A STUDY OF LOCOMOTIVE WHISTLES.

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Some two years ago the writer was employed by a railroad company to make a study of the whistle, bell and headlight of one of the company's locomotives that had killed a score of children in a school hack at a road crossing. The driver had stopped, looked, and listened. Apparently he had not seen or heard. Why?

It is not my intention to try to answer the question why in this paper. It *is* my purpose, however, to call attention to several ways in which my experiments indicate that the efficiency of locomotive whistles may be, and should be, improved.

In the first place, the location of the whistle is bad, usually about as bad as could be found unless it were placed inside the cab or underneath the locomotive. It is always placed behind the smoke stack, usually behind one or more domes and the bell, and frequently immediately behind or at the side of pop-off valves, or other accessories mounted on the top of the boiler. All of us know that if we wish to shout to some one at a considerable distance that we turn toward the listener so that the sound will be projected initially in that direction. All of us know that we can be heard at a greater distance if we do not stand behind a lamp post or a tree when we shout. All of us know that the roar of an aeroplane engine as it passes over us comes and goes, sometimes being very loud and sometimes barely audible, and that the variation in the sound intensity is due to the varying air currents and temperature strata through which the sound must pass to reach the ear. Notwithstanding all this, we continue to locate locomotive whistles from the standpoint of convenience only, with no thought of a possible connection between the whistle's location and its efficiency in doing the only thing it is expected to do—to make as much noise as possible along the track ahead of the locomotive, and as little as possible in directions where it is not only not needed but is usually a nuisance.

When the whistle is placed behind the smoke stack, dome, etc., all these objects reflect the energy of the portion of the sound wave that falls upon them. Since a sound wave is long compared to a light wave, the sound shadows thus produced are not comparable in density or definiteness to the light shadows that would result were the whistle replaced by the head light. Nevertheless, there are sound shadows of more or less intensity, depending on the size of the object casting them and on its distance from the sound source; in other words, depending on the solid angle of the object as seen from the sound source. Where the distance is small and the angle large, as when a whistle is mounted very near a dome or an escape valve—(immediately behind or at one side in some recent practice) the intensity of the sound ahead of the locomotive is decreased and at the side or rear increased over what it would be were the whistle mounted in front of the smoke stack.

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That this effect is not of negligible import is proven by the following observations:

In figure 1 the ten points on the broken line curve give the relative intensity of sound as measured with a Rayleigh disk in the ten indicated directions from the whistle or of a locomotive L standing on the track T T. On the first day the observations were attempted a Webster phonometer was used to measure the sound intensity. On account of the extreme sensitiveness of this instrument to small changes of pitch it was not satisfactory for the work in hand. It was therefore with little regret that the writer was forced to discontinue his experiments

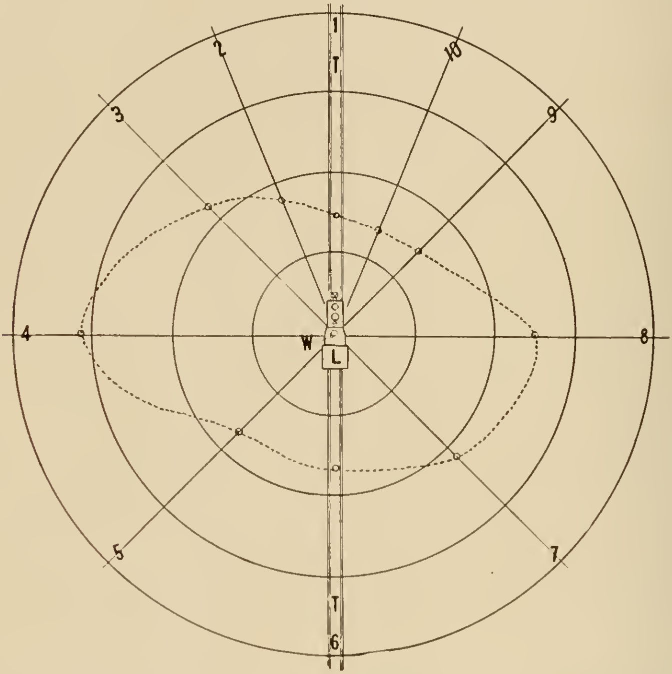

Fig. 1. Sound intensity about a locomotive whistle. 1-10 are the ten points of measurements; L the locomotive; W the location of the whistle; TT the track.

that day on the demand of some one to whom the noise of the whistle was objectionable.

Before undertaking the experiment a second time the writer experimented on different forms of Rayleigh disks. The instrument in the form finally chosen is less sensitive than a tuned Webster phonometer, but has a much wider range through which the pitch of the sound may change without seriously affecting the instrument's sensitivity.

