A METHOD FOR DETECTING CAVE CONNECTIONS BY INDUCED AIR FLOW

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Cavers have used many different techniques in trying to discover where and how to tie smaller caves together into a cave system. These include, but are not limited to: exploration, mapping, stream dye tracing, digging, and air tracing. The admonition "follow the air" is always good advice to explorers but often this proves to be impossible because of passage size or lack of strong air flow. Air scent tracers such as ethanethiol and smoke tracers like white phosphorus have been used with very limited success. This paper discusses a promising (and less polluting) new technique using mechanical methods of generating air flow and micro meteorological instruments to measure the results.

The authors demonstrate that mechanically changing the airflow at one entrance will rapidly affect the rate of airflow at other entrances as measured by sensitive anemometers. The authors also discuss a simple mathematical technique to enhance the sensitivity of the airflow measurements.

Our method involves directing a fan, with a 480 watt reversing motor, in and out of a cave entrance in a periodic fashion. The in and out reversals of the fan are recorded on a data logger. At the same time an anemometer, recording to a data logger, is placed in another remote entrance location. The anemometer signal and the fan reversals are recorded over a period of time. This is repeated between entrances with known connections to each other and between those with no known connections. The result of the measurements shows that the induced airflow causes a measurable change in the rate of the airflow in delayed synchronism with the fan reversals at the connected remote entrances and between some cave entrances where there is no known connection.

Although the technique demonstrates an air connection between caves, it does not guarantee that the connection is humanly accessible.

1. Introduction

"Follow the Air" has certainly been the creed of cavers, rewarding them in many instances. The feel of a cave breeze blowing from some unknown source is intriguing and exciting. Can the source be from some vast cave system not yet discovered? Is it possible that a "far distant blowhole" is somehow connected to a known cave? The possibility of finding such a connection becomes an exciting prospect especially if it might lead to the discovery of virgin cave passages. But air flow can be elusive and trying to follow a tantalizing, barely discernable drift, can be exasperating. Many times the question is raised "Are we on the right track or is this just a local circulation?" "Should we dig here?" or "Is that dome worth a bolt climb?" To have the knowledge of the source or ultimate destination of air flow can be very useful. To determine that a cave is connected, at least by air currents, to another cave six kilometers down the valley is an exciting prospect.

In the past various methods have been used to attempt to trace air currents. These range from injecting some type of smoke into the air stream such as white phosphorus, burning wood, leaves or even tires. Ethanethiol, an air scent tracer producing an “essence of skunk” odor has been used with limited success. But none of these methods has proven to be effective in detecting a cave’s air flow over long distances.

The method described in this paper is simple. It is based on the premise that under certain conditions if two entrances are connected, then mechanically blowing air into (and out of) one entrance will rapidly change the air flow velocity at the other entrance.

The following will show the arrangement of devices, instrumentation and how this premise was determined to be true. All the cave entrance locations discussed in this paper are located in the Burnsville Cove, a significant karst area in the Virginia counties of Bath and Highland. All the large caves in this karst area have strong air flow. It is believed that convection air currents between entrances (or any entry points for outside air) of different elevations is the primary mover of air.

2. Butler Cave –Nicholson and Sofa entrances

Butler Cave has 27 km of passages much of which is large in volume. It has two known entrances. Its Nicholson entrance is located 144 meters to the north and 41 meters higher from its Sofa entrance. The two entrances are separated by about 478 meters of passages generally large in volume (6 m by 15 m) but with many turns and several restrictions (crawlways). The upper Nicholson entrance has an air current consistent with the direction of a convection flow. However the Sofa entrance generally has a neutral or an oscillating air current indicating it is an intermediate (in elevation) entrance and that a lower, presently unknown entrance, exist elsewhere. Figure 1 shows a 480 watt reversing fan (76 cm. diameter) placed in the Sofa entrance (a rectangular opening reduced to the fan’s dimensions). Power was supplied by a generator. A signal is sent from the fan to a recording data logger when the fan changes direction. For redundancy an anemometer is also placed at the fan to record the air flow and direction. Part of the Nicholson entrance is a small opening that allows bats access. The anemometers were placed in this opening during the testing (Figure 2). All anemometers were connected to data loggers and the air velocities recorded at one second intervals.

