

JANUARY 01 1965

Refraction of Sound from a Point Source Placed in an Air Jet



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J. Acoust. Soc. Am. 37, 168–170 (1965)

<https://doi.org/10.1121/1.1909297>



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Procedure. The procedure replicated exactly that of the low-level group of Wernick and Tobias, omitting the control conditions in which no fatigue stimulus was presented during the task. Half of the subjects received MA first and the remainder received REV first. The two trials were separated by 48 h, and the first trial was preceded by several practice threshold determinations. A 3-min rest period followed a 2-min Békésy-type threshold determination for the test tone, after which the fatiguing stimulus was presented for 3 min. A 3-min continuous threshold determination at the fatigue-tone frequency was made immediately following the cessation of the fatigue tone.

The test tone was a 4000-cps pulsed tone (0.2 sec on, 0.2 sec off); the fatigue tone was a 4000-cps continuous tone presented at a sensation level of 40 dB.

The instructions given in the original study¹ were used here and comprised directions for activity during the fatigue stimulus. A subject was instructed either (1) to relax and follow no train of thought or (2) to work a mental arithmetic problem involving continuous division with a constant divisor. A light in the subject room provided the signal for the beginning of the fatigue period during which the subject performed as previously instructed. The experimenter turned off the light to signal the subject to start establishing his postfatigue threshold.

Results. Figure 2 shows the course of recovery from auditory

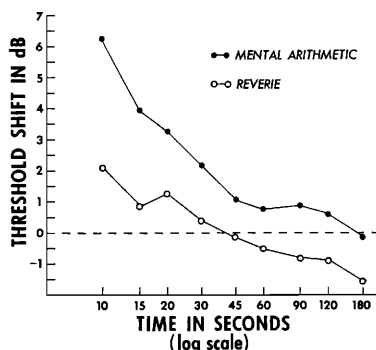


FIG. 2. Mean temporary threshold shift for 10 subjects as a function of instructions regarding mental activity. Subjects were either in "reverie" or performing continuous mental division during exposure to the fatiguing tone.

fatigue for each of the two conditions. It is clear that exposure to the fatigue tone while the subjects were doing MA consistently produced greater TTS than exposure to the tone during REV. The mean TTS 10 sec after cessation of the fatigue tone was 6.25 dB (standard deviation = 3.14) for MA and 2.15 dB (standard deviation = 2.73) for REV, giving a difference of 4.10 dB favoring MA. A *t* test for correlated observations⁷ conducted on the individual differences in TTS between MA and REV at the 10-sec point, yielded a *t* value of 6.16 with 9 deg of freedom, significant at the 0.001 level. All of the subjects tested, including seven who did not participate in the formal experiment but only in pilot studies and such, showed a greater shift for the MA condition.

In addition to the difference in TTS between the two conditions, a longer recovery time for MA seems to be indicated by the curves of Fig. 2.

Discussion. Some possible explanations may be offered to account for the failure of other investigators to obtain these results. Ward and Sweet² used a task involving the adding of columns of figures and failed to obtain a "mental task-reverie" difference under high-level (100 dB SPL) fatigue conditions. Barring the influence of some unknown procedural differences, it is possible that the task employed by Ward and Sweet was simply not so effective as the mental-arithmetic condition used here and in the Wernick and Tobias study. Work in progress indicates that written computational tasks may not have the same effect on auditory fatigue that continuous mental division does.

Similarly, Bell and Stern⁴ used written arithmetic problems (long division) instead of the continuous division task and added a light-tracking task as an additional condition. They compared the TTS obtained with these two tasks to that obtained under reverie with both a high-level (100 dB SPL) and a low-level (50 dB SPL) fatiguing tone and reported no significant differences between the task and reverie conditions. Their data do show, however, that the TTS was greater for the long-division task than for reverie at both low and high levels in the first trials. That the differences obtained on the first set of trials were not greater and that they were not maintained with repeated trials might result from (1) differences in the effectiveness of written long division and mental arithmetic and (2) the fact that some tasks may lose their arousal value with repeated use.⁶

The Riach and Sheposh³ study reported a replication of the Wernick and Tobias procedure but failed to obtain MA-REV differences in TTS with either high- or low-level fatigue. If the mean TTS obtained under the REV condition in the present study and in those of Wernick and Tobias and of Bell and Stern may be used as a criterion, it would appear that Riach and Sheposh did not have appropriate REV conditions. They report a mean 10-sec TTS of about 9 dB for both MA and REV with low-level fatigue. The range of mean REV TTS values at similar levels in the other three studies was 2.1–4.3 dB.

