

CHARACTERISTICS AND MODIFICATION
OF AN AIRCRAFT DISTRIBUTOR FOR
GRANULAR INSECTICIDES

by

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INTRODUCTION

The use of aircraft for distributing agricultural materials is big business. Reports from all parts of the world tell of experiences in distributing various materials such as spray, dust, seed, fertilizer and granules. The feverish motivation for this use of aircraft may be summarized by a quotation from Lehmann (20, p. 442).

The airplane's chief value to most operators is the saving of time. In some operations, such as seeding or when used to apply fertilizer, insecticides or herbicides, the condition of the land or crop may be such that a ground machine could not be used at all.

Hanson (15) of the Civil Aeronautics Administration reported in 1954 that over 7000 aircraft were then being operated by aerial applicator firms in the United States. Of these, only slightly more than one-half were probably registered as full time agricultural aircraft. In 1956, Aviation Week (2) reported 4200 registered full time agricultural aircraft. Civil Aeronautics Manual 8 (9) defines agricultural aircraft as aircraft operated for the special purpose of: ". . . spraying, dusting, and seeding; livestock and predatory animal control."

The use of aircraft for applying material beneficial to crops, vegetation, or soil is not new. In 1917 according to Ford (13), a Louisiana cotton field was dusted with an airplane. In 1918, dusting was attempted near Reno,

Nevada (19). The expediency of early aerial application methods is indicated in an article by Wrigley (37), stating that in 1919 a United States farmer chartered a plane and lay on its wing sprinkling insecticide out of a bag as the airplane passed over his field. Each of the above listed authors contends that the instance he cites is the first attempted use of the airplane for applying beneficial materials. However, Coad et al. (10), French (14), and Thomas et al. (30) agree that the first successful application of insecticide from aircraft brought to public attention was done by the Ohio Experiment Station in 1921.

Aircraft Application of Dry Materials

The United States Department of Agriculture started work on airplane dusting for cotton leaf worm control in 1922. This work is reported by Coad et al. (10). Two Curtiss JN6H, World War I, training planes piloted by United States Army Air Service pilots were obtained for the work. While the dusting done one year earlier in Ohio was accomplished using a hopper hanging outside the fuselage, United States Department of Agriculture workers fitted their hopper inside the rear, observer's cockpit. This hopper was discharged through a circular pipe which passed through the bottom of the fuselage. The design included a cut-off valve in the bottom of the hopper and a hand-

crank-operated paddle wheel for dust agitation.

A second hopper was constructed without a paddle wheel. A four-inch vertical tube with a funneled top inclined into the air stream was substituted to aid in feeding. This tube extended down into the hopper stopping short of the bottom, causing high velocity air to move through the discharge hole in the hopper bottom. Dust was carried with the high velocity air.

The two hoppers were installed in the respective airplanes and extensively tested. The paddle wheel arrangement was more successful, although it had the disadvantage of requiring a man, in addition to the pilot, for the purpose of turning the hand crank and operating the valve upon the start and completion of a swath. Results showed that aerial cotton dusting could be economically practical.

In 1927, Thomas et al. (30) used airplanes for boll weevil control experiments in Texas. He mentioned that a propeller driven agitator was used in the hopper of one of the airplanes. A venturi nozzle placed just forward of the hopper outlet was used on another airplane. Thomas thought that this nozzle was an aid in obtaining distribution of insecticide dust. Little attention had previously been given to distributing material after discharge from the hopper. Air flow about the moving airplane and the propeller

slip stream were the only forces acting to accomplish distribution.

Little further information has been found concerning the development of dry-materials distributors prior to World War II. During World War II, Germany used a distributor on its Focke-Wulff 58 described by Brown (6). The hopper of this device was W-shaped in cross section, each trough of the W feeding into a horizontal venturi tube mounted to either side of the bottom of the fuselage. Air was forced into the 27 cubic foot hopper. The agitator of this distributor was driven by a 25-volt electric motor.

The principle of entraining dry materials from the airplane hopper into the throat of a converging-diverging shaped tube or pan with fore and aft ends open is important. This pan or tube is commonly referred to in the literature as "venturi", "venturi distributor", or "venturi spreader". French (14, p. 10) stated in 1947: "This system [venturi spreader with reel type agitator] is essentially that which is used by practically all aircraft dusters today." In 1954, Roth (28) reported results of tests on this general type of distributor using rice. The same year Weick (32) presented design methods used in developing an improved venturi distributor for anticipated use in applying a variety of dry materials. Nowell (24) reported on recent United States Air Force airplane distributing equipment. The Air

Force is currently using the L-20 DeHavilland Beaver to complement the C-47 Transport. The L-20 is regarded by the Air Force as the light airplane best suited for distributing work. Various experimental sprayers have been tested on the L-20. In 1954, a granular insecticide distributing device was developed. Granular material was held in a 1000-pound capacity aluminum rectangular hopper tilted on edge. A feed chute was attached to a slot running the length of the hopper bottom edge. This feed chute passed through the camera well in the bottom of the fuselage, and joined a box whose fore and aft ends were open. This venturi box was six inches deep, 24 inches wide, and 31.5 inches long. The floor of the box had a three-inch rise resulting in a desired converging-diverging section. The effective swath width obtained with this device was 35 feet. However, further development is being conducted with wider swath width an objective.

Spraying

Brown (6) in an extensive review of literature found that Russia had conducted and recorded the first aircraft spraying experiments in 1922. Little further immediate work was done with sprays, since insoluble arsenicals were then the principal insecticides. French (14) reported in 1947 that he had observed spraying of liquid insecticides with

planes 15 years previous to 1947. He stated that liquid spray applied by airplane does not drift as much as dust applied by airplane. Spray drop size had been controlled sufficiently to reduce the problem. The problem of drift has been the point of much opposition to the aerial application of insecticides. As a result, a great deal of effort has been applied to the problem. Brooks (5) concluded that very fine dusts should not be used for aerial application. Volume of dust lost and poisoning of adjacent pastures and crops were cited as reasons. Thus, in recent years liquid sprays have been favored over dusts for many aerial uses.

The Helicopter

Brown (6) compared the helicopter with the airplane. This comparison was for efficiency in dusting and spraying. Wilson et al. (36) compared a helicopter and an airplane for spraying only. The cost of a helicopter is several times that of an airplane of comparable load capacity. Helicopters appreciably reduce maneuvering time in applying small fields. Since the helicopter's forward speed is usually slower than the airplane's, little total time is saved except for very small fields.

Types of Aircraft Used

Prior to 1950, aircraft used for application of material were conventional aircraft of various sizes with distributing accessories. From the best information found by this author, the first airplane designed explicitly and primarily for spraying and dusting was the Ag 1. This airplane was first designed and flown in 1950, and its specifications are listed by Weick (31), who was a chief contributor to its design. Work on aircraft of specialized design has continued. The Ag 2 Transland, a larger version of the Ag 1, is in production. The Ag 3 has been developed at Texas A & M. Weick and Roth (34) report that the Air tractor, a biplane, and the Callair A-5 are commercially available. The National NA-75, a biplane, is in production (23). Percival Aircraft of Britain is producing an airplane, the EP9, for spraying and dusting (12). Airplanes used for treating intensively tilled crops have been small, usually having load capacities in the 1000 pound range or smaller. Treating larger areas, such as forests, has been successfully accomplished with much larger airplanes. C-47 transports, flying relatively higher and treating wider swaths, are especially successful. In New Zealand, larger airplanes of one ton or greater capacity have shown superiority over smaller airplanes for distributing fertilizers over large areas (1).

Aerial Insecticide Application for Corn Borer Control

Dust and liquid spray

The European corn borer (Pyrausta nubilalis (Hnb)) has caused high monetary loss in damage to sweet corn and field corn (21). Since the corn borer now infests corn in all major corn producing areas in the United States and Canada, serious efforts have been made to control the insect with both aerially and ground applied insecticides. Applying dust for corn borer control with ground machines has been somewhat unreliable because of difficulty in placing dust in the corn whorl where borers feed. The use of ground machines for applying liquid spray has been more successful, although accurate, concentrated placement of insecticides remains a problem.

Aerially applied insecticides have usually been less effective in corn borer control than ground-machine-applied insecticides. Ground and aerial methods were compared in Illinois by Bigger et al. (4). Ground methods appeared to give better corn borer control. Control obtained with liquid spray was thought superior to dust for both aerial and ground applications. Practical control was obtained with aerially applied spray, however; and air application was popular with operators who had large acreages to treat. In 1948, Raun et al. (27) obtained good corn borer control in Iowa field corn using aerially applied spray.

Granular insecticides

Granular insecticides were first used for corn borer control in 1953 when tests were conducted at the Iowa State College Ankeny Field Station (11). Ground machines used to apply the insecticide were two modified grass seeders and a power duster. The modified grass seeders were more satisfactory. Results showed that granular insecticides are as effective, or possibly more effective, than liquid sprays for corn borer control.

The geometry of the corn plant and the physical properties of the granules made it possible to concentrate insecticide in the corn whorl where borers feed. When granular insecticides are released above the corn plant, a large fraction strike the leaves. Of the fraction striking, many strike leaves which slope toward the whorl. These granules may adhere for a time, and then roll into the whorl, or they may roll directly into the whorl. Leaf movement caused by forces such as wind currents and the passing machine affect the rate at which granules are directed into the whorl.

The possibility of successful aerial application was a major impetus to the development of granular insecticides. Aerially applied dust drifts with the wind excessively, severely limiting the usefulness of aerial application. The relatively large particles composing granular insecticides

fall with less drift than dust particles. Since granular insecticides were first used in 1949, both aerial and ground application have become important mosquito control methods in the United States. In Ohio, aerial application of granular insecticides has provided spittlebug control equal to that obtained by ground application of either spray or granules (35). In general, granular insecticides have proven useful whenever reduced wind drift and ability to penetrate dense foliage are desired characteristics.

Although foliage penetration is not a necessary insecticide carrier characteristic for aerial corn borer control, resistance to wind drift is important. The ability of granules to roll into the whorl of the corn plant is important in aerial as well as ground application.

Favorable characteristics of granules offer promise of corn borer control with aurally applied granular insecticides equal to control obtained with ground applied insecticides. Since the present state of aircraft and aircraft distributor development makes it necessary to broadcast material over the field being treated, more insecticide may be required than with ground machine application. Ground machines are capable of applying a narrow band of insecticide over the plant row; however, at the time of second-brood corn borer control applications, usually the corn plants have filled the rows, giving this narrow-band application

questionable superiority over broadcast application.

The additional insecticide required for aerial broadcasting for first brood corn borer control may not be so large as to make this method uneconomical relative to narrow-band ground application. However, large and frequent irregularities in field coverage in aerial broadcasting could result in inferior control and an exaggerated insecticide requirement.

Objectives

This work was undertaken primarily to determine the operational characteristics of a conventional aircraft distributor when used to apply granular insecticides. To determine these characteristics, the subordinate objectives of the work are:

1. To determine the distribution pattern for various flight altitudes.
2. To determine the relative effect of wind upon the distribution pattern.
3. To measure pressures and velocities in and about the distributor, so that the desirability of the distributor's geometry might be evaluated.

With the determination of the operational characteristics of the distributor, this work was further directed

toward finding what modifications, if any, could be applied to the distributor to improve its characteristics when used to apply granular insecticides.

INVESTIGATION

Review of Literature

Distribution pattern measurement

Aerially applied seed and fertilizer patterns have commonly been measured by sampling deposits at various intervals along a line perpendicular to the applying aircraft's line of flight. The weight of material collected at various sampling points is then determined gravimetrically or volumetrically. Sanders (29) developed a portable measuring station which could be quickly moved and oriented with respect to wind. It was 51 feet long and provided nine places for sampling pans or trays. The trays used on this station for collecting fertilizer and seed were approximately four inches deep, 36 inches long, and 35 inches wide resulting in an effective inside area of 0.0002 acres. Sloping plastic bottoms delivered the material to calibrated measuring tubes. Errors were on the order of five percent when deposits were applied at the rate of 40 pounds per acre or greater. Although untried, the use of radioactive materials to measure deposits was being explored.

Weick (33) described a measuring station developed at Texas A & M. This station was in use in 1953 and consisted of 21 modified analytical balances placed five feet on centers on a line perpendicular to the anticipated line of

flight. A light-weight 16-square-inch platform on which aeriaily applied material might be collected was added to each balance. Protective boxes covered delicate parts of the instruments. The success of these balances for coarse material is questioned, since in 1954 Weick (32), also of Texas A & M, reported sampling rice seed distribution patterns with wood frames having fabric bottoms. The frames were placed five feet on centers and after each test the number of seeds collected in each was counted and recorded.

In 1956 Chamberlin and Young (8) reported successful granular material distribution pattern measurement using circular 12-inch-diameter, three-inch-deep milk pans. The weight of collected samples was measured with a torsional balance. Ninty percent of the known discharge was accounted for by the collections measured.

The distribution pattern

A number of variables influence the location and distribution of an aeriaily applied material. Sanders (29) reasoned that deviation from the intended path of flight due to pilot error and meterological and topographical factors prevents uniform coverage with aeriaily applied materials. A rectangular pattern could result in untreated strips between swaths. An overlapping distribution pattern would be more desirable since untreated strips would not be

left. A distribution pattern with sloping sides was thought desirable. Weick (32) noted that a triangular pattern gives the least variation in coverage with deviations from correct swath spacing. The triangular pattern has an effective swath width of one-half the total swath width. Since a wide swath is desirable, and there is a limit to the total swath width which can be obtained, a compromise between the rectangular and triangular patterns was reached in the form of a trapezoidal pattern.

Roth (28) extensively tested the effect of wind and aircraft altitude on rice seed distribution. He used a Boeing Stearman airplane equipped with a seed distributor of conventional design. During all tests, engine speed and manifold pressure were held constant. The hopper load was maintained between the limits of 150 and 300 pounds. A fixed hopper gate opening was also used. Observations on aircraft altitude and wind conditions at the time of the tests were made. The method of measuring altitude was not explained and it is not known what limits of accuracy apply to this measurement. The line of flight relative to the sampling station was noted.

Results showed up to 30 percent variation in seed rate from the average seed rate for a number of runs. An attempt was made to determine if a periodic fluctuation in seeding rate were causing this deviation. Sampling frames were spaced

five feet apart transverse to the line of flight, as well as along the line of flight. Results did not indicate conclusively that there was a periodic or regular fluctuation in seeding rate.

The component of wind velocity transverse to the direction of flight, referred to as cross wind, and aircraft altitude were found related to swath displacement. The lateral displacement of the swath for three altitudes was found and is shown in Table 1.

Table 1. Effect of cross wind on swath displacement for rice^a

Height (ft)	Rate of lateral displacement, (ft/mpg of cross wind)
10	2.2
20	3.2
30	4.2

^aFrom Roth (28, p. 4)

Higher cross winds slightly increased swath width. It was thought that increased turbulence accompanying higher wind velocities was responsible. For a given altitude, greater cross wind tended to change the distribution pattern shape from triangular to trapezoidal.

Increased swath width resulted at higher altitudes, but the shape of the distribution pattern was not greatly changed.

Venturi distributor principles

A fundamental investigation of the behavior of dry materials flowing through an aircraft distributor was conducted by Henry (17). The function of an aircraft distributor is to give proper velocity and direction to the particles of material to be applied so as to obtain the desired distribution pattern. Because numerous variables other than distributor design are encountered in field testing, wind tunnel work was attempted. A representative section of a venturi distributor was tested in a non-recirculating wind tunnel. The height of the distributor section was adjustable to obtain various amounts of convergence and divergence of the distributor section. A metering device fed material into the throat of the distributor in a manner similar to that of a prototype airplane distributor. Wheat, fertilizer, and dust were used at various rates. Velocity of wheat was measured with the aid of a high speed movie camera. Appreciable reduction in throat cross sectional area resulted in a lower exit velocity for wheat, even though the wheat was accelerated more rapidly at first. It appears that for high rates of material flow, a small amount of throat restriction is desirable. The problem might be circumvented by making

the distributor larger. The exit velocity of the wheat was approximately one-fourth the inlet velocity of the air.

