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THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Aerospace Engineering
Gas Dynamics Laboratories

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THROUGH-AIR-DRYER MODEL EXPERIMENTS

D. R. Glass

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ABSTRACT

A one-half scale Plexiglas model of one section of a through-air-dryer has been built and used to study the airflow characteristics within the dryer. The model has been operated at flowrates appropriately scaled, relative to the full scale dryer, allowing for the use of room air in the model tests instead of hot air.

The drying process itself was not simulated, but the effects of various pressure drops across the drying plane as well as the effect of a moving fabric belt in the drying plane were investigated.

The model configuration initially tested produced strong swirls in the lower (inlet) chamber which resulted in low pressure regions on the underside of the drying plane; locally reduced flow through the drying plane resulted from these reduced pressure regions. A set of guide vanes was designed for and installed in the lower chamber. These vanes virtually eliminated this severe nonuniformity of flow through the drying plane.

The essential airflow patterns have been observed, and to a considerable extent documented photographically, with and without the vanes, with the drying plane material stationary and moving, and at various flowrates. Several conclusions have been reached regarding the flow in through-air-dryers; these conclusions are included in this report.

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INTRODUCTION

The satisfactory operation of a through-air-dryer as used in the paper making process requires that the airflow through the drying plane be correctly distributed. The airflow should generally be uniformly distributed, unless a controlled nonuniform distribution is specifically called for.

The early operation of American Can's Pilot Through-Air-Dryer at Neenah, Wisconsin indicated that the airflow through the drying plane was quite probably nonuniform. In an attempt to determine the extent and cause of any such nonuniformities a series of model tests was undertaken. If the flow were found to be objectionably nonuniform, the necessary alterations to the dryer configuration were to be determined.

It was also anticipated that these model tests would provide a better understanding of the various gas dynamic problems of a through-air-dryer (except for the water removal process itself). Such information should be useful in the design of future through-air-dryer machines as well as in the current development of the Pilot TAD.

MODEL DESIGN AND OPERATING CONDITIONS

The particular through-air-dryer under consideration here (the TAD in the Pilot Plant at Neenah) is divided into four fairly similar sections, insofar as the gas flow is concerned. Therefore, a model of one section of this dryer would provide flow information pertinent to all sections. Since the vacuum pumping system in the Gas Dynamics Laboratories could easily handle the appropriate flow rate for a one-half scale model, and since this would be a very practical size to work with, a half scale model was decided upon.

Figure 1 is a photograph of the half scale Plexiglas model constructed for these tests. Figure 2 is a cutaway sketch through the center of this model, as viewed from the "wet end." The inside length of the model is 30 inches; the inlet and outlet ducts are centered between the ends of the model. Insofar as practical, the inside dimensions of the model are properly scaled relative to the Pilot TAD.

The model was constructed almost entirely of Plexiglas so that airflow patterns could be observed and photographed, with the aid of various tracer materials. The various Plexiglas panels of the model are held together with machine screws. This method of construction allows the basic configuration of the model to be altered by replacing only a limited number of the panels.

The sheet metal ducting shown in the upper part of Figure 1 is connected to a vacuum line. The rate of airflow through the model is controlled by a throttling valve in this vacuum line. Air is pulled from the room into the lower duct shown in Fig. 1. The resulting inflow is more symmetrical than would be expected in the Pilot TAD inlet, but this difference should be relatively insignificant.

The 3/8 in. diameter support bars for the fabric are not indicated on Fig. 2, but they are shown in Fig. 1. These "bars" are 3/8 in. O. D. stainless steel tubes. The front end of each tube (bar) is plugged by a 3/16 in. rod which extends into the Plexiglas Plate and positions the end of the tube. The back end of each 3/8 in. tube is similarily positioned except that 3/16 in. O. D. tubes are used; these tubes extend to the outside of the model. Also, along one side of each 3/8 in. tube 5 holes, approx. 0. 1 in. in diameter have been drilled at 2 1/4 in. intervals. With this arrangement smoke, or other flow visualization material, can be injected into the upper plenum chamber from many positions, all just above the fabric belt.

The perforated plate shown installed in Fig. 1 was also one half scale, relative to the perfortated plate in the Pilot TAD. Thus, the holes in this plate are 1/8 in. diameter and located on 3/16 in. centers. (The blockage is therefore about 60% , the same as the full scale plate.) This perforated plate was in place for some of the initial tests discussed in this report, but for all of the later tests it was not installed.

The model test facility also includes provisions for a moving fabric belt. Figure 3 is a photograph of this entire facility. The motor drive and the guide roller system were mounted in the overhead structure so that they would not interfere in the working area. (Both the guide roller assembly and the fabric belts were provided by American Can.) The guide roller was very helpful in keeping the fabric in position.

The fabric belt is driven by an essentially constant speed motor by means of a V-belt and step pulleys. The speed of the fabric is fixed by the particular combination of V-steps used. Tests have been made at fabric speeds of 0, 2180, and 3330 ft/min.

In order that "Model Tests" be valid, it is necessary that geometric and dynamic similarity exist between the model tests and the reference process. The first requirement is met by making a uniformly scaled model. Dynamic similarity is obtained if the value of certain dimensionless parameters in the model tests are equal to the value of the corresponding parameters in the full scale process. While in most processes several parameters can be theoretically derived which could conceivably be important, only a few are usually of practical importance in a given situation. Some experimentation is sometimes needed to determine which parameters are important and which are not. Also, it may be impractical to simultaneously match all of the important parameters.

In planning these model tests of the through-air-dryer, the assumption was made that the air flow patterns upstream and downstream of the drying plane were essentially independent of the flow within the mat being dryed, so long as appropriate values of the pressure drop were obtained. The effects of overall pressure drop across the drying plane, the belt velocity, and the model configuration on the air flow patterns were to be investigated.

Although the relative importance of various parameters was not obvious, it was believed that fabric velocities essentially as high as those used in the Pilot TAD should be tested. Also, it was believed that values of the pressure drop across the drying plane similar in magnitude to those of the Pilot TAD should be tested. With these premises already made, the appropriate relation between model flowrate and full scale flowrate was still in question.

The dimensionless parameter which is most frequently important in low speed flow is the Reynolds number, Re. Also, the magnitude of the dynamic pressure, q, (perhaps relative to the pressure loss) would be expected to be important. The movement of the belt introduces a velocity factor; therefore, the air velocity, V, (the average velocity approaching the belt) relative to the belt velocity also needs to be examined. Since the pressure drop and belt velocity in the model tests were to reach values similar to those in full scale operation, this approach leads to the conclusion that the following similarity conditions should perhaps exist:

$$Re = Re' \tag{1}$$

$$q = q' \tag{2}$$

$$V = V' \tag{3}$$

Here the prime symbol indicates conditions in the full scale operation; unprimed values refer to model test conditions. The various other symbols used in this discussion are defined as follows:

L	= characteristic dimension (e.g. length)	ft
V	= velocity (here, average velocity approaching the drying plane)	ft/sec
ρ	= air density (specific weight)	lb/ft^3
P	= pressure	lb/ft^2
T	= air temperature at dryer inlet	^oR
μ	= air viscosity	lb/ft sec
Re	= Reynolds No. = $\rho VL/\mu$	
q	= dynamic pressure = $\rho V^2/2g$	lb/ft^2
Q	= volumetric air flow rate	ft^3/min

In the discussion immediately following these variables are measured in the lower (supply) plenum chamber.

