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DUSTING COTTON FROM AIRPLANES.

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CONTENTS.

FIRST USE OF AIRPLANES IN APPLYING INSECTICIDES.

The possibility of applying insecticides by means of airplanes was first brought to public attention by the work conducted in August, 1921, by the State Experiment Station of Ohio, in cooperation with the United States Air Service, near Dayton, Ohio.[2] This particular test consisted of distributing lead arsenate from an airplane over a grove of catalpa trees in an effort to poison the larvæ of the catalpa sphinx (*Ceratomia catalpae* Bdv.), which were defoliating the grove. The experiment proved quite successful and immediately suggested the possibility of using the airplane for the control of other insect pests. Especial interest was aroused in the possibility of using the airplane to combat the cotton boll weevil (*Anthonomus grandis* Boh.), and plans were made for such experiments to be conducted

[1] In conducting the experiments described in this bulletin the writers were assisted by a number of men from the Delta Laboratory force at Tallulah, La. They are particularly indebted to the following: A. J. Chapman, R. H. Flake, S. B. Hendricks, R. L. Hodges, I. T. Jones, H. Kirkpatrick, P. D. Sanders, C. M. Smith, and M. T. Young.

[2] Fighting Insects with Airplanes. Neillie, C. R., and Houser, J. L. *In* Nat. Geog. Mag., vol. 41, no. 3, pp. 232–238, March, 1922.

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during the season of 1922. It was evident, however, that in the preliminary tests, since boll-weevil control is not as immediately obvious and easy to measure as that of the leaf-feeding insects, difficulty might be anticipated in determining the thoroughness of poison distribution. Consequently, it seemed likely that the principal measure of success in distribution over the plants which might be obtained from purely preliminary experiments, would be plant analyses to determine the amount of arsenic present, which is a very unsatisfactory expedient at best.

An opportunity to place the tests on an entirely different basis, however, was afforded by the outbreak of the cotton leafworm (*Alabama argillacea* Hübn.) which appeared over several of the Southern States. The first generation of this worm became active during the latter part of July, in rather unusual numbers, indicating a heavy infestation in the next generation, which might be expected about three weeks later. This provided an excellent opportunity for testing airplanes as a means of distributing poison over the cotton fields by making an effort to control the leafworms rather than the weevils. Arrangements were accordingly immediately made with the Air Service of the United States Army for detailing planes for these tests. Tallulah, La., was selected as a suitable location for the experiments, since the conditions found there, as regards flying, are fairly representative of the more favorable conditions encountered in the Cotton Belt. Furthermore, the location of the Delta Laboratory of the United States Bureau of Entomology at that point provided exceptional facilities for the construction and other work involved in the tests. Two planes were detailed to the tests, arriving about the 1st of August. These were piloted by Lieuts. G. L. McNeil and Charles T. Skow. Lieutenant McNeil remained throughout the period of the tests, while Lieutenant Skow was replaced after about 10 days by Lieut. L. C. Simon. All of these men and the equipment were provided by the Montgomery Aerial Intermediate Depot (now Maxwell Field) of Montgomery, Ala. In addition to the pilots, three enlisted men were provided, and the experimental work was further assisted for a few days by the presence of a photographic plane from the same field, piloted by Lieut. L. P. Arnold, the photographic work being done by Lieut. J. M. McDonnell.

DUST HOPPER CONSTRUCTION.

The first flights in these tests were made with limited quantities of poison, carried in bags in the plane and either dropped over the side by hand or emptied out through an opening in the bottom of the fuselage. After a few such preliminary flights, it was found advisable to construct "hoppers" which would carry the poison dust and deliver it into the air at a controlled rate. The hopper which was used at Dayton was constructed to hang outside of the fuselage, but it seemed decidedly preferable to fit the new hoppers inside so as to discharge through the fuselage. The cowling was removed from the observer's cockpit of the plane,[3] and the hopper was designed to utilize as much of the available space as possible and still leave room for a man to ride behind the hopper to operate it.

[3] The planes provided for this work were of the type commonly called the "Curtis H," equipped for training observers, and thus had a rear cockpit, but without dual controls.

THE HAND-CRANK HOPPER.

The type of hopper first constructed is illustrated in Figures 1 and 2, Figure 1 showing the manner of installation in the plane and Figure 2 the hopper as it appeared after removal from the plane. For convenience the discharge was arranged through the bottom of the fuselage, although later developments indicated that possibly this is not the most desirable place. This hopper was constructed of galvanized sheet metal and occupied practically half of the space in the observer's cockpit, leaving barely room enough for the operator to stand and turn the feeder crank. Furthermore, the presence of the walking beam for the controls in the front end of the cockpit made it necessary to undercut the bottom of the hopper considerably.

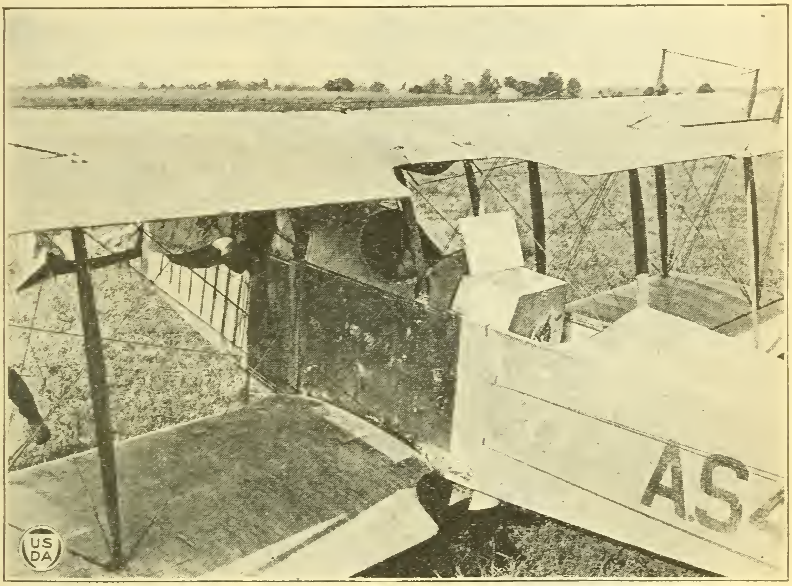

FIG. 1.—Curtis plane equipped with hand-crank hopper. Lid of hopper open for filling. Outlet for discharging dust shown projecting below fuselage.

The apparatus consisted of the dust chamber, the outlet or discharge tube, and the feeding mechanism. A hinged lid was provided for filling from the top, and the capacity of the hopper was about 12,500 cubic inches. The poison used in a majority of the tests was the ordinary calcium arsenate sold on the market for boll-weevil control, and all references to dusts in the following pages refer to this material, unless otherwise stated. As the standard specifications for calcium arsenate for boll-weevil control require a volume between 80 and 100 cubic inches to the pound, and the dust used in these experiments tested practically 100 cubic inches to the pound, the hopper capacity was approximately 125 pounds.

The outlet or discharge tube at the bottom of the hopper was intended merely to carry the dust through the bottom of the fuselage and drop it into the air. It was not possible in the preliminary work to stream-line the exposed portion of this tube and thus avoid air eddies. The air had a tendency to turn up into the outlet tube, and thus interfered with the proper delivery of the dust. The eddies created behind the tube tended also to draw the dust upward around the fuselage instead of permitting it to blow downward. To reduce this trouble a slot was cut through the forward side of the outlet tube, just below the bottom of the fuselage, and a funnel was placed over this opening with the neck inclined downward at an angle of about 30°. The delivery tube was then cut away somewhat toward the rear, and the air blast created by the movement of the plane blowing through this funnel helped to break up the dust, and blew it downward away from the fuselage. The construction of this funnel is shown in Figure 2. While it was not perfect, the idea can be developed and probably used to a very good advantage in directing and breaking up the dust cloud.

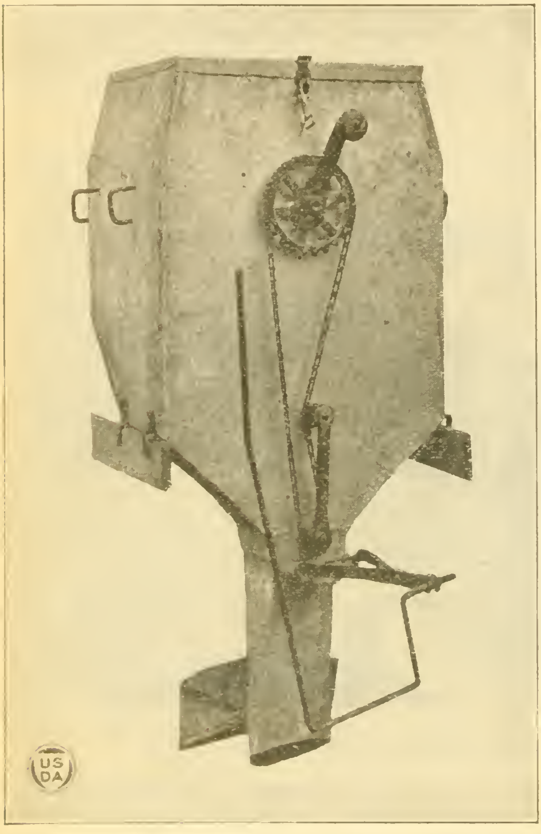

FIG. 2.—Hand-crank hopper removed from plane to show details of construction. Note particularly the lever arrangement for controlling the sliding cut-off valve.

The dust-feeding mechanism consisted of a cut-off valve in the bottom of the hopper and a four-bladed, rotating paddle wheel. The valve was constructed to slide in and out under the paddle wheel and was operated by means of a hand lever and connecting link. The paddle wheel was revolved by the operator through a pair of sprocket gears and a chain leading from the crank gear near the top of the hopper. When the valve was opened and the paddle wheel revolved, the dust was carried from the hopper and dropped into the air through the outlet tube.

Because of the limitations presented by the plane, it seemed impossible to overcome certain difficulties encountered with this type of feeder. These will be discussed in detail under a later heading.

THE AIR-SUCTION HOPPER.

To meet the difficulties encountered with the first hopper, another was constructed as shown in Figures 3 to 5, inclusive. This hopper was intended to be entirely automatic in operation except the opening and closing of the feeder valve. The general shape was much the same as in the first design, and its size and location in the plane were practically identical. In this case, however, the paddle wheel was eliminated and a feeder inserted which consisted of a funnel extending slightly above the upper wing and connected to a 4-inch sheet-metal pipe which extended down through the inside of the hopper and to within 5 inches of the bottom. At the lower end a box-like section, 7 inches square and 5 inches deep, was constructed with its lower side flush with the upper end of the dis-

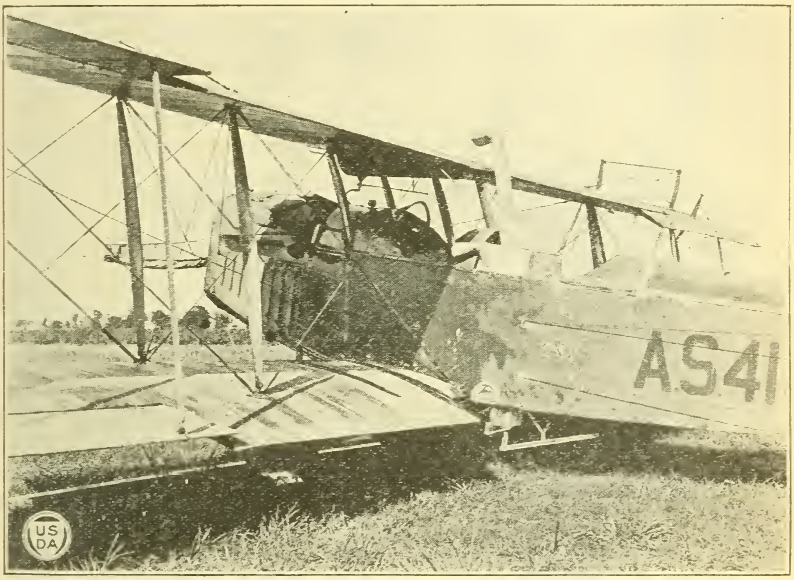

FIG. 3.—Air-suction hopper installed in Curtis plane. Lid of hopper open for filling. Outlet for dust discharge is shown projecting below fuselage, together with a portion of lever arrangement for controlling the feed valve.

charge pipe. This section acted as a guide for a valve or sleeve which fitted closely around it, but which was free to slide up and down. When at its lowest position this sleeve seated on the upper end of the outlet tube and thus prevented the dust from feeding out, while the rate of dust flow could be controlled by varying the height to which this sleeve was raised. The sleeve movement was controlled through a link joining it to a lever hinged to the bottom of the fuselage, with a sliding rod and handle attached to the other end to bring it within reach of the operator.

The details of this internal construction are shown in Figure 5, and the lever controlling the operation of the valve is shown best in Figure 4.

