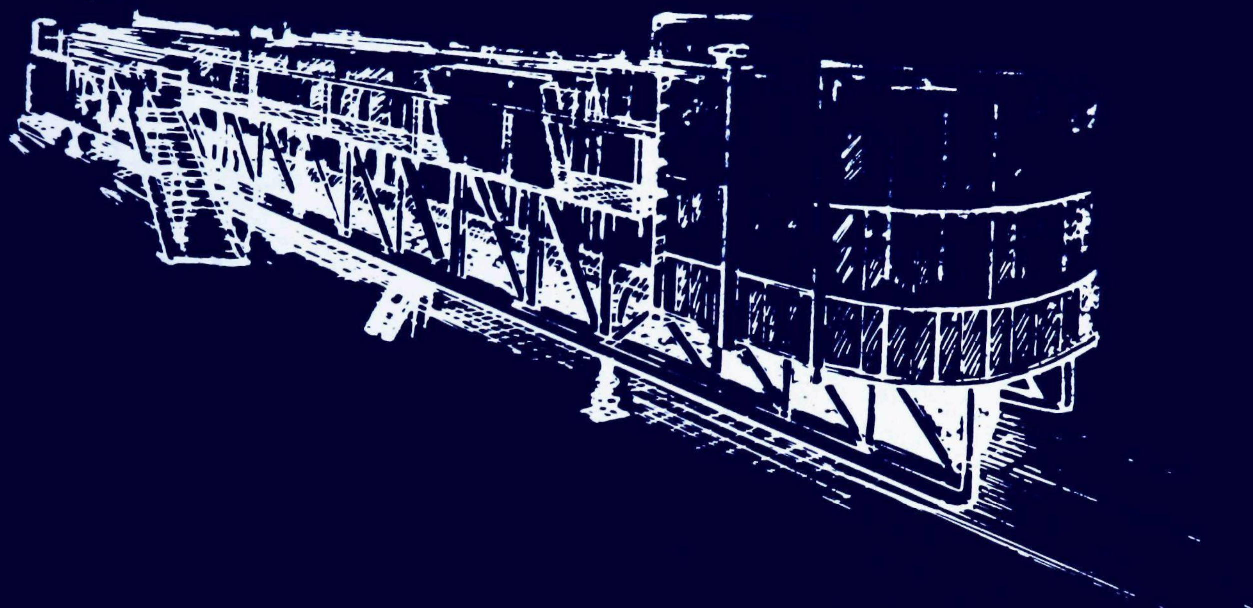
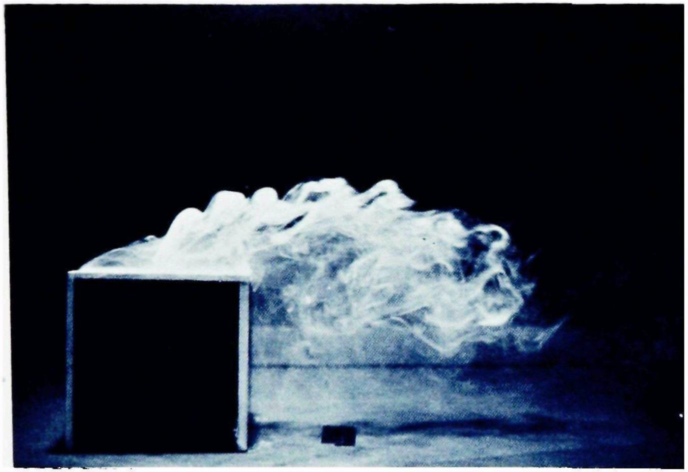
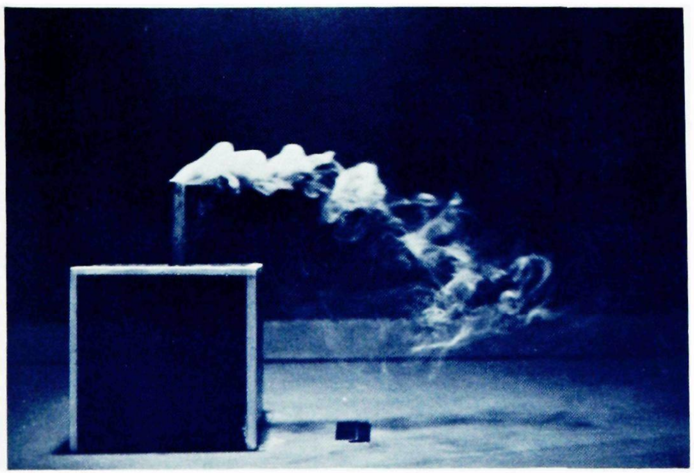


Fluid Modeling Facility

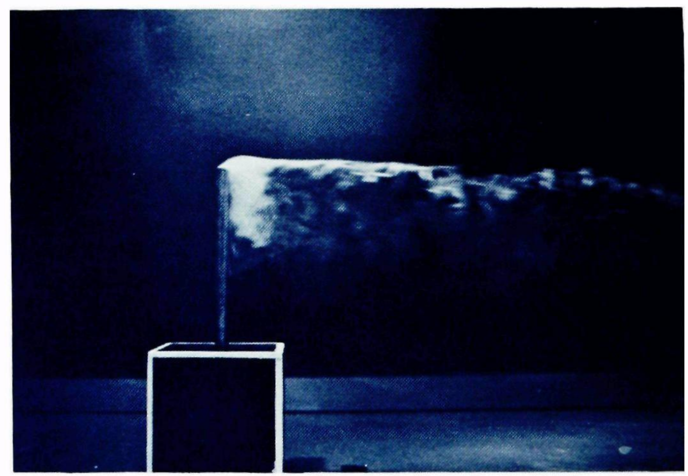
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NORTH CAROLINA 27711



Smoke visualization study shows rooftop exhaust being trapped in airflow wake behind cubical model.



Plume from short stack collects in airflow wake behind model.



Plume from tall stack having low exit velocity produces downwash behind stack.

