Selecting Efficient Equipment

Air Applicator Institute

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SELECTING EFFICIENT EQUIPMENT

Air Applicator INFORMATION SERIES Vol. 4
This volume describes the various components in a sprayer, duster, seeder or fertilizer airplane, and their functions. Emphasis is placed upon the factors which are most important in equipment design. Illustrations are provided of many commercially available units. Beginning with the essential components, the volume finishes with a discussion of airplane types most suitable for agricultural use.

The Air-Applicator Institute wishes to recognize and is grateful to the following equipment and agricultural engineers who so generously contributed illustrations and information for this volume: Arthur Gieser, R. B. Gray, Orve K. Hedden, D. A. Isler, F. L. Timmons and Dr. L. M. Stahler, U. S. Department of Agriculture; Norman B. Akesson, W. A. Harvey, O. C. French, University of California, College of Agriculture; J. A. McClintock, University of Indiana; K. P. Buckholtz, G. F. Warren, University of Wisconsin, School of Agriculture; A. W. A. Brown, University of Western Ontario; Robert L. Warden, James L. Krall, V. C. Hubbard, Montana State College; Fred E. Weick, Texas A & M; Lambert C. Erickson, C. I. Seely, Eugene W. Whitman, University of Ohio; Wayne B. Fisher, Author; Art Whitaker, Equipment manufacturer; W. A. Westgate, Equipment distributor; United States Department of Agriculture; Civil Aeronautics Administration; U. S. Public Health Service; American Association of Economic Entomologists; Monsanto Chemical Company; Piper Aircraft Company; Mississippi Valley Aircraft Service; Svedy-Sorenson Aircraft Incorporated; United Helicopters Incorporated; Bell Aircraft Corporation; Barrie Aeronautical Corporation; Ong Aircraft Corporation; Monarch Manufacturing Works Incorporated; Yakima Aero Service; Aero Sprayer Company; Yingling Aircraft Incorporated; Columbia Exporters.
PART ONE

ESSENTIAL COMPONENTS

Airplanes may be required to spread dusts with cohesive and inflammable properties; suspensions which are abrasive and corrosive; emulsions with colloidal characteristics; solutions that may contain chemicals capable of corroding or decomposing equipment and baits that are dry, moist or sticky. This places broad demands on the designers of equipment and the materials which go into the construction of dusting and spraying equipment.

A considerable amount of knowledge relative to hydraulics is necessary to properly design and build an airplane spray outfit. This involves a knowledge of agitators, pressure regulators, pump pressures and capacities, volume and deposit rates of various types and sizes of nozzles. Much of this knowledge has been developed by individual pioneering operators. They are to be commended for their contributions to the present pool of knowledge, much of which was learned through the expensive trial and error method.

Ready Made Equipment

If you are just getting started in the business of air-application you may save considerable time and money by NOT trying to design and build your own equipment. Experimentation is expensive. The plumbing that goes into a sprayer outfit has a lot of technical aspects. Unless you know hydraulics, including the laws of pressure, volume and flow, you can waste a lot of good time and money doing original work and experimentation that has already been done by others.

First, become familiar with what has already been done. Part three of this volume presents equipment already designed and tested by the U. S. Department of Agriculture, the armed forces, private operators, and commercial concerns. Write to the manufacturers for full specifications and exhaust these possibilities for ready made equipment before investing your own time and money on experiment. Fig. 22 shows one of several well designed agricultural airplanes. This advice does not mean that better equipment is not needed or that present equipment cannot be improved. Get started then embark on experiment and improvement of your equipment and the development of new ideas. The following pages describe the components necessary in a well designed sprayer or duster. Be sure you understand the need for and the function of each component.

Exact knowledge of pressure, nozzle sizes and rate of deposit relationship is absolutely essential in the selection or design of equipment.
Throughout this volume are illustrations of some of the manufactured equipment now available. Inclusion of these illustrations does not constitute a recommendation nor does it infer that these are the best pieces of equipment. There is other manufactured equipment which may be equally efficient but whose illustrations were not available for this edition of the Air-Applicator Series.

**Aircraft to Fit Job**

No single aircraft can be designed to do all types of air-application. In selecting the most practicable and efficient type of aircraft consideration must be given to the following factors:

1. Elevation and type of terrain to be flown.
2. Ability of the aircraft to take-off and land on a strip of minimum length.
3. A high ratio of payload to total weight.
4. Ease with which the airplane can be modified for installation of spray tanks or dust hoppers.
5. Average size of fields to be treated.
6. Average distance of crops area from landing strips.
7. Size and kind of loads to be carried.
8. Type of crop to be treated.
9. Characteristics of the chemical, seed or fertilizer carried.
10. Characteristics of the pests to be treated.

**Components of a Spray Unit**

A unit flexible enough for several types of spraying must have many built in features. A good well-designed spray unit built for use with present type airplanes ought to possess among other things, these basic features:

1. Light planes such as the Piper with a 60 M.P.H. ground speed — the ability to deliver 1 to 5 gallons per acre. This means $4\frac{1}{2}$ to 25 gallons per minute.
2. Heavier planes such as the Stearman N3N — the ability to deliver from 9 to 45 gallons per acre.
3. Quick and positive opening and shut-off valves.
4. An agitation system which will efficiently agitate the entire area of the tank.
SPRAYER COMPONENTS

5. A pressure regulator and bypass system adjustable from the pilots position.
6. A pressure pump capable of permitting wettable powders.
7. A pressure gauge.
8. A tank gauge.
9. A mechanical brake if the pump is propelled by a fan or propeller.
10. Tank and boom drain valve.
11. Screens on both the intake and pressure sides of the pump.
12. A well baffled tank with large filler caps.

Insist on these basic features when purchasing spray unit assemblies or when having an airplane converted. Each of these topics is discussed fully elsewhere in this volume. Care should be exercised in the selection of equipment to allow for quick and easy conversions, replacement, repairs and cleaning. It will be money saved in the long run to analyze your needs well and explore the available units before making final decisions. (See Volume No. Six of the Air-Applicator Information Series for a classified directory of equipment suppliers.) This discussion of components will begin with the tank and progress in the order that the liquid flows through the various parts of the installation ending with the nozzle.

SPRAY TANK

The gross weight at which the airplane can be certificated will limit the size of the spray tank. Spray tanks must be strong enough to resist the stresses of their contents and vibration. Aluminum and stainless steel have been used effectively. The gauge material used will depend upon size, baffle supporting and mounting in the airplane. Some chemicals require plastic lined tanks and booms to prevent corrosion. Consideration then must be given to the types of chemicals intended for the equipment. Notice in Fig. 1 the sump arrangement and the excellent welded seams.

THE TANK FILLER CAP should be at least 3 or 4 inches in diameter to facilitate quick loading from tank truck equipment. A large removable top should be pro-

Fig. 1. Courtesy Dakota Aviation Co. Side view of 40 gallon tank showing sump arrangement.
Fig. 2. Courtesy Dakota Aviation Co.

Note outside strainer attached to pump. Also the manner in which the pump is clamped to landing gear and the single hole cut in the fuselage, which is readily covered with an inspection plate when the spray system is removed from the plane. Note also the convenient outside filler cap in the spray tank.

- A DUMP VALVE for emergency jettisoning of the load should be a part of the tank construction. Rapid dump valves are obtainable from manufacturers. The control must be within easy reach of the pilot. Elimination of the load is a distinct advantage in making a safe forced landing.

- BAFFLING spaced 8 to 10 inches apart is essential to strong tank construction. The baffles should be riveted then sealed by welding to the skin. They are needed also to prevent load shifting with the changes in the plane's attitude. See Figures 3 and 4.

- THE AGITATOR is an integral part of the tank unless hydraulic agitation is planned. Provisions for it ought to be carefully planned before the tank is constructed. See Volume 3 for discussion of formulations needing agitation. In case it is intended to use the overflow bypass from the pump for agitation, it will be necessary to plan the inlet fitting for the bypass line.

Provision for a good contents gauge is also a part of the tank construction. The gauge should be an accurate one and readily visible to the pilot. It will be relied upon both by the pilot to see when he is running low on spray and by the ground crew in filling the tank.

Fig. 3. Courtesy Dakota Aviation Co.
SPRAYER COMPONENTS

TO COMPUTE THE CAPACITY OF SPRAYER TANKS: The capacity of tanks in gallons can be calculated as follows:

Cylindrical tanks (circular cross section): Multiply length in inches by square of diameter in inches, multiply the product by 0.0034.

Tanks with elliptical cross section: Multiply length in inches by short diameter in inches by long diameter in inches; multiply the product by 0.0034.

Rectangular tanks (square or oblong cross section): Multiply length by width by depth, all in inches; multiply product by 0.004329.

AGITATION

A system to be used for straight oil sprays alone does not require an agitator, but for all mixed sprays, agitators are necessary. With oil emulsions and heavy suspensions, the agitator must be kept running constantly. With 2,4-D sprays, only light agitation is needed.

Two types of agitators are commonly used, the mechanical and the hydraulic. The mechanical agitator is more efficient and generally appears to give best results. This system consists of a series of paddles mounted on a shaft which runs through the spray tank. It is driven by a chain and sprocket reduction drive or gears from the pump.

The ends of the paddle blades should have a total width approximately equal to one half the length of the tank, and their length should be sufficient to sweep within 1/2 inch of the bottom. For example, four blades, each 8 inches wide, would be used in a tank 60 inches long. The blade peripheral speed should be between 300 and 400 feet per minute, or 95 to 128 r.p.m. for a 12-inch blade in a 3 foot diameter, 250 gallon tank.

The same length blade in a deeper tank should be operated at a higher speed. The power requirement to drive the agitator increases with the height of the liquid above the paddles. For the example given above, 1/4 to 1/2 h.p. is required. If a flat-bottom tank is used,
the r.p.m. of agitator must be increased 20 percent; and the power required will be increased 50 per cent. Obstructions in the sprayer tank such as pipes, braces and filler screens tend to produce quiet spots and to reduce the effectiveness of agitation.

The agitation equipment should be of such design that it will agitate the fluid in each baffled compartment. This is one of the weak features of the hydraulic by-pass method of agitation which is less likely to provide thorough agitation throughout the tank.

For driving agitators or pumps four bladed wooden propellers are more reliable than the metal fans of automobile type used frequently. Often the metal blades are shed causing damage to gas tanks or fabric.

_Hydraulic_ agitation requires no moving parts in the spray tank, and is readily installed. A centrifugal pump is generally used with this system because of the high discharge volume needed. The excess flow at boom pressure is recirculated to the spray tank and forced out through many small openings in a 1 or 2-inch pipe laid in the tank bottom. The holes may be fitted with nozzles, if desired, which provide replaceable wearing surfaces. This method of agitation is satisfactory if sufficient recirculation is used. The discharge from the jets should not strike the walls or bottom of the tank through less than 1 foot of liquid. If it does, the continuous action of the liquid, especially of one containing abrasives, will remove the lining and, in time, may wear out the tank.

No accurate data are available as to the amount of hydraulic agitation flow required for various spray mixes and tank shapes. However, experience indicates that approximately 30 r.p.m. at 100 p.s.i. should be provided for a 3-foot diameter, round bottom, 250 gallon tank. Flat-bottom tanks should have 30 to 40 per cent more agitation. Power requirement ranges from 3 to 4 h.p. for a tank of these dimensions. Airplane tanks can be proportioned accordingly.

Agitator propellers should be controlled so the pilot can turn agitators off during the turn around and while ferrying. This prevents the materials from packing within the hopper and reduces wear on these parts. One agitator is always needed at the throat of the hopper to provide a continuous uniform flow to the outlet. If sticky or sluggish materials are to be used one or more agitators are necessary for the top of the hopper. A 48 to 1 gear ratio is practical for most agitator drive requirements.

Agitators are made for many types of commercial mixing machines in canning and food processing and for laboratories. A number of stock parts can be utilized in agitator construction such as shafts, paddles, bearings and fittings. See Volume Six of this series for a list of Suppliers of Agitators.
Numerous spray pumps are now available, but they may be classified into four major groups. The large-capacity ground rig sprayers are generally equipped with ordinary piston-type pumps and are used for large-scale operation, especially where the water supply is abundant and high-volume application is made at pressures of 100 p.s.i. or greater. See Fig. 5 for one type of pump and mounting.

Paddle pumps, rubber or fibre blades rotating on a shaft inside a metal housing are satisfactory for certain types of herbicidal applications. They operate best at the lower pressures and generally cannot be used to apply the solvent type of oil sprays. Some sprayers have been built which use various types of centrifugal pumps and have given good service. Such pumps, however, are somewhat more expensive than paddle or gear pumps. This cost differential is offset by the longer life of the centrifugal pumps.

Pumps in aircraft sprayer installations, particularly in weed control are usually of the low pressure type. Every manufacturer has his own special type. For a list of pump manufacturers see Volume Six of this series. Pumps must be selected for the particular material to be sprayed. Pumps of the centrifugal type permit the use of suspensions and emulsions as well as the use of solutions. Rotary vane pumps are usually not adapted to handling of suspensions. Ask the manufacturer to guarantee the pump you buy as adequate for the pressure and the chemical materials your desire to use. Ordinarily you will not need pressures of more than 100 pounds. Pressures of as low as 35 pounds have been found very satisfactory.

Pumps should be of sturdy construction, non-corrosive, and should have a pressure range adaptable to various spraying jobs. Most pumps are run by a fan or wood propeller located in the slip stream. The pump itself should be
large enough so that it can also be used for refilling the spray tank.

Centrifugal pump, Fig. 6, provide a low pressure, therefore, larger tubing, and more nozzles are needed than for the gear pumps. Centrifugal pumps are not affected by grit. These pumps have proven to be the most satisfactory when the spraying of gritty materials or wettable powders are to be used.

The capacity of the pump must be adequate to more than supply the nozzle delivery rate. There should be a by-passing back into the tank to assure a uniform and constant rate of delivery. Gear pumps require fewer nozzles and use a smaller tubing because they give a greater pressure than the centrifugal pumps. Gear pumps, however, are subject to heavy wear by grit and abrasive materials present in the liquids.

Rotary Gear Pump

Rotary gear pumps are relatively simple in construction. See Fig. 7 and 8. They consist of two intermeshing gears. The gears automatically build up pressure on one side and suction on the other.

For low pressure operation where 1 to 5 gallons per acre only are applied, the pump need have a delivery capacity of only about 25 gallons per minute. Flying at 60 m.p.h. with a 45 foot effective swath, approximately 5 acres is covered per minute of flying. See elsewhere discussion on calibration. All types of pump installations other than the centrifugal should be equipped with pressure relief valves to prevent breakage when the spray is shut off. 176
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Some pumps are electrically driven such as the Yingling installation in the Cessna 170 shown in Figure 9.

Centrifugal Pump

The centrifugal pump develops pressure by means of the impeller, which rotates rapidly and imparts velocity to the liquid. The speed with which the impeller moves, at its outer edge, determines the amount of pressure. For this reason, it is important to know the diameter of the impeller (D) and its revolutions per minute (r.p.m.). Pressure is in proportion to D. For example, a centrifugal pump with an impeller 12 inches in diameter will develop four times as high a pressure as one with a 6-inch impeller, if they have the same r.p.m. See Figures 10 and 11.

HOW IS PUMP CAPACITY DETERMINED? The maximum amount of liquid to be discharged from the nozzle dictates the size of pump needed. The pump must be able to handle the desired output and pressure. To compute the pump capacity needed:

(1) Multiply air speed times the number of feet in a mile (5280) times the swath width, times the desired number of gallons per acre.