The operation of this feeder was as follows: The funnel pointing forward over the wing of the plane was, of course, subjected to a violent blast of air while in flight, and this high-velocity current of air blowing down through the tube had a tendency to create a vacuum around its lower end, producing a suction effect which would pull the dust out of the hopper into the air stream whenever the valve was lifted and would thus carry this dust out through the discharge tube. In other words, it provided an air current running down through the hopper and an adjustable opening in the bottom of the hopper so that varying quantities of dust could be drawn out with the air. When first tested some trouble was caused by the dust packing on the sloping bottom and in the corners and not feeding out regularly. This difficulty was overcome by fastening a small funnel pointing forward on each side of the top of the hopper and connecting to each funnel three small air tubes running down the inside of the hopper, discharging along the sides where the dust had the greatest tendency to lodge and in a direction tending to force it under the feeder valve. Figures 3 to 5 show the construction of these auxiliary air lines. This device kept the dust loose and gave satisfactory operation, except for the fact that no method of closing these auxiliary funnels was provided, and when flying with the feeder closed, and with only a small amount of dust in the hopper, the air blowing down these would agitate the dust and force some of it out through the cracks of the cover.

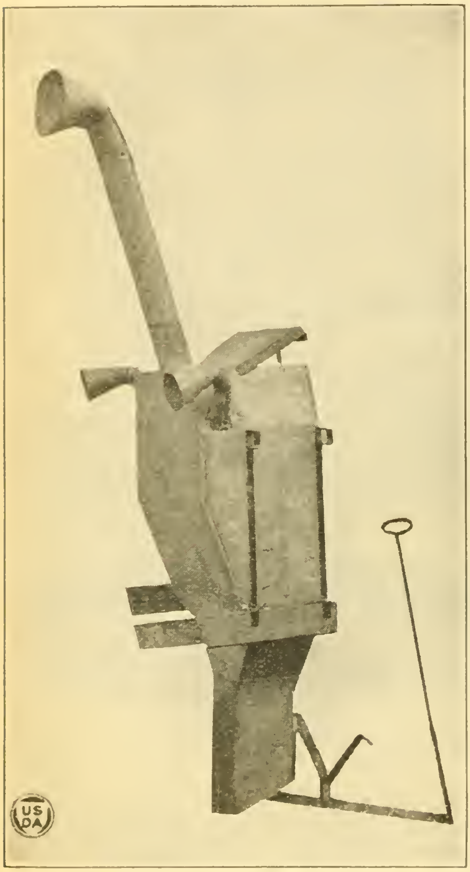

FIG. 4.—Air-suction hopper removed from plane, showing details of exterior construction.

To overcome these difficulties and also to improve the general efficiency of operation, a modified design has been prepared as shown in Figure 6. In this case the auxiliary funnels have been discarded and the same effect obtained by connecting these side air lines to the main air duct inside the hopper. Back pressure in the hopper is prevented by a butterfly valve in the main air duct just below the intake funnel which closes whenever dust discharge is cut off, and thus air is passing through the hopper only when the feeder is open. In addition, the starting and stopping of the feed has been separated from the control of the amount of feed. A special crank controls the elevation at which the feed regulator is set in the hopper, and this regulator remains at this point as long as the same feed rate is desired. The control of delivery is accomplished by a separate sliding valve operating across the bottom of the hopper.

For convenience, the first hopper is termed the "hand-crank" type and the other is called the "air-suction" type. These two were left in the two planes throughout the experiments, and all field applications were made with one or the other. The manner of operating them is shown in Figure 7. The operator stood upright in the rear

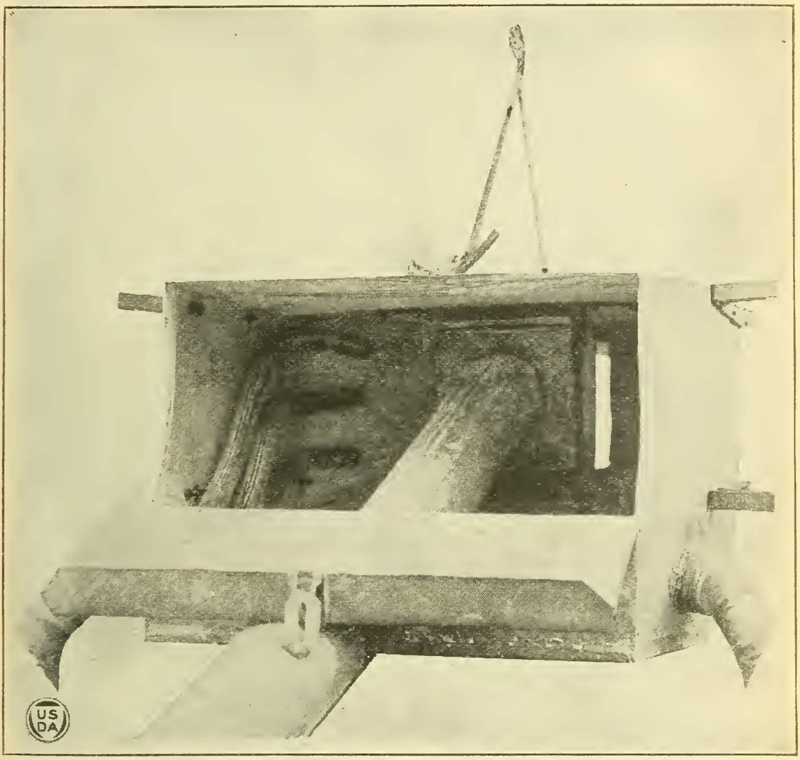

FIG. 5.—Interior construction of air-suction hopper. Shows main air tube extending down through hopper, with box valve at its lower end fully raised. Also shows arrangement of auxiliary air tubes along the side to keep dust from clogging.

cockpit behind the hopper and controlled the delivery of the dust. This was not a particularly pleasant position but sufficed for the preliminary experimental tests.

THE DAYTON HOPPER.

The hopper which had been used in the experiments at Dayton, Ohio, was shipped to Tallulah as soon as the tests were arranged. It arrived about the time the hoppers described above were completed, and was used in a few flights. As shown in Figure 8, this hopper was constructed to hang over the side of the plane to the right of and just in front of the observer's cockpit. The rate of feed was controlled by a sliding valve at the bottom and rear side of the hopper, while the dust was discharged by a small paddle wheel op-

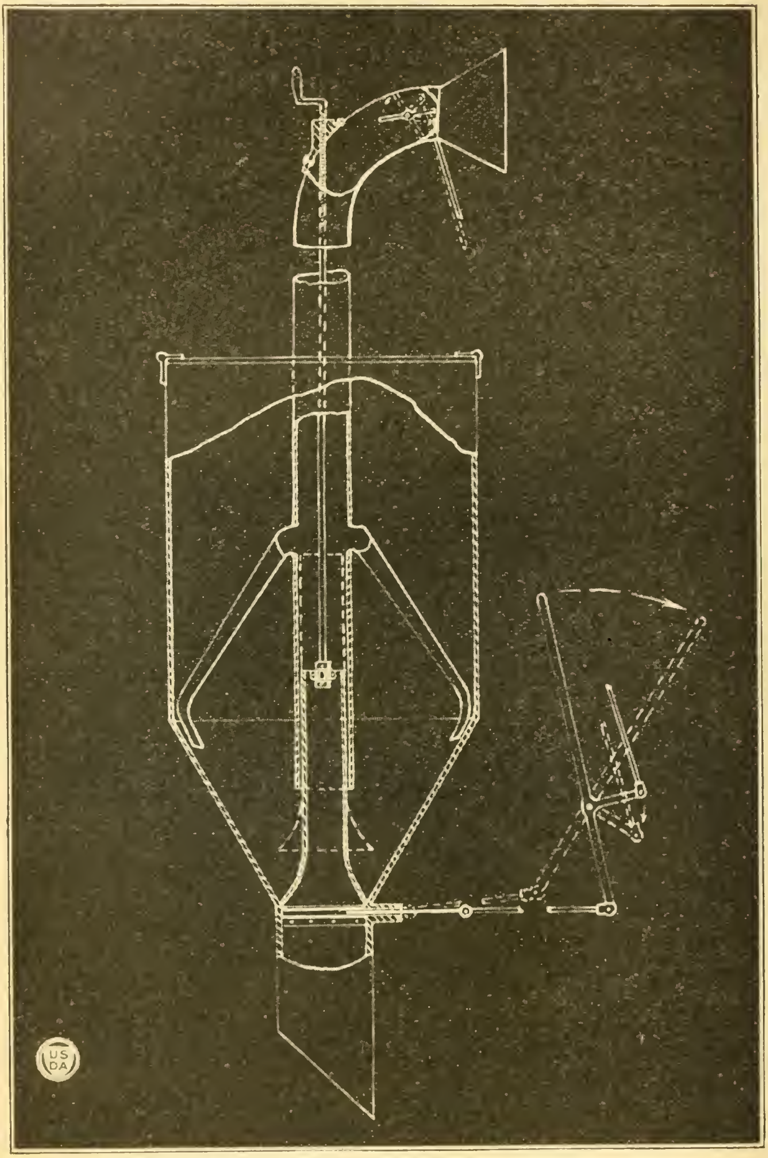

FIG. 6.—Diagrammatic sketch showing details of construction of improved type of air-suction hopper. See text for details.

erated by a hand crank through two sprockets and a chain. Clamps were provided on the inner side for attachment to the upper and lower longerons of the plane.

FIELD DUSTING STUDIES.

Following the completion of the two very crude hoppers described, no further efforts were made to perfect the mechanical delivery of the material, and the tests were devoted to a study of whether cotton plants can be effectively covered with poison by means of airplanes. At the outset two problems were paramount: First. Can the planes be operated over a cotton field in such a manner that the field will be thoroughly subjected to the cloud of dust? Second. Can the dust be forced down from the plane into the cotton plants and be made to adhere to them in a quantity sufficient to control insects?

LOCATION AND PLAN.

Two farms situated from 1½ to 5 miles from Tallulah were selected for the study. Mosaic maps of these made from an elevation of 10,000

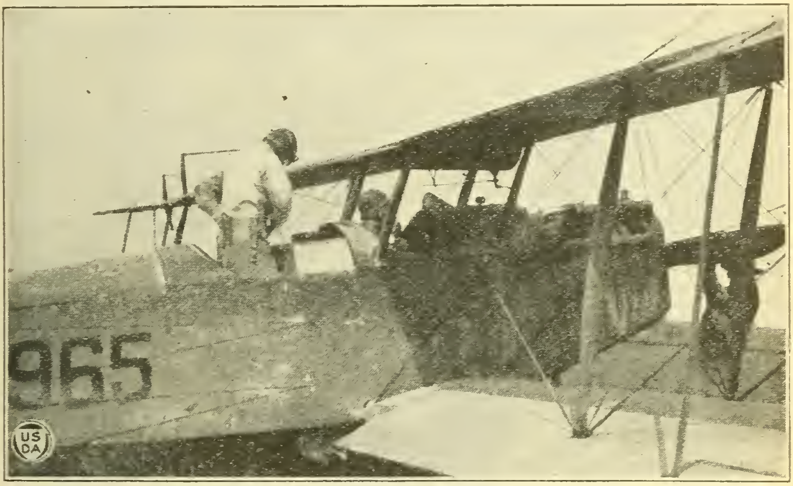

FIG. 7.—Dusting plane as used in 1922 ready to take off. The experimental hoppers used required operation by an extra man who stood upright as shown. Future equipment will utilize this additional space for poison and the dust delivery will be controlled by the pilot.

feet are shown in Figures 9 and 10. A large lespedeza meadow from which the hay had just been cut proved to be an ideal landing field. A tent was provided for the storage of poison and other equipment. Acetylene lights were used for illuminating the field before daybreak when early morning poisoning was planned, although no actual flying was done at night. A tower was erected for the support of wind instruments, to provide definite information on the conditions of air movement under which the experiments were conducted. This tower was so arranged that the anemometer and wind vane were mounted about 15 feet from the ground. Records were taken at five-minute intervals on both wind velocity and wind direction throughout the day for the period of the experiment.

The landing field was near the center of what is called Shirley plantation. This property was selected because it is a fairly typical cotton farm, and also affords a wide range of environmental conditions under which to operate. There are approximately 2,000 acres in the entire property, 675 being in timber and 1,325 in cleared land. The cleared acreage was distributed as follows: Cotton 400 acres, corn 250 acres, meadow 250 acres, soy beans 100 acres, pasture 75 acres, weeds 250 acres.

