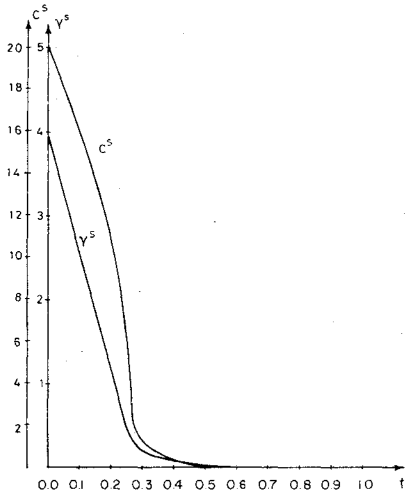

Fig. 2 t-evolution of the parameters c^s and γ^s.

problems. Each one of the minimum problems is solved by a quasilinearization procedure. The advantage of the proposed method is that it provides a substantial increase in the region of convergence of the quasilinearization method. The numerical experiment which is presented demonstrate clearly this useful property.

The necessary price for the observed improvement in convergence properties is a rather large computation time. More work is needed for comparing the computation times of the present method and other estimation methods having a large domain of convergence.

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Electromagnetic Fields Generated by Turbulent Air Flow and Shock Waves

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Introduction

THIS research program is a continuation of studies of electromagnetic fields radiated from regions of high shear observed outside of a glass shock tube and in cold oxygen gas flow,[1] and to a limited extent in von Karman vortices.[2] This research originated in a study of aerodynamic drag reduction.[3] The purpose of this paper is to establish the fact that electromagnetic fields are radiated from regions of high rates of change of shear in turbulent flow and shock waves.

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The electromagnetic field associated with turbulent air flow may be the result of the dynamic motion of H_2O and CO_2 polar molecules and N_2, O_2 and other molecules given induced dipole moments by polarization. The electronic and magnetic probes used, respond only to AC signals, and are therefore sensitive to only the dynamic motion of electric charges possibly associated with these dipoles.

When these natural and induced dipoles are subjected to a polarizing field which is generated by their motion, they are rotated until their polar axis has a direction opposite to the direction of the field. Tests indicate the dynamic motion of these groups of aligned molecules, and any electric charges, produce the signals picked up by the electronic and magnetic probes.

Tests Instruments and Equipment

Two types of probes were used (see Fig. 1). Both of them contain subminiature amplifiers and associate circuits in their housing. The electronic probe is used to pick up the electric vector $\boldsymbol{E}$ in the induction field. It was found the magnitude of this vector was so low that it would only induce low level electric charges in the sensing electrode of the pickup. Accordingly, the electrode was connected to an electrometer type amplifier which was designed to measure electric charges. This amplifier has an input impedance of 1×10^{13} ohms and a sub-picoampere bias current. With the proper design of the feedback circuit and termination resistance, it is possible to obtain a linearity of ± 1 db from 25 Hz to 1.5 MHz. The sensing electrode exposed to the electromagnetic field is 3 mm diam and 40 mm long.

The magnetic probe shown in Fig. 1 for picking up the magnetic vector $\boldsymbol{B}$ of the electromagnetic field in the induction zone, has a sensing element in the tip which is 8 mm diam and 9 mm long. This small sensing element will give a higher resolution to local variations in the magnetic field than the electronic probe. The subminiature amplifier used in the magnetic probe has a high gain with an input resistence of about 50 megohms.

The subsonic tests were conducted in an open return wind tunnel having a test section diam of 298 mm. A vortex generator[4] consisting of a plastic strip 80 mm high by 10 mm thick was mounted horizontally across the center of the test section perpendicular to the direction of the air flow. The top of the vortex generator was machined with a 30° angle between the sloping forward face and the vertical downstream face of the plastic strip. All of the subsonic tests were conducted at an air speed of 17.9 m/s, (40.0 mph).