(2) Divide this by the number of square feet in an acre (43,560) times the number of minutes in an hour (60).
For example:

- Speed of airplane — 65 m.p.h.
- Feet in a mile — 5280.
- Swath — 40 feet.
- Gallons to be applied — 10.
- Square feet in an acre — 43,560.
- Minutes in an hour — 60.

In an equation it would look like this:

\[
\text{Required pump capacity in gallons per minute} = \frac{\text{Airspeed in M.P.H.} \times \text{effective swath in feet} \times \frac{\text{gallons per acre to be applied}}{5240}}{60 \times 43560}
\]

Simplified this formula becomes:

\[
\frac{\text{M.P.H.} \times \text{effective swath} \times \text{gallons}}{495} = \frac{65 \times 40 \times 10}{495}
\]

Solved the pump capacity required is 52.5 G.P.M.

If some of the fluid is to be recycled through the tank for hydraulic agitation this quantity must be added to the desired pump capacity. 151

**PROPELLERS**

Propellers for driving agitators and pumps are usually of the 4 blade wooden type and have a diameter approximately 20 inches and a pitch of approximately 33 1/2 degrees. Metal blades tend to shed, particularly when the common auto fan type is used. The four bladed wooden propeller will turn up between 2000 and 2500 r.p.m. in a slip stream. See Figure 12.

**PROPELLER BRAKE**

A mechanical brake is a “must” if the pump is driven by a fan or propeller. Without a brake the pump will rev up excessively when the fluid is used up and there is no load on the pump.

Mount a small brake drum with an internal brake band on the propeller shaft just behind the propeller. External bands tend to get dirty and less effective. A brake control cable should extend to the instrument panel so as to be readily available to the pilot. See Figures 13 and 14.
VEE BELT DRIVES

Vee belt drives are very satisfactory for some installations. They provide for convenient locating of the pump and agitator. See Figure 15. Pumps require horsepower to run them. They must be turned up to a specified R.P.M. to develop the required pressure. Figure 16 shows the relationship of pressure, R.P.M. and H.P. for the "Simplex" types A & B pumps.

PUMP TACHOMETER

If a tachometer is fitted to the pump, the pilot can be sure of pressure and tell what the pump is doing. The indicating dial should be located in the cockpit.

PRESSURE

At this point it is well to consider rather thoroughly the significance of pump pressures. Gravity systems are occasionally used. They are definitely inefficient and inaccurate as the deposit rate varies with the volume in the tank and the maneuvers of the airplane, resulting in starving or overdosing. In addition to the rate of flow, pressure has a direct bearing upon the size of droplet and the resulting drift potential.

GRAVITY VS. PRESSURE SYSTEMS (Quoting from Arthur Gieser, U.S.D.A. 45) "Test have been conducted, both in flight and on the ground, in rate of flow by gravity with an installation in an N3N. Gravity flow results in a decided variation in the rate of flow, and the tests showed that a 75 gallon upright tank varied in the rate of flow on a ratio of 3 to 1 in comparing a full tank with a low tank; that is, with the head of pressure of a full tank, the rate of flow was 3 times the rate of flow of a tank that was nearly empty. Moving pictures were taken of the aircraft in flight, and the action of the gravity feed resulted in the spray being emitted.
from only one boom at various times. Experiments conducted show that a pressure system is the most reliable."

There is no way to equalize gravity feed for all tank levels. Compensation for the reduction in flow as the tank level lowers can be achieved rather inaccurately by slowing the speed of the airplane.

**Pressure vs. Droplet Size**

Tests show that pressures of 100 to 125 p.s.i. are fully as adequate as higher ones, and for many jobs, pressures of 30 to 40 p.s.i. are desirable. Those lower pressures have certain advantages:

1. Low pressure equipment is less expensive than high pressure equipment.

2. There is less tendency for the spray to fog or drift at low pressures.

3. Large nozzles may be used at low pressures to apply the same number of gallons per acre as smaller nozzles at high pressures. This cuts down on nozzle plugging and gives a more uniform coverage. Most nozzles do not give a uniform droplet size but a band of sizes. For example, the range on the band may be from 10 to 150 microns, these figures representing diameter of the droplets. When increased pressure causes droplets to become smaller, the band of sizes shifts toward the smaller end. There are then fewer droplets in the 150-micron range, more in the 10-micron range, and probably some additional ones below 10 microns. The range around 30 microns and below is classified as an aerosol (airborne) and is highly susceptible to drift (see volume 3 for full discussion).

**Penetration and Distribution** are a function of pressure with a given nozzle. Maximum penetration or drive is ob-
SPRAYER COMPONENTS

obtained with large droplets at high pressure, but increasing the pressure on a given nozzle reduces the droplet size. Distribution is best with small droplets which cover the weeds most thoroughly, but the smaller droplets are more susceptible to drift. A compromise must be made and an optimum pressure used to give satisfactory penetration without serious drift.

Figure 17 shows how pressure affects the size of spray droplets produced by a typical nozzle producing a hollow-cone spray. The data were obtained by using a 0.4 per cent mixture of slaked-process lime and

SPEED AND POWER REQUIREMENTS FOR SPRAYERS AND OTHER SERVICE USING LESS THAN 10 GALLONS PER MINUTE

<table>
<thead>
<tr>
<th>PRESSURE PER SO. INCH</th>
<th>1 INCH TYPE “A” RPM &amp; HP</th>
<th>1 INCH TYPE “B” RPM &amp; HP</th>
<th>1/4 INCH RPM &amp; HP</th>
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</thead>
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<td>10</td>
<td>1350 0.32</td>
<td>1470 0.25</td>
<td>1730 0.4</td>
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<td>15</td>
<td>1600 0.5</td>
<td>1800 0.45</td>
<td>2100 0.7</td>
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<td>1800 0.7</td>
<td>2100 0.7</td>
<td>2400 1.0</td>
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<td>2000 1.0</td>
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<td>2700 1.4</td>
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<tr>
<td>100</td>
<td>4060 8.2</td>
<td>4600 6.5</td>
<td></td>
</tr>
</tbody>
</table>

NOTE: In spray systems both gallons per minute and horsepower are limited by the nozzle. Horsepower requirements over 10 gallons per minute will be much greater.

Fig. 16.Courtesy Columbia Exporters.

water. Spray droplets from gun, carefully collected on clean glass slides were measured with a microscope. The results show that to reduce the average diameters of droplets by one half, one must increase the pressure by four times. According to these tests, to secure additional distance of carry, one should increase the rate of discharge of a nozzle by changing to a larger disk orifice instead of increasing the pressure: a pressure increase diminishes droplet diameters so that the drops tend to travel a shorter distance.

Contrary to popular belief, with a given nozzle and a constant pressure, decreasing the size of disk orifice does not decrease the size of the spray droplets. Pressure is the primary factor controlling the degree of atomization: high pressure produces small droplets; low pressure, large droplets.

Disk-orifice diameters affect:

1. Diameter of spray cone (the smaller the orifice the smaller the cone.)
PART I


Pump-pressure increases result in: 1. Smaller spray droplets. 2. Increased carry of droplets (with pressures up to 800 pounds per square inch). 3. Increased included angle of spray cone.

Eddy-chamber depth increases results in: 1. Increased carry.

Pump-pressure increases result in: 1. Smaller spray droplets. 2. Increased carry of droplets (with pressures up to 800 pounds per square inch). 3. Increased included angle of spray cone.

Pump-pressure increases result in: 1. Smaller spray droplets. 2. Increased carry of droplets (with pressures up to 800 pounds per square inch). 3. Increased included angle of spray cone.

Eddy-chamber depth increases results in: 1. Increased carry.

2. Increased output.
3. Decreased atomization.
4. Decreased included angle of spray cone.

Vortex-opening size increases result in:
1. Increased carry.
2. Increased output.
3. Decreased atomization.
4. Decreased included angle of spray cone.

High pressure means small particle sizes, more FOGGING and possible excessive drift. (Volume of droplets varies with the square of the diameter). Excellent results have been obtained with pressures as low as 35 pounds.

○ FACTORS WHICH AFFECT PARTICLE SIZE: The following factors will control particle size, and although some are inter-related, all must be considered. They are: 299

1. The viscosity of the material.
2. Rate of flow.
3. Type of nozzle or orifice.
5. Speed of the aircraft.
6. Altitude of the aircraft.

○ PARTICLE SIZE AND DRIFT: The reason we must consider particle size is because of the difference in drift of the various size droplets. As an example, for droplets of water in still air:

A 5-micon diameter drop will fall 10 feet in 1.1 hours. A 100-micron diameter drop will

Fig. 17. Courtesy of University of California, College of Agriculture.
The effect of pressure on spray-droplet diameters as discharged from a nozzle giving a hollow-cone type of spray.

Fig. 18. Courtesy Monarch Mfg. Company.
Hand operating pressure valve.
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fall 10 feet in .18 minutes. A 500-micron diameter drop will fall 10 feet in 1.6 seconds.
A further comparison: A 5-micron drop, when dropped 10 feet in a 3 mph wind will drift 3.4 miles. A 33-micron drop, when dropped 10 feet in a 3 mph wind will drift 400 feet. A 100-micron drop, when dropped 10 feet in a 3 mph wind will drift 48 feet. A 500-micron drop, when dropped 10 feet in a 3 mph wind will drift 7 feet.

There are three factors which act on any material once it leaves the airplane. They are (1) gravity, (2) wind, and (3) convectional air currents. Eighty-five degree temperature when the sun is high usually causes convectional air currents such that little benefit will result from either dusting or spraying under this condition. Because drifting chemicals can cause serious damage to nearby crops, wind and convectional currents must be considered in applying insecticides or chemicals to crops.

**COMPARING PARTICLE SIZES:** Particle sizes are measured in microns.

- **Sea fog** ........ 5 microns in diameter
- **Cloud** .......... 33 microns in diameter
- **Mist** .......... 100 microns in diameter
- **Drizzle** ........ 200 microns in diameter
- **Light Rain** ...... 500 microns in diameter

**Determining Particle Size**

The following paragraphs describe in part the method of determining by glass slide test the size of droplets. This information is taken from United States Department of Agriculture Bulletin ET 267. Consult this bulletin for the full discussion. It is doubtful whether anyone less than a laboratory expert with the proper microscopic equipment could make an accurate computation of droplet sizes, however, by using the prepared slides some good ideas of droplet size can be obtained.

The method that has been found for determining the particle size of insecticidal aerosols and fine sprays is to deposit a sample on a glass slide and measure the particles under a high-power microscope. This method shows the complete range of particle sizes involved.
PART 1

Particles of relatively nonvolatile materials can be measured before they evaporate. To prevent excessive spreading, filming, or coalescence, the slide must be coated with an oleophobic substance that will cause the individual droplets to maintain their convexity to some degree. Two of the most satisfactory materials for this purpose proved to be a 1-per cent alcoholic solution of mannitan monolaurate, and a silicon product marketed under the trade name Dri-film 9987. The slides are first immersed in a cleaning solution, dried, then immersed in the oleophobic coating solution, and redried. When dry the slides should be lightly polished with a soft cloth. They may be stored in ordinary slide boxes for several days before they are used.

Particles of volatile materials, which evaporate rapidly, cannot be measured directly, but their size can be estimated by measuring the craters they leave at the points of contact on slides coated with magnesium oxide or carbon soot. It is important to apply the right thickness of coating for the range of particle sizes anticipated.

After the sample of aerosol or spray has been deposited on a slide, it is placed under a microscope and the individual particles are measured with an eyepiece micrometer. A mechanical stage on the microscope is necessary. The diameter as measured on the slide is then corrected for the amount of spread that has taken place, and the diameter of the original sphere is determined.

At least 200 particles should be measured. The more homogeneous the aerosol or spray, the fewer particles need be counted. All particles should
be counted as they are seen in the field. An accurate method is to measure all particles from one edge of a slide to the other that pass through the micrometer scale as the slide is moved by the mechanical stage.

It is sometimes useful to photograph the particles or to project them on a screen through a microscope. Better results have been obtained, however, by measuring the particles directly as seen in the microscope. It is often more convenient to measure in terms of the divisions of an eyepiece micrometer, and convert these divisions into microns after the median has been determined.

A correction factor must be determined for each slide. The original spherical droplet as it is impinged on the slide becomes a convex lens, and the extent of its spread from its original shape can be calculated by determining the focal length of the lens so formed. In the example cited the correction factor is 0.40; therefore 30 microns X 0.40 gives a median particle diameter of 12.0 microns.

OBTAINING A PERMANENT RECORD OF PARTICLE SIZE. As a matter of expediency you ought to keep a permanent record of the particle size and spray pattern on every job completed. There are a number of ways to do this. The best method perhaps is to obtain from I. C. D. Equipment Company, Campbell, California, a kit of materials for this purpose.

The kit consists of sheets and stripes of sensitive paper which can be spread on the ground to record the droplets sizes, check nozzles,
coverage and spray width. This sensitive paper is glazed and treated so as to eliminate any blotting effect and minimize the spread of the droplets. Even the very fine droplets will be recorded. The kit contains a supply of an activating chemical which can be diluted with water in the spray tank to make from 20 to 40 gallons of test run spray. A magnifying glass also included in the kit. The kit sells for approximately $10.00.

Established air applicators use this or similar materials on each spray job to obtain for his own information and that of his customer the record of the nozzle adjustment coverage and swath width. You can readily see the value of this record in case of drift complaints of others or customer questions arising.

PRESSURE REGULATORS

A pressure regulator, Fig. 18, on a spray pump has a threefold function:

1. It is a safety device;
2. It maintains uniform pressure at the spray nozzle; and
3. It allows the pump to operate at greatly reduced load when no material is being discharged.

The principle on which regulators operate is either a spring-loaded diaphragm or a plunger which, if the pressure of liquid exceeds the resistance offered by the compression spring, will lift a ball valve and permit excess liquid to by-pass to the supply tank.

Fig. 22. Courtesy Arrow Sprayer Company.
Pressure regulators are sometimes built into the pumps. These are not always reliable and need to be supplemented with a regulator in the line. It is important that the operator know the pressure at the boom, not necessarily the pressure at the pump. By the use of a check valve between the diaphragm or plunger and the pump discharge line, the regulator becomes a partial unloading device as well as a pressure-relief valve. To function sensitively and positively, both the relief-valve ball and the check-valve ball must fit perfectly in their seats. If the check valve were removed, the regulator would function merely as a relief valve. For good operation conditions, some liquid should by-pass through the regulator while spraying is in progress. If no liquid is by-passing, then the discharge of the nozzles is too great for the capacity of the spray pump.

Adjustment of the pressure regulator ought to be possible from the pilot's position in the cockpit. This enables him to make corrections for changes in ground speed because of up and down wind flying.

A by-pass system is necessary in order to prevent excessive pressure build-ups which might cause a bursting of pipes and other breakage. The by-pass system consists of a pressure regulator valve which permits the excessive pressure to return to the supply tank. In many systems this by-pass is utilized to provide agitation to the tank fluids. Centrifugal and turbine pump installations do not require by-pass pressure regulators. A pressure regulator enables you to select the correct pressure and maintain it. By-pass prevents excessive pressure when the liquid flow to the boom is stopped.

