A Study of the Structure and Ultrasonic Emission of a High-Velocity Air Jet by High-Speed Schlieren and Shadowgraph Techniques

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A high-speed air jet creates an ultrasonic acoustic field which can be visualized by schlieren techniques. In this manner certain relations between the emitted frequency and the generating pressure can be determined. Furthermore, the shadowgraph method supplies, for a given pressure, two types of information according to the duration of the exposure: (1) With exposures of the order of one second one observes, by integration, a characteristic cellular structure. (2) With exposures of the order of one microsecond one observes this structure at a given moment, and — using an ultra-high-speed electronic camera (e.g. at 10^5 frames/sec) — a periodic oscillation of the jet is shown. It is found that this period is the same as that of the emitted frequency. If each single frame of the electronic camera is repeated a number of times on a film, it is possible to project all the details of these phenomena in slow motion.

AN AIR JET which issues at very high velocity from a tapered nozzle emits sound waves which are directly related to its structure.

The *waves* are observed by the schlieren method (which shows up their pressure gradients). See Fig. 1. There is one emission which is centered at the outlet hole of the nozzle and progresses in the flow direction; and another is centered at the point where the jet spreads out, its propagation being in the opposite direction. Both waves have the same frequency.

The *structure* of the jet, on the other hand, can be observed by the shadowgraph method (in which discontinuities of the pressure gradient are made evident). With exposures of the order of one second one observes, by integration, a characteristic cellular structure of a pressure interval; and with exposures of the order of a microsecond one may observe this structure at a given moment. See Fig. 2.

An ultra-high-speed electronic camera, which is used in addition to the usual methods of observation, makes it possible to study the evolution of these events. The camera equipment includes the following main components:

(1) A battery of 16 spark gaps. These serve as light sources and determine the duration of exposure — typically 2 μsec.

(2) A concave mirror which gives a distinct image of each light source.

(3) A series of camera objectives which give, on a

Presented on October 22, 1960, at the Fifth International Congress on High-Speed Photography in Washington, D.C., by François Canac and Marie Merle, Centre de Recherches Scientifiques Industrielles et Maritimes de Marseille, (C.R.S.I.M.), 66 Rue St.-Sébastien, Marseille (VI), France.

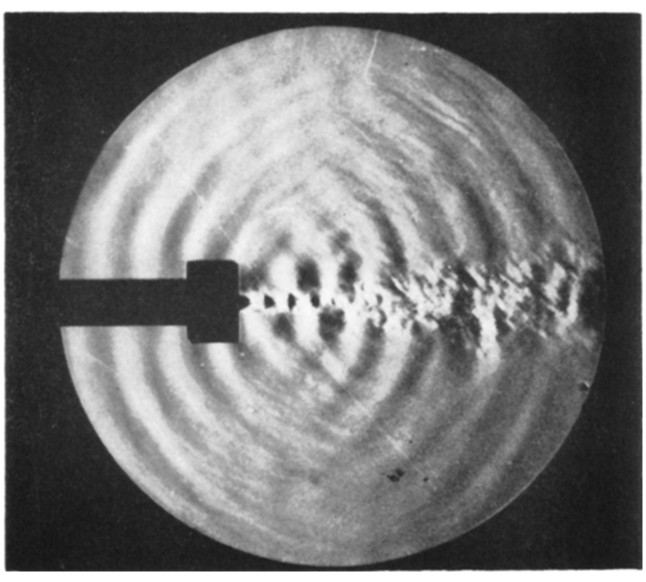

Fig. 1. Schlieren photograph of the sound field created by a jet of circular cross section.

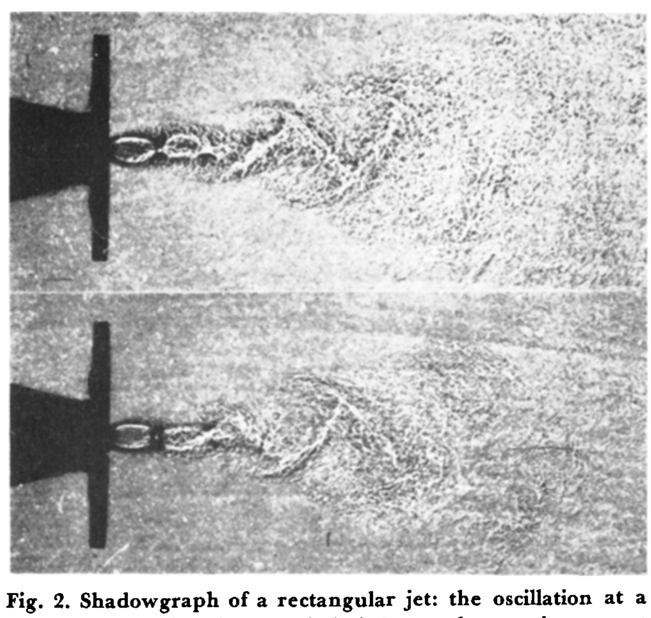

Fig. 2. Shadowgraph of a rectangular jet: the oscillation at a pressure of 4 kg/cm² has a period of 40 μsec; the two views are at opposite phases of the oscillation.