A sketch map was prepared to show the location of the different fields on the Shirley property, and each cut was numbered, for con-

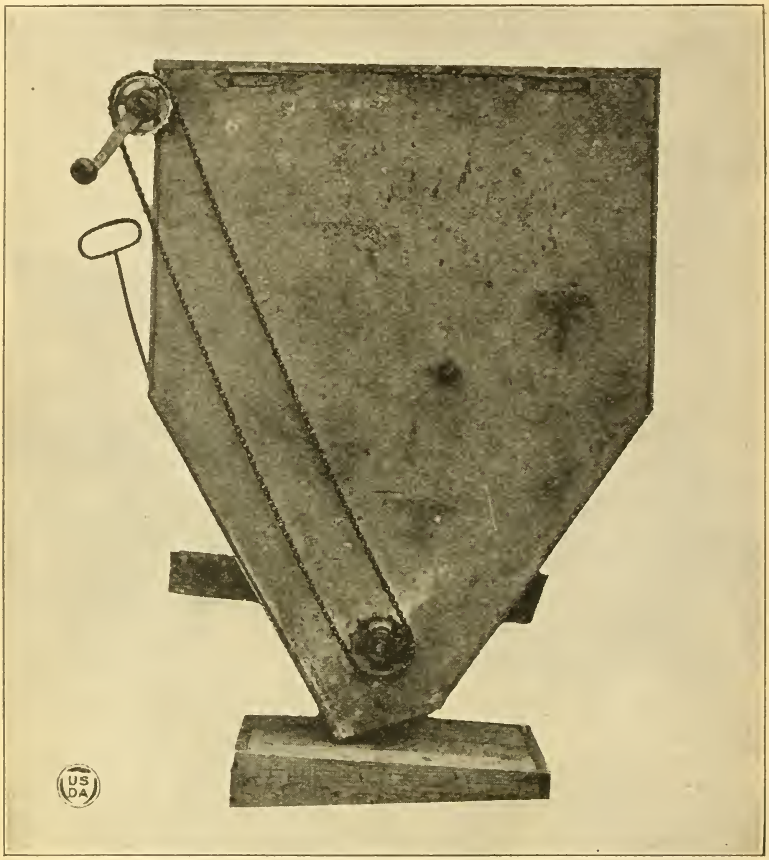

FIG. 8.—The "Dayton hopper" removed from plane. This hopper was attached outside the body of the plane.

venience in keeping records as well as for directing the operation of the planes. The mosaic map taken photographically from a plane, shown in Figure 9, was not available until practically the end of the experiment, but the need for it was very apparent throughout the work. In arranging the program of work for a day, it frequently proved difficult to provide a description based on ground conditions which would exactly locate the area in mind. Such a mosaic map would also have been of great value in planning in advance the methods of flight for each field.

Like all the country in the so-called "Mississippi Delta" district, the Shirley plantation is absolutely flat and consists of a large clearing irregularly surrounded by timber, with some fields out in the

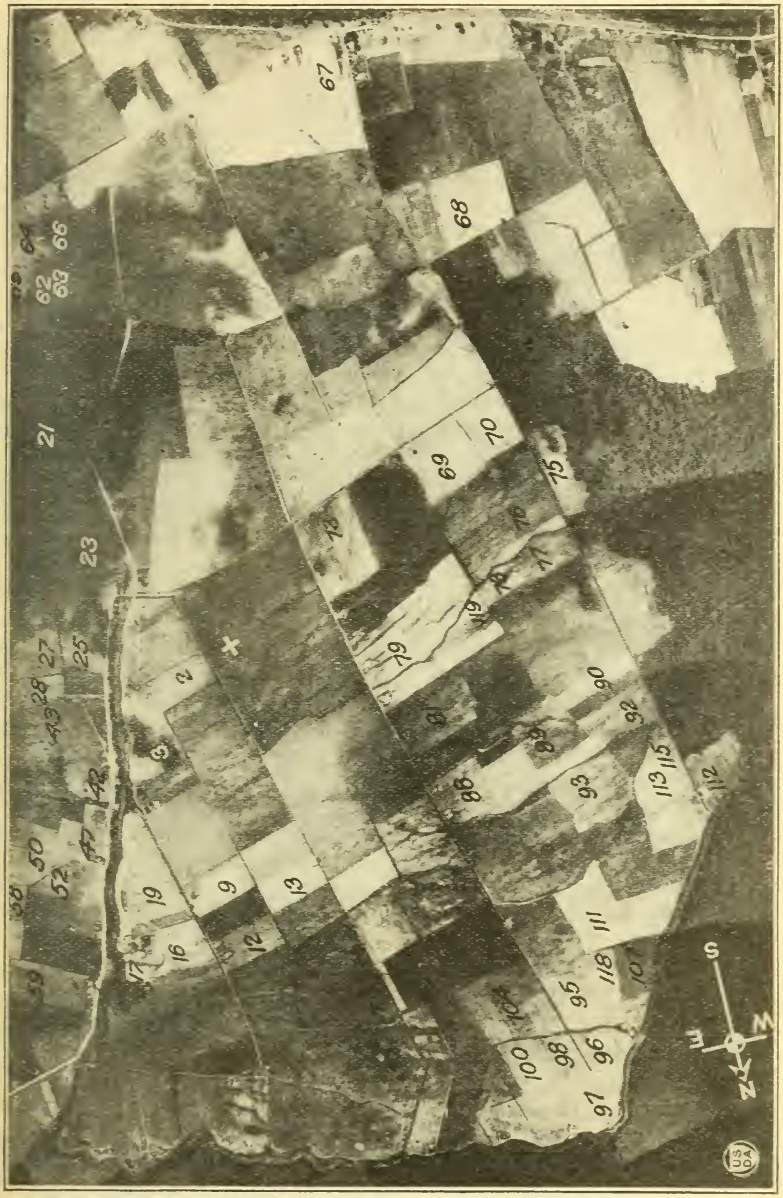

FIG. 9.—Portion of Shirley Plantation, Tallulah, La., showing cut numbers of cotton fields included in experimental dusting. Landing field indicated by cross mark. (Photo made by Lieutenants Arnold and McDonnell, Fourth Photo Section, Air Service, U. S. Army.)

open and others tucked back into the timber line. The treatment of these different fields gave valuable information on the problems which will be presented by different conditions when attempts are made to dust from the air.

Hermione plantation, adjoining the Shirley property, was selected as representing a very different type. (See fig. 10.) This property is a comparatively narrow strip slightly more than a mile long, extending east and west, bordered on one side by a bayou and on the other by small clumps of timber. This property presented much more favorable conditions for low flying than were found on most of Shirley, because only a few cabins were present in the fields, except a row along the edge of the bayou. It was especially favorable for airplane work in the opportunity offered for straight flights a mile long.

Hermione plantation consists of approximately 1,000 acres, 850 being cleared and the remainder in timber. The cleared land was distributed as follows: Cotton 270 acres, corn 175 acres, peas 10 acres, alfalfa 80 acres, pasture 20 acres, open but not cultivated 300 acres.

LEAFWORM CONDITIONS.

The Shirley and Hermione properties were both fairly heavily infested with the cotton leafworm during the first generation. A very large number of these pupated successfully in the fields, which had been practically stripped of foliage by that generation. These pupæ matured and the eggs which were laid by the emerging adults began to hatch about August 20. The number of adults became so exceedingly great that the infestation of worms which developed proved to be one of the heaviest ever noted by the writers. Practically every plant had numerous eggs, and as these hatched some fields were found to have apparently an average of about 50 worms per plant. As the infestation varied somewhat from field to field, and eggs were laid in some fields earlier than in others, it was necessary to poison the fields at different times. Careful records were kept on the worm infestation of each field and the individual fields were poisoned as became necessary for the control of the worms. Many variations were introduced in the experiments. In some instances the worm infestation was allowed to develop more heavily than in others. The operation of the planes was varied to include flights at different elevations, at different times of the day, and under different air conditions. In addition, some poisons were tested merely to study their suitability for distribution from the plane as compared with ordinary calcium arsenate.

BEHAVIOR OF THE DUST IN THE AIR.

The behavior of the dust in the air was the subject of the first studies conducted. In ordinary poisoning of cotton, what has been termed the "dust cloud" method has been developed. The dusting machine passing between or over the cotton rows blows out the calcium arsenate in a fog which penetrates between all portions of the cotton plant, and consequently covers every exposed particle of plant tissue. Successful dusting of this type can be done only when the air is calm, and its success is greatly enhanced by the presence of moisture on the cotton leaves. For these reasons ordinary cotton dusting has become almost entirely a nocturnal operation, beginning usually during the period from 6 to 8 o'clock in the evening and continuing in the morning until the dew dries from the leaves, and the breeze springs up, which is usually some time between 6 and 8

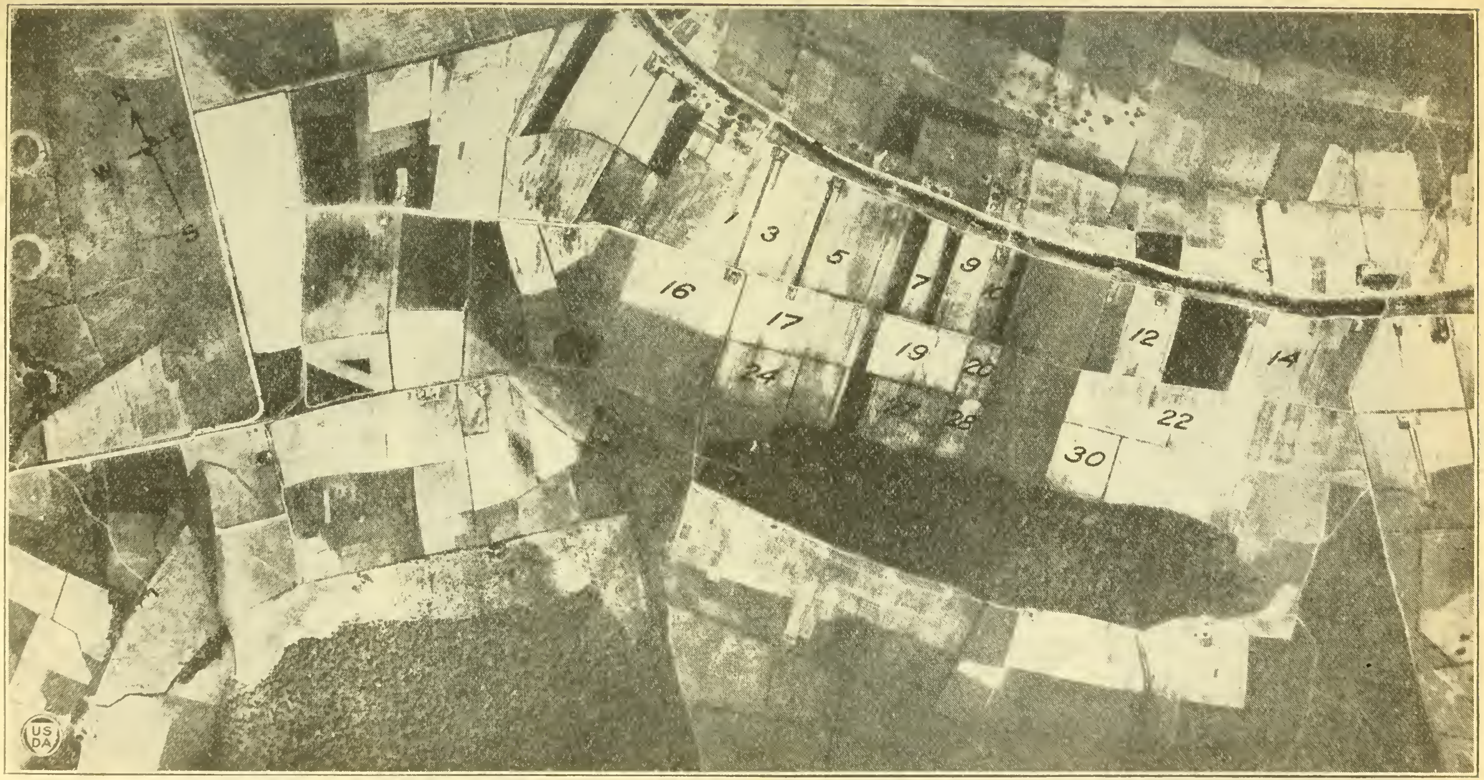

FIG. 10.—Hermione Plantation, Tallulah, La., showing cut numbers used to designate cotton fields included in experimental dusting. (Photo made by Lieutenants Arnold and McDonnell, Fourth Photo Section, Air Service, U. S. Army.)

FIG. 11.—Dusting plane in operation, showing behavior of dust as discharged under the body.

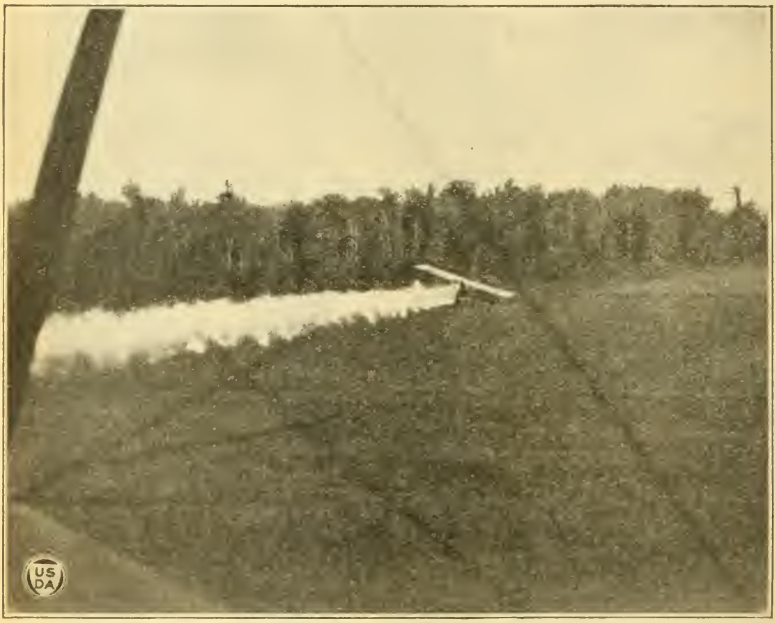

FIG. 12.—Dusting plane in operation showing spiral travel of dust caused by rotational flow of air from the propeller.

a. m. The most favorable conditions for dusting are those existing from daybreak until very nearly the end of the dusting period, as the air is especially humid and hazy at that time, and the dust hangs among the plants well. As a general rule, in the daytime, the dust is whipped away from the nozzles of the dusting machine and blows off in the air without reaching the plant.