The intensities shown in figure 1 were measured in the ten directions shown, at a uniform distance of 1200 feet from the whistle. Instead of moving the observing station the locomotive was placed on a turn table and the observing station located permanently at the side of the track 1200 feet from the turn table. Then the locomotive was successively turned so that the relative direction of the observing station was that indicated by the several radii in figure 1.

Even had it been possible to move the Rayleigh disk and adjust it to the same sensitivity in all ten positions, and had the time required been no consideration, the scheme of turning the locomotive had many advantages. It minimized, by making more nearly constant the disturbing effects of winds, temperature changes and differences, the varying topography of the surrounding landscape, and reflections from houses, trees, and other objects.

The curve in figure 1 shows that the intensity of the sound from the whistle at right angles to the track was double the intensity along

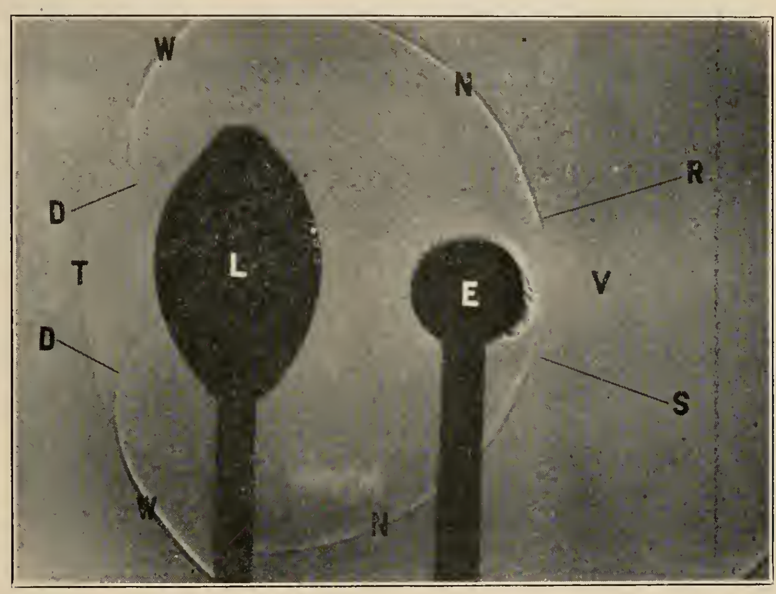

Fig. 2. Sound wave generated by an electric spark, showing reflection, refraction, diffraction and absorption.

the track. The general contour of the curve is about what one should expect from a whistle located as this one was, to the side and rear of, and only four inches from, a steam dome several times as large as the whistle itself. However, the shape of the curve was not determined wholly by reflection. Several other factors contributed to its variation from a circle with the whistle at the center. One of these is that in the case of a whistle located toward the rear of a locomotive boiler the portion of the sound waves that start forward in the direction of the track must pass through the hot air currents arising from the boiler and the hot gases and smoke from the smoke stack. There is consequently more or less energy absorption, reflection and refraction. Indeed, the cylindrical stream of hot gases from the stack is essentially a sound dispersing lens. The sound energy in the shadow of such a lens is less than it would be were the stream of hot gases replaced by a solid cylinder of the same size.

Figure 2 is a picture of a sound wave generated by an electric spark E between two opaque circular disks. W is a portion of the original wave, N of the wave reflected from the near surface of the lens, and T the wave transmitted by the lens L. D and D are portions of the wave diffracted about the edges of the lens into the geometrical shadow. Note that the conditions are entirely different in the region V, apparently almost a sound void. The hot gases due to the passage of the spark absorb the energy in the region V and refraction by the outer