Consider first the relation between model and full scale flowrate when the Reynolds numbers are equal. Substituting in Eq. (1)

$$\frac{\rho VL}{\mu} = \frac{\rho' V' L'}{\mu'} \tag{4}$$

For this comparison the following assumptions are made:

$$T' = 600\ ^{o}F \qquad (1060^{o}R)$$

$$T = 70\ ^{o}F \qquad (530^{o}R)$$

$$P' = P$$

Also, it is assumed that the heated "air" entering the pilot TAD can be considered to be simply air, therefore the gas constant for air can be used in the state equation for both the model and full scale flow. Using the state equation in Eq. (4) and rearranging:

$$\frac{V}{V'} = \frac{P'}{P}\frac{T}{T'}\frac{L'}{L}\frac{\mu}{\mu'} \tag{5}$$

Since the viscosity of air is approximately proportional to the square root of the absolute temperature (within the temperature range under consideration), since for the half-scale model $L' = 2L$, and since $P' = P$, Eq. (5) reduces to:

$$\frac{V}{V'} = 1\ (1/2)\ 2\ (1/2)^{1/2} = 1/\sqrt{2} \tag{6}$$

Thus, in order that the model Reynolds number be equal to that of the full scale operation,

$$V = .707\ V' \tag{7}$$

Consider next the velocity ratio dictated by the assumption that the dynamic pressures are matched. Substituting in Eq. (2)

$$\frac{\rho V^2}{2g} = \frac{\rho'(V')^2}{2g} \tag{8}$$

or

$$\left(\frac{V}{V'}\right)^2 = \frac{\rho'}{\rho} = \frac{P'}{P}\frac{T}{T'} = 1/2 \tag{9}$$

Then

$$V = V'/\sqrt{2} = .707\ V' \tag{10}$$

which is the same as Eq. (7). This peculiar situation results from the fact that the scale factor and temperature ratio just cancel each other, see Eq. (5).

Requiring the model inlet velocity to match the full scale operation results simply in Eq. (3), i.e., $V = V'$.

The relative flowrate for these various conditions can also be determined. From the definition of volumetric flowrate,

$$Q = V\ (L \times \text{width}) \times 60 \qquad \text{CFM} \tag{11}$$

Since the width to length ratio, W/L, is the same in both the model and the full scale dryer,

$$Q = \frac{W}{L} (VL^2) 60 \tag{12}$$

or

$$\frac{Q}{Q'} = \frac{VL^2}{V'(L')^2} = \frac{1}{4} \frac{V}{V'} \tag{13}$$

Table 1 lists the velocity and flowrate ratios needed to make the parameters indicated of equal value in both the model tests and full scale operation.

Table 1

	V/V'	Q/Q'	Q'/Q
Matching Reynolds Number	.707	.707/4	5.66
Matching Dynamic Pressures	.707	.707/4	5.66
Matching Velocities	1	1/4	4

It is obvious that the Reynolds number and the velocity cannot be simultaneously matched.

Most of the model tests were made at either 625 or 1250 CFM, while a few were made at nearly 1875 CFM. (Some observations were also made at very low flows.) The flowrates through one section of the Pilot TAD, corresponding to the model flowrates listed above, have been calculated from Table 1 and are presented in Table 2.

Table 2

Model Flowrate, Q (CFM)	625	1250	1875
Q', Matching Re and q	3540	7080	10620
Q', Matching Velocities	2500	5000	7500

In the initial tests with the Plexiglas model, the model flowrate was related to full scale operation on a corresponding velocity basis, i.e., the flowrate was multiplied by 4 and recorded as Q'. In order to keep the procedures consistent, all of the test results have been expressed in this way. Therefore, when a model flowrate "equivalent" to 5,000 CFM is mentioned in this report, it is to be understood that the average velocity in the model is the same as that in each section of the Pilot TAD where the flowrate is 5,000 CFM.

While the model test conditions of a single test could not simultaneously match Re, q and the velocity of a particular full scale TAD operation, a reasonably representative range of values of each of these parameters was achieved during the series of model tests. Also, the overall trends observed and conclusions reached were found to be generally true for the range of test conditions employed (as will be discussed in the test results section). In view of the above, it would appear that a sufficient degree of dynamic similarity existed in these model tests to make the results and conclusions valid for a full scale TAD.

TEST RESULTS

Initial tests of the Plexiglas model were made with the model configuration as shown in Figs. 1 and 2. For purposes of this report, the configuration of the upper and lower chamber as shown there will be referred to as "standard". Where there are variations from this standard configuration, these variations will be described.

Tests of "Standard" Configuration

The first tests were made with the model in the standard configuration, with a perforated plate installed, and with no fabric or tissue in the drying plane. At flowrates well over 5,000 CFM (i. e., Q' > 5,000 CFM) the pressure drop across the perforated plate was not discernable on a vertical water filled manometer. Static pressure (wall) taps in the upper and lower chamber (the tubes from these taps are visible in Fig. 3) were installed so that the pressure drop across the drying plane could be measured.

In view of the fact that the perforated plate appeared to have so little effect on the overall airflow pattern, it was concluded that tests without an appreciable pressure drop across the drying plane would be meaningless for the purposes of this study. Therefore, almost all subsequent tests were made with at least one layer of fabric in the drying plane.

Many of the initial model tests were made to determine and document the flow patterns within the dryer. The swirling flow in the lower chamber attracted first attention. The general nature of this swirling flow as induced by the incoming air is indicated by the sketch in Fig. 4a. While this type of flow was anticipated, it was not obvious, prior to the tests, how severe the vortex motion would be.

Figure 4b is a photograph of the lower section of the model, "looking" up through the bottom of the model (by means of a mirror). For this photograph cotton "balls" were dropped into the inlet of the lower chamber. These cotton balls were then trapped in the swirls in the lower chamber. The lengths of the streaks in Fig. 4b indicate the distance traveled by the cotton balls during the time the film was exposed (1/30 sec); many of the streaks indicate velocities in the neighborhood of 1,000 ft/min, while a few indicate velocities approaching 1500 ft/min. The value of Q' for this test was about 2500 CFM. The average inlet velocity at $Q' = 2500$ CFM would be 1000 ft/min.

A single photograph cannot completely define the flow conditions. One obvious limitation is the direction of rotation. However, from direct observation it was determined that the direction of rotation was as indicated in Fig. 4a. Motion pictures of the flow in the lower chamber of the model were also taken. For these motion pictures Styrafoam particles and smoke were used to make the flow "visible". (This movie was presented to American Can at an earlier date.) There were two layers of fabric and one layer of dry tissue in the drying plane for the tests of Fig. 4b and for the motion picture tests referred to. The model was in the standard configuration and the perforated plate was in place.

One of the techniques used to make the flow patterns visible was to inject metaldehyde, $(CH_3COH)_n$, particles into the airflow. This process, described in the paper by F. Etzold, Ref. 1, involves first vaporizing the metaldehyde crystals, then condensing the vapor in a swirl chamber in such a way (ideally) as to result in flocculation of the metaldehyde. These floccules have a very high drag to weight ratio; a high drag to weight ratio is obviously desirable for tracer particles in flowing fluids. The cotton balls were not nearly as good in this respect; the cotton balls would centrifuge out and bounce off of the walls back into the swirl. However, the advantage of the cotton for a single photograph such as Fig. 4b is that individual balls would show up as a streak.

