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NEW FLUID MECHANICS FACILITIES IN THE
DEPARTMENT OF AERONAUTICS

by

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ABSTRACT:

A brief description of four new experimental fluid mechanics facilities in the Department of Aeronautics is presented. Each of the facilities was developed with the capability of studying one classical flow situation thoroughly and extended to include a variety of complex secondary effects which are of current interest.

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INTRODUCTION

Since Poiseuille first modelled capillary blood flow by the flow of fluid through small tubes, a succession of experimentalists have obtained fundamental results regarding the flow of fluid in non-ideal situations. Some of these experimental results (e.g. Poiseuille flow) have later been analytically derived, however, much of the information which engineers must utilize to synthesize a fluid system come from highly idealized experiments. The principle reason for this is that most fluid flow situations of real interest are intimately involved with turbulence or the transition to turbulence, the solution of which is not yet amenable to analytical or numerical approaches. This is not meant to slight the extensive literature of analytical work on turbulent fluid flow, which is valuable in providing insight and explanations for complex flow phenomena, it is only meant to put the importance of idealized experiments in the forefront.

With this impetus, a fluid mechanics laboratory has been developed to experimentally study a variety of turbulent fluid flow situations. The following classical configurations have served as the starting points in the design of several flexible pieces of experimental equipment: turbulent pipe flow, wake and jet flow in a uniform freestream, zero pressure gradient turbulent boundary layer, turbulent boundary layer separation and reattachment, and turbulent jet flow into a quiescent reservoir. The facilities described in this report were designed with the basic capability to reproduce classical experimental results in each of the aforementioned areas. Each apparatus was then modified to provide the capability for the study of a number of variations of the original problem. The basic experimental configurations and the variations which each setup now provides are listed in the following table:

TABLE I

CAPABILITIES OF EXPERIMENTAL FACILITIES

BASIC EXPERIMENT	ADDITIONAL EFFECTS
Turbulent pipe flow	swirling flow pulsatile flow flow with heating
Turbulent wake flow	arbitrary pressure gradient heated wakes pulsatile mean flow
Zero pressure gradient turbulent boundary layer	arbitrary pressure gradient flow over a porous surface pulsatile mean flow
Coanda effect: turbulent boundary layer separation and reattachment	planar, concave, and convex walls unsteady mean flow effect of separation inducers
Turbulent jet flow into a quiescent reservoir	stratified reservoir heated jet pulsatile jet flow laminar and transitional jets

The ensuing brief descriptions of these facilities and their capabilities, as depicted in the accompanying figures, are intended to give their current status which is undergoing continuous change and updating.

DESCRIPTION OF FACILITIES

I. Turbulent Pipe Flow Tunnel

The basic pipe flow facility, shown in Figures 1 and 2, is an assembly of four-foot long extruded aluminum pipe sections, eight inches in diameter, attached to an inlet bellmouth. The current configuration of eleven sections provides an overall development length of sixty-five diameters. As shown in the figure, a screen of #16 mesh to break up large turbulent eddies is held taut across a frame in front of a honeycomb flow straightener with a cellular length to diameter ratio of sixteen. The four inch thick honeycomb was cut into a round shape and an aluminum-filled epoxy frame was cast around it. The frame abuts the front of the inlet and a felt air seal prevents influx of air at the junction. The honeycomb frame, shown in Figure 2,is supported in front by three rubber wheels and from the rear by roller bearings. Connected to the lower left rubber wheel is a drive belt, driven by an electric motor through a variable drive hydraulic transmission. Rotational velocities of the honeycomb are continuously variable up to 120 rpm (monitored by a digital tachometer) which, because of the large residence time in the cells of the honeycomb, imparts this solid body rotation to the flow. Once the flow, with or without swirl, passes through the screen and the honeycomb it enters an axisymmetric inlet with a contraction of 16.3. The inlet was cast from aluminum-filled epoxy with a quarter-elliptical profile faired to zero slope at the exit. The straight exit end of the inlet was also cast with a step on the interior wall such that the first section of the main tube slides into the inlet and forms a smooth, non-protruding junction.

Each of the four foot long tubular sections has a single probe access port and a molded probe support block which seals the probe hole, aligns the probe vertically, and directs the probe into the flow. A motorized traverse moves the probes across the tube and provides an electrical position signal. In addition to the probe support hole, each section has four wall static pressure blocks, spaced twelve inches apart, connected to a water-filled tilt table manometer. The static pressure blocks have counter sunk pressure taps which allow the measurement of pressure without having a protuberance along the wall interior. Each of the sections is set in its own cradle which rests on a triangular base with three screw-type height and leveling adjustments. The sections are interconnected by cork alignment gaskets held in place by steel pipe straps.

Finally, at the downstream end of the tunnel is a centrifugal blower, driven by a one and one-half horsepower electric motor, used to draw the air through the tube at velocities ranging up to one hundred twenty feet per second. Prior to the blower entrance a flapper valve, shown in Figure 3, is used as a throttle to obtain velocities down to three feet per second, but more generally it is oscillated by the variable speed drive motor through an adjustable eccentric to provide oscillatory turbulent pipe flow. Amplitudes of the flapper valve oscillation range from five to ninety degrees with a continuously variable frequency from .1 to 30 cps. Both amplitude and frequency of the oscillation are monitored by an electrical signal from a potentiameter attached to the flapper axle by means of an anti-backlash gearing system shown in Figure 4.