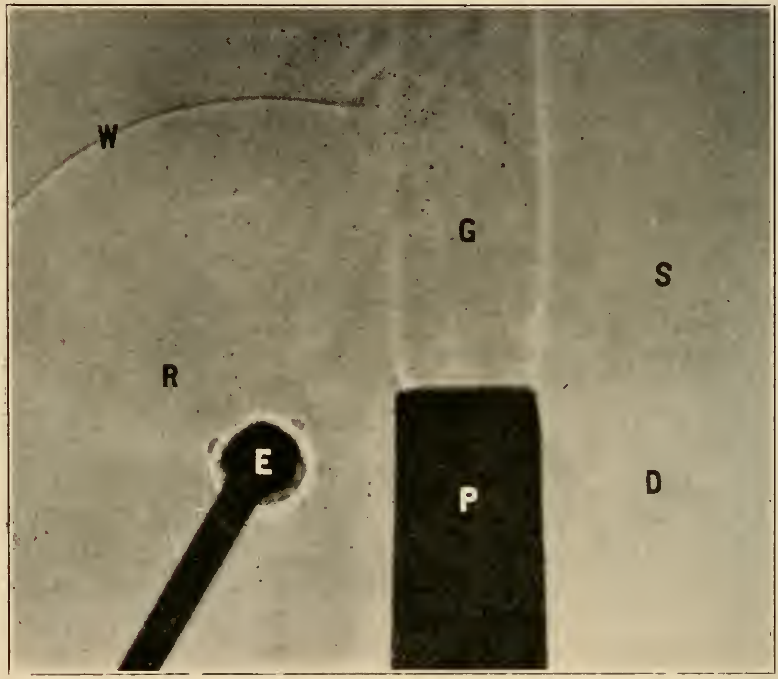

Fig. 3. Sound wave absorption and refraction by a stream of hot gases.

portions of the hot gas region causes the wave to move in the directions R and S, a dispersing effect. Thus normal diffraction into the region V is, to a certain extent, prevented.

In figure 3, G is a stream of hot gases issuing from a vertical cylindrical pipe P, about an inch in diameter and two feet long. The hot gases came from the flame of a Bunsen burner just below the lower end of the pipe. An electric spark E behind the disk produced the sound wave W. R is the wave reflected from the surface of the pipe, D the wave diffracted about the pipe, and S the refracted wave (R and S in figure 2) in advance of the others and therefore undergoing dispersion. When the locomotive is moving rapidly the hot gases form a sort of blanket over the locomotive which still further absorbs and disperses the sound waves produced by the whistle below.

Another factor which had to do with the sound distribution shown in figure 1 is the design of the whistle itself. The usual cylindrical tube forming the resonator (bell) of a single tone whistle is, in the case of the chime whistle used in this study, divided by longitudinal radial vanes into five compartments or pipes, each of the proper length to give one of the notes of the chime, viz, C, E, G, C′ and C″. T in figure 4 is a transverse section of the whistle and L a longitudinal section, with the omission of the valve mechanism at V. The former shows the relative positions and cross sectional areas of the five pipes while the longitudinal section shows the relative lengths of two of the pipes—C and its octave C′. The fraction of the cylindrical steam jet J used in blowing each of the pipes is shown in the transverse section T, and was 26 per cent in the case of the lower tone C, and respectively 22, 19, 17, and 16 per cent for the other four tones. Thus 60 per cent more energy was used in blowing the lower tone than in blowing the upper tone of this whistle. Since the quality or character of a sound depends on the relative intensity of the several tones which combine to form it, it is evident that the quality of the sound from a chime whistle depends to a degree upon which pipe of the whistle is toward the observer. This variation with direction is accentuated when the whistle is placed very near a steam dome, which interferes more or less with the normal functioning of that part of the whistle which happens to be nearest it. Inasmuch as the Rayleigh disk was not equally sensitive to all five tones of the chime, intensity measurements made with the disk showed considerable variation whenever there was a change in the orientation of the whistle with respect to the dome.

The writer would locate a locomotive whistle in front of the locomotive where it would be free from the several disturbing factors named. He would place it in a reflector of such design as to give a maximum of sound intensity ahead of the locomotive and of such size as to serve as a resonator and thus increase the intensity of the sound at the source.

In advocating the use of a reflector to direct the sound of the whistle along the track the writer has continually met with the argument that such a device would be practically useless on account of the fact that the reflector could not be made large compared to the length of the sound waves to be reflected. This limitation does, of course, affect profoundly the rate at which sound wave energy spreads out after the waves are outside the reflector. But it does not change the action of the reflector itself. The energy of the reflected portion of the sound wave can be headed in the right direction, and much of it will continue in the right direction to reinforce the wave originally projected in that direction. In proof of this assertion it is sufficient to call attention to the effectiveness of a megaphone as a sound director. We should expect a relatively greater directive action from a reflector placed about a whistle. In the case of the voice the waves are originally projected in one hemisphere only, the whistle starts them in both hemispheres. The whistle reflector reflects a portion of the waves in the one hemisphere, as does the megaphone; but in addition it turns back those that start in the other hemisphere.