Fig. 23. Aero Mist-Master Courtesy Mississippi Valley Aircraft Service. Aircraft is dispensing approximately 6 gallons per acre in this photo. Dispensation can be controlled from rates of 2 quarts to as much as 8 to 10 gallons per acre.
A poor regulator may result in crop damage and wast of material. The boom is the place where the pressure reading is important. A separate diaphragm or by-pass pressure regulator ought to be placed in the line. See Fig. 19. This shut-off valve pressure regulator unit is built by Sevdy Sorensen and is available through Dakota Aviation.

**PRESSURE GAGES**

- A PROPERLY CALIBRATED pressure gage of good quality should be installed in the line from pump to boom. It is usually connected with flexible copper tubing. The gage should be 3 to 4 inches in diameter, with a maximum reading of 150 p.s.i. It should be easy to read from the pilot's seat. Have gages calibrated each season by a reliable pump or sprayer service, or check them against an accurate gage to make sure their readings are correct. Gages should be equipped with snubbers (check screws) to avoid pulsation of the gage needle. Pressure fluctuations may be due to dirt in the pressure regulator or suction strainer.

- LOW PRESSURES FOR WEED CONTROL: Low pressures (under 100 pounds) usually 30 to 35 pounds are generally used in spraying for weed control. High pressures are neither necessary nor desirable. They cause greater drift, vaporization of the sprays, and excessive wear on the machinery. Also, high pressures require more costly equipment and additional power. High pressure machines can be adapted to low-pressure spraying by proper adjustment and special low-pressure attachments. Exact pressure control becomes more important as the volume of spray per acre is reduced. About 30 pounds pressure is all that is desired with low volume (less than 20 gallons per acre) spraying.

**BOOMS**

Booms are usually made of light weight steel tubing of 3/4 inch or 1 inch diameter. More recently there is being made available aluminum and steel streamlined boom material. Booms should have removable plugs at the ends. They should have T's and Y's at points of directional change so that they can be swabbed out when they become clogged or when a change is to be made in the spray material. The boom requires meticulous cleaning particularly when neutralizing for 2,4-D. and related materials.

![Diagram of A and B](image)

Fig. 24. The resistance (drag) of (A) is fifteen times that of (B).
SPRAYER COMPONENTS

The full length boom has in general proved most satisfactory in gaining a maximum uniform swath. Short booms extending from inboard end of the aileron across underneath the belly to the inboard end of the other aileron are good for weed spraying. Usually a heavy output is used and the short boom keeps the spray from the vorticies effect of the wing tips.

Booms are usually suspended about 9 inches below the wing about midway of the chord on low wing on biplanes. See Figure 20. On high wing models the inboard end of the boom is attached to the fuselage just below the strut fitting and extends at an angle greater than horizontal. Two or three brackets are necessary to suspend the boom from the wing, the last one being attached to the spar at the wing tip. See Fig. 45. Sloping the boom, through raising the height of the outboard end above the ground, provides clearance should the plane ground loop and drag a wing tip.

With the sloping type of boom it is necessary to provide for the releasing of a greater amount of fluid from the outboard end of the boom in order to obtain an evenly distributed swath.

Fig. 25. Courtesy Yakima Aero Service, Photo by Philip Lewis.
STREAMLINED BOOMS: Operators have been surprised at the loss of speed after installing a round pipe boom. It should not be surprising to have a 10 to 15 m.p.h. reduction in speed in view of the tremendous difference between the drag of a round tube and a streamlined tube.

Booms imbedded in the wing with nozzles only in the slip stream give a considerable reduction in total drag. Some wing construction, however are such as to prevent such boom placement. See Fig. 21, 22, and 23. If booms are to be located outside the wing streamlined tubing should be used. Boom drag is a considerable item when round tubing is used. See Fig. 24.

STREAMLINED BOOMS. Air has mass and consequently a force is required to put it in motion. In moving an object through air, air must be displaced from in front of the object to the rear of the object. When the air is thus being moved, if there is a superfluous motion in the form of eddies and burbles, work is being done unnecessarily. In front there is some burbling and at the rear there is considerable burbling. If this can be eliminated the resistance can be reduced tremendously. By adding a round nose and filling in at the rear, the burbling can be practically eliminated. If the diameter of the circular cylinder is the same as the thickness of the streamlined strut, the circular cylinder has 15 TIMES the drag or resistance of the streamlined strut. The formation of eddies in airflow always increases air resistance. The manner in which an airflow leaves an object is of the highest importance. The manner in which the airflow rushes in behind an object plays a big part in the resistance. If the airflow is smooth, the drag is small; but if the airflow is turbulent, the drag may be very high.

SHUT-OFF VALVES

THE BOOM, must have a good, quick shut-off valve. When the spray valve is closed all of the pump output is by-passed into the tank. When the spray valve is open only that part which does not go through the nozzles is by-passed. Its diameter should be the same as that of the boom, and it should be placed in the main boom line, with remote control so that the operator can reach it easily in the cockpit. See Fig. 25. The nozzles should start spraying at full pressure the instant the control is moved to the spray position. Unless positive pressure spray begins the first few yards at the start of each run will be starved. The shut-off must be just as positive to avoid getting spray where it is not intended.

TANK AND BOOM DRAIN VALVE: In addition to the main spray opening and closing valve a drain valve is essential, particularly for cleaning purposes and when changing from one chemical to another. Location of the drain valve will depend upon the lowest point in each particular installation.

BOOM INSTALLATION: Figure 45, shows a typical boom installation on a Cub. The boom constructed of ¼ inch thin wall steel tubing
SPRAYER COMPONENTS

is 193 inches in length on each side of the fuselage. It is attached to the wing by four braces, three of which are attached to the struts and one to the spar at the wing tip.

The boom has 45 nozzle openings spaced on 4 and 21/16 inch centers. Excess nozzle openings are plugged off when not in use. Flying at a height of 10 feet above the ground this installation gives a swath width of approximately 56 feet. Figure 26 shows a typical boom arrangement for a Stearman N2S. In this case the boom is made of 1 inch thin wall steel tubing. The boom is mounted 9 inches below the wing.

Figure 27, shows a DC-3 installation. The boom in this case is constructed of STREAMLINED 2 inch tubing. Some engineers recommend attaching the nozzles to the boom at the side or top. The idea being that a place is thus provided for settling for dust particles. It also to some extent prevents drainage after the flow has been shut off.

Occasionally, such a boom should be flushed out through removable caps on the ends. Nozzles may be brought into the bottom of the boom with a nipple or coupling raised into the boom to provide settling space. However, the coupling obstructs the boom line, making it impossible to force rod cleaners through from the ends. The boom may be drilled, and a 90-degree elbow (1) or a coupling (2) welded over the hole. Or openings may be made in the boom for the nozzles by drilling and tapping the boom, screwing in a street elbow (3) or a nipple (4) and welding in place. See Fig. 28. Welding is necessary to preserve structural strength. Suitable elbows and nipples are used to bring the boom outlet to the proper direction for the nozzles. The outlet may be in a single row, or may be in two rows with alternate nozzles on opposite sides of the boom. This is an advantage when double-coverage application is used. Each row of nozzles is tilted slightly toward the other to give different angles of attack. NOTE: after any welding has been done, remove the scale and cover the metal with a coat of metal priming paint.
PART I

In constructing the boom a standard practice is to drill and tap for more nozzles than average use requires. These additional holes can then be plugged and held for possible future use in which greater volume deposit rate may be required.

Norman B. Akesson, Agricultural Engineer, University of California College of Agriculture, 21 recommends bringing the nozzles into the boom from the sides or top ground equipment. This arrangement provides a settling place for dirt particles. It is questionable if on an airplane with the amount of vibration whether this arrangement would be similarly effective. With removable caps at the ends of the boom it can be readily flushed out. When mounting nozzles in thin tubing, sleeves are slipped over tubing, sweated in place, and holes drilled and tapped. This gives the necessary strength.

Pressure drop is one of the considerations in boom pipe size if the boom is long. One inch diameter is probably sufficient for a 15 foot boom. Longer booms should be 1 1/4 to 1 1/2. Pipe smaller than 1 inch is not practical, for example: in ten feet of 1 inch pipe a 25 g.p.m. flow will suffer a 3 p.s.i. drop in pressure. This would lower the discharge at the outer nozzles. Smaller copper tubing is sometimes used for very low volume work. 3

Some installations provide spring-loaded valves between the boom and each nozzle. These open when the boom pressure exceeds 5 p.s.i. and close below 5 p.s.i. and are used mainly to keep the boom from draining when the shut-off valve is closed. They tend, however, to plug easily and fail to shut-off. 3.

Drooling means the leakage and drip that occurs in the system if it does not have a positive shut-off valve or if the installation is faulty or if there are leaks in the couplings or nozzle connections. A recently developed method for stopping boom drainage and dripping is the reverse-flow valve system which places a suction on the boom and nozzles

Fig. 27. Courtesy of United States Department of Agriculture DC-3 boom equipted.

Fig. 28. Courtesy University of California College of Agriculture. Various nozzle placements.
SPRAYER COMPONENTS

when the pressure is shut off which draws spray materials from the nozzles back into the boom. The suction is provided by discharging the flow from the pump through a venturi or jet when the boom shut-off valve is closed. A 4-way valve makes it possible to combine the main boom-control valve and the suction valve, so that two operations are taken care of by the combination. This is a patented valve and venturi assembly and may be installed on any sprayer.

Short booms have the advantage when spraying weed killers. These booms extend from the inboard end of the aileron under the belly of the plane to the inboard end of the other aileron. Weed killers are usually sprayed with a heavy volume. The short boom keeps the spray away from the wing tip vortices.

Swath width is directly affected by the height of the aircraft above the crop being treated and by the velocity of the cross-wind component. Since these factors are often variable, especially over rough terrain, swath width cannot always be accurately predetermined.

Wing span, design and power of the plane, the position of the boom relative to the air stream, the type of nozzle used and the spacing of the nozzles are other factors which affect the swath width.

On ground equipment spacing the nozzles on the boom is done with reference to the width of crop rows. In constructing booms for air-application this is not a consideration because the spray is done above the crop.

The number of nozzles will be a factor in determining the number of gallons deposited per acre. Spacing should be such as to give a uniform coverage and no striping effect. For a ground rig nozzle spacing on the boom depends upon many factors, such as the volume of spray to be applied, tractor speed, row spacing and height of the crop. For general usage, a spacing of 18 to 29 inches between nozzles and a boom height of 20 to 24 inches is satisfactory. Crops planted in 14 to 16 inch rows obviously will require some modification in the boom arrangement. (ground rigs).

Fig. 29. Courtesy W. A. Westgate
**TUBING**

Thin wall streamlined steel tubing is used extensively as it is easily welded and rust can be kept to a minimum with proper care. Hoses must be of non-detergent material if deterioration by some of the liquids is to be avoided. Deterioration will plug nozzles. Tees and elbows increase fluid friction and reduce pressure—avoid them where possible. Another design feature to be considered is the matter of ease and efficiency in cleaning the system where it is being used for more than one type of material. (See cleaning elsewhere in this book.)

**PRESSURE LOSS:** must be considered. The outboard nozzles will not deliver the same amount of material as the inboard nozzles. Pressure loss in a hydraulic system will vary DIRECTLY with the rate of flow and INDIRECTLY as the 4th power. This means that with twice the rate of flow you will get twice the pressure loss and if you were to cut the size of the tubing in half you would increase the pressure loss 16 times (4th power). The actual pressure loss is caused by friction in the tubing, tees, elbows, screens and other restrictions. In sloping booms the material needs to be raised to the outer end of the boom. Practical tests with color plates or flow tests will indicate the extent of pressure loss in the system.

**STRAINERS**

Strainers are very important, See Fig. 29, they keep the nozzles clear and operative. A strainer should be placed first in the tank INLET. The next one should be placed in the suction line ahead of the pump. A third should screen the material before it goes
SPRAYER COMPONENTS

into the boom. Then each nozzle should have its individual screen for final protection from dirt clogging. An excellent practice is to begin with a fifty mesh and end at the nozzle with a 1 to 200 mesh screen depending upon the orifice size.

- DIRT, SAND, and lumpy materials in the sprayer not only plug nozzles but cause excessive wear on pumps and regulators. Strainers installed at strategic points in the sprayer will reduce these losses. The tank opening should have a 50 to 80 mesh (number of holes per lineal inch) screen to keep out large particles and lumps from improperly mixed spray liquids. A similar mesh screen should be placed in the suction line to the pump, to keep dirt particles out of the pump and out of the tank when the backfill is used.

Another point to be screened is in the boom line from the pump, between the pressure regulator and the boom. This screen should have an area of about 100 square inches, for a general-volume sprayer, with openings of 100 to 150 mesh. The last point for screening is in the nozzles themselves, where small screens of 50 to 200 mesh are used, depending on the size of the nozzle opening. Do not depend on these nozzle screens to do the job of the boom-line screen, because their area is much too small, and they quickly become plugged.

Pump-inlet and boom-line screens can be made detachable, for cleaning, or can be of the back-flush type if the flushed material can be run out of the machine. One manufacturer provides continual screen flushing by drawing liquid and dirt off the dirt collecting side of the screen, using a jet in the pump line to the tank to provide the liquid flow.

The final screens need not be finer than the orifice opening in the nozzle. Good filters, easily cleaned, will do much to insure trouble-free application of the materials.

DROPLET SIZES

Prior to a discussion of nozzle types and sizes it will be well to thoroughly understand about droplet sizes and the factors which affect them. Because droplet size has so much to do with coverage, deposit rate and drift problems it is very important to make the right selection of nozzles.

In the use of liquid insecticides the size of droplets affects both coverage and drift. For some purposes sprays of small particle size have very definite advantages. However, even slight wind currents may keep them from reaching the crops or insects or carry them outside the field upon which coverage is desired. Also very small droplets may not impinge upon plant or insect surfaces or that they may evaporate before reaching their target. Large droplets are much more easily con-
trolled, however, they are more wasteful of materials, burn or other­wise injure foliage or not give uniform or complete coverage. 41

The purpose of any sprayer is to atomize a liquid or a liquid con­taining solid into droplets and to apply this finely divided spray to plant, fruit, or leaf surfaces. Obviously, the object of producing a spray in order to wet a surface is to obtain adequate coverage with a minimum of material. The atomization of a liquid into practical sprays is accomplished by several methods, the most common of which is direct hydraulic pressure forcing the liquid through a nozzle and causing it to disintegrate into droplets. Another method of producing sprays is to use a high-velocity air stream striking either a jet of liquid or a coarsely atomized liquid. This process is merely the reverse of discharging a jet of liquid at high velocity into still air. 53

As stated in our previous discussion of pump pressures, droplet size is mainly influenced by pump pressure, but the very small nozzle orifices will also decrease the average droplet size, depending upon the type of nozzle. A compromise must be made between the small droplets which give more thorough coverage but have a tendency to drift, and the large droplets which settle fast but are not so efficient with respect to coverage. (The number of droplets per square inch varies inversely with droplet size.)

The average size deposited by correctly operating airplane equipment is between 50 and 300 microns, at which size most weed spray mater­ials react satisfactorily. 3

Some of these factors are more important than others. Some are inter-related and some are indirect. But they all must be considered when dealing with droplet size.

1. Pressure of the fluid.
2. Type of nozzle opening.
3. Angle of nozzle into the air stream.
4. Speed of aircraft.
5. Altitude of aircraft.
6. Rate of flow.
7. Evaporation rate.
8. Temperature of material.
9. Viscosity of material.
10. Surface tension.
11. Density of material.

