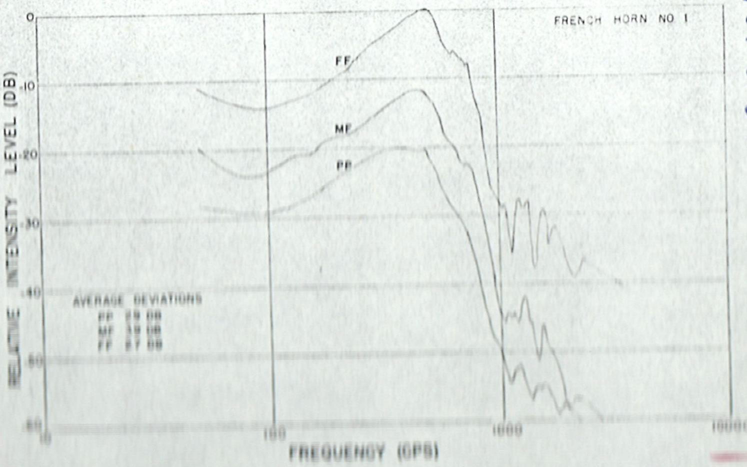

FIG. 10. Spectral envelopes of French Horn No. 1 (stopped horn) at three dynamic markings.

partials reach their steady-state values at successively later times.

- A short amplitude blip or blips occur near the end of the transient period for all the brass instruments and are of greater magnitude for the high-frequency partials than for the low-frequency ones. These blips vary in level from 3 to 20 dB for the different dynamic markings and instruments. The blips have strongly damped "ringing" appearance with the ringing lasting about 5 cycles of the fundamental.

- Insofar as the steady-state spectra are concerned, the trumpet and trombone, at various intensity levels, and the tuba for the pianissimo and mezzo-forte levels behave like frequency-scaled versions of each other. However, scaling for the tuba is not so good as that for the trumpet and trombone, particularly at the higher levels for which the rolloff rate of the tuba appreciably exceeds that of the other two. Figure 14 shows several spectral envelopes frequency scaled as indicated. The deviations from the smooth curves are smaller for the brass instruments than for any other nonpercussive instrument. To the resolution permitted by our experimental procedure, we can state that the spectral envelope of all brasses examined is characterized by a single formant. (The situation is different for certain other instruments and for speech.)

IV. DISCUSSION OF RESULTS

Different specimens of the trumpet, trombone, tuba, and low French horn display similar waveform changes during the attack transient. Furthermore, we have found elsewhere[8] that the trumpet, trombone, tuba, and low French horn belong to a common perceptual family. The significant waveform changes for these instruments in the relevant registers are also similar. These two findings are consistent with the aural importance of the attack transient, as mentioned earlier. The fact that we know the attack transient to be important for identification[1] and the fact that there are properties that do not change markedly for different notes of the scale, for different specimens of the same kind of instrument, or different kinds of instruments within the same perceptual family, suggest strongly that at least some of these characteristics are of aural significance.

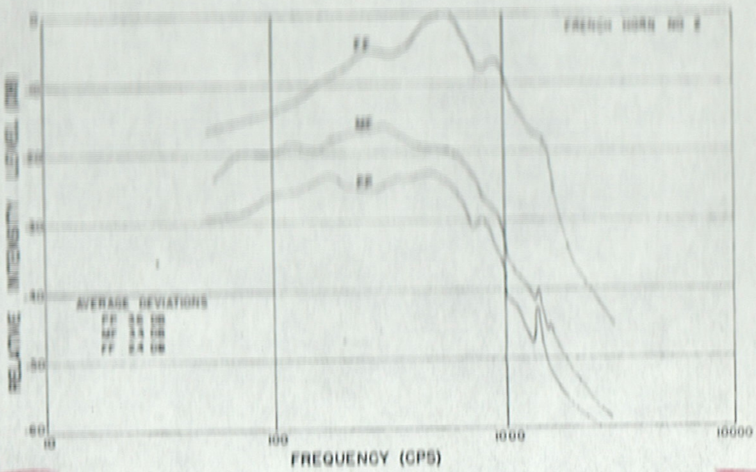

FIG. 11. Spectral envelopes of French Horn No. 2 (open horn) at three dynamic markings.