With air alone flowing through the distributor, negative pressures were observed in the distributor throat. In general, reducing the throat cross section reduced the throat pressure and increased throat velocity. When 138 pounds of wheat per minute were metered into the throat, throat pressure was only slightly negative.

Venturi distributor design

A venturi distributor design partially based on wind tunnel information obtained by Henry (17) was completed at Texas A & M. Weick (32), reporting on this design, reasoned that materials composed of heavy, large particles such as seed and fertilizer are more difficult to apply in wide swaths because they fall rapidly and receive little aid from the outward movement of the air below the airplane wings. It was thought necessary that the particles leave the distributor with a transverse component of velocity if a wide swath were to be obtained. It was speculated that a transverse component of velocity would also be satisfactory for fine materials such as dusts.

A drawing of the distributor as it was developed for the Piper PA-18A airplane is shown in Figure 1. The distributor was made as long as practical so that air would

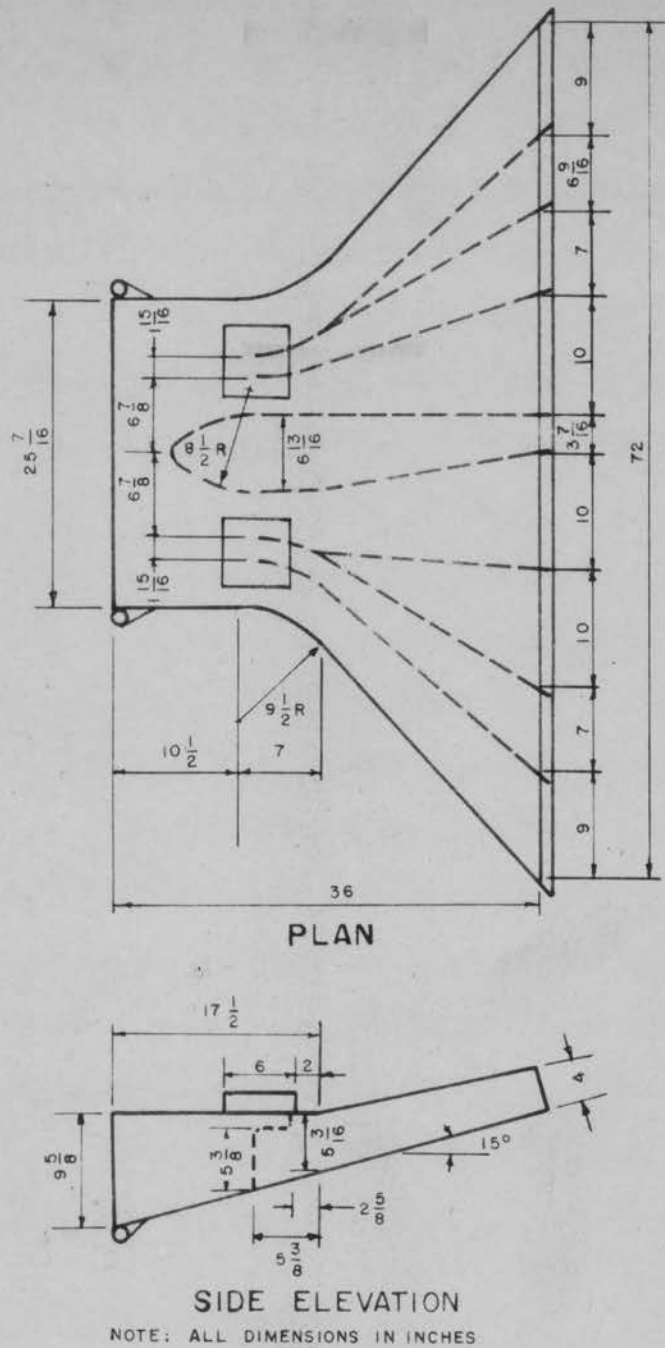


Figure 1. Venturi distributor for Piper PA-18A airplane

accelerate the material in a controlled manner for the longest possible time. The location of the outer set of interior vanes was determined through testing for the greatest possible swath width. The effect a converging passage might have upon pressure at the gate was also considered. Extension tubes of constant cross section on the outer passages failed to yield practical increases in swath width. The application of open-ended tubes to the side of the distributor did not affect swath width.

The location of the inner four passages was determined through testing various trial locations with only one to two passages in operation. The locations found were the ones best suited to fill in the center portion of the pattern in the presence of the propeller slip stream which tended to displace symmetrically dispensed material to the left.

The distribution pattern of rice seed obtained from the resultant design is shown in Figure 2. When this pattern was added to identical adjacent patterns, each pattern spaced 38 feet apart, a deviation of six percent from the average application rate resulted.

Experimental distributors

Henry (16) reported on tests conducted on experimental box shaped distributors with fore ends open and aft ends connected to curved tubes of various lengths, which carry

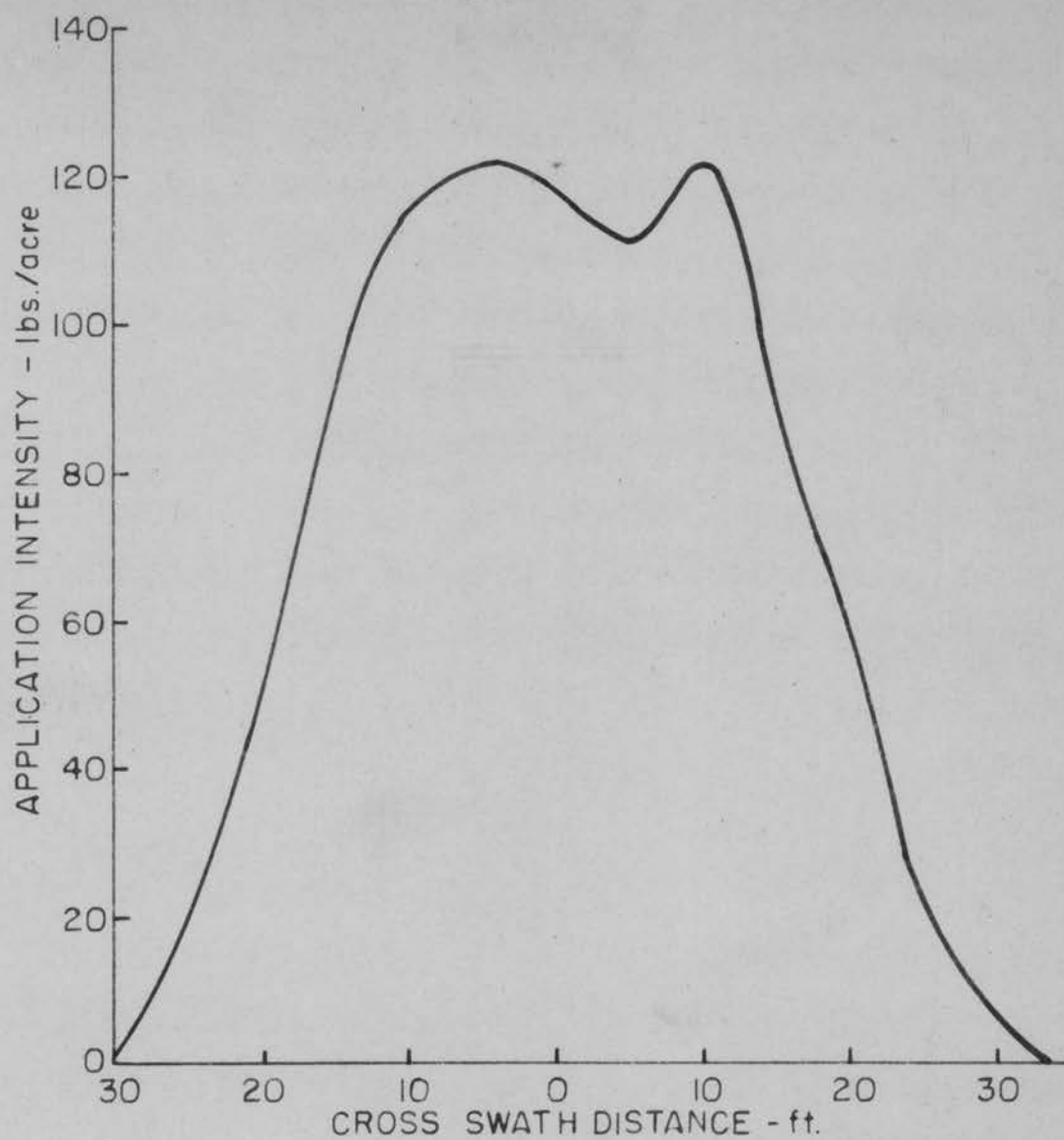


Figure 2. Rice distribution pattern from Weick (32)
Altitude 20 ft, air speed 85 mph, wind 4 mph

material to be applied outboard. A 40 foot effective swath width was obtained with one of these distributors using 30/60 mesh clay applied at a rate of 30 pounds per acre. Wider swaths were obtained with granular fertilizers than with granular clay. A metering device driven by a hydraulic motor had been developed for use on these distributors.

Chamberlin and Young (8) reported in 1956 that they were developing a distributor that produced a 50 to 55 foot swath width with 20/60 mesh attapulugus clay carrier. This distributor includes spreader tubes which discharge a portion of the material six feet from either side of the airplane center line.

Field Investigation

Airplane distributor and material

An airplane equipped with a dry-materials distributor was made available for testing through the courtesy of a commercial applicator, Charles Lavery of Indianola, Iowa. Two pilots who were employed for seasonal work by Mr. Lavery alternately flew the airplane for the tests. Most of the tests were conducted after the 1956 corn borer and grasshopper control season.

The airplane used was a Piper PA-18A equipped with a 135 horsepower Lycoming engine, commonly referred to as a Piper 135 Super Cub. The Piper PA-18A is a modified version

of the Piper PA-18 which facilitates the use of the airplane for cargo hauling, spraying, or dry materials distributing. The airplane was equipped with an 18-cubic-foot aluminum tank which serves as a liquid spray tank or a dry materials hopper. The possible multi-use of this tank permits a rapid change from liquid spray to dry materials distributing equipment.

The materials distributor used was the one designed and developed at Texas A & M as shown in Figure 1. This distributor is currently being manufactured by the Piper Aircraft Corporation. The dimensions shown in Figure 1 were obtained from measurements of the distributor used and were confirmed by Piper (25). Two sliding gates controlled the flow of material from the hopper. With the gates completely forward, each opening is six inches square. Because the application rate of five percent DDT granules for corn borer control is usually 20 to 25 pounds per acre, a relatively low discharge rate is required. When applying a 40 foot effective swath width at 80 miles per hour, nearly 6.5 acres must be treated every minute. For a 25 pounds per acre application, over 160 pounds per minute of material is required.*

Two plates which fit over the sliding gates of the distributor were available for use, however the three one-

* A convenient nomograph has been prepared by Akesson (3) relating the variables of this calculation.

inch triangular openings in these plates over each passage, provided insufficient opening for sufficiently fast flow. Accurate adjustment of the gate opening to obtain a prescribed rate of flow was difficult. Improved plates were constructed making single triangular openings one inch by four and three-fourths inches over each distributor passage.

Other features of the distributor unit included a reel type agitator in the hopper to aid in maintaining smooth flow from the hopper into the distributor. This agitator was driven by a propeller through a 47 to one gear reduction box. Positive pressure was maintained in the hopper by an air scoop on the hopper lid.

A particular granular carrier selected for the tests was 30/60 mesh bentonite clay. The bulk specific weight of this material was found to be 73.1 pounds per cubic foot. A sieve analysis of 200 grams of the material using a vibrating shaker for five minutes was made:

Percent Retained on U.S. Standard Sieve Number

20	30	40	50	60	80	Pen
0.3	21.6	58.8	17.0	1.5	0.5	0.3

It was thought that this granular carrier would be well suited to aircraft application because of relatively large particle size and high bulk specific weight. These characteristics reduced the effect of wind on the distribution pattern. Since the distributor used was known to have good

distribution pattern characteristics for rice, a material whose particle size and density approached that of rice could be used with more certainty of success than a fine, light material. To provide data for comparing lighter granular carriers with 30/60 mesh bentonite, 30/60 mesh attaclay was also selected for testing. Attaclay is a commercially important carrier, readily obtainable. The bulk specific gravity of the 30/60 mesh attaclay used was 32.0 pounds per cubic foot.

Equipment for measuring the distribution pattern

It was not possible to plan the exact location of the testing area prior to the aerial applying season. It was anticipated that some tests might be run in conjunction with commercial applying work. For this reason it was desirable to construct units for sampling the distribution pattern which could be quickly moved and readily stowed in a panel truck. Since limited personnel would be available to help with the work, units were needed which would require minimum manipulation at the test site. The collecting area of the sampling units would need to be large enough to collect sufficient material for accurate gravimetric or volumetric measurement.

Twenty-one pans were constructed of 26 gage sheet steel. The design was basically the frustrum of a right

circular cone with an altitude of six inches. The top diameter was 26.5 inches, forming a collection area of 3.84 square feet. This area intercepts one gram of material for an application of 25 pounds per acre applied. A full fell interlocking seam was used to join the development. This seam was soldered to prevent the retention of granular material by the seam. A 1.25 inch hole was provided in the center of the pans for collection of the granular material in three inch soil sampling cans. Sheet steel rings supported the pans and a plywood base was built for the unit. This base could either be placed on the ground or atop a one-half inch diameter, 52 inch long rod for sampling distribution patterns in corn fields being treated with granular insecticides. A drawing of the unit is shown in Figure 3.

Glass plates approximately five inches by eight inches were made available for use by personnel of the United States Department of Agriculture Corn Borer Laboratory, Ankeny, Iowa. Coating these plates with a diluted water soluble glue, made it possible to collect sample deposits of the distribution and retain the deposit for future inspection.* Since the particles of the deposit are held in place,

*This method was developed by H.C. Cox, entomologist, and W.G. Lovely, agricultural engineer; both of the Agri. Res. Serv., USDA.