Conclusions. The possibility of a central influence on auditory fatigue cannot be discounted on the grounds that the data result from chance variation. The choice of "mental task" and the instructions for "reverie" appear to be primary considerations in experiments designed to study differences in TTS as a function of mental activity.

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Refraction of Sound from a Point Source Placed in an Air Jet

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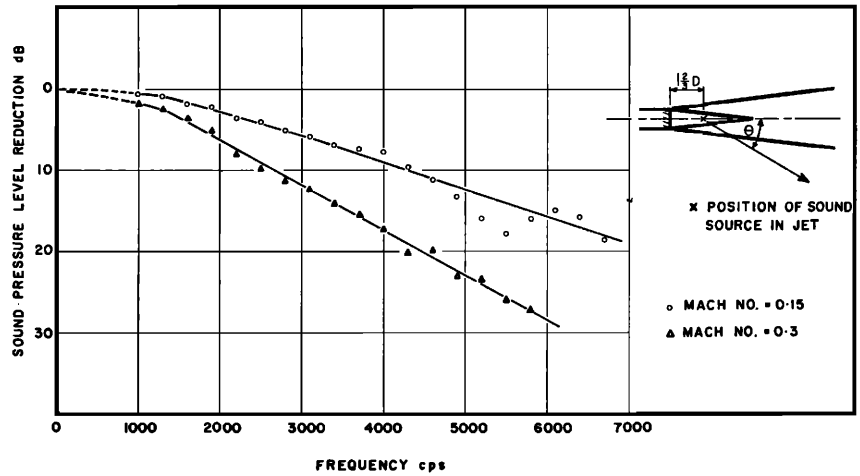
(Received 24 August 1964)

A harmonic point source of sound was placed within the potential core of an air jet and the distortion of its sound field by the jet flow was measured. An axial intensity minimum was observed that increases with increasing velocity, frequency, or temperature. The investigation indicates that the cleft in the heart-shaped directivity pattern of subsonic jet noise can be attributed mainly to refraction.

THE HEART-SHAPED PATTERN OF SUBSONIC JET NOISE NORMALLY peaks somewhere between 15° and 45° from the axis, depending on conditions, falling off sharply as the axis is approached. Conflicting explanations of this directivity pattern appear in the literature.^{1–7} The objective herein has been to investigate experimentally to what extent the explanation may lie in refraction of the sound^{4–7} by the jet velocity and temperature fields.

To this end, measurements have been made of the sound field of a harmonic "point" source placed within the potential core

FIG. 1. Reduction of discrete tone intensity along jet axis ($\theta=0$) due to refraction (scattering) by jet flow.



of an air jet. The source is the orifice of a tube about $\frac{1}{16}$ -in. i.d., driven through a conical coupling by a horn-type loudspeaker driver; this radiates essentially omnidirectionally up to about 15 000 cps (Ref. 8).

The experiments have employed a $\frac{3}{4}$ -in.-diam air jet inside a vented anechoic chamber with a 300-cps low-frequency cutoff. The jet velocity is continuously variable from $M=0$ to $M=1.0$ and the builtin heaters can vary the jet temperature in the present configuration from ambient up to about 600°F for a jet velocity of 150 ft/sec.

Measurements were made at a fixed radius $r=74\frac{3}{8}$ in., with the microphone in a Bruel and Kjaer windshield. For low jet velocities, the microphone signals were passed through a narrow-band filter ($\Delta f/f=0.016$) and measured directly; this proved adequate discrimination against the jet noise. For the higher velocities where the jet noise equalled or exceeded the source noise within the passband, the sinusoidal signal was extracted by a correlation technique.

Reflection and scattering of sound from the experimental apparatus and the anechoic chamber itself could not be entirely eliminated even by careful wrapping with fiber glass. Consequently, a certain amount of scatter of the data points occurred, especially for measurements near the jet axis (Fig. 1). There, the sound-pressure levels were reduced to values that could be of the same order of magnitude as the spurious reflected signals. Each point in Fig. 1 is already an average of three readings 100 cps apart with roughly double the scatter.

The directivity patterns of Fig. 2 were obtained by cross-plotting from a family of curves for various angles θ , Fig. 1 being a typical example.