The first series of flights were made during the day over Shirley cut No. 2, which immediately adjoined the landing field and offered a convenient opportunity for studying the behavior of the dust in a fairly typical field.

These first flights furnished an absolute surprise. It was found that when the calcium arsenate was dropped from the plane it was immediately broken up into a circular cloud which was quickly

FIG. 13.—Dusting plane directly approaching camera, showing trend of dust cloud. Note how this is blown both downward and to the left of the line of flight of the plane.

blown down among the plants. This was obviously due to the tremendous rush of air past the plane and the additional blast created by the propeller, or, as it is commonly termed, the "slip stream." This combined air blast was so terrific that the powder encountering it became entirely subjected to its force and the effect of ordinary air conditions was very largely overcome. Throughout the experimental period flights were made at varying elevations, ranging from 5 feet above the cotton plants to 50 feet above them, and it was almost always possible to distribute the poison from 25 feet or lower, regardless of air conditions. It was sometimes possible to distribute the dust down among the cotton plants from even as high as 50 feet or more. Apparently the explanation of this fact lies in the air currents set up by the plane and its propeller.

Owing to the combined influence of the forward movement of the plane and the rotation of the propeller, the plane in flight is surrounded by a body of air moving backward considerably faster than the plane moves forward, and this air flow follows a spiral course, tending to one side and decidedly downward. Dust dropped from the plane into this air current immediately becomes subjected to its influence, this air current being so exceedingly powerful that it completely counteracts, for some distance behind the plane, all light breezes, or other slight air movements existing on the ground. Consequently, for some distance to the rear of the plane, the dust is still entirely under the control of this air movement set up by the plane itself.

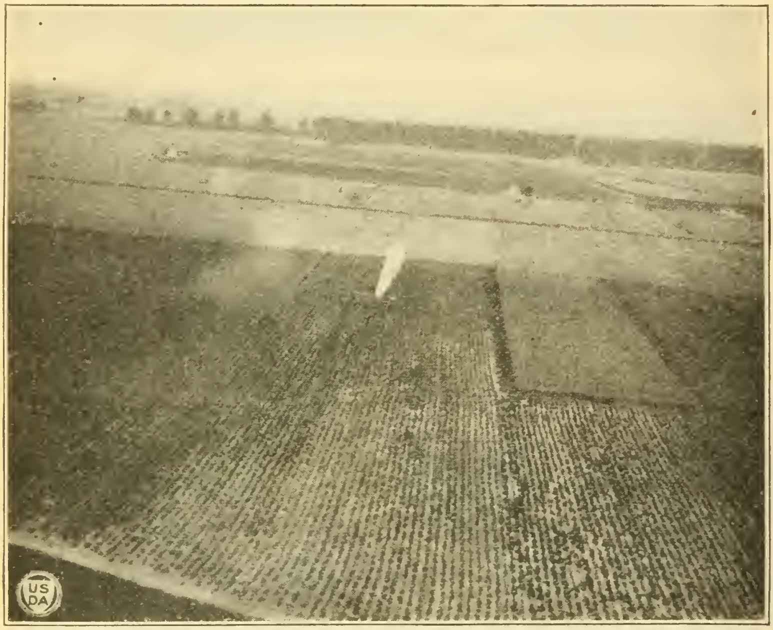

FIG. 14.—Dusting plane just starting across cotton field, illustrating the manner in which the hopper outlet is opened just after passing the edge of the field. The air current from the propeller carries the dust backward to the margin of the cotton.

The dust cloud from the planes used in these tests followed a hollow spiral course, with a decided turn to the left and downward. The three illustrations shown in Figures 11, 12, and 13 bring out fairly well these characteristics of dust behavior.

Owing to the extreme crudity of the hoppers and the feed mechanism used, it was necessary, in order to release the quantity of dust required by the speed of the plane, to drop the poison in large masses, and to depend upon the air current to break these up. This was accomplished fairly well, but there was always a certain percentage of the material which adhered together in the form of pellets and dropped immediately to the ground, thus becoming so much waste. This is an undesirable feature which can be corrected by experimental development, but which it was not possible to eliminate during these preliminary experiments.

In Figure 11 the behavior of the dust immediately after flowing from the hopper is noted, and in Figure 12 is seen particularly the decidedly spiral nature of the cloud following the plane. In Figure 13 is shown, as well as possible, the tendency of the dust to blow to the left of the line of flight and downward. All of these effects were exceedingly important in the dusting operation. In fact, the downward tendency of the air current is probably one of the greatest contributing factors toward success in forcing the poison dust down among the plants, regardless of existing air currents.

The effect of the backward blast of the slip stream was quite important. The dust being delivered under the plane, instead of going directly to the ground, was blown backward from the point of deliv-

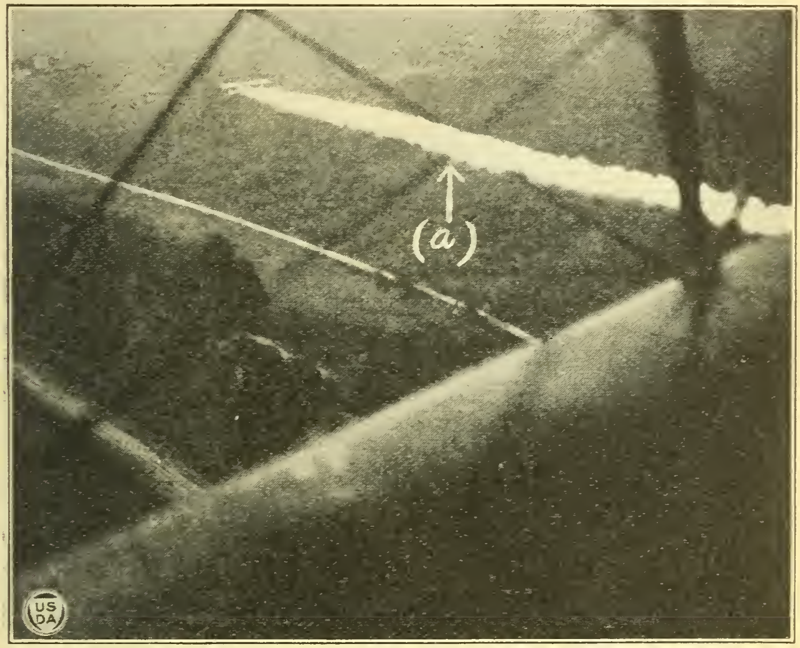

Fig. 15.—Dusting plane in operation in "straight-away" flight. This view shows the beginning of the trail of dust behind the plane. The plane is operating about 25 feet above the plants near midday. The dust does not come in actual contact with the plant until about the point indicated by *a*. See Figure 16 for remainder of dust cloud on this flight.)

ery by this blast, and in some instances it was found that the dust was shot 100 feet or more to the rear of the point where it was dropped from the plane. The practical application of this point is illustrated in Figure 14, which shows the manner of starting the flow of dust in crossing a field of cotton. Instead of opening the hopper at the edge of the field, it is opened a short distance after the plane has passed into the field, and this backward blast shoots the dust back to the margin of the cotton. This is also of importance in connection with maneuvering for dusting difficult situations, as will be shown later.

Figures 15, 16, and 17 probably illustrate as well as possible the behavior of the dust after it passes beyond the direct influence of the air currents created by the plane. In Figure 15, in which the plane is flying about 15 feet above the cotton plants, it will be noted that to the point marked *a* the dust cloud has followed a regular form, and has not yet touched the cotton plants. During this time it is still being carried around the spiral and is rolling over and over. At *a*, however, the poison is beginning to catch in the cotton plants, and at the edge of this picture nearly all the poison is feeling the influence of the plants. Figure 16 is a continuation of the same cloud, merely looking farther to the rear. In this view the dust is spread in a fairly uniform layer over a swath gradually increasing in width as distance from the plane is increased, and distributed among the plants, with only a small amount of material going off in the air above. These

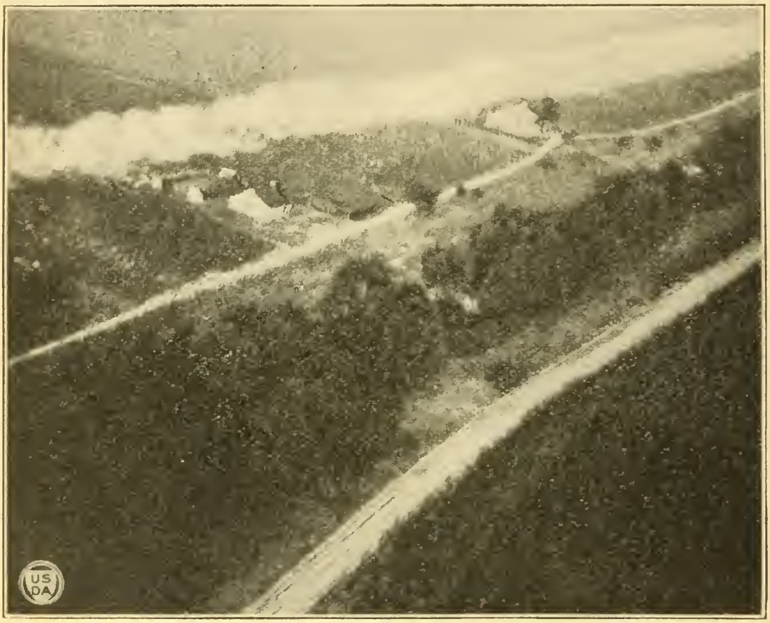

FIG. 16.—After taking the view shown in Figure 15, the photographer immediately snapped this picture looking over the tail of the photographic plane. Thus this view shows a continuation of the same dust cloud being released in Figure 15, but considerably to the rear of the dusting plane. Note how the cloud is spread out among the plants over an area about 200 feet wide. At the time this picture was taken the dusting plane had just laid down such a cloud nearly 3 miles long.

photographs were taken about 11 a. m., with an 8-mile breeze blowing, which would render absolutely impossible any effort to dust cotton with ordinary ground dusting machines. Figure 17 further illustrates the behavior of the dust leaving the plane. In this it will be noted especially that the dust cloud has maintained its spiral shape to the point marked *a*, but is then quickly flattened out among the cotton plants.

INFLUENCE OF VARIOUS AIR CONDITIONS.

In the studies on operating at different times of the day and under different air conditions, wind records were kept throughout the experimental period which showed that, as a general rule, there was a period of absolute calm between daybreak and about 7.30 or 8 a. m. In a few instances daybreak was accompanied by a light breeze, but this did not last long and there were still about two hours of absolutely calm air. As is generally the case in the Delta country, the dews were very heavy in the early morning and usually did not dry off until about 6.30 or 7 o'clock, with sometimes a little dampness persisting until 8 o'clock. There was also nearly always a heavy fog or "ground haze" among the cotton plants for the first hour or so after daybreak.

A short time before daybreak on the day when these particular tests were undertaken, this haze extended from 50 to 100 feet in the

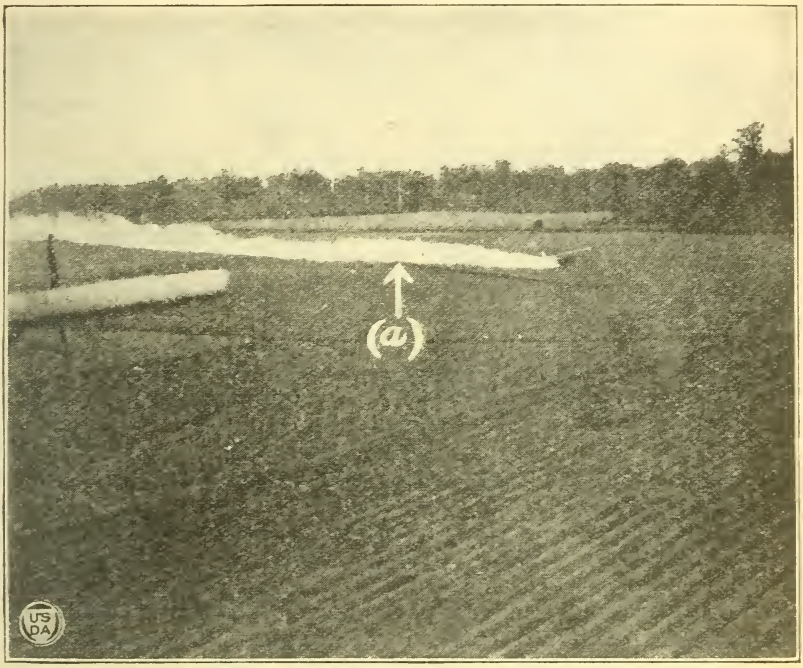

FIG. 17.—Typical dust cloud being laid down in cotton field by plane. Note particularly that from the plane to the point marked *a* the dust cloud is rotating spirally above the plants and without touching them. At this point, however, the diameter of the cloud becomes large enough to reach into the plants and the cloud very quickly loses its spiral shape and flattens out among them. This plane was flying about 35 feet above the plants.

air in a very irregular form. Just about daybreak it settled into a very heavy fog, blanketing the earth in a layer from 20 to 30 feet thick. This condition was ideal for the operation of ground dusting machines, but gave very peculiar results in airplane dusting.