Because of the relatively large size of the metaldehyde floccules, they are filtered out of the air flow as the air passes through the fabric-tissue layers in the drying plane. Even the perforated plate with its 1/8 in. diameter holes (60% blockage) removes much of the metaldehyde. By injecting the metaldehyde into the lower chamber inlet for several minutes under more or less steady flow conditions a considerable deposit is built up on the underside of the perforated plate and the fabric-tissue material. Figure 4c is a photograph of the underneath side of the perforated plate after such a test. The value of Q' for this test was about 2300 CFM. The two dark areas in Fig. 4c, one on either side of the inlet, indicate the "eyes" of the two swirls, where the flow through the perforated plate was very low—possibly the flow in these areas was the reverse of the overall average flow. An inspection of the fabric-tissue combination which had been installed just above the perforated plate showed similar nonuniformity of deposit, but the white metaldehyde on the white fabric made it difficult to record this nonuniformity photographically.

The conclusion that the dark regions in Fig. 4c were regions of reduced upward flow was supported by visual observations of the flow when various tracer materials had been inserted into the air.

A fluid flow field in which the streamlines are circular and the local velocity is inversely proportional to the radius is referred to as "vortex" flow. While the viscosity of real fluids preclude true vortex flow in nature, a tornado, for example approximates vortex flow, except in the central core. While the two swirls induced in the lower chamber could not produce true vortex flow, it is interesting to consider the implications of vortex flow in this situation. For example, consider the lower chamber when Q' = 5,000 CFM. The average velocity through the inlet duct of the model would be 2,000 ft/min. If the radius of the swirl (vortex) is assumed to be about 4 in., based on inspection of

Fig. 4c, and the velocity at r = 4 in. is assumed equal to the incoming velocity, the following values are determined

r in.	V ft/min	$q = \rho V^2/2g$ in H_2O	ΔP in H_2O (Relative to Pressure at r = 4 in.)
4	2,000	.25	0
3	2,670	.45	- .2
2	4,000	1	- .75
1	8,000	4	-3.75

This exercise indicates that at a radial distance of one inch from the axis of the vortex the static pressure is 3.75 in. of water below the static pressure at the periphery of the vortex. Obviously the value of the static pressure at the center, based on $V \propto 1/r$, is meaningless.

With the above consideration in mind, a test was made to determine the extent of the negative pressure in the eye of the swirl. In this test the value of Q' was about 5,000 CFM. There were three layers of fabric and three layers of dry tissue in the drying plane. The pressure drop from the lower to the upper chamber was 6.15 in. of water. A long static pressure probe, 1/8 in. in diameter, was inserted through the end of the lower chamber, about 1 1/2 in. below the drying plane. This probe was moved about in the vicinity of the center of the swirl in order to find the point of minimum pressure. The point of minimum pressure was about 5 in. from the end of the chamber and about 3 1/4 in. from the back wall. (This checks very well with the center of the dark regions seen in Fig. 4c.) The pressure at this point was just over 2.5 in. of water below the pressure near the inside wall of the lower chamber. Since the pressure drop across the drying plane in this test, as measured near the back walls, was 6.15 in. of water, the ΔP across the drying plane at the center of the swirl was, 6.15-2.5, which is a reduction in ΔP of about 40%. A local reduction of 40% in the pressure drop across the drying plane would certainly result in a local reduction in airflow, and hence an appreciable reduction in the drying rate of that portion of the web which passes over these swirls in the TAD operation.

The persistence of the swirl into the upper chamber when there is no fabric or tissue in the drying plane is shown by the photograph in Fig. 5a. This photograph shows the flow in one end of the upper chamber. The tracer material used for this test was oil smoke (particles), injected upward from the holes in the support bar, second from the end. A similar test made with two layers of fabric and two layers of tissue in the drying plane produced no visible swirl in the upper chamber, see Fig. 5b. The material injected for the photograph of Fig. 5b was zinc stearate, in powdered form, which provided a very dense cloud of smoke. The tubes (support bars) used for the tests of Figs. 5a and 5b were at opposite ends of the chamber in order that the powder could be injected through a dry tube. Because of symmetry, Figs. 5a and 5b can be compared. It is obvious that a material positioned across the drying plane which produces an appreciable pressure loss, (in this case $\Delta P = 3$ in. H_2O at $Q' = 2500$ CFM) prevents the swirl induced in the lower chamber from extending into the upper chamber.

After the fabric belt and its drive system were installed and properly aligned, a number of special tests were made to determine if the air flow through the model produced any lateral (frontward or backward) movement of the belt. These tests were made at belt speeds of 2180 and 3330 ft/min. The model was in its standard configuration (no perforated plate was in place for these tests). Air flowrates ranged from 0 to a value of $Q' \approx 7500$ CFM. There was no discernible tendency for the fabric to move laterally. The variation in belt position over a period of several minutes was essentially the same whether the air was flowing or not. It is possible that there was a lateral force on the belt which was cancelled out by the guide roller, but close observation of the guide roller positioning pressure (as controlled by the Guide Palm) revealed no changes due to the airflow through the model.

The fact that lateral movement of the belt was not observed in these model tests does not rule out the possibility that the airflow could produce such displacement in the Pilot TAD. In the model facility, the rollers on either end of the model are about 7 ft apart, while they are over 20 ft apart in the Pilot TAD. Also, the guide roller is very close to the model as compared to the Pilot TAD.

The extent of any lateral forces on the fabric belts due to the swirling flow in the lower chamber could have been explored further, but it appeared more profitable to eliminate the swirling flow itself. The next section deals with the results of installing a set of vanes designed to provide more uniform flow through the drying plane.

Tests with Guide Vanes Installed

In an attempt to make the flow more uniform in the lower chamber, guide vanes were designed and installed. The design of these vanes was a joint effort with American Can (see Refs. 2 and 3). The vane system developed consisted of one set of horizontal vanes and one set of vertical vanes. Both the horizontal and vertical sets of vanes were designed so that, ideally, equal portions of the flow was intercepted either between each pair of adjacent parallel vanes, or between a vane and the adjacent parallel wall of the inlet duct. Uniform flow in the inlet duct was assumed. Figure 6 is a photograph of the guide vanes installed in the lower chamber. These vanes are of the same configuration as the vanes planned for installation in the Pilot TAD.

Tests with these vanes installed clearly showed that the flow in the lower chamber was much more uniform than it was without the vanes. The swirl pattern was essentially eliminated by the vanes. Although local separation on the downstream side of the vanes could be seen when smoke was injected into the flow, no evidence of large eddy motion was observed. Such separation that was observed should, ideally, be eliminated since it increases pressure losses, but the magnitude of these losses would be a small fraction of the incoming dynamic pressure and therefore probably negligible.

In order to obtain an indication of the flow distribution through the drying plane, with the vanes installed, the metaldehyde particle generator was set at the inlet to the lower chamber. The airflow was maintained for several minutes while the metaldehyde floccules were being injected. Since the fabric filters out these particles, the buildup on the lower side of the fabric would be an indication of the flow distribution through the drying plane. After several minutes the metaldehyde buildup increased the pressure drop across the drying plane (2 layers of fabric and 3 layers of tissue) from 7 in. of water at $Q' = 2500$ CFM to over 26 in. of water. This test was terminated when the upper chamber imploded, due to the abnormally low pressure in the upper chamber (and a shortage of retaining screws).

The layer of metaldehyde deposited during this test appeared to be reasonably uniform, although the deposit in the center of the fabric was somewhat heavier. It was believed that this was due to the fact that the metaldehyde had been introduced into the center of the air inflow and not uniformly across it. The layer of metaldehyde built up during this test was relatively thick. Since the higher pressure drop across the metaldehyde layer in those areas where the airflow was concentrated would tend to divert the flow to any normally "low-flow" areas, the effect would be to make the deposit more uniform than was the flow initially. Because of these two problems with this test, another somewhat similar test was made.