The supersonic tests were conducted in the flow downstream of a small expansion-type nozzle machined in the center of a nozzle plate. This produced an underexpanded

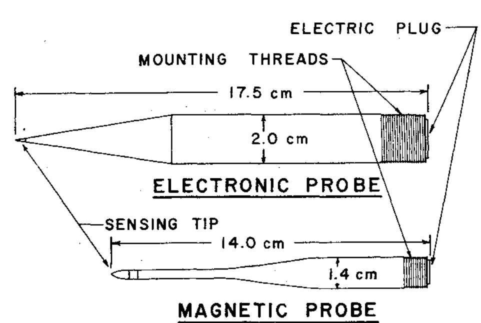

Fig. 1 Supersonic probes.

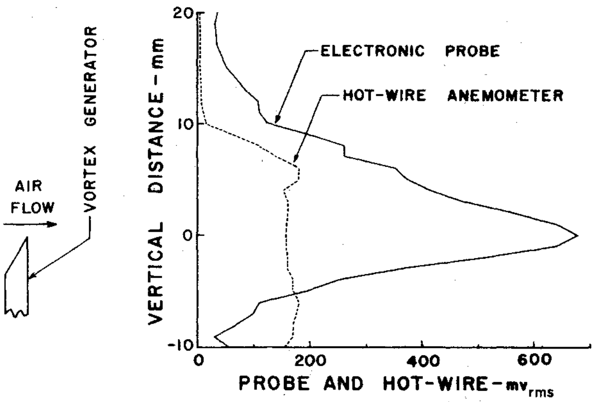

Fig. 2 Comparison of electronic probe with hot-wire anemometer.

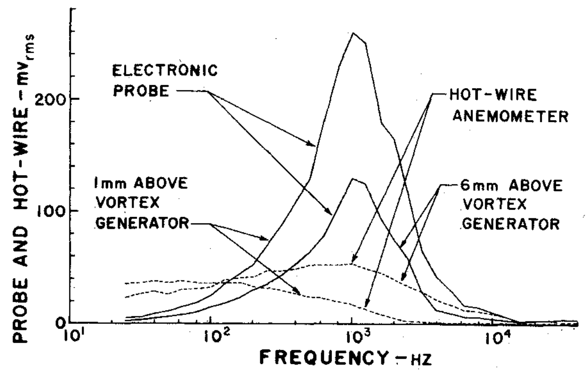

Fig. 3 Frequency spectrums 20 mm downstream of vortex generator.

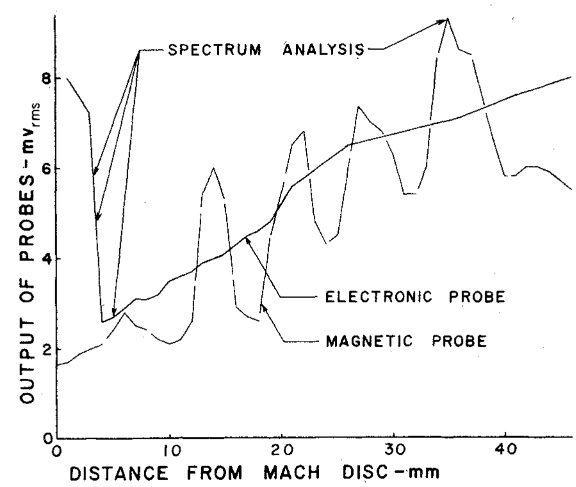

Fig. 4 Probe output downstream of Mach disk.

axisymmetric nozzle flow with a Mach disk.[5] The location of this Mach disk and the relative location of the probe tip were determined by means of shadowgraph optical equipment. The supersonic tests were all conducted with a pressure 5.0 kg/cm^2 at the entrance of the expansion nozzle. The nozzle discharged into the atmosphere.

Results and Discussion

Subsonic Flow

Time averaged data taken by the electronic probe and hot-wire anemometer 20 mm downstream of the vortex generator are plotted in Fig. 2. The gain of the amplifiers in these two instruments was adjusted so that the output was the same at low turbulence levels. This permits the output of both instruments to be compared directly. The turbulence downstream of the vortex generator was in the form of a vortex sheet. The electronic probe data consistently gave a higher signal level and different shape than the hot wire. The signal pattern of these two instruments remained consistent over the downstream distance surveyed.