Figure 1. The rectangular doorway Butler Cave’s Sofa entrance has been sealed around a fan. The fan blows alternately in and out of the cave in even intervals. A signal is sent from the fan to a recording data logger when the fan changes direction.

Figure 2. An ultrasonic anemometer (left) and a mechanial anemometer (right) recording data are located in the bat access hole to measure the rate of air flow.

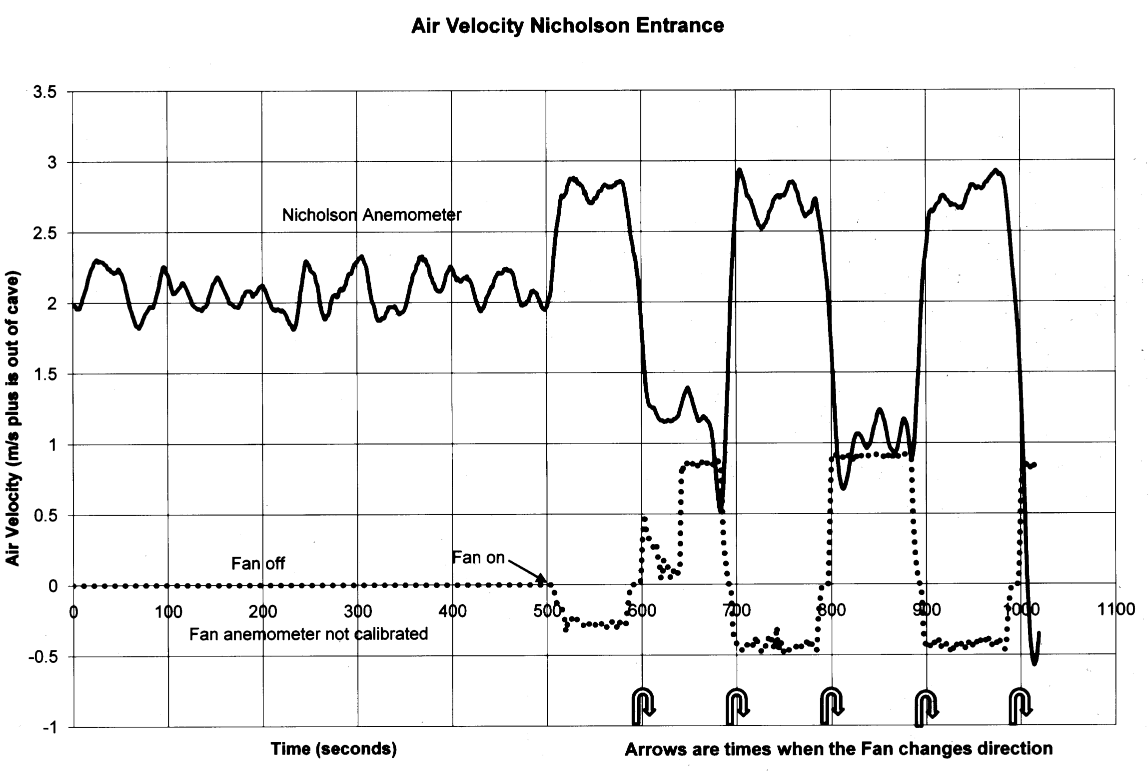

Chart 1. Butler Cave entrances air flow test With the fan placed in the Sofa Entrance and an anemometer placed at the Nicholson Entrance, this chart shows the result of changing air velocities before and during the fan's operation. When the fan begins running for each 100 second interval there is a distinct signal (change in air velocity) measured by the anemometer. At the end of each interval, the fan stops for 9 seconds and begins rotating in the opposite direction.