600R77004

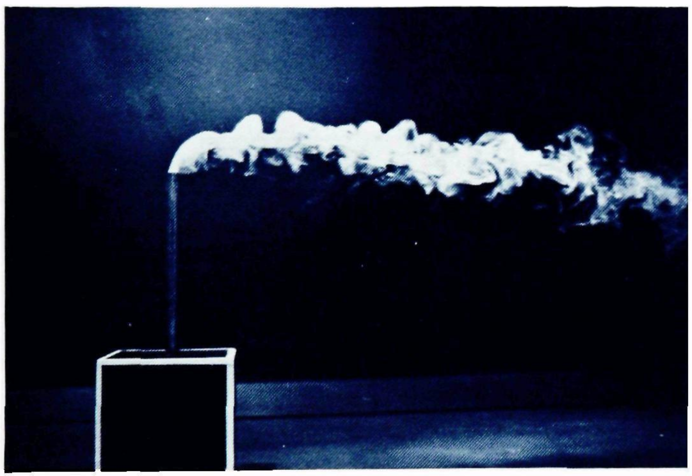
Introduction

Pollutants from a variety of sources are constantly emitted into the atmosphere where meteorological forces transport, diffuse, or otherwise affect their concentrations. Because the U.S. Environmental Protection Agency is charged by Congress with establishing and enforcing air pollution control standards to protect the public health and welfare, it conducts research programs to describe and predict the effects of atmospheric phenomena on emissions.

Measurement of pollutant concentrations at a specific site is relatively simple—instruments merely collect samples at various locations. Prediction of pollutant levels, however, requires knowledge of the characteristics and emission levels of the pollutant and the atmospheric characteristics that influence pollutant dispersal.

An effective method of characterizing atmospheric diffusion involves placing a carefully constructed model of a pollutant source, such as an industrial plant, in a chamber where, using wind or water, an accurate representation of the atmosphere can be reproduced. Examination of the effects of these artificial atmospheres on model pollutant emissions provides researchers with a greater understanding of the interaction of meteorological factors and air pollution.

To carry out this type of research, EPA's Meteorology and Assessment Division has established a Fluid Modeling Facility, which features several wind tunnels, a water channel-towing tank, and support facilities.



Plume from tall stack having sufficient exit velocity remains aloft to disperse smoke.

Wind in the atmosphere is a highly complex, constantly changing phenomenon that—along with stack height, surface terrain, and other factors—affects the diffusion of pollutants in the atmospheric boundary layer. This layer is that region of the atmosphere close to the surface of the earth (600 meters) in which meteorological factors and surface topography influence the flow. For the casual observer, an easy method of visually relating pollutant emissions to meteorological effects is through the examination of the exhaust plume from an industrial smokestack. Harmful pollutants, which may be present in the plume, can be diluted to safe levels by mixing with the air as it moves away from the stack or can rapidly drop to the ground and adversely affect the health of residents near the source.

Both wind speed and direction change with time—from one instant to the next, from one hour to the next, and from one day to the next. Meteorologists have found that wind effects can be separated roughly into two scales of motion: large-scale motions that last an hour or more (weather), and small-scale motions that last less than an hour (turbulence).

These two types of motion can often be seen by studying a smokestack plume for a period of time. At any given instant, the centerline of the plume will normally form a reasonably straight line after its initial bending over at the stack top and in the absence of obstruction to its motion. This straight centerline indicates a reasonably constant wind direction. Spreading of the plume—caused by smaller scales of motion called gusts, eddies, or, more generally, turbulence—occurs as the plume travels downwind. It is these smaller scales of motion, with mean wind speed and direction remaining constant for approximately one hour, that can be simulated in a wind tunnel or a water channel.

The rate of dilution in the plume, however, can vary drastically from one day to the next even if wind speed and direction remain constant. This variability is related to atmospheric stability coupled with solar heating

*METHODS FOR PREDICTING POLLUTANT FLOW AROUND STRUCTURES**

	MATHEMATICAL MODELS	FLUID MODELS	FIELD PROGRAMS
ACCURACY	GOOD	BETTER	BEST
RESOLUTION	COARSE (20 m)	INTERMEDIATE (3 m)	FINE (1 m)
TIME	SHORT (2 TO 4 weeks)	SHORT (2 TO 4 weeks)	LONG (1 year)
COST	MODERATE ($25,000)	LOW ($10,000)	HIGH ($100,000)

NUMBERS REPRESENT ONLY ROUGH ESTIMATES (COMPARATIVE ORDERS OF MAGNITUDE) FOR SPECIAL CIRCUMSTANCES; THEY MAY NOT BE USED FOR INTERPOLATION, EXTRAPOLATION, OR IN ANY OTHER WAY AS A BASIS FOR ESTIMATION.

or radiative cooling of the ground and results in the fanning, coning, fumigating, lofting, or looping of the plume. Because local topography also influences turbulence, plume behavior for a given specific stability, wind speed, and wind direction may still be drastically different if a tall building or hill is located in the vicinity of the stack.