II. Subsonic Wind Tunnel

In order to have a facility in which either free mixing or boundary layer flows could be studied in arbitrarily variable streamwise pressure gradients, the subsonic indraft wind tunnel shown in Figure 5 was designed and constructed. The inlet bellmouth was hand-formed from aluminum pipe halves and joined to the plenum section which consists of four, one foot long, two foot square stainless steel sections between which cork gaskets prevent the influx of air and hold taut the #16 mesh turbulence damping screens. Following the bell-mouth and inlet section is a two foot square layer of four inch thick, one-quarter inch honeycomb which serves as the flow straightener. Immediately downstream of the plenum chamber, one of two available nozzles is positioned and attached to the final square inlet section. One nozzle, shown in Figure 6, is constructed of Plexiglas with contracting vertical walls which form the nozzle while the horizontal walls remain parallel resulting in a seven by twenty-four inch exit and an overall contraction ratio of 3.43. The second nozzle, also shown in Figure 6, contracts along all four walls to form a seven by seven inch exit and a contraction ratio of 11.76. The exit of the nozzle attaches to the test section whose vertical walls are made of half inch thick Plexiglas, twenty-four inches high and sixty-eight and one-half inches long. The upper and lower walls of the test section which close the channel are made of flexible one-eighth inch thick Plexiglas and can be adjusted by means of screw type fixtures anchored in slots on the upper and lower edges of the vertical side walls. The use of these adjustable fixtures attached to the flexible walls allows the channel area to be set to any desired axial distribution and, as a consequence, any desired test section pressure gradient. Therefore, when an initial area contraction is desired in the test section the Plexiglas nozzle is used and when an area expansion is desired the steel nozzle is used.

Along the right hand wall of the test section, thirteen vertical slots three-eighths inches wide by nineteen inches long were milled as probe access ports. Through these slots, shown in Figure 7, pressure and hot-wire probes are inserted and a motorized traverse moves them through the flow and provides an electrical position readout. In those slots which are not used, filler plugs are placed which fit flush with the flow side of the test section in order to prevent influx of air. Once inserted, the plugs are spring loaded between two

Plexiglas rails on either side of the slots by a piece of stainless steel shim stock. In that slot which the probe is placed, a sliding teflon strip is inserted between the Plexiglas rails which seals the access slot being used yet allows continuous movement of the probe.

On the left hand wall of the test section three, three by six inch hand access ports were milled which are used for probe and model positioning. The hand holes were milled to fit flush with the flow side of the test section to prevent any localized separation due to a protuberance in the flow. Additionally along the left hand wall, thirty-three wall static pressure ports are located one and one half inches apart and connected to a tilt table water manometer which indicates the streamwise pressure gradient established by the specified area distribution. Each of the wall static pressure ports is counter-sunk to prevent the pressure tube itself from entering and disturbing the flow.

Once the nozzle is chosen and the desired test section area distribution is established the exit area, and therefore the exit height, is set. To collect the flow exiting the test section and direct it into the diffuser, an adjustable angle flow collector was constructed and attached directly to the exit of the test section. The collector, shown in Figure 8, allows the exit area to be set to any desired value. After the flow passes through the collector it enters two, five foot long, seven inch square buffer sections prior to the diffuser and finally the centrifugal blower shown in Figure 9. The total mass flow rate through the system is controlled by two baffle plates, located atop the exhaust stack, which can be rotated angularly with respect to one another to produce a variable flow area and therefore controllable total mass flow rate. If these plates are continuously rotated with respect to one another, a sinusoidally varying pulsatile flow through the test section can be obtained with a variable frequency dependent on the rotational velocity of the baffle plates.

Because the large mass flow blower shown in Figure 9 is excessively noisy, it cannot be used during working hours. For this reason, an alternate blower with a lower maximum mass flow, also shown in Figure 9, can be used. To switch between blowers one simply redirects the flow with two 90 degrees elbows to the entrance of the alternate blower.

The net result of the overall design of this facility is a versatile variable pressure gradient wind tunnel which is ideal for the study of low speed free mixing and boundary layer problems. In addition, with the use of the steel nozzle and the Plexiglas test section, the tunnel is an ideal facility for the study of diffuser design. Finally, the ability to generate sinusoidally varying flow superimposed on the arbitrary pressure gradient allows for the study of a current and highly complex situation, that of a non-stationary turbulent flow.

III. Coanda Jet

The classical work by Glauert on the Coanda effect on planar walls provides a basis for extensive investigations into turbulent boundary layer separation, recirculation zones, reattachment, and the boundary layer relaxation after reattachment. For these detailed flow studies and for the investigation of the overall Coanda effect on planar, concave, and convex walls the apparatus shown in Figures 10 and 11 was constructed. In this facility a large centrifugal blower is used to drive air through a two and three-eighths inch square jet orifice at velocities up to 200 feet per second. The air from the blower is collected and enters a rapidly convergent favorable pressure gradient section to smooth out the nonuniformities in the blower air. It then expands through a diffuser and enters the plenum section which consists of three, eight inch square, five inch long stainless steel sections followed by the nozzle. The plenum sections house two layers of #16 cooper screen at the two upstream sections and one layer of #36 screen at the furthest downstream section. Prior to the first section of screen, a one inch thick layer of one-eighth inch honeycomb serves to straighten the flow exiting the diffuser.