A micron is a millionth of an inch. A 100 micron drop is .004 of an inch. For comparison think of the average spark plug gap which is .025. 100 micron size is ideal for most weed work.

2 to 6 micron droplets are comparable to dry fog.
10 to 50 is comparable to wet fog or light mist.
200 to 300 is a drifty misty rain ok for weeds.
250 to 500 is fine natural rain.
Do not judge the size of the droplet by the spot — the viscosity of the fluid and the spreading character of the material upon which the droplet falls have much to do with the size of the spot. Under laboratory conditions only can accurate measurement of droplets be made.

A 5 micron drop will descend 10 feet in 1½ hours in a 3 mile wind. It would drift approximately 3½ miles.

A 33 micron drop will descend 10 feet in 2 minutes. In a 3 mile wind it will drift approximately 400 feet.

A 100 micron drop will descend 10 feet in approximately 11 seconds. In a three mile wind it will drift approximately 48 feet.

A 500 micron drop will descend 10 feet in approximately 2 seconds. In a 3 m.p.h. wind it will drift approximately 7 feet.

From these figures you can estimate the amount of drift in winds greater than 3 m.p.h. and altitude of flight greater or less than 10 feet above the ground. No general formula can be given for determining droplet size because of the numerous variables present. Each type of aircraft and each type of application mechanism must be given an individual field test to determine droplet size.

In planning equipment for a variety of uses it's best to allow for some flexibility by providing for the convenient adjustment of the number and size of discharge outlets. Glass slides are used to make numerous tests. Glass plates 12” x 12” are a convenient size. They may be spaced at any desired interval at right angles to the swath. The drops thus obtained may be studied for comparative sizes and numbers. The uniformity of the swath may also be determined, also the pilot's accuracy in opening and closing the spray shut-off valves. See elsewhere in this volume for a method of measuring droplet sizes and estimating total proportions of various sizes.

Fig. 32. Flat fan nozzle Hollow cone nozzle
PART I

It is easy to inadvertently carry an error in thinking on this matter of droplet sizes as compared to volume of deposit. Microns refer to the diameter of the drop. When evaluating droplet sizes and amount of deposit it must be remembered that the difference in volume deposit of a 500 micron drop is not five times (5 to 1) that of 100 micron drop but 125 times or a 125 to 1 ratio.

When applying a liquid at the rate of 1 gallon per acre a 500 micron will be deposited at the rate of 9 drops per square inch. Whereas 100 micron droplets will be deposited at the rate of 1,150 droplets per square inch. (127 to 1) Likewise a 5 micron droplet would be deposited at the rate of 9,200,000 drops per square inch. Bear in mind of course that the amount of material being deposited is the same in each case. This understanding is significant when considering the type of coverage desired.

![Spinner Brush](image)

Before using newly installed equipment it is best to run a color test to verify the spray pattern and deposite rate. Lay a long piece of wrapping paper across the swath. Use red ink, laundry bluing, duPont red oil or other material to color the water for the tests. The distribution of the droplets will give you a fair idea of the uniformity of coverage within the swath. The varying sizes of the droplet stains will give some idea of the proportion of droplet sizes.

PROPER NOZZLES, ACCURATELY ADJUSTED WITH A CONSTANT PRESSURE AND SPEED IS THE KEY TO SAFE, THOROUGH SPRAYING

**NOZZLES**

Most of the nozzles commonly used are known as the eddy-chamber type. See Fig. 30 and 31. In these, liquid flows at high velocity through a vortex plate with spiral or tangentially arranged channels, which sets up a whirl in an eddy chamber. This whirl tends to break up the stream of liquid before it is discharged through the nozzle orifice. Some of the eddy-chamber nozzles are so designed that the depth of the chamber can be varied by means of an adjustable plunger. Variation of the depth of the eddy chamber changes the angle of spray cone emitted from the nozzle orifice. A shallow camber will produce a wide-angle cone of spray; a deep camber, a narrow-angle cone.
SPRAYER COMPONENTS

If the eddy-shamber is increased sufficiently, a jet-type stream will be emitted from the nozzle disk. The symmetry of spray cones is affected by irregularly worn disk orifices or unsymmetrically shaped vortex openings. That is, one side of the cone may contain most of the spray, or the spray may be streaked. Spray cones lose their symmetry at a short distance from the nozzle orifice, usually within 3 feet, because of air-current disturbances; for this reason the type of spray pattern produced is of minor importance except for nozzles operated within approximately 3 feet of the object.

Two types of spray patterns are produced by cone sprays; either a ring or a solid-pattern type. The ring-type pattern is produced by a hollow-cone spray; the solid or disk pattern by a solid-cone spray. The latter pattern is obtained with a vortex or whirl plate having, besides the vortex openings, a central orifice directly in line with the spray-disk orifice and of approximately the same diameter. Addition of a central orifice in the vortex plate simply fills the center of the spray cone; hence the term "solid cone".

Pattern

Spray nozzles designed to give a flat, fan-shaped spray pattern have been found more satisfactory for weed control than the cone-shaped

Fig. 34. Aero Dust King  Courtesy, Ong Aircraft Corporation.
PART I

pattern delivered by the typical insecticide or fungicide spray nozzle. See Fig. 32. They are considered best because they give the most uniform coverage and the strongest drive. This is important when the material needs to be forced through heavy weed growth or tall grain. The advantage claimed for the hollow cone type nozzle is that they fog less under low pressure.

These nozzles are now available in a wide range of sizes, and the technical data supplied by the manufacturer will make it possible to select the size to be used under a particular set of conditions. Because a very definite relationship between nozzle opening and spray delivery per minute exists, it is necessary to know the air speed, gallons per acre wanted, and pump pressure before a nozzle size can be selected. All dealers in spray equipment have charts which can be used to determine the proper nozzle for use under various conditions. Nozzles to be used for low-volume spraying have a small opening, and a screen with openings no larger than that of the nozzle is essential to prevent frequent stoppage of nozzles.

For uniform spraying the proper nozzles must be used. This is particularly true with low volume equipment. Nozzles with either male or female threads are available, usually \( \frac{1}{4} \) inch pipe size. The two types most commonly used are those giving either a flat, fan-shaped spray, or a cone-shaped spray. The tip, or orifice disk, for either type, may be changed by unscrewing it from the nozzle body. Or the opening may be cut in the nozzle itself. If this is done, the entire nozzle must be replaced in order to change the size of the orifice. Most nozzles have small, removable screens to prevent plugging.

How Are Nozzles Selected?

Manufacturers' charts must be consulted in the installation and use of any nozzle. Charts prepared by nozzle manufacturers frequently give gallons per acre directly for a series of field speeds, pressures, and nozzles sizes. A chart of these variables is prepared for each nozzle spacing. Fan width information may also be on these charts, or may be included as a separate item. The fan width also affects the nozzle spacing. Nozzles with the same orifice size, but of a different type or made by different manufacturers, will not have equal discharge rates at a given pressure. Nozzle charts or discharge rates for the specific nozzles to be used must be consulted.

● DISCHARGE INFORMATION in the manufacturers' catalogs may be presented by a chart, or by tables giving discharge and fan width over a large range of pressures. Most nozzle manufacturers identify their products by the orifice diameter or by the gallons per minute (or hour) discharge at a given pressure. In some cases, the identifying code number also includes the fan spray width at the same pressure.
SELECTION OF NOZZLE SIZE is relatively simple, most manufacturers supply catalogs with charts. The charts will show the proper orifice size needed to deliver the gallonage desired per acre for a given ground speed, pressure, and nozzle spacing. See list of manufacturers in volume six.

WARNING: Rate of Pressure Loss. Often the matter of pressure loss is overlooked when adding extra nozzles or substituting nozzles with larger orifices. Remember that when the discharge rate is doubled the pressure loss is doubled. (Pressure loss in a system varies directly with the rate of flow and indirectly as the 4th power.) This means that if the size of the tubing is cut in half the pressure loss is increased 16 times.  

Fluid loss can occur because of check valve clogging. This is particularly true when treating with suspensions. The greatest danger, however, is in the damage that leaking nozzles may do to susceptible plants while flying to and from the treated fields or while making turns over non-treated property.

TIPS ON NOZZLE CLEANING AND CHANGING

Removable tips will enable you to vary the volume of water per acre simply by changing tips and adjusting pressure.

Nozzles which can be taken apart are easier to keep clean.

Nozzle screens help keep nozzle tips from plugging.

No-drip gadgets are available for some nozzles.

To avoid damage, pocket knives or wire should not be used to clean nozzles.

Use a tooth brush to keep the screen and tip clear.

SPINNER BRUSHES

Spinner brushes have been used successfully in many parts of the United States according to the I. C. D. Equipment Co. Positive control over droplet size, volume and pattern can be maintained with the brush type dispersal unit. See Figure 33.
PART TWO

Equipment for applying dust, seeds and solid fertilizers is relatively simple. A hopper, agitator, agitator propeller, gear box and a venturi make up the main components. See Fig 36.

HOPPERS

Hoppers may be constructed of plywood, aluminum, stainless steel or galvanized tin. Frequently it is necessary to remove certain structural members of the airplane in order to install hoppers and spray tanks. These can be removed and reinstalled in the hopper or tank then bolted into place by use of face plates with the approval of the FAA. The slope of the hopper bottom walls must be adequate to assure continuous flow and complete elimination of hopper contents to the agitator and outlet. Usually a slope of at least 55 degrees is desirable for the bottom walls. Hoppers must be built as tight as leak proof as possible. Hoppers

Fig. 35. Courtesy Mississippi Valley Aircraft Service. Dust-Master Venturi (Front View). Note that entire venturi is self-contained, including gear box, agitator, prop etc. This venturi can be adapted to any standard hopper installation.
DUSTER COMPONENTS

may be made liquid tight and with a properly designed plate to take the place of the gate and spreader it then can be used to double as a spray tank.

When using 24 stainless steel aluminum the rivets should be spaced about \( \frac{3}{4} \) inches and the seams treated with zink chromate paste before riveting. Stainless steel and half hard aluminum can be welded and galvanized tin soldered. To provide free flow of the dust a vent should be placed in the hopper.

HOPPER GATES

Hopper gates must be snug to prevent leakage, yet free to move easily. Metal covered wood tends to swell and jam in damp weather. Metal also provides a source of static which might ignite sulfur dust. The best material found so far for hopper gates is \( \frac{3}{4} \) inch micarta (cloth impregnated with plastic).

*HOPPER GATE METERING SCREEN:* (Taken from the United States Department of Agriculture literature) It is often necessary to

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Fig. 36. Courtesy Mississippi Valley Aircraft Service. Dust-Master Venturi (Rear View) Note that greater velocity has been engineered into outer vanes which greatly eliminates streaking.
control the dispensing of seed, fertilizer, etc. very carefully and regu­late the flow to a very small quantity per acre. For example alfalfa seed is very small and only a light covering required. A sixteenth inch opening in a 24-inch hopper throat would be excessive at 60 or 70 m.p.h. A limited flow can be regulated very accurately by installing a shield at the hopper gate similar to the following design. It is necessary to provide agitator blades at each opening to prevent packing and uneven distribution. This metering device, Figure 38, was used by the United States Department of Agriculture and provides micrometer control of volume output.

VENTURI

The venturi is usually built in the shape of an airfoil (full or half venturi) and placed directly under the gate valve. See Fig. 35. It acts to suck the material into the slip stream throat as it passes through the spreader section.

SPREADER

The spreader is often an integral part of the venturi. See Fig 36. Its purpose is to give an even distribution of the material throughout the width of the swath. Verticle vanes properly spaced give an even distribution to the material. See Fig. 37 for side view of venturi.

GEAR BOXES

Gear boxes are used to transmit power from the wind driven propeller to the agitators. A 48 to 1 has been found to be the most practical gear ratio between the propeller and the agitator.

AGITATORS

Agitators are very necessary for many kinds of baits both dry and wet. They are also essential to dusting, seeding and fertilizing materials. A small open drum, piano wire type, is usually placed in the bottom of the hopper directly over the sliding gate valve. One, or sometimes two larger agitators (6 in.) are placed above the bottom small agitator. The upper agitator need turn only 1/6 to 1/8 the speed of the lower one. The lower agitator is usually driven by a wooden propeller mounted on the side of the fuselage or in the leading edge of the lower wing and connected through a reduction gear box to the agitator. The upper agitator or agitators can be connected to and driven by the lower one by a sprocket and chain. Propellers driving agitators should be controllable (see elsewhere, propeller brake) so that the agitator can be stopped during turn arounds. Stopping the agitator when the hopper gate is
closed prevents packing of material within the hopper. The propeller brake control can readily be coordinated with the hopper gate control.

**4-DX STEARMAN DUSTER**

Although the discovery of new highly toxic insecticides has led research agencies to emphasize the development of machinery for dispersing liquids, satisfactory equipment has also been designed for the aerial application of dust and baits. One such device, developed by the Tennessee Valley Authority for use with dust in the control of mosquitoes, is installed in a 4-DX (Stearman) biplane. Fig. 40. It consists of a hopper, venturi, agitators, and a valve (gate). A 24-cubic-foot plywood hopper is installed in the front cockpit. The interior corners are packed with a sealing compound and covered with a doped linen strip. A 3-inch piano-wire agitator of open drum type is located in the throat of the hopper and a 6-inch-diameter agitator of the same type above it. A 4-bladed wooden propeller and reduction gear located on the leading edge of the lower wing drives the upper agitator. The lower agitator

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**Fig. 37.**

*Courtesy Mississippi Valley Aircraft Service.*

Dust-Master Venturi (Side View). This venturi is built on a true NACA airfoil.
PART II

is operated by a sprocket and chain placed between the hopper and the fuselage covering. The ratio of the propeller speed to the agitator speed is 50 to 1.

An aluminum sliding gate valve controls the dust feed. It is operated by a hand lever in the left side of the cockpit. The venturi is actually a half-venturi. It is 30 inches wide and has plywood side walls. The major constriction is accomplished by a sheet-aluminum bottom panel which is built up into an airfoil section having a 43-inch chord very similar in appearance to an airplane wing section. The maximum depth of the venturi is 8 inches, and the depth at the point of maximum constriction is 3 inches. This point is directly beneath the valve opening. The venturi is fastened against the bottom of the fuselage, which serves as the top of the venturi structure.

The hopper in this installation was built of wood because of the structural failures caused by vibration in metal hoppers. It has been found, however, that certain metals, such as 24 ST aluminum, reinforced with light metal angles, are satisfactory for this purpose. For moist baits it is especially desirable to use a metal hopper. It is difficult to waterproof wood satisfactorily. Bait may be spread with equipment similar to that described above. Some changes are necessary, however. Others are desirable. For moist bait, and especially for sticky bait, it is important to provide a sturdier lower agitator, one that will churn the bait and feed it uniformly through the full width of the hopper throat. Bait, being less fluid than dust, requires slower as well as more powerful agitation. Both these requirements can be met by placing suitable reduction gears in the drive shaft between the wind-driven propeller and the agitators.

Fig. 38. Courtesy United States Department of Agriculture.

(Several triangular holes cut in heavy aluminum or steel plate)

Open slightly for light distribution. Open wider for heavier distribution.
DUSTER COMPONENTS

For spreading bait the venturi described above is not the most efficient device. It creates a suction at the hopper throat, which is desirable, but it does not broaden the swath. An outward horizontal thrust is needed for this purpose and is usually obtained in practice in one of two ways—(1) by making the venturi fan-shaped at the outlet end, with baffles in it to force the bait outward to the sides, or (2) by dividing the tail section of the venturi and spreading it to form two separate outlet passages, through which the bait is thrust outward to the sides.