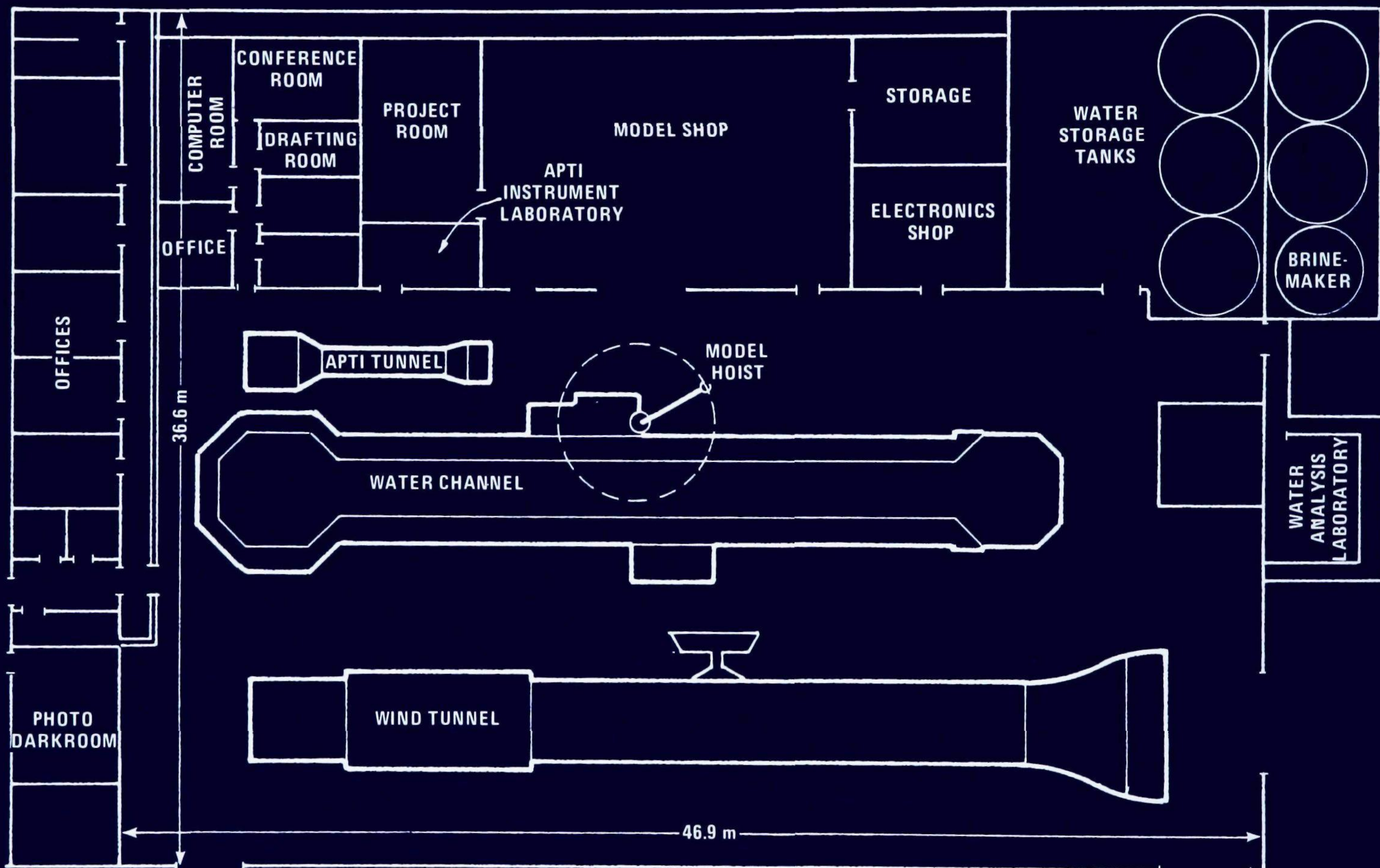
EPA's primary interest in the modeling of atmospheric diffusion processes is an outgrowth of the establishment of National Ambient Air Quality Standards, which are the maximum levels of a given pollutant that are permitted in the ambient air. Control techniques, which are applied to sources of pollution, and control strategies, which determine the necessity for controlling respective sources, are used to assure that pollutants emitted into the atmosphere do not exceed these maximum levels. The dispersal of pollutants to and at ground level, however, depends on atmospheric diffusion and transport. To assure that ground-level concentrations are kept within the standards, three methods are available to predict the likelihood of exceeding an air quality standard at a particular location:

- Mathematical models can be used to evaluate alternative control strategies, but they require gross simplifications. These models are not exact because the fundamental fluid dynamics processes involved in the dispersal are not sufficiently understood and because computer memories are still far too small to keep track of the detailed eddy motions that occur in the atmosphere. Moreover, present mathematical models are not yet adequate for calculating concentrations of contaminants when the plume is strongly affected by obstructions.

- Field programs apparently provide the most reliable results but are very expensive and time consuming. Because meteorological conditions are not controllable, study periods in excess of a year must be spent in the field to obtain a proper range of conditions, and even then specific sets of conditions may not occur. Furthermore, it is impossible to investigate the impact of potential changes in alternative control strategies for a source by means of field programs.

- Fluid models appear to work best where mathematical models fail, that is, where obstructions such as buildings and hills block wind flow. Fluid models also show great promise for simulating surface-induced airflows such as heat island circulation and mountain valley winds. Atmospheric conditions may be programmed into a fluid model so that years of field time are reduced to a few weeks. Fluid model studies can reduce the resources required for field studies and facilitate the development of better mathematical models.

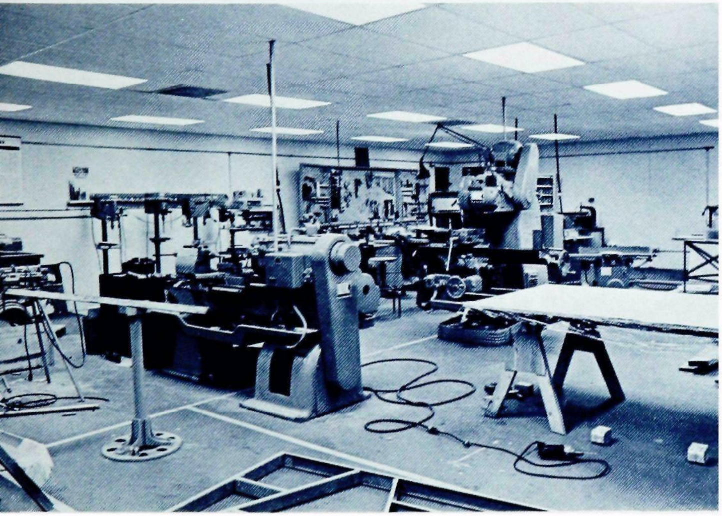
A complete research program includes comparison and feedback among the three methods in order to gain a deeper understanding of the processes associated with atmospheric transport and diffusion of pollutants.