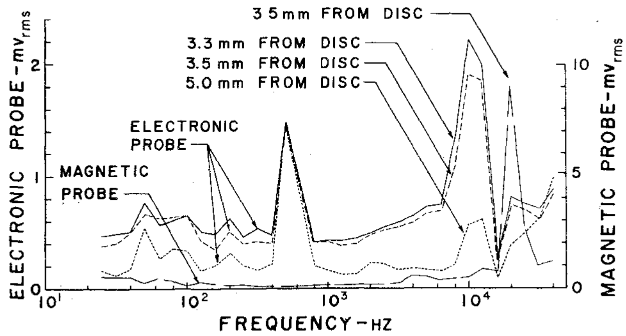

Fig. 5 Frequency spectrums downstream of Mach disk.

Frequency spectrums taken from these two instruments at the same horizontal position are shown in Fig. 3. It is seen the shape and magnitude of the hot-wire spectrum is different from the top and bottom of the vortex sheet, while there is some similarity in the shapes of the electronic probe spectrums. A plot of the cross-correlation of the electronic probe with the hot-wire indicated there is a definite relationship between these two signals. This is most important, since it indicates these two signals originate from the same fundamental parameter in the turbulent air flow.

Supersonic Flow

For the supersonic tests, the time averaged voltage from the two probes at various positions downstream of the Mach disk is shown in Fig. 4. The long length of the sensing electrode in the electronic probe gave average values, while the small sensor in the magnetic probe gave a higher resolution to the local variations in the field strength.

Frequency spectrums at 3.3, 3.5, and 5.0 mm downstream of the Mach disk are shown in Fig. 5 for the electronic probe. A frequency spectrum at 35 mm is also shown for the magnetic probe. In some respects, these frequency spectrums resemble those obtained by McLaughlin et al.[6] with a hot-wire anemometer in a supersonic jet at low Reynold's numbers.

As a final check on the effect of polar molecules on the generation of the electromagnetic fields, commercial grade CO_2 was used instead of dry air in the supersonic test. With the magnetic probe, dry air which does not have a dipole moment, gave a maximum value of 9.0 mv at 20,000 Hz as shown in Fig. 5. CO_2, which has a dipole moment of 0.18, gave a maximum value of 19.1 mv. Dry N_2, which also does not have a dipole moment, gave a maximum of 8.1 mv.

Conclusions

The study of electromagnetic fields generated by turbulent air flow represents a new approach to the study of turbulence in complex flow. Electronic and magnetic probes may be used to study induced electromagnetic processes as they occur in turbulence, shock waves, and gas-surface interactions. Part of the energy in turbulent flow and shock waves is converted into electromagnetic radiation in regions of high shear.

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Recent Observations Including Temperature Dependence of Axisymmetric Jet Screech

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Nomenclature

c	= sound speed in ambient air
c_{sl}	= sound speed in shear layer
d	= jet exit diameter
f	= screech frequency
f_r	= reduced screech frequency, defined in Eq. (4)
$K_1, ..., K_5$	= constants in the empirical representations
PR	= pressure ratio (total pressure/ambient pressure)
PR*	= pressure ratio at the onset of choking
R	= gas constant for air
T_{amb}	= temperature of ambient air
T_e	= jet exit static temperature
T_0	= jet total temperature
T_r	= reference total temperature
γ	= ratio of specific heats
$()_T$	= quantity evaluated at temperature, T

Introduction

UNPUBLISHED investigations at ARL have indicated that jet screech phenomena can be used to increase the rate of entrainment by a confined jet. This was observed in a thrust augmenting ejector, where the screech of the primary jet drove an acoustic resonance within the mixing duct. In many ejector applications, the primary jet will be fed by hot engine exhaust gas. Therefore, it is desirable to quantify the dependence of jet screech of jet temperature.