In this second test to determine the uniformity of flow with the vanes installed, the inlet to the lower chamber was "extended" by a 9 ft length of 10 in. diameter furnace pipe. The metaldehyde particle generator was set at the inlet of this extension tube. Strips of 3/4 in. masking tape were taped diametrically across the inlet, at various angular positions, to increase the turbulence and thereby the distribution of the metaldehyde particles across the entire duct. Figure 7 is a photograph which shows the Plexiglas model with the furnace pipe inlet extension and the metaldehyde generator. The coffee can in this picture is the swirl chamber where flocculation occurs; the metaldehyde particles flow rather slowly out of this swirl chamber and are then swept into the furnace pipe inlet.

During this test there was one layer of fabric, three layers of tissue, and one layer of photographic black cloth across the drying plane. The black cloth was on the bottom, so that variations in the amount of the white metaldehyde deposit would be more visible. The initial pressure drop across the drying plane was just over 10 in. of water at a Q' of 5000 CFM. The test was run at a Q' of about 5000 CFM.

The rate of metaldehyde buildup appeared to be uniform during the test; the total deposit at the end of the test also appeared to be quite uniform. No region on the cloth could be singled out as having either a heavier or lighter than average deposit. No photograph was taken of the deposit on the black cloth after the test because it appeared to be so uniform.

The above tests were, almost of necessity, made at zero belt velocity. It is important to know if the conclusion reached for those tests would hold for operating belt speeds.

The first step in evaluating the effect of belt velocity on flow in the lower chamber was to introduce smoke at various positions in the flow below the belt, with and without the belt moving. It was quite obvious that, at flowrates of interest here, the flow pattern below the belt is essentially unaffected by the belt movement. There may be a very thin layer under the belt which is affected, but if so it was not visible during these tests. Fabric belt speeds of 0 and up to 2180 ft/min were used in making these tests. A flowrate of Q' = 5,000 CFM was used. The fact that the belt motion does not affect the flow in the lower chamber has also been documented by a series of motion picture sequences. This film will be discussed later in this report.

Another aspect to consider in the comparison of a moving fabric belt with a nonmoving belt involves the pressure drop under both conditions. A series of tests was therefore made to determine the pressure drop across one layer of fabric at fabric velocities of 0, 2180, and 3330 ft/min. Values of Q' ranged from 2500 to over 6,000 CFM. The pressure drop was measured by a vertically water filled manometer. No difference in the pressure drop due to belt velocity was discernible. A more accurate measurement of the pressure drop might show some slight difference due to belt velocity, but the tests made certainly indicate that they would be negligible in terms of the drop across the wet tissue in the TAD operation. At Q' = 6,000 CFM the pressure drop across the fabric alone is about 1 in. of water.

While the fabric belt velocity has no discernible effect on the flow in the lower chamber it certainly does affect the flow in the upper chamber. This difference is shown by the photographs of Fig. 8. For all three of these photographs the air flowrate (Q') was 5,000 CFM (the velocity through the drying plane was about 550 ft/min). Zinc stearate dust was injected into the upper chamber through the holes in the support bars, as shown. In the top photograph the belt velocity is zero, and the dust plume is largely vertical. In the bottom two photographs the belt velocity is 2180 ft/min. The strong down-machine component of velocity is quite evident. Since the belt to through-air velocity is about 4:1 (2180/550) it would be expected that the resultant velocity of the air leaving the belt would be more nearly horizontal. The support bars, however, tend to dissipate the horizontal velocity. The overall swirling motion set up in the upper chamber by the belt motion is clearly visible, especially in the bottom picture of Fig. 8.

In order to obtain a comprehensive "picture" of the airflow approaching and leaving the drying plane, a traversing smoke injection system was made. The traversing part of this system is a 5 ft length of 1/4 in. O. D. tubing with a 1/16 in. diameter smoke injection port located midway between the ends of the tube. During the tests this tube was passed through holes at both ends of the model so that the tube was parallel to and about 1 1/2 in. below the drying plane. One end of the 1/4 in. tube was plugged; the other end was connected via Tygon tubing to a smoke generator. For these tests "well aged" smoking tobacco was burned in the smoke generator. This produced the dense smoke needed to make the small smoke plume easily visible. With the 1/4 in. tube oriented so that the smoke port was on the top side, pointed toward the drying plane, the tube was manually moved in an axial direction so that the smoke injection port traversed the entire length of the Plexiglas model. These end to end traverses were made along 4 paths; the paths were 2 3/4, 5 3/4, 8 1/2, and 11 1/4 in., respectively, from the front wall of the model. All paths were 1 1/2 in. below the drying plane.

Throughout this series of tests the vertical and horizontal vanes shown in Fig. 6 were installed. The holes in the lower chamber of the model, through which the 1/4 in. tubing was passed, are visible in Fig. 6, especially in the left (dry) end of the chamber. The air flowrate (Q') during these tests was 5,000 CFM. The fabric belt in the drying plane was either not moving or was moving at 2180 ft/min. (Some observations were also made during belt start-up.)

By moving the smoke injection port along each of its four paths in the manner described above, the local airflow pattern at a great many positions was observed during these tests. In all cases it appeared that the flow just below the fabric belt was the same with the belt moving as it was without the belt moving. While some minor irregularities in the airflow just below the belt were visible, these were induced by the inlet-vane system and were independent of the belt motion. The airflow above the fabric in all cases was strongly influenced by the belt motion. A strong down-machine component was clearly evident, except at the down-machine end wall, when the belt was moving.

Since a single photograph could show only a small portion of the observed flow patterns, motion pictures were taken of this series of tests. Also included on this film are sequences showing smoke being injected into the upper chamber from holes in the support bars. The original of this film, dated September 1, 1971, has been sent to the American Can Company at Neenah, Wisconsin.

CONCLUSIONS

In the process of planning and conducting the model tests described in this report, many aspects of the flow in a through-air-dryer have been considered and several conclusions reached. The more significant conclusions are briefly stated here.

1. The results and conclusions (regarding airflow patterns) based on the model tests should be generally valid for full scale dryers, since the various test conditions employed resulted in a fair "overlap" of the full scale values of the important fluid dynamic parameters, and since fluid flow patterns did not differ significantly in character with changes in air flowrate.
2. The flow pattern in the lower chamber is essentially unaffected by the fabric belt velocity. Therefore, conclusions based on tests with zero belt velocity are equally valid for cases where the belt is moving, insofar as lower chamber flow is concerned.
3. The flow pattern in the upper chamber is strongly affected by the belt velocity; a strong down-machine velocity is imparted to the air as it passes through the moving fabric.
4. The sudden enlargement at the inlet to the lower chamber, in its "standard configuration", results in strong eddies which produce areas of significantly reduced local flowrate through the drying plane.

5. The perforated plate has a negligible effect; the pressure drop across the plate is negligible and the plate does not eliminate the swirls in the lower chamber, nor the effect of these swirls on flow through the drying plane.

6. In tests with the model in the standard configuration (no vanes), no lateral movement (frontward or backward) of the moving fabric belt was produced at flowrates (Q') up to 7500 CFM, but since the belt drive and guide system is more compact in the model facility than in the full scale TAD, this result may not apply to the full scale TAD operation.

7. The vanes installed in the lower chamber virtually eliminated the two major swirls (vortices) in the lower chamber and resulted in an essentially uniform distribution of flow through the drying plane.

