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THE NOISE REDUCTION POTENTIAL OF DUAL-STREAM COAXIAL RECTANGULAR IMPROPERLY EXPANDED JET FLOWS

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The research performed under the subject NASA Langley Grant (NAG-1-1240) began during Spring 1991 as a project to assess the noise reduction potential of rectangular coaxial nozzle configurations for improperly expanded jets. The research plan consisted of:

1.) Design of coaxial rectangular nozzle configuration by Syracuse graduate research assistant;
2.) Construction of nozzles by NASA Langley machinists;
3.) Acquisition of preliminary acoustic and optical data for a variety of inner and outer jet pressure ratios.

The experiments were to be conducted in an existing high-speed jet facility at Syracuse University, and were to include a preliminary evaluation of temperature effects. The Syracuse University facility was designed to accommodate multiple co-flowing jets, but only coaxial and triaxial *round* nozzles had previously been investigated. The design of coaxial *rectangular* nozzles for this facility was more complicated than originally believed for several reasons. Most critically, the geometrical transitions that were needed between the circular plenums and the rectangular nozzles (particularly for the outer, annular flow) necessitated the design of a complex, machinist-intensive structure. Additional concerns about structural integrity of the thin nozzle lips at high pressure ratios, high-temperature effects, and flow quality (in the circular/rectangular transitions) further complicated the design. The end result of the 6-month design process was a set of nozzles that Langley machinists estimated would cost about $250,000 to construct. Dr. Seiner and the principal investigators agreed that this was prohibitive for this modest academic study, and sought to find an alternate way to complete a meaningful aspect of the project.

The remaining NASA grant resources (partial student support and equipment funds) were then focused on a study of a different high-speed nozzle geometry, still with the objective of evaluating methods to reduce improperly expanded jet flow noise. The geometry selected was a "crown-shaped" nozzle originally examined by Longmire *et al.*† in a low-speed flow. This geometry (with the number of "crowns" between four and sixteen) had been found to be an effective means for generating streamwise vorticity and enhancing jet entrainment. The rationale for investigating this geometry in a higher-speed flow, particularly one with a shock structure, was two-fold: the enhanced jet spreading observed in the low-speed study would likely be more significant in the high-speed flow because of the larger pressure differences across the nozzle peaks and troughs; and the azimuthal asymmetry of the nozzle would likely result in a modification of the shock structure and a decrease in shock-related noise.

Pitot-pressure measurements, schlieren flow visualization, near-field microphone mea-

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† *AIAA Journal*, February 1992.

surements, and preliminary hot-wire measurements have been used to assess the effect of the crown-nozzle geometry on improperly expanded jet flows. The crown-shaped nozzles were converging in nature, with varying numbers of teeth at the exit and various tooth dimensions. The jet was operated at an underexpanded pressure ratio of 3.18, which corresponds to a perfectly expanded Mach number of 1.4.

While similar phenomena were observed for each of the crown-nozzle geometries, the most significant deviation from the baseline round-nozzle flow was measured for the "largest" crown: 4 peaks, with the peak height equal to the nozzle exit diameter ($h = D$). Most dramatically, the spreading rate in the trough planes is greatly enhanced until the end of the potential core (see Figure 1). It is important to note that the increase in jet half-width is much larger than can be attributed merely to the increased axial distance over which the flow develops in the trough plane. Jet spreading rate is initially diminished in the peak plane, but the peak and trough planes exhibit similar widths by $x/D \approx 15$, and these are equivalent to those observed in the baseline round-nozzle flow.