Once the air flow exits the jet orifice, it encounters a two-dimensional horizontal channel along a vertical wall as shown in Figure 10. The vertical wall is flush-mounted and hinged to the exit of the jet and can be set at any angle with respect to the initial direction of the flow. The wall angle is indicated by a protractor attached to the floor. Along the vertical wall of the two-dimensional channel a row of forty-eight wall static pressure taps is nonuniformly distributed at locations of particular interest. As the planar wall is moved angularly, the classical Coanda effect as described by Glauert can be observed and easily interpreted on the on the tilt-table water manometer as shown in Figure 10.

In addition to the planar vertical wall configuration, curved channel walls, shown in Figure 11, allow the study of the aforementioned detailed flow phenomena and the integrated Coanda effect on concave and convex walls also. Finally, the effect of inducing separation by displacing the plane of the vertical wall from the edge of the jet can be studied in each configuration.

IV. Transition and Turbulent Jet Flow Apparatus

The classical studies of jets issuing into an ambient medium have reaffirmed the utility of some of the most basic models of turbulent shear stresses in the prediction of mean flow behavior. In addition, the use of a laminar jet issuing into a quiescent reservoir offers an excellent experimental method of visually investigating the transition to turbulence. In order to achieve these experimental capabilities, the apparatus shown in Figure 12 was constructed. The facility was further designed with the ability to extend the investigation to include the study of heated jets issuing into stably stratified reservoirs.

Basically the facility is an optically clear tank with a vertical bank of thermometers to monitor the temperature gradient along one wall. Along the other vertical wall is an array of jets at one inch depth intervals. Stainless steel tubing was inserted into counter sunk holes with the jet fluid issuing into the reservoir through a smooth one thirty second of an inch diameter hole in the tank wall. Each array of jets at a given depth includes one jet which exhausts upward at a forty-five degree angle, one horizontally, and one downward at a forty-five degree angle. A thermocouple probe penetrates the jet flow from the top of the reservoir and another monitors the temperature of the fluid entering the reservoir from the jet supply system. To obtain a variety of jet Reynolds numbers from laminar to fully turbulent flow, the heated jet supply water is pumped to a stilling chamber located at a predetermined height and connected to the jet port by means of flexible tubing. In addition, a constant temperature bath is used to maintain a given temperature for the jet water and therefore hold a specified Rayleigh number.

The data on the spreading, deflection and transition of the jets is obtained optically with two cameras mounted to take photographs both horizontally and vertically. In addition to optical data, a thermocouple probe is used to retrieve the pool temperature of the layer of injected fluid after it has settled in the reservoir. The use of water compatible hot-wire probes allows more quantitative information on the turbulent field, however, the interaction of the hot-wires with the thermal system in the reservoir introduces some serious technical difficulties.

CONCLUSIONS

Turbulence and the transition to turbulence are the fundamental complications in a variety of fluid flow problems of practical interest. With the advent of increasingly complex flow systems and the demand to understand the flow reaction to a variety of complicated effects, increasingly sophisticated modelling must be undertaken by the experimenter. Without introducing extreme departures from classical configurations we have shown the ability to establish viable experimental facilities which aid the researcher in obtaining new experimental data in a variety of untested flow situations.