27

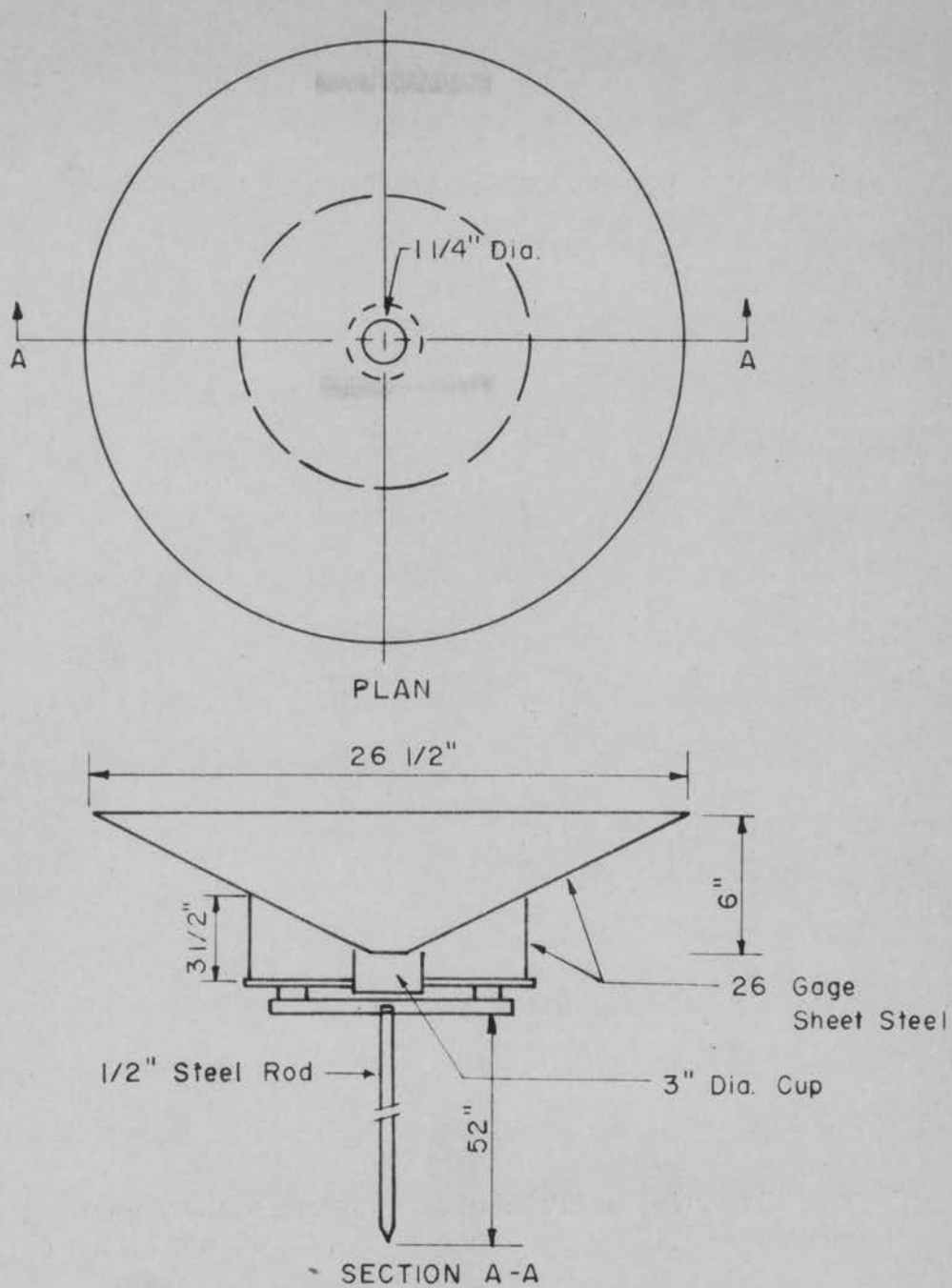


Figure 3. Pan type sampling unit

particle numbers per unit area may be found. Thus a distribution pattern of particles per unit area may be found using these plates.

Preliminary tests

Tests were made using 30/60 granular bentonite carrier over an open alfalfa field used as a landing field for Lavery applying airplanes. Sampling units were placed atop one-half inch diameter rods raising the collection pans four feet from the ground. This was done to make possible comparison of data taken from corn field tests where it was necessary to raise the pans slightly above the corn. Figure 4 shows a test in progress with the airplane passing over and perpendicular to the line of sampling units.

Altitude measurements were based on the height of the distributor from the ground. A surveyor's transit was placed 200 feet perpendicular to the anticipated line of flight. Based on the premise that the pilot could closely approximate an altitude at which he was instructed to fly, the vertical movement of the transit was set at an angle such that the airplane, specifically the distributor, would be viewed when the airplane was flown over the prescribed center line at the prescribed altitude. It was found that the pilot would usually come within plus or minus three feet of the altitude at which he was attempting to fly. Estimation

Figure 4. Pan method of sampling the distribution pattern

29b



relative to known distances on the airplane was necessary on the part of the transit observer in determining the correction.

Wind velocity was measured with a vane type anemometer located 40 inches from the ground at the end of the line of collection units. The anemometer actually measured feet of air passing it. The procedure for measuring was to start the anemometer approximately 15 seconds prior to the test and allow it to run a total of 30 seconds through the progress of the test. Converting feet per 30 seconds to miles per hour gave useful values. The direction of wind was roughly determined through the use of an airsock. This direction was converted to an assumed azimuth based on the line of flight as the meridian.

Engine speed was maintained at 2200 revolutions per minute for all but two of these tests. The airspeed corresponding to 2200 revolutions per minute was approximately 80 miles per hour for the tests. Two tests were run at 90 miles per hour and at a higher engine speed. Wing flaps were not used for any of the tests. Seventy-five to 150 pounds of 30/60 mesh bentonite carrier was maintained in the airplane hopper for the tests, with two exceptions: Two tests were run with 300 pounds of 30/60 mesh bentonite in the hopper. In the three tests using 30/60 mesh attaclay carrier in the hopper, 100 pounds was used. The gate opening

was held constant for all tests using granular bentonite, but was opened wider for granular attaclay. The settings were used to apply a nominal 25 pounds per acre based on a 40 foot effective swath width.

Upon completion of a testing session, the samples collected in the three inch cans were carefully weighed on an analytical balance. The weights measured were converted to pounds per acre by taking into account the area of the pans. The intensity of application over the area of the pan was assumed to represent the intensity at the center of the pan, and this intensity was plotted on a chart using intensity as the ordinate and cross swath distance as the abscissa. A pair of representative distribution patterns is shown in Figure 5. The patterns are oriented as if the airplane were flying into the paper.

Preliminary test results and discussion

Analysis of each plotted distribution pattern reveals the amount by which its center was displaced from the center of flight. The prominent valley in the center of each pattern was taken as the pattern center. Figure 6 shows center displacement plotted against the cross component of wind velocity for altitudes of 19 to 22 feet. An approximate upper limit for displacement in this altitude range for 30/60 mesh bentonite is indicated by a line on Figure 6 with a

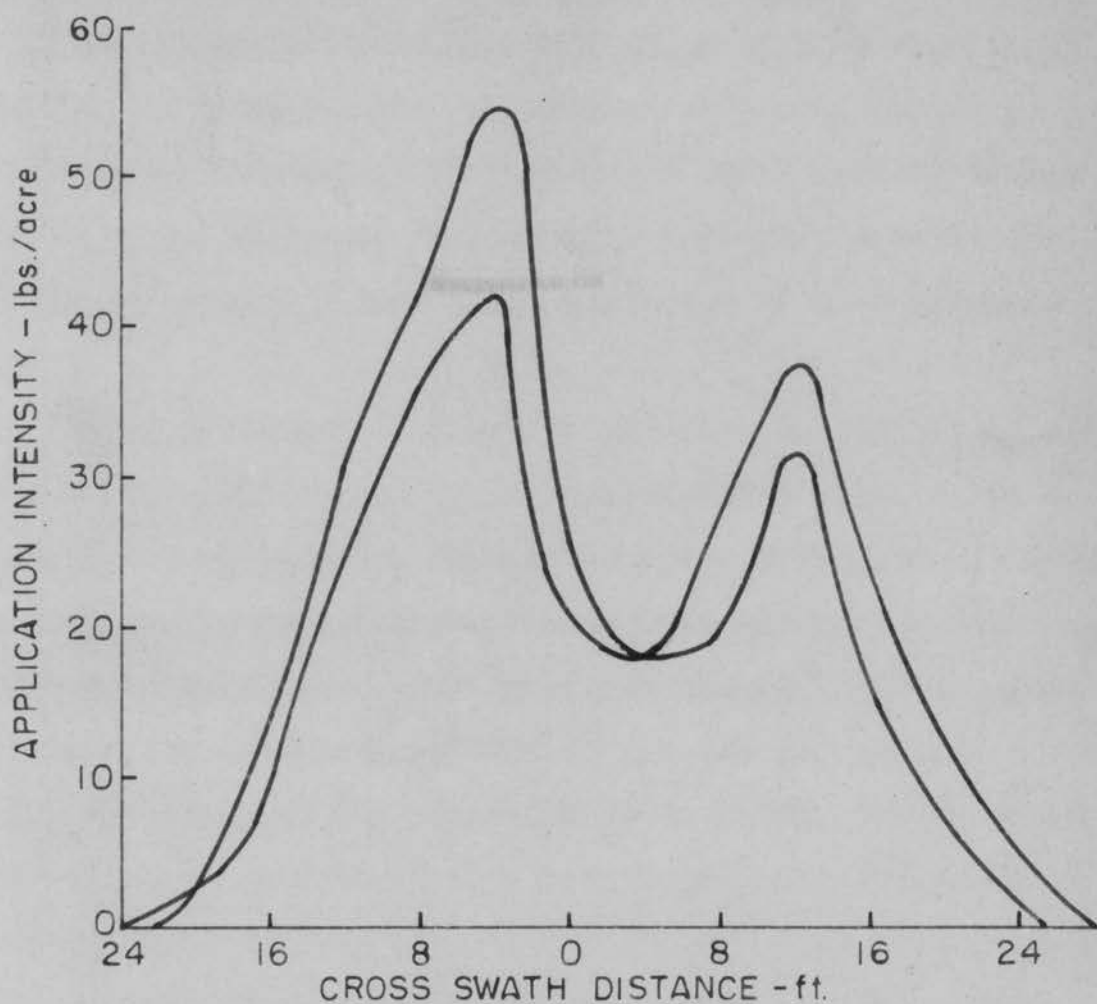


Figure 5. Representative 30/60 mesh bentonite distribution patterns
Altitude 22 ft, air speed 80 mph, wind 3.1 mph
at 260 degrees

slope of 2.3 feet displacement per mile per hour cross component of wind. Wind had an appreciably greater effect on 30/60 mesh attaclay, displacing the pattern center eight feet for one mile per hour cross component of wind. Two tests for an altitude of 40 feet using 30/60 mesh bentonite were in close agreement showing a 16 foot displacement for 1.4 and 1.6 mile per hour cross component of wind respectively.

Figure 7 shows the effective swath width plotted against altitude for all tests. The effective swath width found was based on the application intensity at the prominent valley in the center of each pattern. The maximum spacing of identical patterns which would result in an overall application never less than the application intensity at the swath center valley was taken as the effective swath width. An effective swath width by this definition is a practical value which an aerial applicator could use to maintain a prescribed level of intensity. Higher effective swath widths were obtained at 90 miles per hour than at 80 miles per hour air speed. However, these patterns have larger peaks. The patterns obtained at an altitude of 40 feet have relatively high effective swath widths, but greater difficulty in obtaining uniform swath spacing under gusty wind conditions at higher altitudes tends to outweigh this advantage. Granular attaclay gave relatively low effective swath widths.

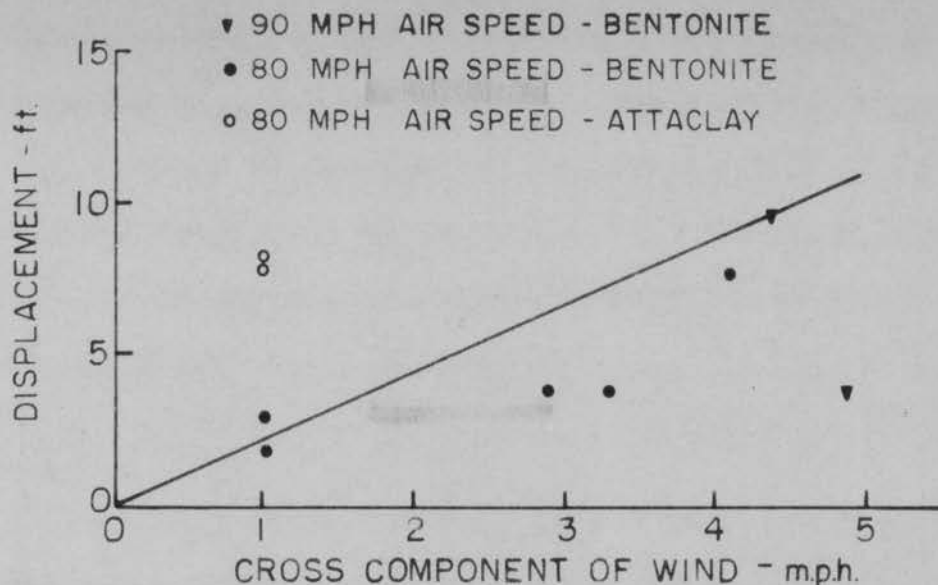


Figure 6. Displacement of swath center vs. cross component of wind for altitude range 19 to 22 feet

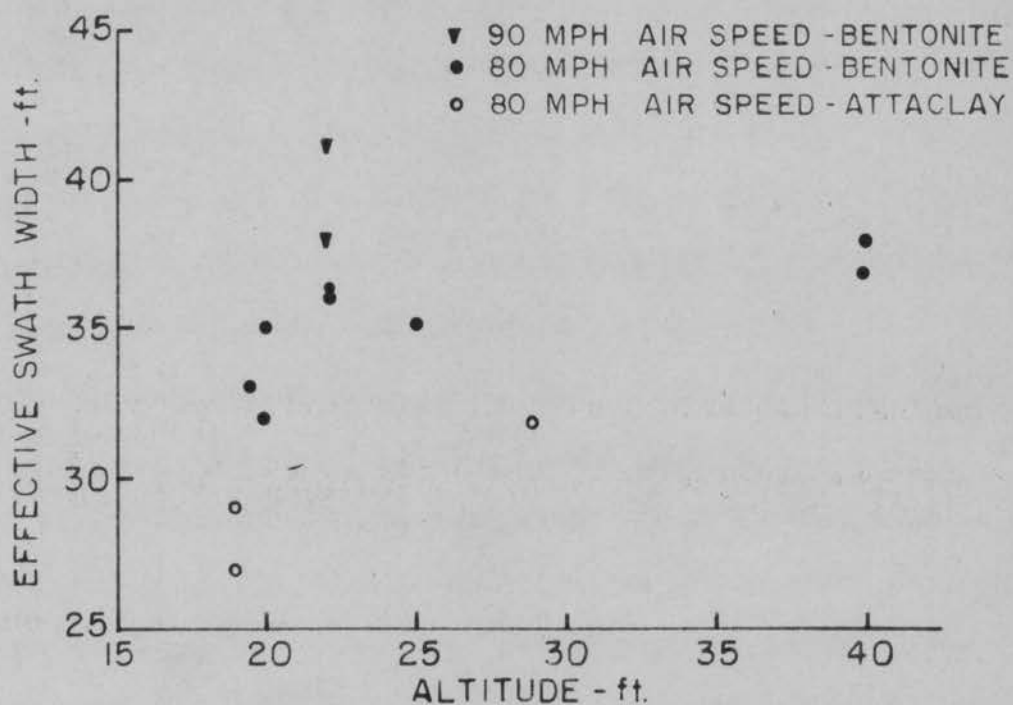


Figure 7. Effective swath width vs. altitude for wind velocity range of one to 5.2 miles per hour

The two peaked configuration was found for all distribution patterns in varying degrees. The maximum ratio of intensity between the center valley and the tallest peak of the patterns for bentonite was 0.58. For attaclay this ratio was 0.75. Data for all preliminary tests are presented in Appendix A, Tables 2, 3, 4, and 5.

Modification tests

From the preliminary tests, it was revealed that the distribution pattern obtained using 30/60 mesh bentonite differs appreciably from the desired trapezoidal pattern. In an effort to improve the pattern, an investigation was conducted to determine which distributor passages contribute appreciable material to the swath center. Tests were made discharging material into pairs of passages only. This was done by closing off the triangular gate openings not wanted. The openings were closed by placing pieces of sheet aluminum over them and allowing the material in the hopper to hold them in place. After each test, the pieces of aluminum were checked to see that nothing had moved them.

Concurrent sampling was carried out for two tests using a row of glass plates parallel to and five feet from the row of sampling units used for the preliminary tests. The glass plates were held 30 inches from the ground by one-half inch rods. Immediately prior to the test, the

plates were coated with a diluted water-soluble glue.* Figure 8 shows glue being applied to a glass plate. After the airplane had passed over the measuring station, the glass plates were filed in boxes with wood separators for holding the plates apart. In the laboratory, the plates were removed from the boxes and placed upon a blackboard marked with one-fourth inch white grid lines. All particles were counted in a randomly selected square and this number recorded and plotted against cross swath distance.