Schlieren visualization (see Figure 2) provided strong evidence for two flow phenomena: weakening of the shock structure as compared to the baseline flow (with significant azimuthal asymmetry), and the existence of large, streamwise-oriented structures emanating from the nozzle troughs. The schlieren visualization also shows evidence of the greatly enhanced jet spreading rate in the trough planes close to the nozzle exit (see, especially, Figure 2c). The weakening of the shock structure was confirmed by near-field acoustic microphone measurements (see Figure 3) that showed elimination of screech tones, as expected for azimuthally asymmetric nozzle geometries. While the streamwise structures are large and quite distinct, no measurements have yet been made that can confirm whether they are vortices. However, the position of the streamwise structures is consistent with a rapid stretching of azimuthal vorticity at the apex of the trough. If the visualized structures are vortices, however, the sign of the vorticity would act to enhance *entrainment* in the trough plane, not increase the spread of high-momentum jet-core fluid. It is therefore hypothesized that the dramatic spreading of the jet in the trough plane is most probably a pressure-driven phenomenon, with the large pressure difference across the trough driving the growth of the jet in these regions. Further investigation of these flows is concentrating on measurements to understand the source and characteristics of the streamwise vortical structures, and the improved characterization of the flow through the trough of the crown.

In all, three graduate students and two undergraduates have participated in this research. Their contributions were divided as follows:

- Robert McAfee (Master of Science student): Responsible for engineering design of original coaxial, rectangular nozzles and proof-of-concept acoustic studies on small-scale jet rig. Received one year of NASA research support.
- Douglas Gilkey (Master of Science student): Designed crown-shaped nozzles and per-

formed flowfield, optical, and (preliminary) near-field acoustic measurements of improperly expanded crown-shaped nozzle flows. Received partial summer support from NASA grant.

- Alison Chamberlain (Master of Science student): Performed flowfield measurements of Mach 0.8 crown-nozzle jet flow and investigated feasibility of simultaneous hot-wire measurements and schlieren visualization of temperature-marked flows. Did not receive NASA support.
- Daedra Studniarz and Tarono Fullwood (undergraduate aerospace engineers): Performed hot-wire anemometer measurements of a low-speed flow issuing from the crown-shaped nozzles.

The most comprehensive investigation was performed by Douglas Gilkey, and open questions raised by his thesis are now being addressed. We fully expect that an AIAA paper will be written once these issues are resolved.

