The Winds in Lilliput

Wind engineers are using wind tunnels and scale models to simulate the effects of natural winds in cities and on structures

by Kendrick Frazier

In Maui, Hawaii, smokestacks of a power plant can be seen to lay a visible blanket of dirty effluents over the local terrain. The stacks are increased in height from 100 feet to 225 feet, and the emissions become sufficiently dispersed in the atmosphere to meet Federal air pollution regulations.

In downtown San Francisco, one of the buildings in a multistructured urban development complex known as the Yerba Buena Center is designed to rest on 40-foot-high stilts, with an open space beneath. But study reveals an amplification factor that produces dangerous winds through the open space that are two to three times faster than at the top of the building. The stilts and open space are eliminated.

In Denver, an inversion layer traps all pollutants released within a few hundred feet of ground level, producing a dramatically visible shroud of stagnant air. But the stagnant air flows downslope along a freeway, which tends to suck the air in from built-up areas along its margins and acts like a ventilation duct for the city.

In New York City, the effect of 150-mile-an-hour hurricane winds on the 1,400-foot-high twin towers of the World Trade Center are measured, and as a result 10,000 damping devices are added to the buildings to reduce their sway to a point not noticeable by their occupants.

These four studies, and dozens of others like them, took place not in the cities mentioned but in a unique laboratory facility nestled at the base of the foothills of the Rocky Mountains on the west edge of Fort Collins, Colo. The cities, buildings and exhaust stacks were scale models placed inside one of three specially built wind tunnels in the fluid mechanics and diffusion laboratory of Colorado State University.

The laboratory has become a national center for a new and developing field of research known as wind engineering. Wind engineering is concerned with the interactions between wind and either man-made structures (from single-story homes to hundred-story office buildings) or natural geographical features (such as hills, mountains, valleys). It draws upon knowledge from many fields: civil and structural engineering, meteorology and climatology, fluid mechanics and aerodynamics, and theoretical and applied mechanics.

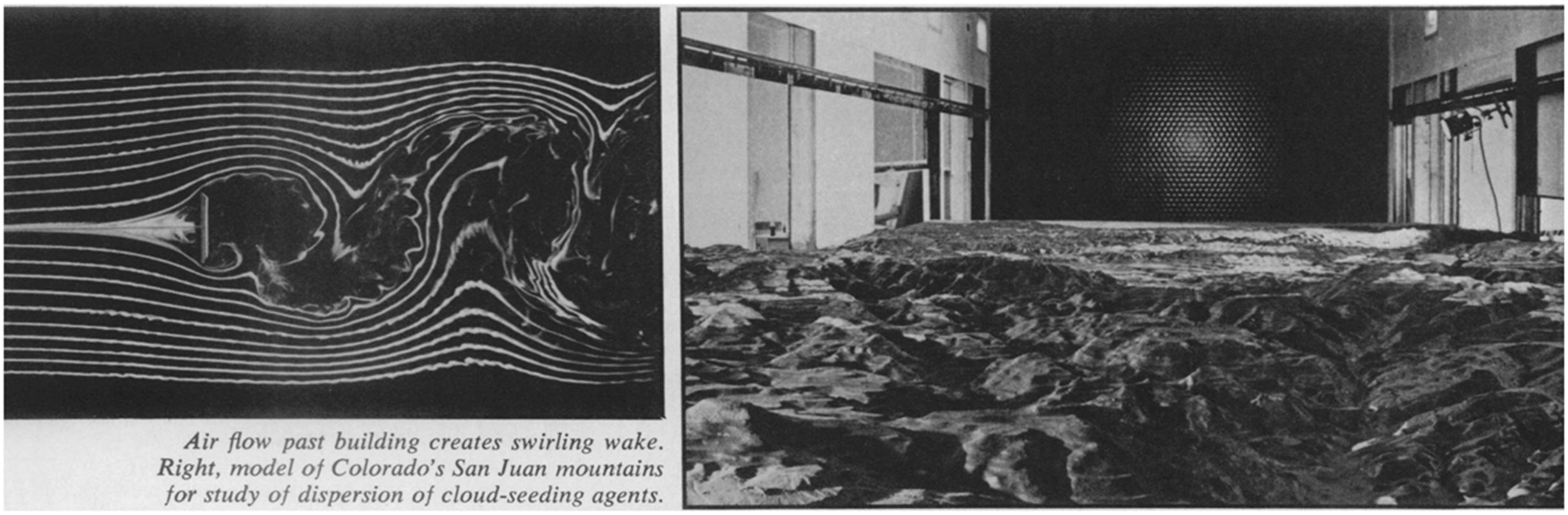
Wind has become a major factor of concern to engineers in the last decade. One reason is the trend toward construction of tall, slim office buildings that are low in mass, have little inherent damping designed into them, and are covered by large expanses of glass and thin metal panels. As dramatically demonstrated by the notorious case of the John Hancock Center Building in Boston, which lost a good share of its windows due to unusual effects of wind and air pressure, wind loading needs to be of primary importance in the design of tall structures.