CALIBRATION

Dusts usually flow at different rates because of the difference in carriers or filler used by various manufacturers. For this reason the airplane needs to be calibrated accurately for the particular dust being applied. To calibrate a duster, first disconnect the fan and lead offs to the boom. Next determine the amount of dust you will want to come through in a given period. The airplane flies 60 m.p.h. It has a 1 rod wide boom. This means that in one minute it will dust 2 acres. In one minute the airplane goes 1 mile—320 rods which equals 2 acres. If you are using 5 percent dust and you wish to apply 1 pound pure chemical per acre then you will use 20 pounds of dust per acre. Two acres, we found, can be dusted in one minute. It will then take 40 pounds to operate the hopper one minute. At the end of a minute weigh the dust

Fig. 39.  Venturi-Spreader.  Courtesy United States Department of Agriculture.

41
which has run through the hopper and adjust as necessary to enable 40 pounds to flow through in one minute.

**WARNING**: Because dust drifts so readily, do the calibrating in a shed or out in an open grain field where there are no sensitive plants to be injured.

**SAFETY FEATURES**

**VENTILATION IN THE COCKPIT**: Some of the insecticides now being used in both dusts and spray form are very toxic to humans. Coordination and vision are easily affected and cases of pilot health impairment have occurred. All cockpits should have good ventilators that will throw ample fresh air into the cockpit at the pilot’s will. This installation cost is small compared to their value as a precaution against poisoning.

**PADDING A PLANE INSTRUMENT PANEL**: At little extra expense you can pad with rubber the instrument panel. Experience has shown that in many cases serious accidents would have been reduced to minor ones had the panel been properly padded.

**USE OF SHOULDER HARNESS**: Air application planes should be equipped with shoulder harness of a quick release type. Harness would have minimized and in many cases eliminated the physical injury of many an agricultural pilot, according to the records of the CAB Safety Bureau and the crash injury studies which have been made.

**ADJUSTABLE SEAT RISE**: Seats that are adjustable up and down are of considerable advantage to pilots of varying stature.

The pilot should be able to raise his seat for extra visibility when he wishes.

United States Department of Agriculture
Fig. 40.

\[ \text{Courtesy 1-10X Stearman Bait Spreader} \]

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TYPES OF PLANES

In general, the biplane for dusting is superior to the monoplane insofar as the wing is concerned because the lower wing of the biplane tends to force the dust down to the ground. The same advantage holds for spraying except the difference is not quite so great.

In the case of the low wing monoplane, there is little if any difference in its efficiency in getting either dust or spray to the ground. The low wing monoplane, of which there are few currently in agricultural use, has the advantage of a wider wing span, making possible a corresponding wide swath. Specially designed aircraft for air application will probably incorporate the low wing feature in spite of its disadvantage in straight down visibility. 45 (See part 6 of this volume—experimental plane).

Size of Aircraft

DC-3's and Ford Trimotors have been very successful in some types of application. In 1947 Johnson Flying Service of Missoula, Montana, used DC-3's and Ford Trimotors in spraying 400,000 acres of fir trees

Fig. 41. Courtesy Mississippi Valley Aircraft Service.
Dust-Master Duster. Photo of standard Dut-Master installation on Lycoming Powered Boeing (Stearman) aircraft.
against the Tussock moth in Washington and Idaho, forests. The federal government operated a DC-3 in 1949 and 1950 grasshopper programs. In spreading dry bait the plane flew at an altitude of approximately 200 feet and obtained an effective swath width of 150 feet. Navy engineers' blue prints of the installation will be available through the United States Department of Agriculture, Grasshopper Control Division sometime soon.

**CANADIAN BAIT HOPPER:** The Canadian Department of Agriculture, in cooperation with the Department of Defense, has recently developed at the Suffield Experiment Station, an experimental device for the dispersal of bait which is worthy of note. It is installed in a C-47 (Douglas) airplane and is particularly significant in that no agitators are employed. The hopper holds approximately 1400 pounds of oil bait. The throat extends down through the floor of the fuselage and is cut off at an angle of approximately 30 degrees with the horizontal. The top of the hopper has a tight, fixed cover. Bait is introduced through hinged self-closing doors in the side walls of the hopper, near the top. The sides of the hopper are perforated with narrow horizontal slits. In flight, when the gate valve in the throat is open, the rush of air past the throat opening induces a vacuum within the hopper. The vacuum is relieved by the passage of air from within the fuse-
TYPES OF AIRCRAFT

large, through the slits in the hopper walls, into the hopper. This flow of air forces the bait lying next to the hopper walls down through the throat, preventing it from adhering to the walls or bridging over the throat. 41

Planes Used on Southern Plains

According to Timmons, 47 the plane most commonly used for spraying weeds in the Southern Plains states are small aircraft such as Aeroncas and Cubs with 85 to 95 h.p. engines carrying a maximum load of 40 gallons of spray liquid. This load is reduced under conditions of high wind or bad air. Larger planes are used to some extent and helicopters in the small fields and in fields adjoining oil well areas. Typical planes used on sage brush were Stearmans with 300 and 450 h.p. engines.

Fig. 43.  Courtesy Piper Aircraft Corporation.

The Lycoming version of the Piper. This model differs from the continental 90 version in that it has 108 h.p., large two-position flaps and balanced elevators. It will take off in five lengths of its own fuselage and use less space in all operations than any other certified airplane available today.

In January at the Miami Air Races, Miss Caro Bayley climbed to 27,510 feet a standard stock model, in April, Karl Crawford established a new record by looping one of these 105 models 1,874 consecutive times.
h. p. engines. These higher powered airplanes are most necessary where one to two hundred gallon loads must be lifted suddenly over power lines, high buildings or trees.

USE OF LIGHT PLANE SPRAYERS: Speaking before the 1949 Spray Conference at Manhattan, Dr. Stahler 172 said this about the light plane sprayer. "In analyzing the data secured through the questionaires sent to the States and Provinces in this area several trends or developments in aerial spray practices and equipment are indicated. The first of these is the almost universal favoritism developing for the light, ninety horsepower, monoplane of the Cub or Aeronca type as replacing the earlier favored war surplus Stearman biplane. Reason given for this change in plane type was in general the lower operational cost of the light monoplane.

In areas of the northern and northeastern part of this region the monoplane is especially favored and indicated to be much more definite in application than the Stearman which tends, through turbulence created by the lower wing, to break up the spray pattern and increase drift hazard. Any of us who have observed many types of planes in

Fig. 44. Courtesy Art Whitaker.
Tandem wheel landing gear, designed to roll and climb over all types of obstacles which would stop a regular gear. It is particularly valuable in the fall and spring months when most farms are wet.

To demonstrate the features of the tandem gear, a Super Cub 105 was landed in a soft field. Landings and take-offs were made in a patch approximately 175 feet long and liberally sprinkled with rocks, boards and clumps of sod, not to mention high tough reeds that in many places hit the wings.
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Spray operations have noted that the monoplane operated at low altitude can actually apply the spray material to the foliage in a true nozzle pattern whereas this can seldom be accomplished with a biplane having the spray boom close to the lower wing surface and in the orbit of its turbulence. Operators who work in the sand sage area were, however, almost universally in favor of the Stearman for this type of work—indicating that its higher load rating has an advantage in long hauls and high gallonage application.

Figure 43 shows the Piper PA-18 typical of the light plane dusters and sprayers. This model is a combination duster and sprayer. See Fig. 42. Light planes are adaptable for many spraying and dusting jobs. When it comes to mountain and high elevation work, higher horsepower equipment is often necessary. The Piper PA.18 is said to take-off and land shorter than any currently operated plane. It has a good climb and cruising performance. Its low cost of operating and maintenance makes it a money maker. This model can be supplied with the popular Whitaker Spray or Duster Unit or a combination sprayer/duster installation. It is also advisable with the tandem type wheels.

Fig. 45. Piper J-3  
Courtesy U. S. Dept. of Agriculture.
The tandem wheel landing gear shown in Figure 44 was especially designed by Art Whitaker to roll and climb over all types of obstacles that a farmer or rancher would be likely to encounter. It is particularly valuable in the fall and spring months when the ground of most farms is wet.

**A TYPICAL PIPER J-3 INSTALLATION**

This installation and the following one for the Stearman N2S were designed by the Division of Agricultural Engineering, United States Department of Agriculture. These installations are presented here as construction guides for operators wishing to build spray systems for the same or similar airplanes. Attention again, however, is called to the excellent spray and dust systems already available in kit form from manufacturers. Kits may prove to be more economical to buy and install than to build. Fig. 45. See list of manufacturers in Volume Six.

Fig. 46. Overflow for agitator. Courtesy U. S. Dept. of Agriculture.
PIPER CUB J-3 AIRPLANE: By Orve K. Hedden, Agricultural Engineer, United States Department of Agriculture. The equipment described here was developed in cooperation with the Bureau of Entomology and Plant Quarantine and fitted to a Piper Cub J-3 airplane used for the experimental application of sprays to field crops. Only a general description of the equipment is given and details are incomplete, as it is intended to serve solely as a guide to individuals in fitting spray equipment to the dimensions of their own planes. The equipment may be adapted for use on other small airplanes by making the necessary changes in dimensions and shapes of parts.

Federal Aviation Administration Aircraft Specification No. A-691 prescribes weight and balance limitations for several models of the Piper Cub. The specification applicable to the plane concerned should be consulted when adapting this equipment to any airplane. Appendix II of Federal Aviation Administration Manual 18 should be consulted as a guide in determining weight and balance characteristics of this equipment after its installation in an airplane.

If a metal pump propeller is used, airplane airworthiness should be care-

Fig. 47. Side view Piper J-3  Courtesy U. S. Dept. of Agriculture.
PART III

Fully studied and the propeller location selected to comply with the safety requirements outlined. If the propeller cannot be located as prescribed, the installation of suitable shielding is another method of meeting the safety requirements of this regulation. It would be well to consult with the nearest FAA Inspector regarding shielding materials before making such an installation.

• SPRAY TANK: The tank shown in Fig. 46 has a capacity of 28 gallons. The equipment installed in a Piper Cub J-3 with 75 HP engine was licensed to carry 211 pounds or about 25 gallons of water mixed spray. Extra volume in the tank prevents leakage during flight maneuvers and provides space for the foam which often forms when sprays contain considerable emulsifying or wetting agents. The tank is made from a 24-gage galvanized sheet iron. Some saving in weight could be made by using sheet aluminum.

Weight of the baffle may be reduced by making several large perforations in it. The shape of the tank bottom is such that it will drain completely in level flight or when on the ground. A filler opening of generous size is located on the right front corner of the tank. The vent tube (½ inch inside diameter) is extended outside the fuselage.

Fig. 48. Typical Piper Installation  Courtesy U. S. Dept. of Agriculture
by a light rubber hose about 46 inches long. The end of the hose can be attached to the lift strut and may be adjusted in position to produce a neutral or negative pressure in the tank not exceeding $\frac{1}{2}$ inch of water pressure when the plane is at normal flight speed with maximum delivery from the tank to spray boom. The float gauge may be an ordinary cork float properly oil and water proofed. A large hand hole is provided for cleaning and inspection.

The Fig. 46 illustrates the return of the overflow to the bottom of the tank as a means of agitation. This also reduces foaming of spray materials. Rear seat, rear safety belt, and rear control stick must be removed for installation in the Cub. The tank can then be attached to the seat cross-member fittings. Bracket bolts attach the tank brackets to the tubular cross bar in the rear seat compartment.

**PUMP:** The rotary pump used has a manufacturer's rating of 1,200 gallons per hour at 50 pounds per square inch at a speed of about 2,000 r.p.m. It is directly driven by a small propeller and is mounted by bolting to the combination first boom stay and pump base on the left side of the fuselage as indicated in Fig. 47.

Fig. 49. Typical Piper Installation. Courtesy U. S. Dept. of Agriculture.
**PROPELLER:** The propeller that drives the pump is made from clear straight-grained white pine, carefully selected for freedom from small knots or imperfections. It is four-bladed and 19 inches in diameter. The blades are 3 inches wide and pitched 38 degrees. It is sanded smooth, statically balanced, and given one coat of clear shellac. When this coat is dry and sanded smooth, the blade ends are taped with 1½ inch pinked edge tape, with care to retain the propeller balance, and a second coat of shellac is applied.

**BOOM STAYS:** Four boom stays under each wing hold the spray boom in place. These are made from ½ inch diameter, 20-gage seamless-steel tubing. They are numbered outward from the fuselage toward the wing tip. The first three clamp to the lift struts and the outer boom stay attached to the wing spars in the wing tip. These stays and clamps are shown in Figs. 48 and 49 and 50. In addition to those shown, four clamps similar to the stay lug clamps shown in Fig. 48, except without lugs, are required for each size of streamlined lift strut, to hold the first boom stays in position. The approximate location of the stays is shown in Fig. 45.

![Typical Piper Installation](image-url)
TYPES OF AIRCRAFT

● SPRAY BOOM: The spray boom for the plane consists of two lengths of 3/4 inch outside diameter, 18-gage seamless steel tubing, as shown in Fig. 46. Pipe couplings cut in half are brazed to each length of tube spaced as indicated. The male hose fitting brazed to the end of each tube nearest the fuselage is a lightweight, 5/8 inch inside diameter fitting. The boom clamps to the boom stays by means of pressed steel tube clamps, AN741-T6, welded to the boom stay. These clamps are a standard item sold by most aviation supply firms. The fore and aft location of the boom can be seen in Fig. 47.

● SPRAY NOZZLES: Spray nozzles used are of the hollow-cone-type with a 1/16 or 5/64-inch diameter orifice. Their capacity is respectively .22 and .44 gallons per minute at 50 pounds per square inch. Openings in the boom which are not in use are plugged. Nozzles are not mounted under the fuselage as those on each side give coverage over the center of the sprayed swath. More spray material should be released near the wing tips than near the fuselage, because the spray from these positions is spread over a wider area and consequently more material is required to give a uniform density of deposit over the entire width of the sprayed swath.

Fig. 51. Typical Piper Installation. Courtesy U. S. Dept. of Agriculture.
Using 46 nozzles of 1/16 inch orifice at 50 pounds per square inch would supply 10.1 gallons per minute, and by adding 10 of the 5/64 inch orifice nozzles (5 at the outer end of each spray boom) supplying 4.4 more gallons per minute, a total of 14.5 gallons of spray per minute would be obtained. This is not to be considered as a recommended nozzle arrangement for this swath width and speed, as several other conditions including length of spray boom, flight height, type of airplane, and other factors will influence the correct nozzle placement to use in each case. Other delivery rates in gallons per minute may be computed as follows:

\[ D = \frac{R \cdot S \cdot W}{495} \]

- **D** = Delivery required in gallons per minute
- **R** = Application rate in gallons per acre
- **S** = Flight speed in miles per hour
- **W** = Swath width treated in feet

Fig. 52. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
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- **PRESSURE RELIEF VALVE:** Referring to the circulation diagram shown in Fig. 46, it will be noted that a pressure-relief valve is shown in the return line from pump to spray tank. This is an adjustable, spring-loaded valve located in the cockpit where the pilot can manually set the desired spray-line pressure while in flight. The valve will then automatically bypass excess fluid back to the spray tank.