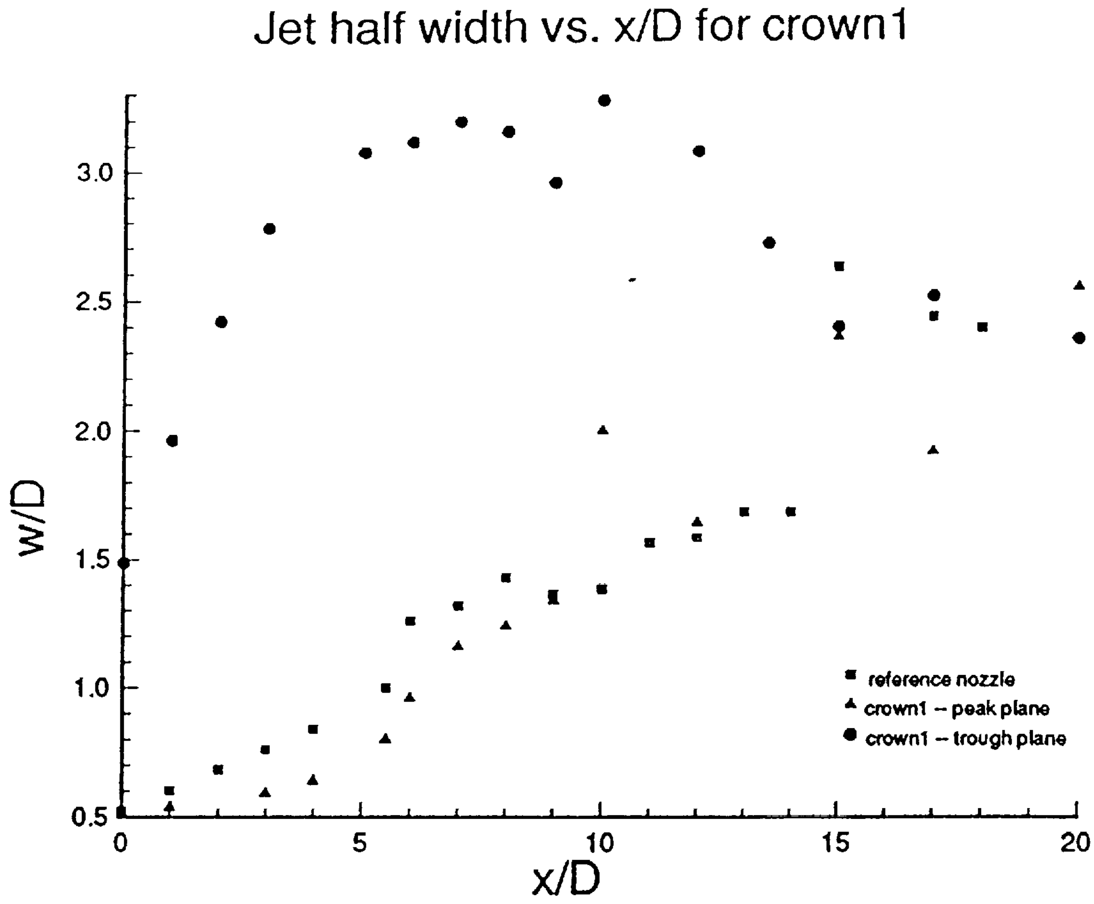

Figure 1. Jet half-width as a function of axial distance for the most severe crown-nozzle configuration. Data is shown from the baseline (round, symmetric) nozzle flow and from the trough and peak planes of the crown-nozzle flow.