Chamberlin and Young (8) found an Oregon applicator using an apron fastened to the lower rear lip of a distributor used on a Boeing Stearman airplane. This apron had the effect of increasing the effective swath width obtained for granular attaclay carrier from approximately 30 to 35 feet. It was thought that secondary eddies had been formed by the apron sending a portion of the material farther outboard.

A similar apron was mounted on the distributor being tested. It extended the entire rear width of the distributor, and was nine inches long. Guy wires held it at an angle of 25 degrees with respect to the distributor floor or bottom surface. Figure 9 shows this installation. It was hoped that such an apron might disturb the strong rotating propeller slip stream sufficiently near the distributor outlet to

*"Elmer's Glue" manufactured by the Borden Company.

Figure 8. Glue being applied to a glass plate for sampling the distribution pattern

Figure 9. Apron mounted on the rear lower lip of distributor



improve uniformity of the center portion of the distributor pattern. Two test runs were made using the apron.

Modification test results and discussion

Results from tests conducted with the inner pair of passages receiving material showed a concentration of material near the center of the swath as shown in Figure 10. Figure 10 also shows the relative agreement between particle numbers as collected with glass plates and weights as collected with pans. The four patterns shown in Figure 10 were obtained from a single run over parallel rows of pans and plates five feet apart. The pattern numbers 1, 2, 3, and 4 of Figure 10 indicate the order which the pans and plates were placed to obtain the patterns shown. Since the application intensity at the center of this swath was less than five pounds per acre with the gate opening used for preliminary tests, a wider gate opening was tried again discharging material only to the inner pair of passages. Figure 11 shows that patterns obtained from these tests had sharp peaks of nearly the same form as those obtained from the preliminary tests. Other pairs of passages operating separately gave two-peaked patterns. Data for these tests are presented in Appendix A, Tables 6, 7, and 8.

It was noted that a twelve-mile-per-hour wind was blowing during the first inner-passages tests. Later tests

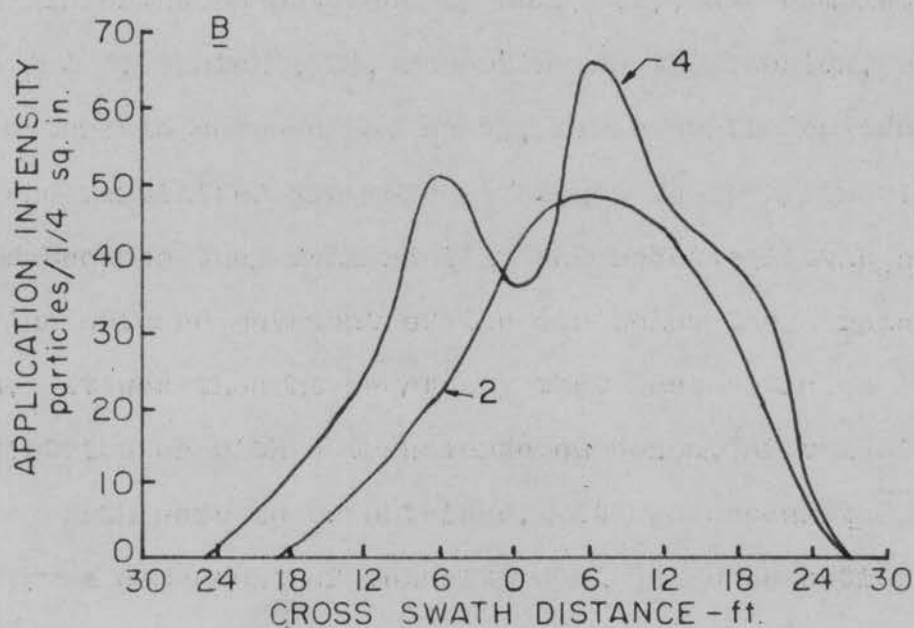
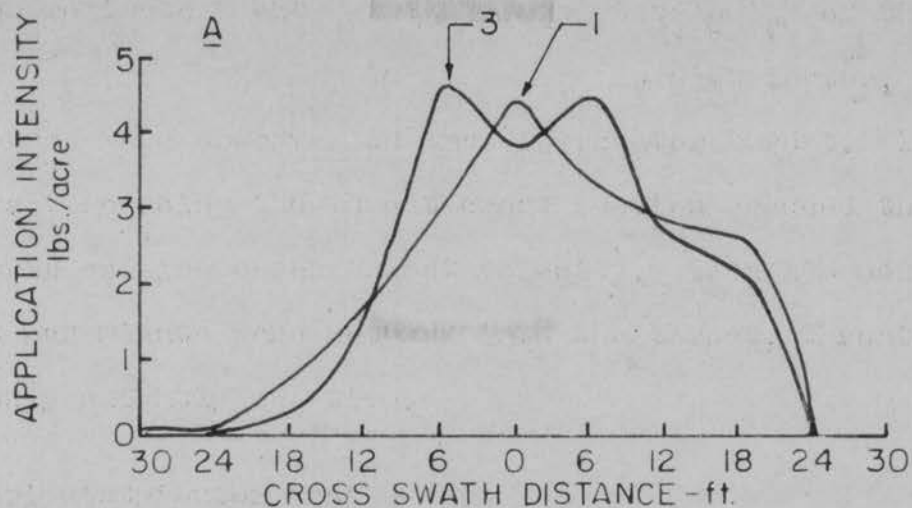


Figure 10. 30/60 mesh bentonite distribution patterns for inner passages only
Altitude 20 ft, air speed 80 mph, wind 12.0 mph at 0 degrees
A--obtained with pans
B--obtained with glass plates

with a larger gate opening were conducted on a calm day. Greater wind velocity could have contributed to the more uniform pattern obtained from the first tests.

The distribution patterns obtained with the apron attached to the distributor are shown in Figure 12. The two pattern forms obtained are not similar in shape. Pattern 1 has one large and one small peak to the left of the pattern center. Pattern 2 has relatively equal sized peaks on either side of the pattern center, which is a form characteristic of patterns obtained from the preliminary tests. Although the same gate opening was used for these two tests as was used for all preliminary tests involving bentonite, the flow rate was greatly reduced. If the decrease in flow rate were caused by increased pressure at the gate, the apron produced a result usually considered undesirable.

Investigation Using a Model

Facilities available

By early November of 1956, it did not appear feasible to attempt more field tests that season. Windy, cold days were frequent. In order that the investigation might be carried forward during the winter months, wind and smoke tunnel tests on a model distributor were planned. Arrangements were made for the use of the recirculating, low-speed wind tunnel located in the Aeronautical Engineering laboratory

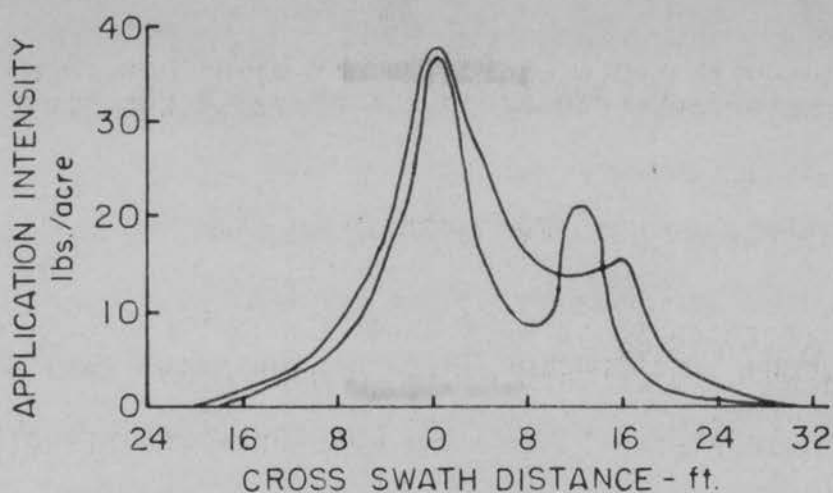


Figure 11. 30/60 mesh bentonite distribution patterns for inner passages only
 Altitude 18 and 19 ft, air speed 80 mph, wind 6.5 mph at 235 degrees

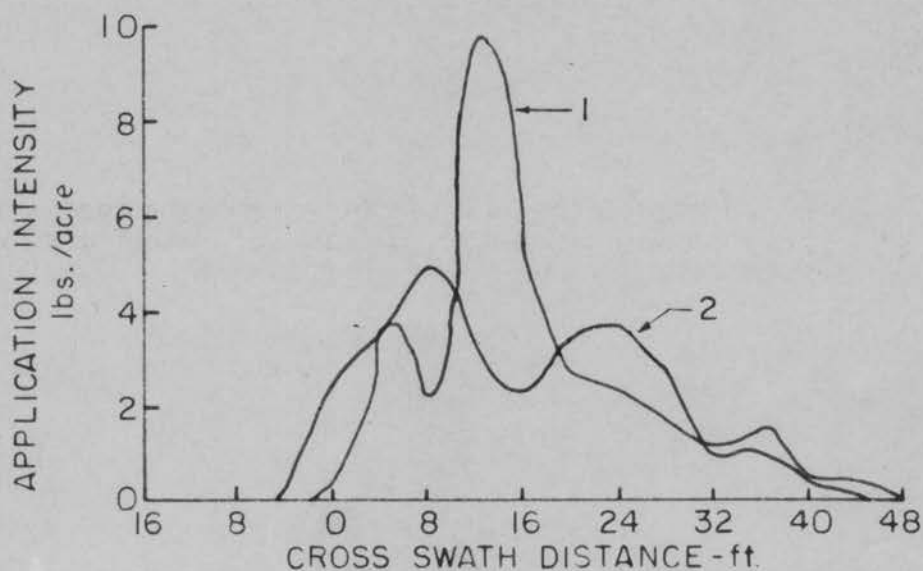


Figure 12. 30/60 mesh bentonite distribution patterns with apron on distributor
 Altitude 20 and 22 ft, air speed 80 mph, wind 6.5 mph at 235 degrees

at Iowa State College. Since this tunnel recirculates in one continuous closed system, it would be difficult to effectively use granular or dry material of any kind in the model. The test section of the wind tunnel was 24 inches high by 39 inches wide in cross section. It thus became evident that any model constructed of the airplane distributor tested in the field must be small scale to maintain similarity of streamlines in the wind tunnel.

Objectives of model investigation

The distributor that was field tested produced a much lower flow rate with an apron than without one. If the presence of the apron were the sole cause of this reduction in flow, the apron caused an undesirable increase in pressure at the gates. To establish the effect of the apron on pressure at the gates and to accomplish the third subordinate objective listed on page 11, supplementary objectives for the wind tunnel work were:

1. To design and construct a model which would indicate the magnitudes of pressures and velocities in the prototype distributor with and without the apron.
2. To measure pressures and velocities in the throat of the model distributor with and without the apron, and to relate the measurements to the prototype distributor.

Model design

When the mathematical equations for a phenomenon are not known, an appropriate first step in model design is to list the pertinent variables affecting the phenomenon (22). In the case under consideration, one phenomenon is pressure in the distributor throat, specifically the difference in pressure between a point in the throat and the free stream. Letting the dimensions of the variables involved be expressed in a set of basic quantities mass, length, and time whose symbols are M, L, and T respectively, a list of pertinent variables with their dimensions are as follows:

Pertinent Variables	Dimensions
P, Pressure at a particular point relative to free stream pressure	ML ⁻¹ T ⁻²
ρ , Mass density of fluid, air	ML ⁻³
μ , Viscosity of fluid, air	ML ⁻¹ T ⁻¹
V _a , Approach velocity of the fluid, air	LT ⁻¹
d, Interior height of distributor at the center of the gates	L
λ , Geometry of distributor	L
r, Roughness of distributor surfaces	---

A relationship among these variables may be expressed in terms of dimensionless quantities. According to the Buckingham Pi Theorem, the number of dimensionless and independent quantities, n, required to express the

relationship is equal to the number of quantities involved, s , minus the number of dimensions, b , in which these quantities may be measured. Hence: $n = s - b = 7 - 3 = 4$ dimensionless are quantities required. A possible relationship among the variables for the distributor is:

$$\frac{P}{\rho V_a^2} = f\left(\frac{\lambda}{d}, r, \frac{\rho d V_a}{\mu}\right)$$

Velocity in the distributor throat relative to the velocity of the airplane is the other important characteristic of the distributor which was desired. A similar set of pertinent variables with dimensions of the variables for velocity at the gates of the distributor are:

Pertinent Variables	Dimensions
V , Velocity of fluid, air, at the gates	LT-1
ρ , Mass density of fluid, air	ML-3
μ , Viscosity of fluid, air	ML-1 T-1
V_a , Approach velocity of fluid, air	LT-1
d , Interior height of distributor at gates	L
λ , Geometry of distributor	L
r , Roughness of distributor surfaces	---

The number of dimensionless quantities required is:
 $n = s - b = 7 - 3 = 4$. Combining the variables into the same dimensionless quantities used in the pressure difference

analysis when possible, it is found:

$$\frac{V}{V_a} = f_1 \left(\frac{\lambda}{d}, r, \frac{\rho d V_a}{\mu} \right)$$

Both the pressure difference and the velocity-ratio dimensionless quantities are found to be functions of $\frac{\lambda}{d}$, r , and $\frac{\rho d V_a}{\mu}$.

Since a model may be constructed which is a function of the same variables, it is necessary that $\frac{\lambda}{d}$, r , and $\frac{\rho d V_a}{\mu}$ must, in general, be the same for the model and the prototype, if accurate values of $\frac{P}{\rho V_a^2}$ and $\frac{V}{V_a}$ are to be obtained from the model.

Geometric similarity requires a choice of an exact length scale to be used for all model lengths. Since blocking effects due to the presence of a model in a wind tunnel require very detailed analysis*, even for common three-dimensional aircraft models; it appeared more feasible to reduce the distributor model size sufficiently to make blocking effects small. To do this, a length scale of six was chosen for the distributor model.

Roughness of distributor surfaces, r , is basically the roughness of the painted 0.032 inch sheet aluminum from which the prototype distributor was constructed. Proper roughness may be obtained in the model by constructing the

*Analysis is described by Pope (26, Ch. 6).

model of a material whose surface irregularities are reduced to the same scale as other model distances. For a small scale model, a material smoother than painted sheet aluminum would be desirable.

Upon examination of Reynold's number, $\frac{\rho dV_a}{\mu}$, it became evident that roughly six times the airplane velocity would be required in the wind tunnel. Undesirable compressibility effects would develop at this wind tunnel velocity. However, an intermediate value of velocity three times that of the airplane would be advantageous. Reynold's number, at a velocity of 120 miles per hour available in the wind tunnel, is approximately 100,000 for the model. This value of Reynold's number indicated that sufficient turbulence might be developed to result in pressure and velocity dimensionless quantities becoming independent of Reynold's number.

Model construction

Developments were made of all parts of the distributor reduced to one-sixth scale. These developments were cut from sheet "Plexiglass" using 0.06 inch for all exterior parts and 0.03 inch for the interior vanes. Wood molds were constructed for the shapes needed. The parts were heated to 250 degrees Fahrenheit, then placed in the molds for shaping. These parts were glued together using two types of glue. Glue made from a mixture of plastic shavings and a plastic

solvent proved more successful.

A drawing of the assembled model is shown in Figure 13. Even though care was taken in shaping and assembling the pieces, certain deviations from the one-sixth-scale design became evident after gluing. The dimensions given in Figure 13 were obtained from measurements of the completed model after gluing. Most difficulty was experienced in shaping and placing the center vane. Its nose was 0.15 inches rearward of design location and its widest portion was 0.08 inches above design width. The radius of curvature of the nose was 0.07 inches too small on the left side giving the nose a slight dissymmetry with respect to the distributor center line. The outlet height of the model was 0.03 inches above design requirements. Discrepancies can be observed by comparing the model dimensions shown in Figure 13 with the prototype distributor dimensions shown in Figure 1.