8. The undesirable effects of sudden enlargements, turns, etc., can be largely counteracted by suitable vane systems, but more efficient usage of air handling power could be attained by optimizing the design of the approach and exit chambers (see Ref. 3).

REFERENCES

1. Etzold, F., "Measurement Techniques for Near Wake Flows," Flow Symposium, May 10-14, 1971, Joint Technical Session with ASME Fluids Engineering Division, Measurements in Fluid Mechanics, Paper No. 5-2-50.

2. Letter from D.R. Glass to Dr. J.A. Van den Akker, American Can Company, dated May 20, 1971.

3. Letter from Dr. J.A. Van den Akker, American Can Company, to D.R. Glass, dated May 28, 1971.

4. Letter from D.R. Glass to Dr. J.A. Van den Akker, American Can Company, dated September 8, 1971.

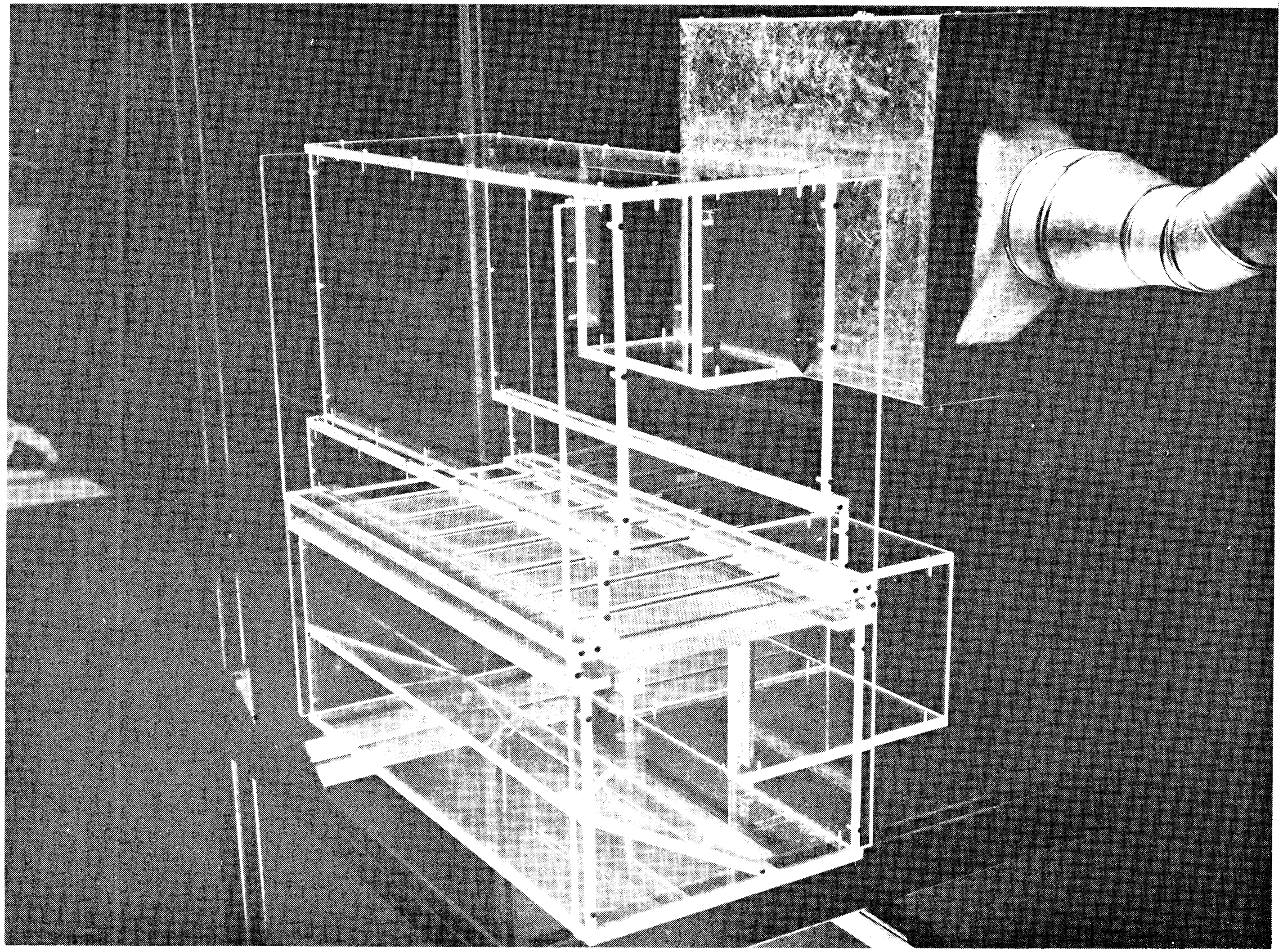


Figure 1. Photograph of Plexiglas Model of One Section of a Through-Air-Dryer

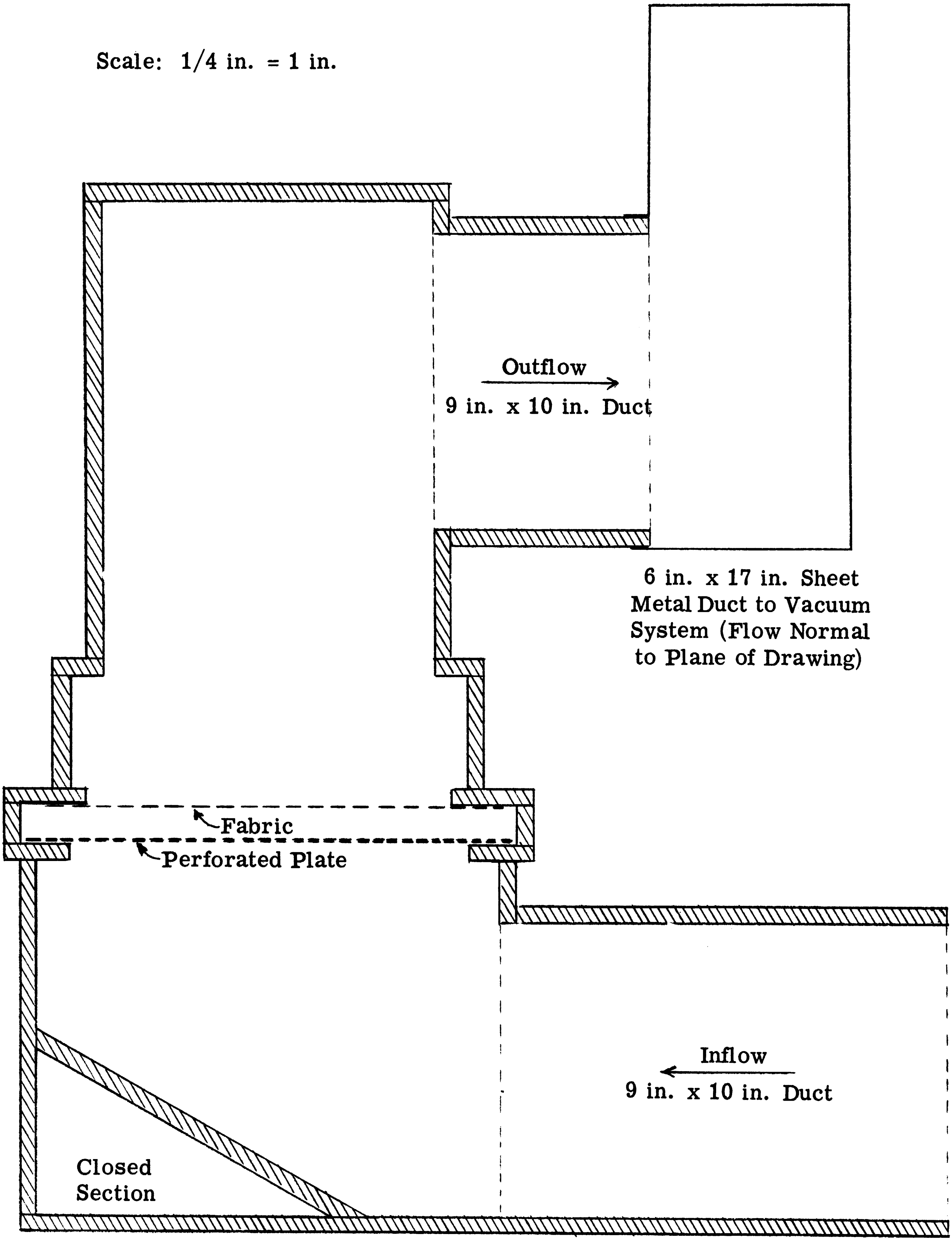


Figure 2. Section Drawing of Plexiglas Model

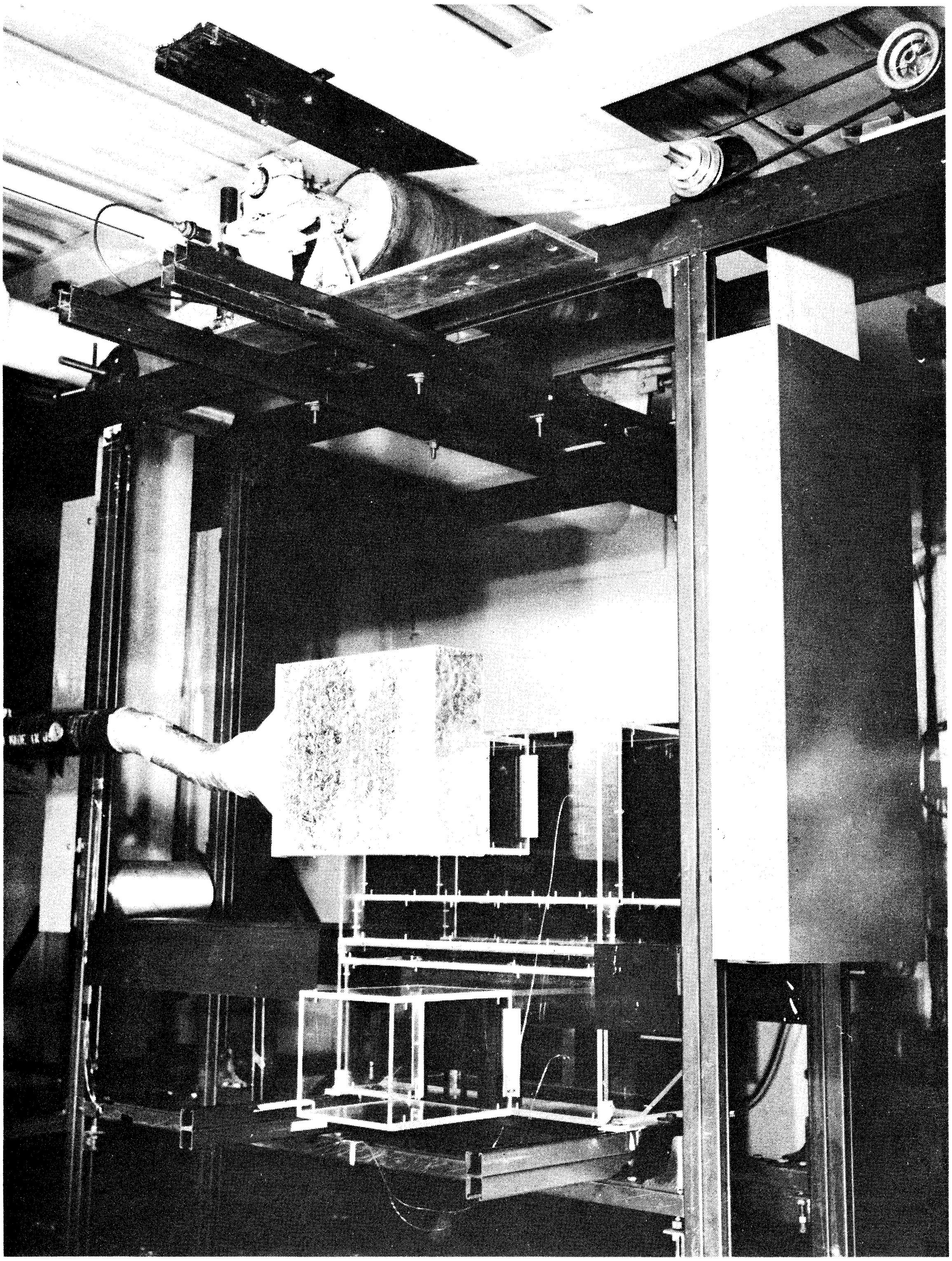


Figure 3. Photograph of Model Test Facility

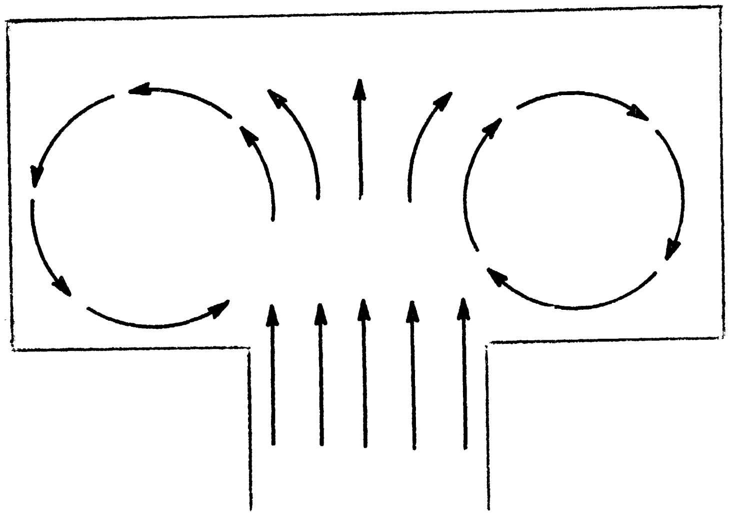


Figure 4a. Sketch of Induced Swirl in Lower Chamber
(Standard Configuration)

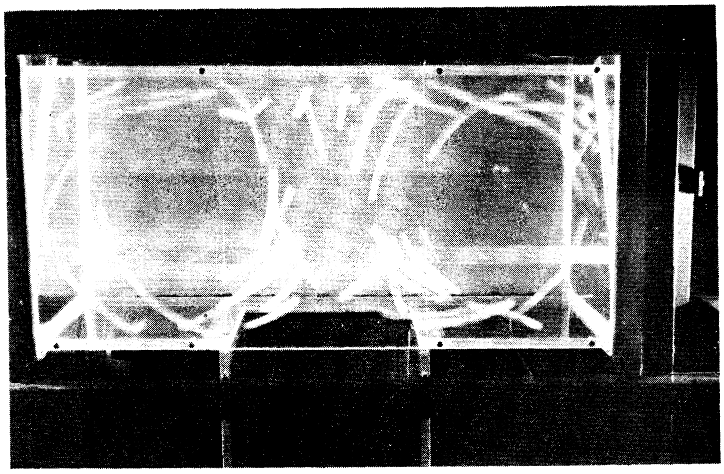


Figure 4b. Photograph of Cotton Balls Swirling in Lower Chamber
(Standard Configuration)