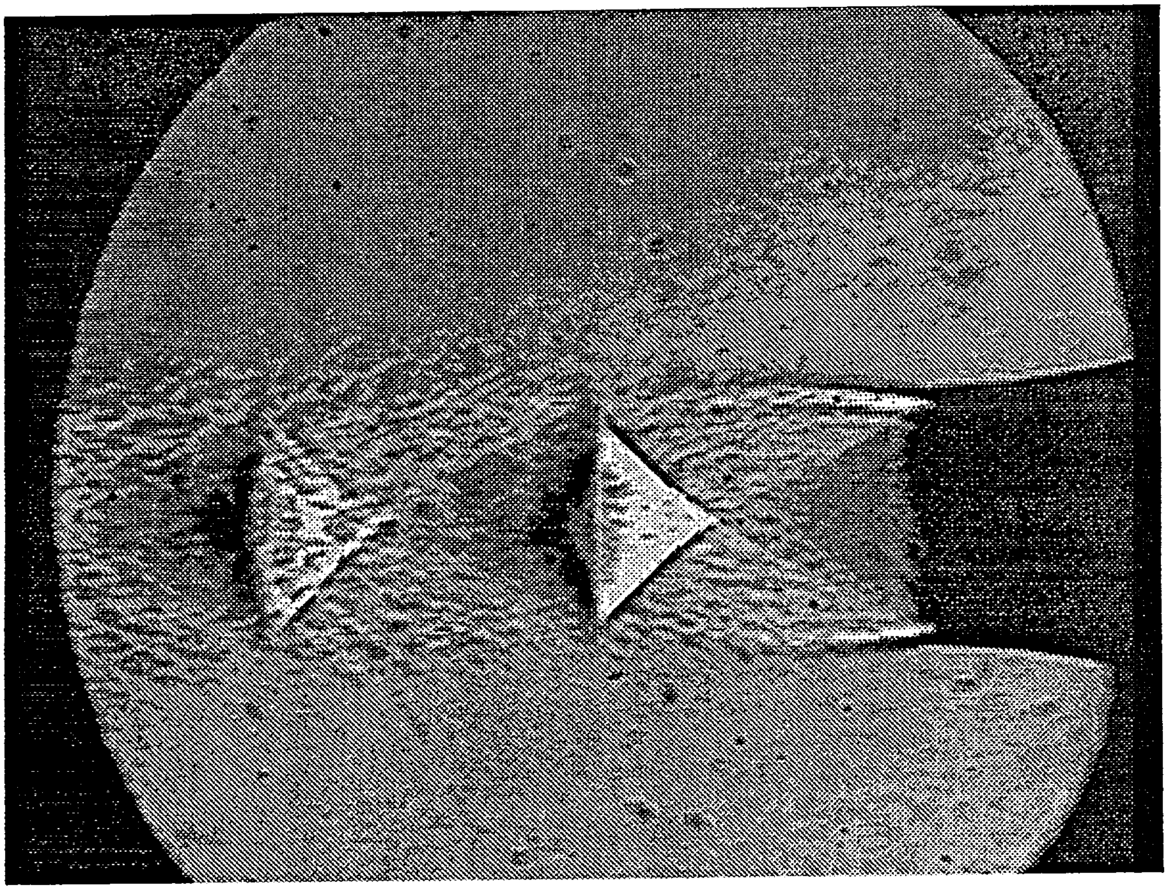

Figure 2a. Schlieren photograph of the underexpanded flow issuing from the baseline nozzle.

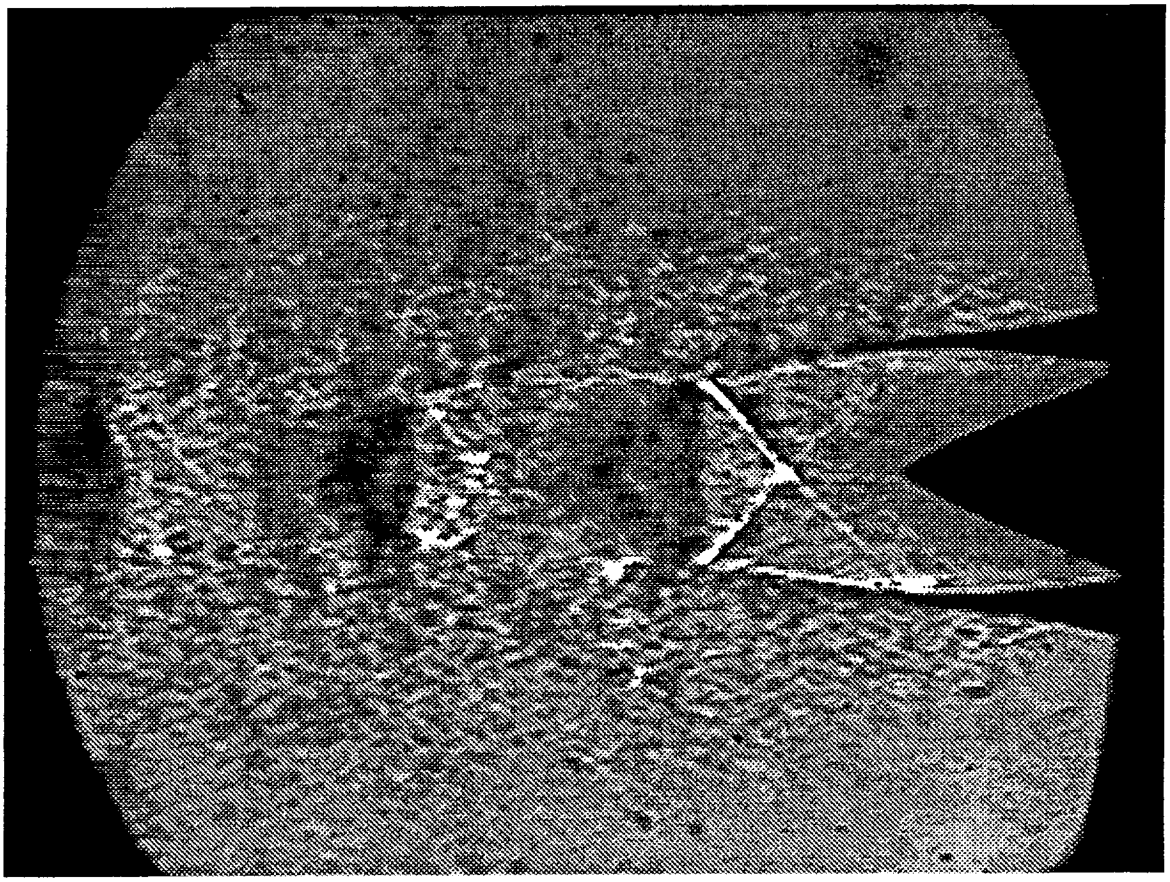

Figure 2b. Schlieren photograph showing the structure in the peak plane of the crown-nozzle flow. Same flow conditions as Figure 2a.