Figure 1. Overall View of Turbulent
Pipe Flow Tunnel

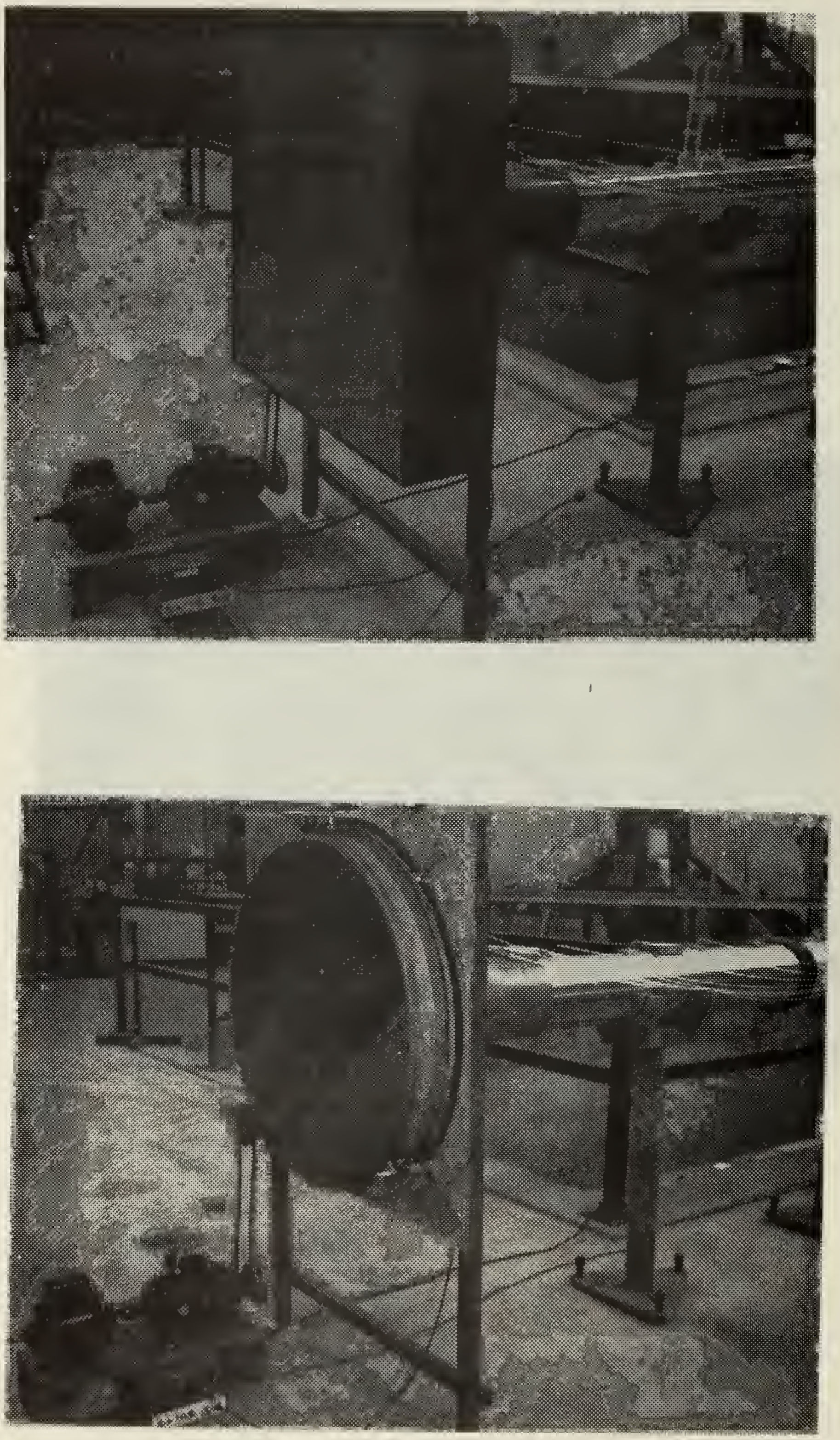


Figure 2. Screen, Honeycomb, Inlet, and Honeycomb Drive Mechanism of Turbulent Pipe Flow Tunnel

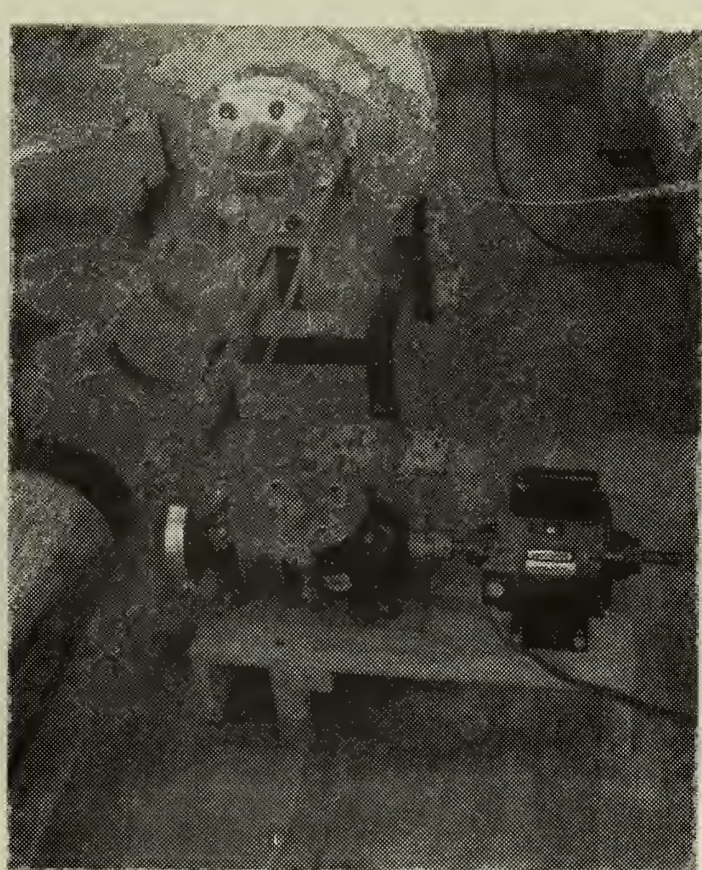
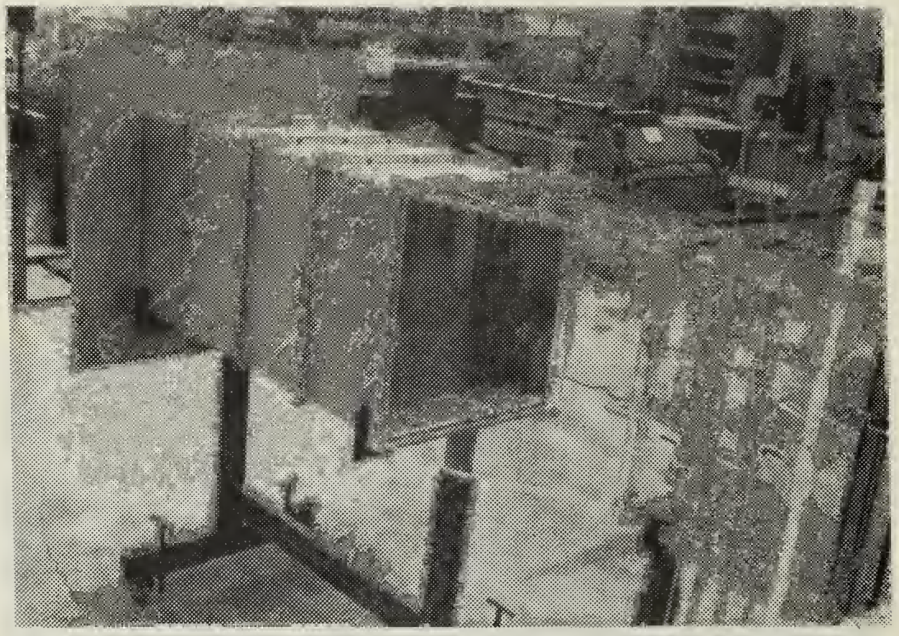