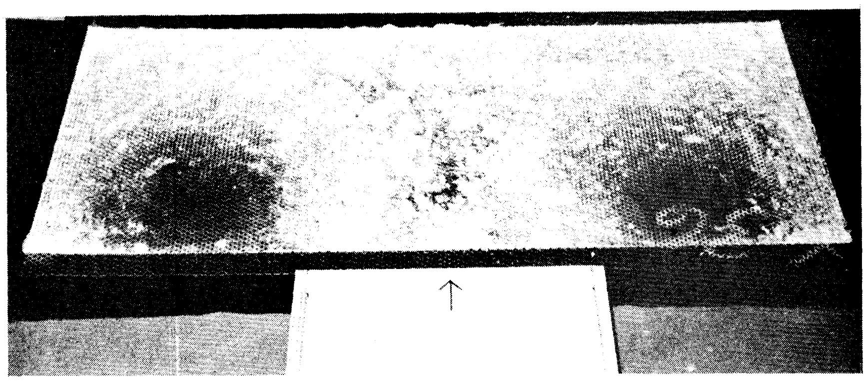


Figure 4c. Photograph of Under Side of Perforated Plate—After
Injection of Metaldehyde Particles
(Standard Configuration)

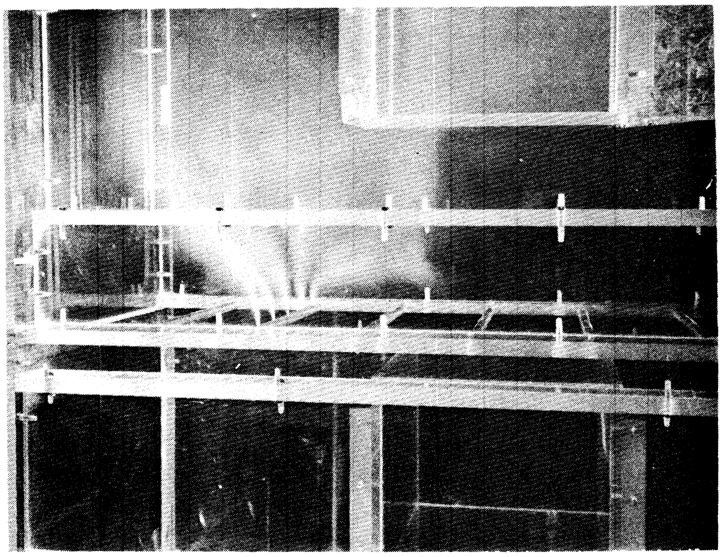


Figure 5a. Photograph of Flow in Upper Chamber — No Fabric or Tissue in Drying Plane
(Standard Configuration, Q' = 2500 CFM)

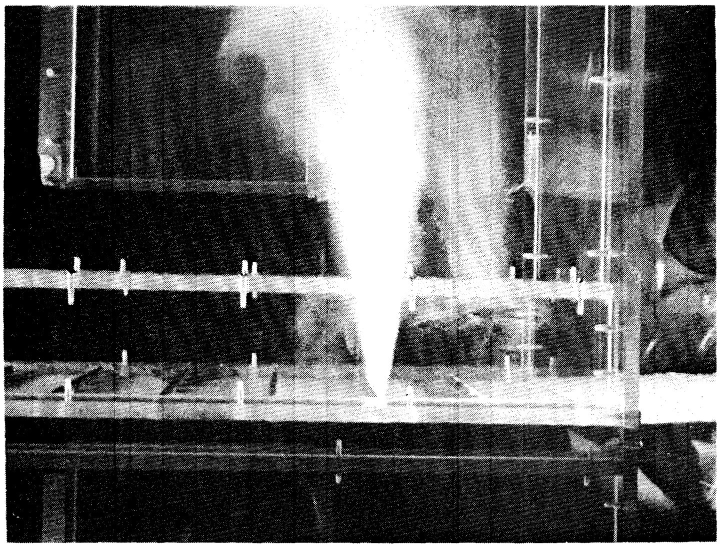


Figure 5b. Photograph of Flow in Upper Chamber — Two Layers of Fabric and Two Layers of Dry Tissue in Drying Plane
(Standard Configuration, Q' = 2500 CFM)