Three pressure taps were made on a line at each gate location at the prototype equivalent of one and one-half inches forward of the center of the gates. Figure 13 shows the location of these taps with an assigned number for each. This number will be used as an identification of measurements at these locations for all figures and tables. Fifty thousandth inch inside diameter, 0.065 inch outside diameter, hypodermic tubing was inserted and cemented into the tapped holes. Care was taken not to project the tubing completely

through the hole. This same hypodermic tubing was used to construct an impact tube which was inserted through a small hole in the side of the model. The hole was located so that the open end of the tube would be positioned one-half the depth of the model directly beneath the static taps. The hole was sealed with cement when not in use.

The model was mounted on a tee frame which could be attached to three struts fixed in the wind tunnel ceiling. The completed model is shown in Figure 14.

Wind tunnel tests

Characteristics of the wind tunnel were obtained from Iverson (18). A four-bladed fan was driven by a 25-horsepower, three-phase induction motor. Forward of the test section were three-inch-square honeycomb straighteners and a flow control screen. With this equipment, the dynamic pressure variation across the test section varied less than 0.5 percent from the mean. The turbulence factor as determined by drag measurements on a standard sphere was found to be 1.25.

Dynamic pressure in the tunnel test section was obtained by measuring the pressure difference between the stilling chamber and the forward end of the test section with a vernier manometer. This pressure difference was related to both dynamic pressure and static pressure by cross plotting

from curves obtained by Iverson (18) for the proposed location of the distributor model 18 inches aft of the forward end of the test section.

A calibration test for the impact tube to be used was conducted. A maximum of ten percent difference between the impact tube and standard pitot tube dynamic pressure measurements was found. Most differences were six percent, the impact tube always being on the high side. A difference of ten percent would result in a difference of five percent in velocity measurement. This difference was accepted and the impact tube measurements were used for the model tests without applying a coefficient. It was found that yawing the impact tube up to ten degrees had no appreciable affect on manometer readings. Very pronounced effects were noted as the impact tube was yawed more than 20 degrees.

The model distributor was placed in the wind tunnel at an angle of attack such that the gate section was horizontal. This position was observed in the field when the airplane was applying. Piper (25) confirmed this observation. Plastic spaghetti tubing was attached to the three pressure taps on one side of the distributor. The three pressure taps not used were closed with plastic caps. Figure 15 shows the installation.

The other ends of the spaghetti tubes were connected to a bank of U tubes. One end of each U tube was connected

to a spaghetti tube using a rubber hose and a hypodermic needle as a reducer. The other end of each U tube was left open to the atmosphere. The U tube was made of glass tubing with an inside diameter of four millimeters. The U-tube bank with connections is shown in Figure 16.

Early tests of the model revealed that the presence of the impact tube inside the model affected the pressure readings obtained on the particular side the impact tube was located. For this reason, total head measurements were taken on one side simultaneously with static pressure readings on the other side.

Tests were conducted on the model distributor with a one inch apron mounted the length of the lower rear lip of the model. This apron made an angle of approximately 15 degrees downward with the bottom of the distributor. For each air velocity, the following instruments were read:

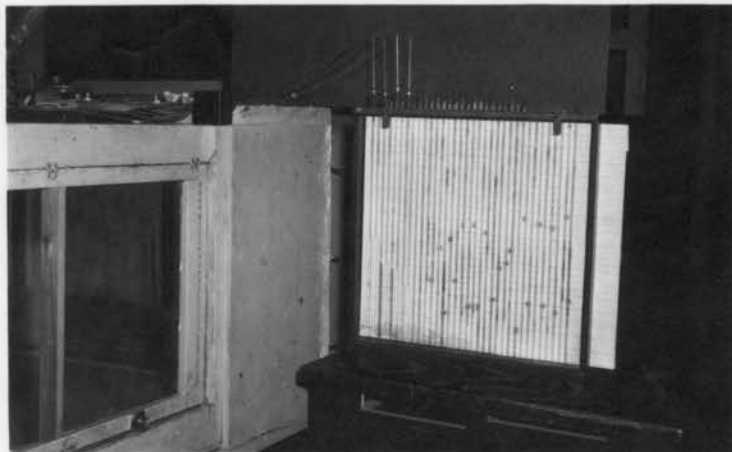
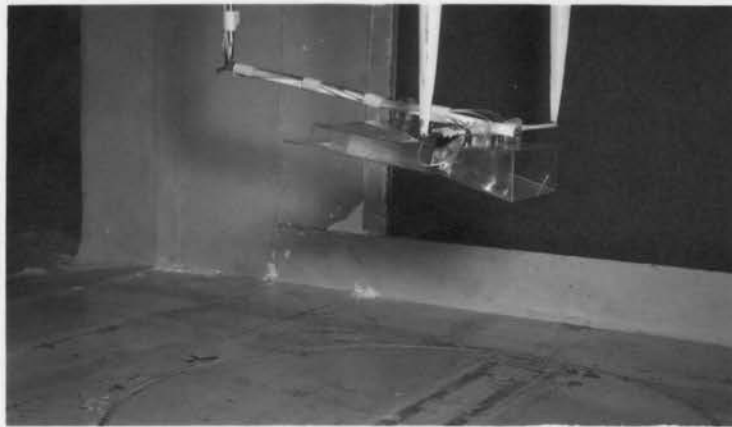
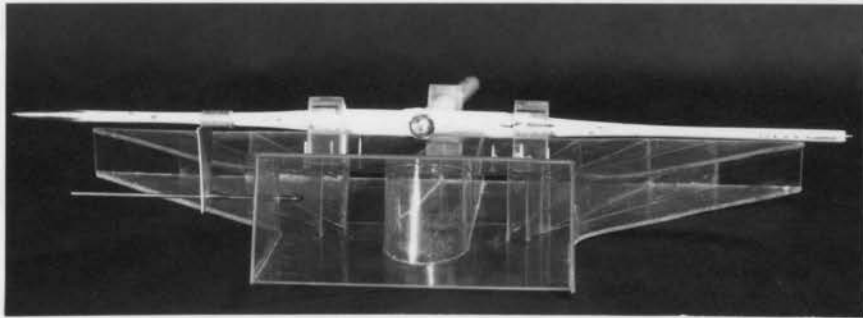
1. Dynamic pressure manometer
2. Static pressure and impact-tube U tubes
3. Free stream air-temperature thermocouple potentiometer

The barometer was read at the completion of each run. Similar tests were run without the apron. Static pressure data for early runs which had the impact tube on the same side as the pressure taps being used are not presented in Appendix B, because they did not represent true static pressure. Pressure

Figure 14. Model with impact tube inserted
and tee frame in place

Figure 15. Model as installed in wind tunnel

Figure 16. U-tube bank with connections



and velocity data for the model are presented in Appendix B, including a sample calculation.

Wind tunnel test results and discussion

Pressures in the throat of the model distributor were negative with respect to the free stream for all pressure tap locations. Pressures were progressively more negative traversing from the outer positions toward the center of the model. Curves in Figure 17 also show that pressures were less negative without the apron on the right side. The apron very slightly changed pressures on the left side.

Velocity in the throat of the model was greater than the approach velocity for all positions tested. The apron caused slightly greater velocity ratios on the right side as shown in Figure 18. Figure 18 also shows the apron caused slightly lower velocity increase ratios for the two outer positions, 1 and 2. The angular position of the apron was ten degrees less on the model than on the prototype distributor, so that apron model tests indicate only in general what happens to airflow when the apron is used on the distributor.

The Reynold's numbers which were computed and used in the presentation of these results are not corrected for wind tunnel turbulence. Correction was not thought desirable because of the turbulence present at the location of the prototype distributor behind the airplane propeller. A

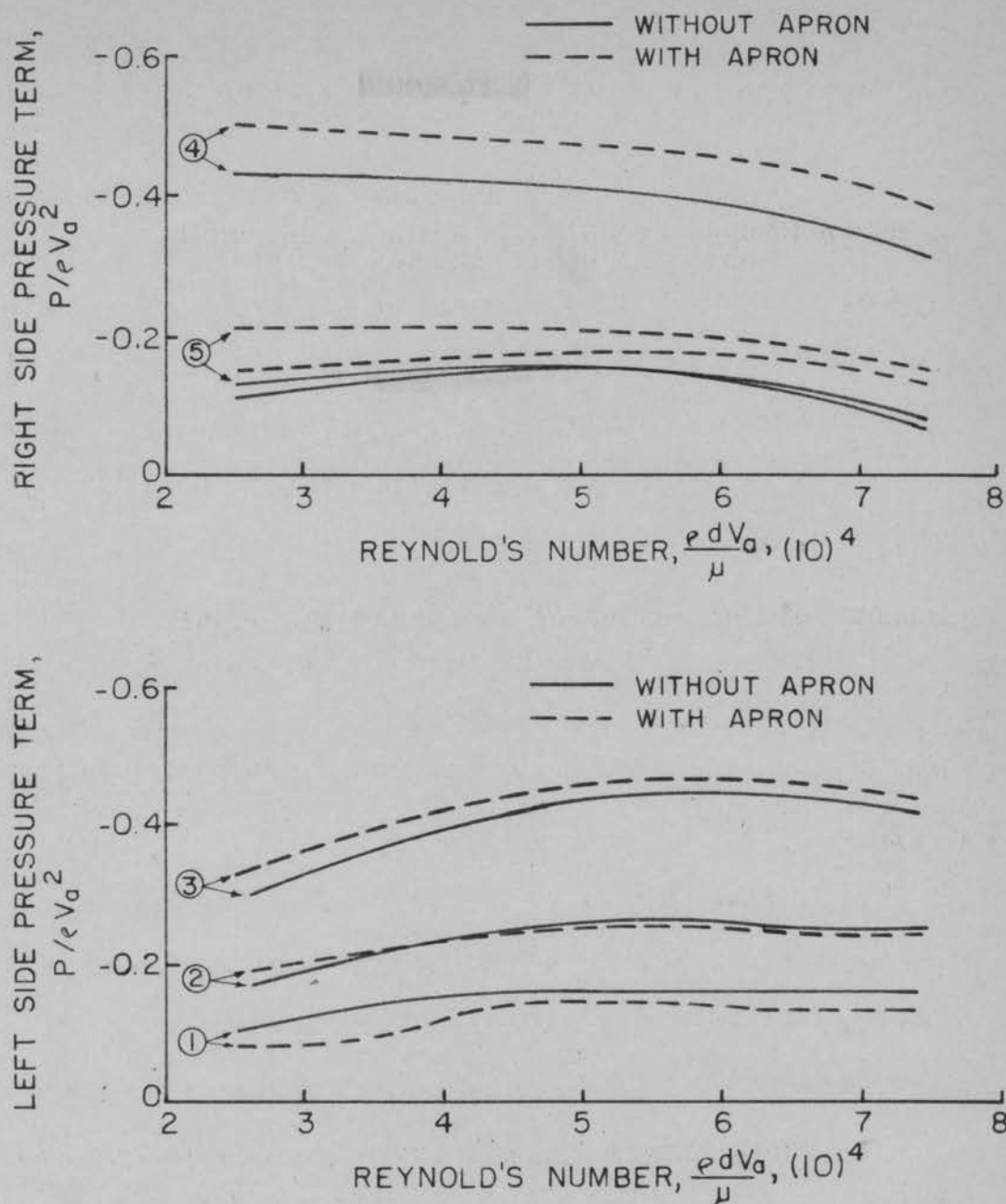


Figure 17. Dimensionless pressure terms vs. Reynold's number for model

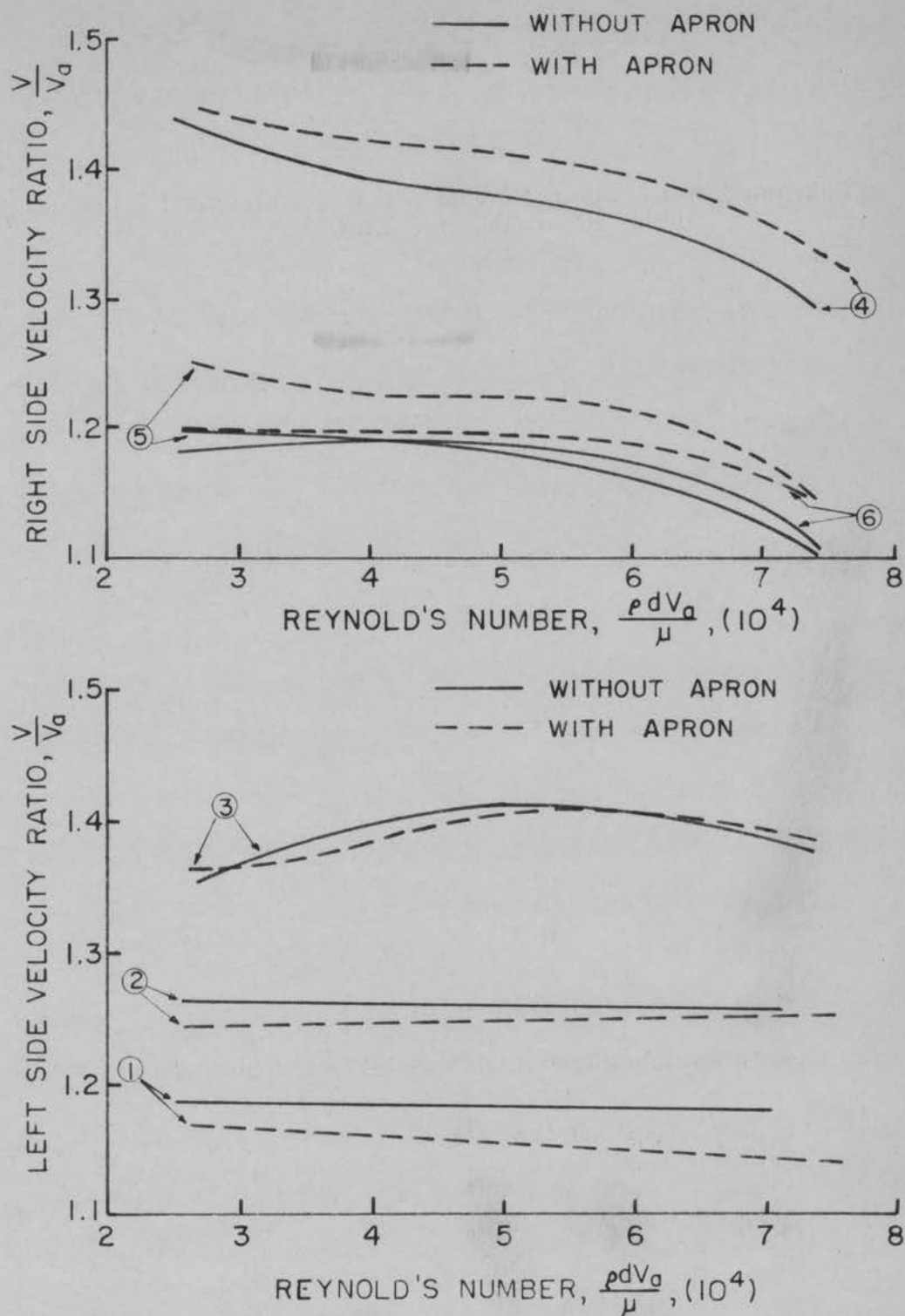


Figure 18. Velocity ratio vs. Reynold's number for model

calculation shows that the prototype operated at an air speed of 80 miles per hour would have a Reynold's number of approximately 360,000. If the results obtained from this model test are to be applied to the prototype, it is necessary to extrapolate these curves. Unfortunately, it appears that turbulence conditions are changing, particularly for the right side of the model, making extrapolation uncertain. If turbulent bands in the wake of the model are narrowing, it is probable that the general range of magnitudes of values found will apply to the prototype.