The planes had been prepared late the preceding evening, and the motors were warmed before the first break of day. Just as soon as it was light enough to see to fly the planes took off, giving a very weird effect in the ground haze. This haze was so heavy that vision did not extend far enough down the field to see them when they left the ground, and they seemed to simply disappear in the fog. Thirty feet above the ground the pilots found that they were out of this fog, with perfectly good air and vision for flying, but from the ground it was difficult to see the planes operate. The planes then crossed back and forth over the cotton fields, flying at about the same level as during the daytime earlier in the work (about 15 feet above the ground), and a most curious effect was noted. Instead of a white dust cloud being swept out behind the plane, almost none was visible, although the feed valve was wide open and putting out dust at the usual rate. At this elevation the planes were flying inside of the fog of ground haze, and they seemed to churn out a channel just slightly larger than the propeller. The dust delivered was entirely confined by the wall of fog surrounding this channel and did not spread out at all, merely coming down in a strip which did not cover more than three rows of cotton.

In the next flights, made just as soon as the hoppers could be reloaded, the planes were operated a few feet above the top of the fog, and the behavior of the dust changed entirely. It was blown downward until it encountered the fog, but instead of immediately penetrating through it, it spread out on the top of the fog in a layer from 50 to 100 feet wide. It seemed to remain at this point without motion, and the observers standing about in the cotton field under this fog were puzzled to know what would become of the dust. It could be observed on the fog for a few moments and then it seemed gradually to disappear. About the same instant, however, everyone in the cotton field noted that the air was filled with fine, almost invisible, particles of dust falling to the plants. After about two minutes the plants, which had been perfectly green before, presented the whitened appearance of a very heavy dusting.

Unfortunately various difficulties prevented more careful studying of this development, so the writers really do not yet know whether such conditions are exceedingly favorable or exceedingly unfavorable for airplane dusting. Certainly it seems useless to fly the plane within the ground haze, but when the dust is distributed on top of this fog it apparently is spread very thoroughly and settles on the plants in an effective manner. Further studies must be conducted on this point, however, before any definite conclusions can be reached regarding operation under these conditions. A few analyses were made of plants treated during the fog, which indicated satisfactory arsenical distribution and adhesion, though these can not be taken too seriously. The fields treated in this manner showed satisfactory worm control, but again no final conclusions are possible because these fields were not as heavily infested with worms as many others in the experimental area.

Following these tests, flights were made over a period of several days at intervals during the day, from early morning until late evening, to study the behavior of the dust under the different air conditions. Immediately after the period of calm in the morning there was usually a light breeze of from 2 to 4 miles an hour, which gradually increased to from 4 to 10 miles an hour by midday. This persisted until about 3.30 or 4 in the afternoon, when the morning process was reversed and the air again became calm slightly before dark. In these flights it was found that the dust could be blown down among the cotton plants at practically any time of day under the conditions prevailing through the period of these experiments.

Considerations of safety indicate, however, that flying for dusting should be confined to about seven or eight hours—about four hours in the early morning and three in the late afternoon. Any attempt at low flying during the middle of the day is dangerous on account of rough air, and the air temperature is such that the motors overheat very badly in a short time.

ADHESION OF POISON TO PLANTS.

To determine the amount of arsenic which adhered to the cotton plants, a series of plants were collected in a line parallel to and directly under the path of the plane, and in parallel lines at varying distances on both sides of the path of the plane. Chemical analyses of these plants showed not only the amount of poison present on the plants directly under the plane, but also the uniformity of distribution and the width of spread.

The first series of records of this sort were used in checking up a flight made at 4 o'clock in the afternoon between 15 and 20 feet above the cotton plants, with a breeze blowing approximately 8 miles an hour at right angles to the path of the plane. The heaviest distribution of poison was of course found immediately under the plane, but there was a strip 45 feet wide on the down-wind side of the path of the plane which showed a fairly uniform dosage of poison. Practically this entire strip showed an arsenic recovery as high as is normally obtained from a hand gun feeding about 10 pounds to the acre operated directly over a row of cotton plants in the early morning when the plants are moist. This result was all the more surprising because it was almost impossible to see any poison on these plants, which still showed a higher content when analyzed than is considered necessary for weevil control. Further analyses only confirmed these, although the series made was by no means complete, and the results are somewhat sketchy.

From the results of the analyses, together with the observations made on worm control, however, it seems quite obvious that an astonishing amount of the poison adhered to the plants over a very wide path under atmospheric conditions such that it would be considered absolutely impossible to make the dust stick to the plants with the best of present ground dusting machines. The exact cause of this adhesion is a complicated matter which is now under investigation.

MANIPULATION OF PLANES.

On the two properties on which these tests were made was found almost every conceivable type of field as regards the difficulties presented for airplane dusting. In the center of each property were some cotton fields absolutely open, without obstructions of any sort surrounding them. Around the margins were the fields extending along the timber line, which was sometimes very irregular. Other fields consisted of small clearings of only a few acres tucked back into the timber and in some cases surrounded on three sides by trees 50 to 60 feet or more in height. In still other fields which had been cleared within comparatively recent years a few deadened tree trunks were still standing, forming snags which were difficult to see while flying and which had to be very carefully avoided. Typical fields along an irregular timber line and containing occasional high snags are shown in Figure 18, which illustrates also the interspersed planting of cotton and other crops, since Fields 21 and

23 are cotton, while Fields 20 and 22 are corn. Cabins and adjoining outbuildings were present in many fields, and the bayou which adjoined Hermione on one side and the canal which ran through the center of Shirley were both lined with trees.

Each type of field was studied as an individual flying problem, and efforts were made to decide upon the most efficient and safest manner in which to fly that particular field. Especial attention was devoted to those fields that presented unusual difficulty for flying. Throughout the work the individual cut of cotton was treated as the unit, rather than lining up a series of cuts in a row which could be treated by straightaway flights. In any commercial use of the planes, every effort should of course be made to arrange the

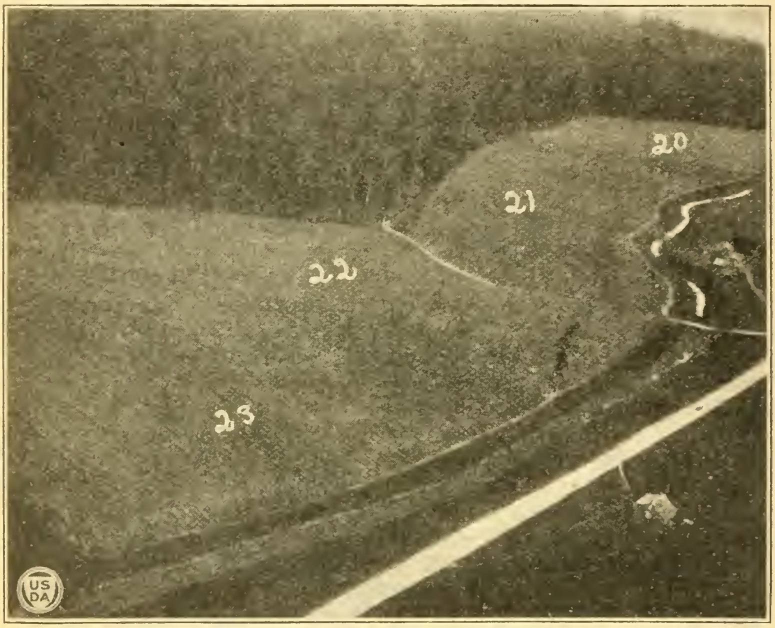

FIG. 18.—An oblique view from about 500 feet elevation of Shirley Plantation, Cuts 20 to 23, inclusive. This illustrates the type of flying problem presented by such fields, extending irregularly along timber and containing occasional isolated tall snags.

cotton and the flying so that straightaway flights as long as possible may be used.

Wind direction occasionally proved important in deciding the manner in which a field should be flown. It is safer to fly low against the wind than with the wind, and the same degree of stability can be maintained with a slower ground speed against the wind than with it. This factor, however, was important only near the middle of the day, as in early morning and late evening the wind velocity was not sufficient to cause difficulty.

FLYING METHODS USED.

The usual manner of treating a field consisted of flying back and forth on paths which permitted the dust clouds to overlap slightly.

The plane would start in along one edge of the field and gradually work over to the other. Whether the plane was flying with the rows or at right angles to them seemed to make no important difference in the behavior of the dust cloud. Usually the plane maneuvered at an altitude of from 50 to 100 feet or more until the right point was reached for entering the field. It then dived down, and if possible reached the desired altitude of from 10 to 25 feet above the plants just before coming over the edge of the field. The plane was then leveled out and shot across the field at this elevation. At first the manner of leaving the field at the end of each trip was based somewhat on the surrounding conditions, but it was soon found that the efficiency of the treatment could be considerably increased by "zooming" or turning upward sharply just as the plane reached the edge of the field. This is because the dust is carried back for some distance by the slip stream, and if the plane is zoomed as the feeder is closed the last dust delivered is blown back into the edge of the cotton field, giving a heavy treatment for the row ends. In many instances, owing to the crude feeder attachments, the delivery of dust did not begin quite quickly enough, and an area of 50 feet or more at the edge of the field where the plane entered was thus left untreated. To correct this condition, after flying back and forth over a field in one direction until the field had been covered, the plane usually made one trip across each edge of the field at right angles to the previous course, thus making sure of getting an application on the row ends. This necessity could of course be eliminated with better feed-valve construction and more accurate control than was possible in this work.

In treating a field extending along timber it was often possible to operate without difficulty by simply flying parallel to the timber line. In some instances, where a field was adjoined on two or more sides by timber, right-angle corners were presented. After a little experiment it was found possible to treat these in either of two ways. If the timber was not too high, the plane would fly directly at the timber line and zoom upward sharply so that the tail pointed downward and the dust was thus blown down in the corner of the field. Where this was not possible the plane was flown parallel to one side of the timber directly toward the right-angle corner and banked sharply into a climb so that the tail of the plane was again turned toward the corner. The backward blast of the propeller then blew the dust into this corner. It was thus found possible to treat any such situation which was encountered, even though the plane could not actually be flown over all of the cotton.

Another problem which presented itself was the dusting of cotton immediately adjoining the cabins. In the district where these experiments were conducted, cotton is raised almost entirely on a tenant basis, each family having its quota of from 10 to 50 acres which is cultivated on some share basis. The average per family is somewhere between 20 and 30 acres. The home is usually either within, or closely adjacent to this area, and with its outbuildings and garden occupies a block of perhaps 100 by 200 feet. A considerable percentage of the cotton fields are dotted with these houses, or "cabins," which present obstructions to entering the field. On the other hand, the cabins are nearly always only one story high, and are usually the tallest portion of the obstruction, unless trees are present in the yard. By maneuvering the plane through sharp climbs, rapid dives, or quick turns, the cabins can be avoided without difficulty, and dust can be delivered to situations which at first seemed utterly out of reach.

Cuts 62 to 64, inclusive, on Shirley plantation presented special problems. (See fig. 19.) A few years ago these fields were the bed of a swamp lake, but they were drained and made subject to cultivation by the canal which now extends through Shirley plantation.

At that time the undergrowth was all cleared from the fields, but many of the cypress trees which were scattered through the lake were left standing. At present these cuts contain 49 such trees from 60 to 70 feet tall and growing at very irregular intervals. Cotton is

FIG. 19.—Oblique view of Shirley Plantation, Cuts 62 to 64, inclusive, taken from 500 feet elevation, showing the difficult flying problem presented by cotton growing among cypress trees.

grown throughout this area right up to the trunks of the trees. These fields were considered the most difficult in the community for airplane dusting. In fact it appeared to everyone except the pilots that the treatment of these fields was absolutely out of the question, but they volunteered to dust them. The leafworms developed a fair infestation only, but still sufficient to require treatment for control on two different occasions.