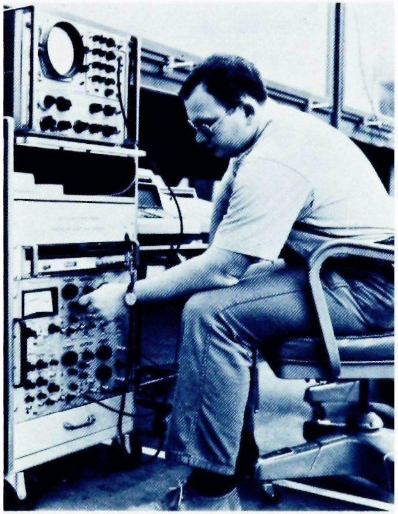


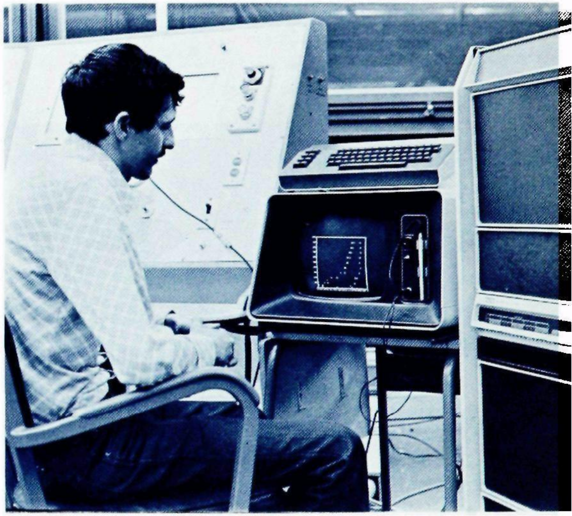
CONFERENCE ROOM
COMPUTER ROOM
DRAFTING ROOM
PROJECT ROOM
MODEL SHOP
STORAGE
WATER STORAGE TANKS
APTI INSTRUMENT LABORATORY
ELECTRONICS SHOP
OFFICE
BRINE-MAKER
OFFICES
APTI TUNNEL
MODEL HOIST
36.6 m
WATER CHANNEL
WATER ANALYSIS LABORATORY
PHOTO DARKROOM
WIND TUNNEL
46.9 m

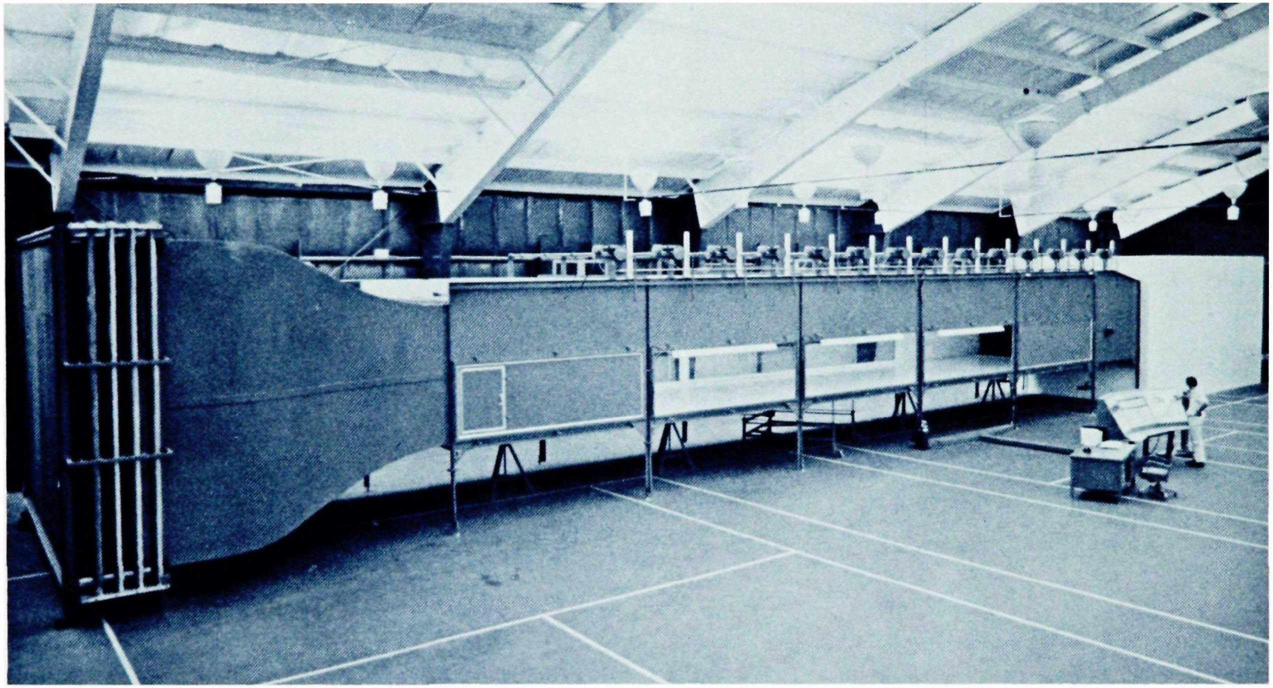
Components of Facility

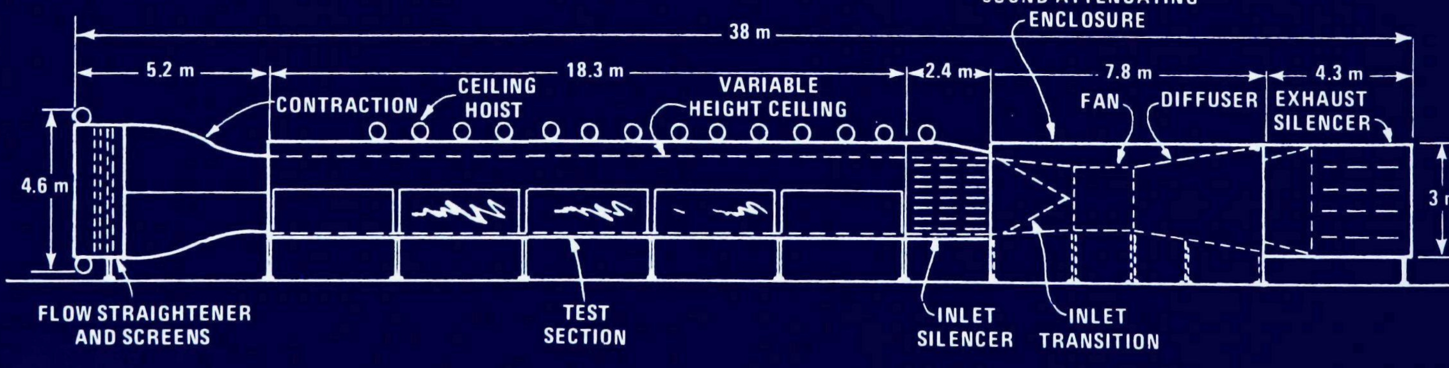
The Fluid Modeling Facility, one of only a few atmospheric dispersion modeling facilities in the world, is available to all EPA organizations, to other Federal agencies, and to state air pollution control agencies. A water channel-towing tank, a meteorological wind tunnel, and an instrument calibration wind tunnel represent the basic components of the facility. In addition, the facility includes a model shop, an electronics shop, a darkroom, and a chemical laboratory. A minicomputer, including an analog to digital converter, magnetic disk and tape drives, electrostatic printer-plotter, and a CRT display unit, is available for real-time data acquisition and analysis. Flow rates and concentrations are measured by various electronic, chemical, and mechanical equipment. The staff includes professionals trained in environmental fluid dynamics, model makers, computer programmers, and laboratory and electronic technicians.