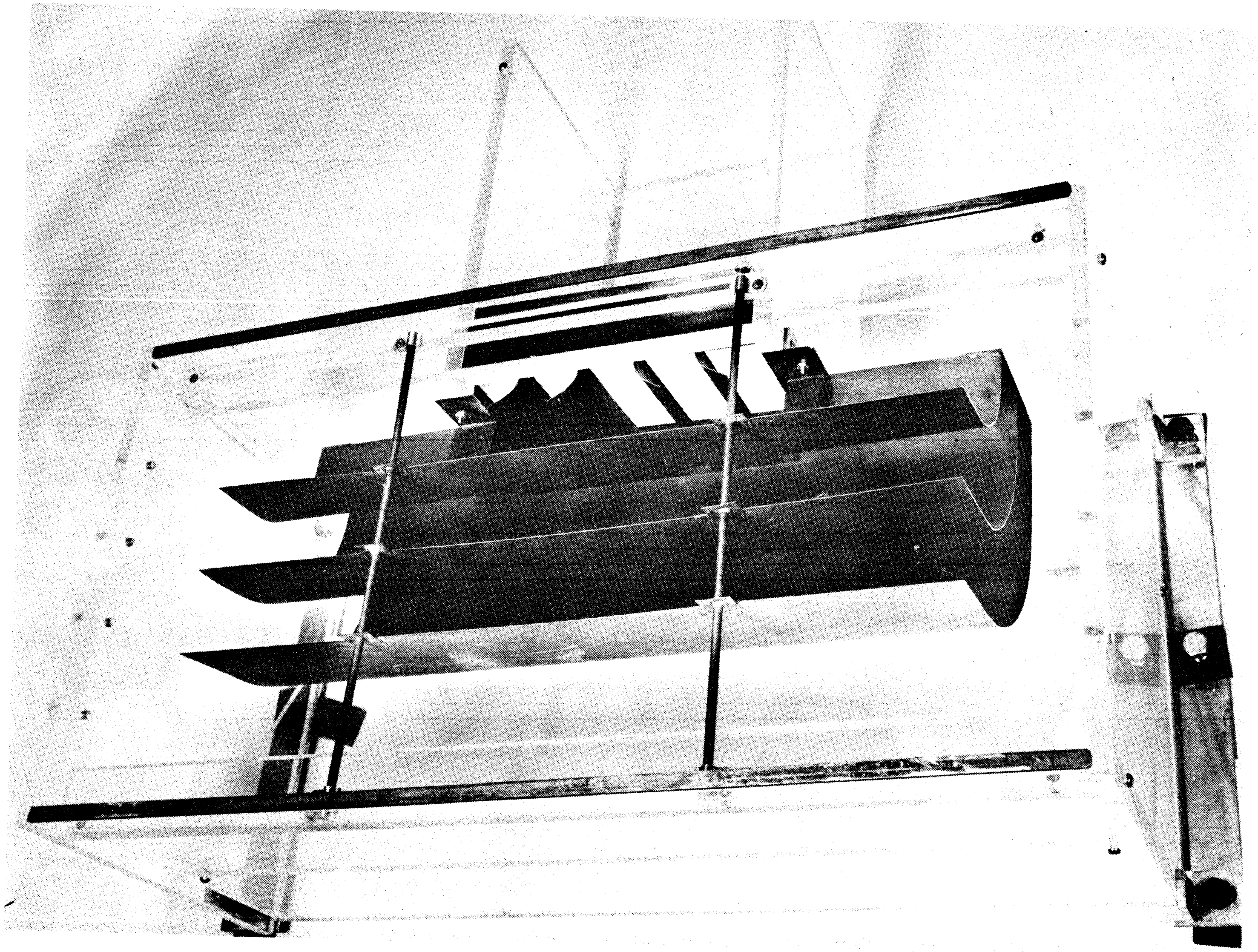


Figure 6. Photograph of Guide Vanes Installed in the Lower Chamber

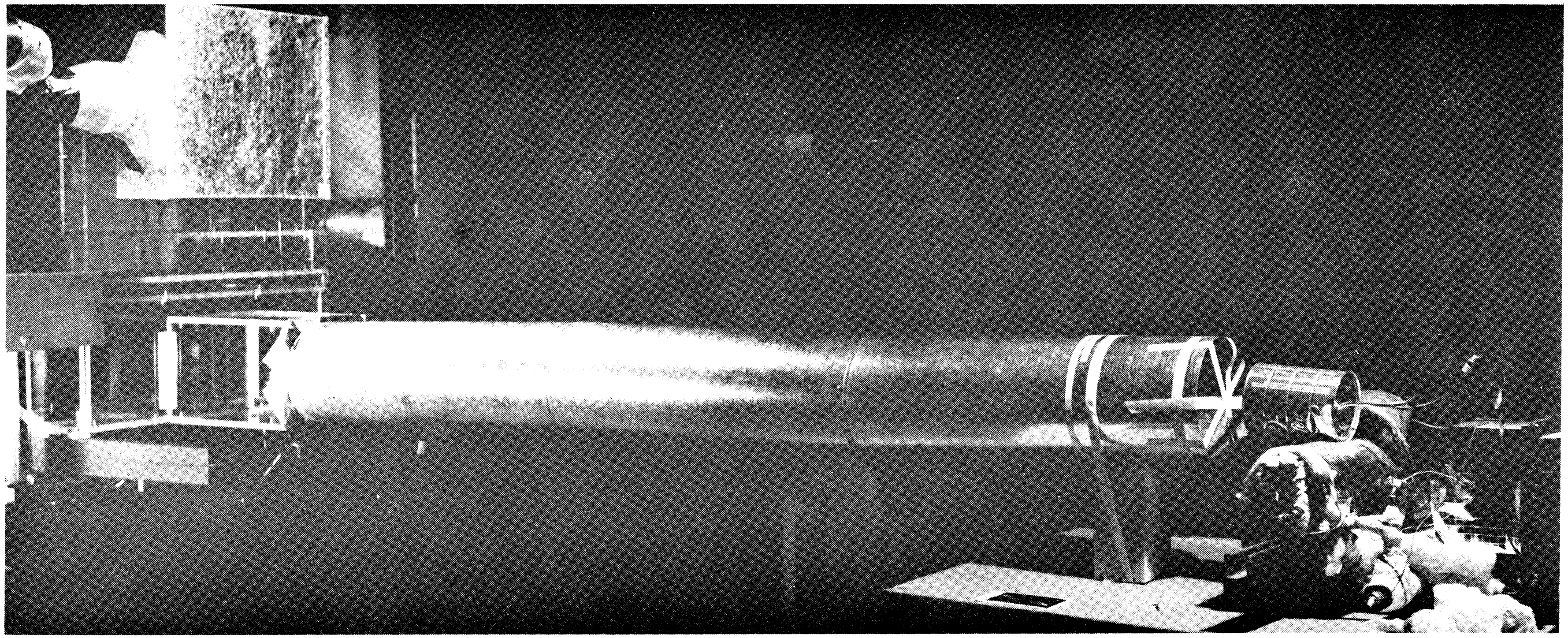
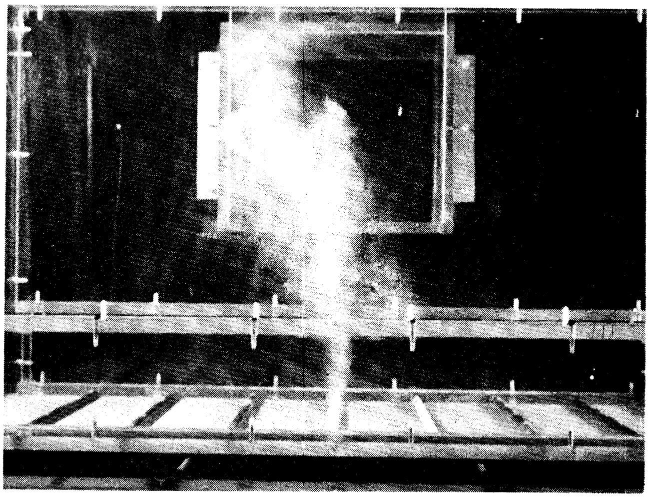
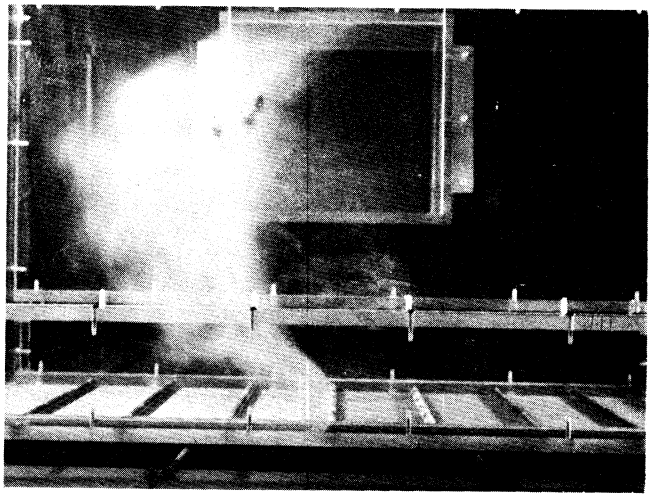


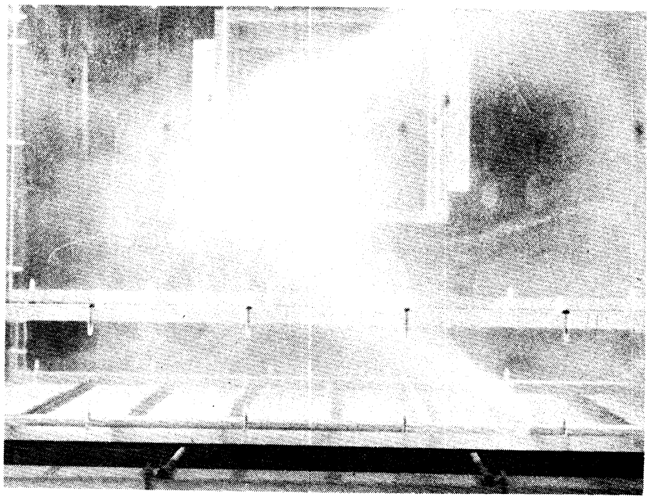
Figure 7. Photograph of Plexiglas Model with Extended Inlet and Metaldehyde Particle Generator



(a) Fabric Velocity = 0



(b) Fabric Velocity = 2180 ft/min



(c) Fabric Velocity = 2180 ft/min

Figure 8. Photograph of Flow in Upper Chamber, with and without Belt Moving
(Vertical and Horizontal Vanes Installed, Q' = 5,000 CFM)