Figure 3. Variable Speed Flapper Drive of Turbulent Pipe Flow Tunnel

Figure 4. Blower, Flapper, and Anti-Backlash Gearing of Turbulent Pipe Flow Tunnel

Figure 5. Overall View of Variable Pressure Gradient Subsonic Wind Tunnel



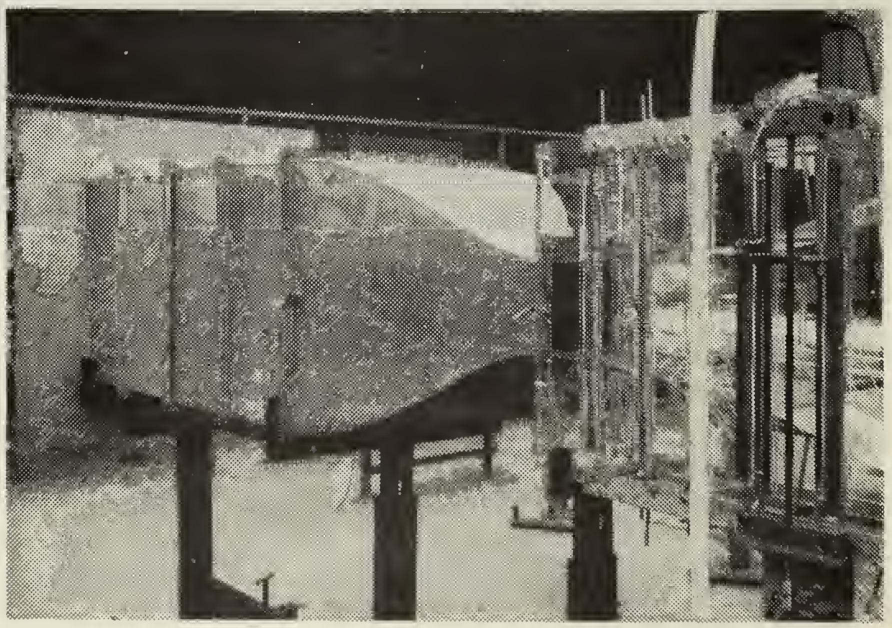


Figure 6. Nozzles for Subsonic Wind Tunnel

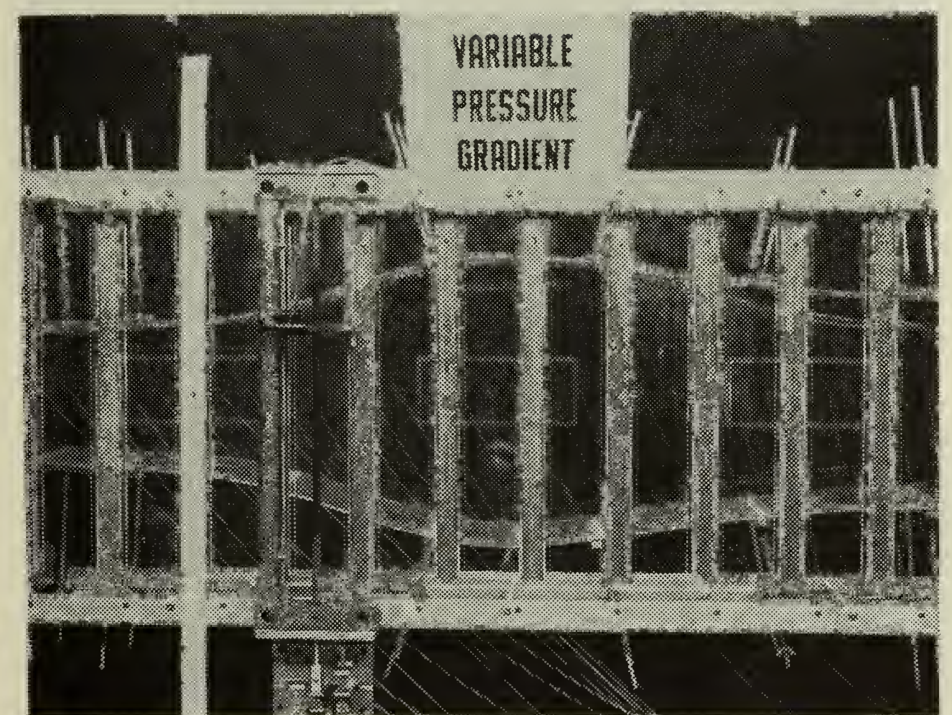


Figure 7. Variable Pressure Gradient Test Section of Subsonic Wind Tunnel

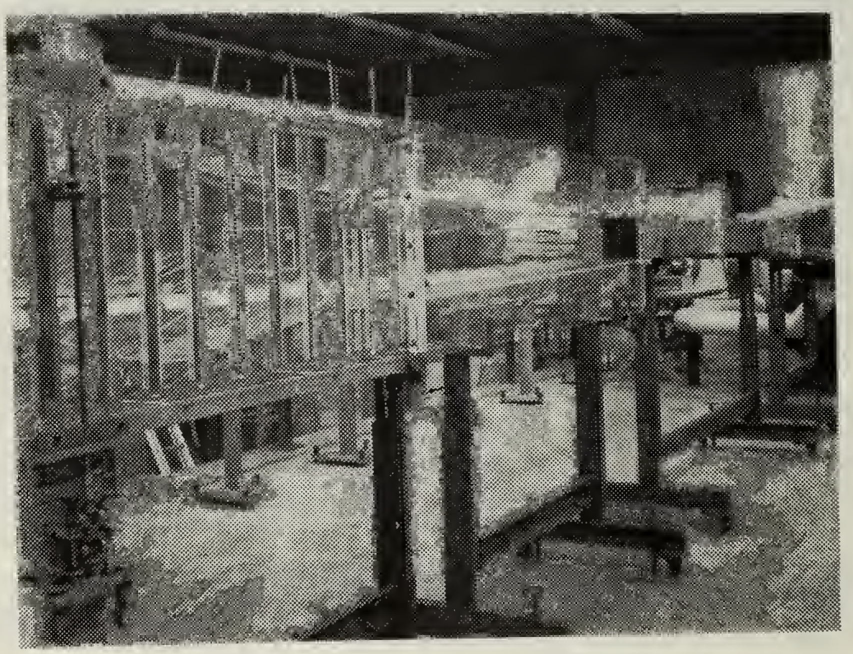
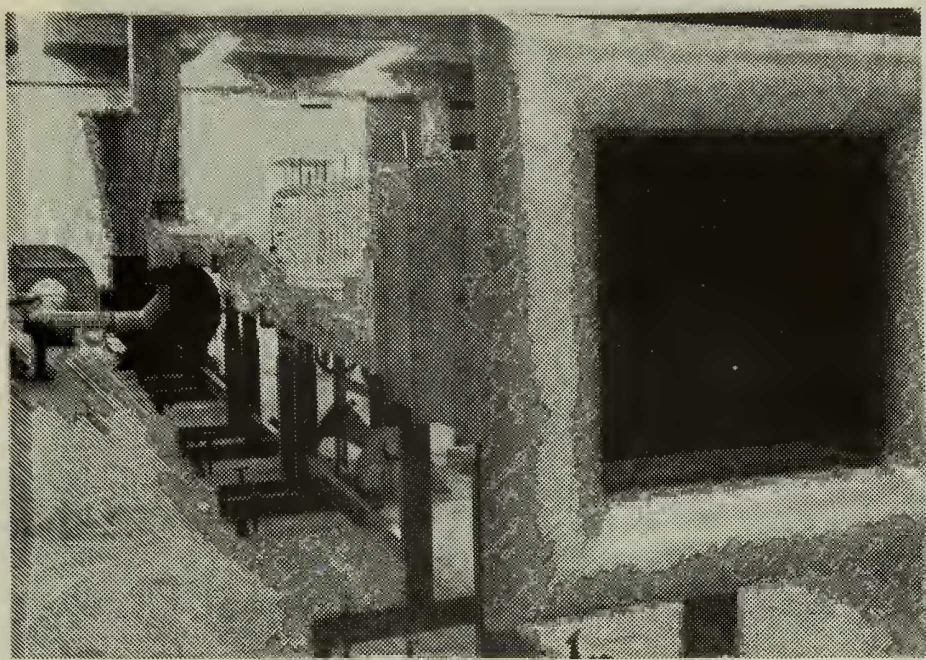


