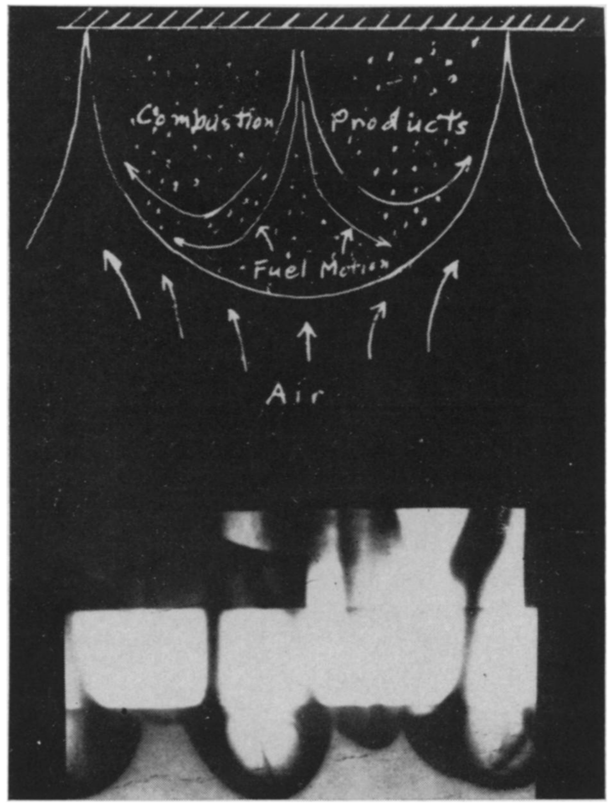


Applying a core discipline

Traffic, fire, air pollution and noise obey some of the same scientific laws that govern water flowing down a pipe

by Jonathan Eberhart

There was a time when fluid dynamics meant simple things like how to avoid putting kinks in the plumbing. In its early days as a science, it confined itself largely to the theorist's so-called perfect fluid, 100 percent incompressible and 100 percent homogeneous, analyzing the actions and interactions of idealized fluids in pipes, pans and other containers.

In recent years, however, researchers have been turning the analytical techniques of fluid dynamics to a broad variety of practical problems, ranging from traffic to air pollution and from jet noise to flash fires. A mass of cars and a cloud of smokestack effluents show many of the characteristics exhibited by a true fluid; both, for examample, are either compressed or spread if an obstacle appears while the upstream pressure remains undiminished.

At a meeting of the American Physical Society in Washington recently, a special symposium on fluid dynamics and urban problems revealed the scientists' view that, although the field is making a contribution, it is still far from realizing its full potential.

Accidental fires are a case in point, says Dr. Howard W. Emmons of Harvard University, who maintains that fire-prevention research is largely ignoring the fundamental physical approach that fluid dynamics can offer.

He does not find this surprising, however. "It's like tying your shoe," he says. "If you notice that your shoe is loose, what do you do? You try a few knots before you go and study knot theory." The fire researchers, according to Dr. Emmons, are just getting past those early knots.

Fire is about the most complex fluid of all, he says, far removed from old perfect fluid ideas by radiation, diffusion, conduction and other effects. A fire on the underside of a ceiling, for example, would be expected by crude, simplistic analysis to burn in a smooth layer, like a coat of paint. But it doesn't. Instead, it burns in irregular, turbulent bubble-like shapes, due to interactions between the rising air from below and the combustion products expanding downward in many directions from the ceiling.

Solving such puzzles, says Dr. Emmons, requires research into the fundamental nature of the fluid mechanics of fire. There is plenty of technique and theory available from fluid studies, he says, but the little applied work that has been done has been confined to idealized situations in idealized empty rooms.

