Flue Pipe Acoustics

(The Physics behind the Sound of Flutes, Organ Pipes and Whistles)

Richard J. Weisenberger

Between 1974-1978 I was doing independent research on the effects of cutup (the cutup is the height of a pipe's mouth—the distance between the lower and upper lip).and scaling on flue organ pipes as to the effect on operating pressure and acoustical output.

Organ Pipes

I found there were direct correlations among these parameters; the operating pressure being directly related to the square of the change in cutup ratio if the scaling is held constant and the operating pressure likewise being directly related to the square of the change in scaling if the cutup ratio is held constant.

Also, the acoustical output power of any pipe, prior to overblowing, is directly related to the fourth power of the change in cutup ratio with a pipe of a given scale and also directly related to the fourth power of the change in scale with a pipe of a given cutup ratio.

Thus, doubling the cutup of a pipe would result in one which would require four times the operating pressure and produce 16 times the output (a 12 dB increase), prior to the onset of overblowing (provided that the mouth area did not exceed the pipe's cross-sectional area). The same holds true if doubling the scaling of a pipe with a given cutup ratio.

I had thus discovered a kind of "Ohm's Law" for flue pipe design, which produced easily verifiable and highly repeatable results. A basic knowledge of the physics involved in flue pipe design is the basis for any further scientific investigation in the field of flue pipe acoustics necessary to relate cause with effect. This was an important first step, as it enabled me to be able to accurately predict the operating pressure and acoustical output capability of virtually any pipe design using open toed voicing.

Of course, coning in the toes will increase the operating pressure and reduce the output of ANY pipe at a given operating pressure.

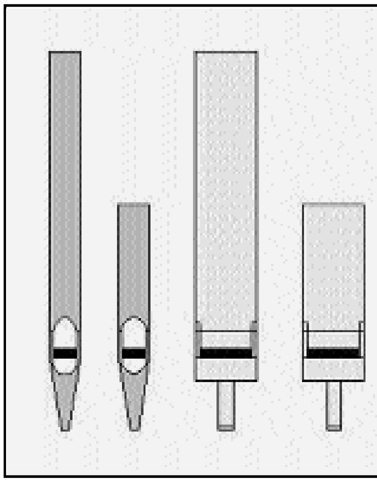

Figure 1. Stopped pipes will require exactly 1/2 the working length, using the same cutups, to produce equal output to their open counterparts at a given operating pressure in terms of both frequency and acoustical power. Their differences lie in their lack of even order harmonic radiation

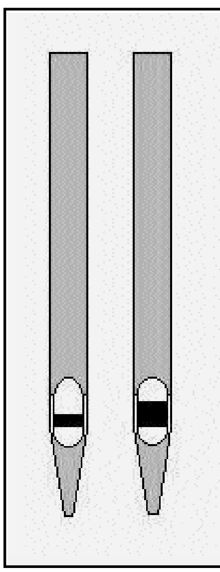

Figure 2. The effect of the cutup on a pipe's performance is very dramatic. The operating pressure will relate to the SQUARE of the change in the cutup and the acoustical power output will be related to the 4th power of the change in the cutup, all other factors being equal.

As an example, provided that the mouth area does not exceed the pipe's cross-sectional area, doubling the cutup will QUADRUPLE the pipe's operating pressure, prior to the onset of overblowing! The increase in output will be 12dB, which is a full 16 times the output of the pipe of lower cutup!

In addition, the air flow to the doubled cutup pipe will also be doubled and the blower power required will eight times that of the lower cutup pipe. Since the higher cutup pipe produces 16 times the output using eight times the blower power, its efficiency is double that of the former.

Steam Calliope Whistles

The next step was to use these formulas to design everything ranging from the softest flutes to whistles which resembled those on the old steam locomotives. The result was that it was possible to design whistles of high output which did not require the customary high pressures found on steam locomotives and steamboat calliopes. I was able to design whistles which resembled steam calliope whistles which would produce outputs as high as 110 dB at 100 ft (140 dB at 1 meter) operating on as little as 15 PSI, rather than the usual 150 PSI.