Smoke tunnel tests

A smoke tunnel* recently acquired by the Aeronautical Engineering Department, Iowa State College, was used for testing the model. The tunnel had a test section 2.5 inches thick and two feet high. Twenty-five smoke jets 0.75 inches apart emitted parafin smoke filaments which were useful in showing streamlines through the model.

Plastic blocks were cemented to the underside of the model distributor, so the model could be oriented with the gates parallel to the smoke tunnel flow. The blocks were taped to the back wall of the smoke tunnel. The smoke tunnel was operated at an air speed of approximately 15 feet per

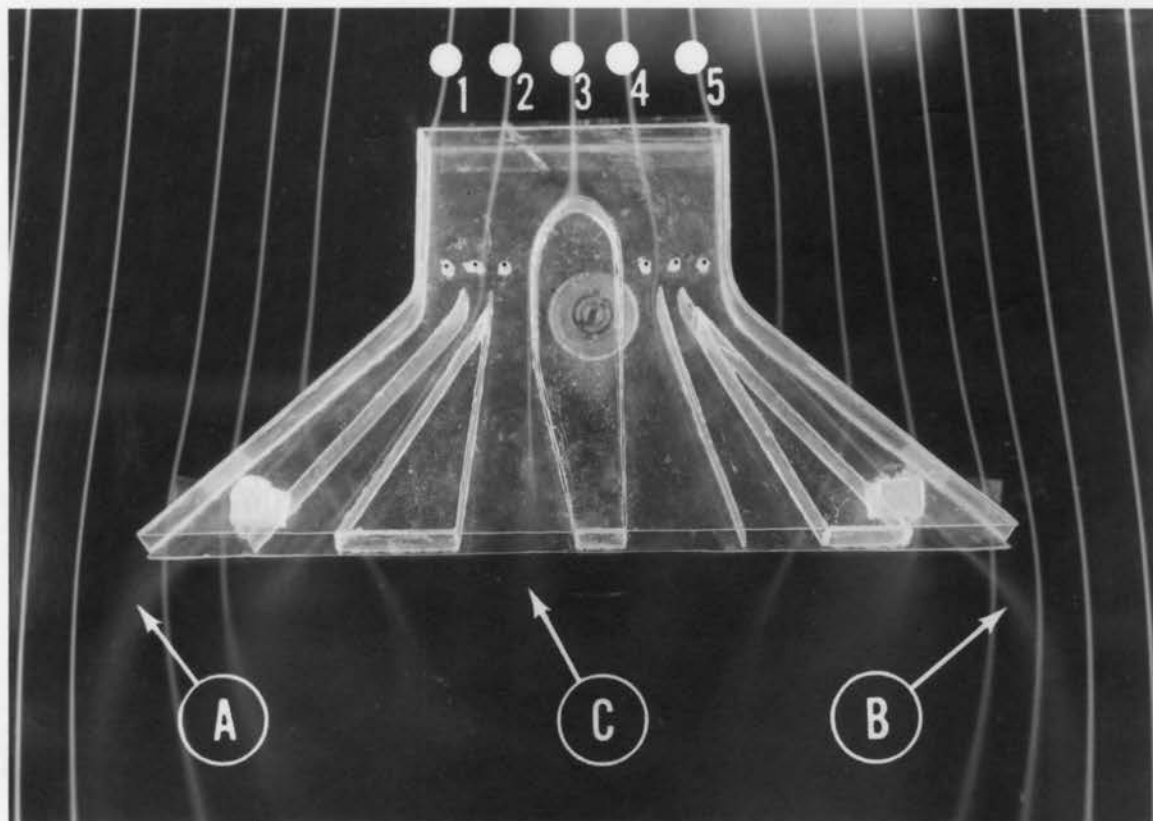
*Manufactured by Collins Radio, Cedar Rapids, Iowa.

second and the phenomenon photographed.

Many irrelevant streamlines are shown in Figure 19. The fact that the lower front lip of the distributor is touching the back wall of the tunnel, is largely responsible for the divergence of streamlines as they approach the model, and the convergence of these same streamlines beneath the rear portion of the model.

The five streamlines entering the model numbered in Figure 19 are worthy of study. The transverse direction imparted by the geometry of the model to lines one and five is rapidly dissipated by the outside air stream as shown at A and B. Line three, after flowing around the nose of the center vane, fails to follow the vane as it leaves the model at C. It is possible that separation of streamline three from the center vane is less pronounced at higher velocity and turbulence, but it appears that the effectiveness of the rear portion of the vane would be improved by streamlining.

Figure 19. Smoke tunnel test of model



Limitations of Study

Arranging exact times for field testing was a perplexing problem encountered in the conduct of this research. Tests were conducted approximately 45 miles south of the Iowa State College campus. It was necessary to coordinate with the pilot and helpers to correspond with wind conditions. This would be greatly facilitated by closer proximity to all facilities and people involved.

The method of locating the center of a pass across the distribution pattern measuring station was not precise. An accuracy of plus or minus two feet was thought possible. The method employed depended on an observer standing under the plane as it passed over the station and estimating which sampling unit was directly under the aircraft. A sighting arrangement or a photographic method could be developed which would improve the accuracy of the determination of this location.

Weick (33) found that gustiness appreciably affects the distribution pattern obtained with liquid sprays. To reduce the variation in gustiness between runs he used anemometers on either side of the swath, and only information obtained from runs made when both anemometers read the same was used. A similar use of two or more anemometers for

granular carrier tests might improve agreement obtained from replicated runs. The glue-coated glass plates used for sampling the granular bentonite distribution pattern gave information concerning the distribution of particle number intensity across the swath. Apparently a separation of particle sizes occurs in the distribution process making the count not uniformly proportional to the weight at various locations across the swath. A sieve analysis of individual samples collected with pans did not give useful information concerning the rearrangement of particle size across the swath. It is thought that the recovery and weight measurement of fines from the pans and sieves was not sufficiently accurate for these small amounts. Detailed inspection of the granular deposit on each plate appears to be a more practical approach in obtaining weight equivalents, since it is likely that rearrangement of particle size across the swath would be different for various wind conditions.

The pans used for sampling the distribution patterns in this research were satisfactory in most respects. They required a minimum space for hauling and storing. They could be quickly placed in position for sampling and the samples for a run could be quickly collected. A check on the amount of 30/60 mesh bentonite recovered for weighing was made by sprinkling one gram amounts over one of the pans. Ninety-five percent or more was recovered in five tests starting with a

pan cleaned with mineral spirits. Ninety-eight percent or more was recovered starting with a pan which had previously collected 30/60 mesh bentonite. Apparently some fines were retained on the pan surfaces from previous collections, and an equilibrium is developed with successive collection.

During field tests using the pans it was observed that some of the granular material was not moving straight down, but rather appreciably rearward of the plane. Although visual observations did not reveal positively that material was bouncing out of the pans, it appeared that the absence of vertical sides on the pans might allow some loss.

With facilities available, model wind tunnel tests could not be extended to a value of Reynold's number sufficiently high enough to obtain information which could be confidently used to predict exact pressures and velocities in the prototype distributor throat. If boundary layer turbulence develops on the under side of the model and narrows turbulent bands in the wake of the model, a situation analogous to that for curved bodies such as cylinders and spheres may exist. Should this be the case, the values of the pressure dimensionless quantity and the velocity ratio should not continue to decrease greatly with increased Reynold's number, but rather stabilize and partially recover.

Suggestions for Further Study

The venturi distributor for aerially applying 30/60 mesh bentonite possesses numerous advantages. It is easy to attach to a small plane and may be used for a variety of other materials. However, in its conventional location, its operation is greatly influenced by the propeller slip stream. Based on Weick's results for rice seed shown in Figure 2, and the results of this research, the distributor's ability to apply a desirable distribution pattern appears to be very sensitive to the properties of particles distributed. Adjustable interior vanes might improve the effectiveness of this type distributor for use in applying a variety of materials. An adjustable gate orifice plate or a set of orifice plates might reduce the problem, although results obtained from this research indicated that pairs of passages would not give a single peaked pattern of a size sufficient to fill in the center valley of the total 30/60 mesh bentonite pattern. Chamberlin and Young (8) discharged 20/60 mesh granular attaclay from points either side of center on a Boeing Stearman airplane. This same investigation for a monoplane should reveal a location from which a greater discharge could be made to correct the pattern. Chamberlin et al. (9) attempted to correct the two-peaked pattern obtained with liquid sprays using fins to change the propeller

slip stream. Of those tried, none were successful.

Two major problems reduced the effectiveness of the venturi type distributor for applying 30/60 mesh bentonite: the peaked distribution pattern and the narrow swath width obtained.

Three suggested investigations are given which might aid in the development of an improved distributor.

1. Investigate the patterns obtained from the discharge of single passages taken in turn with carefully measured airplane location.

2. Redirect passages and study the effect on the distribution pattern.

3. Investigate patterns obtained by discharging a portion of the material aft of present conventional location where effects of the propeller slip stream are less severe.

The use of a model for studying the performance of a complete distributor presents some difficult problems. Air-flow investigation would present few difficulties if conducted in a tunnel of slightly larger dimensions and twice the speed of the one used in this investigation. However, the use of granular material in the model would necessitate an open air or non-recirculating tunnel. Additional restrictions would be placed on velocities required due to the importance of gravity in accelerating the particles. If Reynold's number were relatively unimportant at moderate and higher values,

small scale model investigation would be possible providing a suitable granular material could be found. However, the model results from this research indicate that Reynold's number is important. For this reason in the opinion of the author, further model investigations could most effectively be carried out using a large, low velocity non-recirculating tunnel equipped to handle nearly full scale models.

SUMMARY AND CONCLUSIONS

Aircraft application of dry materials or liquid sprays has become useful where speed and accessibility to difficult areas has been important. Drifting of materials, particularly dusts, has limited the use of aircraft for application purposes. Poor control of some insects has been obtained using dust with aerial equipment. The resistance to drift of granular insecticides has made them particularly successful in mosquito and spittlebug control. The success of ground-machine-applied granular insecticides for corn borer control has indicated the possible success of aeriaily applying the material. An investigation was conducted to determine the characteristics of an aircraft distributor when used for granular insecticides especially for corn borer control. Since narrow-band placement of granules over a single row wasn't feasible, a uniform broadcast distribution was considered desirable.

Field tests were conducted using a Piper PA-18A airplane with a distributor designed and developed for the Piper Aircraft Corporation by Texas A & M. Distribution patterns obtained using 30/60 mesh bentonite were measured for an altitude range of 15 to 40 feet. Three 30/60 mesh attaclay distribution patterns were obtained. Wind velocity and direction was measured and their effects on the distribution patterns noted. Tests were conducted to determine the

possibility of improving the characteristic distribution pattern obtained from preliminary tests. Pairs of distributor internal passages were used in an effort to increase the application intensity at the center valley of the pattern.

An apron was mounted on the rear lower lip of the distributor in an attempt to disturb the propeller slip stream in the immediate vicinity of the distributor exit. The characteristic valley in the center of the swath could possibly be reduced if the material were not caught up by the strong slip stream immediately after leaving the distributor.

A one-sixth scale model of the distributor was built from "Plexiglass" sheet. Pressure taps were made at the throat of the model. An impact tube was inserted through the side of the model to positions directly under the pressure taps. Tests of the model were made in a low speed wind tunnel for the purpose of determining throat velocities and pressures which could be related to the prototype distributor. An apron was used on the model of the same sort used on the prototype distributor. Smoke tunnel tests were run and the streamlines photographed.

Based on test results obtained with a Piper PA-18A airplane and a venturi distributor applying 30/60 mesh bentonite, the following conclusions are drawn concerning this type of equipment and material:

1. Distribution patterns obtained have two peaked configurations.
2. The effective swath width obtained tends to be slightly greater with increased altitude. The average swath width was 34 feet for a 19 to 22 foot altitude range at an air speed of 80 miles per hour.
3. Cross wind displaces the distribution pattern down wind approximately 2.3 feet per mile per hour for a 19 to 22 foot altitude range.
4. Considering high effective swath width, uniform distribution, and small lateral pattern displacement by wind as desirable attributes, airplane application can be most successfully conducted at an air speed of 80 miles per hour and an altitude of approximately 20 feet.
5. It does not appear possible to fill in the center valley of the distribution pattern for all wind conditions with equal material flow through each of the inner pair of distributor passages only.
6. Based on two test runs, a nine-inch apron mounted the length of the rear lower lip of the distributor did not improve the distribution pattern.

Based on a comparison of results obtained from eleven 30/60 mesh bentonite tests and three 30/60 mesh attaclay tests, the following conclusions are drawn:

1. Narrower but more uniform distribution patterns are obtained using 30/60 attaclay.

2. Wind has an appreciably greater effect on the lateral displacement of 30/60 mesh attaclay distribution patterns.

Based on a model of the distributor whose dimensions were reduced one-sixth and which was tested in the Iowa State College Aeronautical Engineering wind tunnel and smoke tunnel, the following information appears applicable to the prototype for air flow:

1. Pressure in the throat of the distributor is negative.

2. Air velocity in the throat of the distributor is 1.1 to 1.4 times higher than the air approach velocity.

3. The left, inner channel of the distributor is relatively ineffective in displacing material to the right to correct for the propeller slip stream.

4. The use of an apron on the rear lower lip of the distributor at an angle of 15 degrees downward with respect to the distributor bottom only slightly effects velocities and pressures in the throat of the distributor.

LITERATURE CITED

1. Aerial Farming. Australia and New Zealand Bank Ltd. Quarterly Survey. Oct. 1952. (Original not available for examination, reprinted in Power Farming in Australia and New Zealand. 61, no. 12: 9, 11, 13, 15. 1952).
2. Aviation Week. Agricultural aviation expands rapidly. 64, no. 11: 281-282. 1956.
3. Akesson, Norman B. Calibration of the agricultural pest control aircraft sprayer and duster. Calif. Dept. of Agr. Bul. 40: 21-26. 1951.
4. Bigger, J.H., Decker, G.C., Wright, J.M., and Petty, H.B. Insecticides to control the European corn borer in field corn. J. of Econ. Entom. 4: 401-410. 1947.
5. Brooks, F.A. The drifting of poisonous dusts applied by airplane and land rigs. Agri. Eng. 28: 233-239, 244. 1947.
6. Brown, A.W.A. Insect control by chemicals. 1st ed. New York, McGraw-Hill Book Co., Inc. 1951.
7. Chamberlin, Joseph C., Getzendaner, Charles W., Hessig, Harold H., and Young, V.D. Studies of airplane spray-deposit patterns at low flight levels. USDA Tech. Bul. 1110. Wash., D.C., U.S. Govt. Print. Off. 1955.
8. _____ and Young, V.D. Forest Grove, Oregon. The distribution of insecticides and other agricultural chemicals in granular formulations by aircraft. Paper presented at Fifth Ann. Ohio-Ind. Agri. Advn. Conf. Columbus, Ohio. Feb. 24, 1956. (Mimeo. rept.)
9. Civil aeronautics administration. Civil Aeronautics M. 8. 2nd ed. Wash., D.C., U.S. Govt. Print. Off. 1956.
10. Coad, B.R., Johnson, E., and McNeil, G.L. Dusting cotton from airplanes. USDA Farmers' Bul. 1204. Wash., D.C., U.S. Govt. Print. Off. 1924.
11. Cox, H.C., Brindley, T.A., Lovely, W.G., and Fahey, J.E. Granular insecticides for European corn borer control. J. of Econ. Entom. 49: 113-119. 1956.