Upon examining the fields carefully the pilots found lanes between the trees navigable for airplane operation, and twice dusted them in a manner which permitted perfect worm control with the use of only about 3 pounds of calcium arsenate per acre at each treatment. It was found that most of this cotton could be treated by direct blast, and that comparatively little of it must be dusted by drift of poison. After watching this performance the writers were convinced that it was possible to deliver dust into almost any field which would be encountered, as certainly this group presents the most difficult flying problem in the entire community.

The remaining type of woodland field is well illustrated in Figure 18. These cuts all extend back into the timber line, and Cut 21 contained several single trees and old snags which stood at some distance from the timber line, thus increasing the difficulty of getting poison back to the cotton adjoining the timber. Nevertheless, all of these fields were poisoned very effectively so far as worm control was concerned.

There were many fields on Shirley out in the center of the plantation, where they are absolutely free from obstructions of any sort (see fig. 9), and thus permit maneuvering the plane at any desired elevation without worry.

Figure 10, showing the general view of Hermione plantation, illustrates fairly ideal conditions for flying. The three tiers of cuts extended between the bayou and the timber line paralleling both. One cabin is present in the corner of Cut 16 and another in Cut 17. Aside from these, all cabins are in a row along the side of the bayou. Since these fields extend slightly over a mile along the bayou, it would be possible to make straightaway flights of a mile back and forth until overlapping strips had been laid down from the woods to the bayou, with only a few cabins to avoid. Cotton extends to the bayou between these cabins and presents a more difficult problem of poisoning, but it was found possible to maneuver the planes in and out between these cabins to treat all of this cotton.

The ends of the fields immediately adjoining the timber presented a slightly different problem. The timber edge is not a straight line (see fig. 10), but curves in and out, and cotton is planted in these small indentations. These were rarely more than 20 or 30 feet deep, however, and they were poisoned very easily in the following manner:

The pilot flew the plane on a line paralleling the timber and whenever he passed one of these short indentations he maintained his straight line until practically at the end. At this point he would bank the plane sharply away from the timber; that is, the plane would be turned somewhat on its side with the wing tip away from the timber lower than the other, and thus presenting the bottom of the fuselage somewhat toward the timber line. In addition the turn of the plane in this maneuver would aim the tail slightly into the indentation. The whole operation took very careful judgment, but no pilot remains healthy very long without this qualification, and if properly done, the slight swing of the plane twisted the dust cloud over and swept it down through the area in the indentation. The plane was then immediately righted and placed on a straight course, to repeat the operation at the next indentation.

The methods which have been described for using straightaway flights of course present the most efficient manner of treating a plantation laid out like Hermione, and furthermore give the largest acreage capacity for the plane. This method, however, was followed only long enough to obtain a few comparative figures, and in all other cases the various cuts were treated individually, the plane turning back and forth until one cut had been completed before moving to another one.

RATE OF DUST DELIVERY.

A number of straightaway flights were made to obtain data on the rate of delivery of dust from the planes. One plane was loaded with a known quantity of dust and flown on a straight line across the fields, paralleling a straight road several miles long. The feeder valve was opened at a certain starting point marked on the ground, and dust delivery was continued until the hopper was empty. A second plane followed this one, flying perhaps 100 feet higher and carrying an observer who watched the behavior of the dust delivered from the first plane, noting carefully with a stop watch the time from first delivery until the end of the dusting. In addition, the point at which the dust supply was exhausted was marked by the second plane, and the distance back to the point of starting was measured. In this way the time of delivery of a hopper charge, as well as the distance it would last, was determined.

The first tests of this nature were conducted with the hand-crank hopper with the feed mechanism as at first designed. One hundred and twenty pounds of 100 cubic inch calcium arsenate were loaded into the hopper, and the dusting plane was flown straight away at full speed above the cotton plants. The type of dust cloud being put out can be judged from Figures 15 and 16, which were taken during one of these test flights.

The average of these flights showed that it required 2 minutes and 15 seconds to empty the hopper each time, and during this time the plane flew 3.3 miles. In other words, it was operating at an average rate of ground speed of 88 miles per hour, and the 120 pounds contained in the hopper lasted over a strip 17,424 feet long.

The poundage per acre being delivered depends, of course, on the width of strip which can be considered as effectively treated. On the basis of the figures obtained on this flight, it would be necessary to take a strip only 50 feet wide with the plane to utilize the dust at an average rate of 6 pounds per acre, the rate at which calcium arsenate is usually applied in ordinary commercial dusting for boll-weevil control. Examinations made during these flights showed very plainly that an effective treatment was being obtained on a strip over 200 feet wide, but reducing this to 150 feet as the average width of the strip would mean that only 2 pounds of poison was being used per acre.

This rate of dust delivery was not considered sufficient for the maximum dust cloud desired, as, of course, every foot which could be added to the width of the strip at each trip by correspondingly increasing the dust delivery, would reduce the number of trips necessary to poison a field of cotton, and, consequently, add much to the acreage capacity of a plane.

The feeder opening of the same hopper was therefore enlarged to the maximum size which could be secured between the cross brace wires of the fuselage. This allowed an outlet about 9 inches square, and the paddle wheel was correspondingly enlarged to cover this entire opening. At the same time the gear ratio of the sprockets used for driving the paddle wheel was changed from 1 to 1 to 2 to 1, so that the paddle wheel was operated twice as fast as by a simple hand crank.

Throughout this work an effort was made to maintain about the same speed of cranking, and the majority of the tests were conducted at a rate of about 30 revolutions of the crank per minute. A few special studies were made to determine the effect of variations in the speed of cranking. Beyond a certain point the rate of dust delivery was not increased in proportion to an increase in the rate of paddle revolution, owing to the fact that after being speeded up beyond this point the paddle revolved so fast that the spaces between the blades did not have time to pick up a full load of dust, and when the paddle was operated at a very high speed the dust delivery was somewhat reduced by the fact that the blades tended to cut out a channel and the dust did not have time to drop between them.

As finally settled upon for use in the field applications, a full opening of the feeder valve with a hand crank operated at about 30 revolutions per minute emptied the hopper in approximately 2 miles, depending on the speed at which the plane was flown. In other words, it was necessary to take at each trip a strip of about 60 feet of cotton if the poundage of dust utilized per acre was not to exceed that distributed by the ground machines. Any additional width which could be taken of course constituted a reduction in the poundage per acre delivered.

These figures were obtained by straightaway flights with the feeder operating continuously from the start until the hopper was empty. When this hand-crank hopper was placed in service in actually dusting cotton fields, a serious difficulty developed, due to variations in the rate of flying speed of the plane as it crossed back and forth over the fields. In turning to enter a field the plane would be flying probably 100 feet or more in the air. It would be maneuvered into position and then would glide downward with a throttled motor into the edge of the field. It was often still descending for perhaps the first 100 feet after crossing the edge of the cotton, especially if any obstructions intervened along that margin of the field. The feeder would be opened and the crank started almost as soon as the plane passed the edge of the cotton. The dust would be blown out behind the plane for some distance, but often for about 150 feet after the plane entered the field it was still gliding downward, and thus traveling at a reduced ground speed. The result was that the dust being put out at the normal rate spread over a rather wide strip at the edge of the field. Then the motor was gradually speeded up as the pilot neared the elevation he desired, and when he reached this point he "gave her the gun" to maintain a safe flying speed at the low level across the field. This rapid increase in speed, with no change in the rate at which the dust was delivered, resulted in a very wide strip being treated at the edge of the field, the margins being pulled in rapidly to a much narrower strip across the center of the field, where the plane was traveling at full speed. Then, when the plane reached the far edge of the field, it zoomed upward quickly and blew back into the field the dust which was delivered as the feeder was being cut off. This practically reversed the conditions experienced while entering the field. The zooming not only decreased the ground speed of the plane but blew the dust downward and backward from a distance beyond the field.

An outline of the dust cloud produced by this trip across the field presented somewhat the shape of an hour glass, wide at both ends and narrowing rapidly to the middle. To avoid leaving untreated cotton with a dust cloud so shaped, it was necessary to take only narrow strips. This results in much overlapping of poisoning near the ends of the rows if the strips are spaced close enough to give a thorough application at the middle. The waste of poison is enormous.

Theoretically this overlapping could be compensated by varying the rate of cranking as the speed of the plane changes. This was attempted but proved impracticable, because it depends on the personal equation and the judgment of the human. When moving at the rate of from 75 to 90 miles an hour, as is the case in this dusting work, ground is being covered so rapidly that the slightest error in calculation on the part of the operator of the crank is tremendously magnified. Although attempted by several individuals it proved impossible to compensate accurately for the change of speed.

The need for a feeder which would perform this function automatically resulted in the construction of the air-suction hopper. In this device the dust is carried from the hopper by means of air suction, created by the stream of air flowing down through the hopper. Since this air is collected by a funnel pointing forward over the plane wing, its velocity is determined by the plane's speed, and the amount of suction created is thus in turn proportional to the speed of the plane.

To test this principle, a series of straightaway flights were made over a stretch of fields, with as much variation as possible in the speed of the plane. The same amount of dust (120 pounds) was loaded into the hopper for each flight and the flights were started at the same point. The time requirement for emptying the hopper was varied from 45 seconds to 2 minutes and 22 seconds. In every instance the hopper was emptied in the same distance, namely 5,470 feet. The ground speed therefore ranged from 31.2 to 90 miles an hour. The fact that the hopper discharge lasted exactly the same distance indicates that, in straightaway flights at least, the use of air suction for dust delivery provides an automatic compensation for variation in plane speed. These figures were of course made with the feeder valve wide open and the dust delivery at the heaviest rate provided in any of the experimental work. More erratic figures probably would be obtained on reduced deliveries, but this point was not tested. The records obtained indicate that to treat cotton at the rate of 6 pounds per acre it is necessary for the plane to cover a swath 160 feet wide, or if this figure is reduced to 2 pounds per acre it will be necessary to treat 480 feet at each trip.

These figures are very satisfactory for straightaway flights, but when short flights were made, with the plane operating back and forth over the field, somewhat different results were obtained. In fact, variation in the feed was noted to some extent in the straightaway flights. When first opened, with a full load of dust in the hopper, the feed was not very heavy, but as this dust quantity became reduced somewhat the feed increased until it quickly reached a maximum delivery, which was maintained throughout practically the remainder of the flight. In other words, the dust delivery was to a slight extent dependent on the amount in the hopper, even in straightaway flying. In flying back and forth over a field where the strips were rarely more than 600 to 700 feet long, this undesirable feature was more accentuated. Not only was the dust feed lighter when the hopper was full, but usually when the valve was thrown open it took a few seconds for the dust to reach its maximum delivery, and in those few seconds the plane traveled a considerable distance.

While these two hoppers were being tested and developed, the one which had been used in dusting the catalpa trees in Ohio arrived. This was immediately attached to a plane and tested in a few trial flights, but was found to be less suitable for cotton dusting than those which had already been constructed. The Dayton hopper had obviously been built to put out a large quantity of dust in a minimum time, without much regard to the regularity of delivery. When tried over a cotton field it was found that it at first fed rather slowly, and then, when perhaps one-fourth of the hopper's contents had been emptied out, it suddenly fed out the remainder in an enormous burst, providing a very inefficient distribution when regular field flights are attempted. Furthermore, hanging this hopper on the side of the plane made the plane slightly side-heavy for such low flying, and since the hopper presented square corners to the air current and was not stream-lined in the slightest, it caused an unequal drag on one side of the plane. This interfered with flying somewhat, and was especially undesirable in that the interference was not regular in making turns, depending on which way the plane was banking. Further work with this type of hopper was therefore abandoned.

DIRECTING PLANE OPERATION.

In operating a plane the pilot is forced to keep a keen lookout forward and has very little chance to judge whether all portions of the field are being thoroughly treated, while the hopper operator is unable to converse with the pilot when in flight and can not give any elaborate directions. Special arrangements were therefore made for directing the flight from the ground, and when actual field poisoning was in progress one or more men were always placed in the cotton field which was being treated, provided with white flags 3 feet square attached to handles about 6 feet long. A system of wigwag signals was then used, by means of which the men on the ground gave the pilots directions for each crossing, and specified the exact points at which the crossing should be made. This seemed the only expedient which could be employed in the preliminary work.

The method of directing the plane for effective dusting will always be one of the most difficult problems in any attempt to use the airplane in commercial work, especially since a slight error in the airplane flight means so much cotton field area improperly treated. This problem will require a considerable amount of experimentation before it will be solved satisfactorily. Probably the care and efficiency of the pilot will always be a very important factor in determining thoroughness of treatment.

LEAFWORM CONTROL OPERATIONS.

In the treatments of the cotton fields for leafworm control, those first infested received applications varying in amount, and the resultant leafworm mortality served as a basis for later plans, the width of swath varying widely, depending on the field being treated, elevations flown, air conditions, regularity of hopper operation, and other considerations. Some flights were made at a reduced feed, using deliberately narrow strips, while others were made at a higher feed, widening these strips as much as possible.