I found that the acoustical output of a whistle is much more dependent upon the flow rate rather than the actual operating pressure, thus if you use a relatively large air slot width of 1/16" and large diameter inlet, whose area exceeds the slot area, you could get the required flow rate at relatively low pressure. Thus, the operating efficiency of a whistle could be greatly increased over that of the traditional high pressure steam whistle. Also, you gain nothing by making the mouth area larger than the whistle's cross-sectional area other than allow high pressure operation without overblowing. You do not get more output.

It makes sense! The whistles designed to be used on locomotives and steamboats HAD to be designed to accommodate the high pressures, since the engines required high pressure in order to be able to produce a useful amount of output. The whistles did not, but would overblow unless they were designed to accommodate the high pressure.

This led to the next stage. How would one go about increasing the output capability of a whistle beyond that of traditional steam whistle designs? It's true that an output of 110 dB at 100 ft. (140 dB at 1 meter) is nothing to sneeze at, but there are mechanical sirens used for warning communities with outputs as high as 135 dB at 100 ft. How would one design a whistle to compete with a siren in terms of overall output and efficiency?

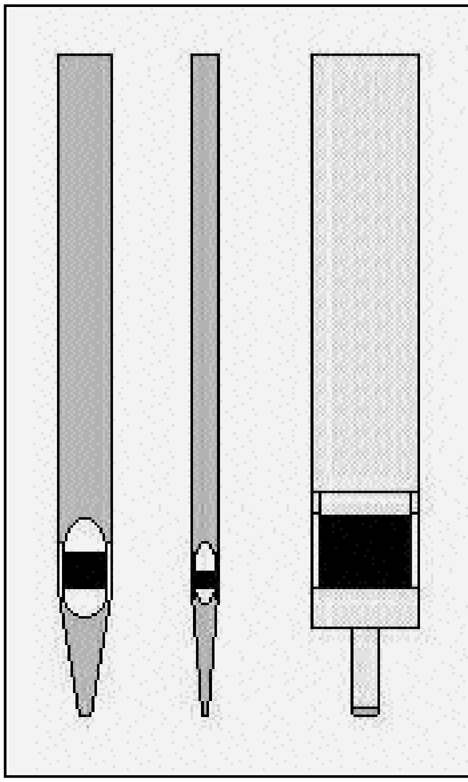

Figure 3. The dramatic effect of pipe scales have long ben known to organ builders. Of course the larger scales are capable of much greater outputs when using the same cutup RATIOS, as the larger scales permit much greater cutup HEIGHTS, without the mouth area exceeding the pipe's cross-sectional area.

With the cutup RATIO being constant (as is often the case) the acoustical power output will be related to the 4th power of the change in the scale of the pipe.

As an example, each time a pipe's scale (with a given cutup ratio) is doubled, the pipe's output will be increased by 12 dB or 16 times! To keep the smaller scales from overblowing at a given pressure, the toe hole areas are reduced to restrict the air flow.

As is always the case, the larger scales will produce the mellower tones, regardless of the cutup.

Toroidal Whistle

This led to my designing the toroidal whistle. Think of a Toroidal whistle as a large phased array of about 30 high output steam whistles all sounding the same frequency. It looked good in theory and when the prototype was tested I achieved an incredible output of 125 dB at 100 ft. (155 dB at 1 meter)! The whistle was about the size and shape of a small automobile tire, required 1,800 CFM at a low 15 PSI and produced 430 Hz at an awesome level. The test was performed in a remote corner of the Greater Cincinnati International Airport in July of 1982. The tests were audible over parts of Erlanger, Florence, Hebron, Elsmere and Ft. Mitchell, KY as well as in Delhi, OH.