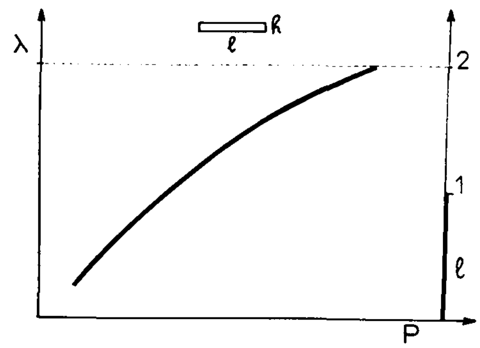

Fig. 3. Rectangular nozzle, of length *l*; curve of wavelength vs. pressure *P*.

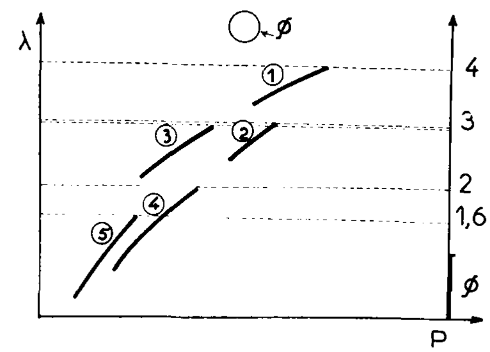

Fig. 4. Circular nozzle, of diameter ϕ; curve of of wavelength vs. pressure *P*.

single photographic plate, discrete images of the air jet placed in the field of view.

The equipment is employed for both purposes mentioned above, namely for schlieren observation and for recording shadowgraphs.

If we examine a two-dimensional jet we find that the wavelength of the emitted wave increases continuously with increasing pressure. There is, however, an upper limit equal to twice the length *l* of the rectangular aperture from which the jet issues. The nozzle functions, therefore, as a high-pass frequency filter. See Fig. 3.

The pressure-wavelength curve obtained with a circular nozzle is not continuous. Five successive segments, arranged in steps, can be distinguished. The upper limits of the wavelengths are approximately whole multiples of the nozzle diameter ϕ. See Fig. 4. Each part of the curve is, moreover, directly related to a characteristic structure of the jet.

By using an ultra-high-speed electronic camera operating at 10^5 frames/sec, it is possible to follow the progress and evolution of the jet in time. At any particular pressure, a very fast oscillation of the jet will be observed. One can determine its frequency which increases inversely with the pressure. Refer again to Fig. 2.

If each camera image is repeated (e.g., four times) on a film, it is possible to obtain a projection in which (with the motion slowed down about 17,000 times) the evolution and form of the jet and certain interesting details of its structure can easily be observed.

It will also be seen that the vibration of the jet is of the same frequency as that of the emitted sound. See Figs. 5 and 6.

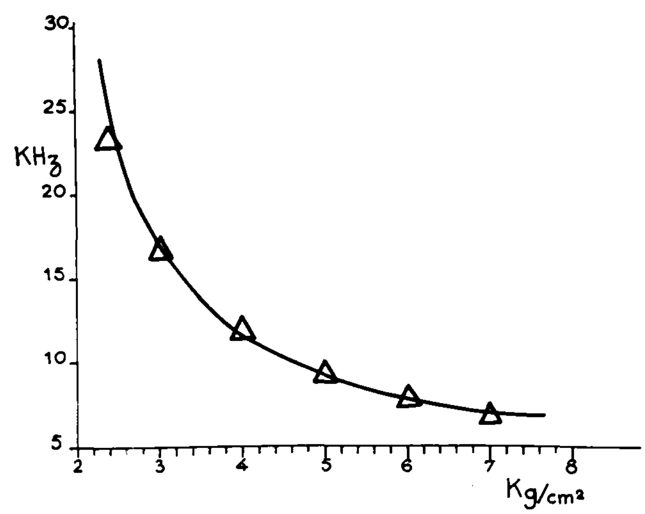

Fig. 5. Rectangular nozzle; frequency of emitted sound and frequency of oscillation as functions of pressure.

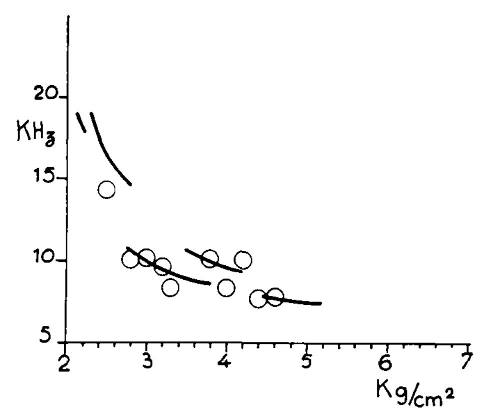

Fig. 6. Circular nozzle; frequency of emitted sound and frequency of oscillation as functions of pressure.