To determine whether or not a reflector of moderate size could be made to exert any considerable directive force on the sound from a locomotive whistle, the chime whistle previously described in this paper was placed in a parabolic reflector, as shown in cross section in figure 4, in which all dimensions are to the same scale. The whistle was 6.5 inches in diameter and the aperture of the reflector 28 inches. The reflector was made of plaster paris P cast in a wooden box B. Wooden strips S were nailed in the box in the manner indicated in the drawing to economize on plaster and lessen the weight. The box was mounted on

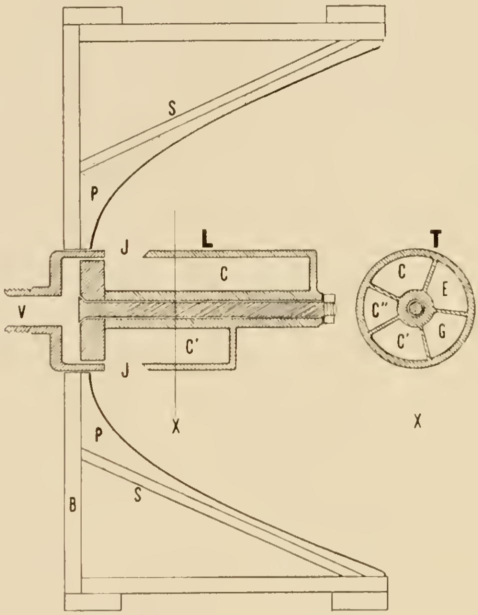

Fig. 4. Transverse section of a locomotive chime whistle, and a longitudinal section of whistle mounted in a modified parabolic reflector. See text for explanation.

castors so that it could be turned on a platform about six feet in diameter and eight feet high. The steam line projected vertically through a hole in the center of the platform and was connected with a union joint to the valve end V of the whistle. This permitted the reflector and whistle to be rotated so that their common axis was in any desired horizontal direction.

The shape of the plaster paris surface of the reflector was obtained as follows: with a focal point on one edge of a board and the edge the axis of a parabola, a curve was drawn on the board and the half parabola sawed out. With the board radial and its straight edge held against the whistle the board was moved around the whistle and the soft plaster paris "wiped" into position. The focus of such a reflector, if the term focus is permissible, is therefore a circle, and not a point. The focus of any particular portion of the parabolic surface is the nearest point on the focal circle. This focal circle was intended to be coincident with the cylindrical sound source—the cylindrical steam jet, at J, J. The length of the steam jet (the distance from the opening to the lip) was two inches. There is a question as to what portion of the jet should be used, or whether some point beyond the lip should be used, as a focal point in adjusting the whistle in the reflector. Experiments were made with the whistle in one position only, quite likely

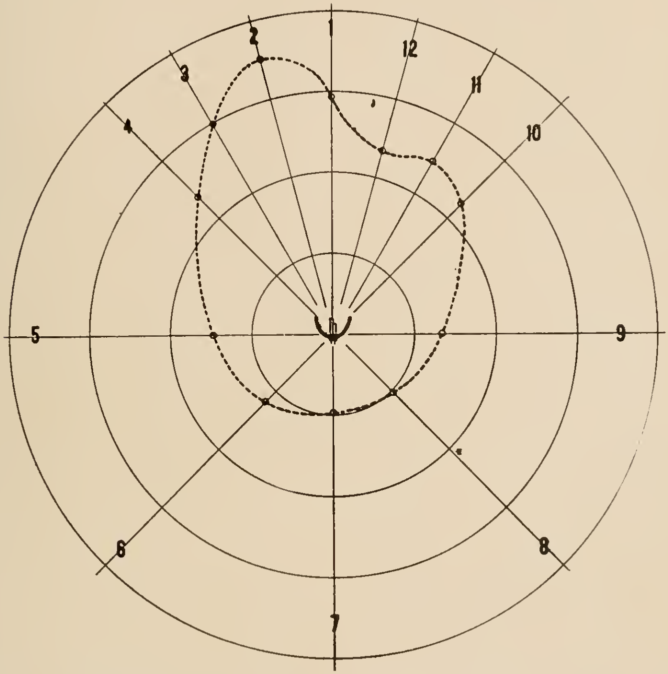

Fig. 5. Sound intensity about a locomotive whistle mounted in a modified parabolic reflector.

not the position to give the reflector the highest possible efficiency. Nevertheless, the action of the reflector was quite marked.

The curve in figure 5 gives the relative intensity of the sound in the 12 directions indicated by the radial lines. The dissymmetry of the curve with respect to the axis in direction 1 is doubtless due to the fact shown in the figure that the whistle was so placed in the reflector that the lower pitched and louder tone was produced on the side of the axis toward direction 2, while the higher and less intense tone was produced on the other side of the axis, in direction 12. Notwithstanding this dissymmetry the curve clearly shows a sound intensity in the direction of the axis of the reflector double that at right angles to the axis and three times that to the rear.

