The rapid changes in observed volume shown in Fig. 1 that correlate with pressure pulses are actually collapses of a part of the main bubble for the early pulses followed by collapses of the remainder of the main bubble.

To determine if the measured pulses were related to the variation in bubble volume, a simple relationship was derived for a spherical bubble in an infinite medium:

$$P(t) = \frac{\rho_d}{4\pi r}\frac{d^2V_B(t)}{dt^2} \; . \tag{1}$$

In Eq. (1)

ρ_d = liquid density

r = distance between bubble and pressure detector

$V_B(t)$ = time-dependent bubble volume.

To test the adequacy of this relation, the observed bubble volume was differentiated twice and compared to the measured signal. The result is shown in Fig. 2. Note that both measured pressure peaks are closely matched by the differentiation. The additional apparent peak at ~65 ms is most likely induced by the high noise contamination to be expected when measured data are doubly differentiated.

De's bubbles have volumes of order 0.04 cm^3 and existence times of order ~7 ms; whereas, Wright's[1] bubbles had radii about six times larger than De's and existence times about nine times longer. Therefore, observation of the details of the collapse mode of these larger, longer lasting bubbles was easier to achieve by photographic means in Wright's case than in De's experiments.

Of course, the analogy between these two results does not prove that De's assumption of one pulse per incepted bubble is incorrect. However, De offered no conclusive evidence that multiple collapse pulses per incepted bubble cannot occur. Since a somewhat similar experiment has conclusively demonstrated that multiple collapse modes are observed, it is possible that such modes are also operative in De's case.

In terms of theoretical understanding, it seems much easier to envision and analyze a situation in which bubbles are incepted randomly at a mean rate and undergo multiple collapse than to conceive of the physics associated with clustered inception. A mechanism that turns clusters of incepted bubbles "on" and "off" according to a Poisson law is not at all understood. A mechanism of bubble collapse where pieces break away from the main bubble and collapse sequentially has been observed and could be understood in principle by analyzing condensation rates at the surface of distorted bubbles.

It is suggested that in future experiments of this type a careful investigation be made to determine if the interpretation is more properly clustered inception or multiple collapse.

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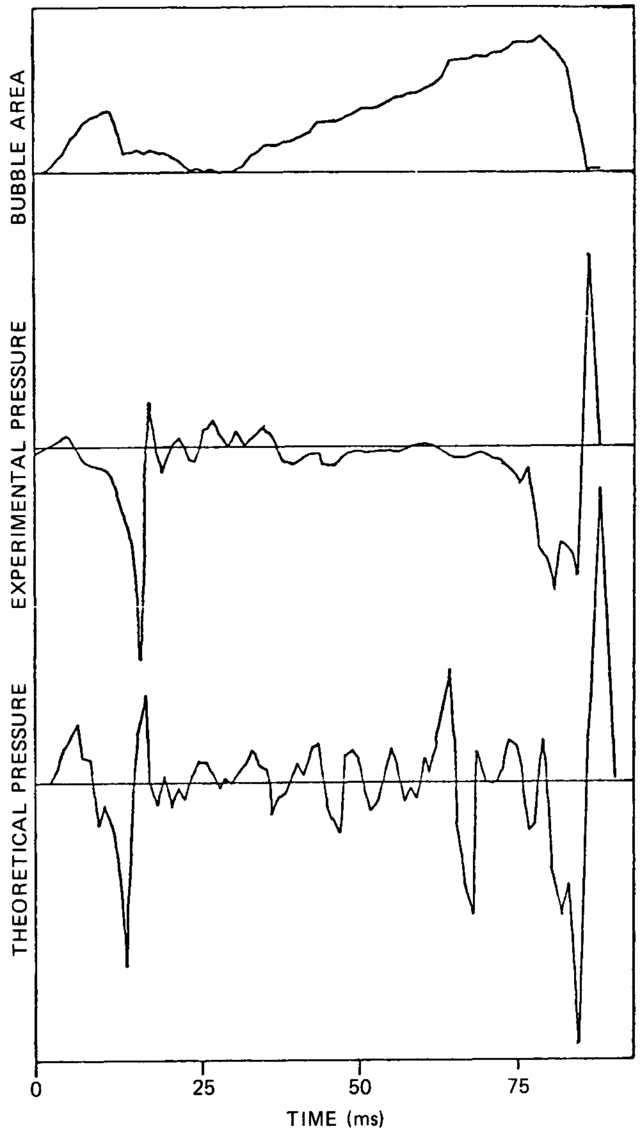

Fig. 2. Measured and predicted pressure.

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REPLY TO "COMMENTS ON 'STATISTICAL CHARACTERISTICS OF INCIPIENT TWO-PHASE NOISE FOR REACTOR DIAGNOSIS' "

The author thanks Albrecht and Wright for their interesting discussion and alternative interpretation[1] of the experimental results. The experiment they conducted showing multiple collapses of a bubble yielding multiple acoustic pulses is very interesting. High-speed photographic observations here[2] in a similar venturi have also shown that bubbles oscillate, and sometimes the oscillation results in the fragmentation and collapse of a portion of the bubble as was observed by Albrecht and Wright. However, the present statistical observations of bubble inception in the venturi cannot be explained by multiple collapse as suggested by Albrecht and Wright. The bubble oscillation frequencies (5.0 to 20.0 kHz) observed photographically[2] and acoustically[3] in the venturi are much too high to cause the large peaks in the time interval distribution (~5 ms). The bubbles in the present study range in diameter (size at full growth) from 0.254 to 1.27 mm, have high natural frequencies (5.0 to 20.0 kHz), and collapse much more rapidly (~100 μs from maximum size) than the steam bubbles observed by Albrecht and Wright. Also note that the distance between the venturi throat entrance (point of inception) and the mean axial location (Fig. 1) of bubble collapse is 10 cm. The bubbles traveling at ~40 m/s (venturi throat velocity) would take ~$2\frac{1}{2}$ ms to travel this distance. The time intervals (~5 ms) at the peaks of the distribution are longer than the total lifetime of the bubble.