As population density increases, property damage from hurricanes and tornadoes has risen sharply, and the need to make buildings more resistant to such severe winds has become evident. Lesser winds cause millions of dollars damage to small buildings, such as single-family homes and apartment buildings, each year. Specialists in wind engineering believe if more consideration were given to wind loads in their design and construction, the damage toll could be cut.

The desire to make cities better places for people to live and work has intensified attempts to reduce adverse affects of wind, especially the movement of air pollutants, human discomfort from wind gusts, and aerodynamic

A 1:4,000 scale model of Fort Wayne, Ind., in CSU's environmental wind tunnel for pioneering study of heat-island effects on circulation of air pollutants. Heating elements provide surface-temperature distributions similar to those in city.

Photos: J. E. Cermak



Air flow past building creates swirling wake. Right, model of Colorado's San Juan mountains for study of dispersion of cloud-seeding agents.

noise (wind whistling through corridors and elevator shafts, for instance).

All these reasons have made wind engineering an important new field and caused the fluid dynamics laboratory at CSU to be a busy place. The laboratory has a vigorous program of basic research (supported by the National Science Foundation and four or five other Federal agencies) and applied research (sponsored by architectural firms, consulting engineering firms, municipalities and Federal agencies). One of the strengths of the laboratory is the presence at the university of a respected atmospheric sciences department, with which it work closely.

If you live in a medium to large city in the United States, there is a good chance part of it, in the form of scale models, has been inside one of the laboratory's three large wind tunnels. Floors, tables and hallways throughout the laboratory are covered with scale models (a 1:500 scale is typical) of the likes of downtown Atlanta, Fort Wayne, Tulsa, Miami or Houston, waiting their turn inside one of the tunnels.

Often just one building in the city is the subject of the study, but the model must include all major upwind buildings since they create wakes that alter the wind that reaches the building. A model may cover an area of 100 square feet or more.

A prime reason for the Colorado laboratory's prominence in wind engineering research (NSF has termed its facilities "the best available in the United States") is Jack E. Cermak, a silver-haired, 52-year-old professor of civil engineering and professor-in-charge of the fluid mechanics program. Cermak might be called "Mr. Wind Engineering." He has pioneered the use of wind tunnels for wind engineering research. Sixteen years ago he designed the first wind tunnel specifically made to simulate the diverse characteristics of natural winds.

Cermak has become a strong promoter of the need to give more attention to wind engineering in the United States. "This whole area of wind engineering has been neglected very sadly in this country," he laments.

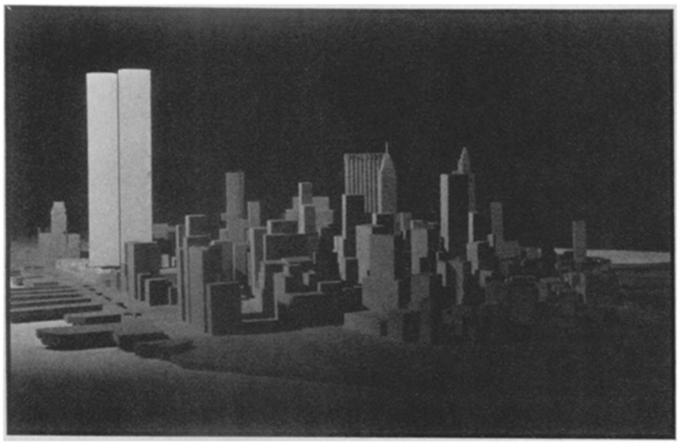
Cermak is the U.S. and Canada regional editor of a new journal of wind engineering research published in Amsterdam. It's titled the International Journal of Industrial Aerodynamics, which is what the field is called in Europe, a term Cermak believes is misleading and overly narrow.

The National Academy of Engineering has created a panel to do a two-year NSF-supported study of the status of wind engineering research in the United States and to recommend guidelines for future research. Not surprisingly, the chairman of the panel, which held its first meeting in Washington in August, is Cermak. "One purpose of the NAE study," he says, "is to try to bring the field up to a level of respectability."