The experiment established the formation of an axial intensity minimum (Fig. 2), which is attributed mainly to refraction. From Figs. 1 and 2, it can be seen that the refracted valley deepens as either the jet velocity or sound frequency is increased, with a maximum reduction of over 28 dB at 6000 cps and $M=0.3$. An increase in the jet temperature appears to widen and deepen

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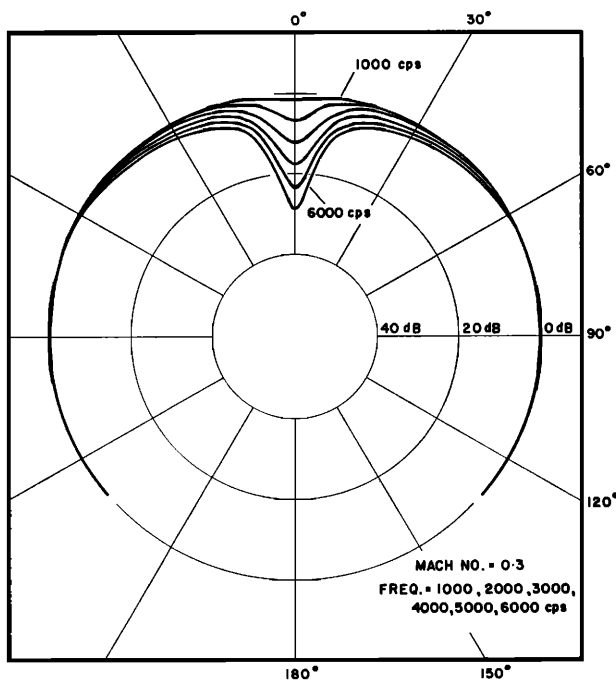


FIG. 2. Frequency effect on refraction.

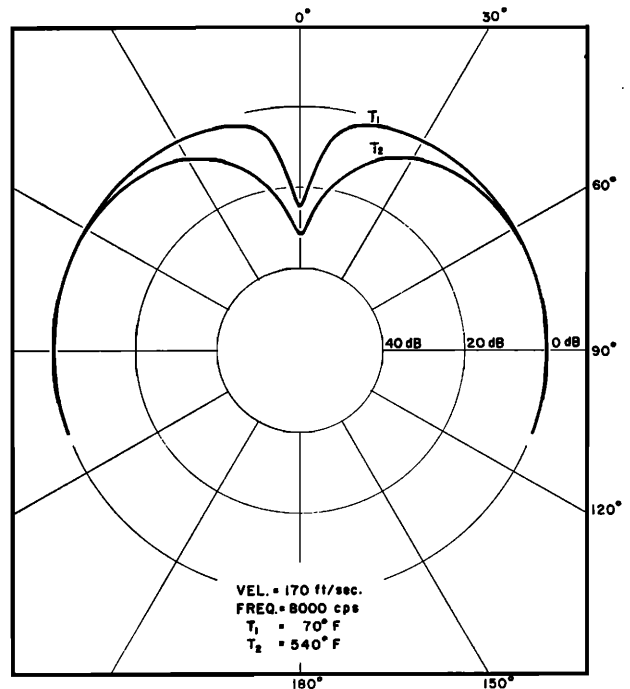


FIG. 3. Temperature effect on refraction

the valley, as seen from Fig. 3, which is plotted from preliminary measurements on the effects of a temperature field on refraction.

Scattering of the sound by the jet turbulence could contribute to the measured effects on directivity, but it is felt that the contribution must be small. It is the velocity gradients (in the isothermal case) that are effective for both refraction and turbulent scattering, and the mean-flow gradients are considered to be much larger than the turbulence gradients.¹ Moreover, the acoustic wavelengths are mismatched to the turbulence scales, being much larger for the most part.^{9,10} The introduction of a series of canted airfoil-type vortex generators at the nozzle failed to make any measurable change in the directivity contours, although a noticeable increase in the volume of the region of strong turbulence is presumed to have resulted.

Work is continuing and further data will provide information on the effectiveness of the velocity field at higher Mach numbers (up to $M=1.0$) in refracting the sound. A more comprehensive investigation of the temperature effects is also being carried out.

Acknowledgment: This work was supported by U. S. Air Force Office of Scientific Research, by the National Research Council of Canada, and by National Aeronautics and Space Administration.