The time interval between pressure pulses due to bubble oscillations and multiple collapse were not recorded in the present experiments because a 500-μs dead time was used during data acquisition. The intent of the experiments was to analyze the intermittent nature of cavitation inception shown in Fig. 2 and which is evident by an unaided audiovisual observation of the bubbles in the venturi.

One can conclude from the above discussion that

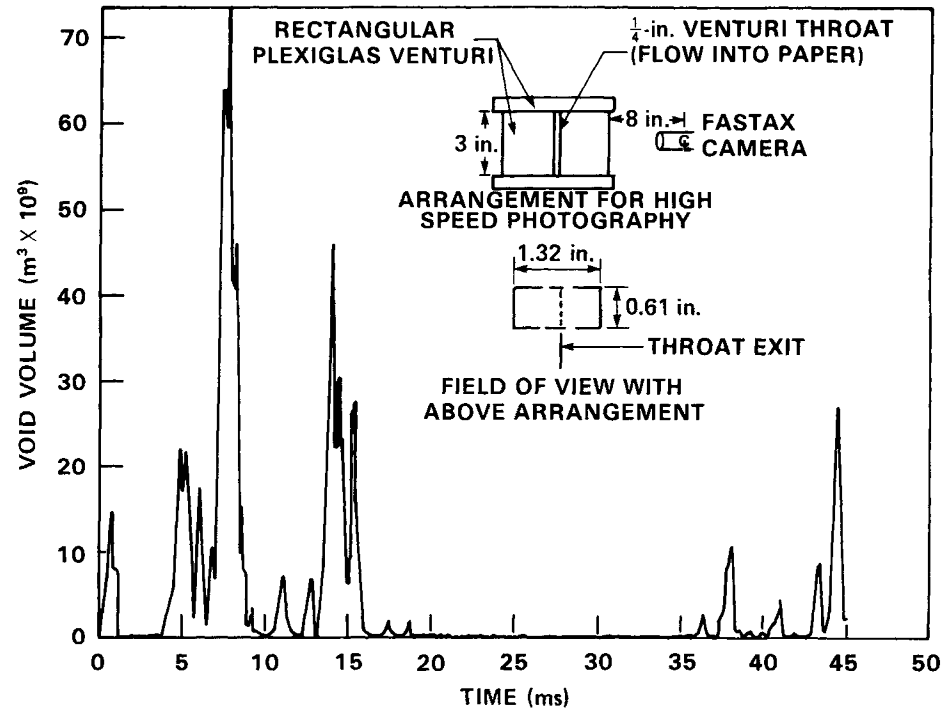

Fig. 1. Plexiglas venturi flow path.

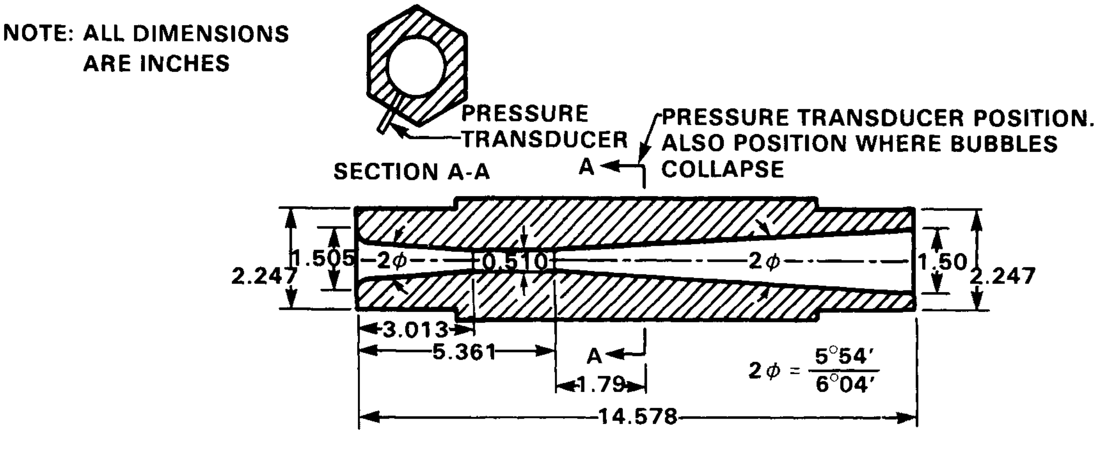

Fig. 2. Total void content in the field of view versus time (see Ref. 4).

oscillations and multiple collapse of a bubble does occur for cavitation bubbles in a venturi, but this phenomenon cannot explain the statistical observations presented in the paper. However, multiple collapse of large steam (or sodium vapor) bubbles in reactor channels can result in another unique feature in the acoustic signature that can be used in a boiling detection scheme.

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