SOUND-ATTENUATING ENCLOSURE
38 m
5.2 m
18.3 m
2.4 m
7.8 m
4.3 m
CONTRACTION
CEILING HOIST
VARIABLE HEIGHT CEILING
FAN
DIFFUSER
EXHAUST SILENCER
4.6 m
3 m
FLOW STRAIGHTENER AND SCREENS
TEST SECTION
INLET SILENCER
INLET TRANSITION

Meteorological Wind Tunnel

SPECIFICATIONS

	METEOROLOGICAL WIND TUNNEL	APTI WIND TUNNEL
DIMENSIONS		
OVERALL LENGTH	38 m(125 ft)	11 m (35 ft)
TEST SECTION LENGTH	18.3 m (60 ft)	3 m (10 ft)
TEST SECTION WIDTH	3.7 m (12 ft)	1 m (3 ft)
TEST SECTION HEIGHT	2.1 m (7 ft)	1 m (3 ft)
CONTRACTION RATIO	2.8:1	4.5:1
TOTAL POWER	75 kW (100 hp)	20 kW (25 hp)
TYPE OF POWER	1.8-m (72-in.) AXIAL FAN	1.2-m (48-in.) AXIAL FAN
SPEED CONTROL	AC MOTOR WITH EDDY CURRENT COUPLER	DC MOTOR WITH SCR CONTROL
SPEED	0.5 TO 10 m/sec (1.5 TO 30 ft/sec)	0.3 TO 21 m/sec (1 TO 70 ft/sec)

A meteorological wind tunnel differs in two basic respects from an aeronautical wind tunnel. First because the top of the atmospheric boundary layer is usually much higher than the buildings immersed in it, the simulated boundary layer in the meteorological wind tunnel must be quite deep in order for the model buildings to be of reasonable size. In tests in an aeronautical wind tunnel, on the other hand, great care is taken to minimize the depth of the boundary layer. Second, high wind speeds are generated in aeronautical wind tunnels to compensate for the reduced size of the models. In meteorological wind tunnels, however, wind speeds generally are reduced so that buoyancy effects, which are very important in atmospheric flows, can be reproduced.

In operation, models are placed on a turntable that can be rotated to simulate different wind directions, and smoke is released from model stacks for flow visualization studies. Air is drawn into the tunnel through a flow-straightening honeycomb, and "vorticity generators" trip the flow at the entrance to the test section to create a thick boundary layer, which simulates that of the atmosphere. If quantitative concentration measurements are required in the study, hydrocarbon gas is used as a tracer in the stack gas, and samples are taken at various locations in the test chamber. The air is exhausted back into the room.

The ceiling of the test section is adjustable to compensate for blockage effects of the model. Acoustic silencers minimize the noise from the fan. An instrument carriage provides for three-dimensional positioning of measuring probes anywhere in the test section by remote control and with readout to within ± 1 millimeter.

A smaller wind tunnel, which belongs to the Air Pollution Training Institute (APTI), is available for the calibration and response testing of wind-measuring instruments and smaller scale studies.

SPECIFICATIONS

DIMENSIONS

OVERALL LENGTH	35 m (114 ft)
TEST SECTION LENGTH	25 m (83 ft)
TEST SECTION WIDTH	2.4 m (8 ft)
TEST SECTION HEIGHT	1.2 m (4 ft)

WATER CHANNEL DRIVE

POWER	75 kW (100 hp)
TYPE OF DRIVE	1.5 m (60-in.) AXIAL IMPELLER
SPEED CONTROL	AC MOTOR WITH EDDY CURRENT COUPLER
SPEED RANGE	0.1 to 1 m/sec (0.3 to 3 ft/sec)

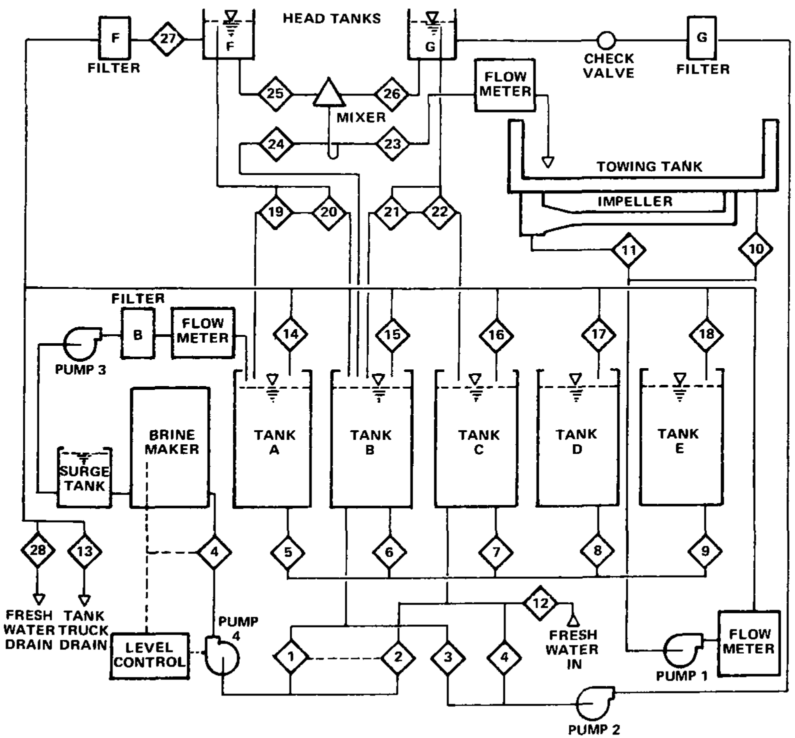
TOWING CARRIAGE

POWER	3.7 kW (5 hp)
TYPE OF DRIVE	CABLE
SPEED CONTROL	AC MOTOR WITH EDDY CURRENT COUPLER
SPEED RANGE	1 to 50 cm/sec (0.03 to 1.6 ft/sec)

