Fig. 7 — The three pitot tubes inserted into duct during measurement.

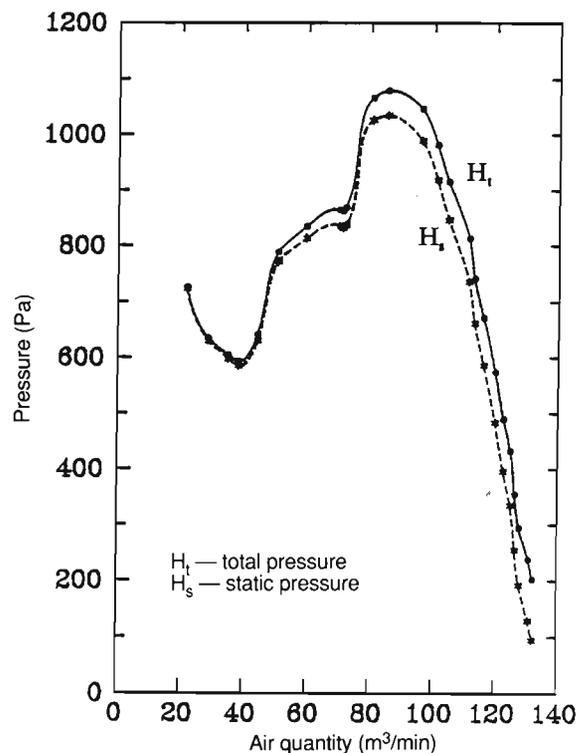


Fig. 8 — The fan curve constructed from laboratory-measured data.

Table 1 — Typical data (pressure, in Pa) recorded for one point on the fan characteristic curve.

		Ring Number				
		1	2	3	4	5
Pitot Tube 1	$H_t$	128	123	115	115	154
	$H_s$	237	239	236	233	235
	$H_v$	104	111	116	114	78
Pitot Tube 2	$H_t$	124	119	116	125	133
	$H_s$	234	234	232	231	231
	$H_v$	98	104	104	95	77
Pitot Tube 3	$H_t$	130	126	127	130	169
	$H_s$	246	246	244	241	241
	$H_v^*$	116	120	117	111	72
Average:		$H_t = 128.9$			$H_s = 237.3$	
* $H_v$ values for this row were calculated from the values for $H_s$ and $H_t$ .						

After the completion of the measurements, the data saved were retrieved one by one, and a curve fitting analysis was performed. In analyzing the analog data, the software displayed the fitting equation, the squared error, the significance of fit and the squared residual. Such analyses were performed for all of the memory channels, and the data were noted.

This was continued for all of the five rings and for all of the 25 points. The data recorded for one point on the fan characteristic curve are listed in Table I. Using this data, the density of the air, average velocity of the cross section and air quantity were calculated. The measured pressures and the calculated quantities for all 25 points were then plotted as shown in Fig. 8.

### Concluding remarks

So far, the design of the duct tubing networks to study fan stall and multiple operating points in multiple-fan ventilation systems has proven to be functioning well during fan characteristic curve measurements. The differences in repeatability were very small and insignificant; the software and hardware and the instrumentation are performing well for data measurement and analysis. Any desired ratios of air quantities in the tubing networks, equipped with air regulators and variable-speed fans, can be achieved without difficulty.

Future work will include the simulation of stall in two- and three-fan ventilation networks. This will be done by

numerically constructing ventilation network problems based on the fan characteristic curves and properties of the tubing networks. The network problem with multiple solutions will then be simulated in the laboratory using the tubing networks.

Although designed mainly for studying the subsystem characteristic curves and operating points for the multiple-fan ventilation system, the experimental setup can also be used in the laboratory sessions for teaching mine ventilation. ♦

### Acknowledgments

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