Figure 8. Test Section, Collector, and
Diffuser of Subsonic Wind Tunnel



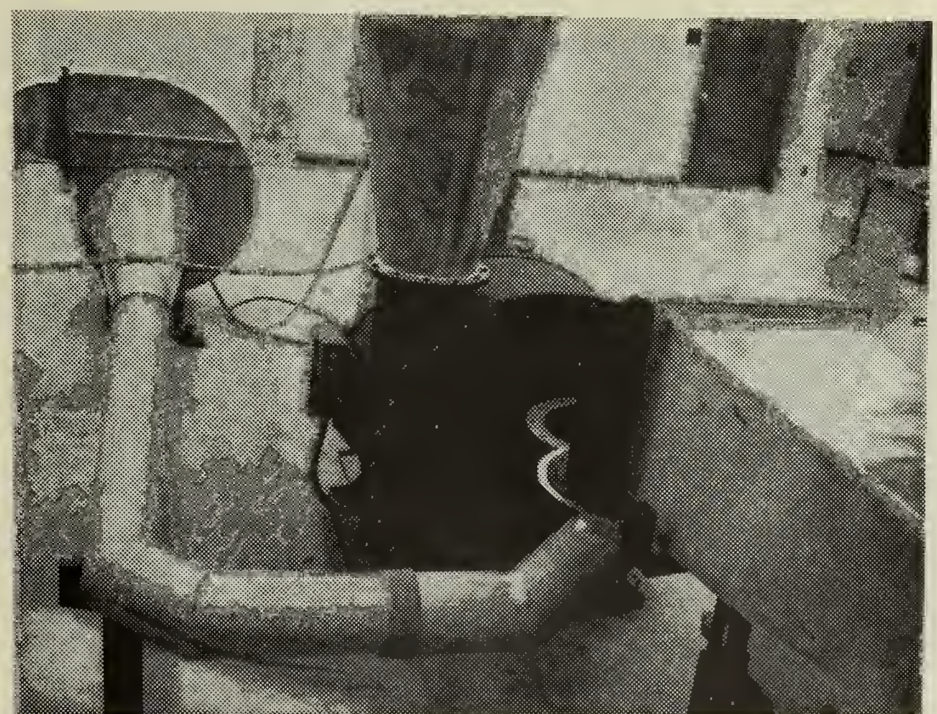