STRATIFICATION CAPABILITY

ARBITRARY STABLE DENSITY PROFILE SHAPES WITH SPECIFIC GRAVITY FROM 1.0 TO 1.2 BY USING SALT WATER

Water Channel-Towing Tank

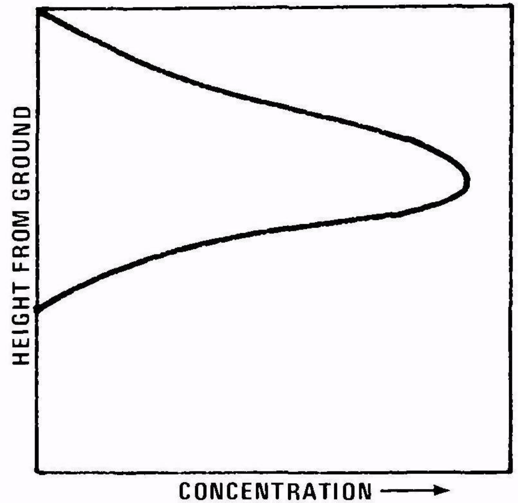


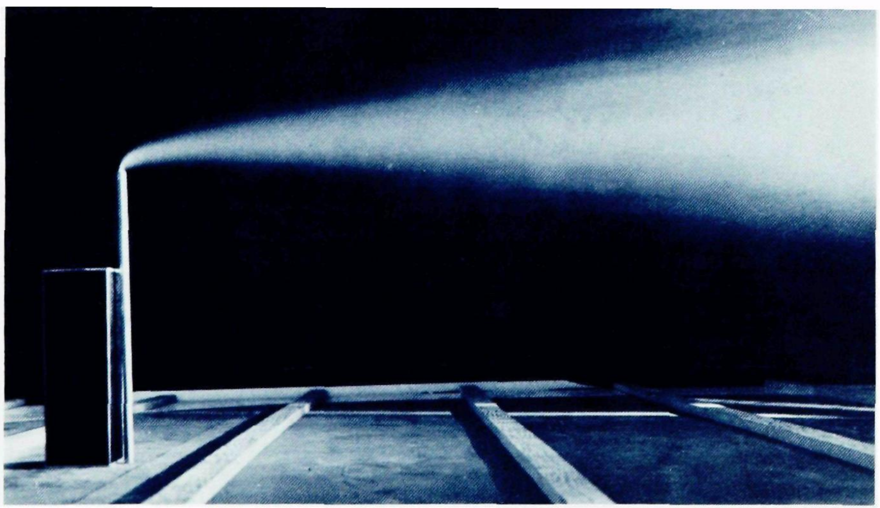
The water channel-towing tank was installed in the Fluid Modeling Facility to make possible the study of dispersion under stably stratified atmospheric conditions. The dual-purpose unit is of closed-circuit design, with a pump in the return leg on the bottom and the test section (free surface) on the top. The test section is constructed of acrylic plastic in an aluminum framework.

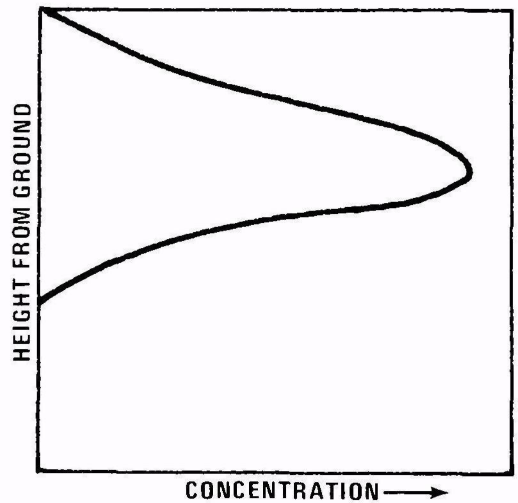
In the water channel mode of operation, the pump recirculates water through the test section, and the facility is used in a manner similar to that of the wind tunnel. Models are fastened to the floor of the test section; dyes are used for flow visualization studies and for quantitative concentration determinations. The channel is supported on jacks that can be adjusted to tilt the entire unit to compensate for the pressure drop through the test section.

In the towing tank mode of operation, the ends of the test section are blocked with gates, and the test section is filled layer by layer with salt water, each layer of different density. Atmospheric density gradients are modeled by the density gradients of the salt water. Models are attached to a turntable that is suspended from a towing carriage into the water, and towed the length of the test section, making possible the study of flow and dispersion around buildings and complex terrain under stably stratified atmospheric conditions.

A filling system comprised of a brinemaker, five large tanks, and numerous pumps and valves provides the capability of filling the test section with a desired stably stratified salt-water mixture in approximately four hours. Any type of stable-stratification from elevated- or ground-based inversions to neutral conditions may be simulated in the towing tank mode of operation.