- **PRESSURE GAGE:** A pressure gage reading up to 100 pounds per square inch is mounted on the instrument panel where it is readily visible to the pilot at all times. It is connected to the pressure line leading to the spray boom by means of a small copper tube and tube fittings.

- **HOSE LINES:** The hose used has a \( \frac{3}{4} \) inch bore and is of synthetic rubber unaffected by oils. Four lengths are required; one from tank outlet to pump inlet, one from the spray-delivery line to the relief valve, and two from the spray delivery line—one to each side of the spray boom. Ordinary screw-tightening hose clamps are used for attaching hose to fittings.

Fig. 53. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
STEARMAN N2S INSTALLATION

This information is offered as a guide for the installation of a boom and nozzle-type apparatus for biplanes such as Stearman or Navy N3N. See Fig. 52 and 58.

Construction and material specifications similar to those for the Piper installation are available. Write to Air-Applicator Institute.

• TANK: Tanks should preferably be constructed of aluminum so as to be as light weight as possible. The tank shown in Figure 53 was constructed of galvanized sheet steel. As the equipment was used only for experimental purposes the tank was smaller than would be desirable for use in large-scale field operations. Tanks of 80 to 90 gallons capacity have been used in a Stearman by enlarging the opening in the front cockpit cowling, removing front cockpit controls and instruments, and removing the yoke from the front end of the control column.

The tank shown can be easily installed in the front cockpit by removing only the seat and front control stick. The bottom of the tank was shaped to permit complete drainage when the plane was on the

Fig. 54. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
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ground or in flight. The cover plate in the top of the tank permits access for cleaning or making repairs. The tank filler neck and air vent were fitted to this cover plate. A fine mesh screen-wire cylinder 10 inches long was fitted into the filler neck. The screen was removable for cleaning. The air vent was 1 1/8 inch outside diameter tubing and a hose was extended from the tubing up to the upper wing. The flanges for connection of the outlet and pressure-relief bypass lines at the bottom of the tank were attached by machine screws and solder. The front flange was 1 1/2 inch pipe size and the one at the rear 1 inch pipe size.

The 1 1/2 x 1 1/2 x 1 8 inch aluminum angles were riveted to the inside of the tank so that the rear tank brackets, part 16, Fig. 53, could be bolted to them. These brackets were then clamped to the seat posts in the front cockpit. The front end of the tank was supported by front tank brackets, part 15, Fig. 53, which were clamped around the cross-member between the lower longerons at Station 2 in the fuselage. The emergency dump-valve assembly, part 23, Fig. 54, was provided with a connection for a ½ inch drain valve. A pull-cable control was extended from the dump valve to the cockpit.

Fig. 55, Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
PUMP: A centrifugal pump, see Fig. 6, was used so that suspensions containing abrasive material could be used. The pump had 1 1/4 inch P.S.I. suction opening and 1 inch P.S.I. discharge opening. It was necessary to build up a special outboard bearing assembly, part 4, Fig. 55, for this pump due to the thrust and radial load of the propeller. This pump will deliver as much as 45 gallons per minute at 25 pounds per square inch with the propeller shown, part 17, Fig 54.

A tachometer was installed on the pump shaft with a direct-reading dial in the cockpit. This installation is not essential except for test purposes. The installation of a brake on wind-driven propellers prevents wear of pump parts when not spraying and permits stopping the pump in case of breakdowns. Details of the pump support, part 3, Fig. 56, may be varied to fit other makes or types of pumps. The front clamps, part 1, Fig. 56, were attached to the landing gear cross-tube and the rear clamps, part 2, Fig. 56, to the diagonal members between lower longerons.

LIQUID LINES AND HOSE: One-inch aluminum pipe was used to make up the line from the pump to the point of connection with the

Fig. 56. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
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boom. Aromatic resistant gasoline and oil hose should be used for all rubber hose connections because natural rubber will break down when exposed to such solvents as xylene.

SPRAY BOOMS: A 1-inch tee was fitted to the lower end of the aluminum pipe extending down through the fuselage to the boom. The boom hose nipples, part 12, Fig. 57, were screwed into the ends of the tee and connected with hose to the boom pipes. The spray booms, part 13, Fig. 57 were 1-inch chrome molybdenum .049 gage tubing. Round tubing was used to permit rotating the boom so that the position of the nozzle orifices in relation to the air stream could be varied. The 4 ¼-inch spacing for nozzle connections permitted 82 openings. When nozzles with a comparatively high discharge rate are used, the unused openings are plugged. The boom pipes were located about 9 inches below the surface of the lower wings approximately midway between front and rear wing spars. The boom stay brackets, part 10, Fig. 57, were attached to the ends of the compression ribs adjacent to the wing spars. See Fig. 52.

Fig. 57. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture
PRESSURE REGULATOR: When a gear— or other positive-displacement-type pump is used, it is essential that a pressure-relief valve be installed to prevent excessive high line pressure when the spray valve is shut off. A centrifugal pump will not build up a pressure high enough to damage the spray system but use of a pressure regulator is advisable in order to maintain uniform pressure regardless of rate of discharge. Rate of discharge is regulated by varying the number of nozzles used and the spray pressure will vary with a change in the number of nozzles unless some means of pressure regulation is used. The liquid bypassed through the relief valve may be returned to the tank to provide agitation, which is essential when suspensions or emulsions are used. The outlet of the bypass line should be below the surface of the liquid in the tank to prevent foaming.

NOZZLES: The nozzle assembly shown, part 37, Fig. 59 consists of a check valve, street elbow, and hollow-cone-type nozzle. The check valves prevent drool and loss of spray material after the main shut-off valve has been closed. The street elbows place the nozzles slightly below the boom to prevent turbulence created by the boom from carrying some of the spray back up onto the boom where it later drools off in rather large particles.

For control of forest insects a hollow-cone-type nozzle with \( \frac{1}{8} \) inch diameter orifice has been satisfactory. For crop-pest control work, which is done at a comparatively low elevation of flight, hollow-cone-
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type nozzles with 1/16 and 5/64 inch diameter orifice have been used. If the orifice size is decreased, it will be necessary to use a greater number of nozzles to maintain the same flow rate. The nozzles should be spaced along the boom to provide as uniform distribution of the spray liquid as possible across the swath width. It is usually necessary to use more nozzles toward the outer ends of the boom than in the center. A check on the distribution of spray may be made by placing pieces of paper at regular intervals across the expected swath and observing the spray pattern after the plane has passed over.

PRESSURE RELIEF VALVE: The valve shown, part 34, Fig. 59, is a common bronze hydraulic pressure-relief valve set at 25 pounds per square inch. These valves are set at the factory for the desired pressure and this setting may be varied about 20 per cent up or down by changing the tension on the valve spring. For greater variations it is necessary to secure different springs or change the entire valve. The valve shown is the 1-inch size, which has a bypass capacity of about 23 gallons per minute at 30 pounds per square inch. The valve is installed so that the adjustment hand wheel can be reached by the pilot while in flight so that the pressure can be easily adjusted.

Fig. 59. Typical Stearman Installation. Courtesy U. S. Dept. of Agriculture.
SPRAY SHUT-OFF VALVE AND PRESSURE GAGE: The spray shut-off valve, part 36, Fig. 59, is the common lever type cam-action quick-opening gate valve. This type valve provides a straight-through full-area opening. It should be the same size as the pump discharge line so as not to restrict flow.

The pressure gage, part 33, Fig. 59, is installed in the cockpit and connected with ¼-inch flexible tubing to the pressure line between the pump and spray shut-off valve. Any hydraulic pressure gage of 0 to 60 pounds range, with a dial about 2½ inches in diameter, is satisfactory.

CONTROLS: Controls must be located so they are readily accessible to the pilot. The spray shut-off valve and brake-control lever, parts 18 and 19, are located immediately forward of the throttle on the left side of the cockpit. The details of fabrication of the controls are shown on Fig. 59. For the brake the linkage between part 22 and the tension spring was a curved piece of flat metal, so that as the top end of part 22 is turned up past center the brake is automatically held in the engaged position.

GENERAL: All alterations and additions to aircraft must be made in accordance with instructions in FAR. The work must be done under supervision and certified by a licensed aircraft and engine mechanic and all installations must be inspected and approved by an authorized
TYPES OF AIRCRAFT

FAA inspector. It is advisable to contact the local inspector before work of converting to a spraying plane is started. He can advise regarding a reasonable gross weight and center gravity limitations.

N2S-3 SUSPENDED TANK

In mosquito-control research two N2S (Stearman) biplanes are being employed. Each is equipped with a 75-gallon auxiliary jettisonable fuel tank suspended from a bomb shackle beneath the fuselage. These tanks are standard Army Air Corps items. One, used for the dispersal of liquid insecticides, has underwing spray booms fitted to it. The other has been reconstructed to provide for the dispersal of dust.

These installations have the following advantages; The front cockpit is left free for an observer (but not in conjunction with a full insecticide load), the tank can be quickly attached or detached from the plane and other tank units substituted for the dispersal of different insecticides. The disadvantages, especially from a control-operation standpoint are as follows: The tanks are of limited capacity, they create a considerable drag on the aircraft, and the aircraft engine must be cut out when the tanks are refilled.

The installation that is used for applying liquids has a centrifugal pump mounted on a special bracket on the front of the tank. The

Fig. 61. Bell Helicopter.  
Courtesy Bell Aircraft Corporation.
pump is driven by a propeller, and its output is carried through 1-inch aircraft tubing, curved to fit the tank, to a 3-way valve mounted on the side of the tank. This valve, which is controlled from the cockpit, directs the liquid either into the spray booms or back into the tank, thus providing necessary agitation for materials in suspension. The spray booms are suspended from the lower wings of the biplane. The arrangement of nozzles attached to the spray booms may be varied to provide a delivery rate of 5 to 14 gallons per minute.

For use in spreading dust the tank was converted by cutting away the bottom two-thirds of the tank and making new sides and a bottom from 0.035 inch sheet metal. Obstructing bulkheads were removed, except the rear one, which was completely sealed to block off the rear portion of the tank. Steel tubing, ½ inch square, was welded around the edge of the upper portion of the tank as a frame and reinforcement. The new portion of the hopper was bolted to this frame.

A gate for releasing the dust was made by cutting 14 crosswise slots, 1 by 4¾ inches, in the new tank bottom. Matching slots were cut in a sliding door, which was made of 0.035 inch sheet aluminum. This door was fitted into a channel that runs the length of the tank, and can

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Fig. 62. Courtesy Bell Aircraft Corporation.
Bell Aircraft's utility helicopter daily is increasing its stature as a revolutionary aid to agriculture. The helicopter pictured above is dusting a citrus grove in Texas with sulfur—another helicopter first.
TYPES OF AIRCRAFT

be opened or closed by means of a lever in the cockpit. An agitator 53 inches long, with four 1/16 inch wide blades set to form a circle 4 1/2 inches in diameter, was mounted above the gate by a bearing at the front and rear ends. The agitator is turned by a wind-driven wooden propeller mounted on the front of the tank.

The installations described above are experimental mechanisms, and in their present form are of limited value in control operation. (For full details of this installation refer to United States Department of Agriculture Bulletin ET 262, October 1948.)

SIKORSKY HELICOPTER

Like most pieces of equipment the helicopter, Fig. 62, has many advantages and some disadvantages. Among some of the advantages are the:

Fig. 63. Hiller-360

Courtesy United Helicopters Incorporated.

This installation features continuously variable metering of dust discharge, motor-driven rotary gate valve, motor-driven internal spiderleg agitator, and vibratory agitator. Hopper capacity 600 lbs., loading at shoulder-height. Airblast over 75 m.p.h. through discharge tubes equipped with cascade baffles for proper aeration discharge rates controllable from pilot's seat through rheostat controls, which can be pre-calibrated. Master on-off control on collective pitch stick under pilot's finger tips. Average effective swath width 60-70 ft., coating on top and bottom of vegetation virtually equal.
ability of the helicopter to maneuver at various speeds. This makes it ideal for small fields and close quarters where there are obstructions. The down thrust of the air is often an added advantage in getting the chemicals in contact with the under sides of foliage, however this advantage is lost somewhat with forward speeds of over 20 m.p.h.,

The helicopter is well adapted for loading which can be done on the spot, eliminating long ferry runs. Two of the limited factors of the helicopter are the high original cost of the aircraft and the relatively small load capacity. This latter factor is somewhat offset by the helicopter's ability to load from almost any spot. Following are some of the specific advantages of the helicopter over the fixed wing aircraft and the ground rig as taken from Sikorsky literature.

The specific advantages which the helicopter claims over the airplane and ground equipment, found only in the helicopter are as follows:

1. The rotor down-wash of the S-51 supplies over 2,000,000 cubic feet of air per minute for crop agitation. This permits complete coverage of even the heaviest foliage and allows treatment of crops such as orchards, hops, corn, grapes, and sugar cane which heretofore has been uneconomical by any other method.

2. Controlled variation in swath width and velocity of air as a carrier into the crop by changing speed and/or height. This makes possible frost prevention, moisture elimination and treatment of all sized plots—small as well as large.

3. Precise boundary control of area of application. Lawsuits for damages caused to crops in neighboring area by unintended application from airplanes of insecticides which were injurious to them, though not to the crop treated, amounted to several hundred thousand dollars during 1948.

4. Treatment by helicopter feasible at higher temperatures and wind velocities, due to controlled rotor down-wash velocities.

5. And perhaps most important — the helicopter offers much greater versatility.

The most efficient modern ground equipment has a swath width of less than thirty feet and travels a maximum of ten m.p.h. Under ideal conditions, it would be possible to treat a little more than one-half an acre per minute or thirty-six acres per running hour. The average conventional airplane has a swath width of less than forty feet and flies at ninety m.p.h. Under ideal conditions, it would be possible to treat seven acres per minute, or four hundred and twenty acres per flying hour. Quite obviously, due to the necessity of landing at an established air strip for reloading and the necessity of maneuvering
out of the field being treated for reversal of direction, the ratio of treatment time to flying time is low. A conservative figure would be twenty per cent treatment time to flying time, which would result in eighty-four acres per flying hour.

The S-51 helicopter, with a swath width of seventy feet or less and an eighty m.p.h. ground speed, could treat under ideal conditions a maximum of six hundred and seventy-two acres per hour. However, to obtain maximum results a slower speed of, say forty m.p.h., and a ratio of eighty per cent treatment time to flying time would result in two hundred and sixty-eight acres per flying hour. This figure is over seven times that of the ground equipment and over three times that of the conventional airplane.

Fig. 64. Hiller-360
Courtesy United Helicopters Incorporated.
This installation features high pressure pumps, hydraulic agitation, automatic shut-off on valve heads, and interchangeable nozzle disks and cores for varying discharge, droplet size and spray pattern. Optional installation includes round tanks total fluid capacity 85 gallons, maximum pumping rate 36 gallons per minute at 100 P.S.I. On-off control through electrically driven multiple valve, with swath under pilot's fingertips on collective pitch stick.
Bell Helicopters in Agriculture

From a half dozen helicopters employed early in 1947 for aerial application of agricultural chemicals, the number of Bell Aircraft model 47's in this field increased to 83 by the end of 1949, see Fig. 62. In addition, most of the 100,000 flight hours which Bell helicopters have accumulated in the United States and 14 foreign countries in the three year span have been logged while performing agricultural assignments.

