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DISCUSSION

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The paper represents a prodigious and important experimental project. The authors present valuable data in an area where only meager results exist. The determination of *intrinsic* amplifier parameters is important, and the authors clearly indicate the inherent deficiencies of transfer function testing. The use of vacuum sources to achieve Mach number/Reynolds number scaling is sound, and should be more widely employed. It is hoped that more examples of such high-quality experimental modeling will appear in the future.

There are some important details of the experimental technique which merit further exposition.

1 How did the authors verify that a *center line* hot wire measurement gave faithful indications of the average flow in the control and output channels? The (variable shape) dynamic velocity profiles cannot generally be parametrized by a centerline measurement, i.e. the average flow is not generally proportional to the centerline velocity. The large cross-sectional areas (0.1×0.25 in.) tend to render the dynamic perturbation profiles uniform, but some error is unavoidable, and a quantitative statement would be helpful.

2 Reference is made to the described method of sinusoidal testing as "reducing greatly the effect or nonlinearities, including confusion between random noise and deterministic overtones." The authors should provide supporting evidence for such a statement. Further, there is no evidence of any dramatic difference between the method of the paper and other methods cited by the authors, at least in the efficacy of handling nonlinearities and/or correlated noise generation.

All admittances were apparently determined by assuming estimates of the in-phase and quadrature amplitudes of the output sinusoid to be given by the outputs of the multiplier—low pass filter system described. (Incidentally, a synopsis of the statistical method, confidence limits, etc., would enhance the presentation significantly.) This is analogous to the well-known describing function technique. The procedure in this case leads to a simple system representation in the form of a linear admittance matrix which is valid for *arbitrary* (small) inputs if the noise is *additive* and *uncorrelated*. The authors make no attempt to consider more detailed behavior, such as the mechanism of the internal noise generation. Realistically, there will usually be a *correlated* input-dependent noise component, and this fact will degrade the utility of the authors' empirical admittance matrix as a "system model." This would be especially critical for the output-control and control-control admittances. Thus, the representation is a valid empirical input-output model for (small) *sinusoidal* inputs, but cannot be fully accepted as a (*broad-band* input) system model without further clarification. Transient response tests might prove quite interesting in this context.

The problem is similar to that treated by the discusser (references [8 and 9]), wherein both broad band inputs and sinusoids were used in conjunction with a spectrum analyzer. Tedious time averaging was necessary only for broad band random inputs; sinusoidal testing was fast. Reference [8] addresses the characterization of the correlated noise itself, a problem of considerable difficulty. The internally generated noise is important for system studies directed towards, for example, maximizing the overall signal to noise ratio of an amplifier cascade.

The authors' views on the utility of their data for broad band inputs and the modeling of the internal noise generation in the context of the present paper should be of considerable interest.

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Authors' Closure

The authors appreciate the kind remarks of Dr. Orner.

The hot wires mounted in the control channels were placed virtually at the converging entrances, where the velocity profile should be slug-like and the difference between mean and centerline velocities should be negligible. Such is not the case for the output channels, however, and Dr. Orner's point is well taken. Accurate corrections for the small deviation between mean and centerline velocities are exceedingly complicated because the flow was observed to be turbulent. The effect of ordinary pipe turbulence on sinusoidal disturbances has been studied by one of the authors,[3] but the results are not strictly applicable here because the present turbulence is induced by the jet and is dissipated downstream. In fact, laminar flow resulted when equivalent flows were introduced through the side vents rather than the power nozzle. The nonuniformity of the channels introduces a further complication. If the results of the study on pipe turbulence are nevertheless used as a guide, it can be deduced that the velocity profile for the superimposed sinusoidal fluctuations probably does not deviate from the velocity profile for the base turbulent flow until the frequency exceeds about 1000 Hz. Since the hot wires were calibrated at d-c by flow meters, the results below 1000 Hz should therefore be virtually (within a percent or two) as accurate as the flowmeters. By the upper limit about 3000 Hz the superimposed profile becomes somewhat more slug-like, however, and the centerline velocity measurements may underestimate the mean velocity fluctuations by perhaps three or four percent. These errors fortunately are relatively insignificant.

The data reduction procedure used, in which each measured signal was correlated with the virtually pure sine wave of the oscillator, was tantamount to the use of a filter with nearly infinitesimal bandwidth. Within this bandwidth the energy in the noise thus was virtually negligible relative to the energy in the signal, regardless of whether the noise was Gaussian or correlated with anything else. Deterministic nonlinearities would have appeared, had they been present and the effort made to measure them, as overtones in the response. Within nearly infinitesimal bandwidths about the known overtone frequencies, these similarly would swamp out the noise. Further, by exciting the system in an infinitesimal bandwidth only, a very small signal was sufficient, and the excitation of nonlinearities was minimized. The rock-steady readings of the data-reduction ap-

[3] Brown, F. T., Margolis, D. L., and Shah, R. P., "Small-Amplitude Frequency Behavior of Fluid Lines With Turbulent Flow," Journal of Basic Engineering, Trans. ASME, Series D, Vol. 91, No. 4, Dec. 1969, pp. 678–93.

paratus, and the insensitivity of the results to changes in the amplitude of the excitation, give direct supporting evidence. (The same cannot be said of the methods involving random inputs described in references [18] and [19].) There is no reason to believe the results do not properly predict the *deterministic* part of the response to a broad-band input.

Understanding of the noise is a more difficult matter, beyond the scope of the present paper. Understanding the linear deterministic behavior is just a necessary first step, and understanding the nonlinearities is a second. Meaningful correlated noise models must depend on broad-band noise measurements in response to a set of input signals with distinctly different spectral contents. The ideal case would be noise measurements in response to sinusoidal excitations.