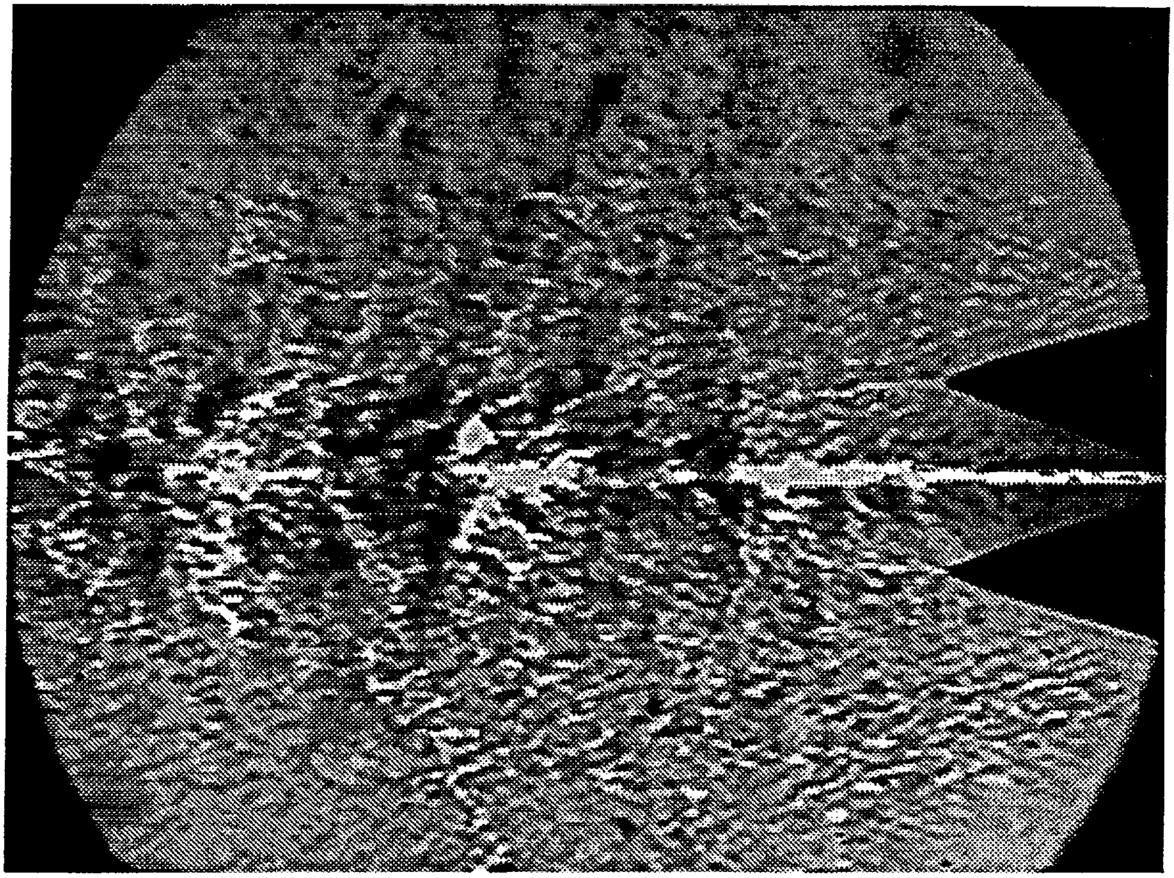

Figure 2c. Schlieren photograph showing the structure in the trough plane of the crown-nozzle flow. Same flow conditions as Figure 2a.