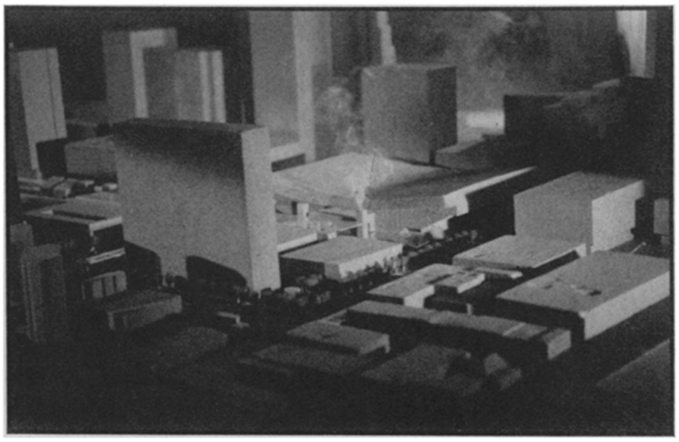
The pride and joy of Cermak and his colleagues (including Robert N. Meroney, Jon A. Peterka, Willy Z. Sadeh and V. A. Sanborn) at CSU is a special meteorological wind tunnel capable of simulating natural wind conditions in sophisticated detail. Wind speed and air temperatures can be varied for different levels of elevation, for instance, and air pressure can be varied along the direction of wind flow.

"There's no other facility like it in the world," says Cermak. Its unique features are a long test section (88 feet), flexible ceiling, and provisions for heating and cooling both the air and the floor at different points. It is powered by a 250-horsepower motor capable of generating 90-mile-an-hour winds inside the 6-foot-square tunnel.

Among the things Cermak and his



New York's World Trade Center had excess sway corrected.



San Francisco's Yerba Buena Center showed wind problems.

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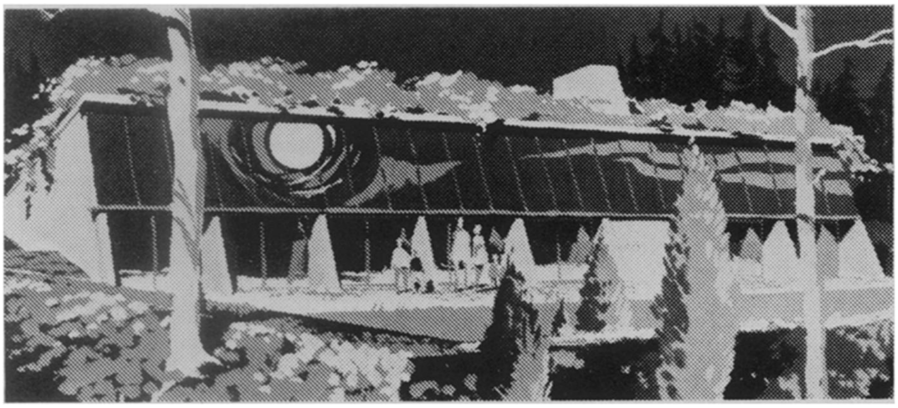

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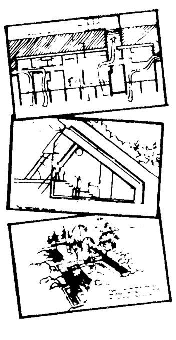

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colleagues can do with the meteorological wind tunnel is to cool the floor and heat the air to create a temperature inversion, trapping a layer of stagnant, polluted air down close to the ground. Then they watch what happens to it, visualizing the air flow by injecting chemical smoke into it, documenting the effects with still photos and movie film. The previously mentioned study making use of a scale model of downtown Denver used this technique.

The observations showed not only that the freeway through Denver acts like a ventilation duct for otherwise stagnant air but also that a row of new buildings perpendicular to the approaching wind acts as if it were a dam and diverts air into the freeway system. "A noteworthy result of this behavior," Cermak reported, "would be the diversion of pollutants from upwind sources onto the freeway rather than into the densely populated region."

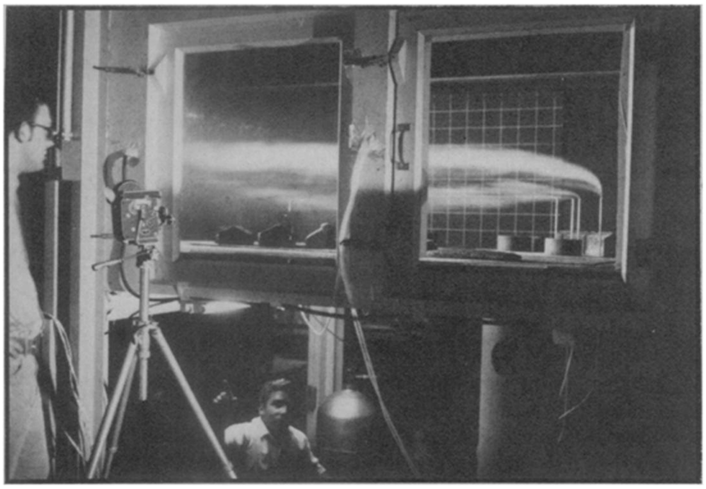
The laboratory also has an industrial aerodynamics wind tunnel with a 60-foot-long test section and an environmental wind tunnel with a 52-foot-long test section. It is much simpler than the meteorological tunnel, and it has no thermal controls, but its wide cross section (12 feet) permits more extensive urban areas to be modeled without any further reduction in scale.