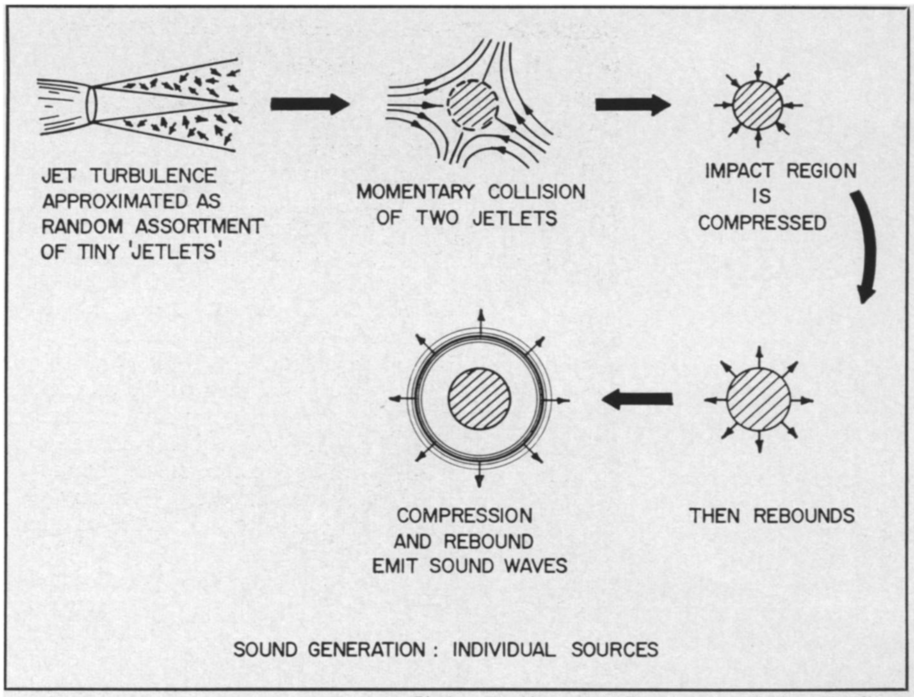
But research, like the war in Vietnam, takes money. "Your neighbor's house is burning brightly," he says. "Will yours catch fire too? Somebody is going to have to face this as a serious social problem and put up the dough."

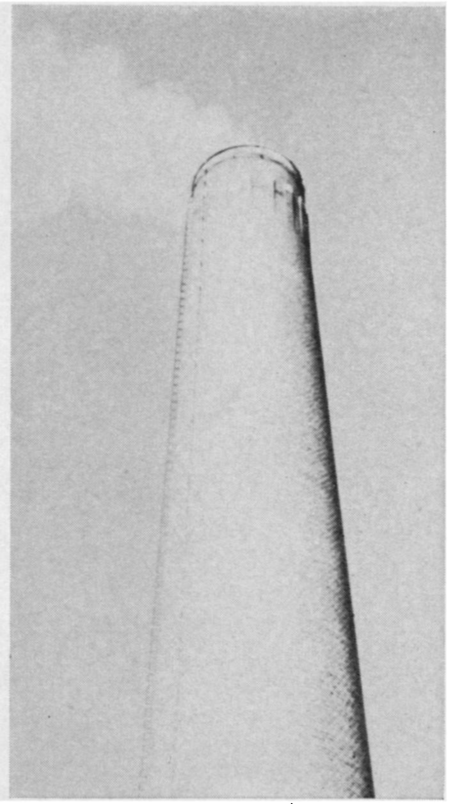
The same financial problem inhibits fluid dynamic research into the growing problem of air pollution, according to Pennsylvania State University meteorologist Hans A. Panofsky. (Tight money, in fact, though always a problem for scientists, has recently become such a common complaint at scientific meetings that it is being reduced to the status of what could be called background radiation.)

Open areas and small, low-built towns, Dr. Panofsky says, can get by perhaps with the simple fluid theory that exists today. The altitude, height of smokestacks, wind speed and a few other variables can provide rough analyses of where pollutants come from or where they are expected to go. Large cities, however, with great numbers of tall buildings and other obstacles to unobstructed flow, need sophisticated mathematical constructions to account for fluid movements in such irregular, turbulent spaces. For actual tracing of pollutant build-up, heat flow and other factors, simplified studies such as those with wind tunnel models become increasingly inadequate.

Where early fluid dynamicists might have concerned themselves with understanding the simple pressure changes at the intersections of a network of liquid-carrying pipes, the meteorologist faces a much greater problem in judging the movements of pollutants from a smokestack, for example. Winds, representing fluid pressures from different directions, can be affected by terrain or other features hundreds of miles away. Variations in heat loss rates over different kinds of surface can cause complicated vertical spreading.