Although completely detailed reports are not available, David G. Forman, Manager of Bell Aircraft's Helicopter Division, conservatively estimates that upward of 15,000,000 pounds of plant protectants and herbicides were applied by Bell helicopters during the 1949 season alone. Approximately half this work was done in the Western States. In order to meet this competition, the price of the helicopter service had to be at the same level as other agricultural aircraft. Even more favorable to the helicopter case is that farmer preference and support in these areas was generally strong after the attributes of helicopter application were demonstrated.

Besides the routine agricultural dusting and spraying jobs, Bell helicopter operators also engaged in other aerial projects associated with agricultural or pest control—such as seeding and re-seeding, fertilizing, frost control, fogging against insects and forest fire fighting.

This same maneuverability has permitted the helicopter to ignore unfavorable weather which ordinarily would ground fixed wing aircraft. In the Cape Cod area last year, helicopters were able to begin spraying for control of the Gypsy Moth at the scheduled time of 7:00 a.m. on many days when fog grounded airplanes until later in the morning. Last year also saw an increase of about 20 per cent in night flying by helicopter, permitting the application of such chemicals as leaf defoliants, which must be used under moist, humid conditions. Application at this time when air conditions are highly favorable for deposit of pesticides holds much promise for wide use of the helicopter. Considerable night flying was done in Columbia, South America, on banana trees. In Florida, ground recording instruments showed that the temperature was raised from 32 to 36 degrees. Potato and tomato crops received the benefit of these treatments.

The distribution of chemical fertilizer is another phase of agriculture in which the helicopter is proving itself. Recently one of the Bell operators deposited 63½ tons of sodium nitrate in 14 hours of flying, for an average of 4½ tons an hour. The speed with which this job was accomplished, Forman points out, speaks well for the helicopter's ability to operate right out of the field that is being treated, if necessary. In this instance, 128 landings for reloading were made by one helicopter in 4 hours and 50 minutes.
TYPES OF AIRCRAFT

In addition to the United States, 35 Bell helicopters are in operation in South America, Europe and Africa in the field of agriculture. In Argentina they have controlled effectively the locust swarms which annually cause billions of dollars worth of damage. In Sardinia they are being used to combat the malaria-bearing mosquito, and in Brazil the coffee weevil is the object of its attack.

Cost of helicopter maintenance has been cut sharply. Maintenance has been reduced 300 per cent on the transmission alone and similar improvements have been made in other working parts. Practical application and experimentation also have increased the efficiency of the dust, spray and fog equipment, completely new and for the most part untried three years ago.

A third helicopter, Figs. 63 and 64, which has become very popular as an agricultural aircraft is the Hillercopter, a large number of these have been placed in agricultural service during the past two years. The Hillercopter is both economical in original cost and operation.

VERIFY ALL DOSAGE RECOMMENDATIONS WITH LOCAL AUTHORITIES BEFORE USING
FOREST SPRAYING EQUIPMENT

Forest spraying for such pests as the tussock moth and the spruce budworm has grown rapidly. With the highly successful treatment of more than 400,000 acres in Northern Idaho in 1947 for the tussock moth forest spraying was proved both economical and efficient. In 1950 more than 1,000,000 acres of fir timber were sprayed in Oregon for spruce budworm. BT's, twin engine Cessnas, DC-3's and Ford Tri-motors were used in these operations.

**SPECIAL REQUIREMENTS:** Forest spraying is done mostly in mountain areas. This involves high elevation and rugged terrain. Airplanes, therefore, must have plenty of reserve power for operating at altitude and for maneuvering in close quarters such as encountered when flying in canyons and draws. This type of flying requires airplanes with good performance and pilots who understand mountain flying. (See Volume III for discussion of mountain flying hazards.)

**Suspended Boom Type (C-47 Douglas)**

A C-47 (Douglas) Fig. 27, airplane has been equipped for the dispersal of DDT solutions in the control of gypsy moths. The installation consists of two 460 gallon aluminum rubber-lined tanks, a pump, and underwing spray booms. Two-inch pipes conduct the insecticide from the tanks to quick opening gate valves. Between the gate valves is a T leading into a 2½ inch line, which leads to the pump. From the pump a 2 inch line carries the liquid to another T, which connects to two 1½ inch aircraft aromatic-resistant hoses inside the center sections of the wings. The outer ends of these hose sections extend down through the lower surfaces of the wings, making connection to the spray booms.

The tanks are placed one in front of the other, 42 inches apart, in the forward end of the fuselage. The pump, which is powered by a 9.2 h.p., air-cooled gasoline engine connected directly to it, is placed in the ater end of the fuselage. The pump is a 2-inch centrifugal type with a capacity of 200 g.p.m. (gallons per minute). At a nozzle pressure of 25 p.s.i. its capacity is approximately 160 g.p.m At 40 p.s.i. its capacity drops to approximately 120 g.p.m.

The booms are of streamlined steel tubing of 2-inch nominal size. Each is approximately 24 feet long and extends from a point 17 feet from the center line of the fuselage outward to about 6½ feet from the wing tips. They are suspended approximately 12 inches below the underwing surface one-third of the distance forward from the trailing edge of the wings. Each boom is equipped with 18 nozzle openings,
some of which may be plugged in order to regulate the discharge rate of the insecticide. This airplane operates at a speed of approximately 150 m.p.h. about 150 feet above the forest canopy.

Numerous other modifications of the suspended-boom type of installation are used. One of the simplest and least expensive of these has been constructed for control of the white-fringed beetle. It is principally used for insecticides in solution, but it is also suitable for any of the emulsions that do not require constant agitation.

A 75-gallon tank is installed in the front cockpit of an N3N biplane, with a 2-inch outlet connected with a T to a 1-inch aluminum boom. Holes, 7/32 inches in diameter, spaced 9 inches on centers, are drilled along the entire boom length on the trailing side, slightly below center. A sheet-iron "breaker bar" is shaped around the upper back segment of the boom, approximately 3/4 inch from it. The leading edge of this bar is flared slightly upward and the trailing edge downward and backward. This flare gives a venturi action between the bar and the boom, which increases the velocity of the air that passes the outlets in the boom. This increase in velocity not only serves to increase the rate of flow of the insecticides but it also decreases the variation in the flow rate. When the liquid is released in flight, it emerges from the holes in the boom, impinges upon the lower edge of the breaker bar, and is released from the bar as a spray.

The principal advantage of this type of installation is that it is simply constructed with no moving parts. Its use consequently reduces repairs and operational delays to a minimum. Since the installation has no pressure pump, constant pressure on the liquid insecticide is not maintained. Therefore, as the level of the liquid in the tank is lowered, the flow rate diminishes. This disadvantage, however, may be at least partially neutralized by the deceleration of the aircraft during the period of dispersal. Investigations are currently being conducted with modifications of this equipment which may provide greater uniformity in flow rate without the use of a pressure pump.

**Wing Tip Nozzles**

The wing-tip-nozzle assembly, Fig. 65, was developed for gypsy moth control in 1945. The installation was made in an N3N biplane. It consists of a 90-gallon tank and aluminum tubing inside each lower wing to carry the insecticide solution from the tank through a pressure pump to twin nozzles mounted under the lower wings close to the wing tips. A sump at the bottom of the tank has a dump valve for the quick release of the insecticide load in emergencies. The pump is of a gear type, equipped with a breaking device, which is mounted on the under side of the fuselage along the center line of the aircraft. It is
powered with a 6-bladed propeller, which rotates at approximately 2700 r.p.m and develops a pump pressure of 140 p.s.i. when the aircraft is traveling at an air speed of 80 miles per hour.

Each wing-tip-nozzle assembly consists of tubing which runs from the feeder line within the wing downward about 18 inches to a section of cross tubing about 12 inches long. One nozzle is fitted to each end of this cross tubing and directed at an angle of 45 degrees forward, downward, and outward.

Self-closing electric-solenoid valves are mounted directly behind the twin nozzles to eliminate drooling when the flow of liquid is cut off at the end of each flight strip. These electric valves are controlled by a pistol-grip trigger mounted on the end of the control stick, so that it is unnecessary for the pilot to remove his hand from the throttle when actuating the valves. When valves are closed the liquid insecticide flows through the relief valve into the bottom of the tank providing some agitation to the concentrate within it.

Flat spray nozzles, which allow a total discharge of approximately 20 gallons of insecticide solution per minute, are used. The output can be readily varied by using nozzles with a larger or smaller orifice and adjusting the pressure to obtain the desired atomization of the liquid.

The wing-tip-nozzle design, although perhaps not as effective as the suspended boom type for treating field crops, has the advantage of being less expensive and producing less drag on the aircraft. However, since a gear-type pump is employed to develop required pressure for this installation, its use is restricted to liquid insecticides that contain no abrasives or suspended solids.

**Wing Tip Nozzle with Tail Nozzle**

Although the installation described above takes significant advantage of the single-tip vortex to achieve a wide swath and satisfactory distribution of insecticide for forest work, a twin-nozzle device similar to that used at the wing tips has recently been added to the installation, attached to the under side of the fuselage at the tail. These additional
nozzles give a more even distribution of insecticide and are particularly important for low-flying applications to field crops. With this arrangement the discharge rate from the various nozzles is adjustable so that the amount emitted from the tail-nozzle assembly is less than released by either wing-tip nozzle assembly. 41

The Department of Gypsy Moth Control of Massachusetts used spinner discs successfully to apply wettable DDT powders. They have also been used in grasshopper and tussock moth control. Spinner discs do not clog with gummy substances which plug ordinary nozzles.

**Spinner Disk**

The spinner-disk assembly, Fig. 67, provides a means of dispersing heavy suspensions and emulsions which may have abrasive or other characteristics that prevent their use in any type of spray-nozzle assembly. It was first installed on a fixed-wing airplane in 1944 and used in spraying forest areas for gypsy moth control. It consists of a 110-gallon aluminum tank mounted in the front cockpit of a White Standard biplane; a 2-inch pipe line extending from the tank outlet to the center of a 2-inch cross boom which is attached to the lower longerons at the rear of the pilot's cockpit; an insecticide-distributing assembly mounted at each end of the cross boom; and gages and operational controls mounted in the rear cockpit, readily accessible to the pilot.

On the forward end of each insecticide-distributing assembly is mounted a 6-bladed fan connected by a steel shaft about 18 inches in length to two 14-inch-diameter, concave steel disks spaced ½ inch apart, mounted at the rear of the assembly. (See diagram 67. Power to rotate the insecticide-dispersing unit (located outside the slip stream, 6 feet from the fuselage) is derived from the forward motion of the aircraft. Both units are equipped with brakes so constructed that they can be operated by a single lever mounted in the pilot's cockpit.

When the airplane is flying at approximately 80 m.p.h., these dispersing units rotate at about 2500 r.p.m. The insecticide flows by gravity from the tank, through the connecting pipe line and cross boom, to the rear bearing housing of the distributing unit, into a 2 5/8 inch diameter cavity in the center of the disks. It then flows onto and spreads
thinly over the concave surfaces of the disks. By centrifugal force it is thrown or sprayed into the surrounding air from the peripheries of the disks. The air blast resulting from the forward movement of the aircraft further breaks up the liquid insecticide that has thus been released. Valves controlling the rate of flow of the insecticide are located in the distributing heads close to the spinner-disk assembly, where they prevent drooling when the flow of liquid is cut off.

This apparatus has effectively dispersed DDT, lead arsenate, and cryolite in concentrated form. Since it does not depend on pressure pumps or nozzles, it can be used for almost any liquid that will readily flow by gravity. It is a relatively expensive installation, however, because of the special machining required in the construction of the high-speed dispersing units. Another disadvantage is that, because constant pressure on the insecticide is not maintained, the flow rate is not uniform. For the dispersal of insecticides now most commonly used, therefore, other types of mechanisms perhaps have greater merit.
FAA’s MODIFICATION REQUIREMENTS

The Federal Aviation Administration is responsible for setting minimum standards of airworthiness for all aircraft. This includes agricultural aircraft as well as those aircraft which are used for carrying passengers. Prior to October 11, 1950, sprayers and dusters were required to be certificated in the same category as those aircraft which were used for hire in charter work and they had to meet the same standards.

It became obvious to the FAA that the agricultural airplane met an entirely different need and service from that of other commercial airplanes and therefore differed in objectives of maintenance and modification. In line with this thinking, Part 8 of Federal Air Regulations was adopted by Federal Aeronautics Board and became effective October 11, 1950.

FAA Part 8

F.A.R. Part 8: F.A.R. Part 8 establishes airworthiness standards for a restricted category of aircraft which takes in agricultural and industrial or other special purpose aircraft.

Copies of Part 8 may be obtained for five cents by writing to the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C. Request F. A. R. Part 8, Aircraft Airworthiness, Restricted Category. Briefly, Part 8 provides for the type certification for (A) aircraft which have not previously been certificated, (B) aircraft which have been manufactured for the military services and subsequently modified for special purpose, (C) aircraft which have been previously certificated in another category and modified for special purpose.

Airworthiness certificates may be obtained for the type certificated aircraft just mentioned after being inspected by the FAA and found to be in good state of preservation, repair and condition for safe operation.

Under the restricted category (Part 8) no gross weight limits are specified by the FAA, however, operating limitations are made a part of the airworthiness certificate and it falls upon the owner of the airplane to demonstrate by test or experience to the satisfaction of the FAA safety agent that the aircraft can be operated safely with the modifications made and the gross weights established.

Part 8 is new and will require interpretation. The Federal Aviation Manual 8, Fig. 68, spells out the requirements of F.A.R. 8.
Sevdy-Sorensen
1949 J-3 Sprayer Instl.

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WEIGHT & BALANCE INFORMATION FOR ENTIRE SPRAYER KIT
ADDED WEIGHT 84 LBS. ARM 32.8 IN.

THIS SPRAYER UNIT IS EQUALLY ADAPTED TO
PIPER J-3C OR PA-11 WITHOUT ANY MODIFICATION TO
SPRAYER UNIT OR AIRCRAFT

Fig. 69. Courtesy Sevdy-Sorensen Aviation Incorporated

Weight and balance data for Piper Sprayer Installation.
FAA REQUIREMENTS

In addition to the operating limitations, aircraft certificated under Part 8 (restricted category) are prohibited from operating over densely populated areas, in congested areas, or in the vicinity of busy airports where passenger transport operations are being conducted unless authorization for such flight has been given by the F.A.A. in the form of a waiver of this requirement.

Special purpose aircraft also are prohibited from carrying persons or cargo for compensation. Seed, dust, fertilizer and chemical are not considered cargo in the case of agricultural aircraft. Also persons other than the necessary crew are prohibited.

In the case of quick convertible aircraft, where the spray or dusting unit can be removed, the airplane may carry a multi-airworthiness certificate.

Modifications

Modifying airplanes for agricultural use by installing hoppers, tanks, spray booms, pumps and other equipment may result in a change in strength of the plane, its weight and balance and may change its flight characteristics.

● WEIGHT AND BALANCE: One of the items that the F.A.A. is particularly concerned with in the airworthiness of an airplane is its weight and balance or in other words its center of gravity location and displacement under various loaded conditions. Fig. 69 shows the weight and balance data for a Piper Cub installation of a Sevdy-Sorenson Spray Unit. This is a typical detailed listing of weight and balance information.

● STRUCTURAL CHANGES: Any changes made in the modification of an aircraft for agricultural use which affects its strength (structural member) is of concern to F.A.A. Manuals 18, 03 and 04 are useful as guides in such modification work.