12. Flying jeep. World Crops. 8: 497. 1956.
13. Ford, E. Farming from the air-American experience. World Crops. 8: 148-150. 1956.
14. French, O.C. Use of the airplane for pest control. Agri. Eng. 28: 240-242, 244. 1947.
15. Hanson, Gale F. Civil air regulations concerning agricultural aviation. Second Agri. Avn. Res. Conf. Proc. 1954: 5-7. Wash., D.C., USDA, Agr. Res. Service, Off. of Administrator (ca. 1955) (Mimeo. rept.).
16. Henry, James E. Metering and distributing equipment studies with dry materials. Fifth Ann. Ohio-Ind. Agri. Avn. Conf. Proc. 1956: sec. 4, e. Columbus, Ohio, Ohio Avn. Board. (ca. 1956) (Mimeo. rept.).
17. _____ Wind tunnel studies of venturi type distributors for agricultural aircraft. Dept. of Agri. Eng. Ohio Agri. Exp. Sta. Nov. 1956. (Mimeo. rept.).
18. Iverson, James. Iowa State College aeronautical engineering low speed wind tunnel tests. Unpublished research. Ames, Iowa, Aeronautical Eng. Dept. Iowa State College. 1957. (Mimeo. rept.).
19. Lehmann, E.W. Agricultural aviation. Agri. Eng. 33: 360. 1952.
20. _____ The airplane as an agricultural implement. Agri. Eng. 30: 442. 1949.
21. Meyers, Herbert Arthur. Equipment for applying granular insecticides for control of European corn borer. Unpublished M.S. Thesis. Ames, Iowa. Iowa State College Library. 1955.
22. Murphy, Glenn. Similitude in engineering. New York, Ronald Press Co. 1950.
23. National NA-75. World Crops. 8: 497. 1956.
24. Nowell, Wesley R. The L-20 as a vehicle for aerial dissemination of insecticide by the U.S. Air Force. Mosquito News. 15: 73-80. 1955.

25. Piper, H. Piper Aircraft Corp., Lockhaven, Penn. Information on aircraft distributor operation. Private communication. Apr. 23, 1957.
26. Pope, Alan. Wind tunnel testing. 2nd ed. New York, Wiley. 1954.
27. Raun, Earle S. and Blickenstaff, C.C. Fight borers by land or air. Iowa Farm Sci. 3: 6-8. 1949.
28. Roth, George A. College Station, Texas. Effects of wind and aircraft height on rice seed distribution. Paper presented at the Third Ann. Tex. Agri. Avn. Conf. College Station, Texas. Feb. 22, 1954. (Mimeo. rept.).
29. Sanders, George S. Equipment and procedures for the measurement of deposits of aeriially applied materials. Ohio Agri. Exp. Sta. Res. Bul. 727. 1953.
30. Thomas, F.L., Owen, W.L. Jr., Gaines, J.C. Jr., and Sherman, Franklin III. Boll weevil control by airplane dusting. Tex. Agri. Exp. Sta. Bul. 394. 1929.
31. Weick, Fred E. Development of an agricultural airplane. Agri. Eng. 33: 361-364. 1952.
32. _____ College Station, Texas. Notes on the design of distributors for agricultural aircraft. Paper presented at the Third Ann. Tex. Agri. Avn. Conf. College Station, Texas. Feb. 22, 1954. (Mimeo. rept.).
33. _____ College Station, Texas. The distribution pattern measurement program at Texas A & M. Paper presented at the Second Ann. Tex. Agri. Avn. Conf. College Station, Texas. Feb. 23, 1953. (Mimeo. rept.).
34. _____ and Roth, George A. Progress of the Texas A & M agricultural aviation program. Second Agri. Avn. Res. Conf. Proc. 1954: 41-45. Wash., D.C., USDA, Agr. Res. Service, Off. of Administrator (ca. 1955) (Mimeo. rept.).
35. Weaver, C.R. Columbus, Ohio. Improvement in aerial applications of insecticides for spittlebug control. Paper presented at the Fifth Ann. Ohio-Ind. Agri. Avn. Conf. Columbus, Ohio. Feb. 23, 1956. (Mimeo. rept.).

36. Wilson, W.F., Philen, E.A., and Kruse, C.W. Experimental use of a helicopter as a larvicidal aircraft for the control of Anopheles Quadrimaculatus. N.J. Mosquito Extermination Assoc. Conf. Proc. 1952: 117-131. (ca. 1953).
37. Wrigley, Helen M. The use of aircraft in agriculture. Australian Institute of Agri. Sci. 20: 214, 220. 1954.

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APPENDIX A:

Field Test Data

Table 2. Across swath intensity of aerially applied 30/60 mesh bentonite carrier^a

Cross swath distance from center of flight, left to right (ft)	Altitudes wind direction amt mtl in hopper	22 ft	22 ft	19 ft	20 ft
		3.0 mph 260°	3.2 mph 260°	1.0 mph 260°	1.0 mph 260°
		100 lbs (lbs/acre)	90 lbs (lbs/acre)	300 lbs (lbs/acre)	300 lbs (lbs/acre)
24		0	0.2	0	0
20		2.5	2.4	0	0.6
16		13.7	9.9	0	6.8
12		30.7	24.8	3.3	26.8
8		42.0	36.0	68.7	34.2
4		54.5	42.2	34.2	60.3
0		25.6	20.5	40.4	44.1
4		17.7	17.6	40.0	39.3
8		19.7	27.4	41.8	33.0
12		31.4	37.5	39.6	33.3
16		16.2	24.3	38.0	26.8
20		7.6	12.3	17.5	13.5
24		1.6	4.8	6.8	3.5
28		0	0.1	1.9	0.6
32		0	0	0.5	0

^aBentonite carrier distributed at a constant air speed of 80 miles per hour

Table 3. Across swath intensity of aerially applied 30/60 mesh bentonite carrier--sampling pans on the ground^a

Cross swath distance from center of flight, left to right (ft)	Altitudes wind direction	15 ft 5.2 mph 2450 (lbs/acre)	20 ft 5.0 mph 2450 (lbs/acre)	25 ft 5.0 mph 3050 (lbs/acre)	40 ft 2.0 mph 3050 (lbs/acre)	40 ft 1.7 mph 3050 (lbs/acre)
24		0	0	0	0	0
20		1.1	0	0	0	0
16		12.0	0.2	0	0	0
12		33.3	4.2	0	0.5	0.7
8		70.3	13.7	1.3	5.8	5.6
4		39.8	41.7	10.7	10.8	17.5
0		21.2	48.6	26.0	21.8	33.4
4		17.8	42.6	57.5	39.7	52.3
8		21.6	26.9	77.1	45.1	46.9
12		19.7	21.6	61.2	38.2	34.2
16		10.8	23.8	34.8	25.8	26.2
20		4.3	23.8	38.8	32.8	33.2
24		0.6	13.0	61.2	46.3	40.3
28		0.1	6.9	46.2	37.6	29.9
32		0	1.8	24.8	18.4	16.7
36		0.5	0	8.2	8.7	7.2
40		0	0	2.3	3.3	1.5

^aBetween 75 and 150 pounds of material maintained in hopper and a constant air speed of 80 miles per hour maintained

Table 4. Across swath intensity of aerially applied 30/60 mesh bentonite carrier for 90 miles per hour air speed^a

Gross swath distance from center of flight, left to right (ft)	Altitudes wind direction	22 ft 4.5 mph 280° (lbs/acre)	22 ft 5.0 mph 280° (lbs/acre)
24		0	0.8
20		0.3	5.0
16		13.4	13.2
12		18.7	29.4
8		47.6	40.2
4		54.2	50.0
0		33.2	21.2
4		22.6	13.8
8		20.2	24.6
12		18.3	20.3
16		27.8	10.8
20		22.8	5.0
24		11.2	0.6
28		2.3	0

^aBetween 75 and 150 pounds of material maintained in hopper

Table 5. Across swath intensity of aerially applied 30/60 mesh
attaclay carrier^a

Cross swath distance from center of flight, left to right (ft)	Altitudes Wind direction	19 ft 1.0 mph 270° (lbs/acre)	19 ft 1.0 mph 270° (lbs/acre)	28 ft 1.0 mph 270° (lbs/acre)
12		0.3	0.2	0.1
8		3.0	3.1	0.4
4		27.1	39.6	4.5
0		29.6	38.1	19.3
4		24.7	31.3	31.8
8		22.6	25.1	30.2
12		29.8	29.8	23.4
16		28.6	28.6	23.4
20		16.4	13.8	29.6
24		7.4	2.3	23.6
28		0.4	0.2	18.4
32		0	0.2	5.6
36		0	0.2	1.4

^aBetween 75 and 150 pounds of material maintained in hopper and a
constant air speed of 80 miles per hour maintained

Table 6. Across swath intensity of aerially applied 30/60 mesh bentonite granular carrier using pairs of passages^a

Cross swath distance from center of flight, left to right (ft)	Altitudes wind direction passages	19 ft 1.5 mph 2350 inner (lbs/acre)	18 ft 1.5 mph 2350 inner (lbs/acre)	20 ft 5.5 mph 2350 middle (lbs/acre)	20 ft 5.5 mph 2350 middle (lbs/acre)	18 ft 6.0 mph 2350 middle (lbs/acre)
24		0	0	0	0	0
20		0.1	0	0	0	0
16		1.9	1.0	0.1	0.1	0.1
12		3.8	3.0	2.2	0.5	1.3
8		8.6	6.4	8.0	1.8	5.2
4		18.3	15.6	17.4	7.0	12.2
0		37.9	37.0	13.3	13.2	17.5
4		26.6	15.8	10.2	6.7	8.7
8		15.8	8.7	9.7	4.0	10.4
12		13.9	20.8	11.8	5.8	7.7
16		15.9	5.6	14.5	11.2	2.5
20		4.6	1.5	3.4	4.5	1.0
24		2.4	1.1	1.4	1.8	0.7
28		0.8	0.1	0.5	-	0.1
32		0.1	0	-	-	0

^aBetween 75 and 150 pounds of material maintained in hopper--a constant air speed of 80 miles per hour maintained

Table 7. Across swath intensity of aerially applied 30/60 mesh bentonite granular carrier using pairs of passages or apron^a

Cross swath distance from center of flight, left to right (ft)	Altitudes wind direction	21 ft 1 mph outer passages (lbs/acre)	18 ft 1 mph outer passages (lbs/acre)	22 ft 6.5 mph 235° apron (lbs/acre)	20 ft 6.5 mph 235° apron (lbs/acre)
28		0.2	-	-	-
24		1.4	2.0	-	-
20		8.3	7.5	0	-
16		20.3	18.9	0	0
12		26.8	23.8	0	0
8		20.1	21.7	0	0
4		7.8	9.2	0.2	0
0		4.7	5.5	2.4	0.5
4		9.8	13.6	3.5	3.7
8		15.0	22.9	4.9	2.2
12		13.3	17.6	3.3	9.7
16		7.4	5.5	2.3	5.0
20		0.7	1.0	3.5	2.7
24		0	0	3.7	2.3
28		0	0	2.8	1.7
32		0	0	1.0	1.2
36		-	0	1.1	1.6
40		-	0	0.5	0.5
44		-	-	0.5	0.2
48		-	-	-	0.1

^aBetween 75 and 150 pounds of material maintained in hopper and a constant air speed of 80 miles per hour maintained

Table 8. Across swath intensity of aerielly applied 30/60 mesh bentonite granular carrier measured simultaneously with glass plates and pans

Cross swath distance from center of flight, left to right (ft)	Altitude 20 ft ^a air speed 80 mph wind 12.0 mph at 0° <u>inner passages</u>				Altitude 20 ft ^b air speed 80 mph wind 11.0 at 0° <u>inner passages</u>			
	(lbs/acre)		particles per $\frac{1}{4}$ sq in.		(lbs/acre)		particles per $\frac{1}{4}$ sq in.	
30	0.1	-	0	-	0.2	-	1	-
24	0.2	0.1	0	1	1.0	0.9	6	12
18	0.8	0.3	1	1	2.5	1.6	16	26
12	1.7	1.5	10	24	3.9	3.6	26	35
6	3.0	4.6	21	51	2.6	4.5	30	45
0	4.4	3.8	42	36	2.9	2.0	18	19
6	3.4	4.5	49	66	3.3	5.3	14	7
12	2.9	2.7	45	48	1.3	1.8	18	16
18	2.6	2.2	28	39	0.1	0.1	5	4
24	0	0.1	5	7	0.1	0	0.5	1
30	0	0	0	0	0	0	0.5	0.25

^aObtained from a single run with pans and plates alternate parallel rows five feet apart

^bAlso obtained from the same run with pans and plates alternate parallel rows five feet apart

APPENDIX B:**Model Distributor Test Data**

Sample Calculations for Model Study

Dimensionless pressure and velocity terms were determined using the following procedure:

For Table 9, 1st run:

Barometric pressure 28.96 in. Hg

Room temperature 78 degrees F

Air tunnel temperature during run 99 degrees F

1. Compute mean velocity in the wind tunnel, V_a

Manometer differential between stilling chamber and test section = 0.981 in.

Specific gravity of manometer fluid at 78 degrees F = 0.858

$$\begin{aligned}\text{Differential pressure} &= \frac{0.981}{12} (62.427) (0.858) \\ &= 4.38 \text{ psf}\end{aligned}$$

From tunnel calibration curve:

dynamic pressure, $\frac{1}{2} \rho V_a^2$, for 4.38 psf = 3.30 psf

Density of air, ρ , in wind tunnel

$$\begin{aligned}&= 0.04115 \left(\frac{\text{Barometric Pressure, in. Hg}}{\text{Abs temp, degrees F}} \right) \\ &= 0.04115 \left(\frac{28.96}{559} \right) = 0.002135 \frac{\text{slug}}{\text{cf}}\end{aligned}$$

$$V_a = \sqrt{\frac{\frac{1}{2} \rho V_a^2}{\frac{1}{2} \rho}} = \sqrt{\frac{2 (3.30)}{0.002135}} = 55.6 \text{ fps}$$

2. Compute Reynold's number, $\frac{\rho dV_a}{\mu}$

Viscosity of air, μ , is needed

$$\begin{aligned} &= [33.85 + 0.0575 (\text{temp})] \times 10^{-8} \frac{\text{slug}}{\text{ft-sec}} \\ &= [33.85 + 0.0575 (99)] \times 10^{-8} \\ &= 39.54 (10^{-8}) \frac{\text{slug}}{\text{ft-sec}} \end{aligned}$$

$$\frac{\rho dV_a}{\mu} = \frac{0.002135 (1/12) (55.6)}{39.54 (10^{-8})} = 2.50 (10^4)$$

3. Compute static pressure at tap 4, P_4

U-tube differential for tap 4 = 0.58 in.

Specific gravity of U-tube fluid at 78 degrees F = 0.997

$$P_4 \text{ relative to atmosphere} = \frac{-0.58}{12} (62.427) (0.997)$$

$$= -3.01 \text{ psf}$$

Using the tunnel calibration curve for free stream static pressure, a correction of -0.12 psf is applied to the U-tube measurement: $P_4 = -3.01 - (-0.12) = -2.89 \text{ psf}$. The dimensionless pressure term for this value of P_4 is:

$$\frac{P_4}{\rho V_a^2} = \frac{-2.89}{2 (3.30)} = -0.438$$

The calculation of P_5 and P_6 for this first run is the same except for using U-tube differential readings for taps 5 and 6.

4. The calculation of the velocity at location 1 involves first finding the total pressure at point 1 from the U-tube

reading for the impact tube.

U-tube differential reading = 0.74 in.