HEIGHT FROM GROUND
CONCENTRATION

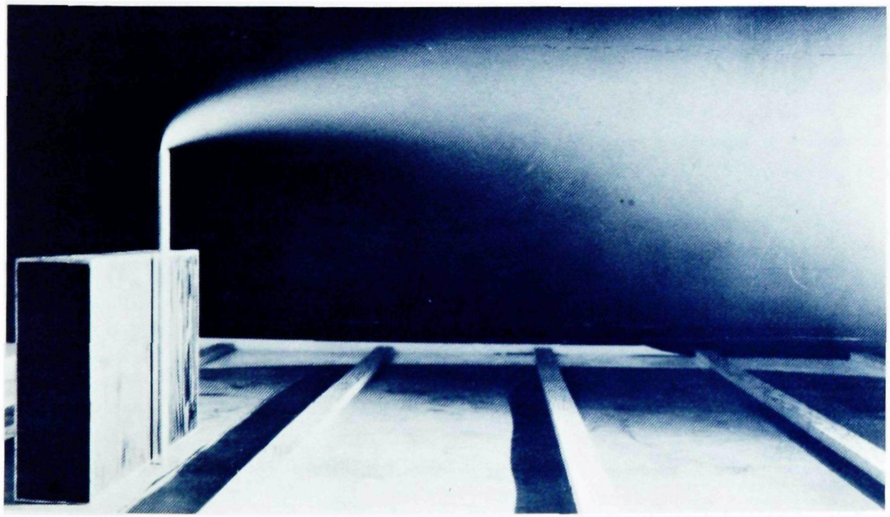


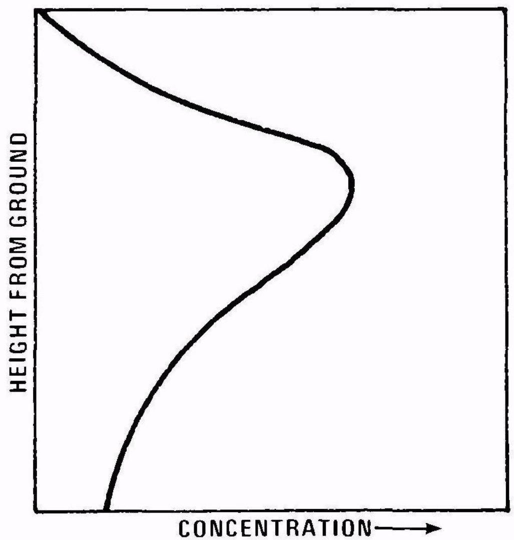

HEIGHT FROM GROUND
CONCENTRATION

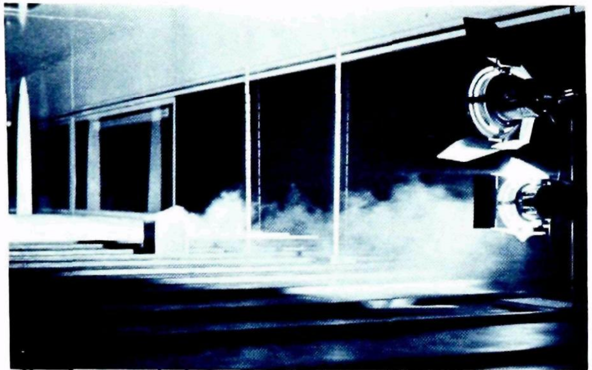
Modeling in Action

An old "rule of thumb" says that a stack placed next to a building must be at least 2½ times the height of the building to avoid downwash of the plume in the wake of the building. Downwash would result in high concentrations of pollutants at ground level. A wind tunnel study showed this to be a good rule for a conventionally shaped building. For a tall, thin building, however, the rule was demonstrated to be unnecessarily conservative and, therefore, wasteful. The photographs and related concentration profiles show plume behavior from model buildings and exhaust stacks in the wind tunnel. Comparisons of the illustrations on the facing page show that a thin building has essentially no effect on plume behavior when the stack is 1½ times the height of the building. The illustrations on this page, however, show that downwash occurs behind a wide building when the stack height is only 1½ times the building height.

This study, then, benefitted the consumer by demonstrating that the construction of costly tall stacks is not always necessary.