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Vocal-Response Synthesizer

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(Received 8 October 1964)

A new speech synthesizer is described. Instead of bandpass filters, it uses oscillators whose phase, frequency, and amplitude can be modulated pitch-synchronously.

NEARLY ALL APPROACHES TO SPEECH COMPARISON AND PROCESSING have been based on an implicit assumption that the human vocal tract can be approximated by an electrical network having essentially constant parameters within the time frame of a single pitch epoch. The design of both channel vocoders and formant vocoders has been based on this premise, and it is implied in analysis-by-synthesis, inverse filtering, and diverse other speech-processing techniques. On the other hand, it has been recognized that this is only approximately true, that in fact both the resonant frequencies and the decrements (or bandwidths) of the vocal oscillations do vary within a glottal cycle. This second-order modulation of speech has been discussed by Fant,¹ Flanagan,² Tarnóczy,³ and others, although information as to its importance in speech perception has been lacking. Stevens has estimated that the first formant might be frequency-modulated as much as 30 cps within

a glottal cycle,⁴ and Fant has estimated the damping effect of the glottis during phonation to be that of a time-varying resistance of the order of 5–15 Ω (Ref. 1).

In view of the relative magnitudes of these effects, it seemed likely that the second-order modulations in vocalic speech, i.e., the frequency modulation and decrement modulation within a glottal epoch, might be significant correlates of natural voice quality, such that a speech synthesizer capable of imposing these second-order modulations on synthetic speech might offer benefits in speech naturalness and quality. A second objective lay in obtaining a speech synthesizer that might be controlled to generate stimuli such that perception of pitch-synchronous frequency and bandwidth modulation could be studied. And motivation for this endeavor was heightened after giving some preliminary consideration to circuit designs for a speech synthesizer to satisfy these objectives: a design approach based on the use of function generators was evolved, in which simple oscillator circuits with provision for phase, frequency, and amplitude modulation could be used to generate waveforms that simulated approximations to the impulse-response characteristics of the vocal resonances. The function generators gave promise of replacing the bulky bandpass filters of a speech synthesizer with relatively simple, low-cost circuitry. While the synthesizer design is based on a parallel-channel system, not a formant vocoder, and can only imperfectly simulate the vocal mechanisms, the potential benefits of this undertaking were felt to outweigh this limitation. Accordingly, a contract was established for circuit design and fabrication of an experimental synthesizer that would permit second-order modulation to be imposed on synthetic speech, based on the use of an 18-channel vocoder system and substituting 18 function generators for the synthesis filters. An experimental synthesizer has now been constructed,⁵ and reports describing the circuit design and tentative evaluation of its performance are in preparation. The following paragraphs elaborate the approach and initial design considerations that led to this undertaking.

The design of the parallel-channel synthesizer was approached from a point of view of simulating by analog circuitry the response waveforms of a time-varying signal that could be controlled electronically to produce the desired modulations. Figure 1 illustrates one of the function generators, and its waveforms are illustrated in Fig. 2. Its basic element is an oscillator, tuned to the center frequency of a particular vocoder channel. Means are provided for pitch-synchronous modulation of the phase, frequency, and amplitude of the oscillations. As the purpose of the function generator is to generate a waveform with the second-order modulations that might occur typically for a vocal resonance in speech and to differentiate this approach from others, this type of speech synthesizer has been named a "Vocal Response Synthesizer." While its initial implementation has been in the context of a channel vocoder, the design concepts are applicable to formant vocoders as well.

With an occurrence of a pitch pulse from the conventional buzz generator as normally used in the vocoder synthesizer, the phase of all of the oscillators for the various synthesis channels is reset to establish a reference starting phase for a pitch epoch, which can be adjusted to occur simultaneously or with a time offset across channels. Simultaneous with the phase reset, an exponential waveform generator is also triggered, causing a sawtooth waveform to be generated that establishes the desired amplitude envelope of a pitch epoch. The oscillator output is modulated by the sawtooth waveform, thus generating an epoch in which the oscillation starts with reference phase, builds up to maximum amplitude during the first half-cycle, and then decays with a simple exponential envelope. The damped oscillation that is created is similar to the impulse response of a single-tuned filter (or, with a more complex exponential envelope function, to a multipole filter), with the exception that the function generator as described has no memory: the amplitude envelope of any pitch epoch is independent of the past history of pitch epochs. A topic under investigation is whether a "memoryless" oscillation train as produced by a func-