Chart 1 shows the air velocity at the Nicholson Entrance. It includes a 500 second period before the fan operation (base-line) and the next 500 second period during the fan's operation of alternately blowing in and out of the Sofa Entrance. The measurements are summarized as follows:

- The "base-line" air flow is blowing out from the cave (the direction of a convection air current) but with small variations. These variations are assumed to be caused by small changes in barometric pressure (atmospheric waves). They are referred to as "noise" in this paper. Much of the noise is caused by surface winds and it increases with increasing surface wind speeds.

- With each fan reversal there is a corresponding change in the air velocity at the Nicholson entrance.

- The change in air flow takes place three seconds after the fan is reversed.

Note that during the period of 600 seconds to 650 seconds, the anemometer was being re-aligned. Being out of the main air stream the blades anemometer slowed their rotation and the effect is seen as lower velocities during that 50 seconds.

3. Big Bucks entrance, Buckwheat Cave, Backyard Cave, and Basswood Cave

Barberry Cave about 5.5 km in length has a large passage extending roughly along a small valley trending northeast. Big Bucks Pit, its northern most entrance, is unusual in that it is located in a small building used as an apple shed. The entrance is a 43 meter pit that extends down from the floor of the apple shed. The building is sealed to the top of the pit. The fan was placed in the apple sheds door which provided the same sealed fan attachment as site 1 (Figure 3). There are three cave entrances that lie to the northeast of the Big Bucks Pit entrance, Basswood, Backyard, and Buckwheat.

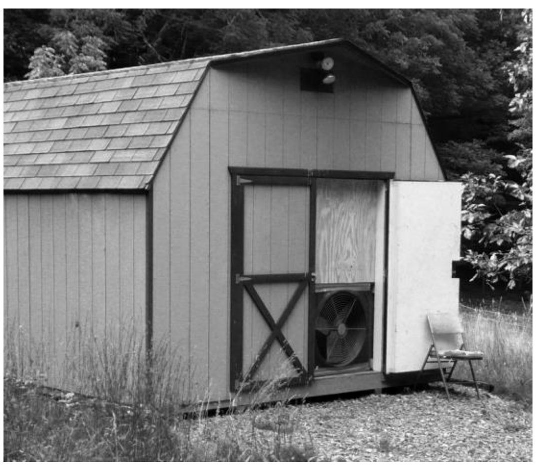

Figure 3. Inside this shed used for apple storage is Big Bucks Pit, a 43 m. drop into Barberry Cave. The pit is sealed to the floor of the building. The door to the building has been reduced to the size of the fan. Accordingly, as the fan blows in and out of the building the air is exchanged in the cave.