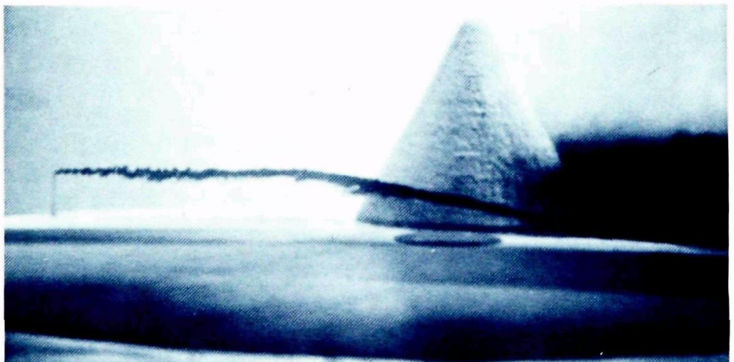




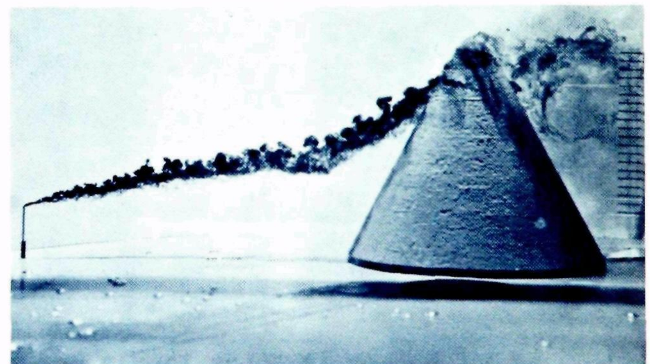


Rooftop emissions in wind tunnel

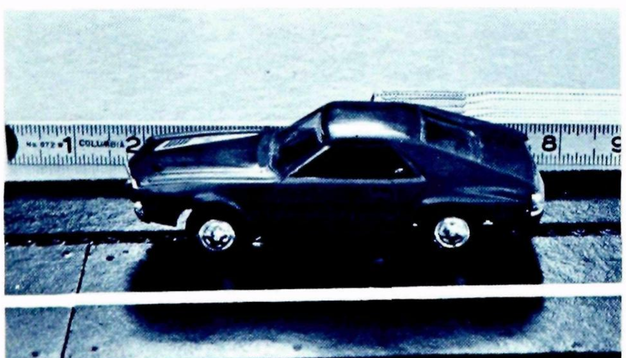
Hill study in wind tunnel



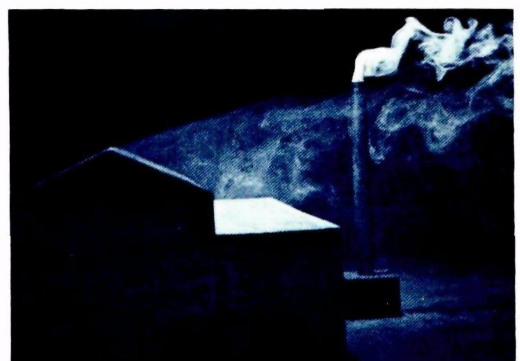
Stable stratification in towing tank



Neutral stratification in towing tank



Highway vehicle study in wind tunnel



Building downwash in wind tunnel

Recent Publications

Thompson, R.S. and D.J. Lombardi. 1976. Dispersion of Roof-Top Emissions from Isolated Buildings-A Wind Tunnel Study. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (in review).

Snyder, W.H., R.S. Thompson, and R.E. Lawson, Jr. 1976. The EPA Meteorological Wind Tunnel: Design, Construction, and Operating Details. U.S. Environmental Protection Agency, Research Triangle Park, N.C. (in preparation).

Huber, A.H. and W.H. Snyder. 1976. Building Wake Effects on Short Stack Effluents. Presented at Third Symposium on Atmospheric Turbulence, Diffusion, and Air Quality, Raleigh, N.C. October.

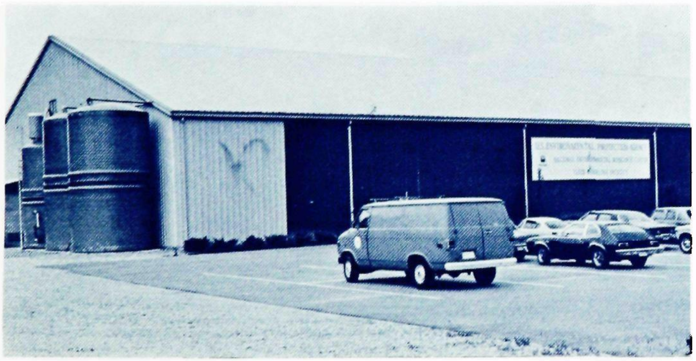
Snyder, W.H. and R.E. Lawson, Jr. 1976. Determination of a Necessary Height for a Stack Close to a Building-A Wind Tunnel Study. Atmos. Env. (in press).

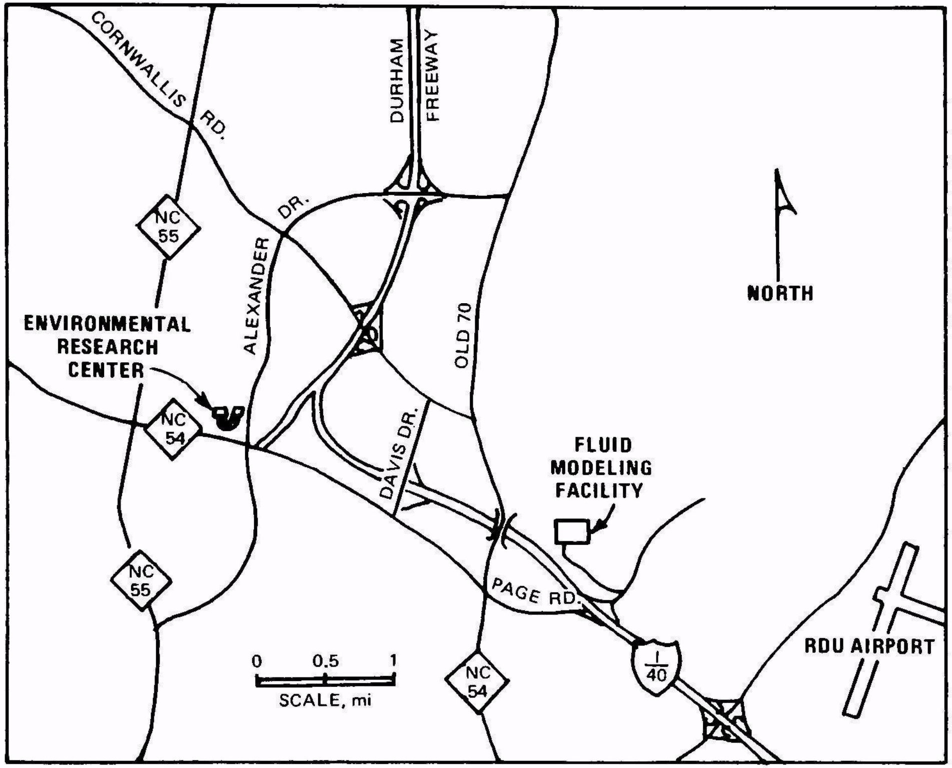
Thompson, R.S. and W.H. Snyder. 1976. EPA Fluid Modeling Facility. Presented at EPA Conference on Modeling and Simulation, Cincinnati, Ohio. April.

Huber, A.H., W.H. Snyder, R.S. Thompson, and R.E. Lawson, Jr. 1976. Plume Behavior in the Lee of a Mountain Ridge-A Wind Tunnel Study. Presented at EPA Conference on Modeling and Simulation, Cincinnati, Ohio. April.

Snyder, W.H. 1974. Fluid Modeling Program of the Meteorology Laboratory, U.S. Environmental Protection Agency. In: Air Pollution: Proceedings of the Fifth Meeting of the Expert Panel on Air Pollution Modeling. NATO Committee on the Challenges of Modern Society. p. 31-1 to 31-47.

Snyder, W.H. 1972. Similarity Criteria for the Application of Fluid Models to the Study of Air Pollution Meteorology. Boundary Layer Meteor. 3(2): 113-134.





For further information on the Fluid Modeling Program, contact:

Chief, Fluid Modeling Section
Atmospheric Modeling and Assessment Branch
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Environmental Protection Agency
Research Triangle Park, North Carolina 27711