● MODIFICATIONS AFFECTING FLIGHT CHARACTERISTICS: Installing of venturies and spreaders or booms in such a manner as to affect the flight characteristics is also of special concern to F.A.A. This alteration or additions must be demonstrated as safe and approved by F.A.A. F.A.A. aircraft agents at district F.A.A. offices and F.A.A. aircraft designees can authorize and advise relative to the requirements and compliance in all matters of structural changes or changes which might affect the flight characteristics and the weight and balance. See Volume Six for a list of F.A.A. District Offices.

● PERIODIC INSPECTION: Agriculture aircraft must be given a 100 hour inspection with each 100 hours of operation and must be issued airworthiness certificates annually.
Sulfur Fire Prevention

Because of the hazardous nature of sulfur dusts the F. A. A. has issued specific instructions relative to the construction and operation of hoppers and arrangement of exhaust stacks. See F. A. A. Airworthiness Maintenance Bulletin No. 63 and 89 for complete discussion.

Although the following suggestions are not made in the form of a regulation, compliance with this bulletin is required in order to obtain aproval and certification.

1. The engine exhaust system must be so arranged that it will not discharge exhaust gases under or along the bottom of the airplane.
2. The fuselage aft of and in the vicinity of the hopper must be completely bonded. All fittings and struts adjacent to the hopper should be bonded to the fuselage and the hopper parts should also be bonded to each other and the hopper bonded to the fuselage.
3. The agitator shaft should be provided with sealed bearings or the bearings should be readily accessible for lubrication.
4. The hopper gate should be of non-ferrous material well fitted to its guide channels to prevent friction and accumulation of dust in the channels and should be bonded to the hopper.
5. The lower surface of the fuselage in the immediate vicinity and three feet aft of the hopper opening must be covered with thin gauge metal or plywood.

Compliance with the above provisions is in the interest of safety and will be prerequisite to recertification of your airplane. An appropriate entry should be made in the aircraft log book of your airplane for the benefit of field inspectors, recording the date of compliance with this bulletin. Airplanes which are being operated as crop dusters that do not comply with this bulletin must be placarded against the use of sulfur for dusting. See also F. A. A. Safety Regulation release No. 89 for further suggestions for prevention of sulfur fires.

Copies of these Safety Releases may be obtained through your nearest F. A. A. District Safety Agent. Parts of the FAA Air Regulations such as Parts 8, 03, 04, 18 and Manual 18 are obtainable at a few cents each from the Superintendent of Documents, Government Printing Office, Washington, D. C.

CLEANING: A considerable portion of the maintenance of agricultural airplanes consists in keeping the equipment clean. Spray systems must be designed and proper installations be made to enable quick and easy access for cleaning. Cleaning after the use of such highly toxic materials as 2,4-D, DDT, parathion, BHC and toxaphene is ma
otry. To clean systems, remove boom plugs and all screens. Use steam along with solvent (kerosene) to cut the oils, if oil carriers have been used, and household ammonia or trisodium phosphate.

SAFETY EQUIPMENT: There are no regulations legally required in using the following items, however, experience and accident records show the value of incorporating these items in every agricultural aircraft:

1. Shoulder harness.
2. Instrument panel padding.
3. Adjustable seat rise.
4. Cockpit ventilation.

YOUR STATE COLLEGE OF AGRICULTURE IS YOUR BEST SOURCE OF SPECIFIC INFORMATION

Fig. 70. Courtesy Dakota Aviation Company. This sprayer, an Aeronca Sedan, is capable of spraying 100 acres without reloading.
Loading delays are uneconomical. Often in air application jobs, time is of the essence. The situation is critical. The planes ought to be in the air every available minute. Pumping and other loading equipment must be fast and efficient.

SUPPLY TANKS

Surplus military fueling equipment such as tank trucks, semi-truck and trailer outfits and small tank trailers have been readily adapted as supply equipment for air-application. Many of these units are still to be found around the used truck lots of the larger cities.

A nurse and mixing tank is used to mix the diluent and chemicals and to transport them to the field from which the plane is operating. Because the time for discharging the spray load is very short, the other time consuming operations—flying to the landing field for refilling, and the refilling operation itself—should be done as quickly

Fig. 71. Aero Mist-Master Loading

In connection with ground equipment. The Mist-Master exclusive loading feature makes it possible to load quickly without outside pumps, etc. You simply attach your loading hose to inlet on side of aircraft and reverse the flow of the spray pump itself. Spray pump draws in the liquid at better than 40 gallons per minute and the constant agitation system builds a complete mixing job without prior mixing.

Courtesy Mississippi Valley Aircraft Service
GROUND SERVICING EQUIPMENT

and efficiently as possible. The nurse tanks may be old orchard sprayers, or special units built for this work—small pumps and engines mounted on 200 to 400 gallon tanks. The pump and engine are used to mix and agitate the spray liquid and also to pump it into the plane. The plane tank may be filled from the top of the tank itself, or through one end of the boom with a special hose connection and shut-off valve.

Some operators are considering the use of a ground sprayer to supplement the airplane equipment and work the field boundaries and small areas difficult to cover by air. The nurse tanks could easily be converted to such supplementary sprayers. 3

● TANK TRUCKS: The tank truck has proven most practical. For all purpose operation a 200 gallon tank truck is needed. The tractor tank truck offers the flexibility of one driver being able to spot tanks at various fields. The airplane in this case must move in close to the tank for loading. This is some disadvantage over having a truck which moves in close to the airplane. The combination of a tank truck with a tank trailer provides maximum transportation at minimum costs. The investment is well justified for large or distant operation. A clean 55-gallon drum is satisfactory as a container for the concentrated spray material.

Fig. 72. Courtesy Piper Aircraft Company
PA-18 Piper with Whitaker 47 gallon suspended spray unit being serviced from pick-up truck.
CALIBRATED MEASURING STICK FOR TANK: It is important to have an accurate calibrated measuring stick for spray tanks. Often a day's work or a field might be completed with a partial tank of mixture left. In order to fill tank it is necessary to know how much water or oil it will take to refill. To make an accurate calibrated stick, fill tank with water, drain a gallon or two at a time and subtract from the total capacity of the tank each time. Mark this amount appropriately on the measuring stick fluid level.

USE OF OTHER GROUND EQUIPMENT

USE OF TWO-WAY RADIO: Walkie Talkies or two-way radios have been used with considerable success and ought to be installed in all agricultural airplanes. The initial cost of installation and the added weight are deterrents. The time saved by being able to give pilots immediate directions more than off sets the cost of such equipment. The use of radio is a strong sales feature for the efficiency of the air-applicator.

USE OF PORTABLE ANEMOMETER: The regulations of some states, for example Louisiana, require that the air-applicator have at the field being treated a portable anemometer for the purpose of accurately determining the wind velocity.
PART SEVEN

EXPERIMENTAL DEVELOPMENT

The United States Government has done a considerable amount of experiment with and development of airplane sprayers, dusters and bait spreaders. During the war a large amount of spraying for mosquito and other insect control was engaged in by the army. A number of airplane adaptions previously shown in this volume were developed which are now being used in commercial agricultural aviation.

In attempting to determine the most practical way to control some of the more economically important insect pests, the Bureau of Entomology and Plant Quarantine has developed, independently or in cooperation with other public agencies and individuals, various devices for dispersing insecticides with aircraft. The more practical installation have been tested extensively under field conditions.

Experiments are currently being conducted with devices for releasing liquid from different points under the wings and fuselage. These devices range from a single emission pipe protruding from the bottom of the fuselage to spray booms that project beyond the wing tips. Although the later type of installation probably takes full advantage of the wing-tip vortices, it cannot yet be definitely stated that it is superior under all conditions to some of the other types.

What kind of spray nozzles are best? How far apart should they be spaced? How low must the pilot fly? What pressure for the spray? These are a few of the questions which we have guessed at and discovered by trial and error. The Bureau of Plant Industry of the United States Department of Agriculture, located at Forest Grove, Oregon, is getting the answer to these and many other questions for you. At the time this volume went to press no published release had been made. The men in charge of this work are most generous in their desire to help. A letter or visit to the experimental station at Forest Grove will be well worth your while. The research station has a full time pilot and operates its own airplane for practical verification of their findings. Make use of this resource. This is but one of the many experimental units of the United States Bureau of Agriculture. (See volume six for complete directory of all agencies related to agricultural aviation.

Exhaust Generator

An exhaust generator for dispersing insecticide solutions for the control of mosquitoes is currently being tested on a N2S (Stearman) biplane. It consists of an extension to the exhaust pipe, leading back-
ward from the engine on the starboard side of the fuselage to a point about 6 feet behind the rear cockpit. Close to the end of this extension is a venturi constriction, into which the spray solution is injected. The rapid flow of the hot exhaust gases at the point of constriction atomizes the solution into fine droplets. A portion of the solvent volatilizes, and the insecticide is discharged as a combination mist and smoke.

Although this equipment emits exceedingly small droplets, many of which penetrate heavy vegetative cover, there appears to be some loss of material through volatilization and carbonization, and there is a considerable loss through the failure of the smaller droplets to reach the target area. 41

**FAA's AGRICULTURAL PROTOTYPE**

(Texas A & M Project

An airplane specifically designed for spraying, dusting, seeding or fertilizing is urgently needed. The war surplus Stearmans are rapidly wearing out and disappearing. Realizing the need for improvements in the fast growing field of dusting and spraying by airplane, the National Flying Farmers Association initiated the project in cooperation with Federal Aeronautics Administration, the Department of Agriculture, and the Texas A & M College. Here is the background history of this agricultural prototype.
EXPERIMENTAL DEVELOPMENT

The first step consisted of design, construction, and development of an experimental airplane especially for dusting, spraying, seeding and fertilizing, together with the initial steps toward the development of improved dispersing equipment. It appears that there will be a fertile field for research in the measurement and improvement of distribution for a number of years ahead. Information on the characteristics most desired in dusting and spraying airplanes was obtained from the dusting and spraying operators, partly by personal interview but mostly from a P.A.A. survey which covered the entire country.

The spread of desirable requirements covered too large a range to be handled by a single type of airplane, and so a medium size was selected for the experiment with the thought that it might be representative for a substantial portion of the work. Any satisfactory developments can, of course, be applied to larger and smaller airplanes after they have been proven.

The operators agreed that the airplane should be capable of operating from small soft fields with full load. It should be able to distribute its load at a selected speed between 60 m.p.h. and 90 m.p.h. It must usually do this at a very low height just clear of the crop, and at the end of a run it must have sufficient buoyancy to zoom quickly over obstacles which may be at the edge of the field. Then it must have excellent low-speed maneuverability in turns in order to make them in minimum time and start another run. Good aileron control in particular should be available under all conditions which may occur in these low speed turns. For this low flying close to the ground and close to obstacles the pilot should have a clear field in view, particularly ahead and downward, and also in the direction to see where he is going in the turns at low altitude.
Loading the airplane should be as easy and quick as possible. The structure should be rugged and at the same time easy to clean, inspect, and repair, for it is important to keep it working without interruption during the busy season.

The airplane has been designed and constructed under a P.A.A. contract which became effective just under a year ago on December 7, 1949. The project has been aided by personnel assigned for various periods by the P.A.A., the Department of Agriculture, two airplane manufacturers and the Texas A. and M. College System; and many important parts including the engine, propeller, landing gear and seat have been contributed by the following list of manufacturers:

Continental Motors Corporation: Engine
Cessna Aircraft Corporation: Landing gear and service
Aeronca Aircraft Corporation: Engineering service
Cornell University Medical College: Pilot protection counsel
U.S. Rubber Company: Tank liners
Goodyear Tire and Rubber Company: Wheels, brakes and tires
MaCauley Propeller Company: Metal propeller
Koppers Company: Aeromatic propeller
Beech Aircraft Corporation: Rudder pedals and brake equipment
Safe Flight Instrument Company: Pre-stall indicator
Vic Pastushin Industries, Inc.: Adjustable 40-G seat
American Seating Company: Inertia rell for shoulder harness
Aircraft Conversion Company: Instruments

The airplane as of the date of this publication was complete except for dusting and spraying equipment. It has been given some preliminary flight tests and adjustments and has been demonstrated to many groups.

When this project was announced there was some misunderstanding as to the objective of the project. Del Rentzel, P.A.A. Administrator at that time, explained that the P.A.A. was not going into the business of building agricultural aircraft—that only a prototype would be developed experimentally. The plan calls for making the blue prints available to those manufacturers and others who may wish to manufacture the Ag-1 at a nominal cost for reproducing the plans.
Specifications for the Ag-1

- **TYPE:** Duster, sprayer, seeder, and fertilizer; single place.

- **PERFORMANCE:** (estimated, full load): Maximum speed 115 m.p.h.; cruising 100 m.p.h.; operating speeds 60 to 90 m.p.h.; landing 45 m.p.h.; (normal landing without pay load 37 m.p.h.); rate of climb 600 feet per minute; service ceiling 12,000 ft., cruising range 400 miles; take-off distance to a height of 50 ft., 1300 ft.

- **SPECIFICATIONS:** Wing span 39 ft., length 29 ft. 8 inches; 8 ft. 7 inches; empty weight 1900 lb.; weight 3400 lb.; fuel capacity 48 gal.; low wing, all-metal construction; landing gear tail wheel type; Cessna type spring steel gear support is shock absorber for both main and tail units; tire size main gear 8.50X10, goodyear tires, wheels, and hydraulic brakes; Scott 8 in. tail wheels steerable full swivel; Beech Bonanza rudder pedals; Continental E-225-104-14X engine; fuel consumption 12 g.p.h. McCauley one piece aluminum alloy propeller.

1. Performance and handling qualities adapted to dusting and spraying work (flying with heavy loads from unprepared fields, flying low over crops at relatively low speed, and climbing over obstacles and turning back quickly for next pass); Obtained with aid of full-span slotted flaps and slot-lip ailerons.

2. Dust hopper in fuselage (27 cu. ft.) and spray fluid tanks (150 gallons total) in wing center panel, either available for use at any time.

3. Provisions for experimental installation of any promising equipment for dusting, spraying, seeding, or fertilizing.

4. Room in outer wing panels for experimental dust hoppers to investigate possible improved distribution.

5. Simple construction for ease of maintenance and repair.

6. Exceptional field of view for pilot, particularly forward and downward while in flight.

7. Sharpened landing gear legs, guide tubes over cockpit, and cable from cockpit to top of fin, all for protection against electric wires contacted in flight.

8. Pilot protection in crash, included 40g seat belt, and shoulder harness, latter supported by inertia reel giving pilot freedom of action while protected; pilot behind loads and all heavy masses, and protected by long forward structure and wing.

* For further information regarding the status of this project write to Fred E. Weick, Director Personal Aircraft Research Center, Agricultural and Mechanical College of Texas, College Station, Texas.
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F.A.A. agricultural prototype
Specifications for Ag 1
The air-applicator must constantly keep in mind the basic concepts of chemical crop treatment. He must know that:

(a) Crops *stage* and *mature* differently in different geographical areas.

(b) That various species of the same plant *react* differently to the same chemical.

(c) That *growth conditions* materially affect toxicity.

(d) That *dry, warm weather* tends to toughen plant foliage.

(e) That the *carriers* used affect the effectiveness of the chemicals.

(f) That *timing* has much to do with results.

(g) That *temperature* has much to do with results.

(h) That the potential hazard of *drift* must always be kept in mind.

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