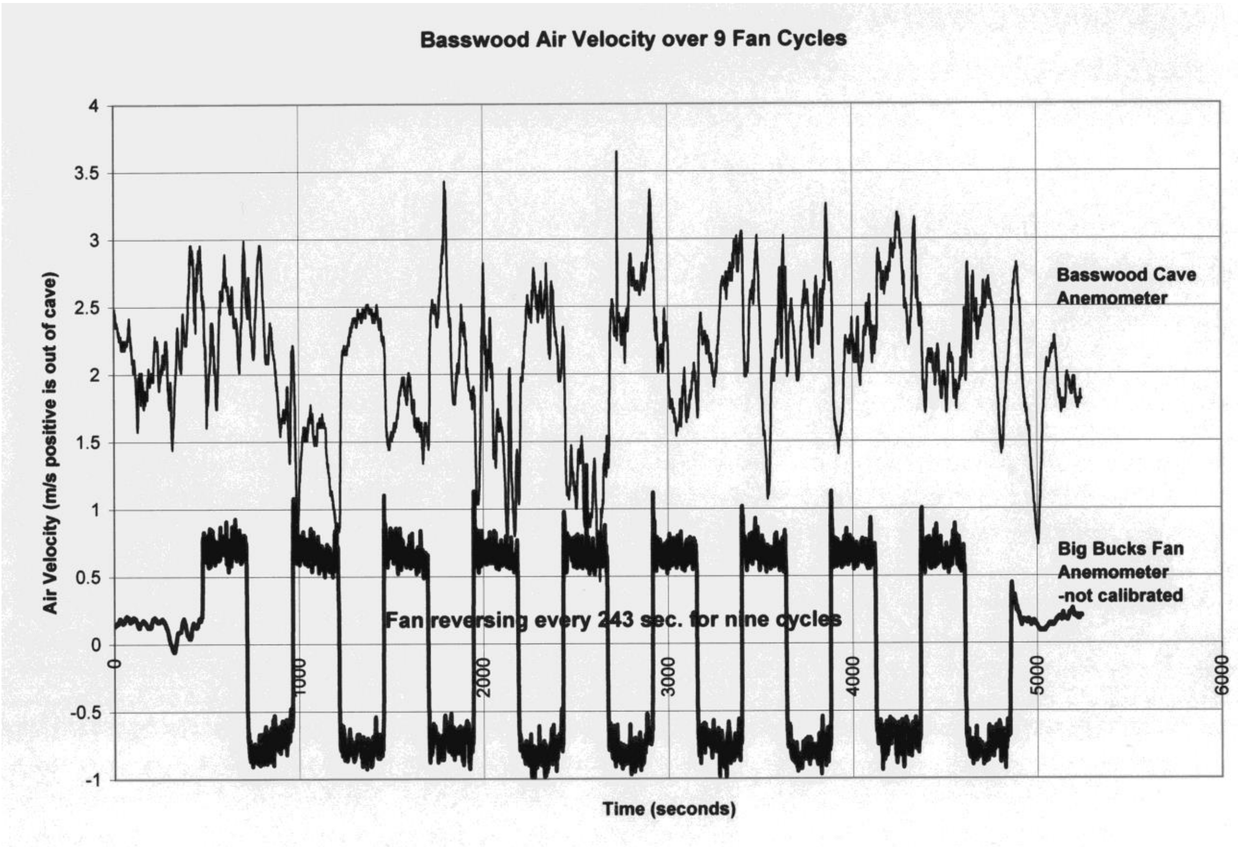

Chart 3. Big Bucks to Basswood Cave air flow test. This shows nine cycles with the fan placed at Big Bucks Pit and anemometer at Basswood Cave. In this instance the signal was much weaker than at Butler Cave entrances.

Figure 4. Cardboard has been placed over the entrance (a vertical culvert pipe) to Basswood Cave. The anemometer placed over a hole in the cardboard records the rate of air flow.

Basswood Cave entrance, a 76 cm. metal culvert, is located just 524 m. northeast of Big Bucks Pit. There is only moderate air flow at the entrance. The cave is formed in upper limestone units above Barberry Cave so a connection to Barberry Cave seemed unlikely. Backyard cave is a 61 cm. metal culvert located 772 m. northeast of Big Bucks Pit. Although it has strong air currents and is in upper limestone units it was not suspected to be connected. The Buckwheat entrance is a 61 cm. metal culvert and is located 773 m. to the northeast of Big Bucks Pit. Prior to this investigation it was suspected that Buckwheat Cave might have some connection to Barberry Cave through an area of breakdown but no human sized opening has been found despite digging.

Chart 3. Big Bucks to Basswood Cave air flow test. This shows nine cycles with the fan placed at Big Bucks Pit and anemometer at Basswood Cave. In this instance the signal was much weaker than at Butler Cave entrances.

The test consisted of anemometers being placed in each of these three cave entrances to record changing air velocities when the fan at Big Bucks Pit was in operation. At Backyard and Buckwheat the anemometers were placed inside the metal culvert entrances that had strong air currents. However at Basswood where air flow was weaker, cardboard was placed on top of the entrance pipe. A small hole in the cardboard accommodating the anemometer concentrated the air flow. Figure 4 shows this arrangement.

Chart 4. Big Bucks to Basswood average. This shows the combined average air velocity for the nine cycles of fan operation compared to the overall average. This calculation produces a clearer signal by cancelling much of the background noise.