Comparing the result shown in figure 5 with that shown in figure 1, it is seen that, by placing a locomotive whistle in a reflector in front of the smoke stack the intensity of sound along the track in front of the locomotive was increased to four times its value when the whistle was located in the position (W) shown in figure 1. In direction 2 the intensity was five times as great. At the same time the intensity at right angles to the locomotive was correspondingly decreased. The maximum intensity could have been changed from direction 2 to 1 by rotating the whistle in the reflector. No doubt the multiplying factor could be further increased by using a single tone whistle instead of a chime whistle, and by making the reflecting surface of a material having a higher reflection coefficient than plaster paris. In fact, the writer has made the experiment and will publish his results in a later paper, along with the results of his experiments on other phases of the whistle problem.

The placing of a locomotive whistle inside a reflector with its longitudinal axis parallel to the axis of the reflector has advantages other than those already noted. One is, that all parts of the circular steam jet function, which is not the case when the whistle is mounted vertically and the locomotive is running at high speed. This point was investigated by placing a locomotive whistle in a stream of air from a compressor capable of delivering 4,000 cubic feet of air per minute at a pressure of 100 pounds to the square inch. The stream of air was adjusted to give air velocity at the whistle of 20, 40, and 60 miles per hour. Very little effect was noticed at 20 miles per hour. At 40 miles per hour the front portion of the whistle (the part against which the air current was directed) functioned rather poorly, the volume of the sound being considerably less than at 20 miles per hour. At 60 miles per hour it did not function at all, nothing but the hissing sound of escaping steam coming from this portion of the whistle. As the whistle was rotated the character or quality of the sound changed noticeably as one after another of the several tones of the chime was silenced. The steam jet whose vibrations about the lip of the whistle produce the sound, must strike that lip in a particular way to give the best result. When a locomotive is running at high speed the head on pressure and the air currents about the sides of the whistle deflect the steam jet so that some portions of it function poorly and others not at all. When the whistle is inside a reflector the body of air about it is carried along with it and the pressure is uniform on all sides of the jet. This permits it to function normally at all speeds.

All the information the writer has been able to get from psychologists and others is to the effect that the average human ear is more sensitive to sounds of from 1,000 to 1,200 vibrations per second than to those of lower frequency. It would appear, therefore, that most locomotive whistles are from one to two octaves too low in pitch. Raising the pitch would mean smaller whistles, smaller reflectors, less steam consumption, and slightly less diffraction loss.

It would seem that the cost of whistle blowing is an item that has been given little attention. A little consideration will convince one that we "pay dearly for the whistle".

According to the company that manufactured it, the chime whistle used in this investigation—a regular locomotive whistle—requires about 8,352 pounds of steam per hour when blown at 200 pounds steam pressure. Locomotive manufacturers say that seven pounds of steam per pound of coal is good average locomotive practice. This means a coal consumption of 1,190 pounds of coal per hour, more than 18 pounds per minute, approximately one pound of coal for every three seconds, or two pounds for every time the whistle is blown—the series of blasts for any signal aggregating, on the average, about six seconds.

Observations are still in progress on the question of the fraction of the time the whistles are blown. Considerable variation has been found for different engine crews and different railway lines. So far the average runs about two minutes per hour. Assuming this figure, a locomotive equipped with such a whistle and operating it at the indicated pressure requires some 36 pounds of coal and 140 pounds of water per hour for whistling purposes only.

There are in the United States, on Class A railroads alone, some 65,000 locomotives. Investigation is still in progress as to the actual number in service at any one time. It is certain, however, that the cost of blowing locomotive whistles runs into the millions per year and that a considerable saving would be effected if a smaller whistle could be substituted without sacrificing anything from the standpoint of the efficiency of the sound as a warning signal. The experiments herein described warrant the conclusion that this change can be made and the whistle's signalling efficiency increased at the same time.

It is a matter of common observation that locomotive whistles on different roads, and frequently on the same road, differ greatly in pitch and in quality. When one hears a whistle, frequently he can not tell whether it is a locomotive whistle or a factory whistle. He becomes so accustomed to hearing such sounds that they may call forth no mental reaction whatever. If all locomotive and traction car whistles were of one pitch and others were prohibited from using whistles of that or near that pitch, the human ear would soon come to recognize that tone and instinctively associate it with danger. Not only this, but the volume of sound required to produce a mental stimulus would be greatly lessened. The writer advocates a legal standard pitch for all locomotives and traction car whistles, and legislation that will guarantee railway companies its exclusive use.

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