Screech tones are emitted by sonic or supersonic jets operating at off-design pressure ratios. The acoustic frequency spectrum contains spikes at the screech frequency and its harmonics. Powell[1,2] has suggested a mechanism capable of explaining the occurrence of dominant frequencies. Briefly stated, he postulated the existence of stationary sound sources embedded in the cellular-flow structure which results from the off-design operation. The radiated sound waves travel upstream to the jet exit, destabilize the shear layer, and give rise to flow disturbances which are convected downstream. Each pass through a shock wave of the flow structure amplifies the disturbances. Ultimately, the disturbances attain sufficient strength to release a significant acoustic energy on traversing a shock wave. Since the waves are regularly spaced, only one fundamental signal frequency is amplified.

Powell investigated the screech emitted by an ambient temperature jet and established the dependence of the screech frequency on jet pressure ratio and characteristic dimension

$$f = K_1(c/d) / (PR - \mathrm{PR}^*)^{1/2} \qquad (1)$$

where: f = screech frequency, c = ambient speed of sound, d = jet exit diameter, PR = jet pressure ratio (total pressure/ambient pressure), PR* = jet pressure ratio at onset of choking, K_1 = empirical constant equal to ⅓ for axisymmetric jets. This expression provided an empirical fit to experimental data which contained a discontinuity in frequency. Powell applied two criteria in explaining the discontinuity. Based on considerations of the phase relationships between the sound waves and the flow disturbances, it was argued that the reinforcement necessary for a stabilized signal could be achieved only in a descrete number of flow conditions. This criterion was strongly linked to the distance downstream from the exit to the embedded sources. The second criterion demanded that the cycle amplification must equal or exceed unity. That is, the disturbance growth must compensate for losses in signal generation and transmission. The apparent discontinuities in dependence of frequency on pressure ratio were attributed to conditions failing to meet these criteria.

This Note presents an experimental investigation of the dependence of screech frequency on the total temperature of an axisymmetric, sonic airjet. In addition, some observations on the apparent frequency discontinuities are presented.

Experimental Apparatus

The experimental system consisted of an axisymmetric freejet, a variable temperature air supply, and a system to measure the sound power spectrum. The freejet had an exit diameter of 0.270 in. (1.06 cm). Air was supplied at either of three nominal temperatures: 60°F, 600°F, 1000°F (15°C, 315°C, 540°C, respectively), over a regulated pressure range exceeding six atmospheres. Pressure settings were held at specified levels to within ± ½%, temperature settings to within = 3%. A ½ in. diam Bruel and Kjaer condenser microphone was aligned at an angle of 30° upstream from the exit. The amplified signal was decomposed using a Tektronix 1L5 spectrum analyzer. Use of the manual frequency scan mode and a counter precisely identified the screech frequency for each operating condition.

Results

Figure 1 illustrates the experimentally determined variation of frequency with pressure ratio. Its form is in general agreement with Powell's expression, also shown on the figure. The deviation becomes substantial, however, for large pressure ratios. This is not surprising since Powell reported for a pressure range: PR < ~3.5. A better correlation is achieved by using an expression suggested by Merle[3]:

$$f = K_2(c/d) + K_3(c/d) / (\mathrm{PR} - \mathrm{PR}^*)^{1/2} \qquad (2)$$

where K_2 and K_3 are constants. This expression is also plotted in Fig. 1 with values: $K_2 = 7.7 \times 10^{-2}$, $K_3 = 0.38$. Of course, neither relation predicts the discontinuity in experimental data. A closer look at the frequency spectra for pressure ratios in the neighborhood of the step revealed an interesting behavior. The apparent sudden shift of frequency was actually a simultaneous decrease in the screech spike at one frequency and increase at another. That is, as shown in the insert of Fig. 1, for increasing pressure ratio a discernable spike diminished until it was no longer distinct at PR ≈ 3.8. Concurrently, beginning at PR ≈ 3.4, a spike of higher frequency appeared. The apparent discontinuity indicated in Fig. 1 denotes the pressure ratio at which the two spikes had equal

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