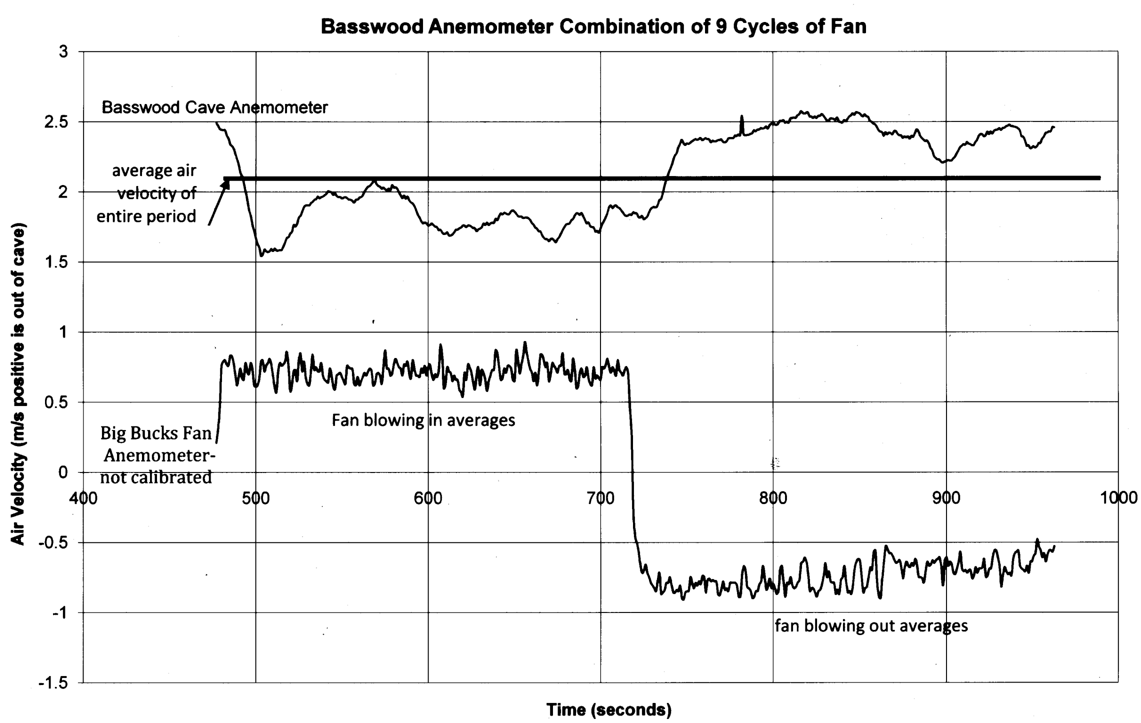

Chart 4. Big Bucks to Basswood average. This shows the combined average air velocity for the nine cycles of fan operation compared to the overall average. This calculation produces a clearer signal by cancelling much of the background noise.

Chart 2 shows the result of an air flow test between Big Bucks and Basswood where the signal is present but being weaker than shown in the Butler entrances test. Shown are nine cycles of the reversing fan operation and the resulting air velocity as measured at the cardboard restriction in the Basswood Cave entrance. Identifying the weaker signal against the background "noise" is still possible with this chart but it demonstrates that weak signals can become buried in the noise. There is a simple mathematical method of supressing the random noise in a signal when the period of the repetitive signal, the fan, is known. If we add the periods together, first second to first second, next second to next second, over all nine periods (in this case), the signal will be enhanced and the noise, being random, will be suppressed. We can make an average out of this by dividing by the number of periods. Chart 3 shows the effect of this method. It shows the nine cycles of the air flow velocity combined to show the maximum effect from any changes from the fan operation. A dark line representing the overall average air velocity for the entire test separates the periods for the fan blowing in each direction. This simple method clearly shows that the velocity is significantly altered from the overall average by the fan's influence and demonstrates the two entrances being connected.