Figure 9. Configuration of Blowers for Subsonic Wind Tunnel

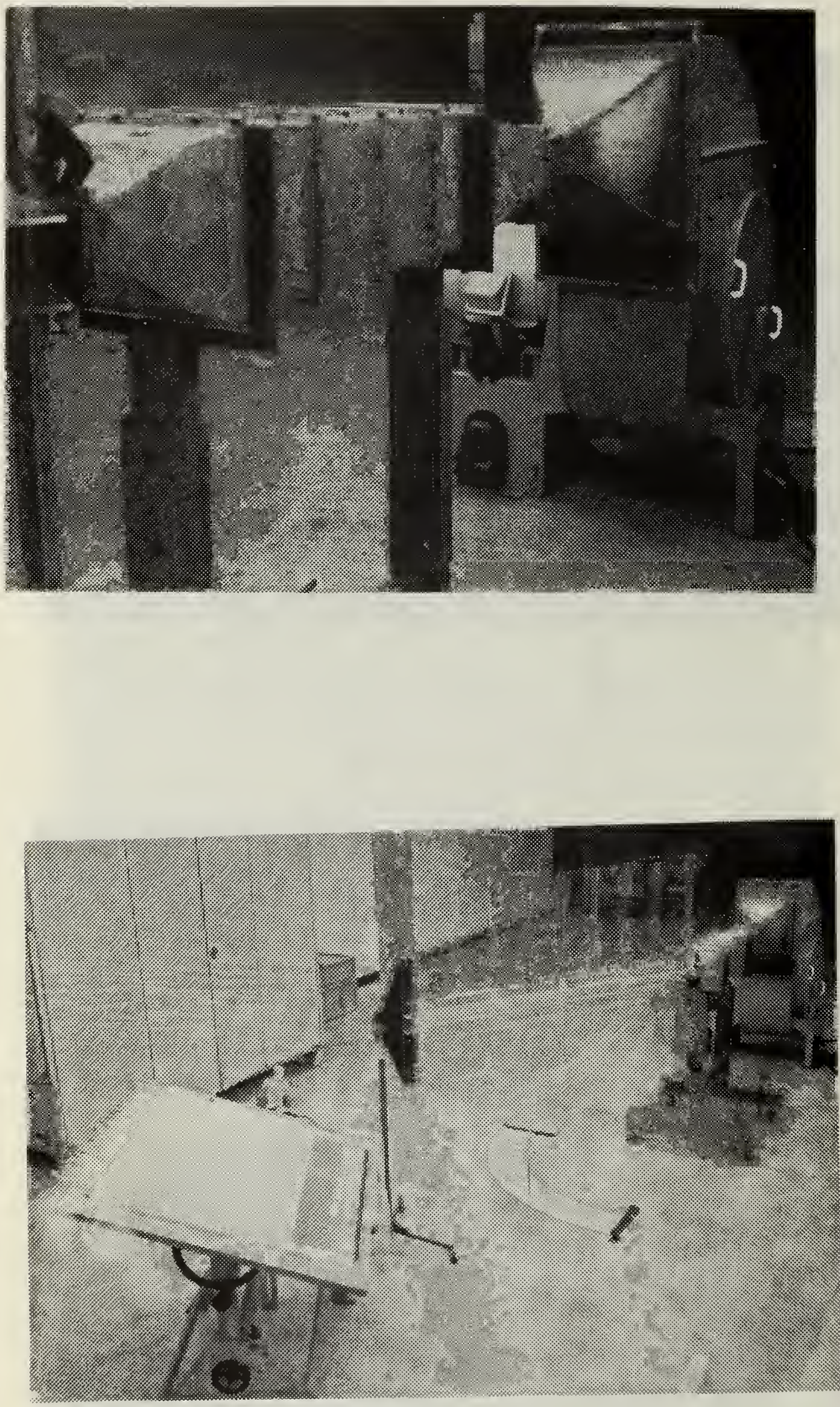
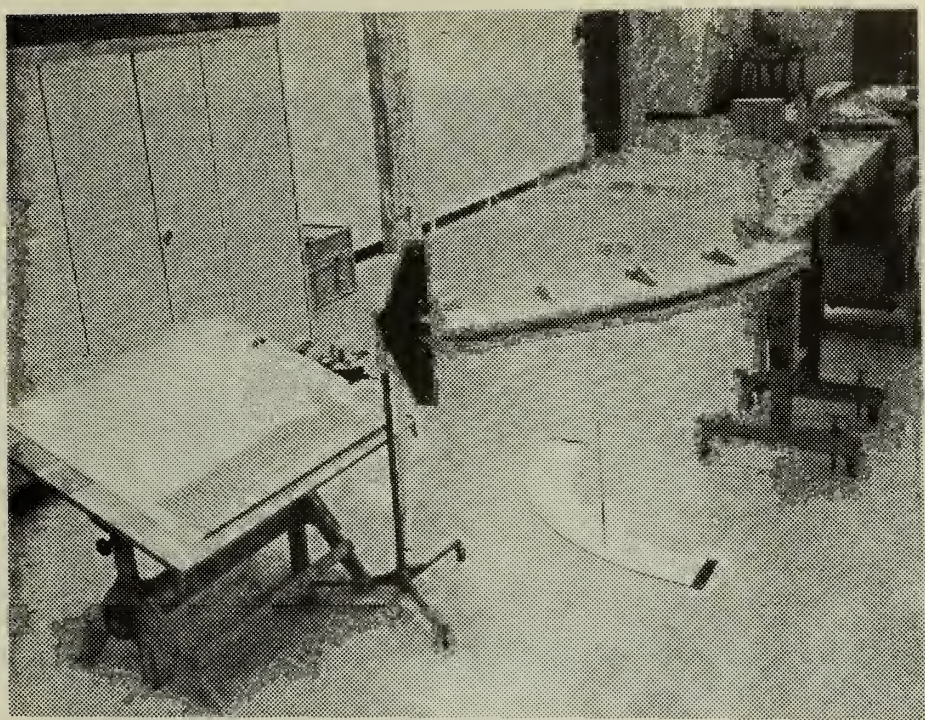