Noise is a different kind of fluid dynamics problem. Its movements do not correspond with those of the air that carries it, nor does it always bunch up at bottlenecks or compress around obstacles as more obvious fluids do. Yet





Photos: Dr. Howard W. Emmons; Dr. Herbert S. Ribner

Fire bubbling beneath a ceiling (left), the noisy interactions of jet exhaust particles (center) and wind-blown, pollution-rich fumes from industrial smokestacks (right) are being scientifically analyzed with new insight, as fluids.

it responds to fluid dynamic laws in its own way, with implications ranging from high-fidelity sound quality to jet engine and sonic boom noise.

Dr. Herbert S. Ribner of the University of Toronto compares a room to a pail with a leaky bottom. Water pouring into the pail becomes sound entering the room; water leaking out the bottom becomes sound being absorbed by rugs, furniture and other objects. With water both pouring in and leaking out, the pail fills up to a certain level at which the inflow and output balance. In a room, this balance point, which Dr. Ribner calls the reverberant level, will be relatively high in a concrete basement with no rugs (a relatively non-leaky pail) compared to a fully carpeted and well-curtained room (a leakier pail).

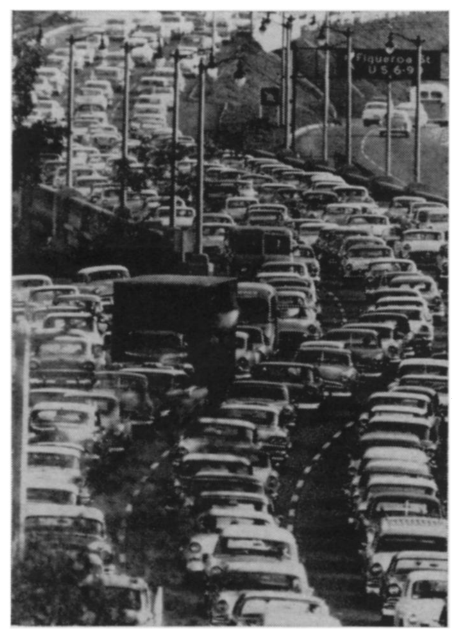
In designing an office building, for example, the problem of sound being carried between rooms is analogous to a pail divided in half by a slightly porous partition. Noise in one room (water poured into one side of the pail) is partly absorbed there (water draining out the bottom), but part of it is transmitted through the wall (the partition in the pail). Thus, reducing the sound flow between rooms requires minimizing sound transmission as well as designing in absorption—which means that acoustic tile and other good absorbants, while necessary, are no substitute for solid, massive walls.

The fluid study of noise extends far higher than the walls of a room, however. A roaring jet engine, for example, is more to a fluid dynamicist than merely a metal cylinder that must be insulated to keep it quiet. The fluid dynamics view is of the engine's exhaust itself as the core problem.

The exhaust stream, says Dr. Ribner, is not just a homogeneous mass, all of which is moving outward from the back of the engine. Within the stream are millions of what the Canadian scientist calls jetlets: minute collisions between particles, causing compressions and sudden expansions which force the particles violently apart in all directions. Superimposed on that motion is the main convection of the engine, forcing all the small motions downstream. In addition, refraction due to the varying net velocities of the particles through the atmosphere produces varying degrees of bending in the particles' trajectories.

Without the other motions, the jetlets alone would produce a simple spherical exhaust cloud, or noise source. Downstream convection stretches this into an eggplant-shape, and refraction distorts the eggplant into a pear-shape, with a depression at the large, rearward end. This kind of analysis can benefit noise reduction and engine efficiency research by helping engineers pick the exhaust outlet design that will lead to a desirable set of composite motions.

Highway designers have been using fluid dynamics for several years to plan the locations of intersections, islands and other obstructions, by treating the traffic as though it were a fluid flowing down a pipe. Intersections are branches in the pipe, and varying traffic conditions at different times of day are analogous to different fluid pressures.



Los Angeles County Air Pollution Control

Heavy traffic: Like water in a pipe.

Fluid dynamics can be applied to virtually anything that flows as an amorphous mass, such as water, air or fire, or to any groups of individual items that are abundant enough to be analyzed statistically. Some applications to which fluid dynamics could apply may seem like methodological overkill—laying out irrigation ditches, for example—but the growing number of practical uses indicates that man is at last learning the scientific way to tie his shoe. ◇