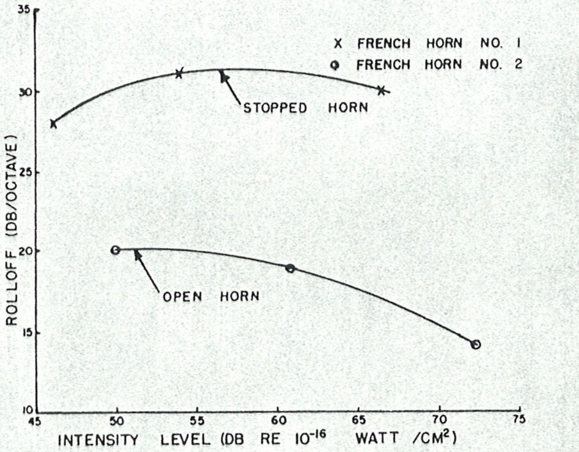

FIG. 12. Rolloff of the French horn spectral envelopes above the cutoff frequency versus the average intensity level of the note scale.

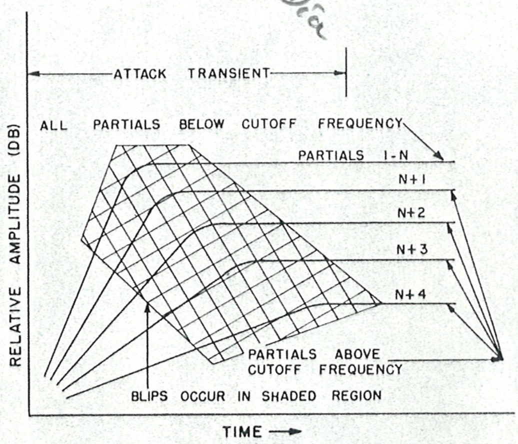

FIG. 13. Idealized representation of the change of the harmonic partials with time for the brass instruments.

In discussing the features of the attack transients of the brass instruments, we note that there are two characteristics that are present very consistently: rapid amplitude modulations and the manner in which the relative amplitudes of the partials change with time. Since the amplitude modulations have a frequency about 20% of that of the fundamental, it is very unlikely that they will be aurally trackable as amplitude modulations and perceived as such. In regard to the second characteristic, during the first part of the attack transient, the lower-frequency partials increase in amplitude more rapidly than the higher-frequency ones (see Fig. 13). During the subsequent second part, successively higher-frequency partials reach their steady-state values at successively later times. A possible explanation of this phenomenon is as follows: The lower the frequency of a partial, the less effectively the sound is radiated from the instrument, and the greater the effective "Q" of the instrument for this partial. Second, the mouthpiece may be considered to be a sort of Helmholtz resonator or low-pass filter when viewing the instrument from the bell. The low-pass character of the mouthpiece implies that the excitation, i.e., the lips of the player, are more strongly coupled to the tube-bell part of the instrument for the low-frequency modes than for higher-frequency ones. If we assume that the lips of the player are strongly affected by the mouthpiece pressure function, then both the characteristics of the mouthpiece and the bell favor the more rapid increase with time of lower-frequency partials. The less favored high-frequency partials radiate more readily from the horn, and the relatively small fractions of these partials that are reflected have a more difficult time reaching the lips of the player. At some point in time, the amplitude of the excitation becomes limited by the mouthpiece with the result that the amplitudes of the low-frequency partials become essentially constant. A continuing increase in amplitude can now occur only by subsequent increases in the amplitudes of the higher partials. This would explain the observed fact that the higher-frequency partials reach their steady-state values at later times.

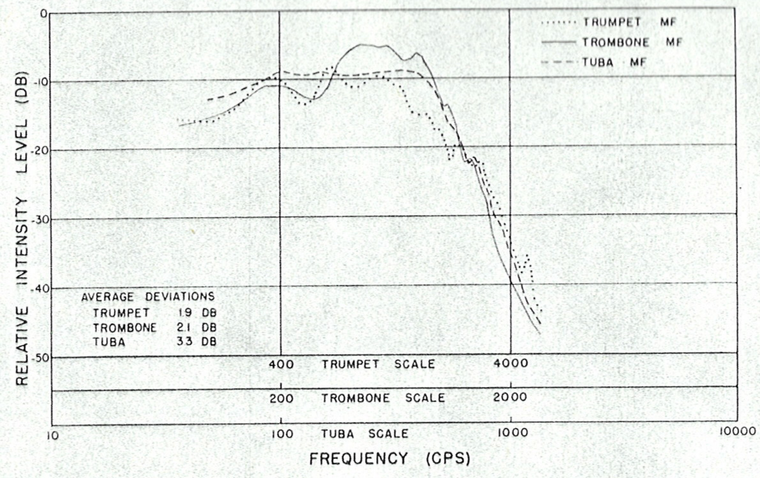

FIG. 14. Trumpet, trombone, and tuba spectral envelopes scaled in frequency as indicated by three different abscissa scales.