Total pressure relative to atmosphere = 3.84 psf

To find the dynamic pressure at point 1, it is necessary to find the static pressure at 1 with respect to the free stream. As was explained on page 52, it is not possible to do this simultaneously with the equipment used because the presence of the impact tube changes the pressure at the location of the taps directly above the impact tube. For this reason, all static pressures were calculated first and plotted in dimensionless form. Using the curve of Figure 17 for point 1 without apron and at a Reynold's number of 0.250, $\frac{P_1}{\frac{1}{2} \rho V_a^2} = -0.102$. Since from step 1, $\frac{1}{2} V_a^2 = 3.30$ psf

$$\begin{aligned} P_1 &= 2 (3.30) (-0.102) \text{ psf} \\ &= -0.67 \text{ psf} \end{aligned}$$

Correcting the total pressure reading for the free stream static pressure and subtracting the static pressure P_1 , the dynamic pressure at 1 is obtained:

$$\begin{aligned} \frac{1}{2} \rho V_1^2 &= 3.84 - (0.12) - (-0.67) = 4.63 \text{ psf} \\ V_1 &= \sqrt{\frac{\frac{1}{2} \rho V_1^2}{\frac{1}{2} \rho}} = \sqrt{\frac{2 (4.63)}{0.002135}} = 65.9 \text{ fps} \end{aligned}$$

The velocity ratio at 1 is:

$$\frac{V_1}{V_a} = \frac{65.9}{55.6} = 1.182$$

Table 9. Model distributor data for pressure at taps 4, 5, and 6 and velocity at location 1 without apron

Pressure, P_4 (psf)	Pressure, P_5 (psf)	Pressure, P_6 (psf)	Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_1 (fps)	Velocity ratio, $\frac{V_1}{V_a}$
2.89	0.92	0.76	2.135	39.54	55.6	2.50	65.9	1.183
5.24	1.82	1.71	2.135	39.54	76.1	3.42	90.5	1.187
--	2.40	2.24	2.135	39.54	86.5	3.89	102.5	1.186
9.17	3.52	3.26	2.135	39.54	104.0	4.67	123.7	1.190
11.31	4.15	3.99	2.130	39.60	115.0	5.15	137.0	1.192
12.99	4.58	4.58	2.125	39.66	127.0	5.67	150.0	1.181
15.26	5.09	5.20	2.120	39.78	140.0	6.21	165.0	1.178
16.72	5.26	5.52	2.105	39.96	149.0	6.55	175.8	1.179
17.21	4.97	5.59	2.100	40.08	155.4	6.78	183.2	1.180
18.10	5.02	5.75	2.095	40.18	162.0	7.04	190.7	1.176
18.37	4.78	5.71	2.085	40.30	166.8	7.06	196.8	1.179

Table 10. Model distributor data for pressure at taps 4, 5, and 6 and velocity at location 2 without apron

Pressure, P_4 (psf)	Pressure, P_5 (psf)	Pressure, P_6 (psf)	Air density, ρ (10 ⁻³ slug/cf)	Air viscosity, μ (10 ⁻⁸ slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10 ⁴)	Velocity, V_2 (fps)	Velocity ratio, $\frac{V_2}{V_a}$
2.89	0.87	0.76	2.150	39.32	56.3	2.57	69.5	1.235
5.39	1.02	1.76	2.150	39.32	77.6	3.54	96.3	1.239
6.75	2.49	2.34	2.150	39.32	86.8	3.95	108.8	1.254
9.37	3.46	3.30	2.145	39.38	104.0	4.72	131.6	1.264
11.36	4.15	4.04	2.145	39.38	115.2	5.23	146.3	1.270
13.09	4.79	4.63	2.140	39.43	127.0	5.55	160.7	1.265
15.56	5.29	5.39	2.130	39.60	143.8	6.44	178.2	1.240
16.91	5.45	5.76	2.120	39.87	149.0	6.61	188.0	1.261
17.64	5.40	5.92	2.110	39.90	155.8	6.85	195.8	1.256
18.41	5.28	6.11	2.100	40.08	162.8	6.99	204.0	1.253
18.71	5.07	5.90	2.085	40.24	167.0	7.14	210.0	1.255

Table 11. Model distributor data for pressure at taps 4, 5, and 6 and velocity at location 3 without apron

Pressure, P_4 (psf)	Pressure, P_5 (psf)	Pressure, P_6 (psf)	Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho V_a}{\mu}$ (10^4)	Velocity, V_3 (fps)	Velocity ratio, $\frac{V_3}{V_a}$
2.94	1.02	0.66	2.20	38.63	54.8	2.60	73.9	1.348
5.54	2.02	1.82	2.19	38.74	74.8	3.53	103.5	1.385
6.86	2.66	2.45	2.18	38.84	86.1	4.02	118.8	1.378
9.56	3.82	3.56	2.17	38.87	103.4	4.83	144.7	1.397
11.92	4.64	4.38	2.17	38.87	114.2	5.31	162.0	1.418
14.05	5.28	5.12	2.16	39.14	126.5	5.81	177.5	1.401
16.11	5.78	5.73	2.15	39.26	140.0	6.39	196.5	1.405
17.78	6.21	6.27	2.14	39.43	149.0	6.74	208.0	1.395
18.58	6.13	6.49	2.13	39.60	155.9	6.96	216.0	1.386
19.16	6.03	6.45	2.12	39.72	165.1	7.35	224.4	1.360
19.53	5.79	6.41	2.11	39.89	167.0	7.35	230.4	1.381

Table 12. Model distributor data for pressure at taps 1, 2, and 3 and velocity at location 4 without apron

Pressure, P_1 (psf)	Pressure, P_2 (psf)	Pressure, P_3 (psf)	Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number $\frac{\rho V_a}{\mu}$ (10^4)	Velocity, V_h (fps)	Velocity ratio, $\frac{V_h}{V_a}$
0.66	1.07	1.84	2.150	39.38	55.4	2.52	79.7	1.440
1.67	2.45	4.06	2.150	39.38	75.2	3.42	105.8	1.408
2.25	3.40	5.62	2.150	39.38	85.8	3.90	119.2	1.390
3.58	5.66	9.75	2.145	39.43	102.2	4.64	141.8	1.388
4.50	7.35	12.65	2.140	39.48	115.1	5.19	158.5	1.377
5.22	8.59	14.86	2.135	39.52	126.0	5.66	172.1	1.366
6.44	10.33	17.85	2.130	39.66	139.9	6.14	188.8	1.350
7.26	11.72	20.33	2.120	39.78	148.1	6.56	199.0	1.344
7.80	12.62	21.82	2.115	39.90	155.2	6.85	205.6	1.323
8.40	13.48	23.44	2.105	40.08	162.0	7.10	213.0	1.315
8.73	13.97	24.61	2.100	40.13	166.2	7.25	216.6	1.305

Table 13. Model distributor data for pressure at taps 1, 2, and 3 and velocity at location 5 without apron

Pressure, P_1 (psf)	Pressure, P_2 (psf)	Pressure, P_3 (psf)	Air density, ρ (10 ⁻³ slug/cf)	Air viscosity, μ (10 ⁻⁸ slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10 ⁴)	Velocity, V_5 (fps)	Velocity ratio, $\frac{V_5}{V_a}$
0.76	1.18	2.06	2.205	39.08	54.6	2.57	65.5	1.200
1.67	2.60	4.37	2.205	39.08	75.0	3.52	89.3	1.190
2.45	3.69	6.18	2.205	39.08	79.6	3.75	99.5	1.250
3.67	5.85	10.05	2.205	39.08	104.0	4.89	120.1	1.155
4.67	7.62	13.02	2.200	39.20	113.5	5.30	134.1	1.182
5.46	8.89	15.22	2.190	39.32	125.2	5.81	147.2	1.177
6.34	10.07	17.44	2.180	39.49	138.5	6.36	158.2	1.142
7.31	11.72	20.18	2.170	39.60	146.9	6.71	167.8	1.142
7.94	12.77	21.79	2.160	39.78	154.0	6.96	172.8	1.122
8.40	13.48	23.49	2.145	39.95	160.5	7.20	178.3	1.112
8.87	14.16	24.59	2.140	40.08	165.0	7.35	183.3	1.113

Table 14. Model distributor data for pressure taps 1, 2, and 3 and velocity at location 6 without apron

Pressure, P_1 (psf)	Pressure, P_2 (psf)	Pressure, P_3 (psf)	Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_6 (fps)	Velocity ratio, $\frac{V_6}{V_a}$
0.66	1.18	1.95	2.220	38.33	53.6	2.59	63.4	1.181
1.72	2.60	4.42	2.215	38.39	74.9	3.60	89.3	1.192
2.40	3.90	6.55	2.210	38.44	85.3	4.09	101.7	1.193
2.83	4.28	7.29	2.205	38.50	89.2	4.26	105.8	1.186
4.75	7.66	13.31	2.200	38.62	113.8	5.40	134.2	1.180
5.67	9.10	14.64	2.185	38.79	125.1	5.90	147.0	1.174
6.72	10.81	18.49	2.175	38.97	139.0	6.46	160.8	1.156
7.72	11.87	21.15	2.165	39.14	147.8	6.78	169.3	1.145
8.41	13.13	22.72	2.150	39.32	155.0	7.06	177.8	1.147
8.78	14.07	24.03	2.135	39.54	162.0	7.29	181.3	1.120
9.27	14.70	25.60	2.120	39.72	166.5	7.41	186.6	1.121

Table 15. Model distributor data for velocity at location 1 with apron.

Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_1 (fps)	Velocity ratio, $\frac{V_1}{V_a}$
2.230	38.27	53.3	2.60	61.9	1.162
2.226	38.33	76.5	3.70	90.0	1.175
2.222	38.39	86.5	4.17	100.8	1.165
2.220	38.44	90.6	4.36	103.9	1.146
2.210	38.56	116.0	5.53	134.5	1.160
2.204	38.68	127.0	6.02	147.0	1.158
2.190	38.85	142.0	6.65	162.3	1.145
2.174	39.09	151.0	6.99	173.2	1.147
2.164	39.26	158.0	7.25	182.0	1.151
2.146	39.48	165.0	7.45	186.3	1.130
2.140	39.60	170.0	7.65	196.0	1.151

Table 16. Model distributor data for pressure taps 4, 5, and 6 and velocity at location 2 with apron

Pressure, P_4 (psf)	Pressure, P_5 (psf)	Pressure, P_6 (psf)	Air density, ρ (10 ⁻³ slug/cf)	Air viscosity, μ (10 ⁻⁸ slug/ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho V_a}{\mu}$ (10 ⁴)	Velocity, V_2 (fps)	Velocity ratio, $\frac{V_2}{V_a}$
3.40	1.48	1.06	2.180	38.97	55.0	2.56	67.6	1.230
6.52	2.84	2.12	2.168	38.91	77.7	3.64	95.7	1.231
8.20	3.79	2.91	2.186	38.91	87.1	4.08	109.3	1.255
8.73	4.27	3.39	2.180	38.97	90.9	4.23	113.3	1.248
11.47	6.44	5.30	2.174	39.09	116.0	5.36	144.8	1.248
16.15	7.23	5.87	2.166	39.14	128.0	5.90	158.7	1.240
19.27	8.43	7.18	2.158	39.32	142.3	6.49	175.8	1.235
21.31	9.07	7.88	2.152	39.37	152.0	6.91	187.3	1.232
22.87	9.13	8.25	2.148	39.43	158.0	7.17	193.2	1.223
23.71	9.08	8.67	2.130	39.66	165.0	7.37	203.8	1.233
23.78	8.84	8.53	2.126	39.78	170.0	7.56	209.0	1.230

Table 17. Model distributor data for pressure at taps 4, 5, and 6 and velocity at location 3 with apron

Pressure, P_4 (psf)	Pressure, P_5 (psf)	Pressure, P_6 (psf)	Air density, ρ (10 ⁻³ slug/cf)	Air viscosity, μ (10 ⁻⁸ slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho V_a}{\mu}$ (10 ⁴)	Velocity, V_3 (fps)	Velocity ratio, $\frac{V_3}{V_a}$
3.24	1.27	0.91	2.180	39.02	55.0	2.56	75.4	1.369
6.21	2.84	2.22	2.180	39.02	77.1	3.68	106.2	1.376
7.94	3.37	2.75	2.180	39.02	87.9	4.09	121.2	1.380
8.43	3.53	3.24	2.180	39.02	89.9	4.18	125.2	1.394
13.34	5.92	4.99	2.175	39.08	116.0	5.38	163.8	1.411
15.80	6.02	5.79	2.165	39.20	127.5	5.91	179.7	1.407
18.56	7.67	6.63	2.150	39.43	141.9	6.45	199.1	1.403
20.18	7.89	7.21	2.139	39.60	151.1	6.80	211.4	1.398
21.18	8.06	7.44	2.128	39.78	158.1	7.05	220.4	1.394
22.01	8.00	7.49	2.115	39.95	165.0	7.26	229.0	1.387
22.42	7.74	7.53	2.105	40.12	169.4	7.38	234.0	1.382

Table 18. Model distributor data for velocity at location 4 with apron

Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_4 (fps)	Velocity ratio, $\frac{V_4}{V_a}$
2.22	38.33	54.5	2.63	79.0	1.450
2.21	38.44	77.2	3.69	110.0	1.423
2.21	38.39	86.6	4.17	123.0	1.418
2.20	38.50	90.9	4.34	129.2	1.422
2.20	38.56	116.0	5.52	162.2	1.400
2.19	38.74	127.0	5.99	177.0	1.395
2.17	38.97	142.0	6.60	195.8	1.380
2.16	39.14	152.0	7.00	205.8	1.352
2.15	39.38	158.0	7.16	214.0	1.353
2.14	39.54	165.0	7.44	220.0	1.332
2.13	39.72	169.8	7.58	224.6	1.322

Table 19. Model distributor data for velocity at location 5 with apron

Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_5 (fps)	Velocity ratio, $\frac{V_5}{V_a}$
2.195	38.79	54.9	2.58	69.1	1.260
2.185	38.91	76.5	3.58	94.0	1.228
2.185	38.91	87.2	4.07	106.7	1.222
2.185	38.91	90.9	4.26	110.3	1.216
2.175	39.02	115.0	5.34	140.3	1.221
2.170	39.14	127.2	5.88	152.8	1.200
2.160	39.32	142.0	6.50	169.7	1.193
2.145	39.49	149.2	6.75	178.3	1.195
2.130	39.72	158.0	7.05	184.4	1.168
2.120	39.89	164.2	7.22	190.8	1.162
2.115	39.95	169.1	7.46	193.7	1.145

Table 20. Model distributor data for pressure taps 1, 2, and 3 and velocity at location 6 with apron

Pressure, P_1 (psf)	Pressure, P_2 (psf)	Pressure, P_3 (psf)	Air density, ρ (10^{-3} slug/cf)	Air viscosity, μ (10^{-8} slug/ ft-sec)	Approach velocity, V_a (fps)	Reynold's number, $\frac{\rho d V_a}{\mu}$ (10^4)	Velocity, V_6 (fps)	Velocity ratio, $\frac{V_6}{V_a}$
0.54	1.27	2.20	2.18	38.84	55.0	2.57	66.7	1.212
1.03	2.74	5.33	2.18	38.84	77.2	3.60	91.5	1.183
2.08	4.05	6.90	2.175	38.91	87.5	4.07	104.3	1.194
2.29	4.36	7.63	2.172	38.97	91.5	4.25	108.8	1.190
4.15	7.73	13.69	2.170	39.08	116.2	5.39	138.8	1.195
4.90	9.04	16.46	2.160	39.20	127.6	5.85	151.7	1.188
5.83	10.66	19.47	2.150	39.38	142.0	6.46	167.0	1.175
6.61	12.00	21.89	2.140	39.54	151.0	6.80	176.7	1.170
7.07	12.99	23.57	2.135	39.60	157.9	7.09	183.5	1.163
7.60	13.98	25.39	2.120	39.84	164.5	7.26	189.7	1.153
8.03	14.51	26.44	2.115	39.90	169.2	7.45	193.2	1.142