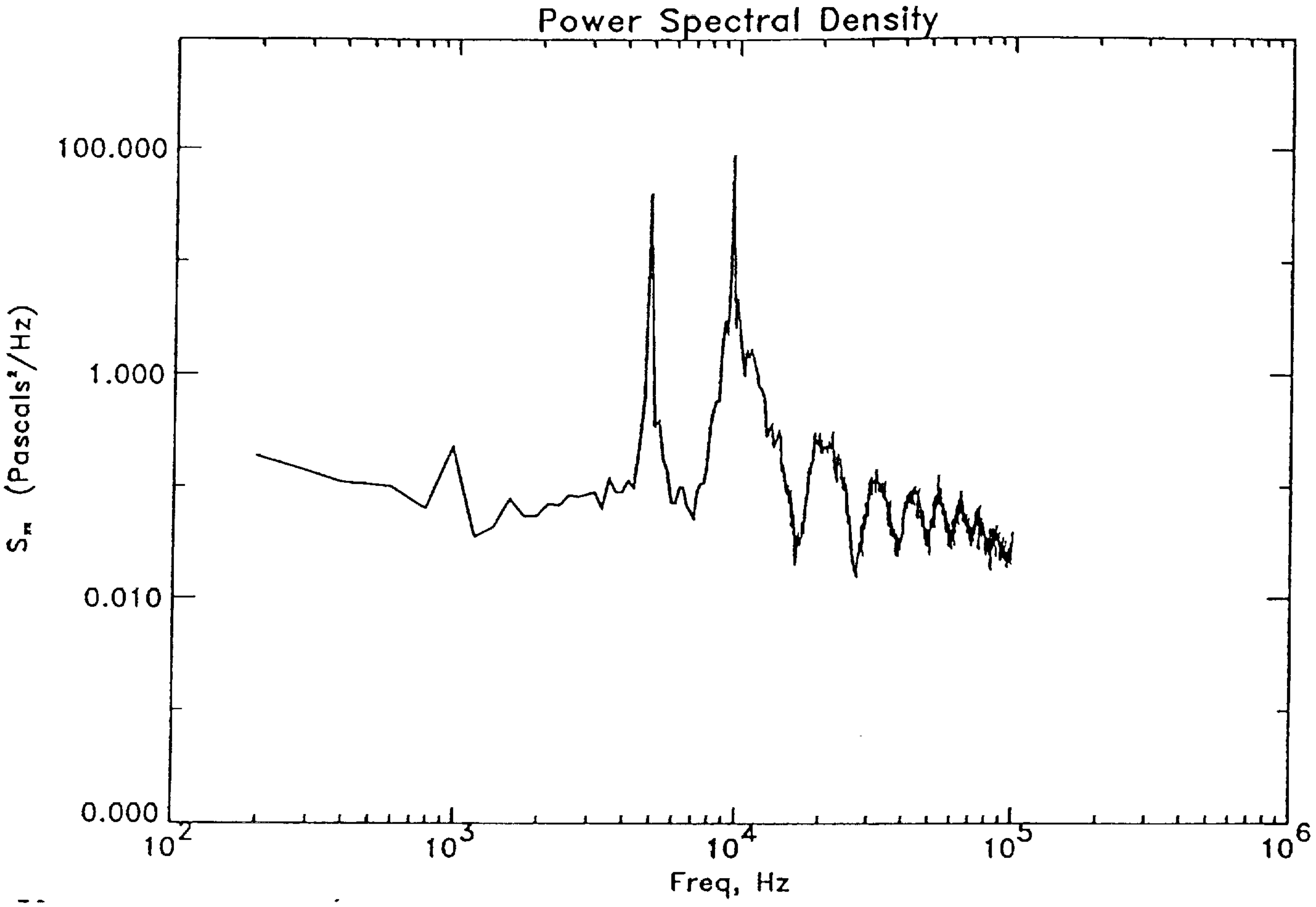

Figure 3a. Representative sound pressure power spectral density in the near field of the baseline-nozzle flow.