According to Cermak, the only possible way to predict the wind forces on a tall building is through measurements on a scale model in a simulated wind. Tall buildings cause strong gusty winds at street level. High winds at upper levels produce pressures on the upper parts of tall buildings often four times as great as at street level. This drives the air downward. Winds frequently blow down the face of tall buildings at speeds up to 30 miles an hour, often creating havoc for pedestrians on the sidewalks below.

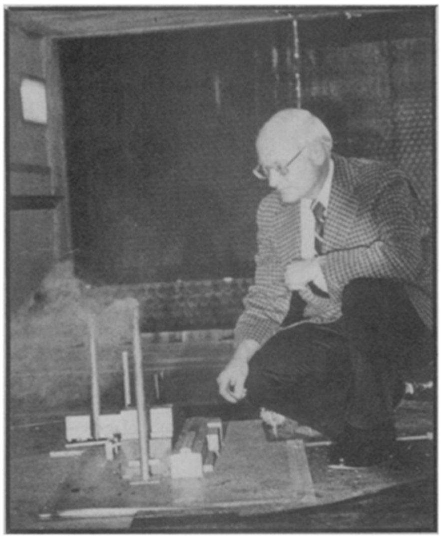
Of course, on the downwind side of tall buildings, the air pressure is less than normal. This can produce an upward air flow. All these vertical winds are usually undesirable because of their action on pedestrians. But at least one structure, the new Qantas building in Melbourne, Australia, was purposely oriented to maximize induced winds during the summer months in an effort to bring cool air from aloft down to street level.

Cermak refers to tall buildings as "vertical stirring rods," helping to move stable, stagnant air. "As tall buildings become taller and more numerous," he says, "it is conceivable, with careful planning, they may be utilized to augment vertical mixing in a city and thus produce a favorable effect upon air-pollution concentration."

By simulating winds on scale models of tall buildings, wind engineering specialists try to identify wind-related



Observing effects of different stack heights on dispersion of air pollutants from Maui, Hawaii, electrical power plant, left. Below, Cermak with model of power plant near Cleveland.



problems in time to be remedied not during the expensive construction process but in the earlier design stages. New York's World Trade Center Towers were modeled in CSU's meteorological wind tunnel before completion of the design. Building sway great enough to be noticed by occupants was predicted, and damping devices were able to be incorporated into the design to alleviate that problem. The study showed that having twin towers rather than a single tower produced no adverse effects.

Scale model studies of the Atlantic-Richfield Towers in Los Angeles enabled better designs to be made of its "skin." The dry Santa Ana winds, with speeds up to 100 miles an hour, were of special concern at that site.

Other tall buildings studied in CSU's wind tunnels include the Bank of America World Headquarters Building in San Francisco, the Standard Oil (Indiana) World Headquarters Building in Chicago, and the proposed Sun Tower in Miami.

The wind tunnel studies on the model of the earlier mentioned Yerba Buena Center in San Francisco identified a variety of wind-related design problems. The amplification of winds beneath the Market Street Building, originally designed to be on stilts, was one of the worst. But a serious problem with inadequate dispersal of automobile exhausts from an underground parking garage was also foreseen. The study used radioactive krypton 85 as a tracer gas to monitor what would happen to auto exhaust pollutants emitted from the garage's exhaust stacks. The study found that the worst situation would result after a late afternoon event at an adjacent sports arena, when cars would be exiting from the garage while people would be congregated below two low exhaust stacks. Cermak and his colleagues recommended that the two short stacks be designed at taller heights.

A somewhat similar situation was discovered during CSU wind tunnel studies of wind pressures and air quality around a proposed facility at Children's Hospital, National Medical Center in Washington, D.C. The studies showed that exhaust gases from the underground parking garage would flow up one side of the hospital building. As a result, the building was designed with no air conditioning vents and no openable windows on that side.

Wind and air quality conditions obviously vary enormously from one proposed building site to another. But from the experience he and his colleagues have gained from their wind tunnel studies, Cermak has this advice for urban planners: "In developing a new city center, it's desirable to space the tall buildings so that you have 50 to 60 percent open area. This avoids the feeling of city canyons, provides good ventilation, allows more sunlight, and makes possible more trees to dampen the winds."

Cermak sees a bright future for wind engineering in the United States. "I look forward to the time when there will be an option in civil engineering departments allowing students to choose wind engineering as a specialty just as they can hydraulics now. It's a very fertile and much-needed field." □