Results of all the air flow tests at these three entrances show that all are connected to Barberry Cave (Big Bucks Pit). Buckwheat's anemometer/logger recorded the strongest signal from the fan's operation at Big Bucks Pit. The delay time was 13 seconds. Backyard Cave had a weak but definite response and had a 13 second delay time. Basswood Cave had a definite response but one that was delayed by 12 seconds. This curious delay might mean that the connection is a long route despite the two entrances being only separated by 524 m.

4. Helictite Cave to Subway

Helictite is a compact maze cave with over 11 km of canyon passages averaging 6 meters high by 2 meters wide. The cave has only one known entrance. At this site the fan was placed directly into the 76 cm. steel culvert entrance to Helictite Cave. The anemometer was placed at an entrance to the Subway (a major section of the Water Sinks Cave). The two entrances are only 159 m. apart but are on opposite sides of a large sinkhole. The air flow testing shows no detectable signal between entrances.

Site 4 Helictite to a blowhole

With the fan placed in the Helictite entrance, an anemometer was placed at a surface blowhole 880 m. to the north. Previously some digging has taken place at the blowhole in an attempt to find a possible cave. As a result of the digging the air flow was coming up through an area of broken loose rock measuring about 4 square meters on one side of the excavation. To concentrate the air flow, a tarp was placed over the loose rock with the anemometer placed in a small hole cut in the tarp (Figure 5). The result of this test shows a connection exists between Helictite Cave and the blowhole. The effect at the blowhole was slight and delayed by 40 seconds.

Figure 5. A tarp was fastened to one side of an excavation to cover an area where air was passing through a zone of rocks. Cardboard was taped to the tarp to provide a rigid surface and a hole was cut in the cardboard and tarp. An anemometer was placed in this hole where the air flow was then concentrated.

An interesting observation was made during the Helictite tests. A strong outflow of air would follow after the fan had been blowing into the cave for a ten minute period. Even though the entrance displays a convection air flow, the fan's operation was enough to create increased pressure within the cave that it far exceeded the outflow for the convection air flow.

5. Conclusion

The results from these tests vary from strong changes in air flow to weak changes or no detectable changes. The time it took for the effect to occur changed from just a few seconds to nearly 30 seconds. As this method of testing was being developed and preliminary testing was performed, it was apparent that testing done on windy days was not satisfactory. Gusty winds over hills and ridges create many pulses that tend to be amplified at entrances and this "noise" overwhelmed the signal the fan introduces. Also the clearest signals were obtained when the outside temperatures and cave temperatures are close to each other thereby creating only weak convection currents. All of the caves tested with possibly one exception are thought to have convection as the primary energy driving the air flow. Helictite Cave's airflow might have a strong barometric component as determined by another test (not described in this paper). Accordingly additional testing using this method between barometric caves entrances will be interesting. Although, these tests reveals a connection between some cave entrances it does not provide information about the nature of the connection or its location. It does not say whether this connection is humanly traversable. The different time delays suggest that some connections are more distant, longer in length or more restricting than others but a more examination of this is needed. This testing requires some preparation of the placement of the equipment, fan, and anemometer/loggers along with a power source. But the outcome can provide a valuable insight about the relationship of caves in a karst area. This method of air tracing is certainly less polluting to the cave than past methods.

Instrumentation and equipment used

1. One 10.16 cm wind run meter modified to act as an optically detected bidirectional anemometer with associated electronics. Startup wind speed 0.27 m/s and a maximum wind speed in or out of 4 m/s.

2. Four 10.16 cm optically detected bidirectional anemometer with associated electronics. Startup wind speed 0.36 m/s and a maximum wind speed in or out of 4 m/s. This instrument was designed and constructed by the authors.

3. One 480 watt 5 blade fan (76 cm. diameter) modified to reverse direction every 65sec, 100sec. or 200sec. which includes a 9 sec. off period while reversing.

4. Five HOBO U12 4-Channel Data Loggers

5. One ultrasonic bidirectional anemometer with associated electronics. The anemometer is able to measure wind speed as low as 0.045m/s with no practical limit on the high end. The output is recorded on two channels of a data logger. The math necessary to calculate a wind velocity is preformed in an Excel Spreadsheet. This instrument was designed and constructed by an author.