Figure 10. Blower, Free Jet, and Planar
Wall of Coanda Jet Facility



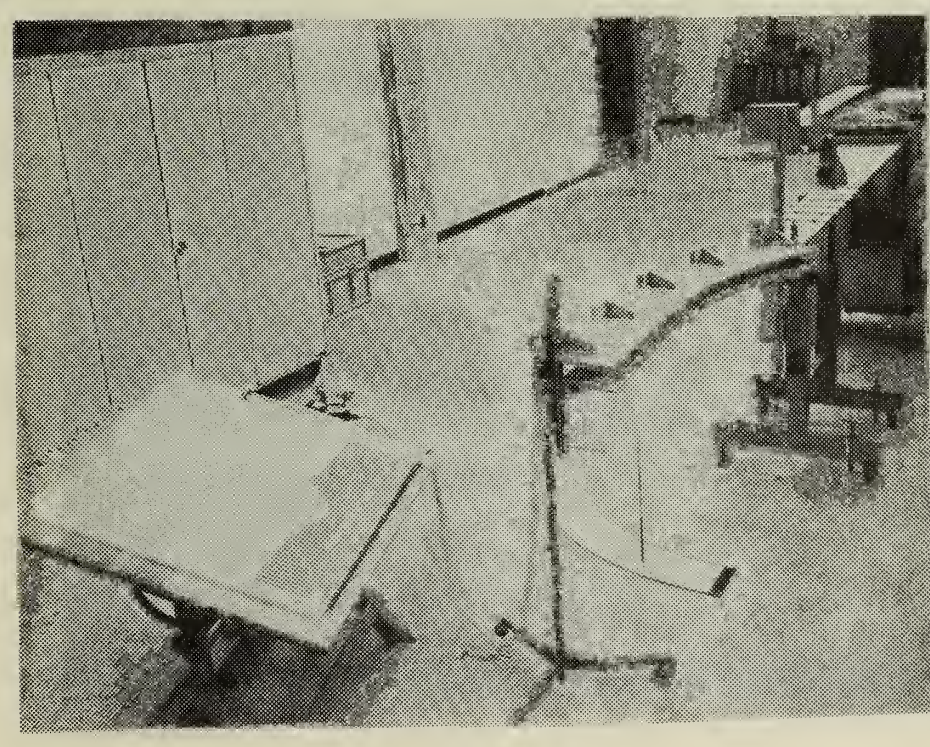


Figure 11. Convex and Concave Walls of Coanda Jet Facility

Figure 12. Reservoir, Jets, Monitoring and Supply System of Free Jet Facility

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13. ABSTRACT

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