As a result of these studies and the observations on the leafworm control effected, it was found that by properly controlling the dust delivery it was possible to give effective treatment to strips varying from 25 to approximately 500 feet in width. Of course in the smaller fields, especially in those immediately adjoining obstructions, where definite direction of the dust was particularly desirable, the narrow strips were utilized, while in the larger fields, where it was desirable to take as much area at a time as possible, the feed was increased to take care of wide strips. These wide strips are possible only under favorable air conditions, and are especially suitable when the plants are moist. As the breeze increases later in the day and the plants become dry, the poisoning can be better controlled and the applications made more thorough and accurate by taking narrower strips at a reduced rate of dust delivery.

In all this field work it was almost the universal rule that excessive applications were made, as compared with the treatments desired in each instance, because in operating over practically every field it was necessary to repeat some flights to correct faulty dust delivery through the feeder. For instance, the feeder might choke for only a second or two about the middle of a field, and with the crude system of signaling available, it would often be necessary to have the pilot make one or more trips completely across this field to make sure of treating the area which had been skipped. In addition, owing to flimsy construction, it was impossible to shut off the feeder completely, and consequently there was great waste of material in banking through the turns outside the field.

For these reasons the figures which were obtained on poundage delivery should not be taken too seriously, though they are in a way rather striking. In using the standard calcium arsenate for leafworm control, following various methods, the poundage delivered to the different fields varied from slightly less than 2 pounds per acre to about 11 pounds per acre. After fairly standardized methods had been worked out, however, and had been checked by the amount required for leafworm control, it was found that from 2 to 4 pounds of calcium arsenate per acre was sufficient for the maximum effect. The results of these dosages so far as leafworm control was concerned, were quite equal to those obtained from the use of ordinary dusting machines applying the poison at the rate of 6 or 7 pounds per acre.

In every instance the effect of the application on the worm was very carefully watched, with respect to the mortality not only of the worms in the field at the time, but also of those which hatched later from the eggs then present. As with any form of dusting apparatus, it was difficult to control infestation when the plants had been rather thoroughly skeletonized before treatment and provided very little leaf surface on which the poison could adhere. On the other hand, the control which resulted from airplane dusting on such fields was fully equal to that which followed the use of the most efficient hand guns or wheel traction machines, ordinarily used for boll-weevil dusting. Under conditions more favorable for control, where the worm infestation had not progressed quite so far, the results were of course much more satisfactory.

It was quite noticeable, however, that the distribution of the material in the path of the plane was not absolutely uniform throughout the width of the strip. In several instances a single application was made in a fairly heavily infested field containing many eggs which hatched later and were then allowed to develop without further treatment. Perfect control was always obtained in a strip from 25 to 50 feet wide directly under the plane, but beyond this strip the dosage of poison was somewhat lighter and more of the worms hatching from the eggs managed to survive, so that the fields treated in this manner with very wide swaths presented alternating strips thoroughly and partially controlled. On the other hand, sufficient control was exerted to prevent really serious commercial damage to any of the cotton, and where two applications were made in such fields, practically complete control was secured.

This experience was compared with the work which was being done at the same time on other properties in controlling the leafworm with calcium arsenate with different types of ground machines, and it was found that to control this unusually heavy infestation two applications of calcium arsenate were usually necessary. As nearly as could be determined, about 2 pounds of calcium arsenate per acre delivered from the airplane proved as effective as 5 pounds per acre delivered from a ground machine. Of course the effectiveness of this application was measured only by leafworm control, and is by no means settled as regards the boll weevil.

TESTS OF VARIOUS INSECTICIDES.

DIFFERENT CALCIUM ARSENATES.

To contrast with the results secured from calcium arsenate of the usual type a number of other varieties were utilized. By a slight variation in manufacturing methods, calcium arsenate can be produced with practically the same chemical analysis, but with a great range in the physical characteristics. For example, its volume may range from 40 to 250 cubic inches to the pound, and the material ordinarily found on the market varies from 60 to 150 cubic inches to the pound. This difference is largely due to difference in the size of particles.

To determine the behavior of these different dusts in the air, flights were made with a product testing about 60 and another about 135 cubic inches to the pound. The heavier material (60 cubic inches) did not behave very well in the air and dropped nearly directly to the ground from the plane, not being as subject to the influence of the slip stream as the standard material (90 cubic inches). The light material behaved very differently. It had been feared that it was so exceedingly light that when released in the air it would float away and never reach the plants, but it proved to be subject to the influence of the slip stream and made a beautifully controlled cloud. Unfortunately it was not possible to make determinations of adhesion of this material, but as far as visual observation was possible it seemed to work fully as well as the standard material.

LEAD ARSENATE.

A few tests were made with arsenate of lead. The material used had a volume of about 80 cubic inches to the pound, which was fairly close to that of the standard calcium arsenate, but the physical characteristics of the particles were rather radically different. The lead arsenate proved to be only a fair dusting material. It was not as satisfactory as either the standard or the light calcium arsenates used, so far as could be judged from the dust cloud formed. Two cuts of cotton on Shirley were treated solely with lead arsenate for comparison with calcium arsenate in leafworm control, and the mortality resulting was hardly as satisfactory as that from similar applications of calcium arsenate. This was probably to be expected, as lead arsenate is usually less toxic to the worm than calcium arsenate.

PARIS GREEN.

Other tests were made with Paris green. This material differs greatly from either of the arsenates tested, being only 33 cubic inches to the pound and possessing almost no adhesion between particles. This material flowed so readily through openings that the valves which had been constructed for using calcium arsenate allowed the Paris green to leak through even when completely closed. This was corrected as well as possible by packing. It was found at the outset that even the slightest opening of the valve gave such a heavy delivery of the Paris green that an excessive dosage resulted. In fact, in the first trips made the material poured out at a rapid rate and was whipped directly to the ground without spreading over any appreciable width. Paris green, if used unadulterated and at a heavy dosage, is injurious to the cotton plants because of the free arsenic present, and the day following the flights which had been made with straight Paris green it was noted that wherever the plane had passed over the cotton there was a row of plants perhaps 10 feet wide directly under the plane which had been almost completely burned up by the poison. This row was very definitely marked and illustrated the lack of spread of the material.

Following this experience the Paris green was mixed in varying proportions with air-slaked lime, and the following were the characteristics of the mixtures tested:

Parts Paris green.	Parts lime.	Cubic inches per pound.
1	1	54
1	3	63
1	5	66

These three materials were then tested from a plane and behaved considerably better than the straight Paris green, as far as delivery from the plane and spread in the air are concerned. Still they were not satisfactory. The lime flowed too fast through the valves and when blown into the air seemed to separate from the Paris green. A very peculiar condition resulted. The Paris green was blown down over a strip of plants more or less directly under the plane, while the lime did not usually reach the same plants so heavily but spread through the cotton at some distance from the line of flight of the plane.

As these difficulties were evidently due entirely to lack of adhesion of the materials, still another preparation was made. This included one part Paris green, one-half part lime, and five parts white flour. This combination worked very satisfactorily in the plane and spread through the cotton and adhered to the plants very well. The adhesive qualities provided by the flour seemed to hold the material together fairly well in the air.

So far as worm control is concerned, the effect of the Paris green was much more pronounced than that of any other chemical used. In every instance practically complete control was secured immediately after such applications, and it was thus shown that probably the instances of partial control with either calcium arsenate or lead arsenate were due to the lower toxicity of these materials rather than to faulty distribution. In ordinary field leafworm control work, a mixture of about 5 to 10 parts of lime to 1 of Paris green is always used, and is distributed at the rate of from 2 to 5 pounds per acre. In the airplane work with the flour mixture, the Paris green was used at the rate of approximately 1½ pounds per acre, and practically complete worm control was found in every field treated.

OBSERVATIONS ON BOLL WEEVIL CONTROL.

Only casual observation was made on the effect of these poisons on the cotton boll weevil. Neither of these properties had been poisoned for boll weevil control during the season, and weevils were exceedingly abundant on both. For fully two weeks before the first airplane poisoning was done the weevils had so thoroughly infested both plantations that not a cotton bloom was visible. This condition persisted during the beginning of the experiments, but by the time the fields on the two properties had nearly all received one or two applications of calcium arsenate for leafworm control, it was suddenly noted that cotton squares not infested with boll weevils were becoming fairly common, and by the end of the experimental period both plantations were blooming rather freely wherever the poisoning had been done.

This can not be positively accredited to the dusting, since it frequently happens that when the weevils have very heavily infested a field for a few weeks they leave this field in search of new food and give it a period of rest, during which a few blooms may struggle through to opening. Considerable weevil control had certainly been accomplished, however, since the blooming on these properties was much more pronounced than on others adjoining, where no applications had been made. Furthermore, this late blooming did not appear on the few fields which had never developed sufficient leafworm infestation to require poisoning.

GENERAL CONSIDERATIONS OF AIRPLANE DUSTING.

The foregoing pages have been devoted to description of the test work. Positive data on the economics of airplane dusting are not available, but some incidental observations bearing on this phase of the problem were made, and the following pages indicate some of the problems now to be solved.

ACREAGE DUSTED PER HOUR.

The number of acres that can be dusted in an hour by means of planes is rather a complicated question, and the information obtained is only suggestive. As the hoppers used held only about 125 pounds of poison, frequent landings were necessary. The treatment of small areas at a time further restricted the speed. Generally speaking, in the work on these two properties, the plane spent from 6 to 12 minutes in the air at each flight. Much of this time was spent in maneuvering, and a certain amount in going to and from the landing field. To avoid loss of time, provisions were made for loading the hopper fairly quickly when the planes landed, but this operation could be greatly expedited by more elaborate loading equipment. Counting both flying and ground time, the airplanes averaged 6 or 7 flights an hour, emptying a hopper of dust during each flight. At least 240 acres were being treated per hour.

Other records based on straightaway flights, with more definite efforts for acquiring speed in operation, usually showed between 400 and 500 acres dusted per hour. Since only a small portion of this time is spent in actually delivering the dust, and much is consumed in going back and forth for new loads, undoubtedly the acreage capacity of a plane can be greatly increased with larger hoppers constructed to hold approximately the maximum carrying capacity of the plane.

ADVANTAGE OF AIRPLANES AFTER RAINFALL.

Airplanes are not in the slightest dependent on ground conditions, so long as the landing field is solid enough to permit landing and taking off, and with a sodded field reasonably well drained this is possible almost any time. An interesting illustration of this fact developed during the work. The leafworm infestation became heavy about August 25 in many fields on both plantations, and on the 25th and 26th all infested fields were carefully treated. Just as the planes were returning from the last flight on the afternoon of the 26th a heavy storm came up and it rained about 3 inches in the next hour. This caused all of the poison which had just been distributed over the cotton fields to be washed from the plants. The worms eat at a tremendously rapid rate and a delay of 24 hours in poisoning them frequently results in the fields being stripped of foliage. The next morning the worms were working actively and the fields were so muddy that it would have been impossible to operate any ground dusting machines. The landing field was dry enough for airplane operation, however, and both planes were put into service to catch up with the infestation. In less than one hour all acreage requiring poisoning had been treated and the crops were thus again protected from damage. For instance, on Hermione plantation 111 acres needed poisoning very badly. These were treated between 11.23 a. m. and 12.09 p. m., or in a period of 46 minutes, using 549 pounds of calcium arsenate on the area, or an average of 4.9 pounds per acre. This was a rather heavy dosage, but the applications were made practically at midday, and the wind velocity was rather high, so that it was deemed desirable to use an extra quantity in the emergency.

SUITABILITY OF TERRAIN.

The contour and environment of cotton fields are particularly important in low flying such as is required for cotton dusting, and will really determine the safety of the fields for airplane operation. At the same time, many obstructions to low flying can be eliminated with comparative ease. For instance, snags can usually be removed with little trouble. Again, if cotton were planted with a view to airplane dusting, the fields could easily be arranged in continuous tiers most convenient for the operation of the plane in long, straight flights.

Of course there are many hilly sections of the Cotton Belt in which it would be too dangerous to use the planes as a regular operation, but throughout the flat country, such as the Mississippi Delta, or large areas in Texas, the conditions are ideal for flying. The ground is perfectly level and meadows provide landing fields on every property. Commercial use of the planes could never be developed if the flying should prove unduly dangerous to the pilots, but under the conditions prevailing in these districts low flying is not seriously dangerous. Forced landings can be made at any point, and even though the motor should be cut off while flying over the fields, if sufficient speed were maintained to bring the plane to a level, it could be landed in the corn or cotton with very little danger to the pilot, although of course some damage would be done to the plane.

Yet the conditions around Tallulah are not abnormally favorable for airplane dusting. The Parish of Madison, in which Tallulah is located, is probably from 15 to 20 per cent cleared. Swamp lakes occur throughout the Parish. These have heavily timbered margins, the woods usually extending for some distance around them, since it is impossible to drain the land for cultivation anywhere near them. The cultivated fields therefore, follow the contour of the land rather than being consolidated in cleared areas.

As such conditions are not the most favorable for airplane operation, a few tests under more favorable flying conditions were made at Scott, Miss., where the planes were kept for two days, and used in special tests of straightaway flights. Scott is in Bolivar County, which is one of the most important cotton-producing counties in the United States. The county has been rather thoroughly drained by large drainage projects and this has rendered possible an extreme consolidation of cleared area. A deliberate effort has been made to clear up the small timbered areas and throw the open fields together as a means of reducing weevil damage.