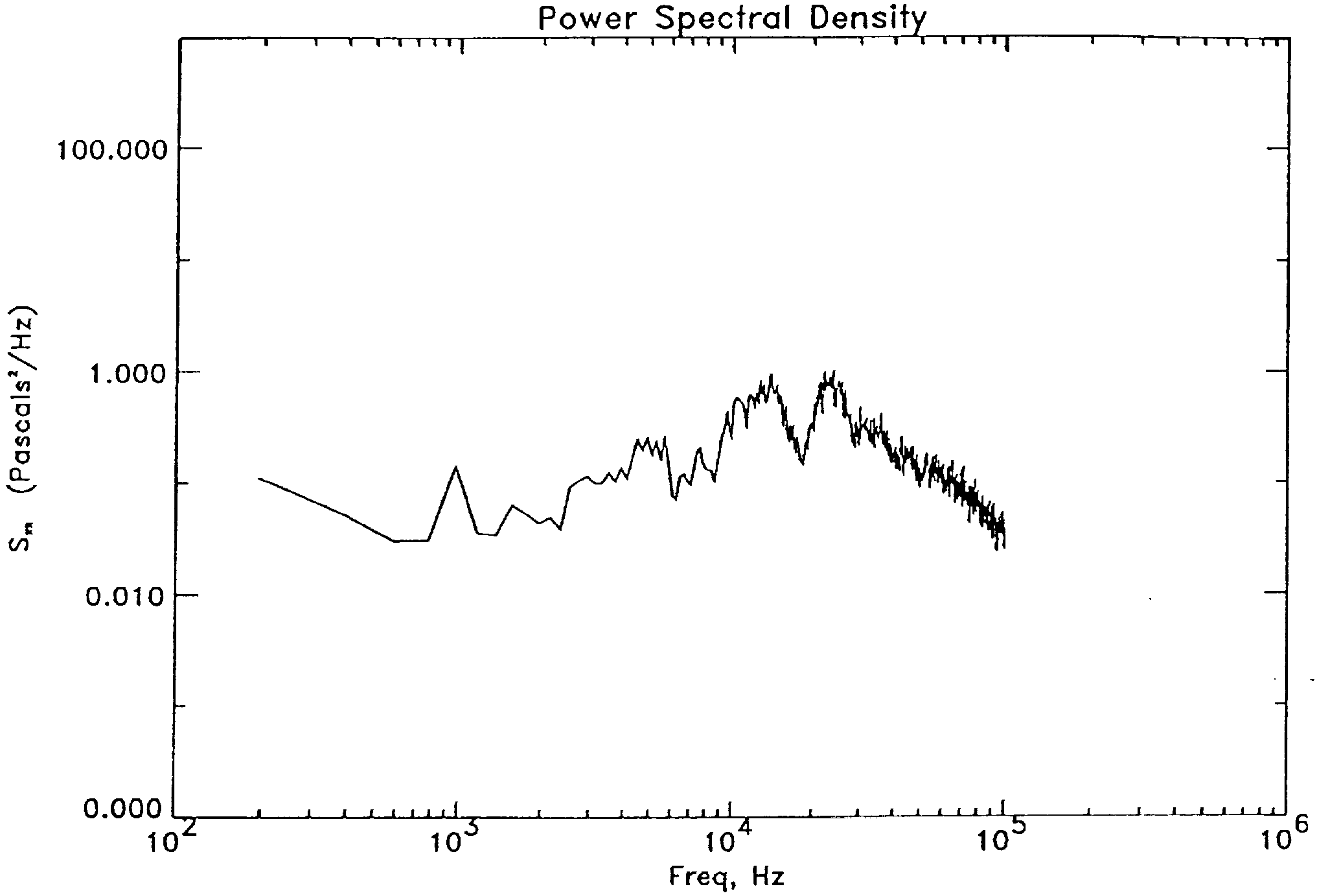

Figure 3b. Representative sound pressure power spectral density in the near field of the crown-nozzle flow.