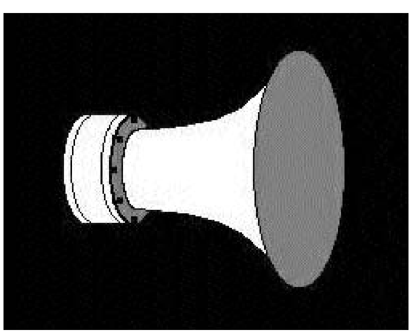

Figure 4. The Toroidal whistle.

I found that because most of the whistle's output was at fundamental frequency, rather than in the harmonics, there was not as much loss due to atmospheric absorption as in a siren of equal near field dB rating. We were still producing a level of 76 dB at a distance of 2 miles on axis from the test site! A siren rated at 125 dB at 100 ft. has a typical 70 dB radius of only 4500 ft. This design resulted in U.S. Patent #4,429,656, which can be searched by number on the IBM Patent Server website.

Still, this design was a full 10 dB short of that of the loudest warning sirens.

The next step was to design a Toroidal whistle specifically to operate in the manner of a compression driver in a horn loaded speaker. With all of the output of a Toroidal whistle driving a suitable horn, an output to equal that of the loudest warning siren was no longer out of the question.

This resulted in U.S. Patent #4,686,928, which can be searched by number on the IBM Patent Server website.

In this design, an INVERTED Toroidal whistle is used to drive a horn with a directivity index of 13 dB or so. Since an inverted toroidal whistle is blown from the INNER edge, rather than from the outer edge of the toroid, as is the case in the earlier patent, this design uses 25% less air flow and due to horn loading, produces an extra 10 dB on axis (135 dB at 100 ft). Thus a 420 Hz whistle of this type will use only 1,350 CFM at 15 PSI. Under ideal conditions the 70 dB radius of a 420 Hz whistle of this type will extend up to 4 miles!

Since the air can be furnished by a 100 HP single stage rotary screw compressor, this is more coverage/HP than the best siren available.

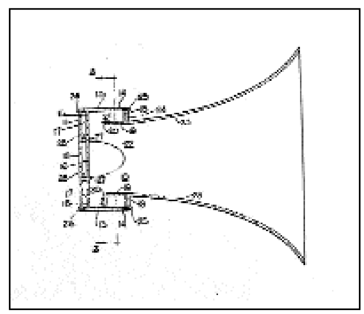

Figure 4. The patent drawing of the Toroidal whistle. The abstract reads: *A single-tone inverted toroidal whistle for producing a uni-directional output of about 135 decibels at 100 feet on axis at a frequency of about 420 hertz. A hollow cylinder having a closed base end is combined with a toroidal body to provide an annular sound chamber the working length of which determines the wavelength of sound generated by passage of air or steam under pressure through an annular slit formed in the interior of the cylinder and impinging against a spaced tapered lip on the inner cylindrical wall of the toroidal body.*

Except for the extreme sound level, the sound is very similar to that of a standard cylindrical calliope whistle, or even that of a stopped flute. With this accomplishment it is time the Guinness record for the world's loudest musical performance is taken away from the rock concert circuit and restored to an all acoustical instrument.

My intention is not to deafen anyone, as I would not advocate such an instrument as my proposed Dynawhistle calliope in a stadium crowed with people, but in an inaccesable spot such as atop a bridge pier or similar structure, or on a bluff overlooking a city, where the sound reaching the people would be at a reasonable level. The best distance to hear such an instrument would be from 0.5 to 2.0 miles (with an audible range extending to 20 miles or so).

C:\WINDOWS\Desktop\Weisenberger Stuff\Flue Pipes Acoustics.htm
or http://home.switchboard.com/fluepipeacoustics

Richard Weisenberger has been granted several patents on flue organ pipes and whistles. He received his degree in electronics and is currently a TV broadcast engineer. He has written for the ATOS journal, *Theatre Organ*, and has published the journal of the Air Horn and Steam Whistle Enthusiasts, *Horn and Whistle* from 1988 through 1994.