The newly cleared fields about Scott presented a particularly interesting condition. Following the drainage, which at many points was provided only a few years ago, large areas on a few plantations have been very recently cleared and put into cultivation. Timber is so heavy in this territory that it is not financially practicable to clear the stumps from the field and they must be left to rot out. Many of the plantations in this district have large areas of such so-called "new ground," where cotton is planted in a very heavy stand of stumps from 4 to 5 feet high. The majority of the plantations are now poisoning for weevil control by means of the ordinary ground dusting machines, and these stumpy fields present a very serious obstacle. In the first place the stumps provide hibernation quarters for the weevil, and thus the fields receive an unusually heavy infestation in the early spring, requiring more poisoning than the older fields farther out in the open. On the other hand, if weevil control can be effected, these fields are the most profitable for cotton because of their greater fertility, and consequent higher potential yield. In using ground dusting machines it is a serious problem to take care of any considerable acreage of this sort, because the larger machines can not be operated under such conditions, owing especially to the necessity of night poisoning, and they would be broken up by striking the stumps.

These stumps, of course, presented not the slighest obstacle for the airplane, except to provide an element of danger if forced landings should be necessary, and with the planes it was possible to produce a much more thorough application than has ever been accomplished in ground work. The plane, operating above the stumps, is not required to dodge them, and consequently can thoroughly dust every cotton plant.

The possibilities of straightaway flying and the acreage capacity of a plane were found to be much greater in the territory around Scott than Tallulah. In the large cleared areas in continuous cotton it was found that strips from 1 to 6 or 8 miles long could be treated in a straightaway flight, reducing the loss of time in turning which is unavoidable in working small individual fields.

Only a few records were obtained under such conditions, but certainly the plane capacity can be increased beyond that indicated for the Tallulah neighborhood, and it seems quite possible, judging from the present fragmentary figures, that with a hopper designed for the maximum carrying capacity of the plane, a single plane can treat as much as from 700 to 1,000 acres in an hour. With such capacity, of course, the area which could be allotted to a plane for each season's work could be greatly increased. Much more definite data must be obtained, however, before any really accurate figures can be provided on the subject.

CONTROL OF DUST SPREAD.

At the beginning it was considered possible that the use of the plane might result in indiscriminate poisoning of every object on the property, including the cabins and everything in them, but as the work progressed it became apparent that no more promiscuous dusting of surroundings was done with the planes than with ground machines as ordinarily operated. It is true that cabins frequently were subjected to a cloud of dust, but this is equally true in the case of ground machines, and the latter have been used for several years without any apparent damage or danger. The poison, except where it is being delivered directly on the cotton plant, is so thinly distributed that the portion drifting to any other point does not settle in injurious quantities.

Many have feared danger from poisoning cotton fields adjoining meadows or corn, the produce from which is to be fed to stock. However, poisoning under such conditions has been done innumerable times for a number of years with ground machines, which permit fully as much drift of poison as the planes, and not the slightest evidence of danger has ever been noted. Considered from this viewpoint there is no apparent reason why airplane dusting should be any more dangerous than the ordinary operation.

SUGGESTIONS FOR FUTURE INVESTIGATIONS.

Before any attempt at commercial airplane dusting can be made various other problems must be considered. For example, the design of the plane should permit a hopper of the maximum carrying capacity. The most efficient dust delivery must be determined. Possibly this will not be through the bottom of the fuselage. As the velocity of the slip stream varies widely at different points around the plane, the propeller effect should be thoroughly charted and the most efficient point of delivery of the dust located. At a point as far forward as the observer's cockpit, where the dust is being delivered, the air stream from the propeller is a comparatively few feet in diameter, so that when the dust is dropped into it, this dust has only a short distance to fall before it reaches quiet air. If this distance could be increased, the effect of the air on the powder would be greater, and probably more of the pellets of material adhering together could be broken up into individual particles. It might be possible to accomplish this by the use of conduits which would deliver the dust into the air at a point near the tail of the plane, where the diameter of the stream is greater. Such questions can be answered only by experiment.

Possibly the exhaust from either one or both banks of cylinders could be piped through a conduit which would not give back pressure on the motor and which would still connect with the dust outlet to break up and dry out the dust. A more efficient spread might be secured by using a bifurcated device, delivering the dust on both sides of the fuselage; or stream-line conduits might be arranged along the trailing edges of the wings to carry the dust for delivery either at the wing tips or at intervals on the wings. All such work would require careful designing and the cooperation of skilled airplane engineers who could appreciate and measure the hazards involved.

The type of plane most desirable for dusting is still to be determined. One important item will be to increase, just as much as is safe, the dust load which can be carried at any time by the plane, in order to increase flying time and decrease ground time and thus correspondingly increase the acreage allotment of a plane. In the experiments conducted the pilot was concerned only with flying the plane, and the dust was delivered entirely by the hopper operator, who rode in the observer's cockpit. Equipment could be arranged, however, so that it would not be nesessary to carry this hopper operator, and poison could be substituted for his weight. Automatically operated hoppers can be easily developed with a very simple control beside the pilot, and he could start and stop the flow of poison whenever desired. The pilot is in a better position to do this than the observer, because he is better protected from the blast of the propeller, and as his view is not obstructed by the lower wings he has a better view of the fields. The development of special dusts for airplane work depends entirely on the perfecting of a regular delivery. If it were found possible to deliver dust uniformly and under thorough control with comparatively light doses, the ideal poison would be a highly concentrated form, which might be slightly more expensive per pound than any other, but would more than compensate for this by the greater acreage handled by a single charge and a single flight of the plane. On the other hand, if it does not prove possible to perfect dust delivery to this degree, and irregular clouds must be used, thus requiring more or less overlapping, the development of the dust would naturally tend toward a diluted form which would be comparatively inexpensive and could be used at a higher poundage per acre and to make sure of absolutely complete covering of all spots.

CHARACTERISTICS OF AIRPLANES USED.

The dusting planes used in these tests were those commonly termed the "Curtis H," or, more properly, Curtis JN6H. They are commonly used for training observers and will safely carry about 350 pounds besides the pilot. This probably means that the maximum dust capacity of one of these planes, with the hopper constructed in the plane, would not exceed 250 pounds. These planes had the Hispano, 150-horsepower, 8-cylinder, V-type motor. The ordinary number of revolutions per minute at flying speed is about 1,400 with the heavy propeller, while it is about 1,500 with the lighter propeller, commonly known as the "toothpick." The minimum safe ground speed of this plane is about 50 miles an hour, and its maximum speed depends of course on the wind direction and velocity, but is at best little over 90 miles an hour.

This plane has a main tank capacity of 21 to 22 gallons of gasoline, with an emergency tank holding 7 gallons. Normal consumption usually approximates 10 gallons an hour, so that the safe flying time on one filling is not more than 2 hours in the air, and when frequent landings are necessary, the small amount which would be saved while filling the hopper is compensated for by the extra gas used for taking off. Gassing and oiling the plane will require about 15 minutes, and in figuring on the operation of the plane this time should be allowed after every 2 hours. The motor holds 16 quarts of oil and will require about 6 quarts per hour of operation. All oil must be drained from the motor every 5 flying hours and replaced. The gasoline used should be special aviation gasoline, testing from 68 to 74, and the oil should be a special quality of extra heavy oil. Both of these items are thus more expensive than for ordinary motors.

In commercial operation, the length of life of a plane will be a very important item. The following figures are probably fair averages. The life of the plane itself will be about 200 flying hours, at the end of which time it must be overhauled. This overhauling will possibly add 150 flying hours to its life. These planes deteriorate in storage, and their period of life would probably not vary greatly, whether or not they were subjected to maximum use. The motor life depends largely on the human element, but the average time will be about 80 to 100 hours. It must be then completely overhauled, and at the end of two overhaulings practically a new motor has been constructed; thus a total motor life in a plane will be from 240 to 300 hours. Such flying as is done in dusting is unusually hard on the motor. It is necessary for the pilot to maintain an excessive speed for safety at the low altitude, and in addition the air temperature is so high near the ground that the motor heats more rapidly than when flying higher.

Another type of plane available for study was the "De Haviland 4B," or, as it is commonly nicknamed, the "D. H." This plane is equipped with a 420-horsepower Liberty motor, a 12-cylinder V-type, with the speed of the propellor ordinarily ranging from 1,480 to 1,550 R. P. M. The main gasoline tank holds 78 gallons and the emergency tank holds 9. The gasoline consumed is from about 20 to 25 gallons an hour, so that such a plane would have a dusting time of about 3½ hours on a single filling. The motor holds about 8 gallons of oil and consumes practically 2 gallons per hour, and it also should be drained after every 5 hours of flying time and new oil added. The minimum safe ground speed of the D. H. plane is about 65 miles, and the maximum speed is about 120 miles per hour. The greater power and lift of this plane makes it possible to climb much more rapidly, and thus it could more easily avoid obstructions than the Curtis. On the other hand in some flying its much larger size might prove a handicap. One decided advantage it would possess is the fact that it has a carrying capacity of between 500 and 700 pounds, which would permit a much longer time in the air for dusting from each filling of the hopper.

These two types of planes are the only ones studied. Other models should by all means be considered, since both of these were developed several years ago and the more recent models probably have more desirable characteristics for this type of flying.

COST OF OPERATION.

A few calculations relating to costs of operation are presented for what they are worth.

Each plane should have one or more pilots and two mechanics. In fact, since a plane would find favorable flying conditions about 7 or 8 hours a day, and it would be difficult for a pilot to stand more than 4 hours of such flying each day, the most economical arrangement might be to provide two pilots for each plane. These pilots would cost at least $300 a month each, and the mechanics would cost $150 a month each.

In the following computations a day's work of one pilot and a plane has been figured at 4 hours. The pilot would probably fly about 5 days a week, and in cotton dusting would have about 6 weeks to fly, or a total of 120 flying hours yearly on this particular assignment. It would of course be necessary to pay his salary for the entire year. At $3,600 a year, this would make a charge of $30 per flying hour for the pilot. One mechanic would be charged to each pilot, and a three months' flying period only charged, because this mechanic could always be used on other duties the remainder of the year. Consequently, the charge is $450 for each season, or $3.75 per hour for each plane.

Summarizing these figures, we have the following costs for a 4-hour day operation of a Curtis plane:

Pilot	$120
Mechanic	15
40 gallons of gasoline at 25 cents	10
8 gallons of oil at $1	8
Total	153

These figures would probably be reduced considerably if the operation were placed on a commercial basis, but they compare very favorably with ordinary dusting machine figures. The figures available indicate that one plane operating 4 hours a day would take care of as much area for the season as at least 40 cart dusting machines, which have the greatest acreage capacity of any machines now used in cotton dusting. To operate these dusting machines of course requires considerable supervision, and a number of special expenses, such as fuel for lights, etc., but, considering only the value of man labor and mules alone, it would cost $236 a night to operate these machines. On this basis considerable economy in favor of the plane would be indicated. The cost of the plane and its upkeep in repairs would apparently figure no more than the original cost plus upkeep of the dusting machines which it would replace. Consequently, it seems possible that the cost of equipment, if each is allowed full acreage, would be about the same as for ground dusting machines, and the operating expenses would be lighter with the airplanes than with the ground machines. Furthermore, all work which has been conducted seems to indicate that the poison required per acre can be greatly reduced with a plane as compared with the ground machines, and this would be a very important item, since the cost of poison is by far the heaviest expenditure involved in dusting cotton.

CONCLUSIONS.

The studies which have been described are far from deciding on the practicability of using the airplane for applying insecticides, but they have shown that the dust can be blown down among the plants from the air above them and that this dust can be made to adhere to the plants under daytime conditions when plane operation is feasible. The planes can be manipulated so that all portions of the field are treated. In fact, the cotton leafworm was controlled with a poison allowance considerably below that necessary when using ordinary dusting machines. Whether this application was sufficiently thorough to control the boll weevil is quite another question, since weevil control requires a much more thorough application than is necessary to control the leafworm, but all records bearing on this question appear to furnish decidedly favorable indications of success.

Financially the use of the airplane does not seem to be out of the question, and in fact there is considerable possibility of pronounced economy as compared with the ground machines. It has the advantage of centralizing the control of the operation and placing it on a more skilled basis, which would undoubtedly greatly tend to increase the quality of the results secured. On the other hand, no farmer can afford to buy a single plane and figure on dusting his cotton, since it is not safe to place all of the eggs in one basket in this manner. Motors will go wrong, and cotton poisoning is an operation which can not be delayed when needed. The operation could be only considered as a community affair or for planters whose acreage would be large enough to justify purchasing more than one plane. In reality, to organize in safety, one plane should be provided in reserve for every one or two which are kept in flight.

All of these are questions which can be worked out only by time and trial, but many districts in the South have now reached the point in public sentiment where the desirability of community weevil control can be seen, and it is only by some such method as the use of the airplane that such community poisoning can be attempted in the near future.

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